Comments On *Report of the Second Mars Affordability and Sustainability Workshop*

Preface

This essay is a personal commentary on a document titled *Report of the Second Mars Affordability and Sustainability Workshop*. This workshop, abbreviated "AM II" herein, was conducted October 2014 under auspices of Explore Mars, Inc. and the American Astronautical Society. A copy of the report may be obtained from http://www.exploremars.org/wp-content/uploads/2015/02/Affording-Mars-2014-Report_1-2.pdf (accessed 26 March 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 arguable, questionable, or unsupported conclusions, findings, and consensus documented in the report. This essay's findings and recommendations for future Affording Mars workshops and reports are intended to improve their utility.

Commentary on the report is organized in subsequent paragraphs according to major section-specific themes or concepts running through the report or absent from it. Page *n* references to the report are therefore not in any ordered numeric sequence and are of the format "p. *n*". Some pages of the report are not numbered, and those are referenced using the format "PDF p. *n*" to correspond with the page count displayed by Adobe Acrobat software. External references with respect to the report are cited in square brackets and detailed in the References section of this essay.

A First International Human Mission To The Surface Of Mars In The 2030s

The report states this milestone as a recommendation in its Summary Workshop Findings & Observations on PDF p. 3. There is no rationale provided in the report for why an initial landing in the 2030s renders human activity on the martian surface more affordable or sustainable than at another time.

On p. 2, "International partnerships will be an essential component of human Mars exploration." is associated with the report's "Workshop Ground Rules and Guidelines". But these partnerships are tacitly accepted without any rationale. On p. 3, "multiple benefits made possible by peaceful international cooperation on major space missions" are associated with how and why humans are going to Mars, but those benefits are not articulated. Conversely, p. 17 of the report states international partnerships lead to constraints limiting options for viable Mars pathway architectures. Contributions from these partnerships, presumably leading to greater affordability, are termed "speculative" on p. 18. Indeed, according to the NRC in 2014 [1, p. 20], "senior NASA officials reported to the present committee that international collaboration does not reduce costs."

Human missions to the surface of Mars "are the priority goal for human space flight" in the report's "Summary Workshop Findings & Observations" on PDF p. 3. Motivation for embarking along a pathway leading to human landings on the martian surface is also a component of the "Summary Workshop Findings & Observations" on PDF p. 4: "The 'story' of human space exploration must be comprehensive and coherent with each activity on the way to the surface of

Mars readily understandable by the general public." On p. 3, the report refers readers to [1] for motivation in sending humans to Mars. Unfortunately, review of [1] indicates this motivation is poorly supported. The assertion that "Mars is a goal most compatible with the committee's enduring questions" [1, p. 34] is highly debatable. These questions are as follows [1, p. 47].

1) How far from Earth can humans go?
2) What can humans discover and achieve when we get there?

If "going farther and doing more" rationale for selecting Mars as a human spaceflight goal is set aside, [1] can only support its assertion with "intrinsic fascination" and "popular imagination" [1, p. 34] associated largely with science fiction. Although science fiction can be a great motivator, human spaceflight strategy should reflect a more factually informed awareness of all destinations with accessibilities equal to or exceeding the surface of Mars.

On PDF p. 4, the report's Summary Workshop Findings & Observations states, "NASA and its partners must further develop new management processes and efficiencies, as well as acceptance of reasonable risk." This statement implies currently acceptable risk for human spaceflight to Mars is too conservative, but that conflicts with the inherently greater risk of interplanetary human spaceflight compared to that of present-day missions in low Earth orbit. Given the extremely tight margins on funding and schedule assumed at AM II, reduced risk acceptance associated with human missions to Mars may incur loss of crewmembers during flight or their premature deaths afterward. Recall NASA's "faster, better, cheaper" mantra from the 1990s [2, pp. 8-9]. This schedule/quality/cost trade space can typically be optimized for only 2 of its 3 parameters. As an example, mass associated with human transport to Mars could be dramatically lowered by also lowering permissible radiation exposure limits applicable to humans. This would lead to schedule and cost reductions in the short-term. But the crew's likelihood of developing cancer during or after a Mars mission would then be dramatically increased. In the long-term, sustainability for human flights to Mars would suffer as flawed infrastructure is reworked at great cost and delay.

Workshop Goals itemized on p. 1 include "Assess minimum path ('lean') architectures on the basis of both affordability and sustainability for initial missions by the mid-2030s." This is another unrealistic schedule/quality/cost trade in which one cannot have it all 3 ways. Architecture sustainability will further suffer if this trade is performed with a focus in the mid-2030s because Mars accessibility is greatest in that time frame [3, p. 4]. Systems cost-optimized for such cherry-picked mission opportunities may be incapable of reaching Mars again for over a decade or more.

A further concern with AM II's major interest in affordability arises with the report's incomplete definition of that attribute on p. 2: "An affordable mission is an activity that people are willing to pay for." Any investor exercising due diligence would append "with a high expectation of success" to this definition. In the AM II context, minimal "success" ought to mean humans sent on a Mars roundtrip will survive the journey. Even in the unsustainable "space race" of the 1960s, President Kennedy recognized landing humans on the Moon successfully also entailed returning them safely to Earth.

Comments On *Report of the Second Mars Affordability and Sustainability Workshop*

Consensus opinion at AM II, documented on p. 4 of the report is, "The goal should be to land humans on the martian surface, unless precluded by, for example, cost or lack of technical readiness." Why should expense and technical obstacles preclude a *goal*? If they did, humanity would still be stuck in the Stone Age. Along with its "goal disorientation", it should be noted this statement appears under the heading "Why and How Are We Going?" In that context, AM II appears to advocate landing humans on the surface of Mars, but the only rationale being offered is attendees reached agreement on this very conditional goal.

Also documented on report p. 4 is the consensus that "motivation for Mars exploration is the response to the human desire for exploring new frontiers and national benefits of collaboration." Unfortunately, the report does not document why exploration and collaboration in a Mars context is more compelling than other plausible human spaceflight destinations. It is also unclear what collaboration is being advocated. It could be any combination of military, civil, commercial, or international partnerships.

Consensus documented on report p. 5 includes "An SLS-class heavy lift vehicle". Concluding heavy lift "is required" as an essential element for interplanetary human spaceflight architecture entails comprehensive understanding of technical documentation including [4] and other multidisciplinary research. Unfortunately, no references or supporting rationale for heavy lift Earth launch capability are cited in the AM II report. It is also by no means clear which member of the evolved SLS "family tree" is being advocated. These launch vehicles range in performance from 70 metric tons (t) to 130 t of payload mass delivered to an unspecified low Earth orbit [5].

On report p. 5, AM II consensus calls for seeking "agreement on a complete architecture for human Mars exploration". Because "costs cannot be reliably calculated at this stage, analogies for cost (e.g., mass, complexity, number of "inventions") should be identified to allow comparison among different scenarios." In seeking agreement on a cost-effective architecture, it is important not to lose sight of AM II's other focus: sustainability. Consequently, the report's appeal should be amended to consider factors influencing architecture life cycle costs. Such factors would include scalability, reusability, and maintainability along with in-situ resource utilization potential.

With the exception of crew size (which is a budget driver), all the "Non-budget constraints to initial human Mars missions" listed at the top of report p. 6 are driven by NASA's budget. Of particular concern is the consequence "Initial human missions to Mars by the 2030s within expected budgets will require changes to current management and risk posture." If NASA budgets remain flat for too long on the 2030s path to Mars, those budgets will inevitably impose increased risk because interplanetary human spaceflight is inherently riskier than human missions performed today in low Earth orbit. Such a budget-driven strategy, with its reduced mission success and safety margins, only invites disaster (likely well before the 2030s arrive). It would also ignore arguably the best researched 21st century assessment of future human spaceflight prospects in which viable interplanetary human spaceflight capability is estimated to require NASA budgets supplemented by an additional $3 billion per year [6, p. 15]. This estimate appears consistent with the report's p. 2 ground rule: "Budget growth above inflation will be necessary to achieve the goal of initial human missions to Mars by the mid-2030s."

Consequently, the report's p. 6 constraints appear inconsistent with its own ground rules. These constraints should instead be termed an initial state for the 2020s, and a NASA funding profile required to achieve human spaceflight to Mars in the 2030s should be documented, citing [6] as its justification.

A list of five milestones for completion "within the next ten years (2015-2025) to support initial Mars exploration" appears on p. 6. These milestones each seem to have merit, but none is substantiated with supporting discussion from AM II proceedings. For example, the first milestone is: "Fully utilize the capabilities of the ISS." This statement implies ISS is currently underutilized. What ISS capabilities did AM II participants feel were not in full use? And what about putting a short-arm centrifuge aboard ISS to simulate Mars surface gravity's effects on humans and investigate protocols to mitigate debilitating effects from microgravity without sending crewpersons to the treadmill for 2 hours every day? Was any of that discussed during AM II?

Missing from the "Recommendations on Next Actions" on report p. 8 are the trade study between low-latency telepresence (LLT) and high-latency telepresence (HLT) cited on PDF p. 4's "Summary Workshop Findings and Observations", a study of human adaptation to martian surface gravity, a study of permissible radiation exposure during Mars surface EVAs, and a study of human mortality risks during direct Earth entry after a conjunction-class mission to Mars. Until risks/gains associated with these studies are quantified, there is no basis for selecting the surface of Mars as a HSF destination or selecting any particular HSF architecture as an affordable means to reach that destination. Unquantified risks in a HSF destination or architecture render that destination or architecture unaffordable by definition because a reasonable expectation of success (meaning crew survival) is also unquantified.

Very little is recorded about nuclear thermal propulsion (NTP) discussions during AM II. Mentioned only twice in the report, readers are left with a very ambiguous impression of NTP's utility. On p. 5, no consensus was reached on "the importance of investment in this technology." Yet on p. 8, NTP is an example of "Promising in-space propulsion systems" warranting continued development by NASA within three years.

Robotic And Human Mars Sample Return (MSR)

In its "Summary Workshop Findings & Observations" on PDF p. 3, the report finds robotic MSR "may be required to learn how to protect against forward and backward contamination before humans land on Mars." If such planetary protection is the primary rationale for robotic MSR, it confers dubious prospects for a successful mission outcome.

One outcome from robotic MSR is returned samples are sterile. In that case, there is no contamination threat from this particular mission, but the entire planet of Mars is not proven to be sterile either. How many additional robotic MSR missions would be required to verify humans will not contaminate or be infected by martian environments, including likely subsurface habitats required for human radiation shielding? How do these multiple robotic MSRs affect the affordability of human missions to the surface of Mars, and how are those missions delayed by a comprehensive global robotic MSR campaign?

Another robotic MSR outcome is returned samples are found to be contaminated with agents of an Earthly origin. In that case, little effective remedial action is likely because any harm to the martian environment's natural state has already been inflicted. Effective remediation is even less likely if this harm was initiated on a previous robotic mission.

Yet another possible robotic MSR outcome would be returned samples containing martian agents harmful to Earth life. This is presumably the scenario justifying robotic MSR, but the report fails to convey how this outcome from a *robotic* mission averts risk to Earth's biosphere any more effectively than if it were introduced on return of a *human* mission to the surface of Mars.

On report p. 5, a "significant sample return" from Mars is proposed using prototype capability under development for human landings on Mars. In addition to planetary protection rationale of dubious merit and surface toxicology knowledge, the report justifies this proposal with "great scientific" [sic]. Ignoring the typo in this quote, OSIRIS-REx mission design indicates planetary science interest in robotic sample return from an object 492 m in diameter (reference http://www.asteroidmission.org/why-bennu/, accessed 13 April 2015) is limited to a mass from 60 g to 2000 g (reference http://www.asteroidmission.org/mission/, accessed 31 March 2015, in the "SAMPLE" section). This level of interest is weak justification for the cost of returning a Mars sample likely at least several hundred kg in mass (equivalent to that of a returning crew with their essential gear) and likely gathered over a very localized area via HLT.

In summary, imposing robotic MSR as a prerequisite for human landings on Mars conflicts with historic lunar exploration precedent. Planetary protection rationale used to justify this prerequisite in the report appears weak. Far better rationale for robotic MSR lies with scientific interests, but these interests fade beyond a returned mass of a few kg if samples are local in context.

On report p. 10, "The use of human flight systems (e.g., much larger returned sample mass to Earth) will bring enhanced capability for science." is cited among "Top-Level Benefits of Human Missions to the Surface". With human landings decades in the future, this is a poorly supported expectation in at least two respects. First, if returned mass is localized to what humans can personally gather near their landing site, scientific interest in more than a few kg of samples will be limited. These samples will likely be contaminated by landing activities and by human consumables. Second, top priority return mass associated with humans and essential gear could leave little margin for MSR mass. At the time of its cancellation, the Constellation Program's performance-challenged *Altair* lunar surface logistics spacecraft had virtually no sample return mass capability.

Also listed among "Top-Level Benefits of Human Missions to the Surface" on report p. 10 is: "Increased human interactions with the environment and materials, especially direct". Rationale for this statement is missing in the report and highly debatable. Scientifically interesting Mars surface locales could be inaccessible to humans due to limited logistics or hazardous terrain. But teleoperated robots might have virtually unlimited surface range and could routinely tolerate hazards excluding human access, thereby offering greater science return. The meaning of "direct" in this context is also obscure. Why is LLT less "direct" than a human in EVA garb? Radiation exposure limits may require most exploration by humans on the martian surface be conducted via LLT anyway.

Listed among "NEXT STEPS" on report p. 16 is "the requirement for a robotic sample return in advance of the initial human surface mission, which will allow improved assessment of surface conditions of the planet." As is evident from preceding paragraphs in this essay, this "requirement" has dubious rationale. It also fails to recognize humans will likely have to occupy sub-surface habitats to be adequately shielded from radiation in the martian environment, particularly during sojourns of 500 days or more.

Low-Latency Telepresence (LLT) For Mars Surface Exploration

The report's "Summary Workshop Findings & Observations" on PDF p. 4 indicates AM II "subject matter experts in Mars geology and astrobiology" only had experience with HLT and were unaware of scientific data-gathering benefits afforded by LLT. Neither were these experts apparently aware of LLT demonstrations with astronauts aboard ISS operating robotic assets on Earth's surface conducted more than a year before AM II (as documented at http://www.nasa.gov/mission_pages/station/research/news/rover_from_space/#.VOKFfyjv2Uc, accessed 28 March 2015). This apparent unawareness is perplexing because at least 3 AM II participants also attended a LLT technical interchange meeting (TIM) shortly after the year 2013 ISS demonstrations (reference http://telerobotics.gsfc.nasa.gov/papers/ISS_LLT_Science.pdf, accessed 28 March 2015). It is also hard to believe AM II attendees were uniformly unaware of LLT examples currently in practice. Telesurgery (also known as remote surgery) requires dexterity meeting or exceeding any Mars surface science requirements.

An unsupported statement on p. 3 of the report substantiates AM II's unawareness of LLT's potential for Mars exploration: "astronauts on the surface [of Mars] is a far more worthy mission objective on the basis of, as one example, scientific return." Excepting human adaptation, every NASA-documented Mars surface science objective [4, Section 3] could be aggressively pursued by currently demonstrated LLT capabilities. These objectives can therefore be achieved earlier, at less expense (report p. 3: "the cost of landing may be as much as ~1/3 of the total mission cost"), and with less risk to crew survival when the crew conducts LLT from Mars orbit with robotic surface assets.

On report p. 4, AM II consensus is "Telerobotic operations from orbit were considered a capability insufficient to achieve compelling goals." The goals presumably unachievable through LLT are not explicitly stated, but this consensus is documented in context with the goal of landing humans on the surface of Mars. While it is undeniable that LLT from Mars orbit cannot land humans on Mars, the report fails to make any rational case for such a landing being a compelling goal.

In apparent contrast to p. 4 of the report, p. 5 states no consensus was reached on "The merit of human missions to Phobos and/or Deimos." This implies at least a minority attending AM II would not acknowledge potential merit in conducting LLT from either martian moon. Given these moons provide copious radiation shielding mass in orbit, conducting LLT Mars exploration from a subsurface habitat at either location is compelling.

Still another contrasting opinion appears on p. 10 of the report: "Humans in the vicinity of Mars substantially improves operability of assets for science (e.g., low-latency telerobotic operation)." This statement is associated with a list of "Top-Level Benefits of Human Missions to the Surface", but it appears better suited to a list of "Top-Level Benefits of Human Missions Limited to Mars Orbit and/or Martian moons" also on p. 10.

Among the "Top-Level Benefits of Human Missions Limited to Mars Orbit and/or Martian moons" listed on p. 10 is: "A human landing on Phobos or Deimos would be valuable to small-body science, but would be of minimal value to the science of Mars itself." This statement appears to make the assumption that humans in Mars orbit or on Phobos/Deimos would be incapable of observing Mars or conducting LLT operations on its surface. Such an assumption is not clearly documented in the report. The next Mars orbit "benefit" in the p. 10 list could explain some of this mission concept myopia and is quoted below.

> Teleoperation of assets on the surface of Mars from either high Mars orbit (areosynchronous) or from the surface of either Phobos or Deimos may be a feature of a human mission to the martian system. However, this would be insufficient to serve as a science justification alone for a human mission. That is, we did not identify compelling advantages over the operation of such assets from Earth.

The foregoing statement is flawed in multiple respects. First, it fails to recognize Deimos is nearly areosynchronous, having an areographic period of 131.2 hours with a westbound ground track. Second, it fails to cite what objectives humans in Mars orbit would be incapable of pursuing that leave their mission scientifically unjustifiable. Third, the statement's failure to recognize the value of LLT over HLT is incredible. From Mars orbit, even at the 23,463.2 km mean orbit radius of Deimos, LLT on the martian surface would be a game-changer compared to HLT done from Earth. For example, Mars Exploration Rover *Opportunity* logged 42.195 km (literally a marathon) in 4076 days (11.16 years) of roving Mars (reference http://mars.jpl.nasa.gov/mer/newsroom/pressreleases/20150324a.html, accessed 5 April 2015). That is a pathetic average speed of 10.352 m per day. Even an underpowered LLT rover would be capable of covering 10 m in minutes unless traversing highly hazardous terrain. After 10 m, an LLT rover would continue its traverse under human control, while an HLT rover might need to await situational assessment and further instructions from Earth.

In the search for extant life on Mars, the report notes possible "teleoperation of sterile rovers, which would require in-depth consideration of forward planetary protection issues" on p. 10. This note does not explicitly state the "teleoperation" is to be conducted with humans in Mars orbit or on Phobos/Deimos, but it is associated with "Top-Level Benefits of Human Missions Limited to Mars Orbit and/or Martian moons" listed on p. 10. Due to planetary protection concerns for preserving martian life in its native state, it can be argued that sending humans to the surface of Mars is the *worst* way in which to search for or study such life. A human presence on Mars could easily mask or destroy this critically important science objective.

Another LLT concept appears on report p. 11: "If humans are teleoperating from the surface of Mars (versus in orbit), then, in addition to more sustained contact and lower latency, they could repair the robot and switch out sensors, etc. This would greatly expand the robot's value." Implicit in this concept is either a robot operating within walking distance of a human habitat or a highly developed Mars surface human transport infrastructure. Otherwise, human radiation exposure concerns on the surface of Mars will require robots in need of human repair be capable of self-transport to the nearest human habitat. The lower latency associated with this surface-based concept would be imperceptible compared to Deimos (with a line-of-sight round-trip latency no more than 0.155 s). The lower surface-to-surface latency would vanish altogether if LLT were conducted between distant Mars surface points through communications relay infrastructure. If LLT were to be conducted from Deimos, line-of-sight communications with a surface asset could be quite sustained compared with surface-to-surface LLT. Here is how.

Imagine 3 diverse Mars surface sites at roughly equal intervals of longitude. At each site, LLT systems are pre-positioned for control by humans in a radiation-shielded, sub-surface habitat on the Mars-facing hemisphere of Deimos. Each surface site can maintain a continuous LLT link with Deimos operators for over 59 hours, ignoring terrain masking. Given the diversity from the 3 sites, being able to communicate continuously with each for over 2 Earth days comes close to optimal use of human and robotic resources in Mars surface exploration. This is accomplished without any communications network other than direct line-of-sight links. See https://www.youtube.com/watch?v=X10GAqA4Ky4 (accessed 5 April 2015) for a simulation of Deimos rendezvous and how Mars appears to a Deimos observer.

Report Table 1 on p. 12 is titled "Science Value Added by a Human Mission versus a Robotic Mission for Different Architectures". It is followed by enumerated remarks titled "Summary of Table 1: The Value Added by Humans on Site". Remark #3 provides yet another AM II viewpoint on LLT: "If humans are in the loop, either being on site or via telepresence, there will be an increase in cognition and a decrease in latency, which should achieve more, and faster and more adeptly." In this remark, no lack of scientific productivity is associated with LLT vice a physical human presence. Such a "virtual presence" via LLT is hard to reconcile with remarks on p. 3 and p. 4 of the report as cited previously in this section.

In the same p. 12 "Summary of Table 1: The Value Added by Humans on Site" enumerated list is Remark #6: "Use of Phobos as an initial site for human exploration is a science convenience and benefit to small body science goals, but is not a good science objective for Mars itself." No rationale for conducting science on Phobos as opposed to Deimos is given anywhere in the report, but Deimos and its nearly areosynchronous motion are excluded from consideration at multiple points, including Table 1. Remark #6 again appears to assume that landing humans on a martian moon somehow precludes observing Mars and conducting LLT with assets on the martian surface.

A list of "Additional Observations about Value-Added Science via Human Presence on Site" appears on report p. 13. One of these observations is particularly striking: "None of the Mars surface science objectives require humans for accomplishment." This remark cries out for elaboration, but one might infer that the chief value of humans to martian science is the rapidity with which objectives can be accomplished. Selectively juxtaposing this observation with other remarks in the report, one might conclude there is no Mars surface science that cannot be accomplished by humans on Deimos via LLT at least as rapidly as with humans on the martian surface.

A list of findings on report p. 14 includes: "Increased human interactions with the environment and materials, especially direct contact, dramatically increases science return." This unsubstantiated claim is, if taken literally, reckless. Direct contact with the martian environment (and possibly with materials from it) is deadly to humans, and science return goes to zero. So how direct do humans need to be in order to realize dramatic science returns? Could LLT, conducted with humans in a sub-surface Deimos habitat, be sufficiently direct?

Almost as an afterthought, with its final contributed words to the report on p. 16, AM II "Breakout Session Two: Science Enabled and Enhanced by Humans in the Vicinity of Mars" documents its unwillingness to consider LLT. Evidently, Session Two participants chose to base their findings only on "current best practices, as published in the peer-reviewed scientific literature." This prerequisite subjects LLT to a unique standard in the report which is, appropriately, full of technology speculation about propulsion, aerocapture, environmental control and life support systems (ECLSS), sustainability, affordability, et cetera. Even the presumed survivability of humans for 500 days on Mars is highly speculative. If LLT speculation was forbidden during AM II, this exclusion was not documented in "Workshop Ground Rules and Guidelines" on report p. 2.

One source of peer-reviewed LLT in practice since 2001 is from the field of telesurgery [7]. This LLT application typically requires a degree of dexterity and tactile feedback likely exceeding any Mars surface exploration requirement. Its operator/robotics interface error tolerance is also likely more demanding than Mars surface exploration. To assist those desiring greater awareness of the rapidly advancing field of telesurgery, a list of clickable URLs appears in Appendix A.

A Sustained Human Presence On Mars

Report p. 3 advocates "a small, sustained human surface presence analogous to an Antarctic outpost and visited by astronauts on a rotating, non-permanent basis". Typically, Antarctic outposts are continually occupied. To maintain this analogy, each Mars outpost crew would need to be away from Earth about 4.8 years. Here is why.

Assuming reasonably efficient high-thrust propulsion (specific impulse in the 400 s to 1000 s range), resulting Earth-Mars or Mars-Earth transits are about 240 days in duration and fall at 780-day intervals on average. The off-going outpost crew has its first opportunity to depart Mars for Earth 240 + 500 = 740 days after departing Earth for Mars (the 500-day outpost loiter interval is in accord with a conjunction-class mission profile per report p. 10). Unfortunately, the oncoming outpost crew cannot reach Mars much before 780 + 240 = 1020 days after the off-going crew departed Earth. Thus, to have any face-to-face handover with the oncoming crew at the Mars outpost, the off-going crew must forego its first Earth return opportunity from Mars to await a second opportunity about 780 days later. The off-going crew would then return to Earth 240 + 500 + 780 + 240 = 1760 days or 4.8 years after it departed.

Workshop Administration

Proposed topics for an Affording Mars III workshop are listed on report p. 9 and include: "Continuing broad community participation in Mars exploration architectures, scenarios, and strategies, especially as it involves younger generations." This proposal is not a topic, but the essay author takes issue with the implication AM II participants represented a sufficiently broad community, regardless of their age demographic. There is no indication the aerospace medicine community was represented to discuss radiation, microgravity, reduced gravity, and atmospheric entry hyper-gravity human exposure issues along with their mitigation.

Another proposed Affording Mars III topic listed on report p. 9 is: "Implementing new management practices to reduce cost." Reducing mission costs could have merit if impact to crew safety and mission assurance will not be compromised as a consequence. Along with this topic should be another to discuss strategies attracting more funding and other contributions offsetting mission expenses. Such strategies, particularly those that are sustainable, lead to mission affordability just as effectively as cost reductions. Affording Mars workshops appear to fixate on cost savings while neglecting opportunities to increase funding and treating gloomy budget forecasts as an immutable ground rule.

Under "Other Issues for Future Assessment" on report p. 14 is an enumerated list of roles ISS could play "to carry out Mars-related science". Role #2 is to "Evaluate telepresence for Mars-related science." Such an ISS role was, as documented in the LLT section of this essay, being exercised well before AM II in 2013. Apparent unawareness of this ISS activity at AM II is a compelling reason to ensure adequate representation from experts in LLT at future Affording Mars workshops. ISS Role #3 is to conduct "Human life sciences for long-stays in deep space/on Mars." Without a centrifuge capable of exerting 38% Earth gravity on human subjects, this ISS role will go unfulfilled. There is no plan to implement such a facility. Open issues like a human centrifuge aboard ISS are further justification to include aerospace medicine expertise at future Affording Mars workshops.

This essay documents multiple inconsistencies in the report regarding findings and consensus between three breakout sessions on the AM II agenda. Why were these inconsistencies not resolved in a plenary session supported by all AM II attendees? Furthermore, conclusive findings documented in the report were often not accompanied by any supporting rationale. Discord on how to explore Mars with humans is rampant among aerospace experts. The AM II did little to quell that discord by publishing a report full of inconsistencies and lacking comprehensive rationale for its findings.

Findings And Recommendations For Future Affording Mars Workshops

The author of this essay did not attend AM II and can only address the report's content. Nevertheless, it is evident from the report that attendees represented a broad spectrum of opinion about Mars exploration by humans. Unfortunately, little was done at AM II to integrate this diverse opinion into actionable report findings and recommendations. In many cases, blatant contradictions were documented in the report, with some opposed opinions labeled "consensus". No plenary or executive session during AM II proceedings was documented in the report. Future Affording Mars workshops should seek to resolve or better document differing opinions among attendees with agenda time dedicated to that end.

Although AM II attendees represented a broad spectrum of opinion, it was not broad enough in at least two critical fields of expertise. Knowledge of human factors, particularly aerospace medicine, appeared absent at AM II. Failing to fully account for radiation and micro/reduced/hyper-gravity human exposure issues in Mars exploration architecture can lead to overly optimistic cost and sustainability findings. A second poorly represented field of expertise at AM II was LLT. With LLT, exploration of Mars might be performed much sooner, more effectively, at less expense, and with less risk than with humans on the surface of Mars. Multiple experts in human factors and LLT should therefore support future Affording Mars workshops.

Finally, the AM II report's integrity suffers in at least two major respects. First, many findings, conclusions, and recommendations appearing in the report are not adequately substantiated. Adopting many of these items based on report narrative requires a leap of faith on the reader's part, and only a handful of citations to supporting literature are made. Second, the report was not thoroughly edited. Numerous typographical errors were published, and there appear to be several incomplete sentences. It is possible the editor chose note to include material supporting report findings, conclusions, and recommendations. Whether or not this was the case, future Affording Mars workshops should devote greater time and effort to thoroughly capturing workshop proceedings in a report with less technical errors. Future reports would thereby begin to identify key issues and knowledge gaps whose resolution would lead to more affordable and sustainable human Mars exploration. Unfortunately, the AM II report leaves too many readers in a perplexed and misled state.

References

1. National Research Council Committee on Human Spaceflight, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, National Academies Press, Washington, D.C., (2014).[*]
2. Lambright, W. H., *Why Mars*, John Hopkins University Press, Baltimore, (2014).
3. Hopkins, J. and Pratt W., "Comparison of Deimos and Phobos as Destinations for Human Exploration, and Identification of Preferred Landing Sites", Lockheed Martin Corporation, (2011).[†]
4. Mars Architecture Steering Group (Drake, B. G., ed.), *Human Exploration of Mars Design Reference Architecture 5.0*, NASA-SP-2009-566, (2009).[‡]

[*] This publication is available for download at http://www.nap.edu/catalog.php?record_id=18801 (accessed 28 March 2015)
[†] This publication, and an audio transcript of its presentation, are available for download at http://spirit.as.utexas.edu/%7Efiso/telecon10-12/Hopkins_10-19-11/ (accessed 30 March 2015).

5. George C. Marshall Space Flight Center, "NASAfacts Space Launch System", FS-2014-08-123-MSFC, G-51857. NASA, (2014).[§]
6. Review of U.S. Human Spaceflight Plans Committee, *Seeking A Human Spaceflight Program Worthy Of A Great Nation*, NASA, (2009).[**]
7. Marescaux, J. (et al), "Transatlantic Robotic Assisted Remote Telesurgery", *Nature* 413, No. 6854, (September 27, 2001), pp. 379-380.

Appendix A: Telesurgery Supplemental Information

The following clickable URLs provide telesurgery information to those desiring an appreciation of current practices in low-latency telepresence (LLT). This technology would be readily applicable to exploring the surface of Mars with robotic systems controlled by humans from Mars orbit, most notably the outer moon Deimos. All links were accessed 12 April 2015 and were contributed by Space Enterprise Institute co-founder James Logan, M.D.

A1. http://www.wisegeek.com/what-is-telesurgery.htm (introductory)
A2. http://www.pbs.org/wnet/innovation/episode7_essay1.html (introductory)
A3. http://www.surgeryencyclopedia.com/St-Wr/Telesurgery.html (introductory)
A4. http://en.wikipedia.org/wiki/Remote_surgery (introductory)
A5. http://www.davincisurgery.com/da-vinci-surgery/da-vinci-surgical-system/?utm_source=bing&utm_medium=cpc&utm_campaign=Brand_dVS_daVinci_KWs (marketing)
A6. http://health.howstuffworks.com/medicine/modern-technology/robotic-surgery1.htm (introductory)
A7. http://www.ncbi.nlm.nih.gov/pubmed/25627435 (paper: "A new Telesurgical Platform--Preliminary Clinical Results")
A8. http://www.ncbi.nlm.nih.gov/pubmed/25627128 (paper: "Robotic Surgery")
A9. http://www.ncbi.nlm.nih.gov/pubmed/25599203 (paper: "An Experimental Feasibility Study On Robotic Endonasal Telesurgery")
A10. http://www.ncbi.nlm.nih.gov/pubmed/25598598 (paper: "Robotics In Urologic Oncology")
A11. http://www.ncbi.nlm.nih.gov/pubmed/25569973 (paper: "Modeling And Control Of Tissue Compression And Temperature For Automation In Robot-Assisted Surgery")
A12. http://www.ncbi.nlm.nih.gov/pubmed/25345417 (paper: "Construction And Verification Of A Safety Region For Brain Tumor Removal With A Telesurgical Robot System")
A13. http://www.ncbi.nlm.nih.gov/pubmed/25328100 (paper: "Role Of Combined Tactile And Kinesthetic Feedback In Minimally Invasive Surgery")
A14. http://www.ncbi.nlm.nih.gov/pubmed/25328078 (paper: "Effect Of Latency Training On Surgical Performance In Simulated Robotic Telesurgery Procedures")

[‡] This publication is available for download at http://www.nasa.gov/exploration/library/esmd_documents.html (accessed 30 March 2015).
[§] This publication is available for download at http://www.nasa.gov/sites/default/files/files/SLS-Fact-Sheet_aug2014-finalv3.pdf (accessed 31 March 2015).
[**] This publication is available for download at http://www.nasa.gov/offices/hsf/home/index.html (accessed 1 April 2015).

A15. http://www.ncbi.nlm.nih.gov/pubmed/25290465 (paper: "Determining The Threshold Of Time-Delay For Teleoperation Accuracy And Efficiency In Relation To Telesurgery")
A16: http://www.ncbi.nlm.nih.gov/pubmed/25197187 (paper: "Pediatric Robotic Urologic Surgery-2014")
A17. http://www.ncbi.nlm.nih.gov/pubmed/25059998 (paper: "A New Robot For Flexible Ureteroscopy: Development And Early Clinical Results (IDEAL Stage 1-2b)")
A18. http://www.ncbi.nlm.nih.gov/pubmed/24671353 (paper: "Determination Of The Latency Effects On Surgical Performance And The Acceptable Latency Levels In Telesurgery Using The dV-Trainer(®) Simulator")
A19. http://www.ncbi.nlm.nih.gov/pubmed/24018079 (paper: "Robotic Hysterectomy Strategies In The Morbidly Obese Patient")
A20. http://www.ncbi.nlm.nih.gov/pubmed/23730051 (paper: "Current Status Of Robotic Surgery")
A21. http://www.ncbi.nlm.nih.gov/pubmed/23528717 (paper: "Future Of Robotic Surgery")
A22. http://www.ncbi.nlm.nih.gov/pubmed/23357931 (paper: "Telementoring In Robotic Surgery")
A23. http://www.ncbi.nlm.nih.gov/pubmed/23224637 (paper: "Robotic Surgery In Italy National Survey (2011)")
A24. http://www.ncbi.nlm.nih.gov/pubmed/16437703 (paper: "Robotic-Assisted Laparoscopic Resection Of Ectopic Pancreas In The Posterior Wall Of Gastric High Body: Case Report And Review Of The Literature")