Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team

Human Research Program

Behavioral Health and Performance

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I. ABBREVIATIONS

ABMS	agent-based modeling and simulation
ANSMET	Antarctic search for meteorites
ARI	Army Research Institute
ASCAN	astronaut candidate
BHP	behavioral health and performance
BMED	behavioral medicine
CHP	crew health and performance
CRM	crew resource management
CSA	Canadian Space Agency
DAG	directed acyclic graph
DRM	design reference architecture
ESA	European Space Agency
EVA	extra vehicular activity
HERA	human exploration research analog
HFBP	Human Factors and Behavioral Performance
HFBP-EM	HFBP exploration measures
HI-SEAS	Hawai'i space exploration analog and simulation
HRP	Human Research Program
HSIA	human-systems integration architecture
HSRB	Human Systems Risk Board
ICC	isolated, confined, controlled
ICE	isolated, confined, extreme
ISS	International Space Station
JAXA	Japanese Aerospace and Exploration Agency
JSC	Johnson Space Center
KSA	knowledge, skills, abilities
LDEM	long-duration exploration mission
LSDA	life science data archive
MCC	Mission Control Center
MTS	multi-team system
NASA	National Aeronautics and Space Administration
NEEMO	NASA extreme environment mission 0perations
NHV	net habitable volume
NOLS	National Outdoor Leadership School
NTSB	National Transportation Safety Board
PAM	private astronaut mission
PPC	private psychological conferences
RSA	Russian Space Agency, Roscosmos
SFINCSS	simulated flight of international crew on Space Station
SFRM	spaceflight resource management
SIRIUS	scientific international research in a unique terrestrial station
SHAQ	spaceflight habitability assessment and questionnaire
SME	subject matter expert
TDT	team dimensional training
USAF	United States Air Force

II. STATUS

Active: Work/research is currently being done towards this risk.

III. RISK STATEMENT

Given that the conditions of spaceflight missions will likely impact the functioning and the behavioral health of teams, including the spaceflight crew and the ground support personnel, performance and behavioral health decrements may occur that will jeopardize mission success and crew health and safety.

IV. EXECUTIVE SUMMARY

The *Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team* (the Team Risk) is primarily performance-focused, with a secondary emphasis on behavioral health outcomes resulting from team performance and interpersonal interactions. Monitoring tools, measures, and countermeasures are aimed at enhancing team processes and team composition configurations to optimize team performance and functioning. Long-duration exploration missions (LDEMs) will include major challenges that could affect team performance, including social isolation, physical confinement, a small and diverse crew, communication delays between crew and ground, limited or no crew rotation or evacuation options, limited or no resupply, and a high-consequence environment. Each of these conditions will affect the crew's coordination, cooperation, psychological well-being, and performance.

Although the International Space Station (ISS) remains important for studies that require spaceflight testing and validation, the current conditions on the ISS do not adequately mimic the exploration environment that is required for National Aeronautics and Space Administration (NASA) teams research, and thus access to terrestrial or ground-based analogs of LDEM conditions is paramount. The emphasis on analogs for research is reflected in this updated evidence review of the Team Risk, and includes data from studies conducted at isolated, confined, extreme (ICE) environments (e.g., Antarctic stations), and from several mission simulation analogs such as the Human Exploration Research Analog (HERA) (HERA Experiment Information Package, 2014), also known as isolated, confined, controlled (ICC) environments. These studies have characterized many team factors regarding LDEMs, and the Team Risk has now matured from risk characterization to focusing more on countermeasure development.

Because spaceflight evidence for team-level research is lacking, no reliable data is available to quantify the impact of team-level variables on individual and team-level outcomes during spaceflight missions. Until recently, no systematic attempt had been undertaken to measure the performance effects of team cohesion, team composition, team training, or team-related psychosocial adaptation during spaceflight. The Team Risk is a relatively young research area for NASA, with substantial growth only since the 2000s, and with limited access to spaceflight performance data. As a result, spaceflight evidence is lacking to identify specifically what team composition, level of training, amount of cohesion, or quality of psychosocial adaptation is necessary to reduce the risk of performance errors in space. However, astronaut journals and interviews and reports from spaceflight subject matter experts (SMEs) provide testimonies that team performance during spaceflight is important for mission success and to maintain crew health. Team spaceflight data is now being collected as part of the Spaceflight Standard Measures task (Clement, 2021)—a set of core measurements related to many human spaceflight risks that are collected from astronauts before, during, and after long-duration missions. The team-related standard measures focus on team cohesion, team performance, group living, team climate, and team processes. Collection of standard measures data is ongoing and published data is not yet available. Finally, although spaceflight evidence is lacking, evidence gleaned from ground studies and spaceflight analog studies will help close the gaps outlined in the Team Risk.

Ground-based studies provide quantitative evidence for team functioning in ICE environments. Academic research on teams has produced dozens of meta-analyses that can be used to understand the general relationships among team inputs (e.g., team member characteristics and skills, job context), team processes, and emergent states (e.g., coordination, communication, cooperation, cohesion, trust, shared cognition), and team outcomes (e.g., effectiveness, errors, adaptation). Teams are complex, incorporating individual characteristics of team members, but also existing at a level that is greater than the sum of its parts. Therefore, the Team Risk must be integrated with other individual-focused NASA Human Research Program (HRP) risks, including Behavioral Medicine (BMed), Sleep, and Human-Systems Integration Architecture (HSIA), and emerging research indicates more integration may needed between the Team Risk and the physiologically oriented risks. Much of this integration occurs through the Human Systems Risk Board (HSRB).

A lack of team functioning may be a stressor in some circumstances, but the team often acts as a countermeasure. For example, support for team leaders and teammates can facilitate individual functioning and encourage psychological and physically healthy behaviors and attitudes. However, more research is needed regarding teams during LDEMs and the remaining gaps in the research are described in the current report.

V. EVIDENCE

A. INTRODUCTION

1. Context and Operational Relevance of the Team Risk

NASA's Human Research Program (HRP) is organized into research groups called Elements. In 2016, the Behavioral Health and Performance (BHP) Element merged with the Spaceflight Habitability and Human Factors Element (SHFH) to create the new Human Factors and Behavioral Performance (HFBP) Element. The HFBP Element includes several Risk areas across behavioral health (i.e., Sleep, Behavioral Medicine or BMed, Team) and human factors (i.e., Risks subsumed under the umbrella of Human Systems Integration Architecture). In 2015, the BHP Laboratory was created. The BHP Lab is tasked with conducting research into 3 primary risks areas: (1) risk of performance decrements and adverse health outcomes due to sleep loss, circadian desynchronization, and work overload (Sleep); (2) risk of adverse cognitive or behavioral conditions and psychiatric disorders (BMed); and (3) risk of performance and behavioral health decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team (Team). The BHP Lab also works across many disciplines, informing other risks beyond HFBP from the perspective of applied and clinical psychology, and sleep physiology. Sleep research is also supported by the Fatigue Countermeasures Laboratory located at NASA Ames Research Center. Thus, the Team Risk is overseen by the HFBP Element, and the BHP Lab conducts research into Team Risk factors. Additionally, the Team Risk informs the practices of the BHP-Operations group, who perform hands-on selection, training, and psychological support of the astronauts and their families. This partnership between research and operations enables research that will meet the needs of future operations by identifying knowledge and countermeasure gaps, and determining the feasibility of implementing research products. Finally, the NASA Human Systems Risk Board (HSRB), oversees the integration of all risk areas and makes evidence-based, risk-based decisions that protect crew health and performance during space missions, and strategically prepare for human spaceflight. The HSRB is a standing committee of scientists from all research Elements in the Human Research Program with representatives from stakeholders across NASA (e.g., the astronaut office). Risk evidence is provided to the board to support research and operations planning. These many diverse areas of expertise culminate in a comprehensive, integrated approach to mitigate the risk of inadequate team performance and functioning.

Team Risk research examining team training, team selection, team composition guidelines, etc., addresses the needs of the operational stakeholders such as BHP-Operations group. For example, a teamwork observation tool that was developed through efforts to address the Team Risk was used during the 2013 astronaut selection process. Similar emphasis on team-oriented competencies was incorporated into the 2017 astronaut selection process (Landon et al., 2017). An updated job analysis for LDEM missions was conducted jointly by BHP operations personnel and the HFBP Element, in conjunction with the NASA astronaut office (Barrett et al., 2015) (Category III[1]). This job analysis informed HFBP research on selection and team composition needs, leading to research that will inform future rounds of astronaut selection supported by BHP operations personnel. Unobtrusive measures related to team cohesion, developed through HFBP research, will help BHP operations personnel to monitor aspects of team cohesion during spaceflight (e.g., Kozlowski et al., 2015).

HFBP also practices transitions to operations with other NASA groups. For example, astronauts and flight controllers engage in a team skills training program known as spaceflight resource management (SFRM), which was adapted from the aviation industry’s crew resource management (CRM). HFBP personnel help to develop, validate, and support SFRM training programs with the help of NASA-funded external experts. This training now incorporates a research tested and validated debrief protocol centered on 4 identified SFRM teamwork dimensions (i.e., information exchange, communication delivery, leadership/followership and supporting behaviors), and was effective at increasing NASA flight controllers’ team and technical skills, and shortening the time it took to complete their certification (Bedwell et al., 2012) (Category II). This training was expanded to other space centers (e.g., Marshall Spaceflight Center, home to many payload flight controllers) and has been used as part of the

[1] See Appendix A for NASA’s Categories of Evidence, based on Silagy & Haines (2001).

astronaut candidate (ASCAN) training program. The HFBP Element and the BHP Lab conducts team-oriented research that will translate validated deliverables to operations, making a lasting, positive impact on spaceflight teams.

2. Team Risk Overview

A team is defined as “two or more individuals who interact socially and adaptively, have shared or common goals, and hold meaningful task interdependencies; it is hierarchically structured and has a limited life span; the expertise and roles are distributed; and it is embedded within an organization/environmental context that influences and is influenced by ongoing processes and performance outcomes” (Salas et al., 2007, p. 189). From the NASA perspective, a team is commonly understood to be a collection of individuals who are assigned to support and achieve a particular mission. Thus, depending on context, this definition can encompass both the spaceflight crew and the individuals and teams in the larger multi-team system (MTS) who are assigned to support that crew during a mission.

The *Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team* (the Team Risk) is primarily performance-focused, with a secondary emphasis on behavioral health outcomes resulting from team performance and interpersonal interactions. Monitoring tools and measures, and countermeasures, are aimed at enhancing team processes and team composition configurations to optimize team performance and functioning. Although each HRP risk is addressed in a separate chapter of the HRP evidence book, each risk interacts and informs the others. For example, several studies of human cognitive performance that were conducted in spaceflight analogs suggest negative effects on learning, cognition, emotions, and attention in novel environments (Strangman et al., 2014) (Category I-III[2]). Risk to cognitive performance is addressed through the BMed Risk, but detrimental effects on cognition that affect learning, training, decision-making, etc., may affect the ability of the team to perform, so team-level cognitive processes are considered throughout the Team Risk. Any long-term health consequences of team dysfunction that occur after a spaceflight mission are addressed in other risk areas, particularly BMed. The Team Risk is concerned specifically with team performance and functioning before and during a mission, and once the team disbands after the mission, the Team Risk no longer applies. Examples of how the Team Risk overlaps with other HRP risks are shown in Figure 1.

[2] Description of NASA’s Human Research Program evidence categories, based on Silagy and Haines (2001), are given in Appendix A of this report.

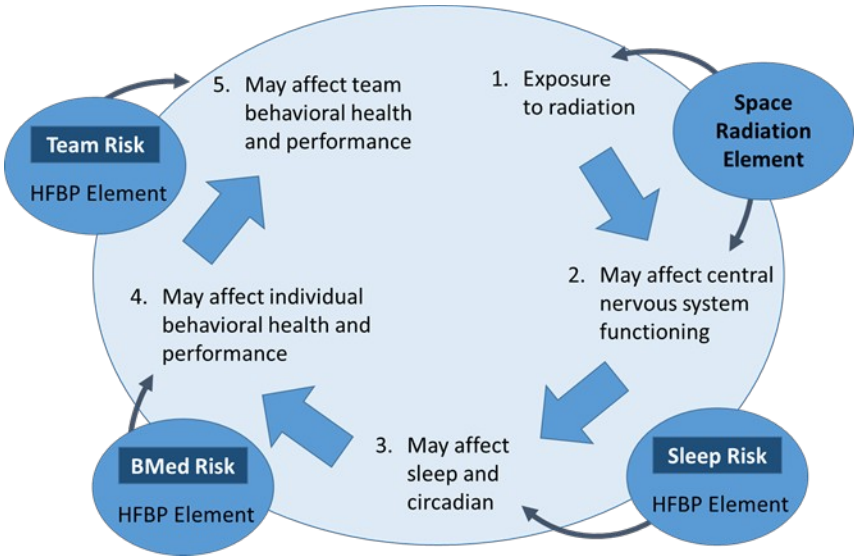


Figure 1. Example of how the Team Risk relates to other HRP risks

The research portfolio for the Team Risk primary focuses on LDEMs to Mars. The extreme distance from Mars to Earth creates a one-way communication delay of over 22 minutes, which significantly disrupts the historically close coordination between the crew in space and the multi-team system in Mission Control. The distance and the communication delay also greatly increase isolation of the crew. For greater context regarding the focus and related hazards of the Mars mission, see the Section titled *Risk in Context of Exploration Mission Operational Scenarios* in the current report.

The Team Risk outcomes of interest are predominantly performance related, with a secondary emphasis on long-term health. This is unusual in the HRP because most HRP risks are medically related and primarily focused on short- and long-term health consequences, which then impact performance. In many operational environments (e.g., aviation), performance is often assessed as the avoidance of errors. However, the research on performance errors is ambiguous. If performance is assessed by focusing on errors, this implies that actions may be dichotomized into "correct" or "incorrect" responses, where incorrect responses or errors are always undesirable. Researchers have argued that this dichotomy is a harmful oversimplification, and it would be more productive to focus on the variability of human performance and how organizations can manage that variability (Hollnagel et al., 2006) (Category III). Two problems occur when focusing on performance errors: (1) the errors are infrequent and, therefore, difficult to observe and record; and (2) the errors do not directly correspond to failure. Research reveals that humans are adept at correcting or compensating for performance errors before such errors result in recognizable or recordable failures. Astronauts are notably adept, high-performers. Most failures are recorded only when multiple small errors occur and humans are unable to recognize and correct or compensate for these errors in time to prevent a failure (Dismukes et al., 2007) (Category III).

More commonly, observers record variability in levels of performance. Some teams make no observable errors but fail to achieve performance objectives or perform only adequately, whereas other teams make some errors but perform spectacularly. Successful performance, therefore, cannot be viewed as simply the absence of errors or the avoidance of failure (personal communication by Johnson Space Center (JSC) Joint Leadership Team, 2008, to past contributing author L. Schmidt). Although failure is commonly attributed to making a major error, focusing solely on eliminating errors does not significantly reduce the risk of failure. Failure may also occur when performance is simply insufficient or an effort is incapable of adjusting sufficiently to a contextual change (e.g., changing levels of autonomy). The surest way to reduce the risk of failure is to achieve optimal performance. If 2 crews have an equal risk of making performance errors but one crew is more likely to perform more of the mission objectives (or otherwise perform better), it follows that the most desirable crew will be the highest-performing crew. Additionally, when selecting a crew, it will be important to consider their likelihood of sustained behavioral health and team functioning along with their performance, to balance the demands of performance and still maintain the crew's long-term health. One of the goals of the Team Risk research is to optimize performance in an already high-performing population, support behavioral health, and extend success to the context of the new LDEM mission profiles to the moon and Mars.

Regarding the Team Risk, performance is divided into 2 main categories: team task performance and team functioning. The performance of a team task can often be assessed with more objective measures of performance, e.g., number of tasks or mission objectives achieved, speed, error rates, and task dependent metrics. Current efforts within the HFBP Element (e.g., Dinges, 2020; Roma, 2020; Bell, 2021) are underway to establish a more robust set of objective performance measures that capture the variability of team performance beyond error rate, e.g., accomplishing mission objectives or task goals. Importantly for astronaut crews, team functioning includes aspects of living and working together in extreme, stressful environments. Team functioning is a broad term, capturing the following elements:

- Teamwork: interdependent acts that convert inputs to outcomes through cognitive processes, communications, and behaviors to achieve collective goals
- Cooperation: attitudes, beliefs and feelings of the team that drive behavior
- Coordination: behavioral and cognitive processes that can be used to transform team resources into outcomes
- Team Cohesion: unified operating while working towards a goal or to satisfy the psychosocial needs (e.g., feeling of belonging and contributing to the team) of its members
- Psychosocial Adaptation: the ability to cope with stressors, and to balance individual and team needs

Many factors typically considered to be inputs and emergent states may be subsumed into team functioning, with the ultimate outcome of interest being team performance. Emergent states are dynamic properties of the team that vary as a function of team context, inputs, processes, and outcomes (Marks et al., 2001). The HRP identifies 5 hazards of space that can influence behavioral health and performance: radiation, isolation and confinement, distance from Earth, gravity fields, and hostile and closed environment (Schorn & Roma, 2021) (Category IV). Isolation and confinement is the primary hazard affecting the Team Risk, and distance from Earth, and hostile and closed environment are the secondary hazards. The bulk of the research conducted to address the teams risk focus on these 3 hazards. Because research into Team Risk is now focused on LDEMs, distance from Earth and communication delays, small habitable volume, isolated and non-rotating crew, and especially the 30-month duration, will add more stress to the crew, and will influence team factors in new and important ways. Journals kept by ISS crewmembers and assessments of operations conducted by long-duration flyers reveal many instances of team disruption and interpersonal frictions during spaceflight (Stuster, 2010 and 2016) (Category III). Notably, decrements in performance and functioning were sometimes attributed to the duration of the mission, that is, the belief that you can get along with anyone for 2 weeks (the duration of many Space Shuttle missions), but that a crew has to be particularly well-suited to working together for very long durations to avoid these performance and functioning issues. Almost all the astronauts' journals stated that "getting along" with crewmates was the highest priority identified on surveys before flight. Cohesion is a 2-factor variable, consisting of task cohesion (working together well) and social cohesion (getting along well). Task cohesion dominates for short-term teams or tasks, but over time, and as isolation and confinement increases, social cohesion increases in importance (Roma & Bedwell, 2017) (Category IV) (see Figure 2). During a Mars mission, both forms of cohesion will be required.

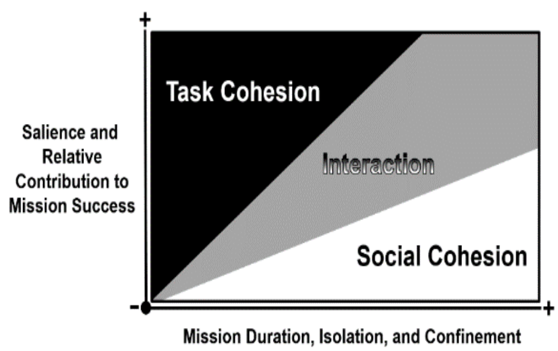


Figure 2. Task vs. social cohesion salience and relative contribution to mission success over time. Adapted from Roma & Bedwell (2017).

A series of NASA-directed literature reviews and operations assessments, experimental and observational studies, and meta-analytic examination of teams and team outcomes supports several trends:

- Teamwork is positively related to performance in technical and team domains and is positively related to outcomes in routine tasks and off-nominal tasks (Schmutz, Meier, & Manser, 2019) (Category I).
- Team cohesion leads to improved performance, which leads to greater cohesion, in a mutually supportive relationship (Mathieu, Kukenberger, D'Innocenzo, & Reilly, 2015; Kozlowski et al., 2015) (Category I,III).
- Scientifically based selection of a team-oriented personality, paired with deliberative team composition, predicts team performance, cohesion, team processes, and well-being (Barrick et al., 2001; Bell, 2007) (Category I). Teams of high-ability individuals can have a synergistic gain in performance (they perform better together than they do individually) (Day et al., 2005) (Category II).
- Team training positively influences team performance and functioning (Delise et al., 2010; Salas et al., 2008) (Category I). Team skills training improves operational performance outcomes above and beyond technical skills, as has been recorded in extreme teams (Hughes et al., 2016) (Category I). However, improvement in performance

may degrade after 6-12 months (Harvey et al., 2019) (Category II), at which time refresher training is needed.

- Debriefing improves performance 20-25% (Tannenbaum & Cerasoli, 2013) (Category I).
- Complex relationships within the multi-team system may be impaired by communication delays and changing team autonomy, but countermeasures mitigate some decrements in performance and team functioning (Fischer & Mosier, 2015) (Category II). The quality of the communication matters more to performance than the quantity (Marlow et al., 2018) (Category I).
- Social support is important for individual well-being and for team and multi-team cohesion, but tends to decline over time, particularly under communication delay (Goemaere et al., 2019; Nicolas et al., 2021; Fischer & Mosier, 2020) (Category III).
- Leaders can positively affect team performance, functioning, cohesion, and individual well-being. Leadership and followership during spaceflight requires training in several leadership models, and training on when and how to switch between leadership models and leader/follower as needed (Gibson et al., 2015) (Category III). Leadership training improves learning, transfer, and results, with an effect size d=.72 to .82.
- Enhanced team cognition and shared mental models lead to positive team performance outcomes, and can be developed in training and supported through team structure and processes (Fiore et al., 2015; DeChurch & Mesmer-Magnus, 2010a; Niler et al., 2021) (Category III, I, I).
- Relationships between team predictors and outcomes (e.g., team cohesion and team performance) may operate differently in ICE environments (Bell at al., 2019a) (Category I). Many team processes (e.g., team cognitive processes, communication, coordination, conflict management) and other moderating factors (e.g., leadership approach, autonomy) have a complex and nuanced relationship with team outcomes, which still require research in a long-duration ICE context.

NASA's 4 categories of evidence (shown in Appendix A) were based on Silagy and Haines (2001) categories for a medical research setting. Because the research conducted in mission simulation analogs and in ICE environments has recently increased, the spaceflight-relevant evidence base is growing, especially in the stronger categories of evidence. Most team research is well-suited for ground-based studies. Thus, research to address the Team Risk relies less on the spaceflight environment than do other HRP risk areas because studies of these other physiologically oriented risks require microgravity conditions and a combination of unique ISS and ICE factors. This reliance on analogs and analogous populations is reflected in the evidence below. This review provides a summary of the state of knowledge, developed measures and monitoring tools for assessing teams, and existing and suggested countermeasures for developing and maintaining team functioning and performance.

B. SPACEFLIGHT EVIDENCE

1. Sources of Evidence

Team-level data has rarely been collected during spaceflight. Most spaceflight data are collected at the individual level, and team-level data is limited to overall team performance or the success of mission objectives. Anecdotal reports of teamwork issues have been noted, but systematic analysis of such data has been limited. More recently, team measurements have been obtained from ISS crews and the MTS, but research from spaceflight is somewhat lacking due to research and operational constraints (e.g., few good outcome measures and performance metrics). Some quantitative data is housed in the NASA Life Science Data Archive (LSDA), and anecdotal examples are important qualitative sources that can be used for content analysis. As an example of the latter, Dr. Jack Stuster's Journals Project (Stuster 2010; Stuster 2016) and the NASA history project and transcripts offer text from which to mine frequencies of mentioned topics and behavioral patterns. Research that addresses the Team Risk relies heavily on ground-based analogs of spaceflight conditions and analogous populations; see the *Ground-based Evidence: Sources of Evidence* below for a discussion of researching extreme teams.

2. Factors contributing to team performance and functioning

a) Astronaut Selection

In the 1950s and 1960s, astronaut candidates (ASCANs) were mostly military test pilots, who were thought to be naturally suited to high-stress and high-risk situations, and little thought was given to team orientation or team skills. Later astronaut selection rounds during the Space Shuttle and the ISS years have included more astronaut-scientists to fill the new mission profiles and perform the required tasks. The crewmembers' expertise and personalities are now more varied, and crews are multi-national, and more gender, sex, and ethnically diverse. This diversity can challenge the performance and functioning of spaceflight teams. Evaluation of psychological characteristics waxed and waned during the first 30 years of astronaut selection, but emotional stability, motivation, and interpersonal relationships were always considered (Santy, 1994). In general, research into selection of spaceflight crewmembers is severely limited due to a lack of data from a small population of astronauts, and to the lack of performance data with which to validate measures and methods. For example, Russian researchers have long collected personality data on cosmonauts (Kanas & Manzey, 2008), but the empirical linking of personality factors to the specific performance levels necessary to provide cut-scores or norms for selection still eludes these researchers, perhaps because of small sample size or inadequate performance data. In addition, astronaut selection data is sensitive and is not made publicly available to protect the integrity of the rigorous and high stakes astronaut selection process. Space agencies have not provided objective, operational performance data on enough astronauts to create a reasonably sized sample on which to perform an analysis. This lack of data also obfuscates the ability to identify optimal selection criteria and methods for teams. Efforts began in the Space Shuttle era to include more rigorous personality testing, foundational job analyses, and psychological evaluations, and interviews were expanded during the early years of the ISS. Additionally, during the 2009 and the 2013 astronaut selection processes, NASA implemented an experimental team simulation to assess the candidates' teamwork capabilities. A multi-trait, multi-method approach is a best practice for job selection and assessment, and space agencies have increasingly added group-task observations to assess individuals on team-oriented factors. Surveys, interviews, and group tasks used by European Space Agency (ESA) during their 2008-2009 astronaut selection targeted interpersonal and intercultural competencies, communication skills, leadership/followership flexibility, group suitability, and teamwork skills, with reported success (Maschke et al., 2011; Inoue & Tachibana, 2013) (Category III). Spaceflight researchers (e.g., Kanas et al., 2009) have also called for the development and validation of behavioral testing tools that include team exercises and isolation tasks that mimic LDEM conditions. In the 2010s, the Japanese Aerospace and Exploration Agency (JAXA) began to answer that call by assessing applicants' teamwork ability and performance for one week in an isolation and confinement facility (Inoue & Tachibana, 2013) (Category III). These changes have enhanced selection practices related to team factors and resilience; however, spaceflight agencies do not currently assess applicants for team challenges specifically related to LDEM such as communication delays. This is somewhat expected because those missions will occur more than 20 years in the future, although, since 2015, some ISS missions have extended from the nominal 3-6 months to one year. Given the target dates for exploration missions, the end of ISS in the mid-2030s, the needed ASCAN and assigned mission training time, and the wait time for astronauts in the flight queue, it is possible that astronaut selection for LDEM will begin within the next 10-15 years. Therefore, space agencies are now beginning to focus on selecting teams for LDEMs, and increasingly, individual selection factors that influence team performance.

In 2014, a job analysis was conducted to determine competencies for missions similar to the current ISS missions, and importantly, for future LDEMs (Barrett et al., 2015) (Category III). Earlier NASA job analytic efforts (e.g., Galarza & Holland, 1999) (Category III) were updated, and the new job competencies were compiled using interview data from 21 ISS astronauts, 2 Space Shuttle astronauts, and 3 veteran NASA behavioral specialists, with advice from a core panel of astronauts and 2 job analysis SMEs. Fifteen astronauts completed follow-up surveys rating the importance and trainability of each identified competency. The resulting 18 competencies highlight the importance of teamwork, small-group living, adaptability, and judgment, and the importance ratings for each of these factors was higher for the short- and the long-duration exploration profiles (Type C, D) than the ISS-like missions (Type A, B) (see Table 1, Table 2). SMEs rated sociability, adaptability, motivation, communication, and teamwork as the top 5 competencies astronauts needed "at hire". Survey respondents stated that although teamwork is part of astronaut training, a minimal competency is needed for a candidate be selected to the astronaut corps. This job analysis highlights the importance of team skills (i.e., the mean scores were high for team competencies), especially for LDEMs, provides data to help develop future selection systems, and provides insight into which skills are needed at hire vs. those that can be obtained during later training. Notably, most competencies were rated higher for the type C and D mission profiles (exploration missions that include asteroid and Mars missions) than for the type A and B mission profiles (the low Earth orbit missions). Although technical competencies are important, especially for the LDEM profile, experts in those technical areas are responsible for selecting for the required technical competencies. For example, the robotics group may insert robotic tasks in the selection process. Applicants must also have science, technology, engineering, or mathematics (STEM) degrees. BHP Operations personnel are responsible for identifying other non-technical and team-oriented characteristics. In addition, the astronaut selection process considers many other factors beyond the Team Risk, for example, candidates must pass a Level 1 physical and psychological evaluations related to the BMed Risk.

Table 1. Mission profiles for 2014 astronaut job analysis.

Mission Type	**A**	**B**	**C**	**D**
Duration (up to)	6 Months	12 Months	12 Months	12 - 36 Months
Distance from Earth	Low Earth Orbit	Low Earth Orbit	Deep Space Exploration	Deep Space Exploration

Crew Size	6	6	4	4-6
Vehicle Size	Large	Large	Medium/Small	Medium/Small
Communication Delay (one-way)	.5 – 3 Seconds	.5 – 3 Seconds	8 – 10 Minutes	10 – 20 Minutes

Note: Adapted from Barrett et al., 2015.

Table 2. Competency importance ratings derived from the updated astronaut job analysis for each mission.

	Type A	*M*	Type B	*M*	Type C	*M*	Type D	*M*
1	Teamwork	82.33	Teamwork	82.71	Self-Care	93.93	Self-Care	95.14
2	Communication	79.40	Self-Care	82.57	Small Group Living	92.29	Technical	94.21
3	Adaptability	79.20	Judgment	81.07	Teamwork	90.50	Small Group Living	94.07
4	Self-Care	79.13	Adaptability	80.43	Judgment	90.21	Judgment	92.57
5	Judgment	78.67	Communication	80.21	Technical	90.00	Motivation	92.00
6	Situational Followership	78.60	Small Group Living	78.86	Autonomous Worker	89.07	Teamwork	91.50
7	Technical	75.80	Situational Followership	78.57	Motivation	88.07	Adaptability	91.00
8	Motivation	75.60	Motivation	76.79	Adaptability	87.79	Autonomous Worker	89.59
9	Learner/Teacher	75.00	Sociability	76.36	Communication	87.07	Communication	88.86
10	Sociability	74.40	Learner/Teacher	75.59	Situational Leadership	87.00	Situational Leadership	87.64
11	Confidence	73.67	Situational Leadership	75.14	Sociability	83.43	Emotional Independence	86.00
12	Operations Orientation	72.73	Confidence	74.21	Emotion Management	83.00	Sociability	85.79
13	Small Group Living	71.13	Technical	74.07	Operations Orientation	82.71	Operations Orientation	84.14
14	Situational Leadership	70.40	Operations Orientation	73.57	Situational Followership	82.07	Emotion Management	83.71
15	Autonomous Worker	69.27	Emotion Management	71.57	Emotional Independence	81.07	Situational Followership	83.29
16	Emotion Management	68.80	Autonomous Worker	70.43	Learner/Teacher	80.14	Learner/Teacher	81.93
17	Family	62.73	Family	66.71	Confidence	79.43	Confidence	81.00
18	Emotional Independence	60.20	Emotional Independence	66.36	Family	75.64	Family	75.86

Note: *M* = mean score of Subject Matter Experts' ratings on a 100-point scale. Colors call attention to ratings of importance, within each mission type. Adapted from Barrett et al., 2015.

Selection of team-oriented individuals with the team skills and other needed-at-hire traits, skills, and behaviors identified in the job analysis competencies have been studied in a limited capacity during spaceflight. Two major models of personality, a variable that informs several of the competencies, have been considered in the NASA context. The Spence-Helmreich, or "Right Stuff", model is composed of instrumentality (e.g., goal orientation) and expressivity (e.g., interpersonal attitudes and behaviors) (Helmreich et al., 1990; Santy, 1994), which are broken down into several positive and negative traits. The dimensions of this model were clustered into the Right Stuff profile (high positives, low negatives). Astronauts, when compared to the general population, scored higher on instrumentality and slightly lower on expressivity (Musson & Keeton, 2011) (Category III). Work orientation was related to achieving an administrative leadership role. Spaceflight studies have found positives were associated with effectiveness on teamwork tasks, and astronauts with the Right Stuff profile positively influenced team performance (McFadden et al., 1994; Musson et al., 2004) (Category III). Astronauts with this Right Stuff cluster also had improved qualities of group living and job competence. Relatedly, small group living was identified as one of the most important competencies for LDEM in the recent job analysis, as was motivation to a lesser degree (Barrett et al., 2015) (Category III). Motivation is related to dimensions of instrumentality, and NASA SMEs considered this an important selection factor for LDEMs when considering the team (Morgeson, 2015) (Category IV). Detailed analysis of crewmembers' motivations recorded in spaceflight transcripts, astronauts' journals, and other biographical materials revealed that ISS crewmembers' need for achievement was mentioned most frequently and was greater during flight than before flight (Brcic, 2010) (Category III). Need for affiliation was the next most mentioned motivation category and this peaked during flight, whereas power motive was relatively low and only increased after flight. Notably, NASA astronauts and commanders had a greater need for power than cosmonauts and engineers, suggesting cultural influences and norms could be related to personality and selection as well. A follow-up study with additional data found the need for affiliation was mentioned most often by veteran cosmonauts (Suedfeld et al., 2018). ISS cosmonauts and astronauts mentioned need for achievement most frequently, but veteran cosmonauts' scores on need for affiliation were higher than need for achievement, highlighting the importance of selecting team-oriented individuals and composing compatible teams. Need for power score were much lower for the ISS flyers than the veteran cosmonauts.

The NEO-Five Factor Model (FFM) measure developed by Costa and McCrae (1992) has been more accepted for spaceflight and ground-based research than other personality models. Analyses of over 15 years of Space Shuttle-era astronaut personality data and career performance found that astronauts had low scores for neuroticism, moderate scores for extraversion, and were very high on agreeableness and conscientiousness (Musson & Keeton, 2011) (Category III). For career performance, commanders scored lower on openness, neuroticism was positively related to time to first flight, and openness was negatively related to number of extravehicular activities (EVAs). No personality trait was related to the number of flight assignments or to assignment to Capsule Communicator (CapCom). Conclusions drawn from the study suggest that individuals who are less neurotic are perceived as more desirable and appropriate for a flight assignment. Other astronaut studies of the 5 factors have found that emotional stability is positively associated with social cohesion, and that flexibility and communication are negatively related to team conflict (Kass et al., 1995) (Category III). High agreeableness and low openness were related to interpersonal and technical effectiveness, and low levels of negative personality characteristics were found only among the most effective astronauts (Rose at al., 1994) (Category III).

Other individual characteristics that astronauts need at hire include adaptability and motivation (Barrett et al., 2015) (Category III). Individual adaptation can indeed influence team processes and outcomes. A review (Collins, 2003) (Category III) suggested that ASCANs must be highly adaptable given the demands of a high-consequence environment. Greater adaptability may enable adjusting to the stressful ICE environment of space, working with a diverse crew, and shifting to autonomy during future LDEMs (Kanas et al., 2009; Kealey, 2004) (Category III). Motivation may also play a role in maintaining focus, affiliating with crewmates, and adapting to the environment because small problems are likely to become bigger over the course of a long-duration spaceflight (Morgeson, 2015) (Category III). Adaptability also allows for greater ease in switching between tasks, leader and follower roles, and interdependent vs. independent work without incurring performance decrements. Indeed, crewmembers often share leadership depending on the expertise needed for particular tasks (e.g., the crew medical officer assumes leadership during medical treatments) (Burke et al., 2017) (Category III). Spaceflight crews share leadership more than Antarctic teams and long-duration ocean racing teams. Other reviews have concluded that astronauts must be flexible in problem-solving, especially when facing unique and unpredictable LDEM events, which is related to the larger selection factor of cognition and team cognitive processes (Fiore et al., 2015; Orasanu, 2005) (Category III). Astronaut selection methods ensure only highly capable and intelligent candidates join the corps (Kanas et al., 2009) (Category III), but specifically selecting for team cognition has been very limited. Several skills may only require some indication of competence at hire, and these skills could be further developed during training (e.g., communication and teamwork; Barrett et al., 2015) (Category IV). Although these skills and the other personality characteristics are considered in addition to the applicants' technical skills, the goal of the astronaut selection committee is to examine the whole profile. No one factor should disproportionally outweigh the others when considering the whole profile of an ASCAN; a balance of different characteristics is important within each individual, and across the team (Fiore et al., 2015; Landon et al., 2017) (Category III).

Summary points related to spaceflight evidence and selection of astronauts

- Currently, astronaut selection follows best practices of a multi-trait, multi-method approach, emphasizing the whole person, which will continue in the future.
    - Technical skills and general physical fitness are not the focus of HFBP research, except as they apply to psychological functioning.
- An updated job analysis highlights competencies related to future LDEM (Tables 1, 2).
    - Some competencies may require a minimum level at time of hire (e.g., communication), with the understanding that astronaut training is extensive.
    - Other competencies require a high level at time of hire (e.g., motivation).
- Preferred astronauts for future LDEMs must be team-oriented, resilient, and emotionally stable, adaptable to different situations and cultures, motivated, cognitively capable, and able to live well with others in a confined environment.

b) Team Composition

Composition Factors and Outcomes

One requirement of strategic team composition is achieving the correct blend of technical skills to cover all technical tasks. Practicing human-centered design to ensure all systems and tools are usable is equally important. In addition to an individual's capabilities to perform mission tasks, the teams' skills and characteristics can enable performance as they function as team of colleagues and roommates. An analysis has indicated there will be over 1200 unique tasks to perform during a Mars mission (Stuster et al., 2019) (Category III). Many of these tasks will require team skills, for example, communicating status to the Mission Control Center (MCC) and to crewmembers while they are performing Mars surface operations, or coordinating use of shared exercise and hygiene equipment to maintain physiological performance. Notably, the crew will be living and working as a team at all times.

Selecting team-oriented individuals or candidates with skills that help them function well in a team setting may be most important when considering the composition of an intact team. When individuals with different personalities and other characteristics interact, this could either mitigate or exacerbate team performance and functioning. These factors include personalities, needs, interests, values and norms, emotional attitudes towards teammates, and demographic differences such as language, gender, expertise, age, ethnicity, and nationality (Kanas & Manzey, 2008) (Category III). Deep-level characteristics, named in the earlier part of the list, have a stronger and longer-lasting influence on team performance and cohesion than surface-level, or demographic, differences (Bell, 2007; Bell et al., 2011) (Category I). When differences on multiple attributes are aligned, faultlines, or hypothetical divides may occur between crewmembers, and this may lead to the formation of subgroups or team fracturing, which then negatively affects team functioning. Even relatively homogenous crews may fracture around faultlines when they are under pressure during spaceflight. A preliminary analysis of transcripts from several Apollo moon missions showed the seemingly homogenous crews (all white, male, American, engineers) with regional cultural differences (e.g., individual-collectivism, tightness-looseness for rule-following, honor-dignity culture, regional personality [friendly South]) in an odd-numbered team of 3 led to some faultlines and implications for teamwork (Huiru et al., 2021) (Category III). Team members in groups with stronger faultlines shared information more frequently when positive group affect was high. They also engaged in more learning when negative group affect was low. Taken together, this suggests that although small cultural differences may create team problems, maintaining a positive team experience and affect can overcome those differences and keep the team functioning. Larger differences demand more attention because they may have an even larger influence on team dynamics. Team cohesion can also motivate team members to be particularly conscientious of potentially problematic differences and can work to ensure those differences are overcome.

When a NASA astronaut was “hosted” by cosmonauts on board the Russian space station, Mir, team functioning was reduced because the NASA astronaut displayed withdrawal behaviors and experienced depressive symptoms (Burroughs, 1998). This situation demonstrated a multi-dimensional faultline, that is, a division on several factors (e.g., host-guest roles, nationality, cultural values) and tokenism, because only one crewmember had a particular characteristic (i.e., NASA astronaut). Faultlines that cause subgrouping, or worse, isolates, amongst team members should be avoided. With a long-duration team, small differences may be exaggerated (Stuster, 2010) and disrupt team functioning as the mission proceeds. Group interaction was the fourth most mentioned topic in astronaut journals, after work, outside communications, and adjustment. One entry stated “I’m finding myself losing tolerance for T. I can’t explain exactly what it is that bothers me.” (p. 22), indicating that small differences may accumulate over time, with potentially little understanding as to why it happens. Much anecdotal evidence relates stories of astronauts and cosmonauts experiencing and dealing with cultural differences in attitudes and behaviors, both for work and non-work interactions. NASA astronauts on Mir experienced a decline over time in crew bonding, personal growth, and task orientation, which often corresponded to faultlines (Kanas et al., 2001). Friendships and trust between crewmembers of different cultural backgrounds has been reported, but these positive feelings decreased over time (Suedfeld et al., 2013). Multi-cultural differences must also be considered when developing space programs in other countries (e.g., China, India) that may one day partner with NASA (Ehrenfreund et al., 2010) (Category IV).

Because many factors influence team dynamics over time, it is critical to address team composition as an ongoing and dynamic process. That is, team composition does not end when the crew is assigned to a mission. Instead factors such as knowledge, skills, abilities (KSAs) to perform the task, physical fitness, and the interpersonal relationships and shared mental models or understanding between crewmembers should be considered for each critical task requiring a subset of the crew or even the full crew. This approach to composition requires robust data-driven models and tools to predict likelihood of success and to prescribe task assignments to enable efficient and effective performance. Agent-based modeling offers one avenue to support this (Antone, et al., 2021a) (Category IV).

Composition of the MTS

Other composition-related variables have received less attention in the spaceflight literature. One consideration is that of the MTS for LDEMs, which includes Mission Control teams. Conflict between MCC and spaceflight crews has been reported (Stuster, 2010) (Category III), but unfortunately, very little research exists for MTS and team composition in spaceflight. CapComs are an important liaison between the crew and MCC, thus, their compatibility with both groups may be more important than interactions between crew and the entire MTS (Bell et al., 2015b) (Category III). However, this relationship will likely change during LDEMs because of the extended communication delays. The CapCom and other MCC personnel rotate during the 3 work shifts during each 24-hour period; thus, a crew may be ideally composed with a particular CapCom and set of MCC personnel during one MCC work shift but have more friction points with personnel on the other shifts. Compatibility should be optimized across all MTS compositions, and individuals should be trained to function as boundary spanners, that is, key individuals that work across teams to integrate information, facilitate communication, and enhance cross-team coordination. Studies that examined astronauts' and cosmonauts' coping strategies found that women were much more likely to employ the emotion-oriented coping strategy of attributing events to luck (Suedfeld et al., 2009) (Category III), suggesting there are some differences between men and women in reactions to spaceflight conditions. Spaceflight SMEs have also reported some conflict due to gender differences (Bell et al., 2015a) (Category IV). Research on variables such as personalities and gender, and suggestions for team composition, is included in the ground-based evidence below. Furthermore, ensuring compatibility between the spaceflight crew and ground support (rotating mission control personnel with different personal characteristics) could also be addressed during team training. That is, training all members of the MTS on a shared model of teamwork (and technical knowledge skills as needed) will maintain coordination and communication across mission control shifts and as natural attrition occurs over the course of a multi-year mission.

Risk of Commercialization and Private Astronaut Missions (PAMs)

A 2021 operations assessment conducted on behalf of the HFBP Element examined the risks related to commercialization and the integration of private astronauts with professional astronaut crews (Landon et al., 2021) (Category III). SME interviewees (e.g., NASA flight directors, flight surgeon, psychological support staff, human factors designers, crew training SMEs, astronauts) identified concerns related to PAM participants, who are not as highly selected or highly trained as the professional astronauts, adding extra burden to the crew (time, stress, performance) and other resources (equipment, vehicle, bandwidth). PAMs are likely to increase risk for astronauts and for the PAM participants. In the words of one interviewee, “The ISS isn’t built for tourism; it’s built for science”. Risks may be psychological (e.g., stress, cohesion), physical (e.g., emergencies, medical, physiological), and organization-related (e.g., risk to NASA reputation, culture differences, equipment, procedures, norms). Work is underway by NASA SMEs and PAM provider organizations to create minimum requirements and recommendations for how PAM participants should be selected (both psychologically and medically), trained, and supported during their time in space. Defining the PAM participants roles and responsibilities and the decision-making process (crew, ground, and organization level) is critical, and this is especially true during off-nominal events such as emergency response. Although most of the operations assessment addressed the many potential risks involved, one astronaut stated that there may be benefits for astronauts, in the form of watching someone experience the wonder of spaceflight for the first time. Overall, the findings highlight the need for more research because the risks are not well understood nor mitigated, particularly because the frequency of these missions will increase in the coming years.

Summary points related to spaceflight evidence and team composition

- Current team composition lacks systematic and data-driven rigor
- Composition is not a onetime occurrence that ends when a crew is assigned to a mission. It is a dynamic, ongoing process that must respond to changing team dynamics and physical fitness throughout the mission.
- Algorithms are needed to compose future LDEM teams, by balancing personalities, technical skills, and other individual differences (e.g., gender, nationality).
    - Strong faultlines and tokenism should be avoided
    - Research is need for team composition that considers the entire multi-team system, and in LDEM conditions.
    - PAMs introduce risks to teams of professional astronauts that are not well-understood nor mitigated.

c) Team Autonomy, Communication, and the Multi-Team System

Priorities and roles in the spaceflight MTS for the exploration era

Throughout the history of spaceflight NASA’s Mission Control has had shifting priorities and norms, denoted by 3 distinct “eras”: early exploration (missions up to the moon landings); experimentation (dominated by the Space Shuttle); and habitation (characterized by longer duration missions on the ISS) (Pendergraft et al., 2019) (Category III). Each era the MTS adapted to the improved technical capabilities, built collaborative relationships, and increased integration with external partners. In this approaching fourth era of spaceflight, which will explore beyond Earth’s orbit and to Mars, technical competencies, internal collaborations and team processes, and cross-organizational collaborations and coordination must all be highly adaptable, especially given the extreme duration and communication delays involved with Mars missions. The goals, priorities, and even the relative authority of various teams in the MTS will change during the course of the mission, so communication and the flow of information must be streamlined, timely, and packaged in such a way that issues are proactively mitigated, and responded to efficiently when they do occur. New methods of structuring the MTS, the training for flight controllers and support staff, and the work processes are necessary. This is not easy because spaceflight MTSs are ambiguous, multifaceted, dynamic, and must address urgent task demands that could result in loss of life (Pendergraft et al., 2021) (Category IV). However, lessons learned from other MTSs offer avenues for determining and developing countermeasures needed for future missions. See Figure 3 for a simplified diagram of a spaceflight MTS.

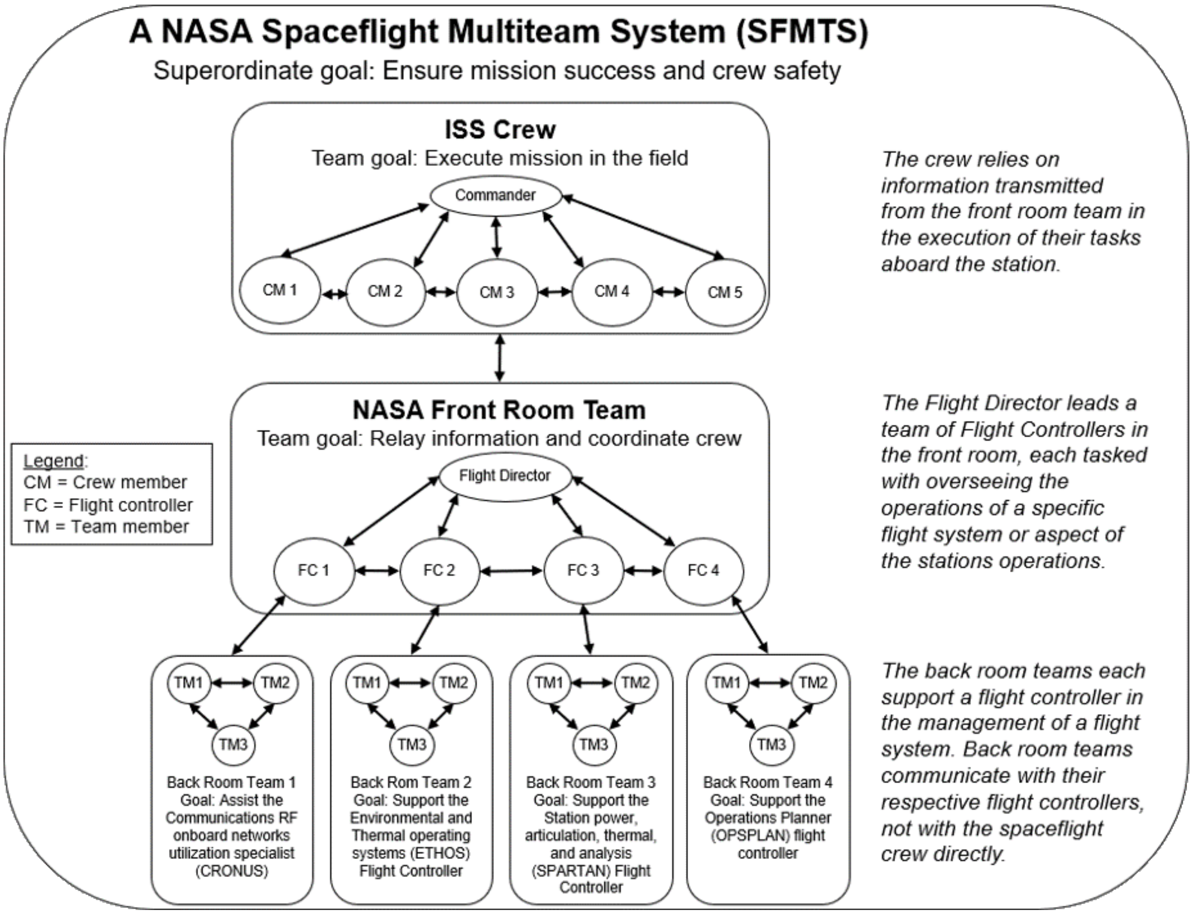


Figure 3. Exemplar NASA spaceflight MTS and associated goal hierarchy.
Adapted from Pendergraft et al. (2021).

Connectedness and autonomy across the MTS

Teams on the ISS are physically isolated from ground and experience some limited psychological isolation. However, real-time communication technologies (e.g., communication loops with MCC, Internet Protocol phone) and other technologies (e.g., email, video messaging, internet) ensure the ISS crews are well-connected with colleagues, professional support personnel, and friends and family on Earth. Because the spacecrafts are primarily controlled from the ground, MCC often acts as the hierarchical leader during operations, an arrangement that requires extensive coordination across the MTS, especially during emergency situations. However, during future LDEMs, communication delays due to the great distance of the vehicle as it travels away from Earth will eliminate the real-time communication between crew and ground and limit the asynchronous communications to periodic data bursts. These communication constraints will likely result in greater spaceflight crew autonomy from MCC, but little is known regarding changing levels of autonomy and the impact of autonomy on the team over the long-duration mission. There are obvious psychological health implications related to this isolation, which are addressed in the BMed evidence report. Regarding the Team Risk, autonomy is conceptualized as the conditions, constraints, and limits that influence the degree of discretion by the astronaut or the crew over choices [decisions], actions, and support in accordance with standard operating procedures. Increased autonomy will likely influence training needs, procedures, infrastructure, and crew composition, and may require greater involvement from the crew in mission planning (Rubino & Keeton, 2010) (Category III). The MTS has been described generally as a network of teams working towards both a common goal and individual team goals (Mathieu et al., 2001) (Category III). The NASA crew/ground MTS is one connection in a larger MTS, which also includes a network of Mission Control teams within teams, and extends across multiple space agencies (e.g., NASA, Russian Space Agency, Roscosmos [RSA], ESA) and specializations (e.g., astronauts, flight controllers, engineers); isolation from the MTS has several implications.

To date, no studies have been conducted on high levels of crew autonomy for extended periods during spaceflight, however, shifts in operational autonomy are expected to impact psychosocial adaptation to the demands of spaceflight (Kanas & Manzey, 2008) (Category IV). A study with ISS crewmembers examined how communication delays of approximately one hour with MCC affected performance and well-being (Kintz et al., 2016) (Category II). A 50-second one-way communication delay led to delays in task completion, greater stress/frustration, and reduced crew well-being. Being understood by others was positively related to performance, but astronauts under communication delays reported lower communication quality and miscommunications. Autonomy was positively associated with crew and team performance and crew well-being. However, autonomy did not mediate the relationship between communication delay and outcomes, suggesting communication delays and autonomy have a unique influence on performance and health outcomes. This study also found notable behavioral changes under communication delays such as asking longer and more detailed questions, discussing and planning with crewmates more before calls, interacting less with ground, and CapCom slowing down and repeating calls. The implications of this study include potential changes to team training, and that team communication tools and protocols must ensure good packaging of information, selection of the most critical information for communication, availability of recorded communications after a call is completed, and training to increase task knowledge. Astronauts suggested they would need to be more autonomous during LDEMs, which would require less communication with MCC and more autonomy written into task procedures. Unfortunately, higher autonomy and less real-time communication may lead to reduced shared cognition between MCC and the crew, as was found in a study of the 3 Skylab crews (DeChurch et al., 2017) (Category III). When the crews and MCC performed interdependent tasks, their shared cognition was increased, whereas their shared cognition was reduced during times of less interdependence. Crews rated switching from working independently or within the crew to working with MCC as the most difficult type of task transition (Mesmer-Magnus et al., 2021), particularly if working with MCC involved a communication delay. Crew-to-solo and MCC-to-solo task transitions were rated as the easiest. Additionally, decreases in similar or shared cognition between crewmembers or between space-to-ground predicted the significant team breakdown that occurred during Skylab 4 (i.e., crew work stoppage) (DeChurch et al., 2017).

The Astronaut Journals Project (Stuster, 2010; 2016) (Category III) offers some additional insight regarding communications and autonomy. Although communication problems were reported as only a small percentage of the category "outside communications", communications with MCC were the second-most mentioned communication problem (a distant second to personal communication problems). The frequency of communications to management and MCC tapered somewhat in the fourth quarter of the mission, indicating psychological closing. Astronauts reported interpersonal tensions with MCC, feelings of being patronized, and conversely, appreciation and positive interactions with ground personnel. A series of studies of Mir and ISS crews found that crews tended to displace negative emotions to MCC, perhaps as a coping mechanism to maintain goodwill with fellow crewmates (summarized in Kanas et al., 2013) (Category III). This pattern also follows general psychology theories of in-group/out-group dynamics. NASA SMEs report that subtle disrespectful and rigid behaviors can occur between teams (e.g., devaluing another's contributions) (Shuffler et al., 2017) (Category III). Other dysfunctional behaviors include withholding information between teams, which was noted as particularly dangerous. Cultural norms play a role in spaceflight as well; NASA astronauts may go almost all day without speaking to MCC and MCC makes social support calls to ISS, whereas Russians participate in "marathon discussions" and work-focused calls, implying that cultural differences should also be addressed when preparing for autonomy and communication mission norms during future LDEMs (Stuster, 2010) (Category III). Crewmembers also remarked on the high workload and a feeling of being chained to the schedule and to procedures, and expressed gratefulness when they were able to "drive their own schedule" and "have some control over our lives". MCC's lack of understanding of the time needed for carrying out tasks or overscheduling the crew was noted as a source of frustration. During the Skylab 4 mission, demanding schedules led to conflict between the crew and ground support personnel, work stoppage, and trust issues (Stuster, 2011) (Category III).

ISS crews have reported the desire for more autonomy, and it is likely that the increased complexity of future LDEM missions will require increased crew discretion, less burdensome procedures, and general flexibility to perform tasks and deal with emergencies (Krikalev et al., 2010) (Category III). Interviews with astronauts and NASA SMEs indicate that there should be a more collective, rather than hierarchical, approach to mission planning between the crew and MCC, allowing the crew greater autonomy and flexibility to meet day-to-day goals and respond to unforeseen events (McIntosh et al., 2016) (Category III). The interviewees acknowledge that "as we go farther out, Mission Control can do less and less" and it is "hard for people on the ground to really have understanding of situation on board a spacecraft" (p.484). Another set of interviews with spaceflight SMEs reported that 75% of interviewees identified leadership as a critical behavior in the MTS, and that leadership must be shared within and across teams (Shuffler et al., 2017). The ISS has become a more complex vehicle over the years, and researchers have already noted that crewmembers naturally distribute knowledge of certain systems, and fail to clearly communicate this localization of knowledge to MCC (Caldwell & Onken, 2011) (Category III). These researchers have begun to examine future mission operations of multiple vehicles and LDEMs from a human factors perspective. For example, off-loading some decision-making to automated systems, with the crew or MCC as the final decision-maker to perform or abort an action, may be a sound countermeasure. Differing levels of command may be more effective for LDEMs, such as short-term control for a specific period of time, tactical control (the crew is given a task or mission objective to accomplish and report back after completion), or strategic control (overarching objectives are set during a daily/weekly planning conference and the crew decides how to accomplish them). Communication delays will change in length during LDEMs, another factor to be considered in the degree of autonomy afforded to the crew.

Team and human factors researchers caution that it is not possible to create a wholesale, onboard replication of NASA's MCC for communication-delayed missions (McTigue et al., 2021) (Category III). A greater understanding of the limitations of automated systems and of human-computer integration and other support tools is needed for LDEMs. An in-depth case study of multi-team problem-solving and coordination from the human factors perspective outlined the differences between MCC and a 4-person Mars-like crew in the number of years of experience (660 vs. 91), training in a vehicle system (2 years to operator plus more years for specialist certification in a single system vs. 4 years of broad training across many systems), and practice and refresher on those skills (constant use and simulations vs. long time gaps between training and use in flight). A crew of 4 simply cannot have the same in-depth expertise in every space vehicle system as the 85+ experts at MCC, which will limit their respond in real-time to anomalies and emergencies. Because of communication delays, LDEM crews will need increased data access, just-in-time training tools and technologies, and troubleshooting decision support. For operations that must rely on MCC, communication protocols and tools to clearly exchange information must be developed as well.

Structuring work in the spaceflight multi-team system

Related to adjusting to different levels of autonomy, the ability of the crew to switch from one type of work structure or task type to another may also affect team performance, coordination, and stress. A detailed case study of the response to an anomaly during a Space Shuttle mission shows the importance of examining information within smaller teams and pushing that information up in larger MTS meetings (Watts-Perotti & Woods, 2007) (Category III). Information gaps and hidden disagreements between teams in their understanding of the anomaly and their approach to problem-solving was identified. Information was distributed across the MTS, but switching from within-team analysis to cross-team analysis requires a cooperative advocacy strategy, which enhanced effectiveness of the MTS. During LDEMs, team task switching may occur after long periods of autonomy, either planned (e.g., destination is reached) or unplanned (e.g., emergencies), requiring coordination with MCC (Smith-Jentsch et al., 2015) (Category III). Furthermore, teams may need to switch from independent individual tasks to interdependent tasks within the team, switch between different sub-teams, switch between tasks (e.g., maintenance vs. science), switch between languages, etc. Although these types of switches often occur on the ISS, the performance decrements due to this switching may be exacerbated during LDEMs because boredom and entrainment may be greater during the journey phase, and greater physical and psychological shift events may occur during other phases of the mission (e.g., arriving to Mars). Entrainment during one working condition can negatively affect performance or situational awareness after a switch, as reported by ISS crewmembers in a recent operations assessment (Smith-Jentsch, 2015) (Category III). This assessment suggested that crewmembers communicate little during autonomous tasks, and in the event of differing schedules or major events (e.g., EVAs), crews may reduce interactions, and in turn, reduce information exchange and supporting behaviors. Team coordination, shared awareness, and supporting behaviors are also likely to be reduced. One astronaut stated, "you look out for people who are excessively tired, rushing, making mistakes", indicating that loss of awareness of teammates and a lack of supporting behaviors may lead to errors. Although each mission has a commander, crewmembers possess expertise in certain areas, necessitating a switch between leader and follower roles as their skillsets are required. Current ISS crewmembers acknowledge this expectation of collective leadership, but a leader's ability to drop back while the appropriate follower steps forward is often easier said than done. Expectation-setting and shared knowledge of each team member's strengths may help to facilitate this switching process. Additionally, coordinating shared knowledge across MCC as personnel rotate on- and off-duty according to the scheduled work shifts is important to avoid process and knowledge loss. Flight notes and console logs are currently used to document what occurred during each shift and to update the next work shift's personnel during handovers, but these have not been studied empirically to determine any needed changes or the impacts of the additional constraints of LDEM. More research is needed to address these issues for LDEM mission designs and to develop training and tools for all teams in the MTS, and especially regarding the impact on team functioning and cohesion. During a 2019 workshop, 20 spaceflight SMEs from several domains (e.g., astronauts, flight/mission control, mission planners, medicine, behavioral health, crew training) derived a list of top concerns related to future autonomous missions that have no real-time communication with MCC (Holden et al., 2020). Experts agreed that NASA is currently inadequately prepared for a crew to operate highly autonomously, especially during an anomaly, stating that the "majority of unexpected situations and problems are, and have been, handled through communication with experts at MCC" (see list below of other concerns). Notably, team skills were identified as being "task enablers" that improved the likelihood of success across all tasks and support crew safety.

The most critical tasks, issues, or functions that will affected by autonomous crew operations, as identified by spaceflight SMEs (Holden et al., 2020):

- Inability to autonomously perform medical diagnoses and interventions
- Isolation-related medical and behavioral problems
- Detection of problematic health or teamwork
- Lack of preparation for scientific missions
- Unknown anomalies
- Catastrophic events on Earth
- Problems with complex information processing during anomalies
- Need for enhanced decision-making capabilities
- Lack of clarity in data handling processes
- System failures and dynamic events
- Lack of long-term training retention
- Inadequate human interaction with smart vehicles/systems
- Insufficient intelligent (smart) systems development
- Human-robot integration risk
- Lack of preflight training

Summary points related to spaceflight evidence and team autonomy, communication, and the MTS:

- The MTSs include the spaceflight crew, NASA mission control, the network of teams within NASA mission control, other space agencies, and other governing bodies directing spaceflight missions.
    - Cultural norms differ in respect to interactions with spaceflight crews and mission control.
- Crews of future LDEMs will have greater autonomy than current ISS crews because of the communication delays between MCC support personnel and the crew during these missions.
- Research is needed to understand how differences in communication delay and autonomy may affect team performance, coordination, shared cognition, and communication, and switching between different styles of working. Countermeasures have grown organically within the space programs, but scientific research should drive development of LDEM countermeasures.

d) Team Skills and Team Skills Training

Long-duration spaceflights (i.e., flights of more than 6 months), such as ISS missions, are so physically, mentally, and emotionally demanding that simply selecting individual crewmembers who have the "right stuff" is insufficient (Flynn, 2005). Training and supporting optimal performance, as well as selecting high performers, is a more effective and efficient approach than simply selecting high performers (Holland e al., 2007) (Category IV). Current astronauts spend a large part of their careers in training. When first selected to the astronaut corps, ASCANs begin an intensive training period lasting approximately 2 years, which includes high-performance T-38 jet pilot training, survival skills and emergency response, technical systems skills (e.g., life support, payload deployment, EVA skills, Earth observation), communication protocols and norms such as using the phonetic alphabet and packaging communications, group training, cultural and Russian language training, physical conditioning, and general professional training for a career in the media spotlight (National Research Council, 2011). Similar programs take place at other space agencies (JAXA, ESA, and Canadian Space Agency [CSA] have sent astronauts to ASCAN and other NASA training), and astronauts from other agencies travel to Houston, TX and to Star City, Russia for training on specific systems and ISS modules. Once an astronaut is assigned to a mission, they begin assigned crew training for that specific mission, and additional training takes place on board the ISS during flight. Astronauts may also be trained in mission simulation analogs such as NASA Extreme Environment Mission Operations (NEEMO). Several Space Shuttle crews have specifically opted to complete ISS Expedition interpersonal training as a team to enhance their "cohesion and performance" (in personal communication with BHP personnel, Shultz, 2007) (Category III).

Training team skills and supporting optimal team performance entails more than educating astronauts about the technical aspects of the job. It also requires equipping those astronauts with the resources they need to maintain their psychological and physical health for an extended duration in an ICE environment. As one astronaut wrote in his/her journal "We spend all of our [training] time on emergency scenarios and spacewalks. Sometimes understanding how to live would go a long way to increasing the success of the mission." (Stuster, 2010, p.20) (Category III). Technical trainers have instituted a "day in the life" training to address this need from a workflow perspective, and the BHP operations group currently addresses this need through a series of behavioral health-related trainings for the ASCANs. Components of behavioral health training include an overview of BHP operations' role in spaceflight support. Other components include aspects of team skills (more information regarding this training and the psychological support services provided by BHP operations group is described in the BMed Risk chapter of this evidence book and below). The oft-repeated astronaut training philosophy is "Train as you fly. Fly as you train", which indicates that team skills training must be set in the context of technical skills training. However, NASA training experts have identified the need for a more integrated approach to training, dubbed "crew-oriented, mission-centered" training, because of often siloed nature of training on each vehicle system, and because team and technical skills training are given separately (Dempsey & Barshi, 2021). In other words, astronauts should learn and practice both types of skills as they will use them on a mission. Although some integrated training occurs, spaceflight training could be improved with more strategic integration. Integration may also make training, which is arduous and time-consuming, more efficient and effective.

It is worth noting that RCA cosmonauts receive training that is quite different from the training received by NASA, JAXA, ESA, and CSA astronauts. RCA currently uses technical, parachute, and survival training events as the venue for behavioral training (Noe et al., 2011). Training is more theoretical and more reliant on note-taking than manuals. Notably, cosmonauts receive pay for performance during their mission, and are evaluated during training with a similar tone, whereas astronauts receive feedback from a variety of sources (e.g., trainers, Astronaut Office management, psychological support) and the tone of feedback is intended to be developmental rather than evaluative, and performance does not influence pay or rewards. Training designers must find ways to understand the implications of these different approaches, and overcome these cultural differences, for the benefit of all crewmembers.

Many of the training events discussed above naturally contain an element of team skills or technical skills that may enhance team performance (e.g., communication norms), but the focus on teamwork during each event and across each space agency varies. Often, team skills are an assumed outcome or by-product of group technical training and activities. Now that effective teamwork is deemed critical for successful space missions, more focus is placed on developing and training team skills according to the available best practices and evidence from team training research. Quite simply, team training works, as demonstrated by meta-analyses of many aspects of team training in ground-based studies. For example, one large meta-analysis found positive relationships between team training interventions and team cognitive, affective, process, and performance outcomes (Salas et al., 2008) (Category I). This training must be grounded in good science to maximize short-term learning and long-term transfer of skills and knowledge to the job (Salas & Cannon-Bowers, 2001). Research and training validation studies conducted in the spaceflight context are limited. However, when developing training programs, several best practices should be followed (Salas, 2015; see Table 3) (Category IV, based on Category I). NASA recognizes that training teamwork skills, especially for future LDEMs, will improve teamwork processes and performance, as well as cognitive and affective outcomes, in a high-stress environment (National Research Council, 2011). This follows team training best practices for creating a learning climate. Additionally, multiple team training needs analyses (Noe et al., 2011; Smith-Jentsch et al., 2015) (Category III) and an updated job analysis have determined the competencies that astronauts will need for LDEMs (Barrett et al., 2015) (Category III). These competencies will continue to be updated. When selecting metrics, it is important to consider performance levels in relation to training team skills. Training should be evaluated to determine the standards of optimal, adequate, or inadequate performance, and the skills that help differentiate high- versus low-performing teams should be determined. In this way, training can be validated by checking the students' progression and the teams' performance before and after training. Therefore, standards for team performance in the spaceflight context should be determined before training is designed. To date, spaceflight teams' performance data is available only to a few researchers, and acquiring such performance data requires a more collaborative partnership between the research and operational communities.

Table 3. A temporal display of the principles of team training.

Before training	During training	After training
• Systematically identify characteristics of the organization, team tasks, and individual team members • Evaluate whether the organization is ready to receive team training • Generate support from organizational leadership • Prepare and motivate the learner for team training • Provide a safe, non-critical team training environment	• Systematically design team training based on what's scientifically shown to be effective • Leverage information presentation, demonstration, practice, and feedback • Employ team training delivery strategies, tools, and technology appropriate for meeting the needs of the organization, team, and trainees • Ensure instructors are prepared to teach	• Determine what to measure during team training and how to measure it • Analyze if the team training program was successful and determine why it was effective (or not) • Establish mechanisms for the continued assessment and improvement of team training • Provide opportunities to foster continual team improvement • Motivate and facilitate the long-term transfer and sustainment of teamwork behaviors

From (Salas, 2015).

NASA uses a multi-method training approach that includes lectures and low-fidelity simulations (e.g., team coordination paper-and-pencil exercise) and high-fidelity simulations (e.g., EVA training in the underwater Neutral Buoyancy Lab) that incorporate elements of teamwork and stress inoculation. NASA's SFRM training programs are important for acquiring teamwork skills and experience, and they are derived from the aviation industry's CRM approach and more recently organized into 4 teamwork elements: information exchange, communication delivery, supporting behavior, and leadership/followership (O'Keefe, 2008; Smith-Jentsch, 2015) (Category III). Astronaut-scientists especially need this training because they are often not directly taught team skills before they become an ASCAN, whereas pilots and flight engineers arrive with CRM skills (Love & Bleacher, 2013). Flight controllers also participate in SFRM training programs because of their role in the MTS. Common team skills across these groups supports a shared mental model of team skills and processes that ultimately enhances multi-team functioning and performance (DeChurch & Mesmer-Magnus, 2015) (Category III). All astronauts receive pilot training, which incorporates CRM, they participate in National Outdoor Leadership School (NOLS) leadership training, and they are evaluated on group interactions during mission simulations that include a mock Mission Control and EVA training. NASA training supports team development activities, not simply task training that happens to be in a group setting, and this type of training has increased over time. The Astronaut Crew Office uses the Expeditionary Skills Training model, which includes leadership/followership, communication, self-care, team-care, and teamwork and general group living skills; these overlap well with the updated job analysis competencies (Barrett et al., 2015) (Category III). The collective leadership framework (Friedrich et al., 2009) is applicable to spaceflight, particularly as NASA mission profiles shift to less of a hierarchical leadership structure (Mulhearn et al., 2016). Key constructs include communication, shared leadership, supporting behaviors, and other team-level affect, which are woven into the SFRM teamwork skills model and the Astronaut Office's Expeditionary Skills model. Astronauts and NASA SMEs have reported that teamwork skills, communication style, and autonomy are the most important leadership variables when considering future LDEMs. Although collective leadership is often used in the context of the crew, it also applies to the larger MTS. The crew must be more autonomous during LDEMs because of communication delays with Mission Control, but the crew and MCC must still be trained to step forward and back into leadership and followership roles as the situation requires.

Many of these training activities include team-based content that follows instructional principles of information, demonstration, practice and feedback; however, few validation studies have assessed the effectiveness of this training. The success of the space program is a powerful, yet anecdotal, testament to the effectiveness of the team training currently in place, but future LDEMs will require better validated evidence to determine the readiness of the crew. Quantitative evidence exists for the effectiveness of SFRM team dimensional training (TDT) debriefs with flight controllers (Bedwell et al., 2012) (Category II). After a simulation, flight controllers participate in a debrief session structured around the 4 SFRM teamwork elements. Flight controllers have reduced their certification time by half using TDT, identified more team errors, and had a less superficial categorization of spaceflight incidents and greater learning. After teams of U.S. Navy submariners completed TDT, their decision making improved significantly and tactical errors were reduced. Because the actions of the flight controllers influence the performance of spaceflight crews and the success of the mission, better training and performance of flight controller teams likely lead to a positive impact on spaceflight teams. It is expected the trend towards enhanced team training across space and ground, resulting in better mission outcomes, will continue because the ASCANs now participate in the SFRM training, but performance data has not been made available.

Other issues related to astronaut training-needs may be gleaned from a series of interviews with a dozen long-duration flyers that identified 5 unique work characteristics of long-duration spaceflight (Smith-Jentsch et al., 2015) (Category III). First, crews will experience variation in their task interdependency. They work independently most of the time, but come together as a team for critical tasks such as EVAs. These critical tasks usually require a great deal of coordination with the MTS on the ground. The shifts in work approach may happen abruptly, or after a long period of working independently as an individual or as a team without the assistance of MCC. Cognitive skills and cues, along with leadership/followership skills, may help crews switch without incurring performance decrements. Training to establish and maintain crew cohesion and adaptability will support team functioning. Second, a variability of tempo, that is, periods of down time or possible boredom during transit on an LDEM may be interspersed with period of intense activity (e.g., arriving at Mars to begin exploration). During high activity times, crews must use a wide range of problem-solving and teamwork skills, as well as shared cognition, to work efficiently. Stress management training is a part of the ASCAN training flow, as is expeditionary skills and NOLS, which also address self-care/self-management. Third, crewmates may not know each other very well before launch due to how crew training is scheduled, leaving little time for team storming or norming. Substantial training with the intact crew must take place before launch. Fourth, teams are often very diverse. As was discussed in relation to team composition, avoiding strong faultlines and incorporating cross-cultural and adaptability training may mitigate this issue. The BHP operations group currently offers ASCANs cross-cultural training that addresses cultural differences and strategies for dealing with cultural differences. Beyond simply understanding cultural differences, crews must also have time to get to know each other as individuals. And fifth, a small team must endure ICE conditions for many months. Again, developing crew cohesion and team resilience is important, as are managing conflict and communication skills. In addition to the trainings previously discussed, assigned crews also receive family-oriented training, covering everything from practical concerns (e.g., writing wills, assigning contact persons, and mission-specific information) to family support services, and psychological training to understand potential psychological health threats that may occur during a mission. More information regarding how the various characteristics of the LDEM may be addressed in training team competencies is given in the ground-based research section of this report.

Summary points related to spaceflight evidence and team skills training:

- ASCAN training and assigned mission training are long and rigorous, covering task work and teamwork skills.
    - Historically, more attention has been given to taskwork skills, but LDEMs call for more attention to teamwork skills and simply living with the team.
- Development of team, maintenance of psychological well-being, and training in interpersonal or soft skills should take place regularly over time, and should consider cultural differences related to leadership, communication, performing as a team, and living in an ICE environment.

3. Team Emergent States

a) Team Cohesion, Trust, and Conflict

Spaceflight evidence regarding cohesion and performance is limited by a paucity of objective team performance data. However, case studies, interviews, and surveys conducted within the spaceflight realm provide evidence that issues pertaining to cohesion exist and are perceived as threats to effective operations. For example, breakdowns in team coordination, resource and informational exchanges, and role conflicts (i.e., common indicators of poor cohesion) were mentioned as contributors to both the Challenger and the Columbia Space Shuttle accidents (Columbia Accident Investigation Board Report, 2003; Launius, 2004) (Category III). Likewise, flight controllers have revealed that mission teams are commonly concerned with team member coordination and communications, and that interpersonal conflicts and tensions exist (Caldwell, 2005; Parke et al., 2005; Santy et al., 1993) (Category III). Additionally, the frequency of reported negative processes and outcomes tend to increase over the course of the mission. For example, cohesion was significantly higher during the early part of missions, and several studies report increased crew tension and conflict during the middle and end of missions that lead to a decline in cohesion (Dion, 2004; Kanas, 2004) (Category III). The Astronaut Journals Project also found a trend of decreasing positive comments related to group interactions over the course of ISS missions, and the same trend of increased conflict in the fourth quarter (Stuster, 2010) (Category III). Conversely, an increased frequency of “getting along” in the fourth quarter has also been reported, suggesting that the group is more aware of group interactions towards the close of a mission. One study suggested that the effects of potential faultlines based on cultural diversity may be intensified in monotonous and isolated environment, resulting in negative outcomes and group conflict (Kealey, 2004). Minority crewmembers on the ISS have reported that they sometimes feel isolated, and more diverse teams have reported lower levels of trust (Suedfeld et al., 2013) (Category III). This interpersonal conflict can increase feelings of frustration, which may result in psychological closing, and a decreased quality and quantity of crew communication (Kanas et al., 2009) (Category III). Differences may also lead to subgroups forming or a token member being treated as a less-trusted “guest” (Sandal et al., 2011; Suedfeld et al., 2013) (Category III). Crews reported perceiving greater differences between members over time (Sandal et al., 2011) (Category III). These trends have negative implications for team functioning, especially during a long-duration mission when small irritants may become bigger over time. Therefore, longer duration missions may involve more instances of conflict. Indeed, analysis of the astronauts’ journals (Stuster, 2010; Stuster, 2016) reveal instances of conflicts occurring in all quarters of the missions, with increases in the second half of the multi-month missions. Training in conflict management and private psychological conferences (PPCs) provide the crewmembers with guidance and skills to combat these friction points, and this can alleviate some of the tension; however, communication delays during LDEMs will eliminate real-time PPCs and place more onus on the crew to address any conflict or decreased cohesion, and to maintain team performance and functioning. In the words of one spaceflight psychology expert, conflict will occur on every mission, but the focus should be on prevention, prediction, and repair (personal communication to L.B. Landon from a NASA operational psychologist, 2019) (Category IV).

b) Psychosocial adaptation, and team adaptation and resilience

Astronauts and cosmonauts adapted and remained resilient during 6 months in orbit on Mir, but reports indicate that many Mir participants who participated in longer duration flights (more than 6 months) developed symptoms of fatigue, irritability, and minor disorders of attention and memory (Boyd, 2001; Kanas et al., 2001) (Category III). Much has been made of the so-called “third quarter phenomenon”, a hypothesis originating from polar research, which contends there is an increase in negative social and emotional feelings, more interpersonal rifts, and more behavioral health and physiological symptoms related to stress during the third quarter of a mission (Bechtel & Berning, 1991). However, a 2021 review of the literature by expert spaceflight psychological researchers concluded that some people may experience such a phenomenon, but it is not a typical occurrence during spaceflight or in analogs of spaceflight (Kanas et al., 2021) (Category I). The researchers offer possible reasons for varying outcomes, which include demand characteristic bias, individual personality traits, training omissions, experimental method issues, and the impact of mission events on crewmember well-being. Behavioral health research has determined that duration of the mission is a more important predictor of individual behavioral health and team problems than mission quarter.

Team friction also tends to increase over the course of an ISS mission (e.g., Stuster, 2010) (Category III); thus, even if crewmembers have adapted to spaceflight, maintaining resilience over time may be difficult. Psychosocial adaptation allows the crewmember to adjust to the stressful ICE environment of spaceflight, whereas the process-based team adaptation results in increased adaptive responses and better performance. Most available data on team adaptation comes from research conducted in analogs of spaceflight; however, the astronauts’ journals and other anecdotal information indicate that astronauts are often successful at adapting to their environment and maintaining resilience. For example, issues that create tension between crewmembers are remedied through informal group discussions (Kanas et al., 2009), and crews respond to emergencies, such as ESA astronaut Luca Parmitano's helmet filling with water during an EVA, without incurring lasting psychological distress. In this case, the MCC and the crew quickly responded to that event, creating an adaptive, timely plan to direct Parmitano to return to the airlock and readied aid to deploy on his return. Parmitano's crewmates quickly came to his aid with towels to clear away the water after he re-entered ISS from the airlock. Astronauts undergo extensive training dealing with survival and emergency situations, which prepares them for quick adaptation to dynamic and high consequence events, and the resilience to recover back to nominal after the event. Countermeasures are currently being investigated to maintain team resilience over time, such as in-flight training, crew activities, and team-based activities in virtual environments.

Support from and positive interactions with team members in extreme environments may influence an individual's well-being and performance, and in turn, the team's well-being and performance (Kennedy et al., 2016) (Category III). Support may also come from others outside the intact team such as family, friends, and operational support professionals. Research to address the BMed Risk assesses the effects of support from family and friends, and the methods and effects of providing psychological support during communication-delayed missions (see BMed evidence report). During PPCs, astronauts discuss their experiences with an operational psychologist who is specifically dedicated to a crewmember for each mission, and who provides acute support during times of crisis such as loss of a loved one while the astronaut was deployed on a mission. Entries in astronauts' journals also highlight the importance of reaching out to friends and family for support from Earth: "We have phone calls every day with home, we have video conferences once a week. The psychological support we get on this flight is amazing." (Stuster, 2016) (Category III). Research to address the BMed Risk will develop countermeasures to alleviate the strain due to lack of real-time support and communication from those on Earth.

Although team research often focuses on adaptation to unexpected, highly critical events such as emergencies, the related risk of inadequate design of missions, processes, and tasks (Sandor et al., 2017) considers the limits of human capabilities because they may degrade over time, and the frustration and lack of efficiency if a human-centered design process is not implemented. Without a human-centered design process, the crew would need to adapt to confusing procedures, inadequate equipment, or excessive workload. Regarding teams, countermeasures would likely include training to be adaptable in creative problem-solving, decision-making and prioritization, and maintaining a shared mental model, which will allow team members to adapt smoothly under changing and unexpected conditions. Tasks with a team component should be identified before launch, the team should be trained on these asks, and a series of refresher and just-in-time team trainings should be available to prevent skill decay in adaptability. More research is required to understand psychosocial adaptation and the ability of a spaceflight team to adapt and remain resilience over an extended duration.

Summary points related to spaceflight evidence and team emergent states:

- Team cohesion, trust, and conflict have been linked to performance changes in past missions. Both surface-level and deep-level differences can lead to and exacerbate problems related to team functioning and performance.
- Current mitigation strategies rely somewhat on real-time communications (e.g., Private Psychological Conferences), which will not be available during future LDEMs.
- Astronauts are generally adaptable and resilient, and are trained to deal with emergencies and manage stress; however, measures to maintain general adaptability and resilience will be more important for LDEMs and will require more research and development.

4. Measures and Monitoring Technologies

Few tools are currently in use to monitor teams during spaceflight from a behavioral and psychological perspective. The Astronaut Journals Project (Stuster, 2010) and debriefs after a mission offer some understanding of team dynamics on the ISS, but the considerable amount of lag time between data collection and the processing and reporting of that data precludes the ground personnel from supporting the crew. PPCs, held regularly throughout a mission, have reportedly addressed some concerns related to team functioning, but these discussions are not recorded for research or public monitoring of the team, and are kept confidential by the psychological support staff. An individual's measures of variables that may have implications for team functioning, such as stress and individual cognitive functioning, are currently covered by the BMed Risk and are described in greater detail in that report. Some ground-based research is focused on developing team-related monitoring tools, and this research is discussed in the section on Measures and Monitoring Technologies in the Ground-based Evidence below. Notably, the HFBP-Exploration Measures (formerly, the BHP Standard Measures, which grew from the Behavioral Core Measure project [Dinges, 2020]) is currently collecting individual- and team-oriented data in a variety of ICE environments, including on the ISS (Roma, 2020; Bell, 2021). Results are forthcoming.

C. GROUND-BASED EVIDENCE

1. Sources of evidence

Almost every research task within the Team Risk requires use of a ground-based spaceflight analog to understand the risk and to develop and validate measures, standards, and countermeasures. Other risks in HRP rely heavily on the ISS for research into the effects of altered gravity and radiation, however, analogs simulating a mission environment and/or the long-duration aspect of LDEM are suitable for assessing many psychological factors, especially Team Risk factors. Spaceflight analogs that simulate the ICC component of a space mission include the HERA at JSC, the undersea NEEMO station, the University of Hawaii's long-duration Hawai'i Space Exploration Analog and Simulation (HI-SEAS), the now-retired Desert Research and Technology Studies (D-RATS), the Russian NEK chamber used for the Mars 105 and Mars 500 studies, and now the Scientific International Research in a Unique terrestrial Station (SIRIUS) studies. The underground Cooperative Adventure for Valuing and Exercising human behavior and performance Skills (CAVES) managed by ESA, and the NOLS, a survival leadership course, are used for short-duration astronaut training in analogs of planetary surfaces.

Long-duration isolated, confined, extreme (ICE) environments include Antarctic stations such as the Concordia Station, the South Pole Station, the McMurdo Station, and the Antarctic search for meteorites (ANSMET). These are working research stations or outposts devoted to scientific research such as geology and climatology. The ISS has also been used to assess the communication delays that will occur during LDEMs (e.g., Kintz et al., 2016). Research that assesses analogous populations such as military personnel, submariners, healthcare workers, aviation personnel, nuclear plant workers, fire-fighters also provides critical evidence on how teams perform in ICE environments that also have high levels of stress and pressure. Team performance and functioning is a robust area of research when considering typical organizations and industries, with tens of thousands of studies on team performance and function focused on areas such as management, industrial/organizational psychology, industrial engineering, human factors, and social and cognitive psychology. Meta-analyses of the preponderance of evidence in this field that may be extended to spaceflight teams are reported below, and specific examples of analogous populations, especially from the military and spaceflight analogs, provide greater detail and evidence collected in environments similar to spaceflight. Indeed, context is important: several spaceflight analog studies found that the relationship between team cohesion and team performance may operate differently in ICE environments (Bell et al., 2019a) (Category I). However, spaceflight-relevant data has been obtained from only a small number of applied studies, preventing robust meta-analysis and highly confident statements as to the magnitude and direction of team effects in extreme environments. Each year sees more progress.

Considerations when conducting extreme-team research

Before preceding to a summary of the ground-based research findings of teams in extreme environments, it is helpful to outline considerations for researchers as the Team Risk matures in both understanding and mitigating the risk for LDEMs. Research into spaceflight teams and other extreme teams is challenging because it is difficult to identify and select appropriate analogs, and to access, collect, and disseminate findings while maintaining participant confidentiality (Bell et al., 2021b) (Category IV). One somewhat outdated analog assessment tool may help researchers understand how a specific research environment relates to spaceflight, and aid in selecting analogs appropriate for a particular research study (see Keeton et al., 2011). For ambitious research teams, or organizations wishing to create environments analogous to spaceflight, NASA has some information online (https://www.nasa.gov/analogs/types-of-analogs), and NASA's experts have written about the development of spaceflight analogs and the management process (see Cromwell & Neigut, 2021) (Category IV).

Experts who study extreme teams have provided insight into designing research studies that lead to the development of countermeasures in real-world situations (e.g., Bell et al., 2018; Driskell et al., 2017) (Category IV). Figure 4 (from Bell et al., 2018) describes an approach for conducting actionable research with extreme teams that was derived from work examining teams in spaceflight and military contexts. This mixed-methods approach leverages qualitative and quantitative study designs to understand the specific context (e.g., a crew on a LDEM) and provides recommendations for how to analyze data and communicate findings that support an extreme team's performance and functioning. Spaceflight conditions (i.e., extreme duration, confinement, and isolation) may alter the typical predictor-outcome relationships found in research into more typical, organization teams. Additionally, longitudinal research would help elucidate the risks that may occur during future long-duration Mars missions; reviews of relevant spaceflight and analogous teams literature suggest longitudinal studies of 45 to 90 days, but ideally several months (Schmidt, 2015; Bell et al., 2019a) (Category I). Longitudinal studies allow a team to progress through the early formation period and begin to function as a team, which is the period of interest for long-duration spaceflight researchers. Studies into spaceflight teams should also employ a common set of measures, allowing data to be aggregated and compared across environments to capture the true predictor-outcome relationships (Bell et al., 2019a; Landon et al., 2017) (Category I, III). NASA's HRP is currently funding work that will develop and validate such measures across the risk areas, and team-oriented measures are included in the *Standardized Behavioral Measures for Detecting Behavioral Health Risks during Exploration Missions* study (Dinges, 2020) and the *HFBP Exploration Measures* study, or HFBP-EM (previously named *Identification and Validation of Behavioral Health and Performance Standard Measures* study) (Roma, 2020; Bell, 2021). Research into LDEM teams that is firmly grounded in the unique spaceflight context may benefit from a careful and context-focused approach.

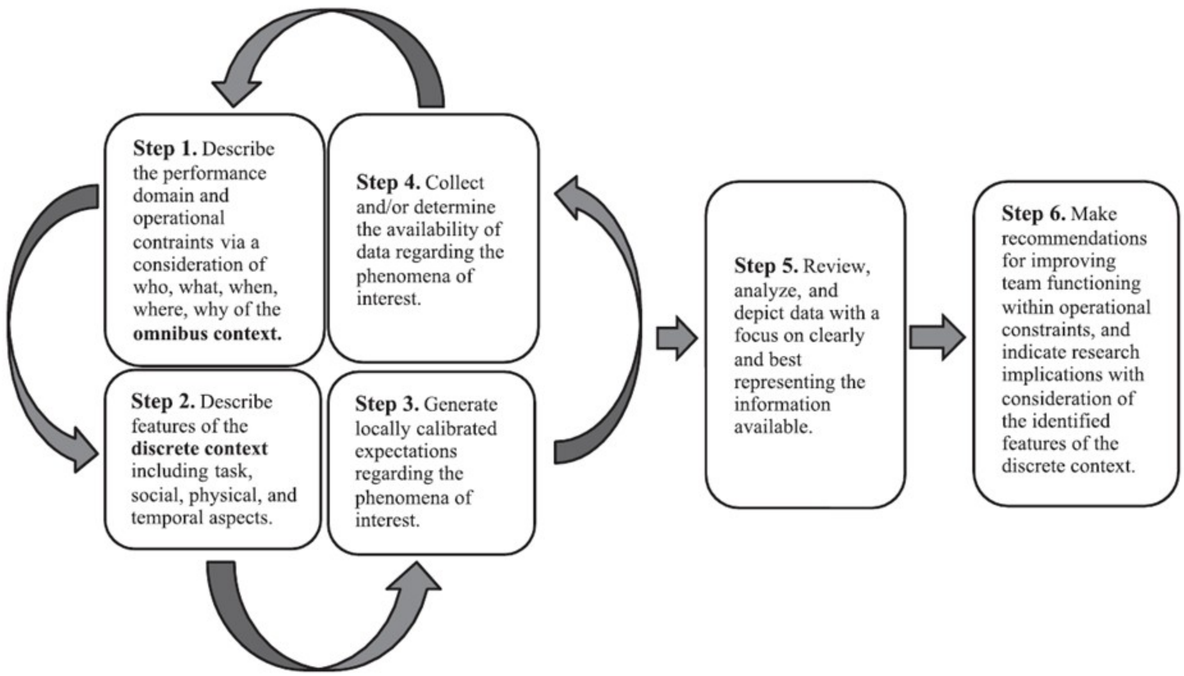


Figure 4. Approach for conducting actionable research with extreme teams (adapted from Bell et al., 2018).

2. Predictors and contributing factors to team performance and functioning

a) Astronaut Selection

Job analyses from many organizations include some common competencies for selecting individuals to work in teams and in high stress jobs. These competencies, which are reflected in the latest astronaut job analysis for LDEMs, include aspects of small group living, teamwork, motivation, and adaptability during LDEMs (Barrett et al., 2015). Systems that select for minimum skill levels and inherent personality characteristics should be anchored by these 18 competencies. Research on submariners and Antarctic teams using the Helmreich

Instrumentality-Expressivity Model of personality found that achievement-oriented individuals use problem-solving coping strategies that predict team success (Sandal et al., 2003; Leon & Sandal, 2003). The more widely established 5 factor model of personality has been studied repeatedly. A classic meta-analysis by Barrick and colleagues (updated in Barrick et al., 2001) (Category I) summarizes the relationship between personality and job performance: conscientiousness and emotional stability is positively related to overall work performance, greater extraversion and agreeableness predicts teamwork, and openness is not related to many work outcomes. These findings corroborate the spaceflight evidence of personality traits in astronauts, and the LDEM oriented job analysis calling for sociability at hire and highlighting the importance of teamwork. Studies in spaceflight analogs have found similar trends. Quantitative reviews of psychosocial factors assessed in analogs of spaceflight environments and analogous populations (e.g., Palinkas et al., 2011; Schmidt, 2015) (Category I) contend that emotionally stable individuals direct more energy towards team performance and functioning. Highly motivated individuals, such as astronauts, are focused on "not letting the team down" and cooperating to achieve goals. Schmidt (2015) (Category I) found that personality characteristics and self-care actions were strongly linked with health outcomes (e.g., coping with stress), which in turn was related to objective team performance. Individual characteristics of self-care and trust were linked to team member exchange, an important team process affecting team performance. An individual's values also affect team performance because teams that consist of members who value being on a team perform better than teams consisting of members who do not value being on a team (Bell, 2007; Salas et al., 2005) (Category I; Category III). Members who do not value being on the team are less likely to be motivated to learn team skills (Salas et al., 2005) (Category III). The results of U.S. Navy research in Antarctica suggest that while technical competence is necessary, it is also important to select individuals who exhibit "social compatibility or likeability, emotional control, patience, tolerance of others, self-confidence without egotism, the capacity to subordinate routinely one's own interests to work harmoniously as a member of a team, a sense of humor, and the ability to be easily entertained" as well as those who are practical and hardworking (Stuster, 2011) (Category III). A historiometric analysis of mission critical teams found that the "entertainer" role was common across teams, and that some roles were consistently enacted independent of temporal considerations (e.g., mission length), whereas the degree to which other roles were enacted varied during missions of differing lengths (Burke et al., 2019) (Category III). Notably, the team builder role was enacted more often as mission duration increased, and for missions over 2 years, there was an increased enactment of behaviors the visionary/problem solver role. Thus, team processes and performance will be enhanced and health maintained if team members have greater individual motivation and traits that lead to positive interaction and coordination/cooperation with teammates. Team orientation and underlying abilities related to group living skills are particularly important when selecting astronauts for LDEMs because these traits are an important foundation upon which other team factors affecting team performance and functioning are built.

Individual characteristics such as cognition and adaptation, as they relate to teams, are also important. Reviews of the literature, when considering the challenges of LDEM, discuss adaptation as both an individual trait and a team-level trait (Maynard et al., 2015) (Category III), and cognition at multiple levels of analysis (Fiore et al., 2015) (Category III). Adaptability may apply to both working with others and to working within varying conditions, situations, and events. Notably, cognitive ability is positively associated with adaptation, as is goal orientation

(LePine, 2005) (Category I). Individual cognition is considered in the BMed Risk, whereas individual cognitive processes are subsumed under team-level cognitive processes. Personality may influence these processes; for example, agreeableness is positively related to the development of shared mental models, and more extraverted individuals are likely to communicate more, facilitating information exchange and coordination. However, a team of uniformly high agreeable members risks groupthink and may lower capacity for creative problem-solving. Some variability above a minimum, while selecting for and encouraging use of divergent thinking processes such as idea generation, exploration, and intuition can enhance creativity and avoid groupthink (da Costa et al., 2015; Fiore et al., 2015; Lungeanu et al., in press) (Category I; Category III, Category III). Additionally, leaders with moderate levels of assertiveness were identified as the best leaders and were associated with positive interpersonal outcomes and performance outcomes, whereas low or high assertiveness led to positive outcomes of only one outcome type (Ames & Flynn, 2007) (Category 1). Meta-analyses have found that information-sharing positively predicts team performance, and that cooperation enhanced this relationship (Mesmer-Magnus & DeChurch, 2009) (Category I). A literature review of military personnel and other analogous populations found that a minimum level of internal motivation and engagement, as well as high levels of commitment and willingness to accept challenges, ability in intuitive decision-making, and emotion regulation are important characteristics for teams that exercise shared or collective leadership (Gibson et al., 2015; Mulhearn et al., 2016) (Category III). Collective leadership is similar to the leadership/followership structure used during spaceflight missions; that is, team members become the leader or follower according to the expertise needed at the time and leadership is more distributed amongst team members. Mission simulation studies in the HERA found that leadership behaviors were shared amongst crewmembers throughout the mission rather than one individual assuming the leadership role throughout (Burke et al., 2017) (Category II). These characteristics should follow needed leadership/followership characteristics identified in the collective, dyadic, socio-emotional, and crisis leadership models. These variables should be considered during astronaut selection.

Summary points related to ground-based evidence and selection

- Individual traits (e.g., emotional stability, agreeableness, self-care, motivation, sociability, team-orientation, leadership/followership flexibility, adaptability and resilience) enhance both the individual's and the team's performance and functioning.

b) Team Composition

Teams are more than simply the sum of their parts. For example, a meta-analysis found that team efficacy and team potency were positively related to team performance (Gully et al., 2002), (Category I) and that team potency remains a significant predictor of performance even when considering the collective ability of the team members (Hecht et al., 2002) (Category II). Several studies in analogs of spaceflight conditions have investigated the compatibility factors listed by Kanas and Manzey (2008) (Category III). Notably, the interactions of these factors have also been examined; for example, the only woman, a Canadian, in the Simulated Flight of International Crew on Space Station (SFINCSS) analog study, was reportedly harassed by one of the male crewmembers from Russia (Sandal, 2004) (Category III), and reports of this incident cited differing cultural views on gender norms as a contributor. Often, gender norms become an issue in the presence of other salient variables such as age or culture (Rosnet et al., 2004; Bell et al., 2015a). Cultural diversity can lead to process loss from increased task conflict and decreased social integration/cohesion (Stahl et al., 2010) (Category I), and faultlines are related to greater conflict, and to lower team cohesion, performance, and team member satisfaction (Thatcher & Patel, 2011) (Category I). Differences in values such as benevolence, tradition, and self-direction were identified as drivers of the Mars 500 crew's decreasing team cohesion over time (Sandal & Bye, 2015) (Category III). Notably, the development of faultlines in ICE environments is influenced by team composition factors in a different way than in non-ICE environments; that is, value- and knowledge-based differences will become more important for team functioning than demographic traits (Antone, et al., 2017) (Category III). When a team forms subgroups this may have health implications; for example, Antarctic winter-over teams with greater subgrouping experienced higher levels of depression, anxiety, anger, and fatigue than more cohesive teams (Palinkas et al., 2000) (Category III). Tokenism negatively affected social support (social support was positively related to team performance) in several studies conducted in analogs of spaceflight (Schmidt, 2015) (Category I), A review of LDEM-related studies found that culture, beyond creating interpersonal barriers, may also influence day-to-day behaviors of the crew through emotion display, power dynamics, time orientation, role orientation, cognitive styles, and individualism vs. collectivism, which influence mood, psychological safety, shared cognitions, and ultimately team decision-making and performance (Burke & Feitosa, 2015) (Category III). For example, practicing shared leadership and switching between leader and follower roles on a mission may not come as naturally to crewmembers from a collectivist culture with larger power distances. Additionally, organizational research has found that individuals from collectivist culture are less adaptable to changes in team composition, which will occur in MCC throughout the mission.

A NASA-sponsored review and operations assessment of team composition in 24 field and mission simulation analogs related to LDEM provides excellent insight into the complexity of factors future mission planners must consider (Bell et al., 2015a) (Category III). The researchers named 5 key composition factors most likely to have a strong influence on team functioning and performance during a LDEM: (1) cultural and sex/gender differences; (2) personality; (3) abilities, expertise, work background; (4) network factors (relationships across the MTS); and (5) team size, such that 6 members offers a greater chance for diversity than 4 members. Regarding the paths through which composition affects mission success (see Table 4), conclusions suggest surface-level differences interfere with social integration, and teams with deep-level similarities of values, needs, interest, and personality had better social integration. However, teams with many dominant or extroverted members were more incompatible. Studies in spaceflight analogs also found these characteristics were predictive of team processes (e.g., coordination), emergent states (e.g., cohesion), stress, performance, and subgrouping, such that greater homogeneity often led to more positive outcomes. In an extensive review of studies conducted in ICE environments, crew homogeneity was positively related to social compatibility (Palinkas et al., 2011 (Category III). However, it is highly unlikely that a homogenous crew will be assembled for future international LDEMs, which require a wide range of knowledge and skills, and call for a multi-cultural representation of humanity. Homogeneity may result in poor team performance stemming from ineffective team processes such as groupthink, and informal leadership roles, and appropriate switching between leader/follower roles may help foster group solidarity in a heterogeneous crew, where varying expertise is needed at different times during a mission and leader support can improve group coherence, as suggested by research on Antarctic teams (Johnson et al., 2003).

Table 4. Summary of how team composition relates to mission success.

	Path 1	Path 2
Brief path description	By affecting social integration	By affecting team processes and emergent states related to team task completion
Detailed path description	• Social integration fosters team cohesion, and prevents subgrouping & isolation • Social integration stems from surface-level (e.g., gender) & deep-level (e.g., values) characteristics, which includes supplementary (similar) & complementary (dissimilar) fit between teammates	• Teammates have diverse skills & expertise, & operate in a multi-team system • Composition influences team emergent states (e.g., shared cognition) & team processes (e.g., coordination), & available skills & expertise
Study findings	• Analogs: Social integration is related to similarity in values; compatibility of personalities; dominance (avoidance of multiple dominant members); similarity in attitudes and interests; diversity of sex, age, & nationality; & other factors (e.g., need for affiliation)	• Analogs: Composition is related to conscientiousness, need for autonomy, shared interests and activities, values, need for affiliation, all-female crew • Traditional teams: Composition is related to shared cognition, information sharing, & transactive memory system

Note: Adapted from Bell et al., 2015a;b. Paths are not mutually exclusive.

Team composition procedures may also examine team cognitive processes stemming from individual cognitive capabilities. Teams with similar values, skills, experiences, and personalities naturally establish a measure of shared mental models, which is related to teamwork and team performance (DeChurch & Mesmer-Magnus, 2010a) (Category I). However, team members with a uniformly high level of agreeableness may risk creating a team that engages in groupthink or lacks the ability to generate creative solutions to problems due to the lack of divergent thinking and critical assessment (Fiore et al., 2015) (Category III). A HERA study found that diversity in individual team members' level of agreeableness better supported constructive shared mental models, which supports team problem-solving because the team is prompted to share more information and perform more critical assessments (Lungeanu et al., in press) (Category III). Thus, the proper balance of different characteristics is needed to ensure that any given personality type does not dominate the group. Similarly, configurations of traits within a single individual can influence the team, such as a highly extraverted, low agreeable individual negatively disrupting team functioning. A study of Army officers identified 7 types of trait clusters, and 2 clusters were identified as more likely to lead to promotion to senior officer: motivated communicators and thoughtful innovators (Mumford et al., 2000) (Category II). A study of Antarctic Station crews examined how combinations of personality traits relate to outcomes on a team-based cooperative task (Roma et al., 2015b) (Category II), and found that teams with low conscientious and high agreeableness were the most cooperative and the most productive. During 4 long-duration HI-SEAS missions, EVAs with individuals who demonstrated more cooperative behavior during a team task (Roma et al.) were found to be more efficient and more stable in that efficiency over time (Binsted et al., 2021) (Category III). Teams with individuals who are more likely to engage in teamwork activities also foster development and maintenance of a shared mental model. One meta-analysis found that a team minimum level of agreeableness is a strong predictor of team performance, as is the team's mean conscientiousness, openness, collectivism, and importantly, preference for teamwork (Bell, 2007) (Category I). Validated algorithms can be used to simultaneously consider trait configurations at both the individual and team level to avoid untenably composed teams and identify potential points of friction, and thus, targets of countermeasures (e.g., frictions) in even the most optimally composed team (Bell et al., 2015b) (Category IV). Some characteristics related to team cognition should be the focus of selection and team composition, whereas other skills and shared cognition or understanding can be developed through training, especially training as a unit (Fiore et al., 2015). Notably, team composition is not a one-time event to assign a crew to a mission. Team dynamics change over time and any team composition countermeasure should consider these fluctuations at any point in time to maintain mission success.

Summary points related to ground-based evidence and team composition:

- Cultural diversity should be recognized and managed through selection and training of shared knowledge and norms, and adaptable, agreeable, team-oriented team members.
- Algorithms are needed to compose future LDEM teams, and to balance personalities, technical skills, and other individual differences (e.g., sex, nationality, values).
    - Strong faultlines and tokenism should be avoided.
- Team composition should be an ongoing, dynamic process that occurs before and throughout the mission to maximize the likelihood of mission success.
- A NASA-sponsored review of team composition in spaceflight and analogs of spaceflight environments named 5 key composition factors: (1) cultural and sex/gender differences; (2) personality; (3) abilities, expertise, work background; (4) network factors (relationships across the MTS); and (5) team size.

Countermeasures related to selection and team composition

Future LDEM will require simultaneous consideration of a multitude of factors when composing the mission team. Acknowledging the importance of skills required for taskwork, and avoiding strong faultlines whenever possible is necessary (Bell et al., 2015b) (Category III). Studies in spaceflight analogs and of analogous populations highlight several key composition factors that must be addressed through selection and training: cross-cultural issues, sex/gender, values/attitudes/interests, personality (especially assertiveness/dominance, extraversion), professional background such as military experience, and specialized expertise such as physician vs. geologist. Currently, NASA relies on suggestions from NASA SMEs (e.g., personnel in the astronaut office, flight surgeons, and operational psychologists) when composing mission teams, and no rigorous, data-driven process is in place to compose mission teams, which is an identified need for future exploration missions. RCA has employed Homeostat and other methods to research crew compatibility (Kanas et al., 2009). Development of composition algorithms, which weight many individual and team factors according to the predicted influence on team performance and functioning, is one potential method of selecting crews. Potential teams identified by the algorithm could also undergo a trial period or engage in team activities and assessments to determine fit and effectiveness before mission launch. Past spaceflight simulations such as the Mars 105 use several individual and group assessments to select compatible crewmates (Vinokhodova et al., 2012), and HI-SEAS employed NOLS to familiarize potential team members with each other, and individuals reported their preferred teammates to the facility's investigators who selected the final crew. Training together for an extended period, including time in ICE environments, will ensure the team has progressed through the forming and norming stages before spaceflight and will give trainers time to address any teamwork issues in-person, when real-time communications is available. In so doing, shared team cognition will be given time to develop. Teams will likely be cross-trained to increase the likelihood of mission success if a team member becomes unable to perform technical and taskwork, which will provide additional avenues of commonality between crewmembers to prevent faultlines. Composition algorithms may also benefit from considering more informal team role experience and orientation. Drawing from past literature, a set of 6 informal team roles were identified: organizer, doer, challenger, innovator, team builder, and connector (Mathieu, et al., 2015) (Category III). An updated review of spaceflight and spaceflight analog studies examined roles, and found that both task and social roles are important, particularly for long-duration teams (Burke et al., 2019) (Category II). Enactment of the team builder role increased as mission duration increased. Prominence of the entertainer role, and increased emphasis on the visionary/problem solver role occurred on missions lasting more than 2 years. Given that an individual's previous experience in one role and role orientation may dictate the role they fulfill, a strategic composition of team members who play a variety of roles according to mission demands, along with training teams on necessary role behaviors to fill any gaps, may enhance team functioning and performance. An ongoing crew composition tool was initially developed using data from a dozen HERA missions (Antone, et al., 2021b) (Category II). The underlying algorithm considered contextual factors (e.g., workload, communication delay), personality, task characteristics, and networks amongst the team members to recommend best and worst pairings during high-fidelity tasks. The teams of "recommended" best pairings of crewmembers were more likely to report positive social relationships and were less likely to report that working together was damaging to their relationship. 'Worst' pairings reported better interpersonal relationships after working together, suggesting that strategic pairing may be a means to repair strained relationships.

Establishing procedures and team standards regarding everything from taskwork (e.g., roles, workload, schedules, conflict resolution) to living conditions (e.g., hygiene, recreation, humor, treating others with respect) sets a new team norm that may supersede potential faultlines (Kanas et al., 2009; Stuster, 2011) (Category III). Educating individuals on differences such as norms regarding leadership and power distance, trust, conflict resolution, and communication, is an important first step, but selecting team members with traits such as openness and adaptability is another area for research. At minimum, teams must be trained in common languages to facilitate communication. English is the declared language for the ISS program; however, all NASA, CSA, ESA, and JAXA astronauts learn Russian. Language barriers in the SFINCSS negatively affected communication and team functioning (Sandal, 2004) (Category III) and, as seen during the Mars 105, may exacerbate team tensions (Sandal, Bye, & van de Vijver, 2011). Creating new group norms that engender a psychologically safe environment to step outside cultural norms as needed should also be addressed during intact team training. Every effort must be made to integrate the team and address any conflicts before the team launches; the current practice of training crewmembers separately for much of the run-up to launch must change for future

LDEMs. Finally, composition of teams across the MTS will likely change over the course of a long-duration mission. A recent review of the MTS literature highlighted several studies examining the fluidity of MTS membership and subsequent challenges to maintaining consistent communications and networks. The transformation of MTS composition over time is an understudied area (Shuffler et al., 2015). It will be important to compose effective teams within MCC for LDEM, but this has received much less attention than spaceflight team composition.

c) Team Autonomy, Communication, and the Multi-Team System

Crew autonomy as a positive

Higher crew autonomy is inevitable during communication-delayed missions, and MCC will likely take on more of a mission-support role vs. mission control role. Meta-analyses (e.g., Stewart, 2006) (Category I) and longitudinal studies (Cordery et al., 2010) (Category II) have determined that team autonomy in workplace teams is linked with better performance. Several spaceflight analog studies have examined team autonomy in an MTS, and the subsequent effects on psychosocial outcomes and team cohesion. A set of studies examining high vs. low autonomy in the simulation analogs NEEMO, Haughton-Mars, and Mars105, found that high autonomy conditions were deemed safe, with no adverse effects, and mission objectives were met (Kanas et al., 2013) (Category II). Highly autonomous teams reported positive moods and greater creativity, but MCC personnel for spaceflight analogs reported role confusion as crews became more autonomous. Some nuanced differences in behavior were observed between analogs. For example, NEEMO mission commanders offered more direction and were less fatigued in high autonomy conditions. Highly autonomous teams in Haughton-Mars had greater cohesion than Mir or ISS MCC members. High autonomy during Mars105 was created by allowing the crew more discretion to plan activities and by instituting a 20-minute one-way communication delay. Crew morale and cohesion was high throughout the mission, and mission objectives were completed, but there were differences between Russian and European crewmembers when moving between low and high autonomy. Perceived autonomy increased for Europeans, while cohesion decreased. Leader support was related to cohesion for both the crew and for MCC. Negative mood, tension, and anger from the crew was displaced to the MCC. Other research from the Mars 105 found that one group of subjects in the high autonomy condition began to practice closed (vs. active) communications, which was correlated to lower scores of mood and activity (Gushin et al., 2012) (Category II).

Other spaceflight analog studies such as the 12-month HI-SEAS mission with a communication delay found a positive relationship between autonomy and outcomes of leader ratings of performance, crew cooperation, motivation, and lower stress (Goemaere et al., 2019) (Category III). The crew was also more cooperative and less defiant of MCC direction when they felt MCC was supportive and not controlling. Another set of studies using a lab simulation of a mission with an MCC, examined participants who were trained for several months on a 3-person, team-based planetary exploration task (Roma et al., 2013) (Category II). After the extensive training, teams then performed a “mission” for 3-4 hours. Subjects were placed in conditions of low autonomy from MCC (i.e., MCC schedule dictated activities) or high autonomy from MCC (i.e., team determined schedule), and in a second manipulation teams had either full communication with MCC or experienced a loss of communication. Both studies found better performance (i.e., collecting higher quality geologic samples) during high autonomy conditions. Regarding psychosocial factors, highly autonomous teams reported more positive moods and had lower cortisol production reflecting lower levels of stress, and increased socially referent language, which the researchers suggest is an indicator of enhanced team affiliation and cohesion. These findings are related to meta-analytic work highlighting that empowering leadership increases team empowerment over their work and decision-making, which leads to better performance (Maynard et al., 2013) (Category I). Leader behaviors or management structure (e.g., MCC providing more autonomy to the field crew) empowers the team such that they experience greater feelings of competence, autonomy, and meaningfulness in their work.

Other times, team autonomy and empowerment may be a natural side effect of the environment. ANSMET requires teams of 4-8 members to live together, on the ice, in tents, away from immediate medical attention, for several weeks, with limited communication, while they survey and collect meteorites in the field (Love & Harvey, 2014). ANSMET teams create their own schedules, task assignments, prioritization, and manage resources and equipment; they do not rely on a control center. Studies benchmarking cohesion dynamics of these highly autonomous teams in both field and mission simulation analogs found that each team had its own ecology; that is, cohesion was observed to be stable and high for one team, whereas another team experienced more fluctuation over the duration of the mission (Kozlowski et al., 2017; Webb et al., 2017) (Category III). Thus, although workplace teams show a clear pattern of increased autonomy leading to empowerment, which in turn leads to improved job satisfaction, commitment, health outcomes, and task and contextual performance (including team empowerment predicting team effectiveness) (Seibert et al., 2011) (Category I), a specific mission team may require methods to attune to their specific needs.

Crew autonomy and disconnect as a negative

Team autonomy is not always desired, especially in high consequence environments when remotely located experts are needed to solve a problem that requires fast action. Mars crews of only 4-6 individuals are unlikely to be experts in every system or situation that occurs during the mission, especially with an estimated nominal task list of over 1200 tasks (Stuster et al., 2019). Communication delays may interfere with the problem-solving process and inhibit coordination with MCC. Collective orientation, which can affect team processes and emergent states such as backup behaviors and trust, may decrease with physical separation and communication delays (Smith-Jentsch et al., 2015) (Category III). It is common to observe a decrease in crew-to-ground connectedness in spaceflight analog studies, with in-groups and out-groups forming between the crew and MCC. For example, during the SIRUIS-19 mission, a decrease in both task and social cohesion was reported across the MTS over time, and a higher level of crew-to-ground cohesion was reported by MCC versus the crew (Fischer & Mosier, 2020) (Category III). A disconnect was also found for the crewmembers' and mission controllers' assessment of MCC's contribution to task success, with MCC reporting higher levels of perceived contribution than that perceived by the crew. This may cause higher-than-planned levels of autonomy if the crew fails to coordinate with MCC when it is warranted. In situations that require input from MCC, switching to a lower degree of autonomy to allow external leadership may be difficult (Smith-Jentsch, 2015) (Category III) and cause negative affective and motivational responses. Studies have suggested that long-duration isolation may increase conflict between crewmembers, and crews displace negative affect and negative behaviors to MCC (Kanas & Manzey, 2008; Palinkas, 2000) (Category III). If the spaceflight crew does not have this outlet readily available to them, negative reactions related to power dynamics and affect may turn inward to the crew and decrease overall performance. Or the communication delay may exacerbate the displacement of negative emotions to MCC as they are more firmly viewed as the disconnected out-group, furthering the disconnect. A meta-analysis found that familiar and face-to-face teams exhibited a stronger relationship between communication and performance (Marlow et al., 2018) (Category I), suggesting that while crew-to-ground may speak less during communication delays, it is more important to maintain within-crew communications.

Psychological closing, or a reduction in quantity and quality/richness of communication, is problematic for crew-to-ground coordination, and is frustrating when trying to maintain relatedness with colleagues and family/friends on the ground. Psychological closing increases over time, particularly during communication delays. A review of mission simulation studies found that the length of commanders' written communication decreased over time (Bell, et al., 2019a) (Category I). This has also been observed in the communication-delayed SIRIUS-17 and SIRIUS-19 missions (Supolkina et al., 2021) (Category III). Misalignment of shared mental models may increase if the spaceflight crew and MCC drift apart literally and figuratively and become entrained to operating autonomously from one another, or simply do not want to coordinate when needed across the MTS to avoid negative interactions and frustrations.

Organizational research has found that coordination is even more important to performance in an MTS setting (Mathieu et al., 2008) (Category III). When coordination is needed in a communication-delayed MTS, one countermeasure approach to mitigate the negative effects of communication delays is to use structured communication protocols. Studies in NEEMO under varying lengths of communication delays found that crews and MCC were talking past each other, that is, they were responding to messages out of order, confusing which responses corresponded to which communications and responding to actions that were outdated (Palinkas, 2012; Fischer & Mosier, 2015) (Category II). During a time-pressured event, the safety of a crewmember can be compromised due to communication delays between space-to-ground. A high-fidelity simulation study of critical, but survivable, medical events requiring a team response found that having real-time flight surgeon support in MCC enhanced crew team behaviors, crew information exchange, and overall technical performance (including adherence to critical processes) (Dias et al., Yule, 2021) (Category I). Team skills (which were based on the NASA SFRM model) were positively related to technical performance, and real-time flight surgeon support decreased crew cognitive load.

Even during typical communication conditions or within team communications, miscommunication and failures to communicate have contributed to transportation accidents and medical errors (e.g., National Transportation Safety Board [NTSB], 1994; Baker, et al., 2006; McKeon et al., 2006; Powell & Hill, 2006) (Category III). Other contributing factors include poor teamwork, coordination, and tactical decision-making, and interpersonal conflicts, which may all be negatively affected by communication problems. MTS teams may develop feelings of in-group/out-group, as has happened with remotely located exploration crews and command centers (Stuster, 2010). HI-SEAS crews under 20-minute communication delays report that crew-ground disconnect is a significant problem (Binsted, 2015), and Mars 500 participants reported 5 times more conflicts between crew-ground than within crew conflicts (Basner et al., 2014) (Category III). Training to recognize symptoms of potential conflict has mitigated this negative effect somewhat. Crews in HERA began to decrease the use of politeness strategies in conditions of communication delay (Wu et al., 2015b). A review of communication delay studies conducted in several mission simulation analogs (NEEMO, Desert Research and Technology Studies (D-RATS 2012), underwater Pavilion Lake, Autonomous Mission Operations project) concluded that communication delay was a significant hindrance to MTS performance and created negative attitudinal responses (Love & Reagan, 2013) (Category III). Identified challenges include confusion of sequence, interrupted calls, wasted time, impaired ability to provide relevant information, confusion regarding who has heard what communication, perception of indifference, slow response to events, and reduced situational awareness. Obvious threats to team coordination, cooperation, performance, and psychosocial outcomes are inherent in those challenges.

Coordination between crew-to-ground may also be challenging throughout the course of the workday as individuals and teams transition between one task to another. Recent research in spaceflight analogs and during spaceflight has identified several factors that may interfere with task switches, harming performance and task engagement: task characteristics (i.e., difficulty, interest, importance, salience), social relations (e.g., affective ties, cognitive ties), technology affordances, individual differences (e.g., personality), and situation constraints such as communication delays (Mesmer et al., 2021) (Category III). A study of HERA crews and firefighters revealed that engagement in one task predicted an increase in positive affect and attention residue (attention that lingers on the first task after moving on from that task), which all predict engagement on a second task (Newton et al., 2020) (Category II). Although engagement on the first task and positive affect predict greater engagement and better performance on the second task, attentional residue hampers the engagement on the second task because the individual cannot move on. Additionally, anticipatory engagement, or looking ahead to the next task, reduces effectiveness on the first task, especially when the next task is seen as more complex (Newton, et al., 2021) (Category II). Team tasks and multi-team tasks are usually viewed as more complex than individual tasks. When examining HERA crews and astronauts as they switch between solo, crew, and multi-teamwork, researchers found that gaining autonomy is easier than losing it, orienting to people is a challenging aspect of transitioning tasks, and orienting to the task is particularly challenging at early mission stages when crews adjust to life in an ICE environment (Mesmer-Magnus et al., 2021). Notably, work transitions toward and away from the MCC are the most challenging for an autonomous crew.

Countermeasures related to team autonomy, communication, and the MTS

Participants of the spaceflight analog studies suggested that training on, and use of, established communication protocols is one way to mitigate negative effects on MTS performance (Fischer & Mosier, 2015) (Category II). Indeed, meta-analytic findings revealed that communication quality has a significantly stronger relationship with team performance than communication frequency (Marlow et al., 2018) (Category I). Information elaboration has the strongest relationship with performance, whereas self-report frequency and objective frequency have the weakest relationships. Quality is better than quantity. To meet this need and alleviate the biases of synchronous communication, communication using text and verbal protocols were tested during NEEMO and HERA missions and in a lab study (Fischer & Mosier, 2015) (Category II, I). Voice protocols segmented a call into initiating with a call sign, stating the topic and keeping track of threads of communications, chunking the message body, and ending a call with “over”. In addition, conventions were established related to stating the time of the call, logging calls, transmitting non-critical calls at appropriate times, acknowledging all communications, and building in transmission efficiencies (e.g., announcing ahead of time when calls will be transmitted to ready the receiving group). In the lab setting, protocol elements decreased errors and predicted task successes, whereas in the spaceflight analog setting, protocols were effective and mitigated the negative impacts of communication delays. Other conclusions suggested text communications were better for routine non-time critical communication, and that voice supported team-building and some protocol elements (i.e., topic, acknowledgement, repeating critical info, logging messages, giving a heads up) were more critical than others.

Several other team factors may offer an avenue for developing countermeasures in the form of selection/composition practices, training, and tools. Social support and leader support are important for improving team performance outcomes and team functioning (e.g., cohesion, cooperation, and empowerment)—factors that may facilitate transition between levels of autonomy, different tasks, and different roles (e.g., leader, follower) (Smith-Jentsch, 2015) (Category III). Training on leader behaviors and expectations across the MTS will ensure collective orientation is maintained during the entire mission: this has been identified as a training need (Smith-Jentsch et al., 2015) (Category III). Those developing countermeasures unique to this communication delayed situation could consider including other outlets to displace within-crew negative affect away from the team (e.g., virtual environments, journaling). Team members of spaceflight analog studies suggest bringing up common ground topics to open lines of communication within diverse groups (Tafforin, 2013) (Category III), but this rapport-building and social support is constrained between communication-delayed groups. Establishing relationships and rapport between crewmembers and ground teams will result in more connectedness at the beginning of the mission and a firmer foundation for maintenance over time. Norms may include the ground teams operating in a more supportive (vs. controlling) role during communication-delayed missions. Training these norms and other procedures will foster a shared mental model of how teams contribute to each task. Autonomous teams, especially in conditions of communication delay, are in danger of losing shared cognitions and awareness with other teams across the MTS. However, one Mars 105 reported that groupthink did not develop among the crew (Sandal et al., 2011) (Category III); more research should be done to understand why some teams are more resilient than others. Scheduling regular coordination between space-to-ground will help support shared understanding over time during missions with real-time communication. During communication delays, regular and low-pressure check-ins between the teams that are more in the spirit of support than control may support some of those needs and update mental models.

In addition to decrements in cognitive processes, a Mars 500 study found decrements in cognitive performance of attention and alertness related to fatigue and stress (Basner et al., 2014) (Category III), further threatening team cognition. Trends reveal negative effects to several individual-level cognition factors (e.g., attention, central executive functioning, psychomotor functioning, reasoning ability) from isolation, microgravity, radiation, and fatigue (Fiore et al., 2015). Shared mental models are a well-established predictor of team performance, regardless of measurement method (DeChurch & Mesmer-Magnus, 2010b) (Category I). Another NASA review of shared mental models in the LDEM context found shared team cognitive processes are strongly, positively related to the quality of communication, coordination, performance, member satisfaction, and viability; and suggested that this shared knowledge must be developed and updated before, and regularly, during a mission (DeChurch & Mesmer-Magnus, 2015) (Category III). The current use of flight logs and other documentation to pass information to rotating teams in mission control will enable rapid updating of mental models between shift changes. Scientifically developing and training the best methods for shift changes and continuous updating of that shared mental model can enhance the current system (Fiore et al., 2015) (Category IV). Mission planners should consider the challenges related to task switching, incorporating recommendations from researchers such as scheduling interdependent work before independent work and crew-to-ground work early in the day, streamlining resources needed for different work with different groups, and adjusting work instructions, procedures and technologies according to mission phase (Mesmer-Magnus et al., 2021). Crews and crew-to-ground relationships may also benefit if ground teams are trained on how to be more supportive vs. controlling as the demands of a mission change. Additionally, finding opportunities for autonomy such as allowing some crew to self-schedule will leverage the positive benefits of autonomous work. Composing a team of resilient crewmembers and training them on self-monitoring and on techniques to adapt to changing conditions, high autonomy, conflicts, and isolation may mitigate decrement to performance and functioning.

Summary points related to ground-based evidence and team autonomy, communication, and the MTS

- Team autonomy leads to better performance, lower stress, positive mood, greater cohesion, better health outcomes, etc., but it may lead to negative outcomes such as groupthink and space-to-ground disconnect.
- Communication delays negatively affect team performance, coordination, decision-making, teamwork, and interpersonal conflicts within a team and across the MTS.
- Countermeasures show promise for mitigating the risk to team performance and multi-team coordination from communication delays and task switching. Examples include communication protocols, selection and composition algorithms to form complementary and well-functioning teams; training related to developing shared mental models, self-monitoring and adaptability; and careful planning and instructions/procedures to avoid performance loss related to task transitions.

d) Team Skills and Team Skills Training

Better team skills lead to better team performance. For example, a meta-analysis of healthcare teams found that teamwork was positively related to performance (r=0.28) in both the technical domain (e.g., providing care) and the team domain (e.g., team decision making) (Schmutz et al., 2019) (Category I). Outcomes were improved for both routine tasks (e.g., planned surgeries) and non-routine or off-nominal tasks (e.g., emergencies). Furthermore, interdisciplinary expertise within the team was positively related to performance. Spaceflight teams are interdisciplinary, bringing a diversity of knowledge and skills to address tasks. Training for team skills relies on a large and robust body of research. The temporal display of training (Salas, 2015; see Table 5) is backed by substantial evidence from this training literature. Once the process structure for developing a team training program is known, attention can turn to determining which skills are most appropriate.

Team training, as shown in another meta-analysis of healthcare teams, is effective under a variety of training strategies, team compositions, trainee types (e.g., students vs. experts), and when the workload of trainees is high (Hughes et al., 2016) (Category I). Thus, it is important for ASCANs and experienced astronauts alike to devote time to team training given their heavy workload and busy training schedules. Evidence indicates that two facets of training are relevant to team performance and functioning: (1) individual training on teamwork and interpersonal skills, and (2) time training as a team.

(1) Training the individual to be on a team

Many individual traits or skills enable a person to function well in a team, as identified in the job analysis of communication and teamwork competencies (Barrett et al., 2015). ASCANs are selected based on minimum requirements in these competencies, however, extensive training on general communication and teamwork, and training on the NASA-specific communication and teamwork styles (e.g., protocols, techniques, terminology, tactical skills) begins after the ASCAN is selected. When training begins, it is assumed the individual possesses these minimum requirements, and the goal of training is to optimize the individual's performance and related team performance. Additionally, trainees must have basic skills to do the task before they train on teamwork skills (Salas et al., 2002), that is, an ASCAN must train on technical skills and reach proficiency in these skills or tasks before they begin training on team skills. A meta-analysis of 97 studies, involving 11 different types of interventions (Guzzo et al., 1985) (Category I), found that training and goal setting are the most effective organizational interventions for increasing motivation and individual performance. Branches of the U.S. military, a population analogous to astronauts, also spend a great deal of time and resources on training. Leedom and Simon (1995) found that when United States Air Force (USAF) aviators were provided with standardized, behavior-based training on teamwork this increased team coordination and improved team task performance. A field study of 92 teams (1,158 team members) of USAF officers determined that mastery of teamwork knowledge predicted better proficiency in team tasks and higher observer ratings of effective teamwork (Hirschfeld et al., 2006) (Category III). A ground simulation of medical emergencies during a Mars mission determined that excellent team skills, as outlined in the SFRM model, are required to successfully manage and survive high-impact medical events (i.e., sudden cardiac arrest, smoke inhalation, toxic exposure, seizure, penetrating eye injury) (Robertson et al., 2020) (Category II), and a follow-up high fidelity simulation study confirmed this (Dias et al., Yule, 2021).

Six team core processes and emergent states identified in the literature may help to focus astronaut team skills training: cooperation, conflict, coordination, communication, coaching/leadership, and cognition (Salas et al., 2015b) (Category IV). Context, composition, and culture, which are additional influencing conditions, may also affect the 6 team core processes and emergent states and are discussed throughout this report. Competencies identified in the astronaut job analysis (Barrett et al., 2015) may be mapped to the team core processes and emergent states to provide a clear picture of how to train individuals to be well-functioning team members and how to train the intact team to work well together, in addition to selecting team-oriented and motivated individuals who possess the preferred personality characteristics. The 6 team core processes and emergent states, from the perspective of an individual's contribution to a spaceflight team are described below.

Cooperation (from an individual perspective)

Cooperation is an attitudinal and efficacy element of teamwork. Training can motivate individuals and prepare them to work on a team and participate in cooperative and supporting behaviors. Training basic understanding and skills related to supporting behaviors is needed for spaceflight crews. Supporting behaviors are one aspect of the TDT that has led to better performance in military and flight controller populations (Bedwell et al., 2012; Smith-Jentsch et al., 2008) (Category II). Building confidence and self-efficacy through successful performance, gradual skill attainment, and reinforcing feedback during training programs can also enhance an individual's propensity for cooperation. A meta-analysis of over 20,000 individuals determined that self-efficacy was positively, but moderately, related to work performance (Stajkovic & Luthans, 1998) (Category I). Cooperation may also encompass aspects of self-care such that the individual is motivated to stay in good psychological and physical health for the good of the team by exercising, eating a nutritious diet, getting adequate sleep, avoiding or managing injuries, and practicing stress reduction techniques. Thus, related training on these self-care skills is also important. Finally, cooperation (and conflict management, as described below) was identified as an important aspect of group living, which is an important part of spaceflight (Kanas & Manzey, 2008) (Category IV). Group living is a unique extreme team skill that acknowledges team skill needs go beyond simply working together; the crew are also roommates (Landon & Paoletti, 2021). The Crew Office Expeditionary Skills model groups teamwork and group living together, but some aspects of group living can be disentangled from teamwork. These aspects include inclusive and appropriate humor, showing appreciation of team members' skills and abilities, interpersonal consideration, being tidy with work and personal items, respectfulness, maintaining a positive team attitude, and resilience and tolerance of differences. When each individual is effectively recognizing and managing his or her needs, the team can trust that everyone will perform as expected when needed.

Conflict management (from an individual perspective)

According to meta-analytic findings of 116 studies, relationship conflict has a strong, negative relationship with team performance and team member satisfaction (de Wit et al., 2012) (Category I). In addition, the negative relationship between conflict and team performance is stronger during highly complex tasks. Astronauts engage in many complex tasks requiring teamwork and team decision-making. Conflict management training is currently a part of the ASCAN training flow, and is used to teach individuals about "fighting fair", managing emotions, de-escalating conflicts, and managing expectations to prevent future conflict. Training may also address disagreements about taskwork or interpersonal relationships and may teach preemptive and reactive strategies to address conflict (Marks et al., 2001). During future long-duration missions, some conflict management strategies may interact to produce more nuanced outcomes. For example, overuse of accommodation to simply comply with orders and keep the peace, may lead to the suppression of dissenting voices (Kass et al., 2010), however, other analog studies have found that higher accommodation resulted in fewer errors but longer reaction times to respond to an emergency (Gonzalez et al., 2015). During a long-duration space simulation, the combination of high accommodation and low collaboration (i.e., low effort to find a solution that works for all parties) led to negative perceptions of individual differences (Kass et al., 2010). Rather than team members being trained to take the path of least resistance (i.e., accommodation), they are trained to have healthy conflict and employ tools such as team debriefs to support difficult conversations that will lead to teams in which all voices are heard. A virtual support system was used to train HI-SEAS crewmembers on cognitive-behavioral therapy techniques as a conflict management tool (Anderson, et al., 2016) (Category III). Crewmembers felt the conflict management program was useful and improved conflict outcomes, and they requested more examples and interactive scenarios, which suggests the acceptance and usability of implementing such a system in an ICE.

Coordination (from an individual perspective)

Coordination training may involve aspects of cross-training individuals on multiple roles so that they understand and anticipate the actions and needs of other team members when backing up or performing complementary roles. Shared knowledge facilitates the development of shared mental models. Conversely, coordination requires communication, and in a complex multi-team setting, this communication may take many forms (e.g., verbal or text person-person, person-group, digital indicators to person or group), but should have standardized sequence, structure, and timing elements to enhance ease of coordination (Salas et al., 2015b). This flow of information establishes and maintains situation awareness. Each individual on the team must have enough shared understanding of each other and the tasks, and the proper communication skills to plan and execute coordinated activities. Adaptation training will also allow individuals to adapt to the actions of others and maintain coordinated processes. Cross-training and adaptation training improves performance (Salas et al., 2008) (Category I). For a culturally diverse team with a variety of ethnic/national backgrounds, training cultural competence and adaptability will allow a multi-cultural crew and a multi-cultural MTS to have a shared understanding related to task and behavior norms (e.g., when to communicate a problem related to carbon dioxide concentration could be standardized across teams, documentation of events) and differences (e.g., perspective taking and cultural awareness) (Burke & Feitosa, 2015) (Category III). Knowledge about other cultures is important as a foundation in training, but perhaps more important is experiential learning with practice and feedback to build cultural competence and flexibility.

Communication (from an individual perspective)

Training a common language is a first step in forming teams across multiple cultures. Training other context-specific terms (e.g., EVA) and norms (e.g., the phonetic alphabet, sequence of initiating a call with "Houston, Station" to indicate who is calling who) is a second. Much of this may require traditional, rote memorization and practice. Individuals should also train in the SFRM communication-related skills of information exchange and communication delivery, which involves packaging information into concise segments, pushing accurate information at the right time, and active listening. For NASA and other astronauts, T-38 training reinforces short, concise transmission of information providing a familiar framework for their mission training and operations. In critical situations such as medical teamwork, effective communication must be open, accurate, and concise (Salas et al., 2008) (Category IV). Failure to practice CRM communication techniques in the aviation industry has led to many fatal incidents (Helmreich & Foushee, 2010) (Category III). Individual knowledge should also be built around protocols and other NASA developed countermeasures, such as the Fischer-Mosier protocols tested in the laboratory and in mission simulation analogs that were developed to address communication delays (Fischer & Mosier, 2015) (Category II). This training should apply to all individuals within the MTS to standardize knowledge and procedures.

Coaching, Leadership/Followership (from an individual perspective)
Leadership, especially leadership of highly autonomous team in an ICE environment, must consider a range of unique factors that go beyond the typical leadership development programs while addressing conflict management, consensus building, forecasting and planning, communication, emotional regulation, and fostering cohesion. A literature review and operations assessment of leadership for the LDEM context offers several evidence-based suggestions (Gibson et al., 2015) (Category III). Although a mission commander is identified for each mission, the diversity of complex tasks required for a LDEM will require a diversity of expertise, and thus, role switching from leader to follower as the situation and task demands. Appropriate switching calls for shared knowledge of each team member's KSAs, on which each team member should be well-versed during training. A leader must also assume different types of leadership, whether it is collective, dyadic-oriented, socio-emotional or crisis-response as dictated by the situation, and training programs should include modules on each of these leadership models. Identifying which type of leadership is needed and when to make the appropriate switch should be trained, but may also be supported through MCC and with automated monitoring that identifies potential role conflicts and prompts switches. All teams in the MTS should be trained on this information, and all should be trained on any monitoring technologies. Cultural differences in the MTS should also be considered. Personnel from ESA and data from studies in spaceflight analogs indicate that some leaders are able to step back into a follower role more easily than others, and the ease seems to differ by cultural power distance; that is, cultures with high power distance expect a clearly defined leader and attribute status to that person (Burke & Feitosa, 2015) (Category III). However, training all members to be leaders and followers increases the leadership capacity of the team and may help performance, which is particularly important because spaceflight analog studies have found that leadership behaviors were shared amongst crewmembers more often than they were concentrated in one crewmember (Burke et al., 2017; Burke, Shuffler, & Weise, 2017) (Category II,III). Findings from these studies also highlight specific leadership behaviors that were more prominent during the transition phase of the task cycle (i.e., sensemaking and structuring/ planning) and the action phase (i.e., problem-solving and social support), which could be considered during pre-mission training to ready the crew for adjusting to different phases. In a spaceflight context, shared leadership occurred to a greater extent during the transition phase. All crewmembers should be trained in these behaviors to enable effective shared leadership.

Cognition (from an individual perspective)
Many aspects of individual cognition affecting performance and interpersonal interactions are covered by the BMed research portfolio. However, a review of both individual and team cognition in a sample of 168 observations from spaceflight, spaceflight analogs, and analogous populations such as the military suggests that individual cognitive processes are nested in and contribute to team-level processes (Fiore et al., 2015) (Category III). Thus, training targeted at developing individual attention, memory, and reasoning is the foundation for team cognitive training. One meta-analysis found that knowledge at the individual level can be critical for use at the team level. Transactive memory systems, or simply, knowing who knows what and who is best at what on a team, can improve team performance (Bachrach et al., 2019) (Category I). This knowledge is positively related to environmental volatility (i.e., when more coordination and skill diversity is needed), and to effective leadership (i.e., when leaders facilitate information exchange). Accuracy of the shared mental model is more important than the degree of agreement

between team members' mental models (Edwards et al., 2006) (Category I). Training each team member to possess an accurate mental model, which can later be shared in whole-team training, can improve performance. This is particularly important during unfamiliar or unexpected situations when shared mental models facilitate team problem-solving. During creative problem-solving, divergent thinking is important to generate solutions and to evaluate those solutions (da Costa et al., 2015) (Category IV). Thus, training team members to a shared mental model of communication norms, and to the structure of idea generation and idea evaluation, while allowing individuals to diverge their thinking within that structure, can facilitate efficient problem-solving with more creative solutions. Finally, stress inoculation training, which is effective in emergency response and military domains, is another important component of cognitive training that may mitigate the negative effect of stress on performance during long-duration spaceflight (Palinkas, 2007) (Category III).

(2) Training the team

Training the 6 team core processes at the team level is the second approach to team training. A meta-analytic review of team training found a positive relationship with team outcomes across 5 categories of team effectiveness: affective (e.g., affect towards the team or leaders, collective efficacy, cooperation), cognitive (e.g., development of shared mental models), subjective-based skill (e.g., ratings of performance, effectiveness, combat readiness by team member or SMEs), objective task-based skill (e.g., points in a simulation game, task errors, time), and teamwork skill (e.g., conflict management, quality of process, information exchange, coordination, leadership) (Delise et al., 2010) (Category I). Furthermore, these results held true for both civilian and military teams in team training. Thus, team training may directly enhance both team core processes, emergent states, and technical skills, which significantly influence team effectiveness. A meta-analysis found that healthcare team training is effective for improving trainee reactions, learning, transfer of knowledge and skills to the job, and improved organizational and patient outcomes (Hughes et al., 2016) (Category I). Notably, evidence exists that the sequential model of reactions to learning transfer to training results, although reactions were significant for all contexts and not for healthcare contexts. For future LDEMs, teams must have time to train together as an intact team to apply the skills they each bring to the table or have learned as individuals in the larger team setting. In other words, teams must have ample time to "storm" and "norm" so that they can begin "performing" as a team prior to launch (Schmidt, 2015) (Category IV). Advanced training improved trauma nurses' team performance and increased their confidence in their skills (Harvey et al., 2019). Most notably for operations planning, the improvement in team performance began to degrade between 6-12 months after the training, with the sharpest decline in the leadership domain.

The 6 team core processes and emergent states, from a team-level perspective, are related to spaceflight teams as described below.

Cooperation (from the team perspective)

Meta-analyses have found that team building is an effective method for developing affective and team process outcomes (Klein et al., 2009) (Category I) including cooperation. Mutual trust, collective efficacy, and a shared feeling of psychological safety are all aspects of this core process that can be developed during training. A study of adventure racing teams, a population analogous to astronauts, found preparation effort was related to collective efficacy (Edmonds et al., 2009). An initial lab validation study of a group cooperation task found that individual incentives decreased team cooperation (Roma et al., 2015a). When this group cooperation task was studied in ICE conditions the researchers found that fairness measured on a group index was generally high, with some exception by team, and fluctuated some over the mission. Morale was positively related to cooperative behaviors. Thus, training should include team-based incentives tied to task performance to encourage cooperation, and to build morale, trust, cohesion, and positive affect within the team. Cooperation may be fostered by composing a team of cooperative individuals. For example, data from 4 HI-SEAS missions (4- to 12-months long) indicates that geology-related EVAs with more cooperative individuals were more efficient and more stable in efficiency, and EVAs with more self-serving individuals were less efficient, less stable in efficiency, and less stable in overall performance of geology tasks (Binsted et al., 2021) (Category III). A spaceflight crew may need to work with teams in the MCC who may be essentially strangers as they rotate through shifts and through permanent personnel changes on the ground. Situations such as remote location or high stress may negatively influence the degree of collective orientation to a team or to the MTS, thus negatively impacting performance by decreasing consideration of others in the team or the MTS and decreasing supporting behaviors. A training needs-analysis for LDEM teams identified multi-team cooperative and supporting behaviors under communication delay are an unmet training need (Smith-Jentsch et al., 2015) (Category III).

Conflict Management (from the team perspective)

Recent studies have reported that team conflicts occur in spaceflight analogs such as the Mars 105 and Mars 500 (Basner et al., 2014; Sandal et al., 2011; Vinokhodova, et al., 2012) (Category III). A greater frequency of conflicts is generally associated with more stress, increases in errors, and decreases in productivity (Alper et al., 2000). In a review of 55 studies, Rasmussen and Jeppesen (2006) (Category III) noted that, in every study, the more time team members spent in training together the fewer conflicts and conflict-related performance deficiencies the team members experienced. Thus, teaching conflict management skills is not the only important consideration; training together allows the team to learn teammates' strengths and weakness and their patterns of thinking and working, and to achieve success in practice simulations. Simulations allow teams to practice realistic conditions and learn how their teammates behave in nominal and unexpected situations. This performance success and development of shared knowledges may lead to greater cohesion, and in turn, performance. In multinational teams, faultlines may be a source of conflict. A review of the literature showed that surface-level differences (e.g., demographics) negatively affect the short-term performance of teams because these teams initially experience more interpersonal conflict, but these differences have less impact on performance the longer that the teams are together (Mannix & Neale, 2005) (Category III). Deep-level diversity negatively affects long-term performance only when teams are not provided with the training and the incentives to manage interpersonal conflicts. When training and incentives for managing diversity are provided, deep-level diversity helps teams to maintain moderate amounts of the positive task conflict that supports team performance. Additionally, task conflict and decision-making quality (a measure of performance) are more positively related than an overall measure of performance (de Wit et al., 2012) (Category I). Indeed, when task conflict and relationship conflict are more weakly related, task conflict and team performance are more positively related. If teams have ample time in which to train together and are instructed on how to take advantage of multiple perspectives, this reduces the odds of interpersonal conflict stemming from either surface- or deep-level diversity and increases the ability of teams to leverage the task conflict. More information related to team conflict is found elsewhere in this report.

Coordination (from the team perspective)

Coordination training at the team level must incorporate a great deal of developing and maintaining shared mental models during a dynamic situation. Enhancing shared mental models in traditional team coordination behaviors, as well as complex cognitive skills (e.g., cultural competence and adaptability), will support coordination efforts. Military applications with naval teams in an anti-air warfare simulation and other teams performing a simulated aerial vehicle command and control tasks found that stress and adaptability training resulted in better team coordination, and teams were more resilient to stress and performed better (Entin & Serfaty, 1999; Gorman et al., 2010) (Category II). Training on other tools that support coordination (e.g., checklists, which are used extensively in spaceflight and aviation) may be another way to reduce coordination errors and support team adaptation and resilience in off-nominal events (Alliger et al., 2015; Love & Bleacher, 2013) (Category IV). Leaders may also promote use of specific coordinating behaviors after training, which may include leadership within the crew or higher-level leadership coordinating across the MTS on standard norms, tools, and processes. The socio-emotional leadership model developed in the context of LDEM (Gibson et al., 2015) (Category III) shows that influencing processes such as boundary spanning and trust building, with leadership behaviors such as building networks and supporting team members, leads to effective coordination, trust, and performance.

Communication (from the team perspective)

If communication among team members is to be effective it must operate along standard procedures, for example, knowing when and how to push and pull information to and from the right people. During 45-day HERA missions, information sharing within the crew was associated with increased decision accuracy (DeChurch et al., 2019) (Category III). Information sharing increased over time and peaked mid-mission, then declined during the second half of the mission, and decision accuracy mapped to that trend. Cultural norms may influence communications, for example, if individuals from cultures with high power distance or collectivist do not speak up to a commander or if a statement that runs counter to the rest of the team is withheld. Spaceflight analog studies and surveys of the ESA personnel found the cultural differences in non-verbal communication and language can negatively influence team functioning (Sandal et al., 2006; Sandal & Manzey, 2009) (Category III); thus, training a new, mutually agreed-upon team norm to supersede other existing communication norms is important. Determining a standard operational language for the mission is also important. Debrief protocols are another way to prompt discussion after a training or periodically during the life cycle of the team to maintain shared cognition. Training improved military and flight controllers' communication skills, which translated to improved performance (Bedwell et al., 2012) (Category II). In NEEMO and HERA and in a lab study, a debrief protocol generated constructive discussions and was related to team effectiveness (Tannenbaum, et al., 2015) (Category III,II).

Coaching, Leadership/Followership (from the team perspective)

Team-level leadership/followership training must be an extension of the individual leadership skills training such that the team practice identifying specific situations, then identify the appropriate leader for that situation, identify the appropriate leadership model for the situation, step forward or back into leader and follower roles, and coordinate these switches with MCC as needed under conditions of autonomy and communication delay similar to future LDEM conditions. A study of a dozen HERA missions found an association between leadership factors and team viability (e.g., if the participant would want to go on a 3-year mission with that crewmember). When a crewmember relied on a crewmember for leadership, believed the crewmember was a valuable source of information, and enjoyed working with that crewmember, the participant was more likely to say they would go on a long-duration mission with them. The more network ties that were reciprocated within a team, the higher the team viability (Johnson et al., 2019) (Category III). Additionally, shared leadership (not hierarchical) supported shared mental models over time, which is related to team viability (Lungeanu et al., in press) (Category III). The SIRUS-19 mission had a hierarchical leadership structure, and the crew experienced a decline and more variability in sharedness understanding in the second half of the mission. These findings reinforce the importance of training a team of leaders and a team of shared leadership, in which crewmembers are capable of switching between leadership and followership as the tasks demand. Leadership/followership skills can be developed more effectively if individuals and the intact team are trained regularly over time, and receive multiple opportunities to practice skills and receive feedback. A review of leadership required for LDEMs identified many key collective processes that should be targeted during training (Gibson et al., 2015). For example, appropriate delegation empowers team members and reduces the leader's stress, whereas collaboratively problem solving and sharing information enhances adaptive performance and team satisfaction and trust. Teams should be trained to recognize emerging situations and problems, and in the skills to efficiently assess the capability of team members to select the appropriate leader and followership roles of each team member. Establishing a shared mental model of overarching goals and a general understanding of individual goals that feed into that overarching team goal may be particularly important during emergencies. Additionally, because all members of the spaceflight team will have areas of expertise distinct from that of their teammates, leadership skills related to mentoring, coaching, and active listening will allow team members to guide each other as needed during the mission (Smith-Jentsch et al., 2015) (Category III), and may also support pre-mission team training. All members, not just the mission commander, should be trained in these transformational leadership behaviors.

Cognition (from the team perspective)

Cognition and learning research shows the benefit of cross-training to create strategic redundancies of role, task, and teammate knowledge among teammates. For example, when submarine attack crews shared mental models and knowledge concerning team members, this increased the number of hits on target, over and above the contribution from operational skills alone (Espevik et al., 2006) (Category II). The more experience crews had working together, the less physiological arousal the crew experienced during attack simulations, indicating lower stress levels. One meta-analysis found that shared mental models are one of the strongest predictors of performance (effect size = .35), even more so when there is shared leadership, external interdependence (e.g., space-to-ground), heterogeneity (cultural, gender), and when the team is working together in real-time (Niler et al., 2021) (Category I), which are all characteristics related to spaceflight operations. During the SIRIUS-19 mission, as the similarity of mental model increased (or decreased), the problem-solving performance of the crew also increased (or decreased). Unfortunately, data from HERA and SIRIUS-19 indicate that team problem-solving decreased over time, and it decreased to a greater degree during the 4-month SIRIUS mission than during the 30–45-day HERA missions (Antone, et al., 2020).

Team debriefs are used extensively in the military and aviation environments as part of team training facilitating meta-cognitive processes, or thinking about cognition and behaviors. A meta-analysis found that teams using team debriefs performed 20-25% better (Tannenbaum & Cerasoli, 2013) (Category I). Debriefs allow the team evaluate cognitions and actions taken, which should help them to improve their performance in the future. When a team engages in this self-evaluation process, they benefit from maintaining shared cognitions of the right course of action, and enhance problem-solving and communication processes. In studies of TDT, flight controllers and military populations used team debriefs of teamwork skills, and this enhanced learning and decreased performance errors (Bedwell et al., 2012; Smith-Jentsch et al., 2008) (Category II). Another potential debrief method for LDEM that has been tested in NEEMO, HERA, and in lab settings also focuses on teamwork, taskwork, and resilience, and as an added benefit to isolated teams; this debrief method can be led by the team (Tannenbaum et al., 2015) (Category II,III). The DebriefNow tool allows teams to answer questions individually and anonymously, and the software produces a customized discussion guide to prompt the team. The team owns the process and can adjust or begin a debrief as desired. Results found that this debrief method was well-received, and it improved performance and resilience. Results also indicated that resilience was positively related to performance, and that this relationship became stronger over time.

(3) Training methods

Many methods exist for training teams, and notably, the physical fidelity of team skills training contexts does not affect the training effectiveness (Hughes et al., 2016) (Category I). Psychological fidelity of the training environment is what matters when practicing team skills. However, it is critical when training astronauts (given their already high workload and disparate travel schedules) to leverage each training event for both team skills and technical skills whenever possible. NASA scientists and operations experts recommend an integrated approach to training "crew-oriented, mission-centered" training, in which operational content is introduced to a crew in the context of use, rather than in a siloed, system-driven approach (Dempsey & Barshi, 2021). In other words, astronauts should learn new skills through a mix of classroom and traditional learning, and should further learn and practice those skills in comprehensive, integrated training simulations of different types of scenarios expected on a mission (e.g., launch day, nominal day, off-nominal or critical operations).

A review of team cognition in spaceflight analogs and populations analogous to astronauts summarized the various training strategies that were appropriate for training team knowledges, skills, and attitudes (Fiore et al., 2015). Future LDEM training programs may use this as a guide to ensure elements of the relevant individual and team competencies are addressed through the appropriate training strategies. According to one meta-analysis, the effectiveness of different training strategies varied such that team knowledge training was the most effective (effect size =.81) followed by tactical training (effect size =.67), critical thinking (effect size =.60), team adaption and coordination (effect size =.56), coordination/CRM (effect size =.47), cross-training (effect size =.44), self-guided training (effect size =.36), and self-correction training (effect size =.27) (Salas et al., 2008; Fiore et al., 2015) (Category I). Overall, team training had a moderate, positive effect on outcomes of team performance and functioning (effect size = .34). A meta-analysis of astronaut-like teams (i.e., healthcare professionals) found team training improves each of Kirkpatrick's criteria (reactions, learning, transfer, results; d = .37 to .89). Findings indicate that healthcare team training is largely robust to trainee composition, training strategy, and characteristics of the work environment (Hughes et al., 2016) (Category I). Similarly, astronaut crews are often a mix of different backgrounds and expertise and are expected to perform a large variety of tasks. Best practices dictate that trainees receive information or declarative knowledge about a specific skill or task, observe demonstrations of the skill or task, practice that skill or task, and receive feedback when performing the skill or task (Salas et al., 2012) (Category IV). A new technology, intelligent tutoring systems, may help spaceflight teams with pre-mission learning and especially during communication-delayed portions of the missions when hands-on and adaptable instruction with Earth-bound experts will be difficult (Landon & O'Keefe, 2018) (Category IV). A meta-analysis of intelligent tutoring systems as applied to teams has led to recommendations to enhance training by linking cooperative learning research with intelligent tutoring system behaviors, considering the roles of the team members and domains to embed intelligent support, remediation for negative teamwork behaviors, applying existing evidence-based team models, and integrating interfaces and sensor configurations to understand the effect of neuronal synchrony during team learning (Sottilare et al., 2018) (Category I). A brief explanation of each training strategy follows:

- Event-based training/scenario-based training—teams work through specific scenarios to practice specific skills
- Self-correction training/guided self-correction training—teams review past performance, self-evaluate, and devise plans for improving
- Cross-training—team members are trained on all job positions through information sharing, demonstration and modeling, and hands-on rotation through other job positions
- Stress training—team members are taught to recognize stress in themselves and teammates, and practice relaxation and other stress-reduction and coping methods
- Team adaptation and coordination training—teams are exposed to examples of high-performing and low-performing teams adapting to stressful scenarios, practice scenarios, and receive feedback
- Team building—team activities meant to build trust and cohesion
- Intelligent tutoring systems—training tailored by artificially intelligent, computer-based tutors with the goal of optimizing learner outcomes

Summary points related to ground-based evidence and team skills training:

- Team skills training can occur at the individual level, to prepare an individual to be on a team, and at the team level, to create a coordinated and cohesive team. Both types of training are needed for future LDEM team.
- Competencies from the updated astronaut job analysis can be tied to the 6 team core processes and emergent states to delineate target areas for team skills training. These processes and states have indirect and direct influences on team performance and team functioning.

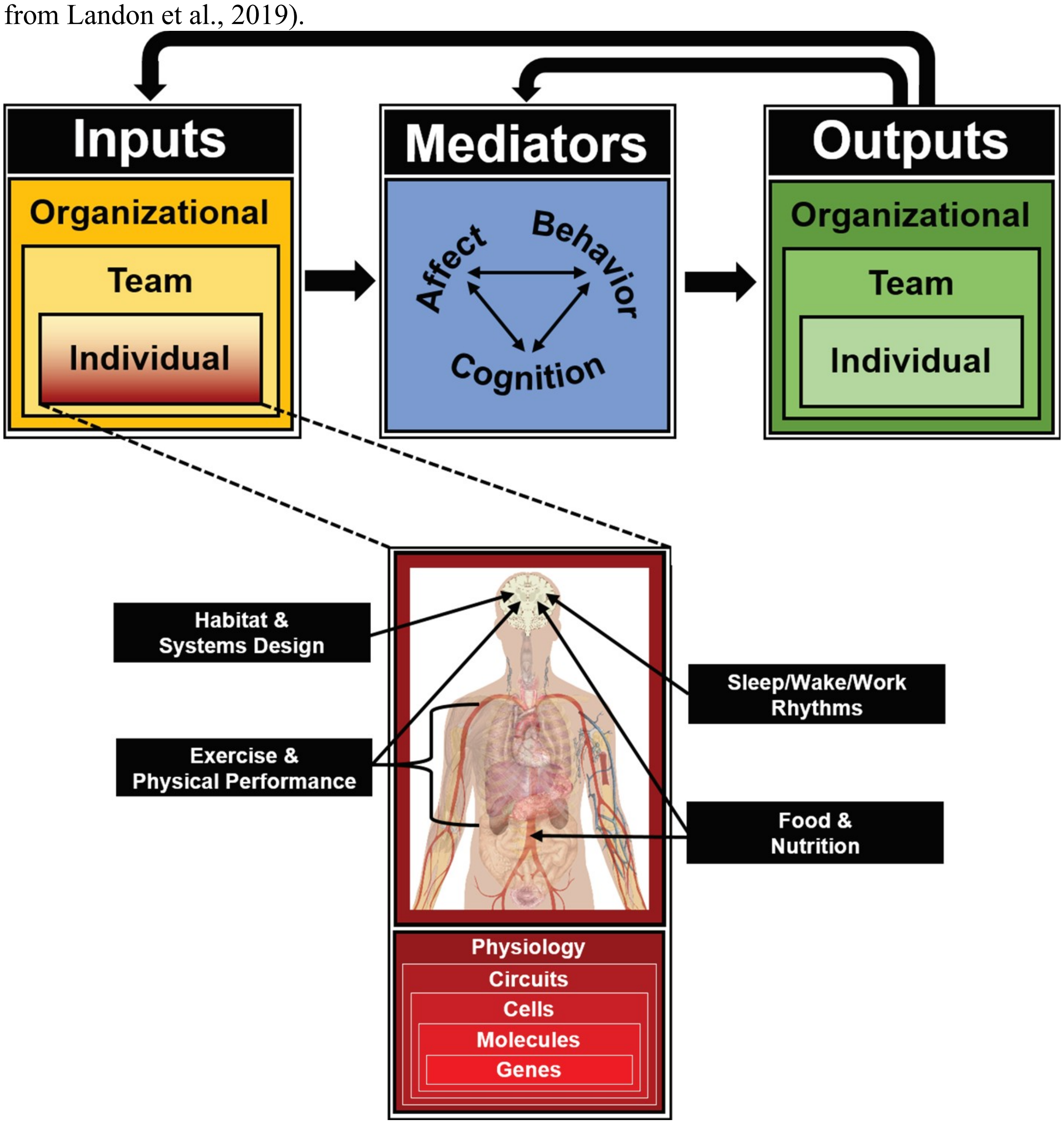
    - Team core processes and emergent states competencies include cooperation, conflict management, coordination, communication, coaching/ leadership/followership, and cognition.
- Training should be refreshed regularly, and training programs should use multiple methods to target the same skills across training events.
- Training as an intact team long before the launch date of the mission is paramount.

3. Emerging Interdisciplinary Factors

a) Physiological Predictors: Neurobiology, Sleep & Fatigue, Nutrition, Physical Fitness

Another area of cross-discipline integration in need of research is that of physiological factors that affect teams. Recent advances in the NASA HRP Research Roadmap have seen the addition of the Central Nervous System/BMed/Sensorimotor Risk, that is, the integration of risk areas considering the central nervous system, behavioral medicine, and space radiation. This and other efforts have renewed focus on the brain and associated neurobiological systems as the nexus of input from the environment and necessary substrate for emergent team dynamics and performance (Landon et al., 2019). However, team science has lagged behind other areas in HRP, and in the broader literature, in targeting underlying physiological systems that may influence and be influenced by team factors. In a closed and tightly-coupled environment such as spaceflight, all components of the system are presumed to interact and can positively or negatively influence team dynamics through direct or indirect pathways (Banks et al., 2019; Landon et al., 2019). When integrating a traditional team science framework, the Inputs-Mediators-Outputs-Inputs model with physiological systems (see Figure 5), researchers and operations personnel may realize an opportunity for a more nuanced and comprehensive approach to deploying countermeasures to enable the success of the crew and the mission. Promising, yet somewhat siloed, research findings offer initial direction for examining these phenomena in a more integrated and strategic method. In this way, the emerging research area of "organizational neuroscience" may drive interdisciplinary research partnership, funding for such research, prompt researchers to explore existing relevant datasets (e.g., in the NASA Life Sciences Data Archive) with simulation techniques (e.g., agent-based modeling and simulation [ABMS]), and consider how the team may factor into an individualized medicine approach to behavioral health and performance.

Figure 5. Input-Mediator-Output-Input model of team function for isolated, confined, and extreme operational environments, adapted to reflect "horizontal" integration of individual input variables inherent to isolated and confined environments, but outside the founding disciplines of team science, and "vertical" integration of multiple biological levels of analysis as targets and substrates for all individual inputs to the team system as an integrated approach toward the behavioral biology of teams. Adapted from Landon et al., 2019).



HRP's Sleep Risk evidence report provides a wealth of evidence related to the physiological need for sleep, it effects on individual performance and functioning (e.g., decision-making, reaction time, sensorimotor, attention, mood), and countermeasures that can be used during spaceflight. Team cohesion and team interactions may serve as a buffer to counteract negative effects of work overload, lack of sleep, and circadian desynchrony, but little research has looked at these issues at the team-level (Banks et al., 2019). Some exceptions do exist, particularly in the military and aviation contexts, which are attuned to the risks of sleep in a high consequence environment. A study of military teams during an artillery operation found that after extended wakefulness of 24 hours, teams decreased communications and coordination, and made errors by firing on prohibited targets (Fletcher et al., 2012) (Category III). Research on high-performing, elite sports teams has found teams from cities on the east coast are at a disadvantage and experience a lower winning percentage when they play night games on the west coast, which translates to a much later start time than for their home games on the east coast (Smith et al., 2013) (Category III). Four of the 6 Mars 500 crewmembers experienced sleep, circadian, or fatigue-related performance deficits, and the 2 crewmembers with the highest ratings of stress and physical exhaustion accounted for 85% of the perceived conflicts (Basner et al., 2014). One crewmember became desynchronized from the rest of the crew's schedule and experienced more pronounced withdrawal from the team. Preliminary serendipitous findings from the HERA teams captured behavioral changes during acute and chronic sleep deprivation events (e.g., Burke et al., 2018; Plummer et al., 2018) (Category III). During 30-day missions with a 36-hour wakefulness period, crewmembers decreased their social support, provided less resources, encouraged team self-management less, and provided less feedback as the leadership structure became more hierarchical. During 45-day missions with a chronic sleep deprivation (5.5 hours sleep during weeknights and 8 hours on the weekends), shared cognition decreased, communication decreased, and supporting behaviors decreased differentially by individual. However, a team may also be able to compensate for the reduced performance of one or more members. For example, in a lab study, fatigued teams had increased errors and processing time at the individual level, but effects were attenuated by team membership (Baranski et al., 2007) (Category II). NASA operates on a 24-hour schedule; thus, team factors and sleep issues related to shiftwork conditions of the MTS in Mission Control operations need to be considered.

Other potential avenues of investigation include food/nutrition and exercise/physical activity, which both have chapters in the HRP Evidence Book and are theoretically examined in the context of team and social factors in Landon et al., 2019. At a basic level, inadequate nutrition can result in mild to severe mood disorders because brain and bodily functions are decremented. Conversely, optimized nutrition may support mental and physical well-being, enabling a crewmember to be a high performing team member. Food is also a behavioral health countermeasure because it offers sensory stimulation, variety in a monotonous environment, and an opportunity for team meals and social interaction. Likewise, exercise can support the team in readiness to perform tasks, enhancing cognitive functions, and as a noted, as a stress countermeasure. Inadequate physical fitness may lead one or more crewmembers to underperform in both cognitive and physical tasks, become irritable due to the build-up of stress, and lower the likelihood of meeting all mission objectives. Again, these physiological factors are inextricably linked to all systems in the human body, and in the close system of spaceflight, to all components of that crew and the vehicle. A more comprehensive examination with experts from biological sciences and team science is warranted.

b) Habitat Design & Net Habitable Volume (NHV)

Other human factors have received little research attention in the spaceflight context as they apply to the team, for example, NHV. NHV is any volume left to the crew after accounting for volume needed for equipment, stowage, and structural inefficiencies (NASA Human Integration Design Handbook, 2010). The HFBP Element has integrated human factors and psychological perspectives in habitat design, and a literature review has been conducted for the BMed factors related to confinement in a small space (see other relevant chapters in this Evidence Book for more information of habitat design in the context of those Risk areas). Suggestions from a NASA SME workshop concluded that the minimum acceptable NHV for a crew of 6 on a Mars mission is $25m^3$ per person, which is significantly smaller than the ISS volume of $85m^3$ per person (Whitmire et al., 2015) (Category IV). This workshop committee approached NHV mainly from the perspective of needed space to engage in a variety of activities such as work, sleep, exercise, hygiene, and stowage. The committee also identified the need for dining and communal activity space to foster team cohesion, to allow for team training and events, and to support psychological health. A recent literature review and operations assessment of NHV and habitat design related to the Team Risk found that many individual issues may scale up to affect team functioning and performance (Kearney, 2016) (Category III). For example, issues of crowding, privacy, and traffic flow all affect an individuals' well-being, which may affect their performance on a team.

Additionally, more research is required to determine how habitat design affects the team performance and functioning. For example, (re)configurability of the environment may facilitate switching from solo to team tasks and vice versa, but if space is used poorly or designed poorly, this may result in more conflict or a fracturing of the team. The physical environment in which the crewmembers perform tasks may need to be separated or a shared, and will have to be reconfigured for tasks that demand differed levels of communication and "co-presence" (Kearney, 2016) (Category III). Numerous ICE team reports, astronaut interviews, and the astronauts' journals describe the importance of a shared team meal to foster cohesion, and the importance of engaging in team recreation activities (e.g., Stuster, 2010; Stuster, 2016) (Category III). Evidence for the importance of dining together led to the creation of a NASA Human-System Standard that states all crews shall have the capability to dine together to support crew psychological health and well-being (NASA Standards 3001, 7.1.2.5 Dining Accommodations). Privacy, typically thought of as an individual need, is also important to team functioning, particularly during confined long-duration missions (Landon et al., 2019) (Category IV). During longer duration missions, ICE teams generally spent less social time together than during shorter duration missions (Bell, et al., 2019a) (Category I), suggesting that private crew quarters is more of a necessity than a "want" at some critical tipping point. Increased social density is generally a stressor, as is reduced ability to regulate the frequency of social interactions, and reduced control over customizing personal space. The HFBP Element has funded a study to develop a measure (spaceflight habitability assessment and questionnaire [SHAQ]) to examine the influence of habitability across outcomes of individual and team performance, stress, mood, sleep, and social interactions, with mediators of privacy, social density, efficiency, control, comfort, and convenience (Roma et al., 2022). Preliminary results from HERA studies, which has no private sleep or crew quarters, indicates that the lack of privacy increases stress initially, but participants adjust over time (Spencer et al., 2020)

(Category III). The SHAQ was designed to be useable in any habitat by instructing respondents to assess key habitat areas (i.e., sleep/bedroom, hygiene/bathroom, work/office, galley/kitchen, recreation) in modular form. More data is needed from other ICE and non-ICE environments over time.

c) Automation, Augmented Reality, & Robotics

The interaction of humans with computers, the integration of humans with automated systems, augmented reality, and robotics are all established areas of HRP human factors research. These systems will be required during future LDEMs to unburden the crews' workload as needed. NASA has a long history of human factors research to enhance cognitive and physical performance (e.g., see relevant HSIA Evidence Book, Vera et al., 2021; Holden et al., 2021a; and Holden et al., 2021b). Because real-time communication between crew and ground will be lost during LDEMs, NASA is investigating how automated systems and augmented reality may support the crew and solve unique problems. Ground personnel roles are usually filled by the experts elsewhere in the multi-team system, and even when astronauts are equipped with adequate training and procedures, they often check-in with ground such that ground enacts supporting and backup behaviors. SMEs have stated that current capabilities are insufficient to deal with communication delays during a Mars mission, for example, the crew is currently unable to autonomously perform medical diagnoses and interventions, address behavioral health problems related to prolonged isolation, make complex decisions without MCC experts, and mitigate these issues through an intelligent (smart) system (Holden et al., 2021a; McTigue et al., 2021) (Category III). Robots developed by NASA and JAXA have been tested on the ISS. NASA's Robonaut 2 is designed to be highly dexterous and capable of performing simple, repetitive, or dangerous tasks on the ISS in place of crewmembers. JAXA's Kirobo is equipped with voice recognition, language processing, communication and speaking operations, and facial recognition to help crewmembers perform experiments and other tasks. However, the psychological response to such a robot team member extends beyond the human factors perspective of strategically offloading tasks and workload to robots, or trusting automated and robotic systems to perform. Recent research suggests designers should consider social capabilities of collaborative robots to improve their effectiveness as "co-workers" and support positive responses to the robot (Sauppé & Mutlu, 2015) (Category IV). For the Team Risk, team robotics considers the robot not simply as a tool or "pet" that can offload work and monitor systems, but as an integrated team member. Relevant research from human factors may inform a robot design that can evoke positive affect and trust in the automated systems. The robot could support team performance and functioning by facilitating learning and operations in new and complex situations. Some tasks may require persistent human-robot teaming, as is currently being explored for use of robot-assisted disaster response efforts by the European Union's Community Research and Development Information Service, and in a new research initiative by the U.S. Air Force. More research is needed to strategically integrate a human factors perspective with teamwork processes in spaceflight.

4. Team Emergent States

a) Team Cohesion, Trust, and Conflict

Defining Cohesion

As researchers at the U.S. Army Research Institute (ARI) note in their review of cohesion as a construct, the definition of cohesion is ambiguous; therefore, the means of measuring cohesion is complex. The ARI authors conclude that "cohesion can best be conceptualized as a multidimensional construct consisting of numerous factors representing interpersonal and task dynamics" (Grice and Katz, 2005) (Category IV). Despite the inexact, less-than-rigorous understanding of cohesion as a construct, the ARI researchers do note that anyone who has worked with or played on a team knows what a cohesive team looks like, and that teams that are more cohesive usually perform better than less-cohesive teams. One review of ways to define and measure cohesion suggested that team cohesion should include task and social dimensions (e.g., team goals, closeness), behavioral and attitudinal markers (e.g., belongingness, group pride, loyalty, morale), and a longitudinal component (Salas et al., 2015a) (Category IV). For this chapter, the general definition presented is simply a team working together towards a common goal or to satisfy members' psychosocial needs. It is also important to note that team cohesion is distinct from individual morale. Although an individual's low morale may influence team cohesion (and possibly vice versa), it is possible for a team with low-morale members to remain cohesive.

Operationalizing cohesion

This summary of cohesion literature also provides examples of what a cohesive team may look like, as assessed through various measurement methods (Salas et al., 2015a) (Category III). Members of cohesive teams sit closer together, spend time with each other outside of work, focus more attention on one another, hold eye gazes, show signs of mutual affection, interact with greater frequency and in closer proximity for longer durations, and display coordinated patterns of behavior. Members of cohesive teams who have established a close relationship are more likely to give due credit to their partners. In contrast, those who do not have a close relationship within a team are more likely to take credit for successes and blame others for failure. Cohesion may be measured through surveys and interviews, or through unobtrusive observations and content analysis of written and oral communications. Newer physiological measures also capture cohesion through brainwave data and algorithms, and sociometric badges that log the proximity and frequency of interactions among team members.

Outcomes of Cohesion

Research summarized above provides information related to predictors of team cohesion. Several meta-analyses have assessed the relationship between team cohesion and team performance, and results suggest a positive relationship between the two (Mathieu et al., 2015) (Category I). However, many studies have neglected to consider duration. An analysis of 40 years of military research noted positive relationships among cohesion and numerous performance outcomes, including individual and group performance, behavioral health, job satisfaction, readiness to perform, and absence of discipline problems (Oliver et al., 2000) (Category I). Another meta-analysis found that the cohesion-performance relationship became stronger as the work required more collaboration, and that highly cohesive teams became more likely to perform better than less-cohesive teams (Beal et al., 2003) (Category I). Mathieu and colleagues' (2015) investigated this relationship over time and found that cohesion and performance were related positively and reciprocally, and that this relationship continued over the life cycle of the team. Studies of HI-SEAS teams, HERA teams, and Antarctic populations found similar patterns of cohesion and performance that were mutually supportive over time (Kozlowski et al., 2017; Larson et al., 2019; Bergerowski & Bell, 2020; Webb et al., 2017) (Category III). Additionally, the cohesion-predicting-performance pathway was stronger than the reversed pathway and grew stronger over time. Shared leadership was positively related to cohesion. A review of analogous populations (e.g., firefighters, special operations teams) found positive relationships between cohesion and performance that ranged from small to large (Bell et al., 2019a) (Category I). Team cohesion can be viewed as both a predictor and an outcome, and it has been referred to consistently as an emergent state (Marks et al., 2001). This pattern is evident in other team-level factors; that is, the relationships between team factors change over time, relating more strongly or weakly to outcomes and being influenced by outcomes in turn. The dynamic nature of these relationships over time has major implications related to monitoring and maintaining team-level variables, especially cohesion, during a LDEM, and hold clues to the implementation of timely countermeasures.

Although relationship conflict is most salient when considering team functioning and performance, a meta-analysis found task conflict, process conflict, and relationship conflict are all negatively related to group member commitment (De Wit et al., 2012) (Category I). Relationship conflict and process conflict were negatively related to cohesion, whereas task conflict was not related to cohesion, suggesting that task conflicts may occur without breaking the team apart and that interpersonal relationships are more important to the emergent and affective states. Task conflict was positively related to performance outcomes when controlling for the other types of conflict, and process and relationship conflict was negatively related to group performance. Thus, interpersonal conflict and conflict about roles and responsibilities result in more negative outcomes, a likely reason that NASA already finds value in providing conflict management training to the ASCANs. A review of ICE teams and teams analogous to spaceflight crews found that while the number of conflicts varied over time, after 40% of the mission was completed (i.e., 90 days for the studies included), all teams had a within-team conflict and/or a conflict with their respective mission controls (Bell et al., 2019a) (Category I). Conflict in ICE environments may be more nuanced rather than explosive, particularly considering the personality profiles of the crews. During 45-day HERA missions, all crews reported conflict (i.e., 4% of conflict reporting opportunities showed conflict), and categorized such conflicts as noted discords, work disagreements, interpersonal tensions, and interpersonal breakdowns (Marcinkowski et al., 2021) (Category III). Early minor tensions suggested bigger conflicts later. Also, the crews reported work conflict as having occurred in the past (or resolved more quickly), whereas interpersonal conflict developed and lingered over time. Similar to findings in astronaut studies, conflict during HERA missions may be less severe and categorized as frictions or tensions, but it may be exacerbated after longer durations. Another study of 30- and 45-day HERA missions examined how task and relationship conflict may create a feedback loop (Somaraju et al., 2021) (Category III). Task conflict predicted next-day relationship conflict, and relationship conflict predicted next-day task conflict. Results indicated a resource loss feedback loop because current-day relationship conflict predicted next-day strain/distress, and current-day strain/distress predicted next-day relationship conflict. However, lower workload mitigated these harmful spirals, indicating that scheduled breaks during tasks may ease conflict.

Some conflict may be constructive. Disagreements about the task may cause teams to reevaluate and think more critically about the content and outcomes of the task, and is a more accepted form of conflict within well-functioning teams. However, other team cognition research suggests that shared task models may help a spaceflight team coordinate more effectively (Fiore et al., 2015) (Category III). A moderate level of task conflict will prevent negative team processes such as groupthink, while allowing for shared mental models that facilitate team effectiveness. Another meta-analysis (Stahl et al., 2010) (Category I) found that cultural diversity may also increase task conflict and decrease social integration and cohesion, which highlights the importance of pre-mission training to overcome differences that may negatively influence teamwork processes. In general, team cohesion is positively correlated with teamwork processes and emergent states of team potency (LePine et al., 2008) (Category I). However, some nuances exist based on the types of tasks being performed. During four, 30-day HERA missions, team psychomotor performance (e.g., a simulated EVA) increased over mission duration, whereas team creativity, ethical decision-making, and problem solving declined (Larson et al., 2019) (Category III). Notably, cohesive teams were able to achieve all or almost all the task objectives on the simulated EVA task, whereas teams with subgroups or isolated crewmembers did not (Nyberg et al., 2021) (Category III). Non-cohesive teams completed only about 50% of task objectives. A strong, positive relationship also existed between time and team performance when teams were cohesive.

Conflict (i.e., task, process, and relationship conflict) was also found to be negatively related to trust (De Wit et al., 2012) (Category I). Trust is often conceptualized as willingness to make oneself vulnerable to others and trusting others has been identified an aspect of the personality trait agreeableness (Stanton, 2011), which has implications for astronaut selection. Within military teams, trust has been studied extensively in intact teams, action teams, distributed teams, and teams from multiple military branches and countries. A literature review and qualitative assessment of trust in distributed Army teams suggested that trust includes aspects of the individual or team's trustworthiness, based on competence, character, and dependability; trustor characteristics that may influence judgment of others as trustworthy; moderators, such as situational conditions; and trust-related behaviors (Cianciolo et al., 2011) (Category III). In the context of military and related LDEM teams, the researchers approach the trust-related behavior as risk management. For example, an individual may be deemed trustworthy due to their KSAs and past behaviors, and if the situation is one in which there is proven success, the team member is unlikely to be deemed a failure. Other factors such as cultural or sex difference may hinder the building of trust due to perceived differences of mental models and other values or KSA characteristics, however, adopting another's conventions and multi-cultural training can overcoming those initial hurdles to building trust. A USAF study found that teams who performed together for a longer duration had greater trust (Lyons et al., 2011) (Category I). Team trust positively affects team functioning and effectiveness in military teams (Lee et al., 2010), and organizational teams reported a positive relationship between trust and team satisfaction and task performance (Costa, 2003). When trust is violated, conflict management techniques and even apology can rebuild that trust (Stanton, 2011). Mutual trust among team members, and across the MTS, ensures that the team can work autonomously and efficiently without wasting resources on too much monitoring, carrying extra workload due to perceived incompetence, or needlessly questioning leadership or expertise. Transformational leaders who empower team members and create a climate of psychological safety foster reflexivity and allow for greater creative problem-solving capacity (Carmeli et al., 2014) (Category II). Leaders can create group norms to engender psychological safety and enhance team trust, which ultimately lead to better team performance (Schaubroeck et al., 2011) (Category II).

Research conducted in the Antarctic has also investigated conflict, cohesion, and performance. During one Antarctic expedition, team members' perceptions of status contributed to conflicts and reduced perceptions of cohesion (Dutta et al., 1999) (Category III). Wood et al., (2005) (Category III) collected data on human performance in Antarctica over a 10-year period, modeling individual and group effects on adaptation to life in this extreme environment using multilevel analyses. Positive team climate and cohesion helped to reduce interpersonal tensions, which, in turn, contributed to work satisfaction. In addition to several meta-analyses showing the link between cohesion and performance, a study of Antarctic ICE teams found that cohesion and performance are mutually supportive, and positive affect was negatively related to conflict and negative affect (Kozlowski et al., 2015; Webb et al., 2017) (Category I, III). This research team found similar results in the HERA (cohesion increased over time and led to less conflict), HI-SEAS (cohesion increased over time and was positively related to performance, increases in positive affect and cohesion were negatively related to next day negative affect), and in lab studies (positive affect was a buffer for negative affect and conflict). Allowing time for a team to reach a stable, acceptable level of cohesion and trust before a mission is important for stability of the team during mission. Conflict due to diversity of cultures or expertise may be overcome through mission simulations in spaceflight analogs such as NEEMO and the HERA (Noe et al., 2011) (Category IV). The multi-national ESA suggests identifying other commonalities to create a new "space" culture (Sandal & Manzey, 2009) (Category IV), and this approach has been a successful on the ISS (David et al., 2011) (Category III).

A less-researched subtopic on the continuum of interpersonal relationships, team cohesion, dynamics, and conflict in ICE, is the possibility of a very close friendship or romantic relationship developing between team members of an LDEM. Close relationships among team members in typical workplace teams can positively influence performance outcomes related to productivity, customer service, product quality, and well-being outcomes of a stable, supportive environment (e.g., Dickie, 2009) (Category II). A review of individual well-being during spaceflight and in spaceflight analog environments identified that eudiamonic well-being, which includes positive social relationships and having a self-realized meaning or purpose in life, is moderately positively related to measures of team cohesion and group functioning (Vanhove et al., 2015) (Category III). Although organizational and social psychology studies have provided insight into the effects of such relationships between co-workers, effects of these types of relationship in ICE environments have been largely restricted to military units. Members of military teams often develop a strong attachment, colloquially known as "unit cohesion", as early as boot camp. This cohesion provides positive effects on psychological well-being and resilience beyond effective teamwork processes in the extreme environments of training and deployment, and can be enhanced with supportive leadership, social support, and familiarity among team members prior to extreme experiences (Bartone et al., 2015; van Epps, 2008) (Category II). These findings support a renewed focus on intact team training (informal and formal) prior to an LDEM to allow the crew to form close bonds with all members.

Conversely, when a close dyadic relationship results in subgrouping, this can decrease performance and team functioning, and individual well-being, similar to the effects of problematic team composition faultlines. If romantic relationships develop, team dynamics and performance may be affected due to both initial subgrouping and the possible dissolution of the relationship. Indeed, humans have a biological drive, largely governed by a complex system of neurochemicals and brain networks, to form close peer- and pair-bonds, which are beneficial to both psychological and physical health and well-being (Whitaker-Azmitia, 2016) (Category III). Studies of workplace relationships demonstrate that a deterioration of these relationships may lead to emotional stress, reduced performance, turnover or withdrawal, decreased motivation, and negative well-being (Pierce & Aguinis, 2001; Sias et al., 2004) (Category III). In ICE conditions, eudiamonic well-being was weakly negatively related to direct measures of performance and consistently negatively related to symptomatology measures (e.g., anxiety, maladaptive coping strategies), while perceived loss of social support resulted in increased interpersonal conflict, impaired cognition, and an increase in the stress hormone cortisol (Vanhove et al., 2015; Whitaker-Azmitia, 2016) (Category III). This withdrawal, stress, or decreased well-being and functioning may reduce the available skills, knowledge, and work volume of the team. Even when a stable intimate relationship exists among two team members, the dyad may act as a unit, influencing team decision-making capabilities, and form competing goals contrary to the team goals. Interpersonal close relationships also naturally raise the possibility of medically relevant outcomes in addition to the noted performance aspects. Any romantic interaction could become sexual with potential medical implications including health issues and pregnancy. The Exploration Medical Capabilities Element addresses these issues (Gap MED01—Concept of Operations, and MED06—Ethics) for research needs, and the Space and Clinical Operations Division addresses them for operational preventive issues. For teams, these issues may constrain the total physical capabilities and work volume of the spaceflight crew.

No investigation in spaceflight analogs has systematically studied this type of event, beyond anecdotally capturing interactions of a sexual or romantic nature (e.g., Powell, 2014) (Category IV), or including these interactions simply as observed interpersonal events among many others (e.g., Sandal, 2004) (Category III). Romantic behaviors between polar station personnel were identified as both a positive and negative experience (Wood et al., 2000) (Category III); however, the researchers simply reported the existence of these events and did not attempt to examine the associated outcomes. More research is needed to understand the effects of close relationships on the well-being and performance of a diverse LDEM team. Although the spaceflight team is likely to be cohesive because the team will be carefully composed and they will train together before the mission, relationships can change during a long-duration mission and current ISS training that support behavioral norms and the appropriate handling of interpersonal conflicts must be enhanced to support the cohesion, functioning, and performance of a LDEM team, as well to support individual well-being.

b) Psychosocial adaptation, and team adaptation and resilience

Spaceflight is an inherently stressful experience, and successful adaptation and performance in ICE conditions and other situations such as military operations can teach us much. Ground-based research involving conditions similar to spaceflight (e.g., submarines, offshore oil rigs, polar stations) has found that such conditions are generally detrimental to psychological health and social well-being over prolonged periods (Braun & Sells, 1962; Britt and Bliese, 2003; Krueger, 2001; NASA, 1987). Mortality rates are higher for socially isolated patients (House, 2001) (Category III), and the rates of depression and somatic illnesses in Antarctic expeditioners increases as they spend longer periods in relative social isolation (Lugg, 1977; Lugg, 2005) (Category III). The process of psychological and social adjustment to environmental conditions is known as psychosocial adaptation, whereas team adaptation and resilience emphasizes the adaptation in responses and outcomes to a trigger event (Alliger et al., 2015; Maynard & Kennedy, 2016; Schmidt, 2015) (Category IV). These different, but related, constructs both influence team performance and functioning. Some individuals may naturally be more suited to these environments. For example, individuals who were low in extroversion and assertiveness adapted better to life in Antarctica (Rosnet et al., 2000) (Category III), and personality predicts stress and health outcomes in individuals who are exposed to isolation and confinement (Schmidt, 2015) (Category I). As noted previously, however, ground-based evidence indicates that teams with more moderately extroverted members, not overly dominant, generally perform better (Bell et al., 2015a) (Category III). Research must still determine what balance of individual extroversion levels encourages psychosocial adaptation and team performance.

The BMed Risk area provides substantial information regarding how individuals adapt to ICE conditions, but the team may support psychosocial adaptation and resilience. For example, research has demonstrated that high levels of social support and strong communication among team members can decrease the impact of individual strain, buffering negative effects on team effectiveness and performance (Guzzo & Dickson, 1996; Theorell & Karasek, 1996) (Category II). Unfortunately, relatedness declined over time in several spaceflight analog environments. For example, less social support and less cohesion was felt among crewmembers in Antarctic stations over time (Nicolas et al., 2021) (Category III). When communications were delayed during HERA and HI-SEAS missions, more social support originated from other crewmembers and with family and friends than with MCC (Goemaere et al., 2019; Roma et al., 2020) (Category III). Notably, during HI-SEAS missions, the relatedness within the crew declined over time, as did the relatedness with home, indicating that crewmembers might need more support from each other as they experience more disconnect from home and MCC, but the other crewmembers may not step in to fill that need. These patterns of declines were both related to increased stress, and relatedness with the crew was related to lower performance. A similar pattern was recorded during Mars 500, SIRIUS-17, and SIRIUS-19 missions, which resulted in psychological closing and reduced communication over time (Supolkina et al., 2021) (Category III).

A group of resilient individuals does not necessarily lead to a resilient team if they have ineffective communication, conflict, disparate mental models, and decreased team-goal orientation (Alliger et al., 2015) (Category IV). A data-supported model was created by considering over 200 articles (with 94 quantitative articles) of psychosocial factors in spaceflight and analogous populations (Schmidt, 2015) (Category I, III), and this model was used to clarify the nomological network of the relationships between team adaptation and resilience from 15 years of research in an operations assessment by NASA SMEs (Maynard & Kennedy, 2016) (Category IV). It is important to note that adaptation may be an individual or a team trait, i.e., adaptating team processes (e.g., changing actions), and adapting outcome such as creating a new plan or tool or social relationship (Maynard et al., 2015) (Category IV). The relationships among psychosocial adaptation, health, learning, productivity, and performance are somewhat reciprocal at both the individual and the team level (e.g., good health improves psychosocial adaptation and learning, satisfaction with learning and team performance improves psychosocial adaptation, etc.) (Burke et al., 2006, Buunk et al., 1993, House et al., 2003; Israel et al., 1989; Kramer, 1993; Vogt et al., 2008) (Category II, III). Additionally, team resilience has a reciprocal relationship with adaptation of team processes such that processes influence the emergent state of resilience (and other emergent states of cohesion and trust), which then influence team processes (Maynard & Kennedy, 2016) (Category IV). For example, a team member might become the leader during a particular task, leading the team to feel enhanced efficacy and trust due to the leader's expertise in the task. Resilient teams effectively defer to expertise over seniority, ensuring the best team member is leading the response to a problem while avoiding the stifling of junior, yet expert, members (Alliger et al., 2015) (Category IV). These emergent states then streamline the team processes as the team members recognize each member is in an appropriate role and that they may decrease their degree of backup and devote more attention to the task.

These literature reviews highlight the importance of selecting and composing a team of individuals who are adaptable and resilient, and that adaptation and resilience may also be developed and maintained through training and using countermeasures during a mission. For example, the individual input layer of the psychosocial model revealed a positive relationship between self-care and team performance (Schmidt, 2015) (Category I, III). Recall that self-care, which involves an individual managing their own personal health, stress, training, schedule, and fatigue to maintain readiness, was also identified as a very important factor in the LDEM job analysis (Barrett et al., 2015) (Category III). Thus, an individual can take actions to remain resilient, in addition to possessing inherent characteristics of resilience. A NASA-funded review of team resilience lists 40 behaviors of resilient teams, which include behaviors that can minimize the frequency of disruptions and triggers (e.g., communicate with each other to be aware of current "capacity levels"), behaviors that can manage triggers effectively (e.g., quickly and honestly assess and challenge, ask for help and seek guidance), and behaviors that can mend the relationship after it is overcome (e.g., conduct team debrief, clarify how situation has changed, express appreciation) (Alliger et al., 2015) (Category IV). Characteristics such as increased autonomy and team autonomy may support adaptation to the situation. Autonomous teams, especially those in ICE conditions, understand their situation better than the command center, and are able to adapt on demand to the changing needs of a situation. When teams of naval officers were introduced to incongruent information, they were able to autonomously adapt to the situation and improve mission effectiveness (Diedrich et al., 2005) (Category II). An adaptable leader may further support this process. Meta-analyses found that psychological empowerment, which can be induced by a transformational leader, is positively related to job satisfaction, organizational commitment, and task and contextual and team performance, and negatively related to employee strain and turnover intentions (Seibert et al., 2011, Stewart, 2006) (Category I). Team empowerment, a transformational leadership behavior, was also positively related to team performance and higher levels of team resilience.

Adaptation to ICE conditions usually includes adaptation to the situation, event, or context, but there is also a period of adaptation to the team and other team members. Training on the competencies required for group living and teamwork, communication, leadership/follower, adaptability etc., and developing shared cognition will provide teams with the skills they need to live and work as a team during LDEMs. It is also important that teams spend at least 6 weeks together before launch, to facilitate adaptation (Schmidt, 2015) (Category IV). Six weeks allows an isolated and confined team to evolve through team development stages of "forming" (i.e., getting to know teammates), "storming" (e.g., recognizing differences, experiencing frictions), "norming" (e.g., establishing shared group norms), to eventually enter into the "performing" stage (e.g., demonstrating competence, motivation, autonomy, effective problem-solving, and team functioning). More research on psychosocial adaptation, the adaptation processes, and resilience of a team over time during the mission is needed to understand how factors support and mitigate each other to maintain optimal psychosocial functioning. For example, a study of 3,339 military personnel on peacekeeping mission deployments found that as the length of the deployment increased so did reports of depression and post-traumatic stress syndrome (Adler & Dolan, 2006) (Category III). Investigation of team countermeasures and countermeasure timing during LDEM is needed.

Summary points related to ground-based evidence and team emergent states

- Team cohesion is a complex construct that includes social dimensions, behavioral and attitudinal markers, and a time component. Cohesion has a positive, reciprocal relationship with team performance.
- Psychosocial adaptation, adaptation, and resilience may occur at both the individual and team level. Successful adaptation and resilience positively affect performance and psychological well-being.
    - Selection, team composition, and training need further development to support positive team emergent states in ICE conditions.

5. Measures and Monitoring Technologies

Measurement for long-duration missions must capture both team functioning data such as team cohesion, as well as team performance data such as completion of mission objectives. Team constructs may be explicit and easily observable (e.g., communication) or may be implicit and difficult to capture (e.g., degree of shared understanding among team members). However, there is a lack of operational team measures in spaceflight, causing the risk to be difficult to quantify. Traditional psychological measurement relies heavily on surveys and behavioral observations, which are obviously obtrusive in the former and a time burden for researchers in the latter. Generally, methods to measure team performance are needed to help develop spaceflight-related assessments of performance (see Salas, Reyes, & Woods, 2017, for an overview). Considerations include a continued focus on measuring team attitudes, behaviors, and cognitions; assessing at both the individual and team level; and creating measures that are pragmatic, relevant, and unobtrusive.

a) Traditional measures: Surveys, observations, team tasks

Astronauts and subjects who have participated in spaceflight analog research have responded to countless surveys, and psychological researchers have poured over hours of audio/video, documents, and live activities over the decades of spaceflight. A meta-analysis examining BMed-related factors from studies of personnel in Antarctica reported challenges related to a disparity of different measures, often multiple measures used to capture the seemingly same or similar variables, which reduced the analyses and conclusions the researchers were able to draw from the data (Shea et al., 2009). Researchers who have examined and attempted to aggregate data across ICE teams have recommended a common set of measures to remedy this problem (e.g., Bell et al., 2018; Bell et al., 2019b; Landon et al., 2017; Landon et al., 2018). Perhaps nothing better encapsulates how varied and wide-ranging these efforts have been than a NASA-funded solution: the HFBP Exploration Measures project (formerly, the Behavioral Health and Performance Standardized Measures; Roma, 2020; Bell, 2021), which grew from the earlier Behavioral Core Measures project (Dinges, 2020). These research and operations projects are meant to create a standardized set of spaceflight measures, which can be used to inform the range of HRP risks. The HFBP-EM project is focused on individual and team psychological variables, sleep and fatigue factors, and the outcomes and processes related to those predictors (see Table 5). These measures, or a subset of these measures, have been used to collect data in various spaceflight analogs and during spaceflight. Refinement of the measures is ongoing.

Table 5. Human Factors & Behavioral Performance Exploration Measures (HFBP-EM) 2020 suite for analogs (Roma et al., 2020; Bell, 2021).

Risk	Modality	Measure	Timing	Description
BMed	Objective	Cognition Battery	~3x per week	Computerized battery of 10 cognitive, neurobehavioral, and sensorimotor tests (Basner et al., 2015).
BMed	Objective	Robotic On-Board Trainer for Research (ROBoT-r)	3x per week	Research adaptation of the computerized NASA robotics onboard trainer as an operational performance assessment (Ivkovic et al., 2019)
BMed	Objective	Heart rate monitor	Daily	Chest strap heart rate monitor, Polar H7
BMed	Subjective	BDI-II	Weekly	Beck Depression Inventory II (Beck et al., 1996)
BMed	Subjective	POMS-SF	Daily	Profile of Mood States Short Form (Curran et al., 1995; Shacham, 1983)
BMed	Subjective, Qualitative	Neurobehavioral Visual Analog Scales	Daily	Self-report ratings of workload, stress, fatigue, conflict (Basner et al., 2014)
BMed	Subjective	Caffeine, Medication	Daily	Self-reported caffeine and medication use (Basner et al., 2014)
Team	Subjective	Cohesion	Daily	Perceived team task and social cohesion questionnaire (Kozlowski, 2015)
Team	Subjective	Team Performance	Daily	Perceived team performance effectiveness questionnaire (Tannenbaum & Mathieu, 2015)
Team	Subjective	Team Performance (rated by MCC)	Daily	Perceived team performance effectiveness questionnaire of habitat MCC rating of the crew (Tannenbaum & Mathieu, 2015)
Team	Subjective	Team Climate	Weekly	7-item Psychological Safety subscale questionnaire

				(Edmondson, 1999)
Team	Subjective	Conflict	Daily	Dyadic conflict with free response for description (Basner et al., 2014)
Team	Subjective	Team Processes	Weekly	Perceived team effectiveness several team processes (Mathieu et al., 2019)
Team / BMed	Subjective	Social Support	Quarterly /10 days	ENRICHD Social Support questionnaire (Mitchell et al., 2010).
Team	Subjective, Qualitative	Group Living	Quarterly /10 days	Rating of self and crewmates (Roma et al., 2015)
Sleep	Objective	Actigraphy	wearable	Philips Actiwatch M400 wrist-worn device measuring sleep-wake patterns, light exposure, and physical activity/workload\
Sleep	Subjective	Sleep Diary & Quality	Daily	Self-report ratings of sleep quantity, quality, and disruption (Basner et al., 2014)
Cross-Risk	Subjective	Spaceflight habitability assessment and questionnaire (SHAQ)	Monthly/ Quarterly	Perceived effects of habitat areas on BHP outcomes with mediators (Roma et al., 2022)
Mediators/ Moderators	Subjective, Qualitative	Multiple	Once pre- mission	Personality (IPIP-NEO-120; Johnson, 2014), demographics social desirability scale (SDS-17; Stober, 2001)

The purpose of the HFBP-EM project is to (1) provide standardized quantitative measures of behavioral health and performance in individuals and teams across laboratory, analog, field, and spaceflight operational settings; (2) estimate risk over time; (3) inform research, operations, and countermeasure development; and (4) monitor, assess, and provide decision aids for autonomous crews (Roma et al., 2020). As of 2022, data is being collected in the HERA, in the Russian NEK chamber, on the ISS, and with various other extreme teams (as requested by researchers and agreed to by the BHP Lab). Importantly, the HFBP-EM is performed as a service to the larger research community: the BHP Lab manages the collection, cleaning, and sharing of the data with other researchers who need those variables. For example, many behavioral health and related research projects require personality data using the 5-factor model (Costa & McCrae, 1992), so the HFBP-EM collects the NEO-IPIP-120—a 120-item measure of the 5-factor model and its sub-factors—once before the mission and shares the data with all researchers who have a data-sharing agreement with the BHP Lab. This data-sharing also eliminates some of the crew time burden related to completing redundant measures and allows data to be compared across the environments. Eventually, this data will be delivered to the NASA LSDA.

By assessing team tasks in spaceflight analogs, we can understand how teams may function differentially while performing different types of tasks. During a 30-day HERA missions, team psychomotor performance (a team behavioral task in which participants simulate piloting a small vehicle to a Mars moon to obtain samples) increased over mission duration, whereas team creativity, ethical decision-making, and problem solving declined (Larson et al., 2019) (Category III). Preliminary results using the team psychomotor task during a 45-day mission, reveal practice effects ending at the 30-day point, and a difference between cohesive and non-cohesive teams such that cohesive teams reached high performance, whereas less cohesive teams were unable to meet 50% of task objectives by the end of the mission (Bell et al., 2021a). Thus, team performance on some tasks may improve over time or may worsen over time, and underlying team functioning factors such as cohesion drive some of this variability. This also demonstrates the importance of assessing teams during month-long studies before attempting to generalize to a Mars mission.

Retrospective studies or historiometric studies are a way for researchers to analyze operational tasks and events to understand team factors. As part of their study design, researchers often perform content coding for themes and specific behaviors displayed (e.g., coding HERA communications between the crew and mission support, astronaut and spaceflight SME interviews, ICE residents' journals), but for the limited team data available for spaceflight, historic data can be an enlightening starting point. Tools such as LIWC (Tausczik & Pennebaker 2010) can also be employed for sentiment analysis. For example, an analysis of Skylab missions 2-4 in the context of shared mental models found the severe disruptions between crew and ground personnel during Skylab 4 were predicted by the lack of sharedness within the crew and between crew-to-ground (DeChurch et al., 2017). Skylab 2 and 3 had greater similarity within their crews and between space-to-ground for each mission, and did not record significant team issues. A historiometric study of social and task roles enacted by extreme teams found that some roles were consistently enacted independent of temporal considerations (e.g., mission length), whereas the degree to which other roles were enacted varied across missions of differing lengths (Burke et al., 2019). Additionally, the researchers found the following trends: (1) increased enactment of the team builder role as mission duration increases, (2) prominence of the entertainer role, and (3) increased emphasis on the visionary/problem solver role on missions over 2 years. An understanding of past real-world operations can inform future research and countermeasure design.

Other attempts have been made to embed individual and team measures into technology. For example, a team of researchers has developed and deployed a multi-team task in the HERA and in the Russian NEK to examine shifts in shared cognition, team composition within and across teams, and the influence of task, tool, and social networks on team performance and functioning (DeChurch, 2020a; Contractor, 2020, Carter, 2020). Teams use the software-based system to interact, creating a rich environment to document actions, communications, and outcomes over time. Gamification can be used to collect data and may potentially be used for training and assessment purposes during a mission, adapting to the needs of the team through near-real-time assessment of team factors (Landon & O'Keefe, 2018). Another example developed for teams in ICEs is the NASA-funded team performance task software package, which uses principles of behavioral economics to determine how personality attributes and demographics (e.g., sex) predict cooperation over time (Roma, Hursh, & Hienz, 2015b). Teams scored individual points through cooperative and competitive actions in a simple gamified interface. Preliminary findings suggest teams with all men behaved more selfishly than mixed teams or teams with all women. Teams with members who were low in conscientiousness and high in agreeableness were the most cooperative. Finally, measures beyond Western and American traditions may hold useful information, especially for multi-national crews. The Russian space program developed the Personal Self-Perception and Attitudes (PSPA), a personality measure that accounts for an individual's view of the world, and used it to make predictions of future interpersonal behaviors. Russian researchers have a history of success in using this measure for team composition, and a recent cooperative study between NASA-funded researchers and Russian researchers at the Institute of Biomedical Problems is using such a measure in the HERA and NEK studies (Bell et al., 2020). Preliminary findings show that team configurations of psychological distance as measured by the PSPA were related to team performance over time. Specifically, when teams were well integrated (members were psychologically close) they were much better performing than when an isolate (one member was psychologically distant from the rest of the team) was present (Bell et al., 2021a).

a) Unobtrusive measures and monitoring technology

Current research in spaceflight analogs has increasingly used unobtrusive methods of measurement, in addition to typical self-report measures, which may provide a rich dataset for assessing team cohesion and other team functioning factors. In addition to eliminating or reducing the number of surveys, which are generally disliked by study participants, unobtrusive measures offer several advantages: they avoid burdening the crew with time needed for surveys or other active measurement techniques, they lessen "survey fatigue" related to constant reporting that may interfere with the accuracy of ratings, they capture dynamic data on team behaviors as they happen, and they provide more frequent, consistent measures to support real-time monitoring and response. However, unobtrusive measures are often difficult to develop and implement, particularly in operational settings. A team of NASA-sponsored researchers developed a set of tools to conduct lexical analysis of both written text (i.e., journals) and transcripts of verbal communications (Wu et al., 2015b) (Category III). Simple words counts, latent semantic analysis (i.e., juxtaposition of a word with positive/negative words), use of phrases denoting politeness, verb tenses, turn-taking, etc., all provide information regarding the underlying moods and attitudes of the individual. Findings from mission simulations and bed-rest studies suggest this is a valid approach for measuring mood and emotions; salience of topics; sentiment towards the past, present, future; and focus on self vs. others; and can be used to track these variables over time. Real-time lexical indicator technology was also developed to track cognitive and emotional states from verbal utterances, especially to detect how stress was related to decrements in performance and well-being (Salas & Driskell, 2015) (Category II). Data collected during 2 mission simulations indicate that these lexical measures were consistent with self-report surveys of emotions, and that they can detect variation in emotion related to off-nominal days (e.g., high workload). Stress was detected in speech by differences in attention, cognitive load, anxiety, negative emotion, and impairment of the team perspective and the social climate.

Sociometric badges, which detect proximity and within-team interactions, have been tested during multiple mission simulations and at Antarctic stations (Kozlowski et al., 2015) (Category III). These wearable sociometric badges can also be used to assess physical motion, vocal intensity, stress, heart rate and heart rate variability, with near-continuous data streams, providing an integrated assessment of each individual and the team (Kozlowski et al., 2017)

(Category III). Interaction and affective data were highly reliable and accurate, suggesting this is a viable technology for classifying team cohesion and collaboration, but additional validation is needed. In a healthcare setting, data collected with sensor-based measures predicted exertion by nurses in a surgical intensive care unit (Rosen et al., 2018) (Category III). Overall, measures of location (time in location, movement through physical space), movement (body movement and activity in location), environmental noise (volume), speaking (time speaking, pitch, volume, burstiness [distribution of activity over time]), and walking (time and burstiness of walking) all predicted perceived mental and physical exertion. Video feeds have been used with an optical computer recognition program to detect displays of emotion, fatigue, and stress through facial movements during the Mars 500 mission and in the HERA (Dinges, 2015) (Category III). Further work is needed to determine if these are valid measures of cohesion and other team dynamic variables, but data show promising trends and validity for detecting emotions among team members. Astronauts already experience some level of physiological monitoring, for example, heart rate and actigraphy. A multi-modal approach integrating several technologies will enrich data for monitoring an individual's health and well-being, and team performance and functioning. Preventing survey fatigue during LDEMs will be an advantage, but unobtrusive measures will also support an autonomous and isolated team. Teams far from Earth under a communication delay may be able to detect growing negative emotions, decreasing team cohesion, or increasing fatigue, and implement a countermeasure to mitigate the impending performance or well-being decrement, all before communications sent from the vehicle even reach MCC. Extending this technology to predict individual and team performance as team dynamics change over time, and to indicate appropriate timing of countermeasures is a long-term goal for future LDEMs. A critical review of continuous physiological measurement in team settings determined that researchers overwhelming measure single physiological systems, and research on the processes linking inputs to outputs (e.g., team cohesion to performance) is underdeveloped (Kazi et al., 2019). Even less is understood about team physiology when moving beyond 2-person dyads. However, some established linkages may be leveraged for future development (see Kazi et al., 2019 for a summary of the evidence-based relationships between physiology and team input, mediators/processes, and outcome variables). Although some researchers (e.g., Kanas at al., 2009) contend that a constant stream of objective data is needed regarding the psychosocial climate of the crew, it is important to have a balanced approach where meaningful information is provided to the crew and to the support team on Earth. Ownership of their data, and subsequent actions, will likely be important to an isolated and highly autonomous crew on a mission to Mars.

Ongoing technology must mature before these unobtrusive tools can be used operationally. For example, lexical and semantic analysis of speech and written materials, which may be directed to oneself in the form of journals or directed to others during team events or in shared mission logs, is slowed by the lack of robust, comprehensive algorithms to process the information quickly. Accurate speech-to-text technologies, while widespread and improving, do not yet possess the degree of accuracy needed for loud, multi-speaker, operational environments, and have certainly not been trained to the pervasive and specific jargon of spaceflight operations. Additionally, when assessing a multi-national crew with multiple languages in use, sometimes within the same sentence, speech-to-text technologies must account for all the nuances of the individual crewmembers' background, languages, accents, etc. Commercial-off-the-shelf technologies are targeting many of these issues, but a period of "learning" will be required for the technology to incorporate the spaceflight jargon. For technology-based measures, technologies may quickly become obsolete and there is a cost of maintaining that old technology. For example, it is increasingly challenging to collect research data using sociometric badge technology when the company no longer supports that software or software version. It is also difficult to maintain the hardware if it is used for many years to collect data and is subject to the typical drops and damage all heavily used devices may experience. Other physiological measures may cause discomfort (e.g., sores where sensors adhere to the skin), or simply get in the way of daily living (e.g., devices worn on lanyards), as has been reported in spaceflight studies. For example, badge data from four 45-day HERA missions only captured approximately 25% of the data needed to conduct team dynamic analyses, a percentage deemed unacceptable by the researchers (Bergerowski & Bell, 2020). Also, crewmembers may have to charge these devices periodically, administer minor medical assistance if they cause discomfort, and troubleshoot issues with the help of the mission support personnel. Thus, the return on investment may be questionable. Although some of these issues may have to be tolerated in research settings to determine the complexities of behavior, the tools may be unsuitable for translation into operations, particularly for the long-term use. Technologies for mission operations should be carefully considered during the research and development phase to meet the expectations for final use (i.e., research vs. operations vs. both). Finally, technologies selected for flight will require automatic capture and analysis of the many data streams into one integrated algorithm (see e.g., Kazi et al., 2019 for some method recommendations) that returns meaningful information to the crew and to others supporting that crew. However, what constitutes meaningful information related to behavioral health and team functioning has not yet been determined. Research has yet to identify the best set of information and variables to present to the crew, how to present that information to the crew, and what information should be shared with those back on Earth (e.g., psychological and medical support personnel).

D. Computer-Based Modeling and Simulation

Researchers in the social sciences and in industrial and organizational psychology have renewed interest in examining teamwork processes and outcomes through modeling and simulation, perhaps because “team tasks and contexts have become increasingly complex” (Mesmer-Magnus et al., 2016, p. 616). Recent research on teams reflects the maturity of complex computing and statistical approaches, particularly through use of agent-based modeling and simulation (ABMS); a small but growing number of spaceflight and spaceflight analog research studies use this advanced method. ABMS, which uses underlying mathematical equations or rules of process mechanisms to describe changes in a system over multiple time points, has been underutilized in organizational research (Hughes et al., 2012; Kozlowski, 2015) (Category IV). Related to the LDEM context, ABMS has been identified as useful for research in high-consequence environments, when practicality or ethics limits real-world research, when researchers are seeking a holistic understanding of systems, and to examine feedback loops and the impact of time. Spaceflight and spaceflight analog research have all these limitations to some degree, and thus, ABMS may be particularly appropriate for studying teams in complex ICE conditions over a long duration. There are several key complex features of space exploration teams that are important for achieving mission success, which warrant more research in the spaceflight context and may be suited for ABMS techniques (see Table 6; Mesmer-Magnus et al., 2016) (Category III).

Table 6. Key features of space teams that warrant additional research with agent-based modeling.

	Key Feature	Example from Space Exploration Team Context
1	Team contexts affect the learning, well-being, and productivity of individual members.	Contributing to the space mission motivates an astronaut to maintain a high level of performance in the high-pressure situation of spaceflight.
2	Team members shift among individual and collective tasks.	Conduct a science experiment independently versus participate in an extra vehicular activity (EVA).
3	Team members are also members of other teams.	Astronaut works towards NASA goals, and is part of an international crew working towards mission goals.
4	Teams are embedded in larger interdependent systems.	Spaceflight multi-team system of crew, Mission Control 'front room', Mission Control 'back rooms'.
5	Teamwork is sociomaterial and multimodal.	Astronauts communicate with Mission Control via headsets, video, and electronic messages with a particular communication structure, but speak to crewmates face-to-face.
6	Teamwork is a moving target.	Team cohesion will change over the course of a multi-month and particularly during a multi-year mission.
7	Team adaptation is the new team performance.	Off-nominal events such as an ammonia leak that required the crew to respond with an emergency EVA.

Note: Adapted from Mesmer-Magnus et al., 2016.

Starting in 2015, several Team Risk projects began collecting data to develop an interconnected set of agent-based models. Multi-year research studies gathered data from traditional organizational teams, military, and other extreme teams to develop initial models for examining factors such as team composition (Contractor, 2020), team and task switching (DeChurch, 2020b), and shared mental models (DeChurch, 2020a), and further extended these models to capture factors across the MTS of crew and Mission Control teams (Carter, 2020). Findings are beginning to emerge. For example, an ABMS that included team member characteristics relevant to team composition, team-level outcomes such as cohesion and performance, and social networks used data from the HERA to set parameters for virtual experiments and for eventual use in informing crew composition (Contractor et al., 2017; Antone, et al., 2021a) (Category IV). This ABMS will power a team composition decision aid to enable future NASA planners to compose teams and predict friction points likely to require countermeasures during the mission. Considering the multiple streams of information that will presumably come from crew attributes (e.g., personality, work preferences), and from the unobtrusive and physiological measures mentioned in the previous section, ABMS may be important for mission planners and for the crew to determine how and when tasks should be performed. Many factors may be loaded into an ABMS such as current team dynamics, workload, fatigue, equipment and tools, and task characteristics to prescribe a best, or at least a minimally acceptable, work plan. The team composition ABMS model that was developed, validated, and applied using HERA data revealed such a model can be used to understand social networks, individual and team characteristics, and the work conditions that influence team functioning and performance (Antone et al., 2021b). The next step is to translate these powerful models into useable and sustainable operational tools.

VI. RISK IN CONTEXT OF EXPLORATION MISSION OPERATIONAL SCENARIOS

A. Constraints for exploration missions

Short-duration low Earth orbit (e.g., ISS) or cislunar (e.g., lunar Gateway) missions will likely last a matter of a few weeks, whereas, long-duration stays on the ISS, Gateway, or a Mars mission will last from 12 to 30 months. The Team Risk is more focused on long-duration missions because long-duration teams living and working together are less studied and the risks are less understood. Anecdotal reports from operational assessments and from astronauts' journals indicate that many astronauts believe they can "get along with anyone" for a short period of time, often recalling the frenetic, quick trips of the Space Shuttle missions. A few ISS astronauts have also self-identified as less suited to long-duration missions after they experienced long-duration spaceflight (Stuster, 2010) (Category III). Throughout this evidence report, attention has been focused on long-duration Mars missions, and this continues to be the focus of the Team Risk research.

Constraints for future long-duration, planetary exploration missions are outlined in the *Mars Design Reference Architecture (DRM) 5.0* (Drake, 2009), and updated considerations are part of the Evolvable Mars Campaign (Crusan, 2014). The overall plan to journey to Mars was significantly updated via the new cislunar missions of the Artemis program, announced in 2017, which will use the Orion Crew Exploration vehicle and the Gateway orbiting platform for lunar-focused missions (NASA, 2019). The lunar missions will vary as to whether they are orbital only or include some surface operations and habitat. The Mars mission design remains largely unchanged. Although some constraints are consistent across exploration mission types, other constraints will vary by mission (see Table 7). Risk characterization and countermeasure development for the Teams Risk are largely driven by the duration of a Mars mission and degree of isolation related to the communication delays. Many of these risks have been addressed above because the Team Risk research portfolio is oriented to future missions, but a summary of threats follows.

Table 7. Summary of characteristics of exploration missions to the Moon and Mars.

Characteristics Similar across Mission Type	Characteristics Varied Across Mission Type
• Multi-cultural crew • Mixed sexes • Mixed technical expertise and experience • Designated mission commander • Smaller-than-ISS net habitable volume	• Mission duration: from <30 days to ~2.5 years • Size of crew: likely ranging from 4 to 6 individuals • Crew rotation: either planned or not possible • Evacuation: from days to months • Resupply: limited to none • Net habitable volume: from mid-size to small

• Communication delay with Earth • Increased autonomy from mission control center as compared to current operations • Lengthy pre-mission training period • Altered gravity • Deep space radiation	• Degree of privacy: limited to private crew quarters • Duration one-way communication delay: from a few seconds to 22 minutes • Degree of autonomy: International Space Station-like mission control to high and mission support • Surface operations possible • Extravehicular Activity (EVA) frequency: from contingency only to multiple EVAs planned per week

B. Exploration mission hazards of interest to the Team Risk

1. Primary and secondary hazards

The primary hazard identified for the Team Risk is isolation and confinement, and the secondary hazards are the distance from Earth and the hostile and closed environment. Of the 5 hazards of human spaceflight (Schorn & Roma, 2021) (Category IV), these 3 most directly affect the psychologically oriented Team Risk. Radiation and altered gravity may be thought of as the hazards, in combination with the other 3 hazards, that drive the minimum level of necessary individual functioning related to general physiological health. Once those basic physiological conditions are met, the performance-oriented Team Risk dominates as a driver of mission success. In other words, the Team Risk operates downstream of many of the individual-level risks related to biological functioning. As the crew travels further from Earth, the physical isolation will be compounded by the one-way communication delay of up to 22 minutes between Earth and Mars. Many factors investigated by the research portfolio for the BMed Risk are related to isolation from family and friends, as well as separation from nature and views of Earth, and the harmful psychological and physiological outcomes of this stressful situation. Because the closed environment of a Mars mission coupled with the distance does not allow for crew rotation, greater attention will must be paid to initial selection of crewmembers, who must possess the technical skills and adaptability to successfully overcome off-nominal events without real-time coordination with ground-support personnel or the possibility of evacuation. In-flight training and other activities to maintain cohesion of crewmembers and their sense of connectedness with others on Earth may reduce stressors on the team and keep the team functioning as a unit within the MTS. Meaningful team task work and group leisure activities such as group meals, movie nights, and milestone celebrations, will also foster cohesion. Careful planning and design of the habitat and the supplies are necessary because no resupply will be possible. Engaging activities that are regularly updated and virtual environments designed for use by multiple team members simultaneously will offer some relief. Countermeasures to support team communication such as a crew-led debrief, which is “owned” by the in-flight team without needed intervention from ground support personnel, will allow the team to maintain function as they become more autonomous and isolated.

2. Other contributing factors

Other LDEM factors may be hazardous to the team, but some could also be leveraged as countermeasures to maintain team performance and functioning. Behavioral competency training should be conducted both before and during spaceflight to ensure the crew has the teamwork skills they will need to complete the mission. Skills that support behavioral health (e.g., stress management) and team performance and functioning are subject to the same skill decay as may occur with technical skills. Workload should be scheduled to mitigate (not exacerbate) psychological or physical stress on the crew and allow time for adequate sleep periods. Some schedules could be self-directed by the crew as their autonomy increases; for example, MCC could set overarching weekly goals that the team could determine how to achieve. Careful selection and composition of teams of diverse crewmembers will avoid faultlines and build a multi-dimensional network of connections, cohesion, and shared team cognition, but additional support will be required through training and other countermeasures. Engaging activities, social events, and communications with home, albeit with communication delays, may support psychological health and lessen the social monotony. Communication delays will prevent the current practice of real-time PPCs and private medical conferences, therefore new avenues for within-team support, telemedicine, and psychologically supportive countermeasures will be required to support mental health and physical health. Finally, habitats must have adequate volume and design layout to support team activities (e.g., training, social time, community meals), privacy, and cohesion.

Unknown hazards to the team likely exist, requiring the team to be psychologically adaptable and resilient to off-nominal events and stress, to develop and maintain adaptability skills through training and countermeasures, and to have tools (e.g., 3D printers, configurable habitat) that will support adaptation. The team and the MTS must plan and prepare, and international partnerships between the space agencies and their respective countries must be agreed to long before launch date.

> "*When we go on the international expedition to Mars, we will have to work a lot harder at coming to a common agreement of what the norms and standards are as currently on the ISS there is still sort of dividing line and we play by whoever's rules it is*." – NASA Flight Director (Burke & Feitosa, 2015) (Category IV).

Emerging research on the physiological threats to teams includes interdisciplinary research examining areas such as the central nervous system, neurobiology, nutrition, physical fitness, and space radiation (Schorn & Roma, 2021) (Category IV). The research domain criteria model developed by the National Institute of Mental Health (which is a part of the National Institute of Health) views the threats to team performance and functioning through the lens of genomics and neurobiology. An individual's underlying biological predisposition to seek out and to provide social support, and the corresponding physiological responses, for example, may influence interpersonal interactions (Whitaker-Azmitia, 2016) (Category III). Likewise, damage to cognitive functioning resulting from increased deep space radiation may also impact teamwork processes such as collaborative decision-making. Although the BMed Risk more directly considers these factors because they affect the individual, downstream affects to the resilience of the team also need more research. The physiological factors relating to the Team Risk call for more research.

C. Risk Posture

The NASA HRP provides research support for many of the risks bookkept by the HSRB (see https://humanresearchroadmap.nasa.gov/architecture/). The HSRB assesses human system risks against 4 DRM. For each DRM and impact category, a risk has a set of risk posture information approved as the HSRB. This includes a likelihood and consequence (LxC) score (with associated drivers and assumptions), a risk disposition (and rationale), a risk color (based on where the LxC scores land in the 5x5 risk matrix), and levels of evidence ratings (that support the LxC scores). The LxCs use a stoplight color coding to visually identify the level of risk, with red 5x5 as the most severe level of likelihood and consequence. The Team Risk posture with LxCs by DRM is shown below (see Table 8). Note that for the long-term health LxCs, the Team Risk is not applicable because the team no longer exists after the mission and any long-term behavioral health concerns are addressed through the BMed Risk.

Table 8. Team Risk risk posture by design reference mission.

DRM Categories	Mission Type and Duration	LxC OPS	Risk Disposition	LxC LTH	Risk Disposition
Low Earth Orbit	Short (<30 days)	4x2	Accepted w/ monitoring	N/A	N/A
	Long (30 d-1 yr)	4x2	Accepted w/ monitoring	N/A	N/A
Lunar Orbital	Short (<30 days)	4x2	Accepted w/ monitoring	N/A	N/A
	Long (30 d-1 yr)	5x3	Requires Mitigation	N/A	N/A
Lunar Orbital + Surface	Short (<30 days)	4x2	Accepted w/ monitoring	N/A	N/A
	Long (30 d-1 yr)	4x3	Requires Mitigation	N/A	N/A
Mars	Preparatory (<1 year)	5x4	Requires Mitigation	N/A	N/A
	Planetary (730-1224 days)	5x5	Requires Mitigation	N/A	N/A

VII. DIRECTED ACYCLIC GRAPH (DAG) REVIEW

A. DAG Review

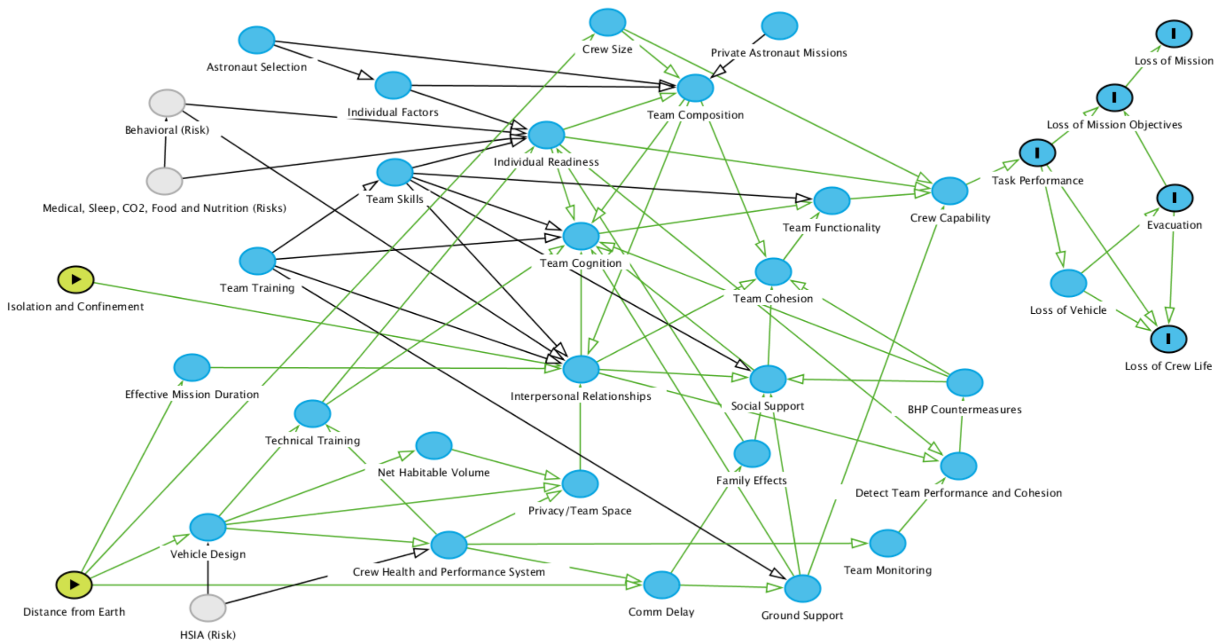


Figure 6. Directed Acyclic Graph for the Team Risk.

The Team Risk DAG was accepted by the NASA HSRB in 2022 (see Figure 6). The Level of Evidence carried by the relationships between the nodes is outlined throughout this report. Although the structure of the DAG does not fundamentally change for different DRMs, there may be more or less data to anchor those relationships for a given scenario. For the sake of parsimony, each node represents several variables (e.g., team skills cover a wide range of skills for working and living together).

The narrative accompanying the DAG is as follows.

- Isolation and confinement affect interpersonal relationships directly and through monotony, boredom, and other possible behavioral affects that are represented in the Behavioral Risk.
- Distance from Earth affects the mass and volume allocations that limit vehicle design decisions. It also affects communications delays, influences effective mission duration, and also affects crew size.
- The central issue in the Team Risk is that team cohesion, team skills, and team cognition come together to influence team functionality, and ultimately, crew capability. The Team Risk operates downstream of many other risks, and at a higher level than the individual, but is heavily influenced by the individuals and individual-level risks in the system.
    - Effective mission duration is related to distance from Earth, but not always, and it has implications for (likely decremented) interpersonal relationships over time
    - Crew size is another potential stressor that is more loosely tied to the 5 hazards, but has implications for the relationships, skills, and simply the person-hours (team composition and crew capability) available onboard.
    - Ground support, which will be heavily impacted by communication delays, is an important part of the spaceflight MTS.

- Team functionality is the degree of coordination, cooperation, communication, and psychosocial adaptation that enables a team to successfully complete tasks and live and work as a team. It is affected by the following.
    - Team cognition is shared understanding among team members that is related to roles and responsibilities; team norms; familiarity with team members' knowledge, skills, and abilities; and engaging in team decision-making and problem-solving. Team cognition is supported by many factors related to team composition and interpersonal relationships, the team training together (in both technical and team skills), engaging in team skills and social support, countermeasures (e.g., debriefs), and the team members' individual readiness (i.e., individual cognition). Ground support is an important part of team cognition across the MTS.
    - Team skills consist of information sharing, backup behaviors, leadership/followership, team care, and providing social support, among others. Team skills are developed through training. Team skills support individual readiness to function on a team, offer social support, create and maintain shared team cognition, and interpersonal relationships.
    - Team cohesion is tendency for a group to operate in a unified fashion while working towards a goal or to satisfy the emotional needs of its members. It is affected by interpersonal relationships that develop through shared values and complementary personalities (team composition) and social support during shared experiences. It is supported by BHP countermeasures (e.g., debriefs).
- Crew capability is the readiness of the entire crew to perform required tasks including the functional capacity as well as knowledge, skills and abilities, at both an individual and team level. Inadequate task performance during critical team tasks (e.g., EVAs for repairs or for surface ops, emergency response) can lead to loss of vehicle or loss of mission objectives or loss of crew life. This is affected by the following.
    - Team functionality as represented above.
    - Crew size effects the pool of available knowledge/skills/abilities and person-hours onboard, as well as interpersonal relationships via team composition.
    - Individual readiness is affected by individual actors present at astronaut selection (a pool of well-qualified, highly skilled, team-oriented individuals), Other risks (human system risks), family effects, and team skills developed through team and technical training.
    - Ground support, which is particularly negatively affected by communication delays in time pressure situations (e.g., emergency response), by restricting timely troubleshooting and coordination.
- BHP countermeasures and other factors influence the level of team cohesion, team skills, and team cognition. These include the following.
    - Training performed before and during a mission. This includes both technical *and* team skills training /behavioral health training. Technical training is dependent on vehicle design and the design of vehicle systems and the CHP System. Training can affect individual readiness and shared understanding (team cognition) of these vehicle systems. Team training affects each individual's readiness to work and live as a team via team skills, affects interpersonal relationships as the team trains together, affects social support behaviors, and affects shared understanding (team cognition) of team norms.

- Team composition is influenced by a given DRM's distance from Earth via crew size (which affects the available knowledge/skills/abilities, or individual factors on board), and by the mission objectives and the individual's readiness to meet those objectives. Team composition is an ongoing consideration because different tasks occur throughout the mission, and it does not end when the crew is assigned.
  - The risk introduced by PAMs and space tourists is an unknown and may severely disruptive the entire system. PAMs will not have the same level of strategic selection, composition, training, or countermeasure support as the professional astronauts.
- The HSIA Risk influences vehicle design and systems (CHP System), affecting the NHV and the availability of privacy and a team space. Both privacy and team spaces (e.g., a dining/work table) influence interpersonal relationships.
- Interpersonal relationships are affected by the mix of individuals on the mission (team composition, Behavioral Risk), the team training experienced together, and the team skills the team uses to support the relationships. Increased isolation and confinement may exacerbate small frictions and degrade interpersonal relationships, particularly during longer effective mission durations. Interpersonal relationships are a strong predictor of team cohesion, and how the team provides work and non-work supportive behaviors to coordinate and cooperate (social support, team cognition).
- Communication delays restrict the degree of social support provided by family, ground support, and psychological support (BHP countermeasures) from experts on Earth. Team monitoring allows experts, team members, or autonomous systems to detect changes in team performance and cohesion and may prompt the team to engage in team-supportive BHP countermeasures (e.g., debriefs).

B. Integration with Other Risks

The HRP has worked to systematically link the many diverse risk areas based on overlapping research activities. As noted in the above Team Risk DAG, team variables and functionality are downstream outcomes of the culmination of many individual-level factors and interventions. The Team Risk is well-integrated in the research portfolios with other behavioral health and human factors risks (i.e., BMed, Sleep, HSIA Risks), but not as integrated with other medically oriented risks that operate at the individual level. An individual-level physiological issue most directly affects teams by reducing the team size (temporarily or permanently), functionally reducing the number of available skills, abilities, and person-hours to accomplish tasks. However, a knowledge gap exists for the degree to which an effective team can overcome the individual-level weaknesses for each team member. For example, a team may experience elevated levels of carbon dioxide if the environmental control and life support system that recycles the air malfunctions, and some crewmembers may experience greater cognitive decrements due to the hypoxia. Monitoring tools that can detect changes may then prompt dynamic team composition to select the most capable 2 crewmembers to perform the repair. Or, if the repair requires all crewmembers, strategic allocation of tasks may increase the chances of the repair being successful. In other words, integration can occur in the research approach and in the deployment of countermeasures. Integrated research should examine team-level factors and outcomes that maintain team performance and functioning in the face of individual-level decrements. The connections described in Banks and colleagues' (2019) and Landon and colleagues' (2019) reviews of the behavioral biology of teams suggests several starting points for research, but many other risks in the HRP may benefit from an integrated approach to supporting performance during a LDEM. See other chapters of the Evidence Book for more information on the other Risk areas.

VIII. KNOWLEDGE BASE

A. Gaps in Knowledge

At the time of publication, HFBP has identified 6 research knowledge gaps related to the risk of performance and behavioral health decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team (Team). A summary can be found in the HRP's Roadmap to Risk Reduction and are as follows:

Team-101: We need to understand the key threats, indicators, and evolution of the team throughout its life cycle for shifting autonomy and interface with automation in increasingly earth independent, LDEMs.

Team-102: We need to identify a set of quantifiable and validated measures, based on 5-12 key indicators of mission-relevant and identified spaceflight acceptable thresholds (or ranges) of team function, to effectively monitor and measure team health and performance of integrated NASA and commercial/private crews, during shifting autonomy in increasingly earth independent, long duration exploration missions.

Team-103: We need to identify psychological and psychosocial factors, measures, and combinations thereof for use in selecting individuals and composing highly effective crews most likely to maintain team function during shifting autonomy in increasingly earth independent, long duration exploration missions.

Team-104: We need to identify validated ground-based and in-flight training methods for both preparatory and sustaining team function during shifting autonomy in increasingly earth independent, long duration exploration missions.

Team-105: We need to identify a set of countermeasures to support team function and enable multiple distributed teams to manage shifting levels of autonomy for all phases of increasingly earth independent, long duration exploration missions.

Team-106: We need to identify how multiple risks (e.g., BMed, HSIA, Sleep) may increase or buffer Team risk, with potential for integrated, synergistic impact on Team performance and functioning during shifting levels of autonomy for all phases of increasingly earth independent, long duration exploration missions.

B. Future Work

Future work is structured under the identified Team Risk gaps, and the specific topics in need of more research are discussed throughout the current report. In the 2020s, the Team Risk will move from risk characterization studies to the development of robust monitoring tools and countermeasures. A summary of high priority future work covers several areas. First, monitoring tools and measures of team factors must be less obtrusive or unobtrusive when possible, e.g., semantic analysis of team cohesion based on automated processing and analysis of vehicle audio and space-to-ground communications.

Second, a suite of evidence-based countermeasures is needed to support team performance and cohesion throughout an astronaut's career, for any team they may join, and during preparation for and execution of a specific mission. These measures must cover selection and composition to identify team-oriented, resilient individuals and to place the right mix of astronauts on a crew for a given mission. Composition measures should be dynamic over the course of the mission; that is, a team may need to identify smaller sub teams for a given task, or a team may need to repair fractured interpersonal relationships by strategic partnering.

Third, countermeasures also include training protocols and evaluation criteria that will build teamwork skills and group living skills. Crew training should integrate team skills and technical training so that astronauts are able to "train as they fly" and enhance fidelity of the mission operations. Communication protocols and coordination support tools should also enable space-to-ground coordination, particularly during communication delayed missions in which communication is much more challenging.

Fourth, crew size trade-offs for each DRM and for each specific mission's concept of operations should be readily provided to mission planners, perhaps with the support of planning analysis tools. A preliminary review of the trade-offs of small crew sizes suggests there is no "right" number of crewmembers for future Mars missions, but bigger (i.e., 6 vs. 4 individuals) is generally preferred because they allow for more diversity in KSAs, task and social roles, and increase the number of person-hours and back-ups to accomplish mission objectives (Landon et al., 2020) (Category IV). A larger team may be less vulnerable to fractures or loss of a crewmember. However, operational constraints (e.g., tasks, consumables, engineering) should be the primary driver of crew size. The review team (Landon et al., 2020) also recommended that there be an even number of crewmembers to avoid creating an "odd man out" or isolate during social and task demands, and planners should avoid faultlines through careful team composition and monitoring. Overall, risk trade-offs are not yet fully understood, and significant uncertainties remain. Ongoing research from psychology and teams researchers and from human factors researchers are examining how team processes, structure, and mission task planning may inform crew size and identify potential problems.

Fifth, future work should also examine of how teams compensate for individual-level risks and weaknesses to accomplish the mission objectives and maintain team cohesion and individual well-being. This necessitates more interdisciplinary research that integrates research and countermeasures across multiple risk areas with the Team Risk. Considering risks beyond those traditionally integrated with the Team Risk (i.e., BMed, Sleep, HSIA) is important to fully reduce risk.

Sixth, building a more robust evidence base is always important. Research on teams is a complex, and assessing long-duration teams is resource intensive. Continuing analog research and extending this data through advanced analysis techniques such as agent-based modeling helps build the evidence base when collecting many data points is not practical. More spaceflight data and space-to-ground data must be collected, particularly during the upcoming lunar missions.

Seventh, more work is needed to understand the impacts of PAMs. Lack of rigorous team-oriented and integrated selection, composition, training, and support for those PAM participants may impact likelihood and consequence levels for the professional astronauts.

IX. CONCLUSION

The HFBP Element provides the knowledge, tools, and technologies that support crew health to prevent or mitigate the Team Risk. These efforts are operationally driven, and mapped to milestones related to the pathway-to-risk-reduction that stems from future LDEMs timelines. Veteran astronauts and ground control personnel have expressed the need for training and countermeasures to improve crew cohesion and reduce the likelihood of performance errors that are caused by inconsistent and suboptimal team dynamics. Some missions may have been jeopardized and, possibly, terminated because of interpersonal frictions in the past; therefore, the priority for reducing the Team Risk involves reducing the risk of team conflict, maintaining cohesion, and developing appropriate countermeasures.

Much work has examined, and continues to examine, workplace teams, and a multitude of meta-analyses can be used as a foundation for team research. The growing body of evidence from ground-based analogs of spaceflight adds unique value to the research on more traditional workplace teams. Differences between traditional workplace teams and teams in ICE conditions, or populations analogous to astronauts such as the military, highlight the future research and countermeasure needs related to LDEMs. Spaceflight evidence related to teams is somewhat limited because measures of team performance and functioning have not been implemented in a systematic way. However, preliminary findings exist, in addition to more concrete conclusions, which are beginning to fill gaps in knowledge required for future LDEM. For example, careful selection of individuals and composition of a team may mitigate faultlines and other threats that result in team conflict. Training on communication skills that are supported by regular team debriefs and feedback events enables the team to maintain shared cognition and overcome conflict. Evidence also indicates that environmental context influences team performance. Thus, leveraging existing research for team selection and composition, and training in the context of LDEMs will shorten the time required to identify best practices for LDEMs.

Similarly, existing or ground-based technologies can be leveraged to support LDEM teams. The second priority of the HFBP Team Risk is to develop unobtrusive monitoring technologies that can detect deteriorating team performance and team functioning, a condition that will ultimately decrease crew performance and well-being. For example, sociometric badges can monitor crew cohesion and interaction patterns real-time, and very little maintenance time is needed by crewmembers. Developing these badges in spaceflight analog research will allow them to be implemented later to assess other co-located workplace teams beyond the spaceflight context, but limitations must be addressed. These unobtrusive monitoring tools will enable LDEM crews to self-monitor in real-time, which is important because communication delays between crew and ground support will increase the crew's autonomy and decrease the coordination of the MTS. The third priority of the HFBP Team Risk is to determine the implications of communication delays and supporting team performance during delayed conditions. Preliminary work has been completed, but more research is needed in this area to understand the risk and to validate training and other countermeasures.

In summary, HFBP research into the Team Risk will support future LDEM teams and will further the overall scientific understanding of teams, especially of teams in extreme environments. The HFBP Element has identified gaps in knowledge and mitigation strategies that are related to these issues. More rigorous, longitudinal research designs and a multi-method research program is needed to close these gaps. High-fidelity space analogs or current spaceflight studies are needed to test the utility of the tools and countermeasures that will be designed to promote optimal performance and to support the psychosocial health of astronauts who are on long-duration missions. Optimal performance and team functioning mitigates the frequency and negative effects of performance errors. Team resilience and cohesion buffers the effects from ICE-related psychological and physiological stressors and supports LDEM success.

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XI. Appendix A: NASA Human Research Program Categories of Evidence

Broad "Experimental" Design Type	Silagy & Haines Levels of Evidence* (for comparison only)	NASA Categories of Evidence
Controlled	Ia. Meta-analysis of randomized trials	I. At least one randomized, controlled trial
	Ib. At least one randomized trial	
	IIa. At least one controlled study without randomization	II. At least one controlled study without randomization, including cohort, case control, or subject operating as own control
	IIb. At least one other type quasi-experimental study	
Observational	III. Non-experimental descriptive studies, e.g. comparative correlation, or case studies	III. Non-experimental observations or comparative, correlation, and case or case-series studies
Opinion	IV. Expert committee reports or opinions or clinical experiences of respected authorities	IV. Expert committee reports or opinions of respected authorities based on clinical experiences bench research, or "first principles"

*Source: Silagy C, Haines A (2001) Evidence Based Practice in Primary Care, 2nd ed., London: BMJ Books.