

Evaluation of Human and Automation/Robotics Integration Needs for Future Human Exploration Missions

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Abstract— NASA employs Design Reference Missions (DRMs) to define potential architectures for future human exploration missions to deep space, the Moon, and Mars. While DRMs to these destinations share some components, each mission has different needs. This paper focuses on the identified human and automation/robotic integration needs for these future missions. The outcomes of our assessment is a human and automation/robotic (HAR) high-level task list for each of the four DRMs that we reviewed (i.e., Deep Space Sortie, Lunar Visit/Habitation, Deep Space Habitation, and Planetary), as well as a list of common critical HAR factors that drive the design of HAR integration.

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1. INTRODUCTION

Future NASA exploration missions will extend human presence beyond low earth orbit (LEO). The variety of possible mission destinations, durations, and objectives are outlined in Design Reference Missions (DRMs) that are proposed by NASA. These DRMs evolve and change over

time as a result of technology advances, participating organizations, and funding priorities. This paper provides a systematic assessment of the critical factors and needs for effective human and automation/robotic integration (HARI) as delineated by a specific set of NASA DRMs.

NASA's Human Research Program (HRP) funds research efforts aimed at mitigating various human health and performance risks, including the Risk of Inadequate HARI Design. As such, the assessment presented here focuses on a set of DRM categories that are defined in the HRP Requirements Document [1] and summarized in Table 1. For example, Low Earth Orbit (LEO) DRM category includes current and near-term International Space Station 12-month long missions (ISS12) and Commercial Suborbital missions. However, this assessment only includes future missions beyond LEO, namely Deep Space Sortie, Lunar Visit/Habitation, Deep Space (i.e., Lagrange Points L1/L2 and asteroid) Journey/Habitation, and Planetary (i.e., Mars) Visit/Habitation.

2. ASSESSMENT METHOD

Each DRM was reviewed and analyzed by a team of HARI experts with varied technical backgrounds drawn from two NASA centers. In order to conduct a systematic assessment of future critical HARI factors and needs, the team's first step was to identify all the human-automation-robotic (HAR) tasks that were described by or inferred from the NASA DRMs. The HAR tasks were those activities (or tasks) identified from the DRMs that operators in spaceflight (i.e., astronauts) or on Earth must complete

Table 1: Human Research Program Design Reference Mission (DRM) Categories

DRM Categories	Mission Duration	Gravity Environment	Radiation Environment	Earth Return
Low Earth Orbit (LEO)	6 months	Microgravity	LEO – Van Allen	1 day or less
Low Earth Orbit (LEO)	1 year	Microgravity	LEO – Van Allen	1 day or less
Deep Space Sortie	1 month	Microgravity	Deep Space	< 5 days
Lunar Visit/Habitation	1 year	1/6 G	Lunar	5 days
Deep Space Journey/Habitation	1 year	Microgravity	Deep Space	Weeks to Months
Planetary Visit/Habitation	3 years	Fractional & Microgravity	Planetary & Deep Space	Months

using automated or robotic systems. The evaluating team also determined the types of human-system integration and/or interaction required to complete these tasks. Next, based on the collection of HAR tasks, a set of critical HARI factors and needs was derived.

Figure 1 summarizes our assessment process. The framework we used for our assessment was devised to provide a consistent, systematic evaluation across all of the DRMs. One challenge in acquiring a consistent assessment across multiple mission architectures was that each DRM is composed of different mission elements and systems. Consequently, our framework employed generic system classes and human-robot/automation interaction that could be leveraged for comparisons *across* all the DRMs. This “bottom-up” approach (i.e., DRMs→Tasks→Factors) was selected to ensure that the critical HARI factors and needs identified actually arose from the DRM requirements and that these needs could be directly compared across DRMs.



Figure 1: Assessment process overview

Background information for each DRM was obtained from published papers, reports, and presentations [2-9]. Since some DRMs were less mature than others, additional materials such as NASA’s Technology Roadmaps [10], NASA-sponsored workshop proceedings [11] and review articles [12] were included in the assessment, with specific attention paid to advanced automation and robotic agent operations.

3. HUMAN-AUTOMATION-ROBOTIC TASKS, FACTORS, AND SYSTEMS

Traditionally, task analysis is defined as “the study of what an operator (or team of operators) is required to do, in terms of actions and/or cognitive processes, to achieve a system goal” [13]. Often task analyses are conducted to evaluate human-machine interactions in systems. Since the present assessment focused on the mission concepts and architectures described by the DRMs, the tasks identified are necessarily high-level and descriptive. Because the mission architectures are described at high levels, assumptions with further specificity or that lead to deeper HAR task decompositions (e.g., the subtask or cognitive decision level) would have been too speculative and, therefore, not necessarily beneficial. Hence, the identified HAR tasks remain at the descriptive level.

All HAR tasks were considered including those performed by crew in flight and by ground controllers on Earth. In order to facilitate the DRM assessment, tasks were classified according to the following four categories: Spacecraft

Guidance, System Management, Robotic Operations, and Mission Planning, that are elaborated upon next.

Spacecraft Guidance Tasks

HAR Spacecraft Guidance tasks involve the dynamic control of space vehicles. Traditionally, these are considered “piloted” tasks—i.e., operators provide inputs to the spacecraft, which in turn affect the state of the spacecraft, such as the vehicle’s position, orientation, or velocity. Depending on the level of spacecraft automation or whether in an emergency scenario, execution of these HAR tasks frequently requires direct manual input. For these HAR tasks, operators would likely interact with spacecraft systems such as attitude control and propulsion. For example, landing the Apollo Lunar Excursion Module on the Moon would be considered a Spacecraft Guidance HAR task. While there may be other dynamic HAR tasks that require hand-eye coordination, we limited Spacecraft Guidance tasks that control large space vehicles (typically pressurized vessels, but not necessarily).

In this assessment, the following HAR tasks are considered Spacecraft Guidance Tasks:

- Ascent, which includes launching from Earth or from any other planetary body with a significant gravity well.
- Entry/Descent, which includes re-entry to Earth or approaching another planetary body with a significant gravity well. It also includes descent to a planetary body with an atmosphere, such as Mars.
- Landing, the flight phase subsequent to entry and descent, including landing on Earth (on land or sea) or another planetary body with a significant gravity well.
- Docking/Undocking, which includes attaching and detaching one spacecraft from another.
- Maneuver/Reboost/Rendezvous, which includes execution of finite, short dynamic changes in spacecraft attitude, typically when approaching other spacecraft or celestial bodies (e.g., asteroids) with very small gravity wells.
- Drive/Navigate, which includes maneuvers on or near a planetary body that require continuous changes in spacecraft vehicle dynamics. This set of tasks could be considered a subset of Maneuvers/Reboost/Rendezvous.

System Management Tasks

The HAR tasks identified under the category of System Management encompass Fault Detection, Fault Isolation, and Fault Recovery, or, collectively, Fault Detection, Isolation, and Recovery (FDIR). This task set, as the name implies, requires the monitoring of spacecraft systems, identifying system failures, isolating the root cause, and resolving or working around the off-nominal condition.

FDIR is particularly important in complex, automated systems, and is viewed as a critical need for future human-robotic missions [14]. Typically, FDIR is more akin to discrete-state process control and typically will have longer operator response times than Spacecraft Guidance tasks (though not necessarily). On ISS, ground flight controllers are responsible for System Management tasks, monitoring and responding to sub-system issues as they arise, correcting and addressing them in a timely-manner. However, future human exploration missions may require astronauts to immediately address off-nominal failures during emergencies. Moreover, System Management HAR tasks are essential for pre-deployed spacecraft, subsystem, and robotic assets, as the automated checkout of habitats and vehicles is an assumed mission capability [15]. For these HAR tasks, operators would likely interact with spacecraft systems such as thermal, power, communications, command and data handling, and environmental control and life support systems (ECLSS).

Robotic Operations Tasks

Robotic Operations tasks focus on the operations of advanced automation and robotic agents. The NASA DRMs mention various types of highly autonomous systems, but tend to not be specific. Additional references [10,11,14, 16] were consulted to obtain a comprehensive set of Robotic Operations Tasks. For instance, Pedersen et al. [16] provide the following list of functionalities for future robotic agents: assembly, inspection, maintenance, human assistance, mobility, instrument deployment, and science planning and perception. Similarly, Mishkin et al. [14] outline the functionality expected of robotic systems that will assist crew in assembly, habitat construction, sample return, science exploration, and human assistants.

The following are considered HAR Robotic Operations Tasks:

- Complex assembly
 - Capture and Berth: Assembly tasks that require a robotic agent to grab and hold a large spacecraft, vehicle, or module. Typically, capture is necessary before connecting two spacecraft.
 - Heavy lift: Assembly tasks that require a robotic agent to move a large spacecraft, vehicle, or module. As the name implies, the robotic agent must be able to lift significant loads, usually due to the size of the spacecraft, vehicle, or module and the gravity well of the planetary body. Robotic agents may be fixed in place or may translate with the heavy load.
- Site preparation assembly
 - Excavation: Assembly task that requires robotic agent to dig up and/or move large amounts of soil, regolith, or subsurface bedrock.

- Spacecraft support
 - System maintenance: Tasks that require robotic agents to conduct typically mundane and/or repetitive spacecraft maintenance. Maintenance may be conducted on subsystems (e.g., a habitat filter system) while more complex maintenance may include servicing other robotic agents.
 - System preparation: Tasks that require robotic agents to build, repair, and/or conduct emergency care on spacecraft, vehicles, or other subsystems. These tasks would be the responsibility of robotic agents when the crew is unavailable (e.g., not on site) or because the task is too dangerous for the crew (e.g., nuclear power systems).
- Science and assigned activity support
 - Science/sample collection: Tasks that require robotic agents to collect and manipulate terrain samples. These tasks do not require the robotic agent to be in the same physical space as crew. Inherently, the robotic agent will be exposed to extreme environments.
 - Payload assistance: Tasks that require mobile robotic agents to autonomously transport items for the crew's use. The agent may or may not be in direct contact with crew.
 - Crew assistance (physical): Tasks that require robotic agents to collect, hold, and handle specific items, such as tools. These tasks require the robotic agent to cooperate directly with crew. The crew and robotic agent team may be inside or outside a pressurized vehicle.
 - Crew assistance (cognitive): Tasks that require an autonomous agent to provide information and/or make decisions that will help crew complete and execute assigned tasks.
- Exploration
 - Scouting: Tasks that require mobile robotic agents to survey terrain of planetary body to enable scientific exploration. Exploration may be on the surface, from above the surface, or sub-surface (e.g., inside caves or lava tubes). Typically, scouting does not have a scientific objective.
 - Mapping: Scouting but with pre-determined science objectives. This implies the continuous use of scientific instruments and data collection.
 - Sampling/analyzing: Tasks that require mobile robotic agents to collect and analyze surface or sub-surface samples. This implies that the robotic agent is conducting in-situ science.

Mission Planning Tasks

Mission Planning HAR tasks enable mission operations (see also [14]), particularly those supporting the autonomy of crew from ground control, and that were not explicitly

identified in the previous three HAR task categories. The following are considered HAR Mission Planning Tasks:

- Staging operations: Tasks that support mission objectives involving pre-deployed precursor spacecraft systems.
- Strategic planning: Tasks that support the predicting and planning needed to maintain long duration mission operations. Examples of strategic planning tasks include determining whether sufficient power is available for upcoming payload; deciding deployment of robotic assets for scouting; projecting the number of EVAs required next week; and determining maintenance schedules.
- Tactical activity scheduling: Tasks that support daily activity scheduling, which determines what the crew needs to accomplish and execute each day.
- Training: Tasks that support training needs, independent of ground control. These tasks may leverage automation or robotic assets.
- Medical Procedures: Tasks that support execution of medical procedures, independent of ground control. These tasks may leverage automation or robotic assets.

Human-Automation-Robotic Interactions

Each DRM makes various explicit and implicit assumptions with respect to the type of interactions between operators and automation or robotic agents. In order to consistently describe these assumptions, the expected interaction was reviewed and documented for each HAR task within each DRM. As a result, each task required an operator to only *monitor*, to only *command*, or to *both monitor and command* the automation/robotic agent(s). Other descriptions of HAR interactions, e.g., teleoperation, were not employed in order to maintain uniformity across the assessment.

Human-Automation-Robotic Factors

HAR factors are critical elements that will significantly influence HARI design. The set of HAR factors determined from the DRM assessments is summarized in Table 2. Because these factors will affect the type and frequency of interactions as well as the expected overall operational human-system performance, engineers of future HARI will have to contend with them in the design of human-system interactions. While these factors were present in all DRMs, their prominence depended on the particular mission phase (e.g., Earth departure vs. planetary surface operations).

Table 2: Human-Automation-Robotic Factors Descriptions

HAR Factor	Description	Options
Communication Infrastructure	Communication availability between Earth and crew, as well as between crew and automation/robotic agent. This includes latency, quality, intermittency, and bandwidth of communication.	Three levels delineated according to latency: no communication latency, some communication latencies, long communication lags with limited bandwidth.
Spacesuit Environment	Use of a pressurized spacesuit by crew while interacting with automation/robotic agent.	Suited and unsuited were the only conditions considered.
Gravitational Environment	Gravity experienced by crew while interacting with automation/robotic agent.	Microgravity, partial gravity, and hyper-gravity.
Colocation (Operator Proximity)	Proximity of the operator to the automation/robotic agent when commanding and/or monitoring the system.	Operator inside or close to system, operator is outside or far from system, and operator is on Earth.
System Diversity	Number and/or distribution of automation/robotic agents the operator will interact with at any given time.	One or many agents were the only conditions considered.

Generic Systems Classes

Each identified HAR task requires a system to execute the task. A generic naming convention for spacecraft and robotic systems was used to compare HAR task needs across different DRMs. This convention not only facilitated the identification of similarities across DRMs and unique needs for each mission type, it also allowed for an unbiased assessment as follows. While one DRM might mention using Robonaut and another would describe robots fixing rovers, the assessment instead focused on dexterity capabilities, not the specific robot.

Each of the generic systems listed below was present in at least one of the DRM categories evaluated. Few of these systems were unique to single DRMs, many were present in multiple DRMs, and some (e.g., the Crew Capsule) are part of all DRMs.

- *Crew Capsule*: Earth ascent and Earth entry crew vehicle. Typically, the DRMs referred to the Orion Multipurpose Crew Vehicle (MPCV).
- *Crew Habitat Module*: Spacecraft module equipped for crew habitation (sleep, exercise, medical, etc.) and may enable Extravehicular Activity (EVA). For Deep Space Sortie, this is currently called the Exploration Augmentation Module (EAM); for Deep Space Habitation it is the Deep Space Habitat (DSH). For the Planetary DRM, the Crew Habitat Module and Crew Capsule together are currently called the Mars Transfer Vehicle (MTV).
- *Logistics Module*: Module that supports stowage for items such as food, spares, and trash. Typically, it is attached to a Crew Habitat Module.
- *Small Pressurized Exploration Vehicle*: A small, pressurized vehicle that can rove on a surface or navigate near/above the surface (like an asteroid). Capable of sustaining a small number of crewmembers from a few days to up to a month. Some DRMs call this vehicle the Multi-Mission Space Exploration Vehicle (MMSEV). The Lunar DRMs have both small and large pressurized exploration vehicles, where the large vehicle acts like a mobile habitat and could support crew for up to a month.
- *Unpressurized Exploration Vehicle*: A small, unpressurized vehicle that can rove on a surface with one or more crewmembers.
- *Descent/Ascent Vehicle*: A spacecraft that can conduct entry, descent, and landing on a planetary surface. Usually has an adjacent module that allows for departure from planetary surface. The Planetary DRM call this the Descent/Ascent Vehicle (DAV) while the Lunar DRM calls it a Lunar Lander, which also includes an ascent module.
- *Surface Habitat Module/Lander*: A spacecraft that supports crew habitation on a planetary surface. This is distinct from the Crew Habitat Module because the Surface Habitat is intended to operate on the surface. For the Mars/Planetary DRM, the Surface Habitat operates in transit from Earth, on Mars orbit, as well as the planetary surface.
- *Power Surface Asset*: An asset that provides an additional power source, particularly for long duration, planetary missions. This is a fixed-location surface nuclear power plant for the Planetary DRM and a portable, solar one for the Lunar DRM.
- *In-Situ Resource Unit*: An asset that uses materials from the destination and outputs useful products for crew. For the Lunar DRM, options include oxygen, hydrogen, and other volatiles to supply life support, fuel-cell replenishment, and propellant. For the Planetary DRM this also includes production of water, and inert breathing gases (nitrogen and argon).
- *Communication Surface Asset*: A dedicated communication system asset on a planetary surface that facilitates communications to Earth. For the Lunar DRM, this asset is portable. For the Mars DRM this includes a high-powered communications terminal adjacent to the habitat in conjunction with an orbiting Mars network of satellites.
- *Science Instrument Station*: Science instrument assets expected to be deployed on the planetary surface.
- *Integrated Multi-System*: An integrated system of multiple surface assets connected and operated as one system. An example of this is an integrated system that includes Crew Capsule, Crew Habitat Module, and Logistics Module, as outlined in the Deep Space DRMs.
- *Asteroid Robotic Retrieval Vehicle*: Unmanned spacecraft that travels into deep space to retrieve either an asteroid or a boulder from an asteroid, and returns it to a different orbit. This spacecraft is unique to the Deep Space Sortie DRM.
- *Robotic Large Manipulators*: Large robotic arms or manipulators that can carry/lift heavy items (either in place or transporting), capture other spacecraft, and dig/excavate large amounts of regolith. This robotic class may include large drilling machines.
- *Robotic Dexterous Manipulators*: Generally, smaller dexterous robotic arms that are on a mobile platform. They are intended to conduct maintenance, emergency repairs, help construct space assets, help crew in procedure/task execution, and maintain other robots.
- *Robotic Surface Explorers*: Mobile robots that can be on or fly above the surface. They may be used for scouting (goal is not science-oriented), mapping (goal is science oriented), sampling/analyzing (using science instruments), drilling or subsurface exploration, and/or payload assistant (transporting, collecting, following).
- *Autonomous Intelligent Systems*: Augmented intelligence, decision support, or artificial intelligence that will interface with crew to help provide state information as well as decision-making. Autonomous Intelligent Systems are always locally resident with the crew.

Figure 2 provides a summary of the generic systems classes identified across the DRMs. The intersection of column (DRM) and row (system) are colored dark blue if the system is delineated (or explicated mentioned) in the DRM, and light blue denotes an assumed (or inferred) presence in the DRM.

	Deep Space Sortie	Deep Space Journey/ Habitation	Lunar Visit/ Habitation	Planetary Visit/ Habitation
Crew Capsule				
Crew Habitat Module				
Logistics Module				
Small Pressurized Exploration Vehicle				
Unpressurized Exploration Vehicle				
Descent/Ascent Vehicle				
Surface Habitat Module/Lander				
Power Surface Asset				
In-Situ Resource Unit				
Communication Surface Asset				
Science Instrument Station				
Integrated Multi-System				
Asteroid Robotic Retrieval Vehicle				
Robotic Large Manipulators				
Robotic Dexterous Manipulators				
Robotic Surface Explorers				
Autonomous Intelligent Systems				

Legend

Assumed
Delineated

Figure 2: Design Reference Mission and Generic System Class

4. DISCUSSION

Four DRMs (Deep Space Sortie, Lunar Visit/Habitation, Deep Space Journey/Habitation, and Planetary Visit/Habitation) were assessed according to the procedure described above. The first step was to determine the distribution of system classes across the DRMs (summarized in Figure 2). Though details are not included in this paper, our team also identified which HAR task categories (Spacecraft Guidance, System Management, Robotic Operations, and Mission Planning) were expected for each system class. Not all task categories were attributed to all system classes. For each HAR task category (per system class), our team determined or inferred the type of human-automation-robotic interactions and the human-automation-robotic factors that would dominate the HAR integration design. Overall, this assessment provided insight as to which are the most critical future HAR integration design needs from the DRM perspective.

One result evident from this study is that the distribution of systems requiring human-automation-robotic integration across DRMs is unbalanced between surface and Deep Space DRMs. Many more systems are required for surface than for Deep Space DRMs. Similar to a recent National Research Council report [14], each DRM builds upon its predecessors, with a growing need for more systems and elements as missions become more complex.

We observed that the four types of HAR task categories received unequal consideration across the DRMs. Spacecraft Guidance and System Management tasks were most prevalent with very little emphasis on Mission Planning tasks. Discussion about Robotic Operations tasks was unevenly distributed across the DRMs. We noted that many of the assumptions about the capabilities of future of automation and automated vehicles is beyond current NASA

human spaceflight operational experience and will therefore require new human-automation integration design and verification methods. Moreover, while many of the Robotic Operations tasks are conducted remotely (i.e., telerobotics), there are a variety of new robotic systems for which novel human-robotic integration design will be necessary.

Limitations of Assessment Method

Many more insights were derived from the assessment, however, for this paper, our discussion emphasizes overall lessons learned from selected methodology. Because of the breadth of the architectures involved, the cited documents do not delve to a level of detail sufficient to depict all robotic and automation systems or all of the specific HARI use cases that can be expected to arise during a mission. For example, our HAR tasks analysis was not detailed enough to extrapolate HAR integration needs based on individual automation and robotic capabilities that would be expected to result from a specific system, such as the Asteroid Robotic Retrieval Vehicle. Most notably, the Asteroid Robotic Retrieval Vehicle is only present in one DRM. However, that is not to say that the technology development from such a system could not benefit other systems in other DRMs.

While many human-automation/robot interactions were directly identifiable from the DRMs, some had to be inferred or extrapolated from the mission description. Figure 2 depicts the system classes that are “assumed” to be present in the DRM. However, the DRMs are still in work and many of their objectives are still in flux, which leads to significant uncertainty about the human-automation/robot interactions that actually will be required. There still may be other HARI needs that have not yet been identified and that therefore do not exist in any documented form. Further,

regardless of whether they have yet been identified, needs may change numerous times before mission is implemented. Thus, this assessment comprises our best guess of future HARI design needs at this point in time.

One lesson learned from this assessment is that the DRMs are inconsistent with their description of expected interactions between operators and automation/robotic system. Additionally, there was little mention of the type of interaction, i.e., whether crew or ground was expected to have intermittent or continuous communication (or both) with these automation and robotic systems. In the absence of documentation on concepts of operations (ConOps) to better identify HARI use cases across the full spectrum of exploration tasks, it is difficult to provide a more concrete understanding of where the mission HARI challenges reside. Short of ConOps documentation, it would be beneficial for the DRM development community to use a consistent categorization of the expected type of human-automation-robotic interaction. Our assessment was based on a very simplistic categorization (monitor, command, or both). Potentially in future DRM development, HAR tasks could be described relative to how frequently operators are expected to interact with a given subsystem or robotic agent (e.g., must command this system once a day).

Scope of HAR Tasks

In retrospect, assessing the NASA DRMs *limited* the types of HARI tasks that could be identified. At least three types of HAR tasks were included in our assessment: tasks that enable other mission objectives, tasks that support crew autonomy, and tasks that alleviate crew time. Nonetheless, these task types were not fully employed within the DRM documentation that the team obtained. Consequently, additional resources, like the NASA Technology roadmaps [11] and published reviews of future human-automation-robotic integration needs [14] were leveraged for a more complete view of potential HARI tasks.

Most of the DRM documentation focused on major components of the respective mission architectures with very little discussion of the automation/robotic systems that could enable other mission objectives. For example, telemedicine will be critical in future planetary missions, likely requiring new automated systems and/or medical robotics. Another example is the control of robotic agents that support surface EVAs such as a supply-carrying robot to replace Apollo's Module Equipment Transporter (MET). Specifically, mission objectives will require crew to interact with other automation/robotic systems that will need to be designed specifically to support science, telemedicine, and training.

Additionally, the DRMs did not explore or delineate the types of automated and/or robotic systems required to adequately support the crew's autonomous execution of mission tasks (i.e., autonomous from ground control). At this time, it is still unclear which systems will be necessary to accomplish this goal. Hence, future NASA technology

development roadmaps in this area could benefit from evaluating current and future automated/robotic systems.

Similarly, the DRMs did not elaborate on automation/robotic systems that could increase available crew time or make it more efficient. While the DRMs identified robotic systems that increased surface capabilities (e.g., heavy lifting robotic arms), mention of robotic systems that increase available crew time are absent. A significant issue with current ISS space operations is the limited amount of time astronauts have available for the conduct of onboard research. A recent study [17] suggests crew will have even less time for science in future missions. By completing repetitive tasks, automated, intra-vehicular robotic systems could offload crew time. For example, robotic agents could be assigned maintenance tasks. Surface DRMs will necessarily increase maintenance chores simply due to the greater number diverse assets (from habitat to robots and rovers). In turn, the deployment of such robots suggests emphasizing the development of Earth-bound operator-control HAR interfaces for remote robotic agents. Further evaluations of current and future systems will be required before determining the scope of these HAR tasks.

5. FUTURE WORK

The Human Exploration Architecture Team (HAT) evaluates a wide range of DRMs such as missions to Phobos and the Earth-Moon Lagrange Points. Most recently, the Evolvable Mars campaign [18] has gained prominence. Evolvable Mars includes several destinations, with each program advancing the necessary technology to reach farther into our solar system, with the ultimate goal of landing on Mars. Principally, our assessment has evaluated each of the campaign's stepping-stone destinations, from cislunar, Moon, asteroid, and deep space habitat, to Mars. Thus, the implications of our assessment will likely extend and apply to the Evolvable Mars campaign as a whole.

Future publications will include additional insights across DRMs, HAR factors, and future automated/robotic exploration systems. Future work will need to further evaluate which HARI tasks and factors will have to be emphasized within each DRM and across various systems. This work will be aimed at developing a method to identify areas of overlapping effort, where research and advancements in one HAR area could benefit the broadest range of DRMs. Finally, this work will have to take the HAR needs differences between crew and ground control teams into consideration.

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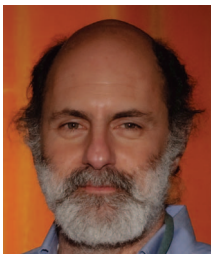
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BIOGRAPHY



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Stephen R. Ellis received the Ph.D. degree (1974) from McGill University in psychology after receiving the AB degree in behavioral science from the University of California at Berkeley. He has had postdoctoral fellowships in physiological optics at Brown University and at UC

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