Topic 2: Individual and Team Problem-Solving Skills Training for Exploration Missions

Background
NASA’s “mission teams” are composed of astronauts and Earth-based support staff (flight crews, Mission Control Center (MCC), flight controllers, flight control teams, etc.) who work closely together to ensure both individual and crew performance. Future Long Duration Spaceflight Exploration (LDSE) missions, potentially including planetary surface missions on Mars, will demand the support and ability of these teams to manage shifting levels of autonomy when crew health, performance and/or mission success are threatened by unanticipated problems. Past missions, notably Apollo 13, involved significant responsiveness of the ground support staff in assisting crewmembers to engage in team problem-solving in serious (and more mundane) situations. Future missions, where the distance from Earth precludes any “immediate” communications may necessitate the crew to autonomously solve other, similar problems.

The distance from earth and unpredictability of what problems may arise given the uniqueness and complexity of spacecraft systems, demands astronauts who are flexible in their problem solving (Fiore et al., 2015; Orasanu, 2005). In addition, in order for crews to work efficiently, they need a shared mental model of the task for completion and use a variety of problem-solving and teamwork skills (Landon et al., 2016).

Team autonomy is not always desired. For example, resolving a problem in a high consequence environment using remotely located experts may offer the greatest likelihood of resolving the problem safely. However, some problems require fast action with distance from Earth confounding the availability of those remote experts to provide assistance. For example, crewmembers, either as individuals or as a Team, will need high-level problem-solving capabilities to execute complex autonomous operations if there are insufficient on-board human-system capabilities. It is important to consider how the crew will need to carry out complex tasks and operations in stressful, demanding, and high-risk (potentially life threatening) situations.

A major part of a crew’s preparation will need to involve the training and development of problem-solving skills that reflect cognitive processing abilities applied under high pressure to resolve unexpected malfunctions. Autonomous response to system malfunctions during a LDSE will demand real-time decision-making that reflects a keen appreciation for vehicle reliability, the risks to crew personal safety, and how problems to be solved will likely affect operational trade-offs and efficiencies related to the mission. Similar to decision-making in other safety- and time-critical domains (e.g., commercial aviation), reasonable benchmarks for decision-making behaviors include: skills-based, rules-based, and knowledge-based benchmarks (Rasmussen, 1983).

Therefore, greater autonomy during spaceflight will require astronauts who possess both the individual and team cognitive problem-solving abilities and performance when facing unique and unpredictable events which may occur during LDSE (Fiore et al., 2015; Orasanu, 2005). They must anticipate and plan for the communication delays that may interfere with the problem-solving process and inhibit coordination with MCC. The ability to maintain a collective
orientation, which can affect team processes and emergent states such as backup behaviors and trust, may be decreased by the physical separation and communication delays (Smith-Jentsch et al., 2015). Research on submariners and Antarctic analogs found that problem-solving coping strategies are predictive of team success when used by achievement-oriented individuals (Sandal et al., 2003; Leon & Sandal, 2003). However, when problems are encountered, autonomous teams in deep space may also need to quickly switch from independent individual tasks to interdependent team tasks and, depending on the international composition of the LDSE, even switch language. Relevant skills for these situations include problem solving ability, ability to deal with misunderstandings, display of cultural sensitivity, and cultural competence within cross-cultural groups, as reviewed in Mendenhall et al. (2004).

If the team on-board the spacecraft needs to problem-solve, they may have to adapt to confusing procedures, inadequate equipment, or excessive workload. During an autonomous mission, effective coordination and problem-solving will depend on the identified information gaps in their understanding of the anomaly (i.e., the potential problem needing solved) and the ability to quickly resolve the potential of hidden disagreements about the approach to problem-solving between individuals on the team. Team task switching may occur during the LDSE, with four autonomous crew operating as a team to problem-solve issues that previously required the participation and cooperation of 140 MCC personnel (for example, see Smith-Jentsch et al., 2015).

Team performance depends on team cooperation coordination and cohesion. In order for the members of a team to adapt quickly to the challenges posed by problems that need solved, they need a shared mental model. In essence, they need the ability to describe, explain, and predict both the environment and actions by other members of their team (Mathieu et al., 2000). Teams will need to predict what actions each member is likely to take, understand the demands of the problem and structure of knowledge possessed by members of the team to address the problem, and promote the selection of actions consistent with, and coordinated with, those of their teammates (Mathieu et al., 2000). Thus, each member of the team needs to possess a shared team mental model of problem-solving in unfamiliar or unexpected situations in which shared mental models facilitate team problem-solving. When creative problem-solving is called for, divergent thinking is particularly helpful in generating solutions and for evaluating the potential solutions (da Costa et al., 2015). The challenge is allowing individuals to engage in divergent thinking to foster a shared mental model of how to structure and communicate their ideas to facilitate more creative and efficient problem solving.

A concern, based in part on observations in analog studies, is that the shared collective orientation needed for team problem-solving may decrease in long-duration missions, with in-groups and out-groups forming between the crew and MCC. This may also set the conditions for the crew to “prematurely” exercise their autonomy, reducing their coordination with MCC and thereby increasing risk to the mission. This could result in reduced levels of trust toward MCC with misaligned mental models about priorities and leadership which could lead to loss of efficiency and effectiveness of overall team efforts to solve problems. Using contextual inquiry techniques (Whiteside, Bennett, & Holtzblatt, 1988), an internal NASA team has been identifying the context to the types of “relevant” problem solving (e.g., anomaly analysis and resolution, contingency planning, etc.) from observations of current mission control processes.
and relevant mission simulations of responses to anomalous events. The goal was to characterize the roles, tools, data flows, teaming, and training elements to understand how tasks are actually performed in the current settings. Among those findings, “problem solving” recommendations included:

- The use of an on-board, “intelligent assistant” to aid crew in prioritizing for fault management, troubleshooting, problem solving, and decision-making using algorithms and approaches that are effective for a wide range of issues.
- Providing crew with automatic audio/video recording and playback of onboard operations to support troubleshooting and diagnostics.
- Providing the crew with standards (onboard flight rules) for problem solving:
  a. Communication rules, including rules for time delay
  b. Mindset - “what-ifs”, “next worse failure” thinking
  c. Consideration of integration impacts
  d. Handover of a problem
  e. “Divide and conquer” strategy
  f. Maintaining situational awareness
  g. Documenting events and outcomes for future use
- Providing standards (onboard flight rules) for validating/vetting candidate solutions to problems, whether from the crew or intelligent system.

Thus, in the spaceflight context, as problems arise, both human systems integration and shared leadership are needed for prompt and effective problem-solving, as well as for structuring/planning and action phase of problem resolutions. Individuals within the Teams improve their performance when they possess and share an accurate mental model. Previous research has demonstrated that when unfamiliar or unexpected situations arise, Teams with shared mental models are more creative problem-solvers, engage in more divergent thinking, and facilitate team problem-solving with more effective generation of solutions and evaluation of those solutions (da Costa et al., 2015). In addition, meta-analyses have found that information sharing positively predicts team performance, and that cooperation enhanced this relationship (Mesmer-Magnus & DeChurch, 2009). In LDSE, the on-board human-system capability will serve as part of the “Team”, helping the crew problem-solve and execute complex autonomous operations when responding to unanticipated malfunctions. NASA research needs include identifying the relevant training, guidelines, and standards related to both individual and team problem solving to help characterize and close this research gap; reducing the risks for LDSE Teams, their training, and their use of on-board decision-support systems helps ensure their safety and mission success.

**Research Emphases**

This research topic is designed to provide standards and guidelines for training individual and team problem-solving skills across all team, medical, and technical domains for both work and non-work situations throughout a long-duration mission. It is also intended to provide standards and guidelines related to human-computer standards and training related to human-systems interface during autonomous missions. Standards and guidelines may impact documents such as NASA-STD-3001 Rev. A Vol. 2 (https://www.nasa.gov/sites/default/files/atoms/files/nasa-std-3001-vol-1a-chg1_0.pdf) and the Human Integration Design Handbook (https://www.nasa.gov/feature/human-integration-design).
The results of this research are intended to provide a cross-cutting, integrative contribution to both decision- and execution-support systems being considered for human capabilities interfaces with intelligent systems. These cross-cutting tasks may include intelligent support systems and/or medical systems in order to provide guidelines for vehicle capabilities that support crew task execution and decision-making for the technical and medical domains. While this research is intended to provide the problem-solving skills training necessary to perform tasks with those systems, it also must be adaptive and responsive to providing training for individual and team problem-solving for situations outside the scope of those systems.

Specifically, proposals should address ALL of the following research aims:

1) Determine how problem-solving skills are developed and used in operational settings such that there is generalization across many tasks and situations.
2) Identify which individual and team skills are most important to performing tasks in normal conditions and surviving in emergency conditions for long-duration space exploration.
3) Determine the relationship of individual cognitive processes/skills (e.g., attention, reasoning) to team cognitive processes/skills (e.g., collaborative problem solving, decision making).
4) Describe how these skills change over time and what may trigger these shifts. A particular interest exists to present a scientific rationale of how the changes in these problem-solving skills during spaceflight may be at risk due to potential changes in brain domains from exposures to the CNS from radiation, stress, and altered gravity.
5) Validation of the measurement, particularly unobtrusive measurement, of the problem-solving skills for both individuals and teams.
6) Development of validated training guidelines and recommendations to develop and maintain individual and team cognitive skills throughout an LDEM, and allow them to be trained efficiently to maintain performance across tasks and situations in mission.

**Deliverables**

1) **Risk characterization** describing individual and team cognitive problem-solving skills for long duration exploration missions (LDEM); which individual and team skills are most important in both nominal and off-nominal tasks/situation, how skills may generalize across tasks/situations (taking into account cross-cultural and mixed gender considerations), and how these skills change over time and what may trigger these shifts;
2) **Specific training recommendations and guidelines** that address validated objective measures of spaceflight relevant individuals and team problem-solving skills for timely operator proficiency and effectiveness, with an emphasis on using human-computer interactions in autonomous (and realistic) mission scenarios;
3) **Standards and Guidelines** recommendations related to training and other countermeasures to develop and maintain individual and team problem-solving skills in LDEM;
4) **Corresponding countermeasure prototypes and training protocols** appropriate for LDEM, supporting the recommended Standards and Guidelines.

Deliverables may include relevant and feasible computer-based training and countermeasure recommendations for pre-mission, but in-flight training and countermeasures **should not be**
solely computer-based. These deliverables and skills need to apply to non-work situations and influence team functioning for both operational and mission control personnel as well. For teams, countermeasures are expected to include training that is adaptable; promoting creative problem-solving, decision-making and prioritization, and maintaining a shared mental model such that team members are able to smoothly adapt under changing and unexpected conditions.

While a review of literature is a necessary component of research, proposers should note that a literature review is not expected to constitute a major portion of the funding for this research. To that end, NASA has funded a literature review that has been published as a NASA Technical Memo: [https://ston.jsc.nasa.gov/collections/trs/_techrep/TM-2015-218583.pdf](https://ston.jsc.nasa.gov/collections/trs/_techrep/TM-2015-218583.pdf)

**Data Sharing Requirements**
In order to maximize resources, all investigators funded by NASA will be required to share data within the team for the duration of the project to include raw, analyzed and meta-data. The investigator team, together, will enter into a Data Sharing Agreement (DSA) that contains non-negotiable NASA requirements.

To optimize resources, NASA pursues the intentional formation of investigator partnerships between individual investigators whose experiments will leverage resources by addressing different facets of the same questions. NASA anticipates that such intentional teaming arrangements will result in better utilization of available resources to resolve specific critical questions. NASA strongly encourages investigators submitting applications in response to this NRA to consider identifying collaborations between individual investigators as part of the development of their individual proposals and to identify this pre-coordination in their management plan. Finally, NASA may integrate proposals if, in their judgments, the goals, objectives or products of the proposals are similar.

**Software Development Requirements**
If any software is developed in the course of this NASA funded research, the team must be willing to provide the source code, short training on how to use the software, and enable NASA to make the software available as an open source product. The team must provide NASA with all methods, technologies, tools, software, software documentation (including start up directions), training and/or materials associated with the developed recommendations. The expectation is that the deliverables will transition to operations at the end of this task. Upon completion of research, any software tools must be delivered to NASA using an architecture where data remains local or on NASA’s server. Federal government will retain license rights for all hardware and software created or modified during the project. The proposer shall output data in a non-proprietary data format that is clearly described by either a publicly available standard or in a proposer-provided data specification.

**Research Platform**
Ground-Based and Analog-Definition

Research is preferred in a long-duration Isolated, Confined, and Controlled (ICC) and/or Isolated, Confined, and Extreme (ICE) analog. Research may also be available in a high-fidelity long duration spaceflight analog. Proposers should identify the characteristics that they require in an
analogous environment for their scientific objectives. However, it is not necessary to propose a specific analog. NASA will work with the investigators to secure an analog with the specified characteristics once funding has been awarded.

If the analog is known and secured at the time of proposal submission, the proposer should include a full description of the analog(s) characteristics. In addition, HFBP will work with the principal investigator to determine the most applicable performance tasks available in the analog(s) secured for the study.

Proposers should provide estimated costs per year for each of their planned analogs to achieve study objectives (e.g., HERA for shorter and a polar (ICE) environment or simulated ICC chamber for longer duration).

Investigators proposing use of the Human Exploration Research Analog (HERA) should review Section H.8.a of the HERO Overview document that describes HERA.

Please note that a maximum of $855,000 total ($285,000 per year for three years) is available for this topic.

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References


Primary Risk | Relevant Gap
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Risk of Performance and Behavioral Health Decrement Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team | **Team Gap 1**: We need to understand the key threats, indicators, and evolution of the team throughout its life cycle for autonomous, long duration and/or distance exploration missions.

**Team Gap 2**: We need to identify a set of validated measures, based on the key indicators of team function, to effectively monitor and measure team health and performance fluctuations during autonomous, long duration and/or distance exploration missions.

**Team Gap 3**: We need to identify a set of countermeasures to support team function for all phases of autonomous, long duration and/or distance exploration missions.

**Team Gap 5**: We need to identify validated ground-based training methods that can be both preparatory and continuing to maintain team function in autonomous, long duration, and/or distance exploration missions.

**Team Gap 8**: We need to identify psychological and psychosocial factors, measures, and combinations thereof that can be used to compose highly effective crews for autonomous, long duration and/or distance exploration missions.

<p>| Risk of Performance Errors Due to Training Deficiencies | TRAIN-01: We do not know which validated objective measures of operator proficiency and of training effectiveness should be used for future long-duration exploration missions. |</p>
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<th>Secondary Risk</th>
<th>Relevant Gap</th>
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<td>Risk of Inadequate Human-Computer Interaction</td>
<td><strong>HCI-06</strong>: We need guidelines to ensure crewmembers receive all of the information required to accomplish necessary tasks in a timely fashion, even when operating autonomously.</td>
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| Risk of Adverse Cognitive and Behavioral Conditions and Psychiatric Disorders | **BMed1**: We need to identify and validate countermeasures that promote individual behavioral health and performance during exploration class missions.  
**BMed3**: We need to identify and quantify the key threats to and promoters of mission relevant behavioral health and performance during autonomous, long duration and/or long distance exploration missions. |
| Risk of Inadequate Mission, Process and Task Design | **MPTASK-01**: We need methods and tools to collect measures of missions, process, and task performance. |