Journal of Space Operations & Communicator (ISSN 2410-0005), Vol. 19 No. 3, Year 2023

Lunar Operations: On the Technology Acceptance of Robotics

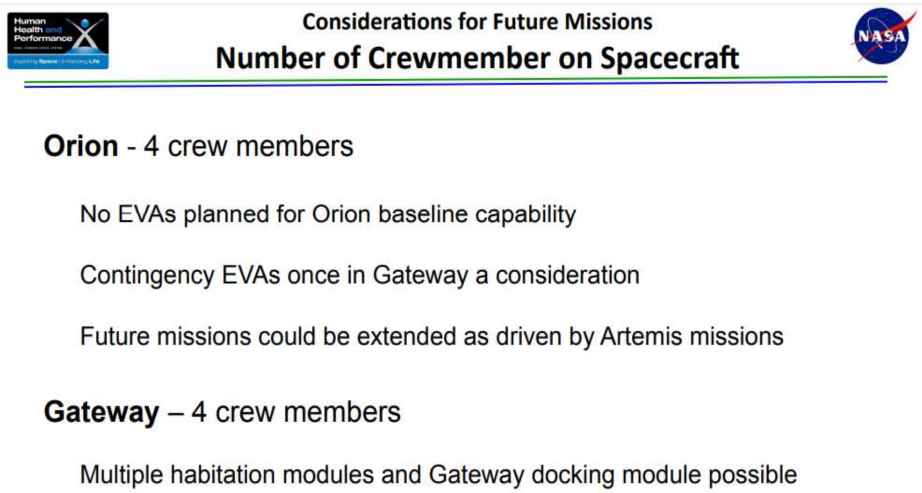
Ronald H. Freeman, PhD
Space Operations & Support Technical Committee, AIAA

Abstract: Lunar dust and radiation threaten both robotic and astronaut-led operations on the Moon. In spite of shielding for both, the risks have not been significantly mitigated. Apollo astronauts complained of health problems. ISS astronauts have been challenged as well. Maintaining the health of astronauts has always been prioritized in space exploration. With technology gains in robotics, the question of robotics replacing astronaut exposure represents a change paradigm. Change management of lunar operations will require technology acceptance of changes in the requirements engineering for lunar operations. NASA standards have instituionalized astronautic practices but documented requirement prioritization has differed over the years. Technology change results in its perception differences for which technological substitutions or minimally their coopted integration may be requred. This paper aims to explore how technology acceptance of robotic operations may be employed on the Moon.

Keywords: Technology Acceptance Model (TAM),Technology-Task Fitness (TTF), Fit-Appropriation Model (FAM), and lunar robotics.

I. Introduction

Emotional connections of over 60 years of Apollo and ISS programs meant astronauts solicited more attention than robots. Robotic missions go farther, sooner, and at less cost. Robots don't match human ability to improvise and respond quickly. Such perceptions represent a behavioral phenomenon modeled out of complex sitational relationships (e.g., BI, ATT, PEOU, and PU) between environment, objects, and people which determine their technology acceptance (TA). The need to investigate innovations that are non-similar to legacy hardware versions of comparable functionality indicates an experientially cognitive dissonance. Consequently, new post-adoptive TA may be problematic due to stakeholder ignorance of TA variability associated with problem-solving activities [1]. Artemis, a campaign of programs, hardware, and capabilities, promises to enable a sustainable operations on the Moon. Science operations will need to be robust enough to operate without intervention for long periods of time. A lunar task, for example, may require a volatile surface sample return be first collected with tools developed by an extra-vehicular activity (EVA) team, stored in a freezer developed and built by a commercial entity, installed and powered in a commercial return vehicle, temporarily installed with resource connections on Gateway, before finally transferring to Orion for ground Earth descent and turned over to scientists. The real-time operational challenges from such a complex sequence of events suggest a need for standardization in order to establish interoperability (mechanical interfaces, connector types, software, data types, etc). Ensuring the health, safety and performance of those exposed to the space environment requires a research and technology portfolio that spans clinical, basic and applied research and technology development activities, as well as the operational and policy issues related to human spaceflight. Therefore, some guidelines for EVAs have been proposed. Depending on the selected provider and mission requirements, science operations, includibg lunar sample collections, traditionally the responsibility of Apollo astronauts may be as easily performed by a robots. Lunar robotics will, however, entail delivery of payloads, internally or externally mounted, for which utilization of power, thermal, and data resources from the vehicle is required. Leveraging decades of experience, Payload and Mission Operations Division (PMOD) at NASA's Marshall Space Flight Center will connect science to space from the ground up, providing a suite of mission operations derived from requirements development and payload integration [2].



Considerations for Future Missions

Number of Crewmember on Spacecraft

Orion - 4 crew members

No EVAs planned for Orion baseline capability

Contingency EVAs once in Gateway a consideration

Future missions could be extended as driven by Artemis missions

Gateway – 4 crew members

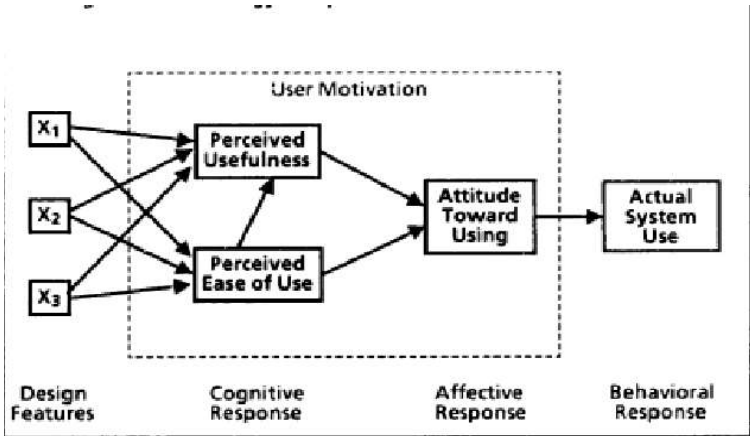
Multiple habitation modules and Gateway docking module possible

Unlike Internatonal Space Station (ISS)) operations, Artemis will experience times with no crew present. Crews will have left behind experiments to operate and monitor, but troubleshooting will only be available remotely or robotically. The human lander system (HLS) transports astronauts from Orion or Gateway to the Moon and back. Astronauts wear EVA spacesuits when exploring the lunar surface and performing EVA activities for maintenance on Gateway. EVAs are not planned for Orion baseline capability. And, continency EVAs once in Gateway will be considered. Voice communications will occur between the various endpoints, such as Orion and Gateway, inside the Gateway between modules, Orion or Gateway with the HLS, HLS (or Gateway) with EVAs, or any communications between EVAs [3]. With a short ~2-5 sec communication latency time, telerobotics operation from the Earth maybe acceptable compared to control conducted by astronauts in cislunar space. There may be a time efficiency and potential for 24-hour operations to be gained by Earth telerobotic operation compared with using very limited cislunar crew time. Such operations precede lunar surface human-robotic operations. Human EVAs bring NASA concepts to reality and sustain them for many years. However, fully robotic missions to deliver scientific payloads to the lunar surface were explored to understand the benefits of and interactions between robotics, Artemis infrastructure, and human extravehicular activity to bring the concepts to reality and sustain them for many years [4].

To enable return of human missions to the surface of the Moon, a new study was initiated to assess the feasibility of developing an evolvable, economical and sustainable lunar surface infrastructure using a public-private partnerships approach. Developing lunar surface infrastructure capabilities will initially support robotic missions and later evolve to full-scale commercial infrastructure services in support of human missions. Note that the challenges of lunar dust encompass both the natural environment as well as induced environments (i.e., plume surface interactions and crew/vehicle activities). Apollo astronauts uncovered a plethora of issues related to the "dust problem" including clogging of joints and mechanisms, human health toxicology, false instrument readings, vision obscuration, abrasion of surfaces, failures of seals, and thermal control. In the Artemis era, dust mitigation should be a consideration for mechanisms, electronics, connectors, seals, softgoods, filtration, crew health and monitoring, thermal systems, power systems, optical systems, and plume surface interactions, among others. Currently, EHP (Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program), HLS, Gateway, Orion, and CLPS, all have dust mitigation requirements and solutions.

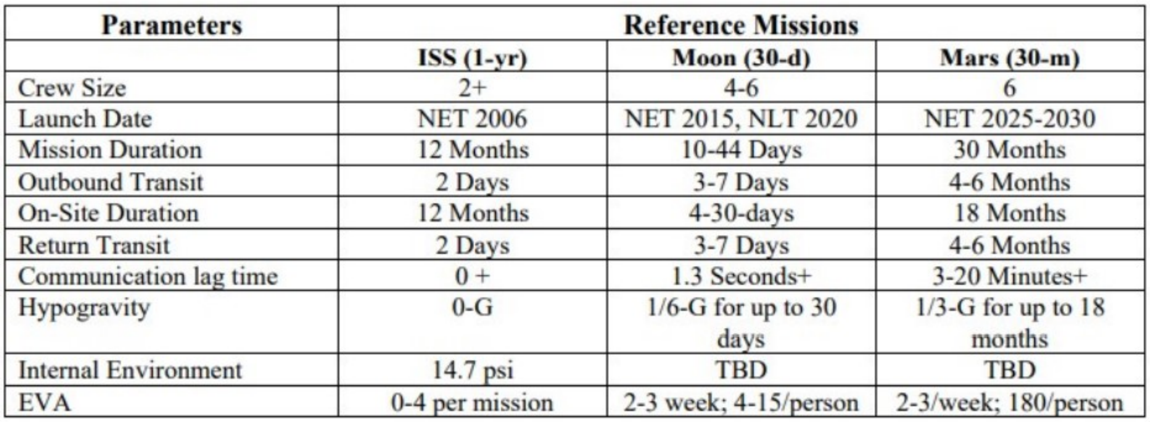
II. Technology Acceptance

Technology acceptance and use is determined by behavioral intent (BI), which is affected by attitude towards use (ATT), and the direct and indirect effects of perceived ease of use (PEOU) and perceived usefulness (PU) (Davis, 1985; 1989).



Technology Acceptance Model (Davis, 1985)

The 2005 Bioastronautics Roadmap: A Risk Reduction Strategy for Human Space Exploration (NASA/SP–2004–6113) may be considered as NASA's design for lunar program's behavior intent. The Research Maximization and Prioritization Task Force (ReMAP) utilized the Roadmap prioritizing lunar operations as priority #2 in determining the effects of exposure to ultra fine and larger (respirable and non-respirable) particles (e.g., lunar dust) on crew health, safety and performance.



Parameters	Reference Missions		
	ISS (1-yr)	Moon (30-d)	Mars (30-m)
Crew Size	2+	4-6	6
Launch Date	NET 2006	NET 2015, NLT 2020	NET 2025-2030
Mission Duration	12 Months	10-44 Days	30 Months
Outbound Transit	2 Days	3-7 Days	4-6 Months
On-Site Duration	12 Months	4-30-days	18 Months
Return Transit	2 Days	3-7 Days	4-6 Months
Communication lag time	0 +	1.3 Seconds+	3-20 Minutes+
Hypogravity	0-G	1/6-G for up to 30 days	1/3-G for up to 18 months
Internal Environment	14.7 psi	TBD	TBD
EVA	0-4 per mission	2-3 week; 4-15/person	2-3/week; 180/person

EVA performance and crew health might have been compromised by inadequate EVA systems, a risk influenced by mission duration, lack of return and re-supply capability, and dust contamination of suit bearings and joints. Long-duration crew stays on the Moon may require astronauts wearing increased EVA hardware with potential decreased suit mobility from contaminated bearings and joints. Since risk of human ingestion or contact with lunar dust is mitigated with heavy spacesuits of low flexibility/ mobility, astronaut attitude towards use (ATT) may compromise their full acceptance.

The 2005 Bioastronautics Roadmap focuses on two types of risks: health and medical risks, and engineering technology and system performance risks. When the President in 2004 authorized robotic missions for Mars, a lower behavior intention (BI) for robots was indicated for the Moon (Roadmap Priority 5 vs Mars # 2). However, the research and technology questions on how to achieve EVA and robotic cooperation ranked Lunar missions #1 priority, an issue that must either be addressed or retired as an accepted risk decision.

The 2020 Technology Taxonomy (Roadmap), an integrated set of seventeen technology areas, informed decisions on NASA’s technology policy, prioritization, and strategic investments. Human-robot system interaction, crucial for future space exploration, had to be effective, efficient, and natural. Requiring human-system interaction across multiple spatial ranges, space exploration needed to function in the presence of multiple control loops, and over a wide range of time delays. A robot may be remotely operated by an astronaut in close proximity, by an astronaut in-orbit above a planetary surface, or by mission controllers on Earth with progressive reductions in situational awareness and response time. The ultimate efficacy of robotic systems depends greatly upon the interfaces that humans use to operate them. Alternatively, autonomous systems (in the context of robotics, spacecraft) are a cross-domain capability that enables the system to operate in a dynamic environment independent of external control. Direct and indirect effects of perceived ease of use (PEOU) and perceived usefulness (PU) are particularly important on deciding autonomous robotic systems as the lunar surface environment undergoes extreme temperature swings between lunar day and lunar night, and is exposed to solar and cosmic radiation, and bombarded with micro-meteorite particles from time to time [5].

The NASA-STD-3001 established standards for designing EVA and robotic interfaces. Collectively, the documents helped establish trust by providing system requirement development. Positive perception of policy usefulness (or perceived usefulness, PU) is very important, whereas ease of use (PEU)is not equally as significant. Some possible ways to ease implementation include open forum discussions and early distribution of information which would focus on how a new policy improved quality of life and reduced the complications of how current procedures are run [7]. As a precursor of attitude towards use ((ATT), trust determines a very strong indicator for system use (SU).

III. Discussion

Spacesuits worn in low-orbit environments or short-duration operations on lunar surface, have experientially been subjected to degradation from dust, radiation, and other factors. One of the major threats to Artemis missions is the reduction of space security. Therefore, countermeasures to such a threat include fully robotic operations. NASA Engineering and Safety Center (NESC) brought together various stakeholders to provide (1) synergistic approaches for human/robotic science exploration, (2) lunar science exploration engineering challenges and approaches for risk mitigation, and (3) methodologies for defining Artemis mission requirements [8]. Whether astronauts or autonomous robots, lunar operations require enormous efforts and monetary outflows. Yet, the fundametal question asks, "Can robots rather than humans accomplish the same tasks more efficiently, more safely, and at far lower cost?" Robotic system usefulness (PEU) strongly relates to usability (PU). The human user can remotely see through the “eyes” of the robot and feel the real torques in the robotic arms. In other words, with virtual robotic connections, the more strongly involved the user to the robot's environment.The almost inseparable connection between system performance and system utilization relates to the impacts that variable performance changes have on the technology acceptance of robotics due to technology-task fitness (TTF).

The TTF model directly relates to system utilization and performance rates and indirectly to cognitive complexity experienced. As TTF does not address change over time, TTF effectivenes is limited in its predictive ability, at least for collaborative technologies [9].Then, the question "Are robots a better technical (safer) fit to tasks assigned? implies "suited astronauts" represent a poorer fit due to demonstrated spacesuit (as an equivalent radiation/ dust shield) degradation. DeSantis and Poole (1994) considered performance to develop from appropriation (or, how technology's features are selected for use and how social structures enable those features) change over time. According to Fit-Appropriation Model (FAM), both TTF and appropriation work together over time to influence performance. In the case of robotics vs "suited astronauts", the more "fit one" would have fewer appropriation changes and maintain consistent outcomes and perceptions, while the "poor-fit" would make more appropriation changes resulting in improved outcomes and perceptions. Ultimately, mitigation of the initial differences between poor-fit and fit result in no significant differences in performance or perceptions. The mitigation of differences could result from equivalency of harm to both caused by the harshness of the extreme lunar environmental conditions or from the upgrade of the poorer's fitness to its counterpart's standard. Alternatively, dissatisfied with their prior interactions, the poorer-fit might enact different interaction structures available within the domains of technology, task, and communication channels (i.e., adaptive structuration theory). Over time, the original norms (structures) for communication are replaced with new interaction structures [10]. Considered as engineered requirements, both robotics and suited astronauts are "change" agents of lunar operations. Although, the latter through Apollo and ISS norms has had greater socio-technical interactions. Both system operations co-evolve with each other. Therefore, system changes result in problem domain evolution

(Orlikowski & Hoffman, 1997). As problem domain evolution persists in post-system adoption, operational context also changes, causing requirements uncertainty [11].Therefore, the question of "better fit" for robotics or suited astronautics remains open for further discussion.

IV. Conclusion

Crewed extraterrestrial space operations have traditionally been performed by suited astronauts. With greater development of robotic technology, the criticality of astronaut exposure to extreme harsh environments requires more drastic management. Robotics is a suggestive option. And, the disruptive technology for Artemis operations on the Moon indicates a shift from the Apollo program, hence requiring what may be referred to as "change management". Technology acceptance of lunar robotics as the mainstay of lunar operations indicates the real adoption of Davis' Technology Acceptance Model (1985) and later, of Dennis' Fit-Appropriation Model (2001). Both models focus on the agency of stakeholders--- system use of TAM's perceived usability and preferential system use of FAM's technology-task fitness. Cultural stakes are tested with greater understanding of the problem domain exposed to operations. With an ever-evolving problem domain, NASA reviews and communications show documentary prioritization of technical objectives that directs the trajectory of technical operations and their health.

References

[1] Lala, G. (2014). The emergence and development of the technology acceptance model (TAM). *Marketing from Information to Decision* (7), 149-160.

[2] Howley, I. & Johnson, J. (2023). Science off the Earth: An integrated approach to science operations in the Artemis Era and beyond. In *SpaceOps 2023-The 17th International Conference on Space Operations*.

[3] Salazar, G. (2022). Establishing trust in NASA’s Artemis campaign Computer-Human Interface (CHI) implementation. In *IEEE Space Mission Challenges for Information Technology/IEEE Space Computing Conference*.

[4] Valinia, A., Grunsfeld, J., Hess, M., Green, J., Schier, J., Haas, J., ... & Stalcup, E. (2022). *Unique science from the Moon in the Artemis Era* (No. NESC-RP-22-01729).

[5] Thangavelautham, J. & Xu, Y. (2022). The design of autonomous robotic technologies for Lunar Launch and Landing Pad (LLP) preparation," *2022 IEEE Aerospace Conference (AERO),* Big Sky, MT.

[6] Valinia, A. (2022). Sustainability of Human Exploration in the Artemis Era A Workshop Report: Unique Science from the Moon in the Artemis Era. In *Future In-Space Operations (FISO) Telecon*. Seminar Presentation.

[7] Pierce, T. (2014). Extending the technology acceptance model: Policy acceptance model (PAM) (Doctoral dissertation, The George Washington University.

[8] Valinia, A., Grunsfeld, J., Hess, M., Green, J., Schier, J., Haas, J., ... & Stalcup, E. (2022). Unique Science from the Moon in the Artemis Era (No. NESC RP-22-01729).

[9] Fuller, R. & Dennis, A.(2009). Does fit matter? The impact of task-technology fit and appropriation on team performance in repeated tasks. *Information Systems Research, 20*(1), 2-17.

[10] Orlikowski, W. J. 2000. Using technology and constituting structures: A practice lens for studying technology in organizations. Organ. Sci. 11(4) 404–428.

[11] Fuller, R. M., & Dennis, A. R. (2009). Does fit matter? The impact of task-technology fit and appropriation on team performance in repeated tasks. *Information Systems Research, 20*(1), 2-17.