

## **Evidence Report:**

# **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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## Table of Contents

I.	Program Requirement Documents (PRD) RISK TITLE: Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team .....	5
A.	Risk statement .....	5
B.	Context .....	5
C.	Operational Relevance .....	6
II.	EXECUTIVE SUMMARY .....	7
III.	INTRODUCTION .....	8
IV.	EVIDENCE.....	10
A.	Spaceflight Evidence .....	10
1.	Sources of evidence .....	10
2.	Predictors and contributing factors to team performance and functioning.....	11
a.	Selection.....	11
b.	Team Composition.....	15
c.	Team Autonomy, Communication, and the Multi-Team System.....	16
d.	Team Skills Training.....	19
3.	Team Emergent States .....	23
a.	Team Cohesion, Trust, and Conflict.....	23
b.	Psychosocial adaptation, and team adaptation and resilience.....	24
4.	Measures and Monitoring Technologies.....	24
B.	Ground-based Evidence .....	25
1.	Sources of evidence .....	25
2.	Predictors and contributing factors to team performance and functioning.....	25
a.	Selection.....	25
b.	Team Composition.....	27
c.	Team Autonomy, Communication, and the Multi-Team System.....	30
d.	Team Skills Training.....	33
i.	Training the individual to be on a team .....	33
ii.	Training the team .....	36
iii.	Training methods.....	39
3.	Other Predictors .....	42
a.	Team Net Habitable Volume .....	42
b.	Teams & Sleep.....	43
c.	Team Robotics .....	43

- 4. Team Emergent States ..... 44
  - a. Team Cohesion, Trust, and Conflict..... 44
  - b. Psychosocial adaptation, and team adaptation and resilience..... 47
- 5. Measures and Monitoring Technologies..... 49
- V. COMPUTER-BASED MODELING AND SIMULATION ..... 50
- VI. RISK IN CONTEXT OF EXPLORATION MISSION OPERATIONAL SCENARIOS. 50
  - A. Constraints for exploration missions ..... 50
  - B. Exploration mission hazards of interest to the Team Risk ..... 51
    - 1. Primary and secondary hazards ..... 51
    - 2. Other contributing factors ..... 52
- VII. GAPS ..... 52
- VIII. CONCLUSION ..... 53
- IX. REFERENCES ..... 54
- X. TEAM ..... 68
  - A. Current Authors ..... 68
  - B. Past Authors ..... 68
  - C. Acknowledgements..... 69
- XI. LIST OF ACRONYMS ..... 69

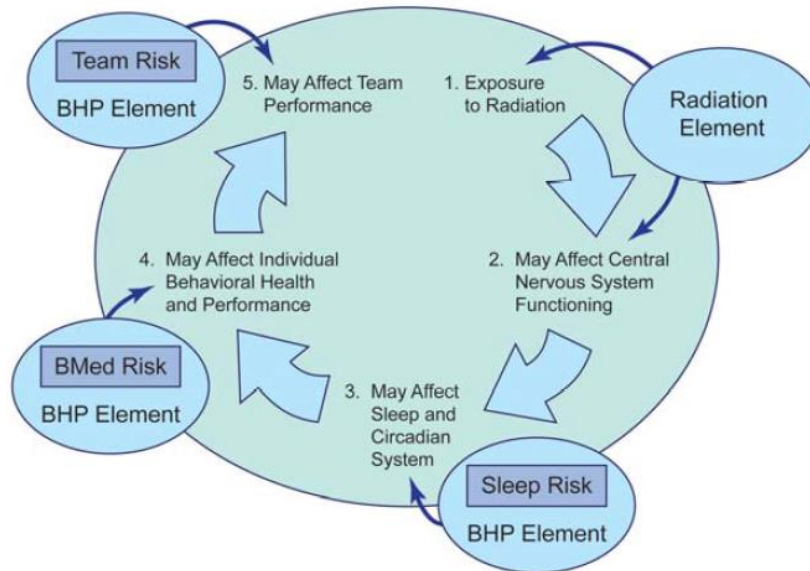
I. Program Requirement Documents (PRD) RISK TITLE: Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team

A. Risk statement

As stated in the Human Research Program Roadmap: Given that the conditions of spaceflight missions will likely impact the functioning and behavioral health of the team, including the spaceflight crew and ground support, performance and behavioral health decrements may occur that will jeopardize mission success and crew health and safety.

B. Context

The National Aeronautics and Space Administration (NASA) Human Research Program (HRP) is organized into topic areas called Elements. The Behavioral Health and Performance (BHP) Element is tasked with the responsibility of managing three risks: (1) risk of performance decrements and adverse health outcomes due to sleep loss, circadian desynchronization, and work overload (Sleep); (2) risk of performance and behavioral health decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team (Team); and (3) risk of adverse cognitive or behavioral conditions and psychiatric disorders (Behavioral Medicine, BMed). The Team Risk is primarily performance-focused. Monitoring tools, measures, and countermeasures developed in this area are aimed at enhancing team processes and composition configurations that will result in optimized team performance and functioning. While each of these risks is addressed in a separate chapter of this book, each risk interacts and informs the others. For example, a recent review of human cognitive performance in spaceflight analogs includes findings from several studies suggesting negative effects on learning, cognition, emotions, and attention in novel environments (Strangman, Sipes, & Beven, 2014) (Category I-III). This individual cognitive performance is addressed through the BMed Risk, but the effects of cognition on learning, training, decision-making, etc., may affect the ability of the team to perform. This is considered in team-level cognitive processes research throughout the Team Risk. Furthermore, BHP risks overlap with risks in other HRP Elements and must be considered in conjunction with one another (see Figure 1). These relationships are outlined in the HRP Integrated Research Plan (IRP). The nature of the IRP implies that BHP is continually reviewing and updating integration points with other Elements. While research is designed to address identified gaps, it will be necessary to update and revise each of the BHP Evidence Reports that constitute this document and the IRP as the element gaps are closed and new gaps emerge.



**Figure 1.** Example of possible BHP risks overlapped with risks in other HRP elements

### C. Operational Relevance

While BHP operations are focused on supporting current crews and missions, the BHP research Pathway to Risk Reduction (PRR) has an applied, clear, future-oriented focus on long duration exploration mission (LDEM). BHP Team research addresses the needs of BHP operations through projects examining team training, selection and team composition guidelines, and general knowledge acquisition through basic research. The 2013 astronaut selection used a BHP Team research supported Teamwork Observation Tool. A recent job analysis for LDEM missions was conducted as a joint effort by BHP-Operations personnel and the BHP-Research group, in conjunction with the astronaut office (Barrett, Holland, & Vessey, 2015) (Category III). This job analysis will inform BHP research on selection and team composition needs, leading to research which will in turn inform future rounds of astronaut selection supported by BHP operations. Unobtrusive measures related to team cohesion developed through BHP Team research will help BHP operations monitor aspects of team cohesion in-flight (Kozlowski, Chang, Perry, Pearce, Dixon, & Santoro, 2015). BHP-Research also practices Transitions to Operations (TtO) in other NASA groups. For example, astronauts and flight controllers engage in a team skills training program known as spaceflight resource management (SFRM), adapted from the aviation industry's crew resource management (CRM). BHP personnel act as consultants to develop and validate SFRM training programs. This training has grown to incorporate a research tested and validated debrief protocol centered on four 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 time to certification (Bedwell, Smith-Jentsch, Sierra, & Salas, 2012) (Category II). This training has spread to other space centers (e.g., Marshall Space Flight Center, home to many payload flight controllers) and has been used as part of the astronaut candidate (ASCAN) training regimen. The goal for BHP research is to transition validated deliverables to operations to make a lasting, positive impact on spaceflight teams, now and in the future.

## II. EXECUTIVE SUMMARY

Team research in the context of LDEM has made great strides in the last few years. In comparison to the earlier edition of the NASA HRP Evidence Book, spaceflight research, and particularly ground-based analog research, has grown substantially. The results of these efforts include studies conducted at traditional, exploration, Isolated, Confined, and Extreme (ICE) environment (ICE) analogs (e.g., Antarctic stations), but now importantly include studies from several mission simulation analogs, notably, Johnson Space Center's Human Exploration Research Analog (HERA); HERA Experiment Information Package, 2014). Utilization of the International Space Station (ISS) for Team Risk research is currently limited. Major challenges relevant for the Team Risk are social isolation, physical confinement, a small and diverse crew, communication delays between crew and ground, a long duration, and a high consequence environment. Each of these conditions affect the coordination, cooperation, psychological well-being, and team performance. While the ISS remains important for studies, which require spaceflight testing and validation, the current conditions on the ISS do not adequately mimic the exploration environment for NASA team research, and thus access to analogs is paramount. The emphasis on analogs is reflected in this updated evidence review of the BHP Element's Team Risk. Additionally, the Team Risk has reached a tipping point; that is, many NASA-funded and –supported comprehensive literature reviews and operations assessment of the major team factors as applied to LDEMs have provided a clarified picture of the “state of the science.” The increasing maturity of this research has highlighted trends in current data and focused the future Team Risk research and countermeasure development plan.

Spaceflight evidence for team-level research is lacking, so it is difficult to quantify the impact of team-level variables on individual and team-level outcomes relying on data from current spaceflight missions. To date, no systematic attempt has 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, defined research area for NASA, with substantial growth only within the last decade, and limited availability to performance data. As a result, spaceflight evidence is lacking with regard identifying 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) and researchers acknowledge the importance of the team to mission success and to maintain crew health, and offer descriptive testimonies as to the importance of the teams in space. Finally, Team Risk research, as noted above, does not rely on spaceflight research to the extent required by many other Risks. Thus, while there is a lack of spaceflight evidence, evidence gleaned from ground and analog studies enables Risk gap closure.

Ground-based studies provide much greater quantitative evidence for team functioning in ICE environments. Academic research on teams has produced dozens of meta-analyses from which 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. This necessitates integration with other individual-focused Risks of the NASA HRP, including BMed, Sleep, and Space Human

Factors and Habitability (SHFH). Much of this integration occurs through the Human Systems Risk Board, a standing committee of scientists from all research Elements in the Human Research Program. A lack of team functioning may be a stressor in some circumstances, but the unit of the team itself often acts as a countermeasure. For example, leadership and teammate support can facilitate individual functioning and encourage psychological and physically healthy behaviors and attitudes. However, more research is needed with regard to teams in long duration exploration missions and the remaining gaps in the research are included in this report.

### III. INTRODUCTION

A team is defined as: “two or more individuals who interact socially and adaptively, have shared or common goals, and hold meaningful task interdependences; it is hierarchically structured and has a limited life span; in it 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, Stagl, Burke, & Goodwin, 2007, p. 189). From the NASA perspective, a team is commonly understood to be a collection of individuals that is 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 who are assigned to support that crew during a mission.

The Team Risk outcomes of interest are predominantly performance related, with a secondary emphasis on long-term health; this is somewhat unique in the NASA HRP in that most Risk areas are medically related and primarily focused on long-term health consequences. In many operational environments (e.g., aviation), performance is assessed as the avoidance of errors. However, the research on performance errors is ambiguous. It 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, Woods, & Leveson, 2006) (Category III<sup>1</sup>). 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 fairly 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, Berman, Loukopoulos, 2007) (Category III).

More commonly, observers record variability in levels of performance. Some teams commit no observable errors but fail to achieve performance objectives or perform only adequately, while other teams commit some errors but perform spectacularly. Successful performance, therefore, cannot be viewed as simply the absence of errors or the avoidance of failure (Johnson Space Center (JSC) Joint Leadership Team, 2008). While failure is commonly attributed to making a major error, focusing solely on the elimination of error(s) 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).

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<sup>1</sup> The four NASA categories of evidence are defined in the Introduction provided for this *Human Health and Performance Risks of Space Exploration Mission* book.



The surest way to reduce the risk of failure is to achieve optimal performance. If NASA is to spend the same amount of money launching one of two crews, and both crews have an equal risk of committing 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 remains the highest-performing crew. Additionally, selecting the crew with an increased likelihood of sustained behavioral health and team functioning is another important consideration that must be proportionately balanced with performance, due to the influence on performance and long-term health. One of the goals of the Team Risk research is to optimize performance in a high-performing population, support behavioral health, and extend success to the context of the new LDEM mission profiles.

Consideration of performance in the Team Risk is divided into two main categories: team task performance and team functioning. Team task performance often includes more objective measures of performance, e.g., number of task/mission objectives achieved, speed, error rates and task dependent metrics. Current efforts within BHP research are underway to establish a more robust set of objective performance measures that capture the team performance variability beyond error rate, e.g., accomplishing mission 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 elements of:

- Teamwork – interdependent acts that convert inputs to outcomes through cognitive processes, communications, and behaviors to achieve collective goals;
- Team Cohesion – the tendency for a group to operate in a unified fashion while working towards a goal or to satisfy the psychosocial needs (e.g., feeling of belonging and contributing to the team) of its members
- Cooperation – attitudes, beliefs and feelings of the team that drive behavior
- Coordination – utilization of behavioral processes needed to transform team resources into outcomes, and,
- Psychosocial Adaptation – ability to cope with stressors, and balancing individual and team needs

Many factors typically considered to be inputs and emergent states (i.e., dynamic properties of the team that vary as a function of team context, inputs, processes, and outcomes; Marks, Mathieu, & Zaccaro, 2001) may be subsumed into team functioning, with the ultimate outcome of interest being team performance. As Team Risk research has shifted focus to LDEM, mission factors of distance to Earth and communication delays, small habitable volume, isolation and non-rotating crew, and especially the 30 month duration, will add to more typical stressors experienced in team and spaceflight settings, influencing the team factors in new and important ways. Astronaut journals kept by ISS crew members and recent operations assessments with long duration flyers of 6 months reveal many instances of team disruption and interpersonal frictions (Stuster, 2010) (Category III). Notably, performance and functioning decrements were sometimes attributed to duration, that is, the belief that “you can get along with anyone for two weeks” (the duration of Shuttle missions), but a LDEM scenario provoked sentiments of concern that the assembled crew had to be particularly well-suited to working together for very long durations in order to avoid these issues. Almost all astronaut journals stated that “getting along” with crewmates was the highest pre-flight priority.

A series of NASA-directed literature reviews and operations assessments, in conjunction with meta-analytic examination of teams and team outcomes supports several trends:

- Scientifically-based selection of a team-oriented personality, paired with deliberative team composition, predicts team performance, cohesion, team processes, and well-being (Barrick, Mount, & Judge, 2001; Bell, 2007) (Category I).
- Team cohesion leads to improved performance, which leads to greater cohesion, in a mutually supportive relationship (Mathieu, Kukenberger, D’Innocenzo, & Reilly, 2015) (Category I) (Kozlowski et al., 2015) (Category III).
- Team training positively influences team performance and functioning (Delise et al., 2010; Salas et al., 2008) (Category I). 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 offer some mitigation of performance and team functioning decrements (Fischer & Mosier, 2015) (Category II).
- Leaders can positively affect team performance, functioning, and individual well-being. Leadership/followership requires training in several leadership models, and training is needed with regard to the knowledge and skill to switch between leadership models and leader/follower as the situation requires (Gibson et al., 2015).
- Enhanced team cognition and shared mental models lead to positive performance outcomes, and are capable of being developed in training (Fiore et al., 2015; DeChurch & Mesmer-Magnus, 2010) (Category III, 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.

#### IV. EVIDENCE

The four NASA categories of evidence are defined in the Introduction provided for this *Human Health and Performance Risks of Space Exploration Mission* book. As the research conducted in mission simulation analogs and ICE field analogs has recently increased, there is a growing spaceflight-relevant evidence base, especially in the stronger categories of evidence. Most team research is well-suited for ground-based studies. Thus, there is less utilization of the spaceflight environment than in other HRP Risk areas, which focus on physiological health effects and rely on microgravity conditions and combination of unique ISS ICE factors to test feasibility of tools and countermeasures. This reliance on analogs and analogous populations is reflected in the evidence below. The 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.

##### A. Spaceflight Evidence

###### 1. Sources of evidence

Collection of truly team-level data in spaceflight has historically been a rare occurrence. Most data is collected at the individual level, and team-level data has mainly received attention only insofar as overall team performance or mission objective success is a concern. Anecdotal reports of teamwork issues have been noted, but systematic analysis of such data has been limited. In the

more recent ISS missions, teams and the multi-team system have received more attention, and thus, more measurement, but research from spaceflight is somewhat lacking due to research and operational constraints (e.g., few good outcome measures and performance metrics). More quantitatively-orientated data is housed in the NASA Life Science Data Archive (LSDA), but other qualitative sources allow rich anecdotal examples and allow for content analysis. As an example of the latter, Dr. Jack Stuster's Journals Project (2010) and the NASA history project and transcripts offer text from which to mine frequencies and behavioral patterns.

## 2. Predictors and contributing factors to team performance and functioning

### a. Selection

Early candidates for astronaut selection in the 1950s and 1960s were largely military test pilots, thought to be naturally suited to high-stress and high-risk situations, with little thought given to team-orientation or team skills. Later selection rounds during Shuttle and ISS years have reoriented the astronaut corps with more astronaut-scientists selected to fill the new mission profiles and tasks, and has seen an increase in varying expertise and personalities, multi-national crews, gender diversity, and ethnic diversity. These diversity factors have large implications for spaceflight team performance and functioning. Evaluation of psychological characteristics waxed and waned during the first 30 years of astronaut selection, but did include consideration of emotional stability, motivation, and interpersonal relationships (Santy, 1994). In general, selection research in spaceflight is severely limited, due in part to a lack of data from a small population of astronauts, and in part 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 specific performance levels that are necessary to provide cut-scores or norms for selection still eludes these researchers, perhaps because of small samples or inadequate performance data. Typically, space agencies have not provided objective 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 begun in the Shuttle era to include more rigorous personality testing, foundational job analyses, psychological evaluations and interviews were expanded during the early years of ISS. Additionally at NASA in 2009 and 2013, an experimental team simulation to assess teamwork capabilities was included. 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) in the 2008-2009 astronaut selection targeted interpersonal and intercultural competencies, communication skills, leadership-followership flexibility, and group suitability and teamwork skills, with reported success (Maschke, Oubaid, & Pecena, 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. The more recent Japanese Aerospace and Exploration Agency (JAXA) rounds of selection have begun to answer that call by using an isolation and confinement facility to mimic mission conditions, and assessing applicants' teamwork ability and performance, for one week (Inoue & Tachibana, 2013) (Category III). However, the current assessments employed by spaceflight agencies do not spotlight LDEM. This is somewhat expected as those missions may be 20+ years in the future, but ISS missions beginning in 2015 have longer durations of one year, as compared to the previous standard of 6

month mission durations. As years targeted for exploration missions, the end of ISS in the mid-2020s, the needed ASCAN and assigned mission training time, and the wait time for astronauts in the flight queue are all considered in tandem, astronaut selection for LDEM may begin within the next 10-15 years. Agencies are beginning to turn the focus to LDEM selection and increasingly, individual selection factors that influence team performance.

In 2014, a job analysis was conducted to determine competencies for missions similar to current ISS missions, and importantly, for future LDEMs (Barrett, Holland, & Vessey, 2015) (Category III). To update earlier NASA job analytic efforts (e.g., Galarza & Holland, 1999) (Category III), this job analysis collected interview data from 21 ISS astronauts, 2 Shuttle, and 3 veteran NASA behavioral specialists, with advisement 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 increased when comparing the ISS-like missions (Type A,B) to the short- and long-duration exploration mission profile (Type C,D) (see Table 1, Table 2). For skills needed at hire, sociability, adaptability, motivation, communication, and teamwork were rated as the top five by the SMEs. Respondents stated that although teamwork is part of astronaut training, a minimal competency is needed for selection. This job analysis highlights the importance of team skills (i.e., the means were fairly high), especially for LDEM, provides a target for the development of future selection systems, and provides insight into which skills are needed at hire vs later training. Notably, mission profiles for Types C and D, exploration missions that include asteroid and Mars missions, received higher ratings of importance for most competencies when compare to Types A and B, the low Earth orbit missions. While technical competencies are important, especially for the LDEM profile, selection of technical competencies is the responsibility of technical areas (e.g., Robotics may insert robotic tasks in the selection process), and applicants are screened to select out non-STEM (Science, Technology, Engineering, and Mathematics) degrees. BHP is responsible for 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 be able to pass a Level 1 physical for physiological health assessment and psychological evaluations related to the BMed Risk are also assessed. Other chapters in this evidence book cover the associated characteristics that are evaluated in the selection process that are relevant to other BHP Risks in more detail.

*Table 1. Mission profiles for astronaut job analysis.*

<b>Mission Type</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
<b>Duration (up to)</b>	6 Months	12 Months	12 Months	12 - 36 Months
<b>Distance from Earth</b>	Low Earth Orbit	Low Earth Orbit	Deep Space Exploration	Deep Space Exploration
<b>Crew Size</b>	6	6	4	4-6
<b>Vehicle Size</b>	Large	Large	Medium/Small	Medium/Small
<b>Communication Delay (one-way)</b>	.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 SME 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 individuals with a team orientation, team skills, in addition to other needed-at-hire traits, skills, and behaviors identified in the job analysis competencies have been studied in a limited capacity in 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 is 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, tend to be 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, Helmreich, Rose, & Fogg., 1994; Musson, Sandal, & Helmreich, 2004) (Category III). This cluster was also related to 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 was recommended in a series of NASA SME interviews to be an important selection factor for LDEM when considering the team (Morgeson, 2015) (Category IV). Detailed analysis of crew members' motivations recorded in spaceflight transcripts, crew journals, and other biographical materials revealed ISS crew members' need for achievement was mentioned most frequently and increased from pre- to in-flight (Brcic, 2010) (Category III). Need for affiliation was mentioned next most frequently and peaked in-flight, while power motive was relatively low with an increase in post-flight. Notably, NASA astronauts and commanders had a higher need for power when compared to cosmonauts and engineers, respectively, suggesting there may be cultural influences and norms related to personality and selection as well.

However, the NEO-Five Factor Model measure developed by Costa and McCrae (1992) has been more accepted in spaceflight and ground-based research. A study of over 15 years of Shuttle-era astronaut personality data and career performance found that astronauts had low scores for neuroticism, moderate 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, openness was negatively related to number of Extravehicular Activities (EVAs). No personality trait was related to number of flight assignments or assignment to Capsule Communicator (CapCom). Conclusions drawn from the study suggest that less neurotic individuals are perceived as more desirable and behaving appropriately for flight assignment. However, these findings call for more research. Other astronaut studies of the five factors have found emotional stability to be positively associated with social cohesion, flexibility, communication and negatively related to team conflict (Kass, Kass, Samaludinov, 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, Fogg, Helmreich, & McFadden, 1994) (Category III).

Another individual characteristic likely needed at hire (Barrett et al., 2015) (Category III) includes adaptability and motivation. Individual adaptation can indeed influence team processes and outcomes. A review (Collins, 2003) (Category III) suggested that astronaut candidates are ideally highly adaptable, given the high consequence environment. Greater adaptability may enable adjustment to the stressful ICE environment of space, working with a diverse crew, and the shifting of autonomy in future LDEM (Kanas et al., 2009; Kealey, 2004) (Category III). Motivation may also play a role in maintaining focus, affiliation with crewmates, and adapting to the environment as smaller problems are likely to become bigger over the course of the long duration (Morgeson, 2015) (Category III). Adaptability may also allow for greater ease in switching between tasks, leader and follower roles, interdependent vs. independent work without incurring performance decrements. Other reviews of the spaceflight context have argued 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, Wiltshire, Sanz & Pajank, 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 attention to specifically selecting for team cognition has been very limited. Several skills needed at hire may only require some indication of competence with the intention to develop those skills during training, for example, communication and teamwork (Barrett et al., 2015) (Category IV). While these skills and the other personality characteristics are considered in addition to the technical skills of the applicants, the goal of the astronaut selection committee is to choose a whole person. No one factor should outweigh the others when considering the whole profile of an astronaut candidate.

Summary points related to spaceflight evidence and selection:

- Current selection follows best practices of a multi-trait, multi-method approach, emphasizing the whole person, which will continue in the future.
  - Technical skills and physical fitness are not the focus of BHP research.
- 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 future astronauts in LDEM are team-oriented, resilient and emotionally stable, adaptable to different situations and cultures, motivated, cognitively capable, and live well with others.

#### b. Team Composition

Selection of team-oriented individuals or candidates with skills that help them function well in a team setting may be most relevant for this risk area when considering the composition of an intact team. The interaction of personalities and other characteristics may mitigate or exacerbate situations that may cause team performance and functioning decrements. These factors, or potential faultlines, include homogeneity of personalities, complementary needs, shared interests, shared values and norms, emotional attitudes towards teammates, and demographic differences such as common language, gender, expertise, age, ethnicity, and nationality, (Kanas & Manzey, 2008) (Category III). Deep-level characteristics, named in the earlier part of the list, affect team performance and cohesion more strongly and for longer than surface-level, or demographic, differences (Bell, 2007; (Bell, Villado, Lukasik, Belau, & Briggs, 2011) (Category I). These differences may also lead to subgroup formation, which then negatively affects team functioning. Mir missions, in which a series of NASA astronaut was “hosted” by cosmonauts one at a time on board the Russian space station, saw reduced team functioning during one mission when one 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, being the only crew member with a particular characteristic. With a long duration team, the small differences may be exaggerated (Stuster, 2010) and cause disruption to team functioning as the mission proceeds. Group interaction was the fourth most mentioned topic in the journals, following 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. Mir astronauts

experienced a decline in bonding among the crew, 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, Wilk, & Cassel, 2013). Further consideration of multi-cultural differences must consider the development of space programs in other countries (e.g., China, India) (Ehrenfreund, Peter, Schrogl, & Logsdon, 2010) (Category IV).

Other variables have received less attention in the spaceflight literature. One consideration is that of the multi-team system for LDEMs, which includes Mission Control teams. Conflict between Mission Control Center (MCC) and spaceflight crews has been reported (Stuster, 2010) (Category III), but unfortunately, very little research exists for Multi-Team System (MTS) and team composition in spaceflight. CapComs were suggested to be an important liaison between the crew and MCC, thus, their compatibility with both groups may carry more importance than interactions between crew and the entire MTS (Bell, Brown, Outland, & Abben, 2015) (Category IV). However, this relationship will likely change in LDEM with communication delays. With regard to gender, work examining coping strategies of astronauts and cosmonauts found that women were much more likely to employ to emotion-oriented coping strategy of attributing events to luck (Suedfeld, Brcic, & Legkaia, 2009) (Category III), suggesting there are some differences between men and women in reactions to spaceflight conditions. Interviews of spaceflight SMEs also reported some gender differences and conflict due to gender (Bell et al., 2015) (Category IV). Research on variables such as personalities and gender, and suggestions for team composition countermeasures, is included in the ground-based evidence below.

Summary points related to spaceflight evidence and team composition:

- Current team composition lacks systematic and scientific rigor.
- Algorithms are needed to compose future LDEM teams, balancing personalities, technical skills, and other individual differences (e.g., gender, nationality).
  - Faultlines and tokenism should be avoided.
  - Research is need for team composition considering the entire multi-team system, and in LDEM conditions.

### c. Team Autonomy, Communication, and the Multi-Team System

Teams in space are physically isolated from ground, and experience some limited psychological isolation. However, real-time communication technologies (e.g., communication loops with MCC, Internet Protocol (IP) phone) and other technologies (e.g., email, video messaging, internet) ensure the ISS crews are well-connected with colleagues, professional support, and friends and family on Earth. Due to the design of the vehicles to be primarily controlled from the ground, MCC has been the brain of the operation, while the crew acts as the eyes and hands, an arrangement that fosters much coordination across the MTS, especially during emergency situations. However, in future LDEM, 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 impact of autonomy on the team over the long duration. There are obvious psychological health implications related to this isolation, which are addressed in the BMed chapter. For 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” (Rubino & Keeton, 2010). The MTS has been described generally as a network of teams working towards both a common goal and individual team goals (Mathieu, Marks, & Zaccaro, 2001). The NASA crew/ground MTS is but 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 (RSA), ESA) and specializations (e.g., astronauts, flight controllers, engineers); isolation from the MTS has several implications.

To date, there have been no studies of high crew autonomy in spaceflight for extended periods of time, but shifts in operational autonomy are expected to impact psychosocial adaptation to spaceflight demands (Kanas & Manzey, 2008). However, a recent related study with ISS crew members examined the impact of communication delays of approximately one hour with MCC on performance and well-being (Palinkas, Vessey, Chou, & Leveton, 2015) (Category II). Using a 50-second one-way delay compared to no delay, results showed comm delays led to delays in task completion and stress/frustration were higher. Being understood by others was positively related to performance, but astronauts under delays did not understand others as well. Autonomy was positively associated with crew and team performance and crew well-being. However, autonomy was not a mediator of the relationship between comm delay and outcomes, suggesting comm delays and autonomy have a unique influence on performance and health outcomes. This study also found notable behavioral changes under comm delays such as asking longer and more detailed questions, discussing and planning with crewmates more before calls, less interaction with ground, and CapCom slowing down and repeating calls. Implications of this study may be incorporated into training and communication tools and protocols to ensure good packaging of information, selection of the most critical information for communication, and availability of reviewing communications via recordings after a call is completed.

The Astronaut Journals Project (Stuster, 2010) (Category III) offers some additional insight regarding communications and autonomy. While communication problems are reported as only a small percentage of the “outside communications” category, communications with MCC was second-most mentioned category (a distant second to personal communications). The frequency of communications to management and MCC tapered somewhat in the 4<sup>th</sup> quarter of the mission. 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. Spaceflight studies also found cultural norms play a role here as well; astronauts reported they may go almost all day with speaking to MCC and MCC does make social support calls to ISS, while they observe Russian “marathon discussions” and work-focused calls, another implication for LDEM preparation in addressing autonomy and communication mission norms (Stuster, 2010) (Category III). Crews 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 lack of understanding of the time needed for carrying out tasks or overscheduling

the crew was noted as a source of frustration. In Skylab 4, demanding schedules led to crew/ground conflict, 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, Kalery, & Sorokin, 2010) (Category III). As the ISS has become a more complex vehicle over the years, researchers have already noted that crew members 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 the future mission operations of multiple vehicles and LDEM 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 command levels may allow a MCC more control (e.g., issuing frequent commands), 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). For LDEM, the communication delays will change in length during travel to and from long distance destination, another factor to be considered in the degree of autonomy afforded to the crew.

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 MCC MTS response to an anomaly from a 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). Coordination across levels identified information gaps and hidden disagreements between teams in their understanding of the anomaly and approach to problem-solving. Information was distributed across the MTS, but switching from within-team analysis to cross-team analysis required a cooperative advocacy strategy, which enhanced effectiveness of the MTS. For LDEM, 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. While these switches currently take place on ISS with high frequency, the performance decrements may be exacerbated during a long duration mission, in which exists a higher likelihood for boredom and entrainment on one style of working during the journey phase, and includes large physical and psychological shift events (e.g., arriving to Mars). Entrainment in one working condition can negatively affect performance after a switch or situational awareness during the working condition, as reported by ISS crew members in a recent operations assessment (Smith-Jentsch, 2015) (Category III). This assessment suggested that crew members 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 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. While each mission has a commander, crew members possess expertise in certain areas, necessitating a switch between leader and follower roles as their skillsets are required. Current ISS crew members acknowledge this expectation of shared 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. More research is needed to address these questions for LDEM mission designs and development of training and tools for all teams in the MTS, and especially with regard to the impact on team functioning and cohesion.

Summary points related to spaceflight evidence and team autonomy, communication, and the multi-team system:

- The multi-team systems includes 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 with regard to interactions with spaceflight crews and mission control.
- Future LDEM crews will have greater autonomy than current ISS crews, with communication delay as a major contributor.
- Research is needed to understand how these differences 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 for LDEM countermeasures.

#### d. Team Skills Training

Long-duration space flights (i.e., flights that are in excess of 6 months), such as ISS missions, are so physically, mentally, and emotionally demanding that simply selecting individual crew members 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, Hysong, & Galarza, 2007) (Category IV). Current astronauts spend a large amount of their careers in training. When first selected as an ASCAN to the astronaut corps, ASCANs begin an intensive training period lasting approximately two 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 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 in-flight. Astronauts may also experience training 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 that are needed to maintain their psychological and physical health in an ICE environment over an extended period of time. 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). The BHP Operations group currently addresses this need through a series of BHP-related trainings for the ASCANs. Components of this training are simply NASA knowledge training, for example, an overview of BHP Operations’ role in spaceflight support, while others include aspects of team skills. More information regarding this training and the psychological support services provided by BHP Operations is described in the BMed Risk chapter of this evidence book and below.

It is worth noting that the training of astronauts from NASA, JAXA, ESA, and CSA are more similar to each other than the approach of Roscosmos cosmonauts. Roscosmos 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 while on a mission and are evaluated in training with a similar tone, while astronauts receive feedback from a variety of sources (e.g., trainers, Astronaut Office management, psychological support) and the tone of feedback is more constructive than punitive. Future training must find ways to understand the implications of these different approaches, and overcome these cultural differences, for the benefit of all crew members.

Many of the training events discussed above naturally contain an element of team skills or train 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. Greater focus on the importance of teams in space has led to a more targeted focus on developing team skills and team skills training according to the available best practices and evidence of team training. Quite simply, team training works. Meta-analyses of ground-based teams have examined many aspects of team training related to team outcomes in support of that statement. For example, one large meta-analysis found support for positive relationships between team training interventions and team cognitive, affective, process, and performance outcome (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, there are several best practices to follow (Gregory, Feitosa, Driskell, Salas, & Vessey, 2013; see Table 3) (Category IV). Related to principles applied before training, NASA recognizes the importance of training teamwork skills in the unique operational culture, and especially for future LDEMs, to improve teamwork processes and performance, as well as cognitive and affective outcomes, in a high-stress environment (National Research Council, 2011). These suggestions follow team training best practices for creating a learning climate. Additionally, team training needs analyses (Noe, Dachner, Saxton, & Keeton, 2011; Smith-Jentsch et al., 2015) (Category III) and an updated job analysis to determine LDEM astronaut competencies (Barrett et al., 2015) (Category III) have been conducted, and will continue to be updated. For measurement planning, performance levels are an important

consideration in relation to training team skills. When considering optimal performance, any training design should be accompanied by an evaluation to determine the standards of optimal, adequate, or inadequate performance, and what skills help differentiate high- versus low-performing teams. In this way, training can be validated by checking student progression and the performance of teams before and after training. It is therefore recommended that team performance standards and levels be documented in the spaceflight context before effective training is designed. To date, this type of information is in limited availability to researchers, and acquiring such performance data requires a more collaborative better partnership between the research and operational communities.

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

Before training	During training	After training
<ul style="list-style-type: none"> <li>• Prepare the climate for learning</li> <li>• Create conditions for teamwork</li> <li>• Team training needs analysis</li> <li>• Design a measurement plan</li> </ul>	<ul style="list-style-type: none"> <li>• Include appropriate team-based content</li> <li>• Follow the appropriate instructional principles</li> <li>• Support team development activities</li> </ul>	<ul style="list-style-type: none"> <li>• Evaluate the team training</li> <li>• Promote transfer of team training</li> <li>• Sustain the conditions that foster teamwork</li> </ul>

From (Gregory, Feitosa, Driskell, Salas, & Vessey, 2013).

During training, NASA uses a multi-method approach using lecture and low-fidelity simulations (e.g., game-like team coordination paper-and-pencil exercise) and high-fidelity simulations (e.g., EVA training in the Neutral Buoyancy Lab), incorporating elements of teamwork and stress inoculation training. An important aspect of teamwork skills and experience is NASA's SFRM, derived from the aviation industry's CRM approach and more recently organized into four teamwork elements: information exchange, communication delivery, supporting behavior, and leadership/followership (O'Keefe, 2008; Smith-Jentsch, 2015). This is particularly needed for astronaut-scientists who are often not directly taught team skills prior to becoming an ASCAN, while pilots and flight engineers arrive with CRM skills (Love & Bleacher, 2013). With regard to the multi-team system, flight controllers also have SFRM as part of their training flow. Common team skills across these groups supports a shared mental model of team skills and processes and ultimately, enhances multi-team functioning and performance (DeChurch and Mesmer-Magnus, 2015) (Category III). All astronauts receive pilot training, which incorporates CRM, and participate in National Outdoor Leadership School (NOLS) leadership training, and are evaluated on group interactions during mission simulations with a mock Mission Control and EVA training. NASA does support team development activities, not simply task training that happens to be in a group setting, and this support has increased over time. The Astronaut Office utilizes Expeditionary Skills Training, 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). Many of these training activities include team-based content and seem to follow instructional principles of information, demonstration, practice and feedback, but with regard to after training best practices, true validation studies of the effectiveness of this training are largely absent from public data. The success of the space program is a powerful, yet anecdotal testament to the effectiveness of team

training currently in place, but future LDEM demands better validated evidence to determine the readiness of the crew. Quantitative evidence does exist for the effectiveness of SFRM using Team Dimensional Training (TDT) debrief methods with flight controllers (Bedwell, Smith-Jentsch, Sierra, & Salas, 2012) (Category II). Following a simulation, flight controllers participate in a debrief session structured around the four SFRM teamwork elements. Flight controllers reduced their certification time by half using TDT, identified more team errors, and had a less superficial categorization of incidents and greater learning. Prior TDT studies with U.S. Navy teams of submariners found a significant improvement in decision making and reduction in tactical errors. While this population is not a spaceflight crew, the actions of the flight controllers do influence the performance of spaceflight crews; better training and performance of flight controller teams likely lead to a positive impact on spaceflight teams. It is expected these trends will continue with the ASCANs now participating in the SFRM training, but performance data has not been made available.

Other issues related to astronaut training needs may be gleaned from a recent series of interviews with a dozen long duration flyers, identifying five unique work characteristics of long duration spaceflight (Smith-Jentsch et al., 2015) (Category III). First, crews will experience variation in their task dependency. They work independently a majority 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. The shifts in work approach may happen abruptly, or after a long period of working independently as an individual or from MCC. Cognitive skills and cues, along with leadership/followership skills, may help crews switch without 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 in transit on an LDEM may be interspersed with period of intense activity (e.g., arriving at Mars to begin exploration). In 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 prior to 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 prior to launch. Fourth, teams are often very diverse. As was discussed in relation to team composition, avoiding faultlines, and cross-cultural and adaptability training may mitigate this issues. As such, BHP Operations currently offers cross-cultural training to ASCANs, which 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, the ICE environment with a small team must be endured for many months. Again, development of crew cohesion and team resilience is important, as is conflict management 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, contact persons and mission-specific information) to family support services, and psychological training to understand potential psychological health threats that may occur on-mission. Ground-based research has more to add with regard to how these various characteristics of the LDEM context may be addressed in training team competencies.

Summary points related to spaceflight evidence and team skills training:

- Astronaut candidate training and assigned mission training are long and rigorous, covering task work and teamwork skills.
  - Historically, more attention has been given to task work skills, but LDEMs call for more attention to team work skills and simply living with the team.
- Development of team, psychological well-being maintenance, and interpersonal or soft skills should take place regularly over time, with consideration of cultural difference 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 that have been done 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, interviews and surveys that were conducted with flight controllers reveal 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, Holland, Looer, & Macondes-North, 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 a summary of several studies showed a decline in cohesion during the middle and end, with increased reports of crew tension and conflict (Dion, 2004; Kanas, 2004) (Category III). The astronaut journals have 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, there was a reported increased frequency of getting along in the fourth quarter, suggesting that the group is more aware of group interactions towards the close of a mission. One study suggested that in a context of monotony and isolation, the effects of potential faultlines, such as cultural diversity, may be intensified and result in negative outcomes and group conflict (Kealey, 2004). ISS minority crewmembers have reported that they sometimes feel isolated, and more diverse teams have reported lower levels of trust (Suedfeld, Wilk, & Cassel, 2013) (Category III). This interpersonal conflict can increase feelings of frustration, which may result in psychological closing, a decreased quality and quantity of crew communication (Kanas et al., 2009) (Category III). Differences may also lead to subgroup formation and treatment of a token member 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 the functioning of a team, especially a team in a long duration mission in which small irritants may become bigger over time. Conflict management training and Private Psychological Conferences (PPCs) alleviate some tension and allow the crews to receive guidance and skills to combat these friction points, but communication delays will eliminate real-time PPCs and place more onus on the in-flight crew to address conflict, decreased cohesion, and maintain team performance and functioning.

#### b. Psychosocial adaptation, and team adaptation and resilience

From a spaceflight perspective, Russian space station Mir's operations indicate that astronauts and cosmonauts are capable of adapting to 6 months in orbit, but reports also indicate that many Mir participants who took part in longer duration flights (in excess of 6 months) developed symptoms of fatigue, irritability, and minor disorders of attention and memory (Boyd, 2001; Kanas et al., 2001) (Category III). ISS evidence discussed above also shows the trend of increased team friction over the course of a mission (e.g., Stuster, 2010) (Category III), thus even if they have adapted to spaceflight, maintaining resilience over time may be difficult.

Psychosocial adaptation focuses more on the adjustment to the stressful ICE environment of spaceflight, while team adaptation emphasizes process-based adaptation resulting in adaptive responses and increased performance. Most available data on team adaptation is a result of analog research, but astronaut journals and other anecdotal information indicates 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 lasting psychological distress. MCC and crew quickly responded to the event, creating an adaptive, timely plan to direct Parmitano to return to the airlock and readied aid to deploy upon his return. Parmitano's crewmates quickly came to his aid with towels to clear away the water after re-entering ISS from the airlock. Astronauts undergo extensive training for survival and emergency situations that prepare them for quick adaptation to dynamic and high consequence events, and the resilience to recover back to nominal after. Countermeasures are currently being investigated to maintain team resilience over time, such as in-flight training and crew activities, and team-based activities in virtual environments. Understanding psychosocial adaptation and the ability of team to adapt and remain resilience over an extend duration requires more research.

Summary points related to spaceflight evidence and team emergent states:

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

#### 4. Measures and Monitoring Technologies

There are few true tools in use to monitor teams currently in-flight from a behavioral and psychological perspective. The astronaut journals (Stuster, 2010) and post-mission debriefs offer some understanding of team dynamics on the ISS, but a considerable amount of lag time between data collection and processing and reporting of that data does not help ground personnel support the crew. PPCs, held regularly throughout a mission, have reportedly addressed some concerns related to team functioning, but those are not recorded for research nor public monitoring of the team, and are kept confidential by the psychological support staff. Individuals 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 described in greater detail in that chapter. Development of several team-related monitoring tools is a significant focus of ground-based research.

## B. Ground-based Evidence

### 1. Sources of evidence

Almost every research task within the BHP Element requires utilization of a ground-based spaceflight analog to understand the risk and to develop and validate measures, standards, and countermeasures. Unlike other Risks in HRP, which rely heavily on ISS for research, analogs simulating a mission environment and/or the long duration aspect of LDEM is the best proving ground for many BHP factors, especially Team Risk factors. Spaceflight analogs include controlled, mission simulation analogs such as HERA at JSC, the undersea NEEMO station, the University of Hawaii's long duration Hawai'i Space Exploration Analog and Simulation (HI-SEAS), now-retired Desert Research and Technology Studies (Desert RATS), and the Russian chamber used for the Mars 105 and Mars 500 studies. Short duration field analogs used for astronaut training include the underground Cooperative Adventure for Valuing and Exercising human behavior and performance Skills (CAVES) managed by ESA and NOLS, a survival leadership course. Long duration ICE environment analogs include Antarctic and Arctic stations such as Concordia Station, and the Antarctic Search for Meteorites (ANSMET); these are working research stations or outposts devoted to scientific research such as geology and climatology. Research sampling analogous populations from the military, submariners, medical, aviation, nuclear plants, fire-fighters, etc., also provides critical evidence for teams operating in isolated, confined, and extreme environments in which there is a great deal of stress and pressure to remain high-performing. Team performance and functioning is a robust area of research when considering typical organizations and industries, with tens of thousands of studies across management, industrial/organizational psychology, industrial engineering, human factors, social and cognitive psychology journals. Meta-analyses of the foundational relationships in this field are reported below to establish a preponderance of evidence that may be extended to spaceflight teams, while specific examples of analogous populations, especially from the military and spaceflight analogs, provide greater detail and evidence weighted with environmental similarity.

### 2. Predictors and contributing factors to team performance and functioning

#### a. Selection

Job analyses across many organizations show some common themes for selecting individuals to work in teams and in high stress jobs, which is reflected in the latest LDEM identified competencies of small group living, teamwork, motivation, and adaptability (Barrett et al., 2015). Selection systems for minimum skill levels and inherent personality characteristics should be anchored by these 18 competencies. Using the Helmreich Instrumentality-Expressivity Model of personality, research of submariners and Antarctic analog personnel found that achievement oriented individuals use problem-solving coping strategies, which was predictive of team success (Sandal, Endresen, Vaernes, & Ursin, 2003; Leon & Sandal, 2003). The more widely established five factor model of personality has been studied repeatedly. A classic meta-analysis by Barrick and Mount (updated in Barrick, Mount, & Judge, 2001) (Category I) offers a summary when considering personality and job performance. That is, conscientiousness and emotional stability is positively related to overall work performance, greater extraversion and agreeableness predicted teamwork, and openness was not related to many work outcomes. These findings

follow the spaceflight evidence of personality traits in astronauts, and reflect the LDEM oriented job analysis calling for sociability at hire and highlighting the importance of teamwork. Analog research has found similar trends. In quantitative reviews of psychosocial factors in analog environments and populations (e.g., Palinkas, Keeton, Shea, & Leveton, 2011; Schmidt, 2015) (Category I), emotional stability allows individuals to direct more energy towards team performance and functioning. More highly motivated individuals, as typical of astronauts, are focused on “not letting the team down” and cooperating to achieve goals. Schmidt (2015) (Category I) found a strong link between personality characteristics and self-care actions with health outcomes (e.g., 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. Individual values also make a difference, as teams that consist of members who value being on a team perform better than teams that consist of members who do not value being on a team (Bell, 2007; Salas, Kosarzynski, Tannenbaum, & Carnegie, 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). Thus, selecting for greater individual motivation to maintain performance and health as well as selecting for traits that lead to positive interaction and coordination/cooperation with teammates will enhance team processes and performance.

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, Kennedy, & Sommer, 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). While individual cognition is approached from the BMed Risk, 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. 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 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 leadership (Gibson et al., 2015). Shared leadership is similar to the leadership/followership structure used for current and future spaceflight missions. These characteristics should follow needed leadership/followership characteristics identified in the collective, dyadic, socio-emotional, and crisis leadership models. Consideration of these variables during selection is warranted.

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 individual and team 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, Allen, Klammer, & Kelly, 2002) (Category II). Several analog studies 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 crew members from Russia (Sandal, 2004). Reports of the 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, Jurion, Cazes, & Bachelard, 2004). Cultural diversity can lead to process loss from increased task conflict and decreased social integration/cohesion (Stahl, Maznevski, Voigt, & Jonsen, 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 decreasing in team cohesion over time (Sandal & Bye, 2015) (Category III). Subgrouping may also 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, Gunderson, Johnson, & Holland, 2000) (Category III). Tokenism had a negative relationship to social support (which was positively related to team performance) across several analog studies (Schmidt, 2015) (Category I). 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., 2015) (Category III; see Table 4). Conclusions suggest surface-level differences interfere with social integration, but teams with deep-level similarities on values, needs, interest, and personality had better social integration. However, teams with a greater number of dominant or extroverted members were more incompatible. Trends across analog research 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 ICE environments, crew homogeneity was positively related to social compatibility (Palinkas et al., 2010) (Category III). However, caution is needed; it is highly unlikely that a homogenous crew will be assembled for future international LDEM that requires a wide range of knowledge and skills, and calls for a multi-cultural representation of humanity. Homogeneity may result in poor team performance stemming from ineffective team processes such as groupthink. 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 Antarctic research (Johnson, Boster, & Palinkas, 2003).

Table 4. Summary of How Team Composition Relates to Missions 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	<ul style="list-style-type: none"> <li>• Social integration allows team cohesion, avoid subgrouping &amp; isolation</li> <li>• Social integration stems from surface-level (e.g., gender) &amp; deep-level (e.g., values) characteristics, which includes supplementary (similar) &amp; complementary (dissimilar) fit between teammates</li> </ul>	<ul style="list-style-type: none"> <li>• Teammates have diverse skills &amp; expertise, &amp; operate in a multi-team system</li> <li>• Composition influences team emergent states (e.g., shared cognition) &amp; team processes (e.g., coordination), &amp; available skills &amp; expertise</li> </ul>
Study findings	<ul style="list-style-type: none"> <li>• Analogs: Social integration related to value similarity; personality compatibility; dominance (avoidance of multiple dominant members); similarity in attitudes, interest; sex, age, &amp; nationality diversity; &amp; other (e.g., need for affiliation)</li> </ul>	<ul style="list-style-type: none"> <li>• Analogs: Composition related to conscientiousness, need for autonomy, shared interests and activities, values, need for affiliation, all-female crew</li> <li>• Traditional teams: Composition related to shared cognition, info sharing, transactive memory system</li> </ul>

*Note:* Adapted from Bell et al., 2015. Paths are not mutually exclusive.

Team composition may also consider team cognitive processes stemming from individual cognitive capabilities. Similarity of values, skills, experiences, and personality naturally establishes 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 which engages in group-think, or lacks the ability to generate creative solutions to problems due to the lack of divergent thinking (Fiore et al., 2015) (Category III). Thus, the proper balance of different characteristics is needed to ensure that any given personality type does not dominate the group. Preliminary analyses of Antarctic Station crews examined combinations of personality related to outcomes on a team-based cooperative task (Roma, Hursch, & Hienz, 2015) (Category II). Low conscientious and high agreeableness teams were the most cooperative and most productive. Selecting individuals more likely to engage in teamwork activities also fosters development and maintenance of a shared mental model. Meta-analysis of general field studies report a team minimum level of agreeableness is a strong predictor of team performance, as is team mean conscientiousness, openness, collectivism, and importantly, preference for teamwork (Bell, 2007) (Category I). While some characteristics related to team cognition should be the focus of selection and team composition, other skills and shared cognitions can be developed through training, especially training as a unit (Fiore et al., 2015).

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 adaptable, agreeable, team-oriented team members.

- Algorithms are needed to compose future LDEM teams, balancing personalities, technical skills, and other individual differences (e.g., gender, nationality, values).
  - Faultlines and tokenism should be avoided.

*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 for taskwork, avoiding faultlines whenever possible is necessary (Bell et al., 2015) (Category III). Analog and analog population studies 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 has no formalized process to compose mission teams from a scientific perspective, but this is an identified need for future exploration missions. Roscosmos 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 countermeasure. Potential teams formed by the algorithm may also undergo a trial period or engage in team activities and assessments to determine fit and effectiveness prior to mission launch. Past spaceflight simulations such as the Mars 105 utilized several individual and group assessments to select interpersonally compatible crewmates (Vinokhodova, Gushchin, Eskov, & Khananashvili, 2012), and HI-SEAS employed NOLS to familiarize potential team members with each other so that they were able to report preferences for who they wanted to crew with to the facility's investigators picking the final crew. Training together for an extended period of time, including time in ICE environments, will ensure the team has progressed through the forming and norming stages pre-flight and will give trainers time to address any teamwork issues in-person and with real-time communications 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, which will provide additional avenues of commonality between crew members to prevent faultlines.

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 various differences such as norms regarding leadership and power distance, trust, conflict resolution, and communication, is an important first step, but selection of 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 in the Mars 105, may exacerbate team tensions (Sandal, Bye, & van de Vijver, 2011). Every effort must be made to integrate the team and address any conflicts prior to launch; the current practice of training separately for much of the run-up to launch date must change for future LDEMs.

### c. Team Autonomy, Communication, and the Multi-Team System

Team autonomy in workplace teams has been linked with higher performance in meta-analyses (e.g., Stewart, 2006) (Category I) and in longitudinal studies (Cordery, Morrison, Wright, & Wall, 2010) (Category II). Several spaceflight analog studies have examined team autonomy in a MTS, and the subsequent effects on psychosocial outcomes and team cohesion. A set of studies examining high vs. low autonomy at simulation analogs NEEMO, Houghton-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). Crews in high autonomy reported positive moods and greater creativity, but analog MCCs reported role confusion as crews became more autonomous. There were also some nuanced differences between analogs. For example, NEEMO mission commanders offered more direction and were less fatigued in high autonomy conditions. High autonomy in Houghton-Mars resulted in greater cohesion, when compared to data from Mir/ISS MCC members. High autonomy at 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. Russian crew members, compared to European crew members, had a bigger change in work pressure scores in the high autonomy condition, but European crew members had higher scores in both conditions. The researchers attribute this finding somewhat to the fact that this was a Russian analog with a Russian commander. Russian and European crew members experienced changes in opposite directions when moving from the low and high autonomy conditions on factors of commander support and direction (Europeans increased), expressiveness (Europeans increased), cohesion (Europeans decreased), and autonomy (Europeans increased). Leader support was related to cohesion for both the crew and for MCC. Related to MTS, 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, Vinokhodova, Vasylieva, Nitchiporuk, & Balazs, 2012) (Category II).

Another set of studies using a lab simulation of a mission with an MCC, examined participants trained over a long duration of several months on a three-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 into conditions of low (i.e., MCC schedule dictated activities) or high autonomy (i.e., team determined schedule) from MCC, and in a second experiment, an additional manipulation either had teams with full communication to MCC or experience a loss of communication. Both studies saw better performance of collecting higher quality geologic samples in high autonomy conditions. Regarding psychosocial factors, high autonomy teams reported more positive moods and researchers found lower cortisol production reflecting lower levels of stress, and increased socially-referent language, which the researchers suggest is an indicator of enhanced affiliation and cohesion. These findings are related to meta-analytic work highlighting the role of empowering leadership to increase team empowerment over their work and decision-making, which leads to better performance (Maynard, Gilson, O’Boyle, & Cigularov, 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, autonomy and empowerment may be a natural element of the environment. ANSMET requires a 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 surveying and collecting 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. Preliminary studies benchmarking cohesion dynamics of these high autonomy teams found that each team had its own ecology; that is, cohesion was observed to be stable and high for one team, while another team experienced more fluctuation over the duration (Kozlowski, Chang, & Biswas, 2015) (Category III). Thus, while workplace teams see a clear pattern of increased autonomy leading to empowerment, in turn leading to improved job satisfaction, commitment, health outcomes, and task and contextual performance (including team empowerment predicting team effectiveness) (Seibert, Wang, & Courtright, 2011) (Category I) consideration of a specific mission team may require countermeasures attuned to their specific needs.

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. However, communication delays may interfere with the problem-solving process. When coordination is needed in a communication delayed MTS, one countermeasure approach to mitigate the negative effects of communication delays is to utilize 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). During an emergency medical simulation under the 5 minute condition, the safety of a crewmember would have been compromised due to communication delays between the flight surgeon and the crew had the medical emergency been real. Even during typical communication conditions or within team communications, miscommunication and failures to communicate have been cited as a contributing factor in transportation accidents and medical errors (NTSB [National Transportation Safety Board], 1994; Baker, Day, & Salas, 2006; McKeon, Oswaks, & Cunningham, 2006, Powell & Hill, 2006) (Category III). Other 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 conflicts between crew-ground at a rate five times greater than within crew conflicts (Basner et al., 2014) (Category III). Training to recognize symptoms of potential conflict mitigated this negative effect somewhat. Crews in HERA began to decrease the use of politeness strategies in conditions of communication delay (Wu, Miller, Schmer-Galunder, Ott, & Rye, 2015). A review of communication delay studies across several mission simulation analogs (NEEMO, D-RATS, 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.

*Countermeasures related to team autonomy, communication, and the multi-team system*

A recommendation from participants in these analogs suggested that training on, and utilization of, established communication protocols is one way to mitigate negative effects. To meet this need and alleviate the biases of synchronous communication, communication using text and verbal protocols were tested in NEEMO and HERA missions (Fischer & Mosier, 2015) (Category II) and a lab study (Category 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). Lab findings showed protocol elements decreased errors and predicted task successes, while analog findings showed protocols were effective and mitigated the negative impacts of comm delays. Other conclusions suggested text communications were better for routine, non-time critical communication, 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.

There are several other team factors that may offer an avenue for countermeasure development in the form of selection/composition, training, and tools. Social support and leader support are important for improving team performance outcomes and team functioning (e.g., cohesion, cooperation, and empowerment) and these factors may facilitate transition between levels of autonomy, different tasks, and different roles (e.g., leader, follower) (Smith-Jentsch, 2015). Within analog teams, team members report 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 comm delayed groups. Autonomous teams, especially in conditions of comm 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). In addition to these cognitive process decrements, a Mars 500 study found cognitive performance decrements 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) due to ICE factors of 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). Composing a team of resilient crewmembers as well as training them on self-monitoring and techniques to adapt to changing conditions, high autonomy, conflicts, and isolation may mitigate performance and functioning decrements. As is common call in team LDEM research, little is known regarding these effects over time.



Summary points related to ground-based evidence and team autonomy, communication, and the multi-team system:

- Team autonomy leads to better performance, lower stress, positive mood, greater cohesion, health outcomes, etc., but it may lead to negative outcomes such as groupthink.
  - However, there may be some nuanced differences stemming from culture.
- Communication delays negatively affect team performance, coordination, decision-making, and teamwork, and interpersonal conflicts, within a team and across the multi-team system.
- Countermeasures show promise to mitigate the risk to team performance and multi-team coordination from communication delays. Examples include communication protocols, selection and composition algorithms to form complementary and well-functioning teams, and training related to developing shared mental models, self-monitoring and adaptability.

#### d. Team Skills Training

Team skills training relies on a large and robust body of research. The temporal display (Gregory et al., 2013; Table 3) discussed previously 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. 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.

#### i. Training the individual to be on a team

There are many individual traits or skills that enable a person to function well in a team. Recall the job analysis identification 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 the NASA-specific communication and teamwork styles (e.g., protocols, techniques, terminology, tactical skills) begins after selection. Training the individual to be on a spaceflight team assumes astronauts possess these minimum requirements, and the goal of training then becomes optimizing the individual's performance and related team performance. Additionally, trainees must have basic skills to do the task, before training teamwork skills (Salas, Burke, & Cannon-Bowers, 2002), similar to ASCAN technical training that requires an ASCAN to reach proficiency in a skill or task before training team skills. A meta-analysis of 97 studies, involving 11 different types of interventions (Guzzo, Jette, & Katzell, 1985) (Category I) found that training and goal-setting are the most effective organizational interventions that are aimed at increasing motivation and individual performance. Branches of the U.S. military, an analogous population that also spends a great deal of time and resources on training, offer other supporting examples. Leedom and Simon (1995) found that providing United States Air Force (USAF) aviators with standardized, behavior-based training on teamwork increased team coordination and improved team task performance. In a field study of 92 teams (1,158 team members) in a USAF officer development program, Hirschfield, Jordan, Field, Giles, and Armenakis (2006) (Category III) found that team member mastery of teamwork knowledge predicted better team task proficiency and higher observer ratings of effective teamwork. Salas, Shuffler, Thayer, Bedwell, and Lazzara (2012, cf. Gregory et al., 2013) identified six team competencies: cooperation, conflict, coordination, communication, coaching/leadership, and cognition. Individual competencies identified in the

astronaut job analysis (Barrett et al., 2015) may be mapped onto the team competencies 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 possessing preferred personality characteristics.

The six team competencies, from the perspective of an individual's contribution to the team, are related to spaceflight teams as follows:

*Cooperation (from an individual perspective)*

Cooperation is an attitudinal and efficacy element of teamwork. In the individual sense, training can work to motivate individuals to work on a team and participate in cooperative and supporting behaviors. Training basic understanding and skills related to supporting behaviors is needed. Supporting behaviors are one aspect of the Team Dimensional Training, which led to better performance in military and flight controller populations (Bedwell et al., 2012; Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008) (Category II). Building confidence and self-efficacy through successful performance, gradual skill attainment, and reinforcing feedback during training programs can also enhance the individual propensity for cooperation. Self-efficacy was positively, moderately related to work performance through a meta-analysis of over 20,000 individuals (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 trainings on these skills is also important. Finally, cooperation (and conflict management, below) was identified as an important aspect of group living, which is an important part of spaceflight (Kanas & Manzey, 2008) (Category IV). 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)*

Relationship conflict strongly, negatively affects team performance and team member satisfaction according to meta-analytic findings across 116 studies (de Wit, Greer, & Jehn, 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 the individual about "fighting fair", managing emotions, de-escalating conflicts, and managing expectations to prevent future conflict. Training may also consider disagreements about taskwork or interpersonal relationships, and may teach preemptive and reactive strategies to address conflict (Marks, Mathieu, & Zaccaro, 2001).

*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. 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). 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).

*Communication (from an individual perspective)*

Training a common language is a first step. 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 is open, accurate, and concise (Salas, Wilson, Murphy, King, & Salisbury, 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 lab and mission simulation analogs, that are developed to address communication delays (Fischer & Mosier, 2015) (Category II). This training should apply to all individuals within the multi-team system for a standardization of knowledge and procedures.

*Coaching, Leadership/Followership (from an individual perspective)*

Leadership, especially leadership in an ICE environment with a highly autonomous team, must consider a range of unique factors which go beyond the typical leadership development programs in organizations of 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). While there are identified mission commanders, a diversity of complex tasks for an 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 knowledge, skills, abilities (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. Preparation for 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 automated monitoring for potential role conflicts and prompting switches. Thus, other teams in the MTS should be trained on this information, and all should be trained on any monitoring technologies. Consideration of cultural differences in the MTS is also a concern. Personnel from ESA and spaceflight analogs stated 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 (Burke & Feitosa, 2015) (Category III).

*Cognition (from an individual perspective)*

Many aspects of individual cognition affecting performance and interpersonal interactions is covered by the BMed research portfolio. However, a review of both individual and team cognition in a sample of 168 observations from 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 to developing individual attention, memory, and reasoning is the foundation for team cognitive training. For shared mental models, accuracy of the mental model is more important than the degree of agreement between team members' mental models (Edwards, Day, Arthur, & Bell, 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 in unfamiliar or unexpected situations in which shared mental models facilitate team problem-solving. In addition, stress inoculation training, which has found support in emergency response and military domains, is another important component of cognitive training that may mitigate the negative effect of stress on performance found in long duration spaceflight (Palinkas, 2007) (Category III).

#### ii. Training the team

Training the six team competencies 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 five 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, Gorman, Brooks, Rentsch, & Steele-Johnson, 2010) (Category I). Furthermore, the meta-analysis found these results held true for both civilian and military teams in team training. Thus, team training may directly enhance both team competencies and technical skills, which significantly influence team effectiveness. 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).

The six team competencies, from a team-level perspective, are related to spaceflight teams as follows:

#### *Cooperation (from the team perspective)*

Team building, as established through meta-analysis, 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 competency that can be developed during training. A study of adventure racing teams, an analogous population, found preparation effort was related to collective efficacy (Edmonds, Tenenbaum, Kamata, & Johnson, 2009). An initial lab validation study of a group cooperation task, found that individual incentives decreased team cooperation (Roma, Hursh, Goswami, Kumar, Kaimakamis, & Golemis, 2015). Expanding this work in ICE analogs 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 may use team-based incentives tied to task performance to encourage cooperation, and build morale, trust, and positive affect within the team.

*Conflict Management (from the team perspective)*

Recent studies have reported the occurrence of team conflicts in 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 every study found that 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 time together provides an opportunity for the team to learn teammates' strengths and weakness, patterns of thinking and working, and 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 cause of conflict. A review of the literature showed that surface-level differences (e.g., demographics) negatively impact the short-term performance of teams as 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 impacts long-term performance only when teams are not provided with the training and 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. Giving teams ample time in which to train together and instructions on how to take advantage of multiple perspectives 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.

*Coordination (from the team perspective)*

Training coordination at the team level must incorporate a great deal of developing and maintaining shared mental models during a dynamic situation. Military applications with naval teams in an anti-air warfare simulation and other teams in a simulated aerial vehicle command and control task 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 (Love & Bleacher, 2013).

*Communication (from the team perspective)*

Communication amongst team members must operate along standard procedures, for example, knowing when and how to push and pull information to and from the right people. Cultural norms may influence communications such that individuals from high power distance cultures or collectivist cultures may not speak up to a commander or when a statement runs counter to the rest of the team. Analog environment studies and surveys of the European Space Agency personnel found the cultural differences in non-verbal communication and language can

negatively influence team functioning (Sandal, Leon, & Palinkas, 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 with military and flight controllers found that communication skills were improved, which translated to improved performance (Bedwell et al., 2012) (Category II), and another debrief protocol tested in NEEMO and HERA analogs and in a lab study found it generated constructive discussions and was related to team effectiveness (Tannenbaum, Mathieu, Alliger, Cerasoli, & Donsbach, 2015) (Category II,III).

*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 may practice identifying situations, identifying the appropriate leader for that situation, identifying the appropriate leadership model for the situation, stepping forward or back into leader and follower roles, and coordinating these switches with MCC as needed under conditions of autonomy and communication delay similar to future LDEM. Development of leadership/followership skills is more effective if trained regularly over a long period of time, with multiple opportunities to practice skills and receive feedback.

*Cognition (from the team perspective)*

Cognition emphasizes the benefit of cross-training to create strategic redundancies of role, task, and teammate knowledge among teammates. For example, in a study of submarine attack crews, shared mental models and knowledge concerning team members adds to the number of hits on target, over and above the contribution from operational skills (Espevik, Johnsen, Eid, & Thayer, 2006) (Category II). The more experience crews had working together, the less physiological arousal the crew experienced during attack simulations, indicating lower stress levels. Team debriefs are another effective countermeasure 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 of 46 samples (N=2,136) found that teams utilizing team debriefs performed 20-25% better, aligning and structuring teams (Tannenbaum & Cerasoli, 2013) (Category I). Debriefs facilitate evaluation of cognitions and actions taken in order to improve for 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. As seen in studies of Team Dimensional Training, flight controllers and military populations were able to use team debriefs of teamwork skills to enhance learning and decrease performance errors (Bedwell et al., 2012; Smith-Jentsch et al., 2008) (Category II). Another debrief method for LDEM that has been tested in NEEMO, HERA, and 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). This DebriefNow tool allows teams to individually and anonymously answer questions and the software is able to produce 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 effectively improved performance and resilience. It was also found that resilience was positively related to performance, and that this relationship became stronger over time.

### iii. Training methods

Many methods exist for training teams. A recent review of team cognition across 168 studies/observations in spaceflight analogs and analogous populations summarized the various training strategies that were appropriate for training team knowledges, skills, and attitudes (see Table 5) (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. The effect size of different training strategies varied according to one meta-analysis, 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/crew resource management (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, cf. Fiore et al., 2015) (Category I). Overall, team training was found to have a moderate, positive effect on outcomes of team performance and functioning (effect size = .34). For specific methods, best practices dictate that trainees receive information or declarative knowledge about that skill or task, observe demonstration of the skill or task, practice that skill or task, and receive feedback when performing the skill or task (Salas, Tannenbaum, Kraiger, & Smith-Jentsch, 2012) (Category IV). 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 positions through information sharing, demonstration and modeling, and hands-on rotation through other positions
- Stress Training – teams are taught to recognize stress in the self 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

Table 5. *Summary of training strategies, delivery methods and associated knowledge, skills, and attitudes.*

Training Strategy	Method	Knowledge	Skills	Attitudes
Event-Based Training / Scenario-Based training	<ul style="list-style-type: none"> <li>• Simulation</li> <li>• Paper-and-Pencil Vignettes</li> <li>• Role Play</li> <li>• Embedded Instructional Agent</li> </ul>	<ul style="list-style-type: none"> <li>• Task Knowledge<sup>1,2,3,5,6,7</sup></li> <li>• Equipment Knowledge/Technology Model<sup>1,2,3,5,6,7</sup></li> <li>• Characteristics<sup>1,2,3,5,6,7</sup></li> <li>• Situation Awareness<sup>4, 5,7,8</sup></li> <li>• Team Interaction Knowledge<sup>1,3,5,6,7</sup></li> <li>• Transactive Memory Systems<sup>2,3,5,6,7</sup></li> <li>• Larger Mission<sup>2,5,7</sup></li> <li>• Constraints<sup>5,6</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Mission Analysis<sup>9,10,11</sup></li> <li>• Goal Specification<sup>9,10,11</sup></li> <li>• Planning<sup>9,10,11</sup></li> <li>• Mutual Performance Monitoring<sup>9,10,11</sup></li> <li>• Monitoring Goal Progress<sup>9,10,11</sup></li> <li>• Systems Monitoring<sup>9,10,11</sup></li> <li>• Task Structuring<sup>9,10,11</sup></li> <li>• Adaptability<sup>9,10,11</sup></li> <li>• Conflict Resolution<sup>9,10,11</sup></li> <li>• Assertiveness<sup>9,10,11</sup></li> <li>• Boundary Spanning<sup>9,10,11</sup></li> <li>• Team Leadership<sup>9,10,11</sup></li> <li>• Stress Management<sup>9,10,11</sup></li> <li>• Decision Making<sup>9,10,11</sup></li> <li>• Affect Management<sup>9,10,11</sup></li> <li>• Compensatory Behavior<sup>9,10,11</sup></li> <li>• Information Exchange<sup>9,10,11</sup></li> <li>• Motivating<sup>9,10,11</sup></li> <li>• Intra-team Feedback<sup>9,10,11</sup></li> <li>• Coordination<sup>9,10,11</sup></li> <li>• Cooperation<sup>9,10,11</sup></li> <li>• Flight Skill<sup>9,10,11</sup></li> <li>• Navigation<sup>9,10,11</sup></li> <li>• Risk Assessment<sup>9,10,11</sup></li> <li>• Visual Scanning<sup>9,10,11</sup></li> <li>• Handoffs<sup>9,10,11</sup></li> <li>• Teamwork<sup>9,10,11</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Risk Perception<sup>12, 13</sup></li> </ul>



Training Strategy	Method	Knowledge	Skills	Attitudes
Self-Correction Training / Guided Self-Correction Training	<ul style="list-style-type: none"> <li>• Lectures</li> <li>• Behavioral Modeling</li> <li>• Use of structured after action reviews</li> <li>• Simulation</li> </ul>	<ul style="list-style-type: none"> <li>• Task Knowledge<sup>1,2,3,5,6,7</sup></li> <li>• Equipment Knowledge/ Technology Model<sup>1,2,3,5,6,7</sup></li> <li>• Teammate Characteristics<sup>1,2,3,5,6,7</sup></li> <li>• Situation Awareness<sup>4, 5,7,8</sup></li> <li>• Team Interaction Knowledge<sup>1,3,5,6,7</sup></li> <li>• Transactive Memory Systems<sup>2,3,5,6,7</sup></li> <li>• Larger Mission<sup>2,5,7</sup></li> <li>• Constraints<sup>5,6</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Mission Analysis<sup>9,10,11</sup></li> <li>• Goal Specification<sup>9,10,11</sup></li> <li>• Strategy Formulation<sup>9,10,11</sup></li> <li>• Mutual Performance Monitoring<sup>9,10,11</sup></li> <li>• Monitoring Goal Progress<sup>9,10,11</sup></li> <li>• Systems Monitoring<sup>9,10,11</sup></li> <li>• Task Structuring<sup>9,10,11</sup></li> <li>• Adaptability<sup>9,10,11</sup></li> <li>• Conflict Resolution<sup>9,10,11</sup></li> <li>• Assertiveness<sup>9,10,11</sup></li> <li>• Boundary Spanning<sup>9,10,11</sup></li> <li>• Team Leadership<sup>9,10,11</sup></li> <li>• Stress Management<sup>9,10,11</sup></li> <li>• Decision Making<sup>9,10,11</sup></li> <li>• Affect Management<sup>9,10,11</sup></li> <li>• Compensatory Behavior<sup>9,10,11</sup></li> <li>• Information Exchange<sup>9,10,11</sup></li> <li>• Motivating<sup>9,10,11</sup></li> <li>• Intra-team Feedback<sup>9,10,11</sup></li> <li>• Coordination<sup>9,10,11</sup></li> <li>• Cooperation<sup>9,10,11</sup></li> <li>• Flight Skill<sup>9,10,11</sup></li> <li>• Navigation<sup>9,10,11</sup></li> <li>• Risk Assessment<sup>9,10,11</sup></li> <li>• Visual Scanning<sup>9,10,11</sup></li> <li>• Handoffs<sup>9,10,11</sup></li> <li>• Teamwork<sup>9,10,11</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Risk Perception<sup>12, 13,14</sup></li> <li>• Motivation<sup>12, 13</sup></li> <li>• Trust<sup>12, 13</sup></li> <li>• Loyalty<sup>12, 13</sup></li> <li>• Team Satisfaction<sup>12</sup></li> <li>• Cohesion<sup>12, 13</sup></li> <li>• Team Psychological Safety<sup>12, 13</sup></li> <li>• Affect<sup>12, 13, 14</sup></li> <li>• Collective Efficacy<sup>12, 13</sup></li> <li>• Team Commitment<sup>12, 13</sup></li> <li>• Trust in Automation<sup>12, 13</sup></li> </ul>
Cross-Training	<ul style="list-style-type: none"> <li>• Lectures</li> <li>• Role Play</li> <li>• Behavioral Modeling</li> <li>• Paper-based vignettes</li> <li>• Simulation based vignettes</li> <li>• Embedded Instructional Agents</li> </ul>	<ul style="list-style-type: none"> <li>• Task Knowledge<sup>1,2,3,5,6,7</sup></li> <li>• Equipment Knowledge/ Technology Model<sup>1,2,3,5,6,7</sup></li> <li>• Teammate Characteristics<sup>1,2,3,5,6,7</sup></li> <li>• Team Interaction Knowledge<sup>1,3,5,6,7</sup></li> <li>• Transactive Memory Systems<sup>2,3,5,6,7</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Adaptability<sup>9,10,11</sup></li> <li>• Cooperation<sup>9,10,11</sup></li> <li>• Coordination<sup>9,10,11</sup></li> <li>• Decision Making<sup>9,10,11</sup></li> </ul>	
Stress Training	<ul style="list-style-type: none"> <li>• Lectures</li> <li>• Behavioral Modeling</li> <li>• Simulation</li> <li>• Vignettes</li> <li>• Embedded Agents</li> </ul>	<ul style="list-style-type: none"> <li>• Mental Models<sup>1,2,3,4,5,6</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Stress Management<sup>9,10,11</sup></li> <li>• Affect Management<sup>9,10,11</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Risk Perception<sup>12, 13</sup></li> </ul>

Training Strategy	Method	Knowledge	Skills	Attitudes
Team Adaptation and Coordination Training	<ul style="list-style-type: none"> <li>• Lectures</li> <li>• Behavioral Modeling</li> <li>• Simulation</li> </ul>	<ul style="list-style-type: none"> <li>• Team Interaction Knowledge<sup>1,3,5,6,7</sup></li> <li>• Team Knowledge/ Team Characteristics<sup>1,2,3,5,6,7</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Monitoring<sup>9,10,11</sup></li> <li>• Adaptability<sup>9,10,11</sup></li> <li>• Compensatory Behavior<sup>9,10,11</sup></li> <li>• Cooperation<sup>9,10,11</sup></li> <li>• Coordination<sup>9,10,11</sup></li> <li>• Teamwork skills<sup>9,10,11</sup></li> <li>• Temporal patterns of team performance<sup>9,10,11</sup></li> <li>• Collaboration<sup>9,10,11</sup></li> <li>• Inter-team Communication<sup>9,10,11</sup></li> <li>• Dynamic Reallocation of Functions<sup>9,10,11</sup></li> <li>• Information Exchange<sup>9,10,11</sup></li> <li>• Workload Distribution<sup>9,10,11</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Collective Efficacy<sup>12, 13</sup></li> <li>• Perceived Support<sup>12, 13</sup></li> </ul>
Team Building	<ul style="list-style-type: none"> <li>• Role Play</li> <li>• Behavioral Modeling</li> <li>• Ropes Courses</li> <li>• Interactive Collaborative Exercises</li> <li>• Trust Games</li> <li>• Ice Breakers</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>	<ul style="list-style-type: none"> <li>• Motivational Skill<sup>9,10,11</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Motivation<sup>12, 13</sup></li> <li>• Trust<sup>12, 13</sup></li> <li>• Perceived Support<sup>12, 13</sup></li> <li>• Loyalty<sup>12, 13</sup></li> <li>• Team Satisfaction<sup>12</sup></li> <li>• Cohesion<sup>12, 13</sup></li> <li>• Team Psychological Safety<sup>12, 13</sup></li> </ul>

*Note.* Adapted from Fiore et al., 2015. Superscript key detailing methods for evaluating listed KSAs: 1=Concept Map, 2=Card Sorts, 3=Pairwise Ratings, 4=Queries, 5=Questionnaires, 6=Verbal Protocols, 7=Communication Analysis, 8=Eye Trackers, 9=Questionnaires, 10=Communication Analysis, 11=Observation Scales, 12=Questionnaires, 13=Communication Analysis, 14=Physiological

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.
- Competencies from the updated astronaut job analysis can be tied to the six team competencies to delineate target areas for team skills training. These competencies have indirect and direct influences on team performance and team functioning.
  - Competencies include cooperation, conflict management, coordination, communication, leadership/followership, and cognition.
- Training should be reinforced regularly, and use multiple methods to target the same skills.

### 3. Other Predictors

#### a. Team Net Habitable Volume

Other contributing factors have received little to no research attention in the spaceflight context, for example net habitable volume (NHV) as it applies to the team. 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 Spaceflight Human Factors and Habitability Element of NASA's HRP currently examines NHV from a human factors perspective, 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 NHV in the context of those Risk areas). Suggestions from a NASA SME workshop concluded that minimum acceptable NHV for a crew of 6 on a Mars mission is 25m<sup>3</sup> per person, which is significantly smaller than the ISS volume of 85m<sup>3</sup> per person (Whitmire, Leveton, Broughton, Basner, Kearney, Ikuma, & Morris, 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, sleeping quarters, exercise, hygiene, and stowage. It also identified the need for dining and communal activity space to foster team cohesion, allow for team training and events, and support psychological health. A recent literature review and operations assessment of NHV related to the Team Risk has found many individual issues may scale up to affect team functioning and performance (Kearney, 2015) (Category III). For example, issues of crowding, privacy, and traffic flow all affect individuals' well-being, which may affect performance on a team. Additionally, there are several team-specific issues that call for more research as to how NHV affects the team and that have implications for habitat design to support team performance and functioning. The physical environment for performing tasks may call for separation or a shared space, configurable as the tasks demands differing levels of communication and "co-presence". Configurability of the environment may facilitate team task switching, but used poorly or designed poorly, may result in more conflict or a fracturing of the team. Research in this area is needed.

#### b. Teams & Sleep

Another area of cross-discipline integration in need of research is that of sleep and circadian factors as they affect teams. The Sleep Risk chapter of this Evidence Book provides a wealth of evidence related to the physiological need for sleep, effects on individual performance and functioning (e.g., decision-making, reaction time, sensorimotor, attention, mood), and spaceflight countermeasures. Team cohesion and interactions may serve as a buffer to counteract negative effects of work overload, lack of sleep, and circadian desynchrony, but little research takes place looking at these issues at the team-level. Military teams are attuned to the risks of sleep and have conducted some research in this area. 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, Wesenten, Kandelaars, & Balkin, 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, Efron, Mah, & Malhotra, 2013) (Category III). NASA operates on a 24 hour schedule; thus, consideration of sleep and the multi-team system of MCC operations is needed.

#### c. Team Robotics

Human-Computer Interaction (HCI) is an established human factors research area and future LDEMs will require the use of robotics and automation to unburden the crew of workload as needed. Robots developed by NASA and JAXA have been tested on ISS. NASA's Robonaut 2 is designed to be highly dexterous, capable of performing simple, repetitive or dangerous tasks on

the ISS in place of crew members. JAXA's Kirobo is equipped with voice recognition, language processing, communication and speaking operations, and facial recognition, to help crew members perform experiments and other tasks. However, consideration of the psychological response to such a team member has seen little research beyond the human factors perspective of strategically offloading tasks and workload to robots. Recent research suggests designers consider social capabilities of collaborative robots to improve 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 tool or "pet" for the crew to offload work and monitor systems, but as an integrated team member. Relevant research from human factors may inform the robot design to evoke positive affect and trust in the automated systems. Team-level factors may approach this to the extent that the robot supports team performance and functioning by facilitating learning and operations in new and complex situations. For some tasks, there may need to be persistent human-robot teaming, as is currently being explored for use in robot-assisted disaster response efforts for the European Union's Community Research and Development Information Service (EU CORDIS) and in a new research initiative by the U.S. Air Force.

#### 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 the cohesion definitional and measurement literature 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, Grossman, Hughes, & Coultas, 2015) (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 to remain cohesive with low-morale members.

###### *Operationalizing cohesion*

This summary of cohesion literature also provides examples of what a cohesive team may look like, as operationalized through various measurement methods (Salas et al., 2015) (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 logging the proximity and frequency of interactions among team members.

### *Outcomes*

Research summarized above provides information related to predictors of team cohesion. The relationship of team cohesion and team performance has been the subject of several meta-analyses, with results suggesting a positive relationship between the two, but many studies have neglected to consider duration (Mathieu et al., 2015) (Category I). 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, Harman, Hoover, Hayes, & Pandhi, 2000) (Category I). Another meta-analysis found that as work required more collaboration, the cohesion-performance relationship became stronger and highly cohesive teams became more likely to perform better than less-cohesive teams (Beal, Cohen, Burke, & McLendon, 2003) (Category I). Mathieu and colleagues' (2015) recent investigation of this relationship over time found that cohesion and performance were related positively and reciprocally, and that this relationship continued over time. Studies in Antarctic populations found similar patterns of cohesion and performance as mutually supportive over time (Kozlowski, Chang, & Biswas, 2015) (Category III). Additionally, the cohesion predicting performance pathway was stronger than the reverse, grew stronger over time, and shared leadership was positively related to cohesion. Team cohesion can be viewed as both a predictor and an outcome, and has been referred to consistently as an emergent state (Marks, Mathieu, & Zaccaro, 2001). This pattern is evident in other team-level factors; that is, the relationships between team factors change over time, relating more strongly/weakly to outcomes and being influenced by outcomes in turn. For LDEM, the dynamic nature of these relationships over time have major implications related to the monitoring and maintenance of team-level variables, especially cohesion, and hold clues to the implementation of timely countermeasures.

While relationship conflict is most salient when considering team functioning and performance, a meta-analysis of 484 effect sizes 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 was negatively related to cohesion, while task conflict was not related to cohesion, suggesting that task conflicts may occur without breaking the team apart and the interpersonal relationships are more important to the emergent and affective states. For performance outcomes, task conflict was positively related 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. Conversely, disagreements with regard to 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. Other team cognition research suggests, however, 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 these differences that may negatively influence teamwork processes. In general, teamwork processes and emergent states of team potency and team cohesion are positively correlated (LePine et al., 2008) (Category I).

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 as an aspect of the personality trait agreeableness (Stanton, 2011), which has implications for selection. Within military teams, trust has been studied extensively for 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 their judgment of others as trustworthy; moderators, such as situational conditions; and trust-related behaviors (Cianciolo, Evans, DeCostanza, & Pierce, 2011) (Category III). For 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 KSAs and past behaviors, and if the situation is one in which there is proven success, the team member is likely to be assigned as the likelihood of failure is deemed low. Other factors, such as cultural or gender diversity, may lead to difficulties in building that trust due to perceived differences of mental models and other values or KSA characteristics, but adopting other's conventions and multi-cultural training together and overcoming those initial hurdles to building trust. A United States Air Force study found that teams together for a longer duration had greater trust (Lyons, Funke, Nelson, & Knott, 2011) (Category I). Team trust positively affects team functioning and effectiveness in military teams (Lee, Bond, Russell, Tost, Gonzalez, & Scarbrough, 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 is effective to rebuild that trust (Stanton, 2011). Mutual trust among team members, and across the multi-team system, ensures that the team can work autonomously and efficiently, without resources wasted on too much monitoring, carrying extra workload due to perceived incompetence, or needlessly questioning leadership or expertise.

Research that was conducted in the Antarctic also investigated conflict, cohesion, and performance. In one Antarctic expedition, scientists reported that team members' perceptions of status contributed to conflicts and reduced perceptions of cohesion (Dutta Roy & Deb, 1999) (Category III). Wood, Schmidt, Lugg, Ayton, Phillips, & Shepanek, (2005) (Category III) also 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 recent 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, Chang, Perry, Pearce, Dixon, & Santoro, 2015) (Category I,III). This research team found similar results in 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 mission is important for stability of the team during mission. Finding ways to bridge gaps due to diversity of cultures or expertise may be accomplished through mission simulations in analogs such as NEEMO and HERA (Noe et al., 2011) (Category IV). Identifying other commonalities to create a new “space” culture has been a suggested tactic at the multi-national European Space Agency (Sandal & Manzey, 2009) (Category IV) and been a successful approach on the ISS (David, Rubino, Keeton, Miller, & Patterson, 2011) (Category III).

b. Psychosocial adaptation, and team adaptation and resilience

Spaceflight is an inherently stressful experience, and many aspects of ICE analogs and other environments such as military operations, have much to say regarding successful adaptation and performance. Ground-based research involving similar conditions (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 and Sells, 1962; Britt and Bliese, 2003; Krueger, 2001; NASA, 1987). Epidemiologists have noted higher mortality rates among socially isolated patients (House, 2001) (Category III), and physicians have described more issues with depression and somatic illnesses in conjunction with longer periods of relative social isolation among Antarctic expeditioners (Lugg, 1977; Lugg, 2005) (Category III). Some individuals may naturally be more suited to these environments. For example, individuals who were low in extroversion and assertiveness adapt better to life in Antarctica (Rosnet, Le Scanff, Sagal, 2000) (Category III), and a review of the psychosocial literature for LDEM found that personality predicts stress and health outcomes (Schmidt, 2015). As noted previously, however, ground-based evidence indicates that teams with more moderately extroverted members, not dominant, generally perform better (Bell et al., 2015) (Category III). Research must still determine how to balance individual extroversion at levels that are encouraging to both psychosocial adaptation and team performance. The process of psychological and social adjustment to environmental conditions and demands is known as psychosocial adaptation, while team adaptation and resilience emphasizes the adaptation in responses and outcomes to a trigger event. These different, but related, constructs both influence team performance and functioning.

The BMed Risk area provides substantial information for individuals’ adaptation to ICE conditions, but the team may act as a buffering and supporting mechanism for psychosocial adaptation and resilience. For example, research has demonstrated that high social support and strong communication among team members may decrease the impact of individual strain, buffering negative effects on team effectiveness and performance (Guzzo & Dickson, 1996; Theorell and Karasek, 1996). Recent NASA-sponsored reviews of the literature created a data-supported model by considering over 200 articles (with 94 quantitative articles) of psychosocial factors in spaceflight and analogous populations (Schmidt, 2015) (Category I, III) and clarified the nomological network of the relationships between team adaptation and resilience across 15 years of research and a forthcoming operations assessment with NASA SMEs (Maynard et al., 2015) (Category III). It is important to note that adaptation may be an individual and team trait (i.e., adaptability), the adaptation of team processes (e.g., changing actions), and an adaptive outcome such as creating a new plan or tool or social relationship (Mathieu & Kennedy, 2015)

(Category IV). The relationships among psychosocial adaptation, health, learning, productivity, and performance are somewhat reciprocal at both the individual and the team levels (e.g., good health improves psychosocial adaptation and learning, satisfaction with learning and team performance improves psychosocial adaptation, etc.) (Burke, Stagl, Salas, Pierce, & Kendall, 2006; Buunk, Doosje, Jans, & Hopstaken, 1993; House, Landis Umberson, Salovey, & Rothman, 2003; Israel, House, Schurman, & Heaney, 1989; Kramer, 1993; Vogt, Rizvi, Shipherd, & Resick, 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, 2015) (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. 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 the degree of needed backup and devote more attention to the task.

These recent reviews highlight the importance of selecting and composing a team of individuals that are adaptable and resilient, but that adaptation and resilience may also be developed and maintained through training and on-mission countermeasures. 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 states that an individual manages 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 may take actions to remain resilient, in addition to possessing inherent characteristics of resilience. Characteristics of the situation may support adaptation such as increased autonomy and team autonomy. Autonomous teams, especially those in ICE environments, have a greater understanding of the situation they are experiencing than the command center, and are able to adapt on demand to the changing needs of a situation. In a lab study of Naval officers introduced to incongruent information, teams were able to autonomously adapt to the situation and improve mission effectiveness (Diedrich, Freeman, Entin, & MacMillan, 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 was also positively related to team performance.

Adaptation to ICE environments usually emphasizes the adaptation to the situation, event, or context, but there is also a period of adaptation to the team and other team members. Training competencies of group living and teamwork, communication, leadership/follower, etc., developing shared cognition, and undergoing adaptability training will provide teams with the skills they need to live and work as a team during long duration. It is also important that teams spend considerable time together, a minimum of six weeks, to allow adaptation to occur pre-mission (Schmidt, 2015) (Category IV). Six weeks allows an ICE 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 considering psychosocial adaptation, and the adaptation processes and resilience of a team over time during the mission are needed to understand how factors support and mitigate each other to maintain optimal psychosocial functioning. For example, a study of longer peacekeeping mission deployments for 3,339 military personnel were associated with increased 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 affects 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

Current spaceflight analog research has increasingly turned to the utilization of unobtrusive methods of measurement, in addition to typical self-report measures. Unobtrusive measures offer several advantages: avoidance of crew time burdens needed for surveys or other active measurement techniques, lessening “survey fatigue” related to constant reporting that may interfere with accurate ratings, and acknowledgement of and response to the general dislike of surveys. Additionally, unobtrusive measures allow for more frequent, consistent measures to support real-time monitoring and response. 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, Miller, Ott, Schmer-Galunder, & Rye, 2015) (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 across mission simulation analogs and bed-rest studies suggest this is a valid approach for measuring mood and emotions, salience of topics, and sentiment towards past/present/future, self- vs. other-focused, and tracking these variables over time. Other real-time lexical indicator technology was developed to track cognitive and emotional states in verbal utterances, especially how detected stress was related to decrements in performance and well-being (Salas & Driskell, 2015) (Category II). Findings from two mission simulation analogs found that these lexical measures were consistent with self-report surveys of emotions and detected emotion variation 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.

Another technology tested in multiple mission simulation analogs and Antarctic stations is the sociometric badges detecting proximity and within-team interactions (Kozlowski, Chang, Perry, Pearce, Dixon, & Santoro, 2015) (Category III). High reliability and accuracy were found for interaction and affective data, suggesting this is a viable technology for classifying the team cohesion and collaboration. Video feeds have been used with an optical computer recognition

(OCR) program to detect emotion, fatigue, and stress displays through facial movements during Mars 500 and in HERA (Dinges, 2015). 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. Unobtrusive measures lessen the demand for astronauts' time needed in-flight to fill out surveys or perform other obtrusive reporting mechanism. A multi-modal approach integrating several technologies provide a richness of data for monitoring individual's health and well-being as well as that of team performance and functioning. On a LDEM, preventing survey fatigue is one plus, but a more important outcome of unobtrusive measures stems from the increased autonomy and isolation of the 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 predicting individual and team performance and indicating appropriate timing of countermeasures is a long-term goal for future LDEM. While some researchers (e.g., Kanas et al., 2009) have stated a constant stream of objective data regarding the psychosocial climate of the crew is needed, it is important to have a balanced approach where meaningful information is provided to the crew as well as the support team on Earth.

## V. COMPUTER-BASED MODELING AND SIMULATION

Researchers in the social sciences and Industrial/Organizational psychology have renewed interest in examining teamwork processes and outcomes through modeling and simulation. Recent research on teams reflects the maturity of complex computing and statistical approaches, particularly through use of agent-based modeling and simulation (ABMS), but there is a dearth of spaceflight and analog research using this advanced methodology. ABMS has been underutilized in organizational research (Hughes, Clegg, Robinson, & Crowder, 2012) (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 analog research have all of these limitations to some degree, and thus, ABMS may be particularly appropriate for studying teams in complex ICE conditions over a long duration. Future research leveraging the potential of ABMS is needed.

## VI. RISK IN CONTEXT OF EXPLORATION MISSION OPERATIONAL SCENARIOS

### A. Constraints for exploration missions

Exploration missions are divided into different lengths of duration. Short duration, conceptualized as an asteroid mission, will likely take place over a matter of a few weeks. Long duration, conceptualized as a planetary or Mars mission, will last up to 30 months. The Team Risk is more focused on preparing for long duration missions, since the risks of long duration teams living and working together is less studied and less understood in the literature. Anecdotal reports from operational assessments and the astronaut 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 Shuttle missions. A few ISS astronauts have also self-identified as less suited to long duration after they experienced long duration spaceflight (Stuster, 2010) (Category III).

Throughout this evidence report, attention has been focused on long duration, which continues to be the focus of the Team Risk for exploration mission research.

Constraints for future long duration, planetary exploration missions are outlined in the *Mars Design Reference Architecture (DRM) 5.0* (Drake, 2009), with updated considerations as part of the Evolvable Mars Campaign (Crusan, 2014). While some constraints remain static across exploration mission types, other constraints will vary by mission (see Table 6).

Table 6. Summary of characteristics across exploration mission types.

Characteristics Similar Across Mission Types	Characteristics Varied Across Mission Types
<ul style="list-style-type: none"> <li>• Multi-cultural crew</li> <li>• Mixed gender</li> <li>• Mixed technical expertise</li> <li>• Designated mission commander</li> <li>• Small net habitable volume and limited privacy</li> <li>• Communication delay with Earth</li> <li>• No crew rotation</li> <li>• Increased autonomy from MCC as compared to current operations</li> <li>• Lengthy pre-training</li> </ul>	<ul style="list-style-type: none"> <li>• Size of crew (i.e., 4-6)</li> <li>• Size of habitat (i.e., 9m<sup>3</sup> transit vehicle vs. transit vehicle and 80m<sup>3</sup> surface habitat)</li> <li>• Length of communication delay (i.e., a few seconds vs. 22 minutes)</li> <li>• Mission duration (i.e., 30 days vs. 30 months)</li> <li>• Degree of autonomy (i.e., minimal but to a greater degree than ISS vs. large degree)</li> </ul>

Many of these risks have been addressed above as the Team Risk research portfolio is oriented to future missions, but a summary of threats is as follows.

## 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, while the secondary hazards are the closed environment and extreme distance from Earth. 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 BMed Risk are related to isolation from family and friends, as well as to nature and views of Earth, and the harmful psychological and physiological outcomes of this stressful situation. A closed environment does not allow for crew rotation. For teams, this isolation requires greater attention to initial selection and team composition due to a non-rotating crew that must possess technical skills and adaptability to successfully overcome off-nominal events without real-time coordination with ground or the possibility of evacuation. In-flight training and other activities to maintain within team cohesion and a 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 taskwork and group leisure activities such as group meals, movie nights and milestone celebrations, will also stimulate the team and foster cohesion. Careful planning and design of the habitat and the supplies are necessary as there will be no resupply possible. Digitizing engaging activities with regular updates sent to the team and virtual environments designed for use by multiple team members simultaneously will offer some relief. Creating countermeasures such as the DebriefNow, which is “owned” by the in-flight team without needed intervention from ground to support team

communication, will allow the team to maintain function as they become more autonomous and isolated.

## 2. Other contributing factors

Other LDEM factors may pose a hazard to the team, but some may also be used as leverage points for countermeasures to maintain team performance and functioning. Behavioral competency training, both pre-training and in-flight, will ensure teamwork skills meet the needs of the mission. Workload and scheduling should be designed as to not create undue psychological or physical stress on the crew, and allow time for adequate sleep periods. Allowance of some self-direction of schedules, for example, setting overarching weekly goals at MCC while the team determines how to achieve those goals is one avenue to address increased team autonomy. Careful selection and team composition of a diverse crew that avoids faultlines and builds a multi-dimensional network of connections, cohesion, and shared team cognition, requires additional support through training and other team countermeasures. Engaging activities, social events, and communications with home, albeit with communication delays, may help psychological health and lessen the social monotony. Communication delays preventing the current practice of real-time PPCs and Private Medical Conferences (PMCs) call for new avenues of within-team support, telemedicine and psychologically supportive countermeasures to support mental health and physical health. Finally, habitat design calls for adequate volume and layout supporting team activities (e.g., training, social time, community meals) and cohesion. There are likely unknown hazards to the team, 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. Pre-mission planning and preparation of the team, the multi-team system, and the international partnerships between the space agencies and their respective countries must come to an agreement 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).*

## VII. GAPS

At the time of publication, BHP has identified eight 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 (“Risk”, 2015) and are as follows:

- Team1: We need to understand the key threats, indicators, and life cycle of the team for autonomous, long duration and/or distance exploration missions.
- Team2: We need to identify a set of validated measures, based on the key indicators of team function, to effectively monitor and measure team health and performance fluctuations during autonomous, long duration and/or distance exploration missions.
- Team3: We need to identify a set of countermeasures to support team function for all phases of autonomous, long duration and/or distance exploration missions.

- Team4: We need to identify psychological measures that can be used to select individuals most likely to maintain team function for autonomous, long duration and/or distance exploration missions.
- Team5: We need to identify validated ground-based training methods that can be both preparatory and continuing to maintain team function in autonomous, long duration, and/or distance exploration missions.
- Team6: We need to identify methods to support and enable multiple distributed teams to manage shifting levels of autonomy during long duration and/or distance exploration missions.
- Team8: We need to identify psychological and psychosocial factors, measures, and combinations thereof that can be used to compose highly effective crews for autonomous, long duration and/or distance exploration missions.
- Team9: We need to identify spaceflight acceptable thresholds (or ranges) of team function, based on key indicators, for autonomous, long duration and/or distance exploration missions.

## VIII. CONCLUSION

BHP research provides the knowledge, tools, and technologies that support crew health to prevent or mitigate the Team Risk. These efforts are operationally driven, and mapped onto milestones related to the PRR that stems from future LDEM timelines. Veteran astronauts and ground control personnel have expressed the need for training requirements 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 as a result of interpersonal frictions in the past; therefore, the first priority of the BHP 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 there are a multitude of meta-analyses to use as a foundation to team research. The growing body of evidence from ground-based analogs adds unique value to the research on more traditional workplace teams. Differences between traditional workplace teams and teams in ICE analogs or analogous populations such as the military, highlight the future research and countermeasure needs related to LDEMs. Spaceflight evidence related to teams is somewhat limited insofar as team performance and functioning measures have not been implemented in a systematic way. However, there exist preliminary findings, in addition to more concrete conclusions, that are beginning to fill gaps 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. Communication skills training, supported by regular team debrief and feedback events, enables the team to maintain shared cognition and overcome conflict. Evidence also supports the important role of environmental context in influencing team performance. Thus, investigating best practices in selection, composition, and skills training in the particular context of LDEMs leverages existing research to shorten time to identifying best practices in LDEMs.

In a similar way, existing or ground-based technologies can be leveraged for LDEM teams. The second priority of the BHP Team Risk is to develop unobtrusive monitoring technologies for detection of deteriorating team performance and team functioning, a condition that will

ultimately decrease crew performance and well-being. For example, the sociometric badges offer real-time monitoring of crew cohesion and interaction patterns with very little maintenance time needed by crew members. Development of these badges in analog research also allows later implementation for other co-located workplace teams, beyond the spaceflight context. These unobtrusive monitoring tools enable LDEM crews to self-monitor in real-time, which is important as communication delays between crew and ground increase the crew's autonomy and decrease multi-team coordination. Understanding the implications of communication delays and supporting team performance during these conditions is the third priority of the BHP Team Risk. Preliminary work has been completed, but more research is needed in this area to understand the risk and validate training and other countermeasures.

In summary, BHP 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 BHP Element has identified gaps in knowledge and mitigation strategies that are related to these issues. To close these gaps, the BHP Team Risk needs to pursue more rigorous, longitudinal research designs and a multi-method research program. 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 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. Ensuring team resilience and cohesion buffers the effects from ICE-related psychological and physiological stressors and supports long-duration exploration mission success.

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## XI. LIST OF ACRONYMS

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

CAPCOM: Capsule Communicator

CAVES: Cooperative Adventure for Valuing and Exercising human behavior and performance Skills

CRM: Crew Resource Management

CSA: Canadian Space Agency

D-RATS: Desert Research and Technology Studies

DRM: Design Reference Architecture

ESA: European Space Agency

EU CORDIS: European Union's Community Research and Development Information Service

EVA: Extra Vehicular Activity

HCI: Human-Computer Interaction

HERA: Human Exploration Research Analog

HI-SEAS: Hawai'i Space Exploration Analog and Simulation

HRP: Human Research Program

ICE: Isolated, Confined, Extreme  
IP: Internet Protocol  
IRP: Integrated Research Plan  
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 Operations  
NHV: Net Habitable Volume  
NOLS: National Outdoor Leadership School  
NTSB: National Transportation Safety Board  
PMC: Private Medical Conferences  
PPC: Private Psychological Conferences  
PRD: Program Requirements Document  
PRR: Pathway to Risk Reduction  
RATS: Research and Technology Studies  
RSA: Russian Space Agency  
SFINCSS: Simulated Flight of International Crew on Space Station  
SFRM: Spaceflight Resource Management  
SHFH: Space Human Factors and Habitability  
SME: Subject Matter Experts  
STEM: Science, Technology, Engineering, and Mathematics  
TDT: Team Dimensional Training  
TtO: Transitions to Operations  
USAF: United States Air Force