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NOVEL WAYS TO USE THE INTERNATIONAL SPACE STATION AS AN EXPLORATION ANALOG: INTERNATIONAL PROGRESS IN PLANNING "ISS4MARS"

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Abstract

In October 2020, International Space Station (ISS) Partner Agencies held a set of international workshops to solicit and develop creative and forward-looking ideas for using the ISS as an analog for preparation for Mars missions during its 3rd decade of operations. The workshops brought together participants from nine international space agencies or organizations, with stakeholders consisting of research managers, discipline experts, technology developers, flight physicians, flight operators, and astronauts. Breakout meetings and brainstorming sessions were conducted focusing on the following topics: Critical hazards and countermeasures for the transit to Mars; gravity transitions and early surface operations; environmental control and life support systems; food systems; human microbiome, microbial monitoring, and planetary protection; medical operations for Mars missions; isolation and confinement; autonomous systems and crew-centered autonomy; and communications delay effects on operations.
In many cases the scenarios and approaches identified were compelling but challenging to implement under the current utilization structure used to manage the ISS for experiments. Following the series of workshops, a team of utilization leaders across the ISS partnership worked to compile the workshop recommendations and extract a set of use-cases with their prerequisites and constraints. The work considered the following aspects: what can be effectively done on ISS; which new technologies, approaches and scenarios are feasible; what alternatives could be considered; and what steps should be taken to enable integrated testing and future use of ISS as an analog for Mars missions. The final report will be published so that the use cases can be considered in each agency's strategic planning processes.

This paper will cover the process of international assessment in detail and how this process has influenced and broadened the vision of ISS utilization beyond single experiments to integrated studies and testing for future Mars missions. This approach to international collaboration informs both the next decade of international exploration research on the ISS and advancement

of its utilization as an analog for deep space missions. For many of the participating partners, it also helps to frame the strategy for human research in Artemis as we begin planning for human missions to the moon. We conclude with a summary of the progress on the actions in the report and the additional implementation discussions that have occurred across the partnership.

Introduction

The International Space Station (ISS) international partnership has been discussing how to strategically use the ISS and any future Low Earth Orbit platforms to the greatest extent to prepare for human missions to Mars[1]. These efforts culminated in the virtual 2nd International ISS4Mars Workshop to assess and make recommendations for future work. The workshop approached a fundamental strategic question: *What research approaches would be beneficial on ISS but were not being proposed because they did not fit in the current utilization boundaries?* Although first intended to be a face-to-face meeting in 2020, it was replanned for a series of remote meetings with two major parts in October 2020 and April 2021. Spreading the meetings in a longer time span, even if in remote, proved to be quite successful, providing the needed international expert opinion and commentary. The results included development of innovative ideas for ISS utilization as an analog for crewed missions to deep space and realistic approaches and goals for implementation.

Background

The concept of using ISS as an operational model or simulation of a human mission to Mars has matured internationally over the past decade. In 2011, a NASA technical memo [1] stated that "the highest-possible fidelity simulation of the Earth-to-Mars transit phase is the best fit to ISS capabilities," leading to a focus on ISS as model of the physiological stresses of microgravity during a transit to Mars. However, at that time, the difficulties for modifying ISS operations from the original vision of a laboratory in space toward a deep space flight analog were viewed as too difficult. In 2015 at the IAA Human in Space Symposium [2], the idea of a full Mars mission dry run on ISS was presented as a plenary, and the term "ISS4Mars" was introduced for the first time. Since then, the human exploration scientific and technological community has discussed major issues raised under this idea:

1) What value does the ISS as a deep space analog add beyond ground analogs and smaller steps on ISS?

[1] The workshop was co-organized and -hosted by the ISS partner space agencies, Agenzia Spaziale Italiana (ASI, Rome, Italy), Canadian Space Agency (CSA, Langueuil, Quebec, Canada), Centre National D'Études Spatiales/Institute for Space Medicine and Physiology (CNES/MEDES, Toulouse, France), Deutsches Zentrum für Luft- und Raumfahrt (DLR, Cologne, Germany), European Space Agency (ESA, Noordwijk, Netherlands), Institute of Biomedical Problems (IBMP)/Roscomos (Moscow, Russia), Japan Aerospace Exploration Agency (JAXA, Tokyo, Japan), and National Aeronautics and Space Administration (NASA, USA).

2) What would be the feasibility from the perspectives of both being able to technically achieve Mars analog simulations and manage the scientific impact to other utilization on ISS?

3) What synergies exist with other objectives such as ISS visibility to the general public, extension of ISS operations, and privatization of low earth orbit?

In 2017, NASA began an agency effort to consider whether additional operational changes on ISS could provide opportunities to advance research and countermeasure development for Mars missions. One set of studies looked at options to test medical operations procedures under communications delay, isolation and confinement effects of deep space transit, and surface operations after physiological deconditioning on ISS [3]. A framework of considering every spaceflight as an analog with some level of fidelity for Mars missions (Figure 1) was developed strategically as NASA considered its human research plans for ISS, future low Earth orbit platforms and Artemis [4].

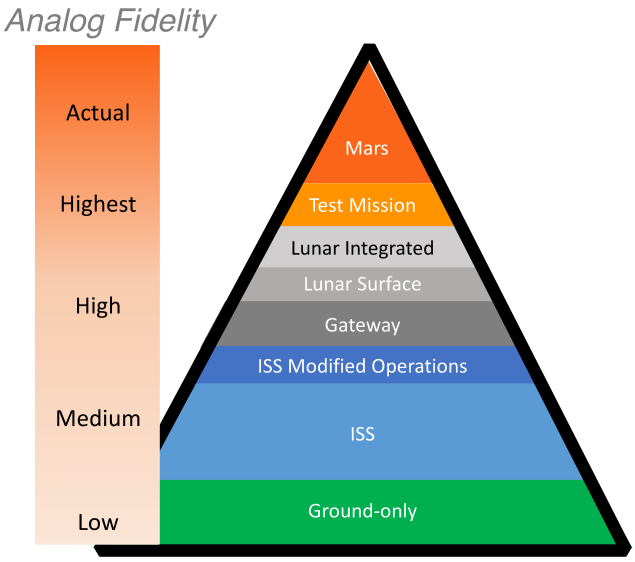

Figure 1. Human Research Cross-platform Flight Testing Approach

In 2018 the ISS international partner community of space agencies gathered for the 1st ISS4Mars workshop, held in Rome in conjunction with the International Space Life Sciences Working Group (ISLSWG) meeting. This workshop was important to start world-wide thinking and lively debates with all the ISS partners involved. A second set of NASA-Russian discussions added testing of operations under situations that validated approaches to communications delay and autonomy across the mission [5]. Following further international discussions at the 2019 IAC in Washington, DC and the 2020 Human Research Program Investigators Workshop, the ISS international partners agreed that it would take significant effort to develop the ideas, it was worth planning for a multi- agency and multi-disciplinary discussion and organization of the

2nd International ISS4Mars Workshop in 2020 and 2021. Previous international papers and congresses are listed in Table 1, and the progression of the ISS4Mars workshops is depicted in Figure 2.

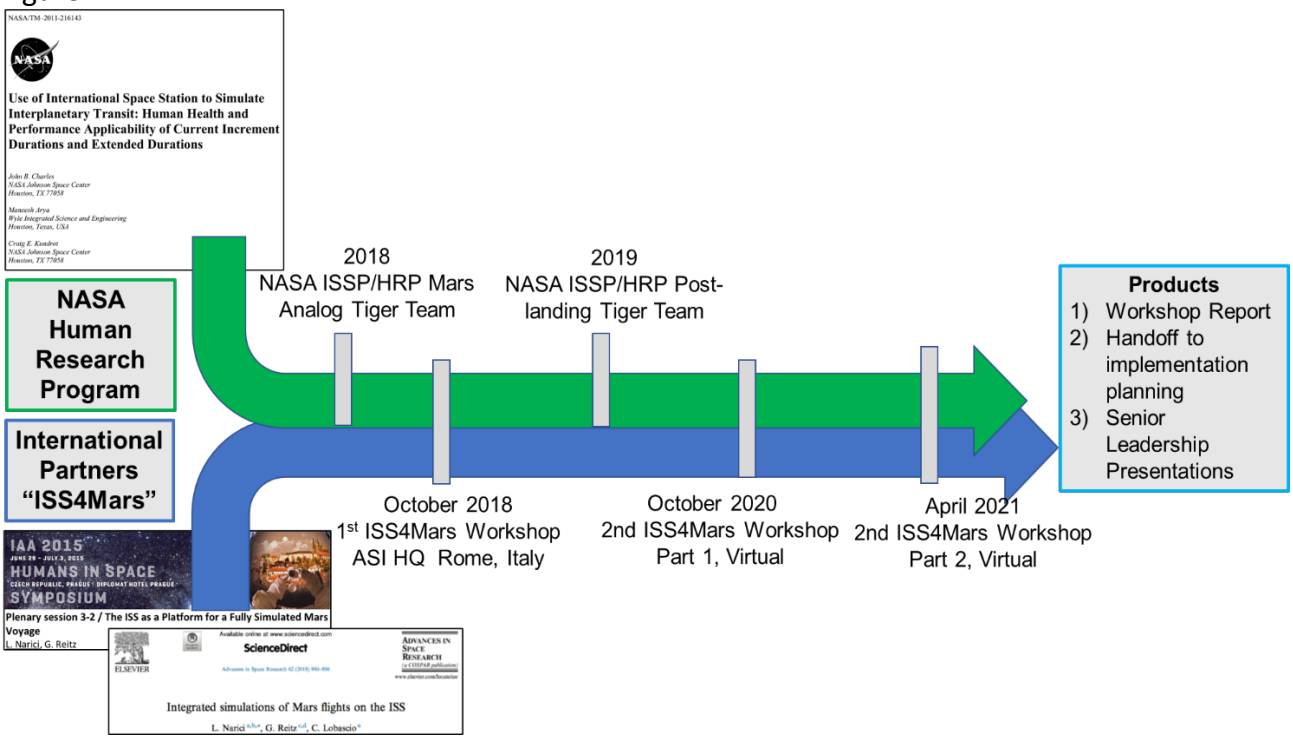

Figure 2. Convergence of NASA and International Discussions for ISS4Mars

Workshop Structure

The purpose of the 2nd International ISS4Mars workshop was to obtain structured responses to the questions previously mentioned and make recommendations for new and innovative uses of ISS as an analog for Mars missions. The ISS4Mars organizing committee achieved these objectives by bringing together international strategic leaders in human spaceflight to develop creative approaches to be implemented in the third decade of ISS operations. By including perspectives from all ISS partner agencies and bringing together expertise from the research and technology communities, medical operations, and flight operations community, the goal was to develop synergies between these communities to define the best exploration-enabling approaches. The ISS could enable future exploration by evolving the operations paradigms to foster success in challenging new environments and aiding in the understanding of the crew operational and medical capabilities in those environments. A key assumption was that with a few temporary and short-term changes in operational approaches, the ISS partnership could simulate key aspects of Mars missions, including challenges of communication outages and latencies and crew autonomy for planetary missions. The workshop defined exploration challenges, developed recommendations about temporary changes in operations to simulate those challenges on ISS, and provided suggestions for future implementation.

The workshop was first thought to be an immersive 2-day face to face workshop, hosted by DLR in the :envihab facility. When the pandemic forced moving it into a remote meeting, the organizers carefully replanned to a virtual format and made several choices to exploit the peculiarities of remote assemblies. In the end, the immersive face-to-face 2-day meeting was divided in two remote 2-day meetings, held six months apart, with part I in October 2020 and part II in April 2021, as shown in Figure 3. The organizing committee identified a writing committee to work, also remotely, between the meetings to review the output and prepare the materials as input for the second meeting. Also, following the second remote meeting, the same committee was then tasked with producing a full workshop report.

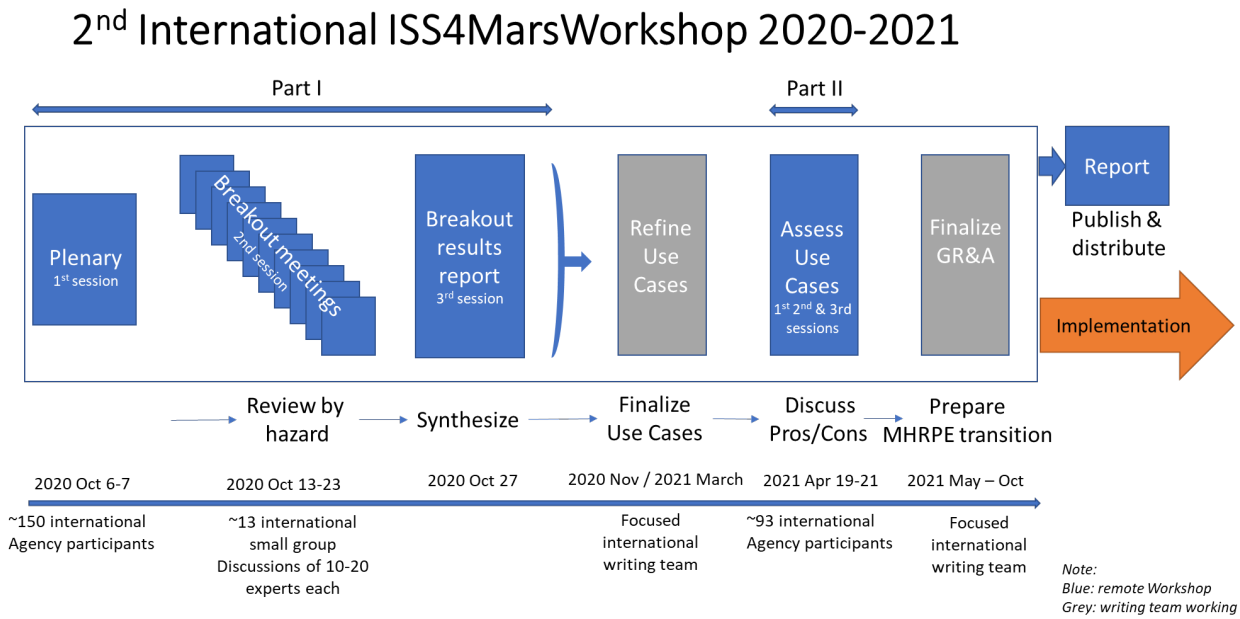

Figure 3. ISS4Mars Process Structure

The format for the ISS4Mars workshop was designed to encourage and enable inclusive, diverse discussions and identification of innovative ideas for defining recommendations for using ISS as a Mars mission analog. The Five Hazards of Human Spaceflight for deep space and Mars missions, as defined by NASA's Human Research Program, were used as a central reference [6, 7, 3] for structuring the workshop. The ISS4Mars participants were invited from within each participating Space Agency, and they included strategic leaders; experts in space-based biomedical research and technology, flight surgeons, physicians, astronauts, ISS Program science management, and flight operators.

The **ISS4Mars workshop part I** was in October 2020 and divided into four sessions. The *first session* (October 6-7) was a series of short plenary talks by the different agency's representatives describing agency leadership perspectives on Mars exploration, enabling architecture for Mars missions and flight operations, the fidelity of Mars analogs, and medical operations for a Mars mission. The *second session* (October 12-23) of the workshop was a set of breakout meetings covering different issues designed to address two key topics:

1) What are the key challenges in the area for a Mars Mission?

2) How could ISS be modified to help address or simulate these challenges?

Each group was also asked to provide one to two recommendations to the ISS Partnership to increase exploration relevance, simulation opportunities for research, and testing of candidate solutions. The participants of each breakout meeting were invited experts from the ISS international partner agencies. For the *third session* (plenary, October 27), a representative from each breakout meeting gave a report about the findings, answers to the questions, and recommendations of the group, answering the questions from the audience. The *fourth session* was a discussion session on use of ISS for longer simulations and ISS partnerships for using ISS as an analog.

After part I was completed, the writing committee, coordinated a series of remote meetings to develop use-case scenarios and ground rules and assumptions based on the findings from the breakout meetings, which would be used for ISS4Mars Workshop part II. Each of these use cases incorporate one or more of the relevant five hazards of human spaceflight. For each recommended use case, the writing committee identified attributes, pre-requisites, and an approach to international coordination. The writing committee comprised of technical and scientific experts from ASI, CSA, DLR, ESA, and NASA.

ISS4Mars Workshop part II was held in April 2021 and divided into three sessions. The *first session* (April 19) focused on presenting the ISS4Mars analog use-cases, which were derived from the findings and recommendations of the first part of the workshop. The *second session* (April 19) was a panel discussion about existing ISS technical information and scientific findings that were relevant to the use-cases. Specific topics examined were:

8777i1) What makes an effective ground analog for isolation and confinement and how can it be applied to the use of ISS or future low Earth orbit platforms?

2) What do we know from sensorimotor testing after ISS missions and what can we still learn?

3) What do we know about microgravity countermeasures and artificial gravity?

4) International management approaches to using ISS for simulation.

The *third session* (April 20) included two breakout meetings to further examine the use-cases from ISS stakeholder perspectives. Two specific questions were addressed:

1) What are the main concerns that you would raise about the proposed use-cases and why?

2) What supporting rationale could you offer to counter the list of concerns?

The perspectives were provided by participants that included Astronauts, Flight Controllers, Senior Management, and Utilization Community. Following each breakout meeting a report of the findings was prepared. The wrap up of the 2-day meeting included next step suggestions, schedule for producing a public report of the whole workshop, and a roundtable discussion with concluding remarks from senior leadership management from the ISS partner agencies.

After the workshop part II, the writing committee further consolidated, reviewed, and developed use-cases, made recommendations for implementation, and wrote a final report.

Use-Cases and Ground Rules & Assumptions

A series of use-cases and ground rules and assumptions were used for follow-on discussions by the workshop participants on specific Mars simulation concepts, feasible implementation plan within the framework of ISS standard operations, innovative ideas for expanding ISS capabilities to support the use-cases, and international partnerships. A total of eight use-cases were studied and developed. However, after more in depth evaluation and comment, three of the use-cases were determined to be too challenging to be currently implemented on ISS, or dependent on infrastructure or precursor studies that had not yet been completed. The five recommended use-cases are as follows:

Earth-independent Medical Operations Analog. This use-case simulates nominal medical operations, such as crew monitoring their health status, care, and nutrition needs and contingency medical emergencies, and would go beyond typical telemedicine approaches [8] to incorporate simulated blackout periods or communications delay [9].

Earth-independent Integrated Operations Analog. The ISS would implement an ISS-to-ground communication time-delay and simulated exploration mission control center. The communication time delay would be a maximum of five minutes as a start over a period of two weeks [10].

Earth-independent ECLSS, Food, and Autonomy Analog. This use-case builds off ground analogs to test available exploration food and Environmental Control and Life Support System (ECLSS) on ISS over a one-year period. It would demonstrate Earth-independent monitoring, decision-support, maintenance, and repair procedures for habitation systems components [11] Additionally, the use-case will include the entire ISS and an exploration-class food for the entire crew, though individuals may opt out of the research [12].

Lower Body Negative Pressure (LBNP) Countermeasure Analog. This use-case would implement an LBNP countermeasure [13] for individual crew members.

Post-landing Surface Fitness Analog. This use-case tests post-landing task performance after long-duration spaceflight with supervised autonomy [14] and sensorimotor countermeasures implemented pre-, in-, and post-flight [15].

In addition to specific guidance for how to approach the use-cases that will be included in the final report of the workshop, a set of ground rules and assumptions were developed to assure all stakeholders across agencies that the plans will ensure crew health and safety during the simulation, preserve research best practices, and aid in the further development of the use-case scenarios. These are as follows: 1) the crew will be briefed on and committed to mission parameters before mission naming; 2) flight, medical, or crew operations personnel can stop the analog at any time; 3) current process for ensuring crew well-being through regular check-ups will continue; however, if during a comm-delay, the checkups will be over comm-delay; 4)

the ISS will provide crew with countermeasures, including Mars-relevant and established protocols for treatment of potential health issues; 5) research data privacy will be maintained per current protocols; and 6) research will be planned within normal increment planning cycles.

Next Steps

For each use-case and test, the next step is development of an end-to-end implementation plan considering all aspects of the mission and enabling the selection of investigators to perform the research either as directed or competed research opportunities. On September 1, 2021, The full set of use cases, recommendations and ground rules and assumptions were transitioned from the workshop organizing committee to the existing international working group, the Multilateral Human Research Panel for Exploration (MHRPE), who already works on coordinating human research on the International Space Station and includes many members of the writing committee and authors of this paper. Coordination of implementation planning by MHRPE will 1) confirm that plans have direct linkage to exploration missions and demonstrate why each planned study is needed, and 2) ensure research has been appropriately tested on the ground prior to flight, including completion of pre-requisite work. ISS4Mars activities will be coordinated with international, science, engineering, ops, crew, transportation providers, and safety stakeholders and will be scheduled so that they are compatible with ISS operations (e.g. visiting vehicle, EVAs, other research activities, etc.). Other research users will opt-in/out during simulation windows, and this will be coordinated during ISS planning cycles. The ISS Program will 1) implement appropriate procedures, training, and crew selection to support research objectives and safe operations, 2) preplan for breaking simulation in case of emergencies, and 3) communicate with and support crew families.

Summary

ISS has been a key testbed as an analog for the hazards of a microgravity transit to Mars. The ISS4Mars international coordination and visioning had the expected outcome of assessing validity and feasibility of analog concepts, imagining possible implementation procedures (even if different than the past), involving the whole partnership, incorporating this strategy into national programs, and proposing technical and scientific calls toward this ISS4Mars initiative.

Through these series of workshops, the international community responded to the question: *What research approaches would be beneficial on ISS but were not being proposed because they did not fit in the current utilization boundaries?* The discussions led to a set of ideas about innovative uses of ISS as an analog for a broader set of human challenges for deep space exploration and has been consolidated between NASA and international partners under the name “ISS4Mars.” Recommended Mars analog activities close knowledge gaps that cannot be accomplished on Earth were identified that will benefit the future of international exploration of deep space. Future Mars programs will need to test missions with sufficient fidelity and integration for confidence in mission success. ISS4Mars will provide ISS enhanced fidelity for Mars risk-reduction research across all five hazards of human spaceflight (gravity changes,

radiation, isolation and confinement, distance from Earth, and hostile closed environments). ISS International Partners have endorsed the approach and developed strategic recommendations for ground rules and assumptions and use-cases. ISS4Mars will proceed through implementation steps under international leadership of the Multilateral Human Research Panel for Exploration (MHRPE), ISS Program leaders, and other stakeholders for further planning and implementation.

Acknowledgments

We want to thank our amazing advisor and facilitator, Sally Rideout from the CSA whose creative solutions made this workshop more effective than it would have been in person. We also thank Erin Welshans who helped us keep the work flowing across so many sessions and virtual meetings. We also want to thank NASA ISS Program Manager, Joel Montalbano for encouraging us to think outside the box and helping to create a supportive space for new thinking. His guidance about how to work together internationally to make steps in new directions, had significant influence on this collaboration.

Table 1. ISS4Mars: Major International Congresses and Papers

	Title	Authors	Congress and Session or Journal	Paper
2015	*The ISS as a Platform for a Fully Simulated Mars Voyage*	L. Narici, G. Reitz	IAA – Humans in Space, Prague (CZ), Plenary	[2]
2017	*Exploration and the International Space Station*	S. Scimemi	IAC – Adelaide (AUS) A1.4 The International Space Station in LEO and the Deep Space Habitat in Cis- Lunar Space as platforms for simulated Mars voyages	--
	Integrated Simulations of Mars flights on the ISS	L. Narici, G. Reitz		[16]
	ISS4Mars: Employing ISS Modules for a Mars Mission Dry Run	C. Lobascio, F. Bandini, M. Cardano , E. Gargioli , D. Saia		[17]
	Evolution of the International Space Station Life Support and Habitation Systems for Deep Space Exploration	R.L. Gatens, M.S. Anderson		[11]
	Utilizing the international space station as a simulation platform for deep space travel	E.E. Morgan		[18]
2018	*Integrated simulations of Mars flights on the ISS*	L. Narici, G. Reitz, C. Lobascio	*Advances in Space Research*	[19]
	ISS4Mars, Integrated Simulations of Mars Flights on the ISS: the radiation issues	L. Narici, G. Reitz	COSPAR – Pasadena Ca (USA) F2.2 Space radiation risk, quality of radiation and countermeasures	--
	The ISS as a Platform for a fully simulated Mars Voyage	L. Narici, G. Reitz	COSPAR – Pasadena Ca (USA) PEX.2 Human and robotic exploration of the Moon, Mars and NEOs (*)	--
2019	ISS-Moon-Mars: Using spaceflight platforms to study and simulate future missions	**Speakers**: O. Orlov, J. Jordan, WH Paloski, O. Kotov, J. Fogarty, M. Shirakawa, M. Kharlamov, R. Gatens, M. Rucker, MA Perino	IAC – Washington D.C. (USA) ***Special Session**: Panel discussion* **Moderators** L. Narici, J. Robinson	--
	Innovative Approaches to using the International Space Station as a Mars Transit Analog	J. Robinson, M.C. Waid, D. Korth, M. Rucker, R. Renfrew	IAC – Washington D.C. (USA) B3.3 Utilization & Exploitation of Human Spaceflight Systems	[3]
	A strategic vision for the use of ISS and the lunar vicinity as human research analogs for future Mars missions	J. Robinson, S. Scimemi, M.C. Waid, W.H. Paloki, O. Kotov	IAA Humans in Space Symposium, Dubai, UAE Plenary	--
	Simulations of Mars Flights on the ISS: an update	L. Narici, P. Graef, O. Kotov, G. Mascetti, G. Reitz, J. Robinson, S. Scimemi, M.C. Waid	COSPAR – Sidney (AUS) *Remote* F2.2 Space radiation risk, quality of radiation and countermeasures	--
	Use of ISS and ARTEMIS as analogs for future Mars missions: a strategic view	J.A. Robinson, S. Scimem, M. Rucker, M.C. Waid,	COSPAR – Sidney (AUS) *Remote*	--

2020		J. Fogarty, W.H. Paloski, O. Kotov	F5.2 There and Back Again - An Astronaut's Tale: NASA	
	ISS (and Lunar platforms) as Exploration analogs for human missions to Mars	J. Robinson, W.H. Paloski, J. Fogarty, M. Waid, C. Kundrot, K. Sato	NASA Human Research Program Investigator's Workshop Plenary	--
	Exploration research strategy for human missions to Mars: Planetary protection research on the ISS and Artemis	J. Robinson, W.H. Paloski, J. Fogarty, M. Waid, C. Kundrot, K. Sato, N. Rayl, F. Chiaramonte	COSPAR Planetary Protection Meeting Plenary	--
2021	*Novel Ways to Use the International Space Station as an Exploration Analog: International Progress in Planning "ISS4Mars"*	J.A. Robinson, T.J. Ngo-Anh, I. Marcil, B. Shishkov, K. Murakami, K. Stang, K. Oleg, V. Cotronei, L. Narici, V. Savinkov, M.C. Waid, K. Sato, S. Scimemi, R. Gatens	IAC – Dubai (UAE) B3.3 Utilization & Exploitation of Human Spaceflight Systems	This paper
	Use of the International Space Station and Artemis to Prepare for Human Missions to Mars	J.A. Robinson, S. Platts, W.H. Paloski	Submitted for publication	[4]

Table 2. ISS4Mars 2nd International Workshop Key Contributors

Organizing Committee, *Writing Committee & Key Contributers	
ASI	*Livio Narici*,* Cesare Lobascio, Dario Castagnolo, Vittorio Cotronei
CNES	*Didier Chaput, Allain Maillet*
CSA	*Isabelle Marcil*, Isabelle Tremblay*, *Sally Rideout,* David Saint-Jacques, Raffi Kuyujian, Perry Johnson-Green*
DLR	*Michaela Girgenrath*, Peter Graef, Katrin Stang*,* Jörn Rittweger, Juergen Drescher, Jens Tank, Jens Hauslage, Jens Jordan, Ruth Hemmersback, Petra Rettberg, Ralf Möller, Kristina Beblo-Vranesevic, Stefan Schneider, Sarah Piechowski, Christian Mühl
ESA	*Jennifer Ngo-Anh*,* Angelique van Ombergen, Guillaume Weerts, Christophe Lasseur, Christel Paille, Gerhard Kminek, Rüdiger Seine
IBMP	*Oleg Kotov,* Oleg Orlov
Roscosmos	Boris Shishkov, Vasily Savinkov
GCTC	Maxim Kharlamov, Pavel Dolgov
JAXA	*Keiji Murakami,* Sogo Nakanoya, Masaki Shirakawa, Chie Matsuda, Satoshi Furakawa, Sayaka Umemura
NASA HRP and CHP SCLT	*Jennifer Fogarty, Michael Waid*,* Marissa Rosenberg, Grace Douglas, Sarah Wallace, Sharmi Watkins, Kris Lehnhardt, Moriah Thompson, Jim Picano. Tom Williams, Sandra Whitmire, Jancy McPhee, Steve Platts
NASA HEO	*Sam Scimemi, Julie Robinson*,* Robyn Gatens, Jim Broyan, Bette Siegel
NASA SMD	*Kevin Sato*,* Aaron Regberg
NASA STMD	Terry Fong, Jeremy Frank
NASA ISSP and FOD	Kirk Costello, Jennifer Buchli, Joel Montalbano, Serena Auñon-Chancellor (FOD), Whitney Maples (FOD)
Discussions from many additional leaders from NASA, IBMP, GCTC, DLR, ASI, ESA, CNES, CSA, and JAXA	

Table 3. Interdisciplinary NASA Tiger Teams Involved in Developing and Evaluating ISS4Mars Use-Cases

Team	Year	
HRP Element Scientists Providing Content	2017-2019	Dr. Kris Lenhardt (Exploration Medical Capability) Dr. Peter Norsk (Human Health and Countermeasures) Dr. Thomas Williams (Human Factors and Behavioral Performance)
ISS as a Mars Analog Tiger Team	2018-2019	Dr. Erik Antonsen (Human Research Program) Dr. Megan Behnken (JSC Flight Operations Directorate, Crew Office line of site) Kyle Brewer (ISS Vehicle Office, Mission Evaluation Room Manager) Jennifer Buchli (ISS Program Science Office) Dr. Steven Platts (Human Research Program Deputy Scientist) Royce Renfrew (JSC Flight Operations Directorate, Flight Director Office line of site) David Korth (ISS Systems Engineering & Integration Manager) Dr. Kris Lehnhardt (Human Research Program

		Jennifer Scott Williams (ISS Research Integration Office) Dr. Leo Yowell (ISS Research Integration Office) Dr. Julie Robinson (ISS Program Office), Tiger Team Lead Michael Waid (Human Research Program Office)
Post-landing Tiger Team	2019	Dr. Megan Behnken (JSC Flight Operations Directorate, Crew Office line of site) Corey Davis (JSC Flight Operations Directorate) Michael Gernhardt (JSC Engineering Directorate) Dr. Steve Hoffman (JSC Exploration Integration) Vincent Lacourt (Commercial Crew Office) David Read (JSC Engineering Directorate) Dr. Steve Piper (JSC Medical Operations) Dr. Julie Robinson (NASA Headquarters) Marissa Rosenberg (JSC Sensorimotor Team) Nichole Schwanbeck (Human Research Program) Holly Vavrin (ISS Transportation Integration) Michael Waid (Human Research Program Office), Tiger Team Lead

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