NASA/TM-2011-216162

Team Training for Long-duration Missions in Isolated and Confined Environments: A Literature Review, an Operational Assessment, and Recommendations for Practice and Research

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October 2011

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Contents

Acronyms

AMMT	aircraft maintenance team training
ASCAN	astronaut candidate
AUM	anxiety and uncertainty management
BHP	Behavioral Health and Performance
CRM	crew resource management
CSA	Canadian Space Agency
DDD	Distributed Dynamic Decision Making
ESA	European Space Agency
EVA	extravehicular activity
HRP	Human Research Program
ISS	International Space Station
JIT	Just in Time
KSA	knowledge, skills, and ability
MTS	multi-team systems
NEEMO	NASA Extreme Environment Mission Operations
NOLS	National Outdoor Leadership School
SFRM	space flight resource management
SME	subject matter expert
STAR	stop, think, act, and review
TeamSTEPPS™	Team Strategies and Tools to Enhance Performance and Patient Safety

Introduction

The Behavioral Health and Performance (BHP) element addresses human health risks in the NASA Human Research Program (HRP). BHP supports and conducts research to help characterize and mitigate risks for long-duration missions and, in some instances, current flight medical operations.

Although crew members and the ground crew currently receive training, additional training capabilities will be required for future exploration missions to Mars. These missions will have substantially different requirements for success than any previous NASA mission, so training will have to be revised accordingly. To ensure crew safety and accomplish mission work tasks, effective application of the skills and knowledge learned in training is critical. There is a need to understand recent developments in the team training literature as well as current team training strategies to help direct future training efforts in preparation for long-duration missions.

This report provides the results of a literature review on team training, operational assessment, evaluation, and recommendations for the current NASA team training strategies and future research that are relevant to the Team Risk (specifically focusing on monitoring task performance, psychosocial performance, and teamwork).

Literature Review

The purpose of the literature review was to identify research on current team training strategies, including general models of training but also specific strategies for team training in isolated, confined, and extreme environments. Teams are defined as a distinguishable set of 2 or more individuals who interact dynamically, adaptively, and interdependently; share common goals or purposes; and have specific roles or functions to perform.[1] There are several different types of teams (eg, top management teams, task forces, surgical teams, shuttle crew teams, sports teams). Teamwork is defined by a set of interrelated knowledge, skills, and attitudes that facilitate coordinated, adaptive performance and support one's teammates, objectives, and mission.[1-5] Teamwork depends on each team member's ability to: 1) anticipate the needs of others; 2) adjust to each other's actions and the changing environment; and 3) share an understanding as to how a procedure should happen to identify when errors occur and how to correct for those errors. Marks, Mathieu, and Zaccaro[6] identified 3 dimensions of teamwork behavior that have been empirically supported (eg, Lepine et al[7]). The dimensions include transition behaviors related to evaluating and/or planning to guide the accomplishment of a team goal or a mission (mission analysis, goal specification, strategy formulation, and planning), action behaviors or activities leading to goal accomplishment (monitoring, backup, and coordination behaviors), and interpersonal processes (conflict management, motivation, and confidence building), and how they affect management.

In team-based work environments, team members must have the knowledge, skills, and abilities (KSAs) that allow them to communicate and coordinate with other team members and perform complex tasks that require integration of team members' competencies.[8] Team members also are expected to use their KSAs and perform tasks in stressful situations such as emergencies, when under time pressure, in distributed team environments, and facing information overload or deficiencies. As a result, team training is believed to be critical for effective team performance.[9] Team training is a planned effort administered in a team environment to improve team performance.[10-12] Team training is especially important for aviation, medicine, and space teams, all of which share the need for decision making based on incomplete or conflicting information, the need for coordination among professionals with different skills and ranks, and the likelihood that poor team performance will lead to serious consequences or death.[2,13] Team performance is defined as an emergent phenomenon resulting from a goal-directed process whereby members draw from their individual and shared resources to display task work, teamwork, and integrated team-level processes to generate products and provide services.[14,15] Effective team training is typically evaluated by determining the relationship between team training and one or more outcomes, including cognitive, affective, process, and performance outcomes.

The literature review is organized as follows: First, an overview is provided of the process used to identify the articles and chapters included in this review. Second, the paper provides a general summary of team training and team effectiveness literature. Third, team training research related to cross-training, training in isolated and confined environments, team mental models, and cross-cultural training is discussed.

Literature review process

The articles and book chapters included in this literature review are based on a search of electronic databases, including journals from business, psychology, aviation, medicine, and engineering. The key words used to search these journals included team training, cross-cultural training, team mental models, isolated work, confined space, extreme environment, Antarctica training, aviation training, and environmental medicine. Additional articles were also identified by examining the reference lists of these articles. As a result of this process, 97 articles from 41 journals were identified and included in this review. A complete list of journals included in the review is found in Appendix 1. An Excel spreadsheet and a Word document are available from the authors. The Excel spreadsheet includes a citation and abstract for each article and chapter reviewed. The Word document consists of a detailed summary of each article, including citation and a narrative describing the hypotheses or research questions addressed, study results, and implications for research and practice.

Overview of research on team training effectiveness

A series of meta-analyses strongly suggests that team training has a positive influence on team effectiveness. Delise and colleagues[8] conducted a meta-analysis of studies of the effectiveness of team training conducted between 1986 and 2007. They found that team training had a positive relationship with team effectiveness (as determined by d or effect size). Overall team training was found to be related to team outcomes (d=0.85). Team training was positively related to affective outcomes (d=0.80), cognitive outcomes (d=1.37), subjective task-based skill outcomes (d=0.88), objective task-based skill outcomes (d=0.76), and teamwork skill outcomes (d=0.64). The differences in effect sizes were not significant, suggesting that team training did not have a significantly stronger relationship with any one type of effectiveness outcome.

Team training also has been shown to be related to improvements in specific team processes and skills. Klein and colleagues,[11] based their meta-analysis of team training on Crew Resource Management training, cross-training, guided team self-correction strategies, scenario and simulation-based training, and team building. From this they concluded that team adaptation and coordination training as well as Crew Resource Management training were the most effective in improving team performance and the performance of team behaviors, especially communication and coordination behaviors (r=0.629). Team training interventions had a larger impact on team processes and performance than team member affective outcomes. Salas and colleagues[16] found that team training was useful for improving cognitive, affective, process, and performance outcomes. Across all outcomes, team training interventions were more effective for team processes than for any other types of outcomes. Team training with a mixed training content (focus on teamwork and task work) was not found to be superior to team training focusing either on teamwork or task work. The stability of team membership moderated the relationship between team training and team outcomes such that intact teams that underwent training improved the most on process and performance outcomes.

Team Training, Generic Team Training, and Team Training Methods

There have been a number of efforts to develop team training programs and recommendations regarding the skills, design, and delivery methods that are most effective. Ellis and colleagues[17] emphasize that the success of team training programs depends on conducting a thorough team training analysis, starting with a skills inventory to identify needed competencies.[18] According to Ellis and colleagues,[17] competencies can be categorized into 1 of 4 groups depending on whether they are specific or general to a particular team and specific or general to a particular task. Past research has identified 5 categories of task- and team-generic competencies: 1) conflict resolution, 2) collaborative problem solving, 3) communication, 4) goal setting and performance management, and 5) planning and task coordination.

Planning and task coordination refer to team members' capacity to effectively sequence and orchestrate activities, as well as to manage procedural interdependencies among team members. *Collaborative problem solving* refers to team members' capacity to effectively use collective induction and deduction to resolve challenges and difficulties. *Communication* refers to team members' capacity to understand information exchange networks and to use these networks to enhance information sharing. Through the use of students participating in the Distributed Dynamic Decision Making (DDD) simulation, Ellis and colleagues[17] found that generic teamwork skills training significantly increased declarative knowledge within the team, and that trained teams demonstrated significantly greater proficiency than untrained teams in the areas of planning and task coordination, collaborative problem solving, and communication in a novel team and task environment. The DDD is a dynamic command and control simulation that requires team members to monitor activity in a geographic region and defend the geographic region against invasion from unfriendly air or ground tracks that enter it. The training, which was neither task- nor team-specific, provided participants with no information regarding situations that they might encounter in the DDD simulation. The training also was conducted at the individual level; that is, team members were trained individually without any interaction with their soon-to-be teammates.

Stachowski and colleagues[19] examined the relationships between characteristics of team interaction patterns and team effectiveness during crisis events. Crisis events were defined as "low-probability, high-impact events that are characterized by time pressure and ambiguity and that have significant consequences for an individual, team, and/or organization."[20] Yu and colleagues studied 14 intact nuclear power plant control room crews. The 14 crews were participating in a regularly scheduled training simulation that included simulated crisis events designed to portray realistic scenarios often based on events that occur at other plants. Effective teams are able to shed routinized, rigid interaction patterns and, as a result, are better able to adapt to emerging crisis situations. Results showed that higher-performing crews exhibited fewer interaction patterns than did less-effective crews ("regular sets of verbalizations and [nonverbal] actions intended for collective action and coordination"). More effective crews engaged in less actor switching (2-way exchange of information), involved fewer team members in their patterns, and engaged in shorter, more concise interaction patterns that contained fewer behaviors than patterns of less-effective crews. Superior crews exhibited fewer, shorter, less complex, and more flexible patterns of crisis response than did average performing crews.

The results of the Yu and colleagues study highlight the limits of training teams to respond in a highly procedural manner or to adhere necessarily to an established pattern of interaction. The disadvantage of training that does emphasize adherence to specific procedures is that it may reduce trainees' awareness of the need to deviate from these patterns and prevent them from acquiring the skills that would foster such deviation. Post hoc analysis of videos of crews in simulations suggest that the most effective crews used protocols as tools but did not allow them to guide their pattern of interaction. Stachowski and colleagues[19] suggest that training should foster team interaction that is briefer and involves fewer actors and less back-and-forth communication. Training designed to teach teams to engage in briefer, more directive, and less inclusive interactions without sacrificing team knowledge would also seem useful.

A study by Katz-Navon and colleagues[21] suggests that it may be naïve to conclude that an active learning climate by itself is enough to ensure that learning occurs that meets organizational objectives, especially in high-risk jobs and high-reliability industries. Their study involved resident physicians in the health care industry and the medical treatment errors of these physicians. In general, resident physicians are responsible for the health and well-being of patients while, at the same time, they are in the process of learning their profession. The authors proposed and investigated a multilevel model of how an active learning climate (a department-level phenomena) influences the number of errors (individual level); they did this by testing the moderating effect of safety priority and managerial safety practices (department level). They found that an active learning climate was associated with a greater number of errors. The interaction between an active learning climate and a priority of safety was significant, suggesting that a highly active learning climate with an immediate level of priority of safety was related to a low number of errors. They also found a significant interaction between active learning climate and managerial safety practices, thus showing that the higher the active learning climate, the fewer the treatment errors when managerial safety practices were high. Their results suggest that different aspects or dimensions of a safety climate have a differential impact on error rates.

For flight crews on a long-duration mission in a confined environment, a needs assessment and task analysis are necessary when identifying the team skills that should be emphasized in training. These skills likely include conflict resolution, collaborative problem solving, communication, goal setting and performance management, and planning and task coordination. Team training for long-duration missions should ensure that both flight crews and flight controllers will be able to shed routinized patterns and become more flexible in dealing with crisis events.

Simulations, software, and virtual worlds

Several articles discuss the use of simulations, virtual worlds, and software for aviation and medical team training.[22-26] For example, Hamman[22] discusses the implications of aviation team training for medical team training. Two primary types of training are discussed: the Advanced Qualification Program and the simulation scenario design process. Hamman[22] emphasizes that simulator design must be interdisciplinary in focus, requiring real communication. Discrete events should be identified and tested, and specific skills should be identified for each event. Team training skills must be identified by task analysis, have identified topic proficiency objectives, supporting proficiency objective skills, and behavioral markers of performance. From the first day of training, team skills should be integrated into the curriculum lesson plans and supported by curriculum design. Team training skills must share equal importance with the technical skill requirements. Hamman[22] recommends that the curriculum must be designed to support cross-cultural training and must integrate a carefully designed simulation that is based on scientific models of team training generated from performance data from the environment. The team training elements must be integrated into the event set design with defined criteria for successful outcomes.

Kraus and Gramopadhye[24] examined the role of team training and the use of advanced technology in the aircraft maintenance environment. computer-based team training software (aircraft maintenance team training [AMTT] software) was developed as part of their research. In this study, usefulness of AMTT was tested against a traditional classroom method of instruction in terms of team knowledge, acquisition, and usability issues. The authors of the study found no significant differences in user satisfaction between instructor-based and computer-based training. Subjects with low levels of computer literacy were able to interact and use the AMTT software after minimal instructions on basic computer operations. Computer-based training was as effective in delivering team training instruction as instructor-based training.

The use of simulations, virtual worlds, and software for team training is promising. These methods will be especially important on long-duration missions because crew members will be responsible for "learning as they go" (on-board learning) to refresh previously trained skills or acquire new skills to deal with unexpected crisis or events. Regardless of when, how, and where team training occurs, it should receive at least a similar level of emphasis and importance as technical skills and, to the extent possible, be integrated into operational training.

TeamSTEPPS™

The Department of Defense and the Agency for Healthcare Research and Quality developed TeamSTEPPS™ [Team Strategies and Tools to Enhance Performance and Patient Safety], an evidence-based curriculum. TeamSTEPPS™ evolved from research in high-risk fields such as aviation and aeronautics, nuclear power, and the military, where poor performance can lead to serious consequences.[27] TeamSTEPPS™ focuses on the core principles of teamwork identified by researchers such as Mumford and colleagues[28] and Kraiger and colleagues[29] by teaching specific tools and strategies that can be used to improve teamwork performance in the military medical environment. Core skills of TeamSTEPPS™ include leadership, situation monitoring, mutual support, and communication. *Leadership* refers to the ability to coordinate the activities of team members by ensuring that team actions are understood, changes in information are shared, and team members have the necessary resources. *Situation monitoring* is the process of actively scanning and assessing situational elements to gain information, understanding, or mutual awareness to support team functioning. *Mutual support* refers to the ability to anticipate and support other team member's needs through accurate knowledge about their responsibilities and workload. *Communication* is the process through which team members clearly and accurately exchange information. TeamSTEPPS™ is being integrated into obstetrical emergency training (see Ref. 30).

Fox and colleagues[31] used TeamSTEPPS™ to train senior surgical residents on teamwork skills. Generally speaking, the residents do not typically receive training in leadership or teamwork skills. Residents attended one 4-hour training session followed by attending a trauma conference. Following training, 2 surgical grand rounds were dedicated to reinforcing team training skills. Comparison of pre- and post-training surveys of the residents showed that residents perceived improvement in the ability of the team to measure performance. They also felt that team roles were better defined, the team worked well together and communicated more effectively, and they perceived an improvement in the ability of the team to resolve conflict.

Research on TeamSTEPPS™ suggests that team training in leadership, situational monitoring, mutual support, and communications can help flight crews and flight controllers more clearly understand their roles and enhance communications, coordination, and conflict resolution.

Team cognition and effectiveness

Emerging research suggests that team cognition, which is important for team performance and effectiveness, may be developed through team training. Team cognition is an emergent state that refers to the manner in which knowledge important to team functioning is mentally organized, represented, and distributed within the team, allowing team members to anticipate and execute actions.[32] Two important cognitive constructs have been identified as being important for teams**.** First, team mental models or shared mental models are a "team members' shared, organized understanding and mental representation of knowledge about key elements of the team's relevant environment."[33] Shared or team mental models can be considered mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states. Teams that have members who share models of both task work and teamwork can better anticipate the needs and actions of other team members, resulting in better team performance. Teams with a well-developed team mental model should have a common view of events and incidents, what these events and incidents are likely to lead to or cause, and why they are occurring. Team mental models are a mechanism through which team members can coordinate actions and adapt behaviors that lead to improved decision making and performance. Team mental models are a property of teams that emerge as a function of team member characteristics, including context, processes, and outcomes. Second, transactive memory refers to knowledge that is distributed among team members. Team mental model similarity refers to the extent to which team members' mental models are shared, consistent, or converge.

Cannon-Bowers and colleagues[34] proposed that a team is most likely to be effective if its team members share 4 non-independent mental models: the equipment model, the task model, the team interaction model, and the team model. *The equipment model* captures team members' shared understanding of the technology and equipment with which they carry out their team tasks (task work). *The task model* captures team members' perceptions and understanding of team procedures, strategies, task contingencies, and environmental conditions (task work). *The team interaction model* reflects team members' understanding of their responsibilities, norms, and interaction patterns (teamwork). *The team model* summarizes team members' understanding of each other's knowledge, skills, attitudes, strengths, and weaknesses (teamwork). Each mental model may be influential in predicting team performance. Findings suggest that teams whose members structure and organize their team-related knowledge in a similar fashion are likely to find it relatively easy to coordinate activities. They are likely to agree on team priorities and strategies, yielding efficient task performance. In practice, researchers have tended to collapse team mental model content into teamwork categories (interpersonal interaction requirements and skills of other team members) and task work categories (work goals and performance requirements) (see Ref. 35).

Recent empirical evidence suggests that mental model similarity improves team coordination processes, which in turn enhances team performance.[36,37] Unlike Mathieu et al,[37] Lim and Klein[38] found a direct relationship between team mental model similarity and performance. This may reflect the high stress and intense time pressure context in which the teams that they studied were trained to operate. Under such circumstances, there is very little time for explicit coordination and communication. To succeed in their tasks (eg, reacting to an enemy's ambush), team members must have a shared understanding of the emerging situation and the collective action required. It is precisely in this type of context that shared mental models have been hypothesized to be most predictive of team performance. Lim and Klein's[38] results also suggest that team mental model accuracy is instrumental for team performance. Teams whose average mental models were most similar to experts' mental models performed better than did teams whose average mental models were less similar to experts' mental models. Team mental model convergence has been shown to be related to team processes (backup behavior quantity and quality, coordination, communication), emergent states (team collective efficacy, norms) and effectiveness (performance, viability, team member growth, strategy implementation) (see Mohammed et al's[35] 15-year review of research on the team mental model construct).

Research has examined how team mental models evolve over time. McComb[39] suggests that team mental model convergence proceeds through three phases: orientation (becoming familiar with the team situation), differentiation (creating unique views of the situation), and integration (allowing team member perspectives to develop into a collective focus). Langan-Fox[40] suggests a skill acquisition framework for the development of team mental models involving orientation/negotiation (acquiring facts about the task and team), refinement/learning (constructing skills through processes and interaction), and high performance (expert team mental models).

DeChurch and Mesmer-Magnus's[41] meta-analysis examined three questions: First, how important is cognition to team performance? Second, what aspects of cognition are most important for team processes and performance? Third, which types of teams benefit from team cognition? The study examined both the broad relationships among team cognition, behavior, motivation, and performance outcomes as well as potential moderators of these relationships. They found a positive relationship between cognitive and behavioral processes overall (0.43), as well as between cognition and both transition and action processes ($r=0.43$ and 0.29, respectively). They also found a positive relationship between cognition and overall motivational states (0.37) and, more specifically, between cognition and cohesion (0.40). Their results also suggest a positive relationship between team cognition and team support (0.38) and show that cognitive cognition makes a unique contribution beyond team cohesion and team behavioral processes in understanding team performance. Compositional cognition was more predictive of process for action and decision-based teams, and most predictive of performance in project and decision making teams. These results emphasize that team cognition is an important team property, and training is needed to shape the collective cognition needed for effective teamwork.

It is fairly clear from the large number of studies of team mental models that developing shared mental models for flight crews and controllers is critical for long-duration missions in which crisis may leave little time for explicit coordination and communications.

Training to develop team cognition: Cross-training and cross-understanding

Training is the primary mechanism by which to enhance team mental model development. Various types of team training, including self-correction, team-interaction training, computer-based, and cross-training, have been found to increase team mental model similarity and accuracy.

How might team co0gnition be developed to enhance team performance? Pearsall and colleagues[42] found that role identification behaviors that occur in the initial stages of team development are positively related to team mental models and transactive memory development. Role identification behaviors refer to purposeful interpersonal interactions directed toward understanding teammates' roles and capabilities. Team members share information regarding their specialized knowledge and skills and abilities with the rest of the team. The degree to which team members engaged in role identification behaviors predicted the development of team interaction mental models. As the coordination gained through the exchange of role-based behavior led to more effective and efficient teamwork, these cognitions mediated the effects of role identification behaviors on team performance during team compilation. Similarly, Huber and Lewis[43] emphasize cross-understanding, which is the extent to which the group's members posses accurate perceptions of the mental models of other members, as important for team effectiveness. This differs from team mental model studies that have focused on the extent to which team members actually do share teamwork and task work models rather than on their perceptions of sharing. Huber and Lewis[43] discuss how different levels and distributions of cross-understanding affect group performance and learning. They differentiate cross-understanding from transactive memory system, emphasizing that it does not depend on, nor does it necessarily lead to, a division of cognitive labor. Huber and Lewis[43] suggest that the challenge is determining how to staff teams to obtain both the likelihood of a high-quality group product that would occur from members having diverse mental models and the smoothly coordinated processes that would follow from cross-understanding.

Cross-training is a type of team training in which team members rotate positions to develop an understanding of the basic knowledge necessary to successfully perform the tasks and duties of other team members. Research shows that cross-training appears to positively influence the development of shared mental models but is less effective than other types of team training in improving team effectiveness. Marks and colleagues[44] studied the impact of cross-training of action teams on team effectiveness. An action team is any team in which expertise, information, and tasks are distributed across specialized individuals, where team effectiveness depends on rapid, complex, and coordinated task behavior and the ability to dynamically adapt to the shifting demands of the situation.[45] Action teams contain more specialized skill sets, rely more heavily on coordination, perform in less familiar and more challenging environments, and may be more temporary than traditional teams. Marks and colleagues[44] proposed that cross-training influenced the development of shared mental models among team members, which in turn facilitated development of coordination and backup procedures and team performance. They also identified three different types of cross-training: positional clarification, positional modeling, and positional rotation. The least in-depth form of cross-training, *positional clarification*, involves verbally presenting team members with information about their teammates' jobs through lecture or discussion methods. *Positional modeling* entails both verbal discussion and observation of team members' roles. *Positional rotation* provides a hands-on approach to learning inter-positional information by giving members experience carrying out teammates' duties through active participation in each member's role. Individuals are provided with training and first-hand experience of their team members' roles. This type of training parallels the concept of job rotation. Marks and colleagues[44] conducted two studies using student samples engaged in simulations. They found that cross-training significantly influenced development of team mental models, team mental models accounted for significant variance in team backup behavior and performance, and positional modeling and positional rotation were superior to positional clarification in terms of teammates having a greater understanding of each other's responsibilities. They also found that teams receiving positional rotation were more comfortable switching roles than teams receiving positional modeling and clarification, and that teams receiving positional modeling and positional rotation developed mental models with a higher percentage of shared team interaction knowledge than teams that received positional clarification. The relationship between shared mental models and team performance was completely mediated by team coordination.

Salas and colleagues[46] used meta-analysis to compare the effectiveness of cross-training, team coordination and adaptation training, and guided team self-correction. Guided team self-correction refers to team training in which team members learn to diagnose team problems and develop effective solutions. Guided team self-correction training is assumed to help develop correct expectations (ie, shared mental models) among team members, thus contributing to more effective performance. Smith-Jentsch and colleagues[47] found that guided team self-correction organized around an expert model of teamwork results in more accurate, but not more similar, mental models of teamwork. Team coordination and adaptation training refer to team training in which team members are asked to alter their coordination strategy and reduce the amount of communication necessary for successful task performance. Salas et al[46] found that cross-training ($r=-0.09$) was not as effective as self-correction training ($r=0.45$) and team coordination and adaptation training ($r=0.61$).

Team training positively influences the development of shared mental models and team performance. Analogues, simulations, and other instructional methods used to train teams for long-duration missions should incorporate experiences that facilitate the development of guided team self-correction and the ability to alter their coordination strategy.

Multi-team systems

Multi-team systems (MTS) consist of two or more teams that interface directly and interdependently in response to environmental contingencies to accomplish goals.[48] For example, mission accomplishment depends on both the effective coordination and communication among flight controllers on the ground and the flight crew on the space vehicle as well as between the two teams. Marks and colleagues[49] studied MTS's composed of a leader team and two operational teams. They investigated teamwork processes that occurred during two phases of team performance: action and transition. *Action* processes include monitoring progress toward goals, system monitoring, team monitoring, and backup behavior and coordination. *Transition* processes include planning, mission analysis, and goal specification. Cross-team processes predicted MTS performance beyond that accounted for within team processes. Cross-team action processes were more important for MTS effectiveness when there were high cross-team interdependence demands. Positive transition processes related significantly to MTS performance both directly and mediated by MTS action processes. In a longitudinal study, Hoegl and colleagues[50] studied multi-team research and development projects. They found that collaborative processes between teams during the project predicted later team performance. Inter-team coordination was especially important for teams that had technical interfaces with other teams. Collaboration both within and between teams in the early project phases effected subsequent performance. Based on the study results, Hoegl et al[50] suggest that managing inter-team coordination, project commitment, and teamwork quality early on in the project helps to detect and counteract problems before project-controlling instruments are able to detect deviances.

DeChurch and Marks[51] studied leadership in MTS's. Leaders were trained in two forms of process facilitation (strategy development and coordination), and the leaders' interactions with the two teams were examined. Strategy training had a stronger effect on explicit coordination. Coordination training had a stronger effect than strategy training on implicit coordination between teams. MTS leaders who were trained in inter-team planning and coordination skills were able to align and integrate efforts across teams, resulting in superior MTS performance.

The success of a long-duration space mission is dependent on the collaboration and coordination not only within flight crews, flight controllers, and other teams on the ground, but between the teams that make up the larger multi-team system. The small, but developing, research on MTS's suggests that team training for long-duration missions should emphasize both within and inter-team coordination as well as collaboration.

Team Training in Isolated and Confined Environments

Several researchers addressed the psychological and teamwork issues that individuals face in polar expeditions and polar analogue training. Palinkas and Suedfeld[52] describe the psychological effects of polar expeditions, which included sleep deprivation, effectual changes, and interpersonal conflict. Gouriant and colleagues[53] provide a brief review of a space-type training mission that occurred in a polar outpost in 2007.

> Ball and Evans[54] emphasize that astronauts on long-duration space missions will confront a range of intra- and interpersonal challenges, the nature of which cannot be accurately determined at present. Therefore, substantive features of training must be based on continuously accumulating experiences in actual space flight environments and analogue settings. High-fidelity training experiences should be developed based on specially designed algorithm software packaging technologies that accurately model space flight experiences and outcomes of flight crew actions. Naturalistic studies on the efficacies of specific training procedures must follow in both simulated and actual space mission settings. Additionally, they emphasize that personalized individual training approaches must incorporate and evaluate countermeasures based on procedures for the evaluation of cognitive and behavioral functioning that are adaptable for computerized administration as self-assessment and supportive intervention procedures (work cited by Refs. 55-62). These programs were designed within a stress management context and were effective when combined with a range of interventions, including biofeedback, relaxation techniques, systematic desensitization, and pharmacological treatments. Ball and Evans[54] suggest that empirical studies of both individual and team behaviors in simulated flight exercises, conflict resolution strategies, and cockpit resource management programs can help increase our understanding of how behavioral patterns influence performance effectiveness and guide decisions about group composition and training.

They also provide several recommendations for training, comprising an integrated approach that includes ground-based monitoring and support groups that are specifically selected to participate in such operations. Ball and Evans[54] first suggest that NASA behavioral health personnel should be directly involved in crew selection in training crew members and ground control personnel in crisis intervention and problems with interpersonal functioning. They also emphasize that appropriate assessment tools and countermeasure development are required to address emergencies and technical assistance requirements under conditions that involve multinational crews and the complexities related to cultural and language differences, as well as under conditions that involve crews of mixed sexes and with command structure constraints (work cited by Refs. 63 and 64). Within this context, it is not enough to have the leader be the buffer, because he or she could be addressing specific problems or could be too involved in a task-oriented emergency. Finally, Ball and Evans[54] state that crew resource management for long-duration missions also requires consideration of technical as well as nontechnical skills (eg, corporate citizenship, interpersonal skills, and compatibility). Individual differences in personality functioning become important when the job requires corporate citizenship or the use of "people skills."[65-68] They recommend use of the distributed interactive simulation methodology.

Distributed interactive simulation environments are based on multi-person, computer-generated workstation networks that represent operational elements consisting of both individuals and functional groups. Such techniques involving real people can be used for selection and training under conditions of simulated mission operations in a realistic environment. Participants communicate via electronic channels to exchange information, discuss work requirements, and evaluate data for decision making; exchange the outcomes of specific actions; and evaluate mission-oriented scenarios. Space mission simulations also permit inquiries of Earth-based mission control for information or instructions, or both. Groups of individuals are trained to interact within the simulation environment to engage with assigned crew members and Earth-based mission control. Distributed interactive simulation methodologies with performance tasks requiring repeated exchange of information among participants and between groups provide an automated means by which to systematically monitor and analyze the effects of experimental variations on psychosocial interactions, decision making, and both individual and group performance effectiveness. The operational performance measures evaluated include pattern analysis, task completion, and timing parameters.

Similarly, Kanas and colleagues[69] identify specific training issues that need to be considered in isolated confined environments during long-duration space missions. These include participation of all space agencies, training in self-care and self-management, teamwork, and group living, language training, sensitivity training, leadership and followership, and cross-cultural training. Kanas[70] also emphasizes the need to sensitize astronauts to interpersonal issues, be trained to monitor themselves for interpersonal problems, and develop problem-solving exercises to be used in training that involve both astronauts and ground control.

Dion[71] emphasizes that crew selection, training, and backup plans are critical to successful long-term space missions. He also emphasizes that team cohesion is very important to success and should be reinforced in training. Team cohesion needs to be monitored continuously, the crew needs to be trained in cohesion-building skills such as team interventions, and training needs to build team identification rather than subgroup identification to avoid problems of in- and out-group dynamics.

Orasanu[72] cautions that although training is important, many events that space crews face will be unique and unpredictable; the author further emphasizes the importance of good decision making in the face of uncertainty. Poor decisions are likely to occur when relevant knowledge of the problem is not available, available information is of poor quality, accurate information is available but is difficult to interpret, and inaccurate projection of decision consequences has taken place (which means that mental models of the situation are important). She also emphasizes that training is important because it increases self-efficacy and increases meta-cognitive strategies such as planning ahead for difficulty later. Training should explicitly address what decision making will be encountered under stress. Lastly, Orasanu summarizes the work of Lipshitz and Strauss,[73] who in their studies of military decision makers found five principal strategies for coping with uncertainty. These five principles, known by the acronym RAWFS, are as follows:

1) Reducing uncertainty by collecting additional information;
2) Assumption-based reasoning (filling gaps in knowledge by making assumptions that go beyond directly available data);
3) Weighing the evidence of at least two competing hypotheses;

4) Forestalling (developing an appropriate response or response capabilities to anticipate undesirable contingencies); and
5) Suppressing uncertainty (eg, by ignoring it or by relying on unwarranted rationalization).

Flight crews and controllers who are involved in long-duration missions cannot be trained before the mission for every experience they might encounter. As a result, flight crews and controllers need to be provided with a strategy for approaching crisis and uncertainty. In preparation for long-duration missions, flight crews need to be evaluated on self-care, communications, teamwork, contributions to team cohesion, decision making, crisis management, and cultural agility.

Crew management training, crew resource management training and space flight resource management training

O'Connor and colleagues[74] conducted a meta-analysis of studies of crew resource management (CRM) effectiveness. Their results supported the effectiveness of CRM. CRM had a positive relationship with trainee reactions, attitude change, and knowledge acquisition. It is important to note that these results should be interpreted with caution because only a small number of studies of CRM effectiveness (n=16 out of 74 total studies) had sufficient data (eg, correlations, effect sizes) for inclusion in the meta-analysis.

One important issue in CRM and space flight resource management (SFRM) is to clearly identify the behaviors that should be observed and the behaviors that are appropriate for specific situations. Flin and Martin[75] note that CRM has been required for some time for pilots, but that there is little evidence as to its effectiveness because the incidents of accidents are too low to have sufficient variance to study. They suggest that establishing behavioral markers and having instructors or trainers provide ratings of crew members on these markers is one way in which to evaluate the effectiveness of CRM. The behavioral markers should be based on the cognitive and interpersonal skills emphasized in CRM. The cognitive dimension of CRM training includes: situational awareness, workload management, planning, and decision making, which make up most problems according to instructors. Interpersonal dimensions include crew coordination, communications, leadership, and group climate. During simulations or actual flight, it is important that event sets are clearly specified to ensure that instructors agree and are aware of the behaviors the crew should be exhibiting to demonstrate competence in a specific CRM dimension. It is also important that instructors be asked to identify actions that indicate that a decision has been made, not the actual decisions. Because evaluation of the behavioral markers is based on subjective assessment of trainers/instructors, Flin and Martin[75] emphasize that rater training is critical. They also emphasize that the best way to evaluate CRM training is to observe the crew during simulation or flight. In their study of MC-130P aircrews, Nullmeyer and Spiker[76] found that 75% of observed variability in mission performance ratings was accounted for by ratings of CRM skills. Rated skills included: functional allocation, tactics employment, situational awareness, time management, and command-and-control communications. Behaviors that were related to high ratings included: giving greater consideration of the "big picture"; viewing the crew as only part of the larger team and mission; raising extensive "what-if" questions about main mission events (including input from the entire crew); accepting the need to change the plan based on the evolving mission and changing situation, inclusive of explicit alternatives within permission briefings; and crew members responding well to their own errors or changing conditions. Time management also was highly correlated with mission performance. Exceptional crews were aware of time and the use of time by crew members throughout mission planning and execution. In the most effective crews, individual crew member's duties were also overtly and explicitly designated based on crew member strengths rather than position. Other important process behaviors that did not fit into the CRM categories used in the Nullmeyer and Spiker[76] study included mission focus, development and use of aggressive plans, and emergence of a clear, single leader who worked to integrate the crew together in all aspects of the mission.

SFRM was originally modeled after the CRM used in the airline industry and by the military. It was designed to address the team skills required for crew members and flight controllers during time-critical scenarios found throughout a mission. SFRM training emphasizes eight interrelated team skills; these are: communication, cross culture, teamwork, decision making, team care, leadership/followership, conflict management, and situational awareness. SFRM also provides a technique to deal with momentary loss of situational awareness; this is known by the acronym STAR for Stop, Think, Act, and Review. Before reacting to an event or beginning a task, the individual should *Stop* and take the time available to focus on what he or she is about to do. Next, that individual should *Think* about the situation at hand. What are the defining factors and critical circumstances of the situation? How is the situation similar and different from previous situations he or she has experienced? Once the individual has gained a clear awareness of the task or situation, he or she then should develop options including risks, consequences, worse-case scenarios, and contingency plans for each option. After deciding on an option, the individual must *Act* on the option using error-prevention techniques. During and at the completion of each step of the selected course of action, this same individual is expected to *Review* the process and outcome. If the option does not go according to plan (or starts to show signs of deviating from the expected plan), the individual starts the STAR process over again. SFRM helps teams increase situational awareness, learn to work together as a team, and check and back up other team members. It helps the crew to know how to handle situations in which the only available resources are those on the spacecraft.

SFRM skills are important for flight crews and controllers involved in long-duration missions. Analysis is needed to determine which current SFRM skill or new skills are needed for effective performance on long-duration missions. It will be difficult for flight crews on long-duration missions to interact with the ground, and the types of events and crisis they will face may differ significantly from those experienced on shuttle and International Space Station (ISS) flights. SFRM skills are especially important for increasing flight crews' and controllers' situational awareness and improving problem-solving skills needed to deal with emerging situations using the resources available on the spacecraft.

Cross-cultural Training

There is a small but growing body of research and awareness of the importance of cultural differences in space missions and analogue environments. Survey research and anecdotal evidence suggests that cultural differences between crew members can impede the effectiveness of space missions, especially when these missions involve astronauts from different international agencies (eg, Ref. 77). Helmreich[78] (found that Hofstede's dimensions of individualism-collectivism and power distance were important determinants of error rates in aviation environments. Kealey[79] presents key research findings about intercultural effectiveness and discusses their relevance for space missions, highlighting some of the issues that should be addressed to help minimize problems related to this intercultural effectiveness, and providing suggested action steps needed to address issues associated with multicultural functioning. Kealey defines intercultural effectiveness as "the ability to live contentedly and work successfully in another culture."[79] He emphasizes that the success of multicultural crews may be more influenced by their interpersonal skills than by their technical skills. Some of the issues identified and action steps provided by Kealey[79] include:

- It appears that most people rate themselves as interculturally effective, even when their fellows and supervisors do not agree. This may explain why most people, across many analogue settings, are satisfied with their assignments, even if they do not possess effective multicultural skills.
- Individuals tend to interact with fellow crew members from their own culture; countermeasures for this "in-group/out-group" effect should be considered during training.
- Hardship tends to bond participants, which should help during long-term missions. Monotony may counteract this effect.

- Mission control is often viewed as crews as outsiders making unrealistic demands; this needs to be addressed ahead of time as miscommunication with mission control can be dangerous.
- There has been some research on identifying the kinds of skills that facilitate intercultural success. However, insufficient attention has been given to contextual factors (what constitutes “the right stuff” changes depending on the situation).
- Intercultural training, like other kinds of training, is increasingly focused on competencies; this approach can likely be adapted to training for space missions

Ritsher[80] identifies the cultural differences between Russian and U.S. space station crew members and provides training recommendations to increase crew member awareness of these issues. Some of the cultural differences highlighted by Ritsher[80] include personality differences (eg, extraversion and openness to experience are generally higher among Americans; Russians are higher in expressivity). In addition, Americans are more reliant on roles, as opposed to Russians who generally depend on personal relationships. Further, Americans are accustomed to more personal space and have different personal hygiene habits; gender norms also differ between Americans and Russians.

Ritsher[80] recommends that specific training be designed to address these issues. Team-building exercises and other team training activities should deal explicitly with the cultural issues the team configuration will face. The crew should be led to think about cultural differences before flight and develop strategies for dealing with them. Crews should be trained to act as “psychological health officers” to evaluate the extent to which cultural differences are creating issues that are inhibiting crew effectiveness.

In a study of the European Space Agency (ESA) using surveys measuring cultural factors and their effects, Sandal and Manzey[81] found that national cultures significantly impact the ability of a crew to accomplish the mission, and that cooperation within and between space agencies is important. These results suggest that despite the ESA having its own organizational culture, national cultures still strongly influence cooperation. Tomi and colleagues[82] also found that mistrust between organizations was a major issue preventing cooperation, along with the usual miscommunications and differences in work style. Clement and Ritsher[83] investigated cultural effects in mission control and found these effects affected performance; the researchers suggested that strong communication efforts and robust relationships were important to overcome cultural differences. Based on interviews with flight controllers for the ISS, Clement and colleagues[84] found that Russian and U.S. controllers have different approaches to documentation, planning, and problem solving. Both junior and senior flight controllers reported that it is necessary to be aware of cultural differences, try to accommodate differences, and look for clues that partners are operating under different assumptions.

It is important to note that there is a voluminous body of cross-cultural research in the management literature, some of which may be applicable for understanding cultural differences between crew members and training crew members (eg, see the review by Gelfand et al[85]). This literature includes studies addressing different cross-cultural training methods, repatriation, and predictors of success in cross-cultural assignments. For example, consider the recent work by Brandl and Neyer[86] on virtual teams. Global virtual teams are culturally diverse, involve two or more nations, work across temporal and physical distance, are interdependent, and rely on technology-mediated communication (Baba et al[87]). Global virtual teams are challenged to overcome the anxiety and uncertainty that influence the effectiveness of their communication.[88] Anxiety and uncertainty management (AUM) theory proposes that anxiety and uncertainty are central elements influencing the effectiveness of intergroup communication.[88-90]

In cross-cultural interactions, the ability to manage uncertainty and anxiety are central elements of effective communication according to AUM theory.[88] Communication becomes more difficult if uncertainty and anxiety are too high.[88] High levels of uncertainty and anxiety in cross-cultural interactions reduce one's ability to predict and interpret the behavior of others.[86] Effective communication also suffers when uncertainty and anxiety are too low. Low levels of anxiety and uncertainty result in overconfidence and decreased motivation to communicate, gain new knowledge, and accurately interpret cultural differences. Effectively communicating and establishing trust are especially difficult in technology-mediated interactions in global virtual teams.[91] There are more misunderstandings among global virtual teams because these misunderstandings are characterized by a high degree of uncertainty and anxiety that needs to be overcome. To communicate effectively in cross-cultural settings, people must be open to new information, aware of alternative perspectives, and able to adjust quickly to unknown situations so they can make more accurate predictions about the behavior of others.[88]

Newcomers need to change their mental models as a requisite for effective communication in cross-cultural interactions.[88] To perform effectively in a context of uncertainty, global virtual team members must learn how to interpret the vernacular of the other culture and how to express themselves in the vernacular of the other culture to achieve goals. Team members must also become familiar with the "letting go and taking on"[92] strategy toward the perceptions of the other culture.[86] Thus, the effectiveness of cross-cultural team communication and interactions depends on the reorganization of mental maps, adaptation of behavior to the intercultural situation, and sensitivity to the specific set of behaviors that is appropriate in the setting.[93] Social interaction can be supported by certain types of cross-cultural training.

Brandl and Neyer[86] suggest that cultural awareness training will result in more effective cross-cultural communication among teams than traditional cultural orientation programs. Cultural orientation programs attempt to reduce uncertainty in unknown situations by educating newcomers about country-specific knowledge that basically equates to teaching cultural stereotypes. Brandl and Neyer[86] argue that "country-specific knowledge is not a substitute for in-depth knowledge of interpersonal interactions." These authors also suggest that "ready-made concepts by themselves are not sufficient to capture the other team members' cultural pattern." The proposed shortcomings of cultural orientation training are not an issue in cultural awareness training, which, "seeks to enhance the team members' capabilities to adjust to unknown situations."[86]

Cultural awareness training encourages participants to master unknown situations by seeking information to enhance their awareness of alternative perspectives.[86,88] The objective of cultural awareness training is to help newcomers better deal with unfamiliar situations when working together with people from different cultures by developing newcomers' openness to new information and their awareness of alternative perspectives.[88] Brandl and Neyer[86] suggest that cultural awareness training facilitates the adjustment process to new situations in three ways:[94-96]

> First, team members become aware that uncertainty inevitably arises during their participation in global virtual teams. Second, as in cultural awareness training, when team members experience how to achieve solutions and activate supportive resources, they are more willing to explore unknown situations. Third, the complexity of team members' mental maps improved in this form of training enhances their ability to link schemata to contexts.

Earley and Peterson[97] suggest that most cross cultural training has focused on country-specific knowledge. They argue that the general approach to cross-cultural training suffers from several weaknesses; namely that:

- It assumes that everyone needs to know the same thing.
- It assumes a similar level of interaction at a common location.
- It tends to focus on cognitive skills, giving less emphasis to the metacognitive skills needed to be adaptable.

Finally, Earley and Peterson[97] criticize cross-cultural training emphasis on analogical learning because most individuals cannot transfer that kind of learning to new settings. They propose an alternative approach focusing on cultural intelligence. Cultural intelligence [CQ], as they conceive it, focuses around three primary issues: metacognition, motivation (in the face of failures), and behavior (mimicry and behavioral repertoire). For metacognition, training should focus on how to learn from experience and how to deal with new knowledge. Goal-setting training will be helpful to build motivation (eg, set small goals and build toward larger goals). Role modeling and self-presentation training are good for developing appropriate behavior.

Cultural agility is the ability to quickly and comfortably work in different countries and with individuals from diverse cultures.[98] Cultural agility is important for flight crew members to develop credibility and communicate and work together effectively. Caligiuri[98] suggests that individuals need three concurrent orientations to operate across countries and in multicultural settings. These orientations include cultural adaptation, cultural minimalism, and cultural integration.

Cultural agility is not cultural adaptation; however, there are times during which cultural adaptation is critical. *Cultural adaptation* is an individual orientation to be sensitive and strive to adapt to the nuances of cultural differences, often leveraged in situations requiring individuals to behave in the most culturally appropriate ways to be successful. While cultural agility does not mean we should pretend cultural differences are nonexistent, there are times in which higher-order demands will supersede cultural expectations. *Cultural minimalism* is an individual orientation to reduce the perceived influence of cultural differences either in one's own behavior or in the behavior of others. Cultural minimalism is a highly functional cultural orientation in situations in which there are important strategic reasons to override or play down cultural differences. Cultural agility is not merely merging multiple cultures to create a new set of behavioral norms, but there are times in which cultural integration is most important. *Cultural integration* is an orientation to understand the cultural differences of each person in a multicultural or cross-cultural context while striving to create something that is a combination of many cultural perspectives.

Culturally agile individuals are able to operate within each of the three cultural orientations, depending on situational demands. They will leverage the behaviors of a cultural minimalist when the situation demands that their behaviors supersede local context. They will adapt their behaviors when the situation demands attention to local context. They also will be able to create a new behavioral set taking elements from multiple cultural contexts. Cultural agility is gained over time as an individual builds a repertoire of appropriate responses and becomes more fluent in reading and assessing a given cultural context. Most of this learning is experiential, as individuals interact with peers from other cultures and learn to test their assumptions and the limits of their personal knowledge.

It is highly likely that a long-duration mission will include a multinational, multicultural flight crew and flight controllers. For flight crew and flight controllers to effectively communicate (verbally and nonverbally), live together, work together, and understand each other's stress points and skill strengths and weaknesses, they need to be trained in language skills and general cultural knowledge. More importantly, to develop cultural agility, they need to have substantial interpersonal interaction, including social events and participating as a team in analogues and other team training events.

Operational assessment

From June 14 to June 16, 2010, the research team visited the NASA Johnson Space Center in Houston to interview subject matter experts (SMEs) who were familiar with team training in isolated and confined environments for current missions as well as with the training challenges associate with long-duration missions (eg, Mars). Sixteen interviews in total were conducted. Five of the interviews were conducted via teleconference because of scheduling conflicts. Each interview lasted approximately 1 hour. The SMEs who were interviewed included astronauts (astronaut candidates [ASCANs], short- and long-duration), flight controllers and managers, training and psychological support specialists in extravehicular activity (EVA) and robotics, space flight resource management (SFRM) trainers, and psychological support personnel. Interviewees were asked to briefly describe their position and role at NASA and discuss their involvement with training. Next, interviewees were asked to discuss current team training at NASA and to consider training needs, emphasis, and methods for long-duration missions. Each interview was recorded and transcribed. The research team identified content categories based on a review of the recorded and transcribed interviews. Interview responses were grouped according to these categories. Below, we provide a summary of the main points or "take aways" organized by content category. The interview comments are organized by topic area and are available by request from the authors.

Team Training

NASA has applied team training research results to its current missions by using training to ensure that flight crews and flight controllers as well as their interactions result in safe and successful missions. A number of training methods are used to develop team-related skills, cross-training, and shared mental models in flight crews and flight controllers, and to facilitate effective interaction between the flight crew and various supporting teams on the ground. These include analogues, simulations, tabletop simulations, formal courses, virtual reality, and T-38 training. SFRM skills are increasingly recognized as being important for crew safety and mission success. SFRM skills are embedded in training for new ASCAN classes. Crews attend required cross-cultural courses, intensively study the Russian language, and interact with crew members from other space agencies during ASCAN training. When a flight crew is assigned, members of the crew spend time training and visiting with the other crew members both in the U.S. and in other countries (primarily Russia). As part of formal training and mission debriefings, senior, experienced astronauts are also providing coaching, mentoring, and sharing knowledge to help new or less-experienced crews obtain both tacit and explicit knowledge gained during previous missions. In addition to team training, psychological support is available to crew members and their families preflight, during flight, and during reintegration.

NASA has modified the training flow to ensure that new ASCAN classes develop SFRM skills. These skills are emphasized in courses and integrated into analogues, simulations, and technical training. SFRM training has been approached in a less systematic manner for flight controllers and astronauts from previous ASCAN classes.

Analogues

NASA Extreme Environment Mission Operations

Aquarius is an undersea laboratory that is used during the NASA Extreme Environment Mission Operations (NEEMO). The base, which is located several miles off the coast of Key Largo, Florida, is owned by the National Oceanic and Atmosphere Administration and managed by the University of North Carolina. The NEEMO experience places astronauts in an environment with challenges that parallel the hostile physical and stressful psychological environment experienced during long-duration missions. These challenges can include allowing the crew to experience the effects of gravity in space, on the moon, and Mars; providing a compressed timeline for completing tasks; practicing procedures such as EVAs and emergency procedures used to rescue crew members; and performing tasks with delayed and limited communications with the mission control crew. For example, on May 10, 2010, NASA sent two astronauts—a veteran undersea engineer and an experienced scientist—to Aquarius to learn more about working in an environment that is analogous to space (NEEMO 14). The crew lived aboard the underwater laboratory, ventured out on simulated spacewalks, operated the crane, and maneuvered the vehicles much as explorers would in setting up a habitat on another planet. As the crew members interacted with these developing technologies, they provided information and feedback to NASA engineers. The crew simulated removing a mock-up of the lunar electric rover from the lander, retrieving small payloads from the lander and the ocean floor, and also simulated the transfer of an incapacitated astronaut from the ocean floor to the deck of the craft. The rover and lander mock-ups were similar in size to vehicles NASA is considering for future long-duration missions.

National Outdoor Leadership School (NOLS)

The National Outdoor Leadership School (NOLS) is a remote wilderness expedition involving teaching technical outdoor skills, leadership, and SFRM skills in a stressful, rugged outdoor setting with extreme environmental conditions (eg, backpacking for 2 weeks with other astronauts in a cold, hostile environment to understand and develop team skills, leadership skills, team dynamics, and survival skills as well as to create an awareness of stressors in self and others).

The informal feedback from astronauts, ASCANs, and trainers about NOLS and NEEMO experiences has been uniformly positive. Both NOLS and NEEMO are necessary for crew training and contribute uniquely to mission success. NOLS is a good way for members of a crew to get to know each other quickly (how they respond to stress, trigger points) so they can understand each other's strengths and weaknesses and who can best play specific roles in different types of situations. NOLS is good for helping build teamwork, eroding hierarchies and professional issues by rotating leadership roles (eg, civilians may artificially place more value on military crew opinions and expertise), and identifying pressure points at the beginning of ASCAN training and/or assigned crew training. NEEMO is a better analogue for long-duration space flight than NOLS because it includes many of the conditions that a crew will face; such as living in a small area, experiencing a work schedule that is not under personal control, having limited food and supplies, experiencing indirect or limited communications with mission control and experts from a distance, and being exposed to physical hazards. NEEMO is a good introduction to risk elements for individuals who have not previously flown in space.

Interviewees report that while NEEMO is a good analogue for isolated confined environments, current stays should better simulate long-duration mission conditions. There is a need to evaluate whether the current duration of NEEMO is sufficient to elicit conditions and psychological reactions present in long-duration mission (eg, stress, trigger points, disruption of sleep cycle, and interaction in confined space); that is, there is a need to ensure that NEEMO has the highest fidelity possible to a long-duration mission environment. The interviewees emphasized that whatever analogue is used for long-duration missions, it needs to involve confined space, several awake-sleep cycles, and delayed communications, and that it will test the ability of crew resourcefulness. Interviewees expressed concern that the time the crew spends in NEEMO not be lengthened to the point at which the experience adds to the physical and emotional stressors the crew is already experiencing, exhausting crew members beyond what they will experience as a result of their demanding training schedule for a long-duration mission.

Analogues are useful for evaluating and developing flight crews SFRM skills. The effectiveness of analogues depends on the extent to which the environment parallels the hostile physical and stressful psychological environment that crews will experience on a long-duration mission in a confined space. NOLS is better suited for ASCANs training as it introduces ASCANs to a stressful environment, teaches them survival skills, emphasizes the importance of SFRM skills, and helps identify self and other's "pressure points." Assigned flight crews should attend NEEMO because it best represents the psychological and physical conditions found on a long-duration space mission.

Astronaut candidates training flow

The training flow for the current astronaut class is new. As there is no more shuttle training, the focus has shifted to the ISS. The length of the training is 18 to 20 months. After 18 to 20 months, ASCANs are given a technical position (management) until they are assigned to a flight. If they are assigned to the ISS, they will have to complete an additional 2 years of training before their mission.

ASCAN training starts with NOLS, which emphasizes team building and survival training in a cold climate. Next, the ASCAN class is divided into aviators and non aviators to fly in a T-38 jet trainer. The ASCANs receive 6 weeks of basic aviation training with the U.S. Navy in Pensacola, Florida. Pilots fly in the front seat of the T-38 and non aviators fly in the back seat with a more experienced pilot (eg, a current astronaut) in the front seat. Aviation training includes CRM training and 12 flights. ASCANs also attend training in three flows/areas: ISS system, robotics, and EVA. They receive Russian language training for approximately 5 to 6 hours per week. After graduation in May 2011, ASCANs are ready to be assigned to a mission/flight. Until they are assigned, they are given technical duties such as supporting flight controller training. They also continue T-38 training to maintain certification (100 hrs for pilots; for "backseaters," training hours are needed to become certified as a "backup"), Russian language training, and advanced EVA and robotics skills classes. Starting with the 2009 class, ASCANs have to be proficient in ISS, EVA, and robotics. This is different from previous ASCAN classes. In previous ASCAN classes, astronauts were assigned to specialize in the specific task (EVA or robotics) in which they were proficient. This reflects the differences in shuttle and ISS missions. Currently in ISS, each astronaut must demonstrate proficiency across ISS, robotics, and EVA. When ASCANs are assigned to a flight, they are assessed for their skills and tasks (formal qualification) to identify what they have retained and what refresher or additional training they need.

The current ASCAN training flow places appropriate emphasis on developing and evaluating team skills, including SFRM skills. However, long-duration missions in confined space introduce new environmental and psychological challenges for effectively using SFRM and other team skills. The ASCAN training flow should include a higher-fidelity training experience related to long-duration missions in confined environments (e.g., NEEMO).

Flight controllers training flow

Flight controllers become operators after 1.5 years of training and simulation. Astronauts in the unassigned pool assist with these simulations. Flight controllers need to complete three generic simulations per week for certification. In each simulation, a checklist of skills and attitudes must be displayed. The simulations, which are high fidelity, use software simulating all systems as well as the space environment. Data similar to what you would see and in the form you would receive them on a mission are driven to both the crew and the flight controllers.

After obtaining operator certification, flight controllers sit console for night shifts and basic operations for the station. They continue to train on more sophisticated operations and gain more experience within a specific area, at which point they become specialists and handle more delicate operations. It is a 2- to 3-year process for each "seat" to get certified. The flight controllers can get certified for multiple seats. The assumption is that, after the flight controllers become certified for multiple seats, they will be able to train other controllers and astronauts. This is a relatively new and motivating aspect of flight controller training.

The rationale for adopting this training flow (instead of the previous "front room/back room" dichotomy) was that efforts to reduce staffing at night and on weekends led to the more cross-trained and experienced flight controllers being assigned to console on weekends, which appeared to an inefficient use of talent. In the new training flow, individuals gain experience on console during quiet times and should be more prepared when they step into more difficult roles (eg, during EVA or docking). The training flow also was changed to make it more appealing by providing quicker certification and new training flows focused on development of specific expertise. The new training flow was developed to reduce turnover of controllers who were trained by NASA but left for other positions at private firms with government contracts.

The new flight controller training flow helps ensure that NASA retains a sizable pool of talented individuals with multiple certifications. This will give NASA flexibility in determining how to schedule and assign flight controllers for long-duration missions (eg, number of flight controllers assigned to the mission and length of their work shifts). SFRM experiences for flight controllers appear to be less systematic and institutionalized than for ASCANs. Flight controllers need to receive more opportunities to develop SFRM skills. A needs analysis also should be conducted to identify what new skills sets flight controllers need for a long-duration mission.

Space Flight Resource Management Training Program

SFRM is a continually evolving process in crew and flight controller training. It has been the topic of specific courses, and is embedded in other types of astronaut training such as tabletop and high-fidelity simulations. Beginning in 2009, every ASCAN class is required to have an SFRM element. It is a formal "class" and embedded in other training. Formal courses focus on self-care, self-management, leadership, and cross-cultural issues. NOLS, NEEMO, the T-38, the moon-base tabletop simulations, and other high-fidelity simulations require use of SFRM skills to deal with normal, preventive, and problem situations. Moon-base simulations work well to elicit SFRM skills related to communications, conflict resolution, and decision making. The use of movies and video clips from previous missions and anecdotes provided by more experienced astronauts in the SFRM class has made the training meaningful and interesting. Expansion of SFRM into training has positively impacted crews, given the constraints that ISS crews are announced at different times and have different training flows, and crew members can be replaced during training. SFRM likely will be more critical in long-duration missions because of the need to deal with the unknown, ground communications delays, an international crew, more confined personal space than on station, and the need to work together to solve new and unfamiliar issues and problems that will occur in a new vehicle heading toward Mars.

Some interviewees suggested that SFRM is an underserved area for flight controllers (and astronauts). Little team training is embedded in technical training, and SFRM is not mandated for flight controllers . Departments have the discretion to have flight controllers participate in SFRM training, but they have limited resources to conduct and support the training. However, these departments recognize that SFRM training is important for flight controllers who operate together as a team and are part of a larger multi-team system (crew, flight controllers) whose members need to work together to ensure crew safety and mission success. SFRM training with the flight controllers is primarily technical and not done with the crew. This may be due to time constraints. SFRM training involving both the crew and the flight controllers is important for: developing trust; increasing awareness of each other's roles; helping both crew members and flight controllers to learn how to best communicate, given the anticipated communication delays on a long-duration mission; and understanding each other's verbal and nonverbal behaviors (eg, what does it mean when a crew member speaks loudly or talks in a low tone of voice?). This is also important because a long-duration mission will represent a significant change in operations from flight control to flight support. Flight controllers and mission control will be unable to be part of "real-time" operations. This is currently not the case with the ISS, which is controlled by ground commands. For a long-duration mission, such control will be difficult or impossible because of communications delays.

SFRM skills are evaluated by psychologists observing training. For example, debriefs in moon-base simulation from psychologist evaluators focus on SFRM skills. However, the feedback/evaluation piece of SFRM is underdeveloped. There are concerns about the validity of the rubrics and scales used for measurement, the criteria used, and how evaluations are shared and used. There also are concerns about whether the feedback provided is of sufficient quality and quantity to be useful for SFRM skill development.

It is necessary to determine whether the current skills emphasized in SFRM are appropriate for long-duration missions in confined space, and whether additional skill sets should be developed. To help ensure proper assessment and development of SFRM skills, an evaluation of the metrics, scales, and quality and quantity of feedback provided should be conducted.

Long-duration flight issues

A long-duration mission to Mars or an asteroid will pose significant new challenges that have not been faced during shuttle and current ISS missions. Flight crews will find themselves in a confined space for many months with significant "quiet" time, especially during travel to and from Mars. Communication will experience significant delays of 20 minutes or more between the crew and the ground. Crews will have to learn new skills, refresh previously learned skills, and exercise significant autonomy in applying these skills to the problems and issues that they will face. Thus, we anticipate that long-duration flight will significantly influence training issues for both astronauts and ground control.

Cross-cultural issues

A long-duration mission, which will be similar to ISS missions, will likely involve an international crew that includes astronauts from the U.S. and other nations including Canada, Japan, Europe, Russia, and China. The effectiveness of multicultural teams can be affected by a unique set of issues, including cultural differences in communications, decision-making norms, adaptation, reactions to stress, conflict management strategies, gender roles, and attitudes towards hierarchy and authority. Currently, assigned crews for ISS may spend limited formal training time together as a crew, and the critical training that they do receive focuses on specific tasks with limited time to assess and develop SFRM skills. For example, members of an ISS crew meet each other but do not train together until later (in some instances, not at all) in the training flow (ie, at 18 months, crews are involved in full crew event simulations in both the U.S. and Russia). The amount of time spent training together is based on the crew's travel schedule rather than on requirements to participate, needs assessment, or an evaluation of the crew's SFRM skills. The barriers to more team training include the fact that other countries have their own team training, crews are at different points in the training flow (making it difficult to bring them together), and the costs associated with travel. However, it is important to emphasize that significant efforts are made by the various space agencies to get the crews and their families to visit each other in their home countries and socially interact to become familiar with each other's personalities and habits and to help facilitate an understanding of cultural norms and values that may have been emphasized in language training (eg, Russian language training).

Most emphasis has been placed on U.S. astronauts understanding Russian language and culture because the Soyuz is the primary vehicle used by astronauts to reach the ISS, and the U.S. and Russia are the two most advanced space programs in the world with a history of joint missions. U.S. and Russian training also differ in approaches and philosophies, and these differences are larger than the differences between the other international space agencies whose astronauts participate in the ASCAN training flow (eg, Japanese Space Agency, ESA, Canadian Space Agency [CSA]). These differences include:

1. Russians fit their behavioral training into technical, parachute, and survival training.
2. Russians emphasize observation and evaluation in last two simulations and, while in space, pay is based on performance of tasks (eg, the last two simulations are evaluated by a "commission"). U.S. astronauts also receive feedback from instructors, trainers, and psychologist observers, but this feedback is used to identify weaknesses and areas that need further training.
3. Russia does not send its cosmonauts to ASCAN training, unlike astronauts from ESA and CSA.

4. Russian training tends to be more theoretical. Crew members are responsible for taking notes and are more directly responsible for learning with less documentation provided (eg, books, technical manuals).
5. Extensive psychological support is provided to U.S. astronauts but not to Russian cosmonauts. Russian cosmonauts are less likely to ask for support, perhaps because it will negatively affect their evaluation and pay.

Language competency has affected both Russian cosmonauts and U.S. astronauts. Russian cosmonauts are not assigned EVA and robotics tasks on ISS because of language difficulties. For the Soyuz vehicle, U.S. astronauts who struggle with language cannot sit in the "left seat" because the left seat requires flight engineering skills to control critical systems and, thus, a complex understanding of the Russian language to comprehend procedures, panels, displays, switches, etc. Great strides in trust and communications with Russia have been made over the years through joint missions (Skylab, shuttle, ISS). The cosmonauts and the astronauts do get to know each other on a personal level and develop SFRM skills through travel and simulation training in U.S. and Russia. More senior astronauts from both the U.S. and Russia have also provided useful insight into the personal and cultural nuances that crew members can expect to experience while on a joint mission.

Team training and participation in analogues for assigned crews is especially important because of the need to understand the "trigger points" of other crew members, which may be difficult to appreciate because of cultural differences. Understanding of these "trigger points" is important for the crew to be able to exchange roles that will capitalize on strengths and weaknesses to deal effectively with certain situations, develop a common language, understand nonverbal communications (eg, gestures), and recognize how crew members deal with conflict and stress. It is important to emphasize that issues that arise between crew members may result from both individual style differences and/or cultural differences (eg, autocratic leadership style). Team training experiences in high-fidelity analogues and simulations can help crew members understand both individual and cultural differences and develop cultural agility.

Changes in skills and mindset

All of the interviewees suggested that there are several new types of skill sets as well as changes in mindset that crew members and flight controllers need for a long-duration mission. First, for the crew, its members will be faced with the need to cope with the loneliness and boredom that they will be especially vulnerable to during the anticipated 6-month trip to and from Mars. This continues the evolution of crew time being completely scheduled on space missions to the crew having more autonomy to schedule and complete most tasks. For example, on shuttle the crew was always busy with ascent, descent, and experiments. ISS crews are occupied while en route to and from the space station aboard the Soyuz but, once on board, the work pace is slower and free time is available, and they also have time to exercise and work by themselves. A long-duration mission to Mars will give the crew much more free time on a vehicle than previous crews have experienced on shuttle and ISS, most likely in a habitat that provides less personal space. There will be a need for both private space for crew members as well as a common gathering space. Crew members will need to find some designated personal space to get away from their fellow crew members and psychologically recharge. It is also important that the crew not be given "busy work" to cope with boredom but instead be provided with experiments and tasks that are mission focused. The crew should be involved in value-added, mission-related work (ie, meaningful work) while en route to and from Earth on a long-duration mission. This could include training, mission planning, tactical planning, work on assignments, completing debriefs, and analyzing data. The concept of a "job jar," currently used on ISS missions, also could be useful.

A second issue that the crew and flight controllers will face is a communication delay of 20 minutes or more. This has several implications. First, the crew will have to be self reliant, autonomous, self sufficient, and unable to rely on the ground. The crew will have to troubleshoot problems and take action, consulting experts as the second step only if the situation allows. Second, the crew will have to be trained in general principles and have on-board expert systems and simulations. Currently, crews for ISS missions can train for specific task and skills proficiency right up to launch. Refresher training for ISS is limited to emergency drills and reentry training. The exact specifications for EVAs and landing are well known. Proficiency due to skill decay is not an issue. For long-duration missions, training will have to focus on the dynamic parts of flight with refresher training on board.

Crews and their families currently receive excellent psychological support before launch, during the mission, and in reintegration when they return from their mission. From a self-care perspective on a long-duration mission, crew members will need to establish some type of communication with Earth and their families and friends, even if the communication is asynchronous (eg, prerecorded audio or video). A major issue will be how to deal with the effects of long-term confinement. Astronauts will need to understand the psychological effects of long-term confinement and be encouraged to ask for support from the ground when they need it. Materials related to personal hobbies and activities and projects that keep the crew "healthy" will also have to be carefully identified and included on the vehicle before launch because these items will not be able to be sent on a resupply spacecraft.

Recommendations for Practice

Based on the operational assessment and the literature review, we make the following recommendations for team training for long-duration missions:

1. Assigned long-duration mission crews should spend time together in high-fidelity analogues such as NEEMO to ensure that crew members are aware of "stressors" or "pressure points," and that the crew develops a "common language," trust, SFRM skills (eg, resourcefulness), and the guided self-direction needed to successfully execute the mission. Members of the crew should spend sufficient time in the analogue to experience stressors such as several asleep-awake cycles, each other's personal habits, and reduced personal space. The exercises that take place in the analogue should mimic, to the extent possible, the emergency situations and day-to-day operations that the crew will encounter on a long-duration mission, including communication delays, having to troubleshoot and fix problems that require the use of general principles and on-board training systems, and switching roles to maximize team success and minimize individual personal and skill weaknesses. NEEMO is especially valuable for assigned flight crews because the situations they will encounter on *Aquarius* will require them to shed routinized, rigid interaction patterns and prepare them to adapt to emerging crisis situations that may occur on a long-duration mission to Mars.
2. The NOLS and NEEMO analogues are popular, but they are perceived to be elective and not formally and explicitly required in preparation for space flight. NOLS was recommended for shuttle; NOLS and NEEMO are currently optional for station. Current ASCAN classes attend NOLS, but assigned crews do not have to attend an analogue. Given the challenges that crew members will face on long-duration missions (eg, stress, the need to be resourceful, the need to identify team member trigger points to facilitate effective role exchanges), it is especially important that the use of both NOLS and NEEMO be continued. Because of its high fidelity with long-duration mission conditions, there needs to be an institutional requirement for assigned crews to attend NEEMO. This institutional requirement also is important because many current astronauts have not received the same level and type of SFRM training as newer ASCAN classes. This would allow experienced astronauts to further strengthen their SFRM skills and share their explicit and tacit knowledge about their missions with the less-experienced crew members. Requiring assigned crews to attend NEEMO is also a recommendation supported by research, which has found that the stability of team membership moderated the

relationship between team training and team outcomes.[16] Intact teams that underwent training improved the most on process and performance outcomes.

3. A review should be completed with emphasis on time spent in different types of training: in this instance, the length of the training flow is not the most important issue. The most important issue is: "Is what I am learning necessary?" Unnecessary training depletes crew emotional resources and strains family and other relationships because crew members have to continually travel to and from home.

4. The amount of time spent on certain types of training involving extreme or unusual conditions—eg, emergency situations on take off and landing that would be catastrophic for the crew, robotics that involve grappling, drawing blood—should be evaluated. Astronauts reported that they felt it was not useful to go through every exact extreme scenario that could occur. Rather, they preferred to focus on general principles that they could apply to extreme or unusual circumstances. This is especially important for long-duration mission, because critical tasks can be completely or partly trained for before the mission with refresher training or remaining training modules provided on board the vehicle. Training should involve more general principles (mechanics, troubleshooting) as the crew will have to take primary responsibility for fixing urgent problems (eg, equipment failures that could compromise crew safety). Because of communication delays, a long-duration mission crew will not have the luxury of contacting the ground and waiting for experts to respond. Contacting experts on the ground is possible for less important problems, but the crew will still have to deal with long delays in communications.

5. Team training needs to be based on the concept of operations. On long-duration missions, the crew will be out of touch with ground control. The crew will have to know tasks and time constraints, and will be given more tactical control (ie, what tasks have to be completed at a certain time vs. at the discretion of the crew?). Clear guidelines need to be provided to the crew and training needs to be made available using a Just in Time (JIT) tool. The culture of mission control would have to evolve from ISS; Mission control needs to become mission facilitation. This change in philosophy especially differs from shuttle missions, which had a full working schedule with crew activity controlled by the ground.

6. Long-duration crews will have to be self reliant. Resourcefulness is a current training objective that will increase in importance for long-duration missions. This means that the crew needs to have support tools and know how to apply these tools in the correct situations. Simulations, analogues, and emergency response training can be used to teach resourcefulness by having crew members use what is available and apply general principles to solve problems. A long-duration crew must be capable of dealing with psychoses as well because even normal, well-adjusted crew members can experience psychoses after long periods of isolation. This is especially important as ground support will be limited in the psychological support that it can provide during a Mars mission due to the time lag in communications.

7. Training time should be devoted to dynamic situations that could compromise safety and mission. These dynamic situations need to be identified. Key questions need to be addressed such as: What tasks and skills need to be trained early with repetitive practice? Which tasks and skills can receive less repetition but can be competently established through refresher training before flight and/or on board the vehicle using data packages, and high-fidelity virtual reality (immerse yourself in task before performing it) or simulators?

8. Flight controllers will have to be trained on how to deal with the time delay and on keeping mission safety the first priority and mission success the second priority. Flight controller staffing and scheduling will need to be reviewed. For example, one issue that needs to be considered is: Should the current schedule with three shifts of seven or eight teams rotated be maintained, or should fewer teams with the "best" flight controllers be used throughout the entire mission?

9. Both research on MTS and the operational assessment suggest the need to enlarge the "team" involved in training to include controllers, crew members, and all personnel involved in the mission. On successful ISS missions, crew and flight controllers have interacted together to build trust and understand each other's reactions to communications. It is especially important that the multi-team system (ie, crew and flight controllers) develop and maintain high levels of SFRM skills given the conditions on a long-duration mission.

10. Because of the importance of SFRM skills for long-duration missions, more frequent evaluations of crew member skills need to be provided from the perspectives of peers, instructors, and trainers. Mentoring and coaching resulting from these evaluations should be framed positively; ie, not seen as improving a weakness but rather helping to sharpen a strength. One model that should be considered is that of executive coaching. Psychologists should be involved before a team crisis or an individual crisis occurs. The focus should be on diagnosing and preventing SFRM problems and issues rather than "fixing" them after they occur.

11. Coaching, mentoring, and various types of interpersonal relationships and knowledge sharing strategies are currently being used. The interviewees' view of these is uniformly positive because of both the tacit and the explicit knowledge that new and less-experienced astronauts can learn from more "expert" colleagues. The use of peer-to-peer, expert-to-peer, and other types of relationships should be formalized within the astronaut program. This would also increase the meaningfulness of training and engagement of the crew. It would also be useful if "lessons learned" from previous ISS missions can be formally documented and shared with astronauts, flight controllers, trainers, and instructors. This information should be summarized in a way that protects the identity and preserves the confidentiality of crew members. This information also needs to be formalized to augment current astronaut debriefings because the types of tacit and explicit knowledge of ISS crews may be invaluable in helping crew members who are preparing for long-duration missions to anticipate issues and obstacles, and to develop the resourcefulness they need to cope with the uncertainty that they will encounter. This information could be accessible through a knowledge management system that is similar to The Center for Army Lessons Learned that the U.S. Army has established for sharing lessons learned in the battlefield (Ref: http://usacac.army.mil/cac2/call/index.asp).

12. The results of the ongoing "Mars 500" study should be carefully followed and reviewed. This study can help us better understand team training needs. Questions being investigated in this study include: adaptation, group structure, and communications of confined and isolated crews; determining the effects of group dynamics and loneliness on cognitive and emotional adaptation to extreme, confined environments; and the implications of personal values for interpersonal compatibility and individual adaptation during a long-duration mission. NASA should conduct similar types of studies of team effectiveness and team processes using crews in the NEEMO analogue.

13. Crew members on long-duration missions will need cultural agility. It is imperative that, for long-duration missions, crew members' levels of cultural agility can be assessed so they are aware of it, and that they are assigned to flight crews early enough so that together they can share training and team-building experiences such as NEEMO, NOLS, and simulations. This will help them to better assess and develop their task work and teamwork skills, understand crew members' stress points, develop backup behaviors, and develop cultural agility that will be critical for the success of long-duration missions. The current emphasis that NASA places on language training and country-specific knowledge is important, but it is not the only prerequisite for cross-cultural agility. The development of cross-cultural agility also depends on significant peer-to-peer contact with persons from different cultures as well as opportunities to question personal assumptions and realize the cultural limits of personal knowledge and behavior.

Research Recommendations

Teams and team effectiveness

The need is greater in long-duration missions to ensure that team training allows for greater development of task work and especially teamwork. This includes equipment, work procedures and strategy, awareness of member responsibilities and role interdependencies, and understanding of team member's preferences and skills. Specifically,

1. Most studies of team mental models have examined either teamwork or task work content.[104] The relationship between teamwork and task work content has not been established. Research is needed to examine the interactions between types of mental models. For example, benefits accrued from the teamwork mental models may depend on whether the task work mental model is shared. Is the same or a longer time needed to develop teamwork and task work mental models? What are the implications on performance of a crew that has not fully developed a teamwork model but has a fully developed task work model? What are the implications of experiences such as NEEMO and NOLES for the development of shared teamwork and task work models as well as the development of cultural agility? Research is needed to examine other indicators of team effectiveness such as cohesion and psychological safety. What are the implications of shared teamwork and task work models for crew effectiveness in MTS such as is found at NASA (flight controllers, astronauts)?
2. A fundamental assumption of the team mental model literature is that greater sharing of knowledge among team members results in increased team effectiveness. But, is this the case? Which roles will require greater convergence of knowledge? In which roles are complementary or distributed roles better? What team mental model content domains should converge? Would a team mental model consisting of distributed task work knowledge and overlapping teamwork knowledge result in higher performance? In what cases do team mental models result in a dysfunctional crew? F or example, too much similarity across member models may result in inaccurate views that are validated by other team members rather than ignored or discarded. Do certain team norms (eg, constructive confrontation norms) moderate the relationship between teamwork and task work model similarity and performance?
3. The interviews we conducted suggest that while many of the tasks and the knowledge, skills, abilities, and other requirements of a long-duration mission will be similar to those that were encountered in shuttle or are encountered on the ISS, there will be significant differences. A team task analysis is needed to identify the job and task requirements that a team will encounter on a long-duration mission. A thorough team task analysis involves: performing a requirements analysis; identifying the specific tasks that compose the target job; identifying the teamwork taxonomy (teamwork behaviors that are frequently performed or needed in team performance situations); performing a coordination analysis; selecting relevant tasks for training; translating KSAs or competencies that will become the target for selection, training, and development; and linking the KSAs back to the team tasks.[99] The result of the team task analysis can identify which types of competencies or KSAs are required for teamwork on a long-duration mission. According to Cannon-Bowers and colleagues,[5] these include:
   - context-driven competencies specific to both the task and the team; these are best developed through practice with actual team members in realistic task environments (eg, vehicle simulators, NEEMO);
   - task contingent competencies that are specific to the task but not the team and that can be trained with or without actual teammates (eg, EVA, robotics);
   - team-contingent competencies, which are specific to the team but not the to the task that require a training environment that includes actual team members across a variety of tasks (eg, SFRM); and

- transportable competencies that are generic to both the task and the team, and that can be trained using a variety of tasks and team members (eg, T-38 training).

4. The operational assessment suggests that on a long-duration mission in a confined physical space, knowledge of team members' pressure points and stressors is critical and backup behaviors may be especially important. Backup behaviors include providing a team member with feedback or coaching, assisting a team member in carrying out a task, and taking charge of and completing a task for a teammate. It is especially important for team members to understand when a teammate is overloaded or experiencing some other factor (eg, stress, boredom, loneliness) that decreases his or her performance. In such case team members should deploy their own resources to help this struggling team member. Despite conventional wisdom that backup behavior is a critical team characteristic, few empirical studies have evaluated the role of backup behavior in team effectiveness. Barnes and colleagues[100] suggest that backup behaviors might actually encourage negative social behaviors such as social loafing, dependence, and neglect of personal task work. Research is needed to identify the types and taxonomy of backup behaviors that are related to effective crew performance so that team training in analogue environments and simulators can create problems and issues that would evoke team backup behaviors.

5. Research is needed to establish the relationship between cross-level understanding, shared mental models, and team performance. Huber and Lewis[43] suggest that a high level of cross-level understanding is related to high team learning and performance regardless of the degree of convergence of the team mental model. A high level of cross-understanding allows members to discuss their differences and perspectives while mitigating the negative impact of discussion bias favoring commonly held information (a bias that can occur when mental models are shared). While a high level of cross understanding might help explain why diversity of opinions and ideas would be expected to negatively affect group cohesion and performance, it does not.

6. Crew members on a long-duration mission are also part of a larger multi-team system that includes flight controllers and other experts on the ground. This larger multi-team system can be considered a virtual team because its members must coordinate their work through asynchronous electronic communications. It is estimated that communications between the crew and the flight controllers during a long-duration mission will be delayed for at least 20 minutes. Driskell and colleagues[101] proposed four processes to be especially important for virtual teams: cohesiveness, status, counter-normative behavior, and communications. Bowers and colleagues[102] note that trust, collective efficacy, and team orientation may all be affected by distance. The current research on virtual teams focuses on processes and attitudes that may affect the interaction between team members. Research is needed that examines the processes and attitudes that are important in virtual MTS, which will be the reality of long-duration missions.

7. Research is needed to understand how cultural agility influences crew effectiveness. For example: How does each crew member's cultural orientation (minimalist, adapter, integrator) influence team processes such as coordination, communication, backup behavior, and overall crew effectiveness? How is cross-cultural agility developed within a flight crew, and how do crews adapt and integrate cultural differences to effectively deal with normal and abnormal situations? Do analogue experiences such as NOLS and NEEMO improve crew member's cultural agility?

Team training and training systems

It is not possible to train ahead of time for every possible scenario or problem that may be met on long-duration missions, or to maintain skills that were trained on the ground but may require refresher training due to long time periods of lack of use. The training requirements will continue to evolve from those that were used on shuttle to those currently used on ISS and thereafter to long-duration missions. Training for certain aspects of the mission, such as ascent and descent, will likely continue be highly scripted; but, due to the novel equipment and new and unexpected circumstances, problems, and challenges that will be encountered during long-duration missions, crew training on the ground will need to place greater emphasis on general skills and principles that they can apply to a wide variety of tasks. Moreover, due to communication delays for urgent problems, there may not be sufficient time for astronauts and mission control on the ground to learn about, practice, and/or model how to deal with the situation and then communicate it to the crew (as was the case for the astronauts on the Expedition 24 mission, who were faced with an EVA to replace a failed ammonia pump module). On-board individual and team training as well as decision-support systems are needed for long-duration missions to provide refresher training for the skills acquired on the ground, learn new skills, and understand how to apply general skills to specific tasks that occur during the mission. These training and decision-support systems could be embedded in flight systems and be specifically designed for supporting on-board training and decision support.

The following research issues need to be identified to ensure safety and achieve success in future long-duration missions:

1. Research is needed to identify the dynamic situations that could compromise safety and mission success on a long-duration mission. Care must be taken to identify the tasks and skills that need to be trained early with repetitive practice, and those that can receive less repetition but provide a refresher right before flight and/or on board the vehicle using data packages and/or virtual reality (eg, immerse oneself in a task before performing it). The following question will also need to be answered: Which part, if any, of training should occur on the ground and which should be left for on-board training, also known as expanding and progressive training?
2. Research is needed to identify skill decay patterns to determine which skills are best trained on the ground and/or in flight and the level of refresher training that needs to be provided. For example: Which learned skills have a slow or gradual decay pattern compared to skills that have a quick and steep decay pattern? How do instructional characteristics (eg, variable practice, active vs. passive learning, contextual interference) influence skill decay patterns? What is the best training schedule for skill maintenance? How could refresher training needs be determined? Should training be based on the task, the skills, or both?
3. Although the potential advantages of technologies such as simulations, virtual reality, virtual worlds, iPads® (Apple, Inc., Cupertino, Calif), and handheld devices for learning and delivery of instruction have been touted, little research has been performed to examine their effectiveness or what features of instruction should be included to maximize learning and transfer. Research is needed to identify whether these devices are most effectively used as primary instructional devices, as part of a blended learning approach, or to facilitate transfer of learning by providing skill and knowledge refresher training.[104] The instructional features that need to be included (or deemphasized) in these devices also need to be determined. For example: Does the novelty of experiences in a 3-dimensional world help trainees recall the experience but interfere with retention and transfer of training? Does the ability to synchronously or asynchronously collaborate with expert peers, instructors, or mentors enhance learning beyond just providing learner control?
4. The effectiveness of SFRM training needs to be evaluated. Research is necessary to collect data linking SFRM training to improved mission performance using naturalistic observations of crew interactions (process) and mission performance (outcomes) during tabletop and high-fidelity simulations and analogues such as NEEMO.[106] It is also possible to assess whether the crew meets the required SFRM proficiency level for training events related to the mission profile through the use of training records and instructor evaluations, ratings, and written comments. Naturalistic observations and instructor evaluations should continue to be collected and reviewed and used to improve SFRM stand-alone and embedded training.

It is important to note that the research issues we have identified above are unique, but have some overlap with those identified by Barshi.[103] Barshi also identified other important research questions related to training philosophy, methods, and content; training delivery; and vehicle interface and design that should be addressed to enhance the effectiveness of long-duration missions.

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Appendix: Journals Included in the Review

Academic Emergency Medicine: Official Journal of The Society For Academic Emergency Medicine
Academy of Management Learning and Education
Academy of Management Proceedings
Academy of Management Review
Acta Astronautica
Administrative Science Quarterly
Annual Review of Psychology
Applied Ergonomics
Aviation, Space, and Environmental Medicine
CA Magazine
Communications of the ACM
Computers & Industrial Engineering
Contemporary OB/GYN
Current Directions in Psychological Science
Ergonomics
Human Factors
Human Resource Management Review
Human Resource Management
International Journal of Aviation Psychology
International Journal of Industrial Ergonomics
Journal for Healthcare Quality: Promoting Excellence in Healthcare
Journal of Applied Psychology
Journal of Applied Social Psychology,
Journal of European Industrial Training
Journal of Organizational Behavior
Journal of the American College of Surgeons
The Lancet
McGill Journal of Medicine
National Productivity Review (Wiley)
Organization Science
Organization Studies
Performance Improvement Quarterly
Personnel Psychology
Quality & Safety in Health Care
Safety Science
Small Group Research
The Mount Sinai Journal of Medicine
Theoretical Issues in Ergonomics Science
Training & Development Journal
World Journal of Surgery

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE October 2011	3. REPORT TYPE AND DATES COVERED NASA Technical Memorandum

4. TITLE AND SUBTITLE
Team Training for Long-duration Missions in Isolated and Confined Environments: A Literature Review, an Operational Assessment, and Recommendations for Practice and Research

5. FUNDING NUMBERS

6. AUTHOR(S)
Raymond A. Noe, PhD; Ali McConnell Dachner; Brian Saxton; Kathryn E. Keeton

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS
S-1109

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TM-2011-216162

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the NASA Center for AeroSpace Information (CASI)
7121 Standard
Hanover, MD 21076-1320 Category: 53

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The Behavioral Health and Performance (BHP) element addresses human health risks in the NASA Human Research Program. BHP supports and conducts research to help characterize and mitigate risks for long-duration missions and, in some instances, current flight medical operations. Although crew members and the ground crew currently receive training, additional training capabilities will be required for future exploration missions to Mars. These missions will have substantially different requirements for success than any previous NASA mission, so training will have to be revised accordingly. To ensure crew safety and accomplish mission work tasks, effective application of the skills and knowledge learned in training is critical. There is a need to understand recent developments in the team training literature as well as current team training strategies to help direct future training efforts in preparation for long-duration missions.This report provides the results of a literature review on team training, operational assessment, evaluation, and recommendations for the current NASA team training strategies and future research that are relevant to the Team Risk (specifically focusing on monitoring task performance, psychosocial performance, and teamwork).The purpose of this literature review was to identify research on current team training strategies, including general models of training but also specific strategies for team training in isolated, confined, and extreme environments.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
training, long duration space flight, aerospace environments, simulation	44	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

Standard Form 298 (Rev Feb 89) (MS Word Mar 97) NSN 7540-01-280-5500
Prescribed by ANSI Std. 239-18
298-102