NASA/TM-2015-218589

Training "The Right Stuff": An Assessment of Team Training Needs For Long-Duration Spaceflight Crews

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September 2015

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Acknowledgement

This work was supported by a grant from the National Aeronautics and Space Administration (#NNX09AK48G). Send comments to Dr. Eduardo Salas, Eduardo.Salas@rice.edu. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

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Executive Summary

The current report is the first in a three-part series that describes a team training needs analysis conducted for long-duration spaceflight (LDSF) crews. The ultimate goals of the overall needs analysis effort are to: (a) identify unique factors associated with the tasks, team member characteristics, and the organizational environment likely to affect LDSF team training needs; (b) identify opportunities to leverage prior team training research and development efforts conducted using team types that share common task, team member, and organizational characteristics; and, (c) specify directions for future training research and development efforts that will be needed in order to best prepare for future extreme long-duration missions. The present report details the first part of our training needs analysis. This component is dedicated to identifying characteristics of the task environment LDSF crews face that are both unique to this type of team and are expected to have a significant impact on team competency requirements and the strategies used to address those training needs based on prior research. The current report is organized into four sections. First, we synthesize literature indicating the major categories of team task characteristics that have been shown to moderate team training requirements and effectiveness. Second, we describe the methods used to interview twelve National Aeronautics and Space Administration (NASA) astronauts during the months of February and June 2010. Third, we identify five task characteristics associated with LDSF crews that were derived from transcripts of the interviews conducted that are both unique to this type of team relative to other teams operating in high-risk environments and are expected to impact team training requirements. Fourth, we identify the specific team competency requirements that should be impacted by these unique characteristics and discuss the manner in which they are expected to be affected. Finally, we identify research questions that should be answered in order to inform the development of strategies designed to address these unique team training needs.

Structured Interviews

Twelve NASA astronauts who had experienced at least one long-duration spaceflight mission (i.e., three months or longer) were recruited to participate in semi-structured interviews that lasted approximately one hour. All participants were asked to provide informed consent, and the study was conducted under approval of the UCF Institutional Review Board and the NASA Committee for the Protection of Human Subjects. The mean time that each participant had been working at NASA as an astronaut was fifteen years. In addition, the amount of time that each of the participants had spent in spaceflight averaged to 223 days. The length of their longest single spaceflight was an average of 163 days.

Interviews were conducted at Johnson Space Center (JSC) in Houston, Texas, over the course of five days during February and June of 2010. Each astronaut participated in an interview, or a set of interviews, which lasted anywhere from 30 to 90 minutes. During the interviews, two principal interviewers asked a series of open-ended questions designed to elicit information regarding the participants' experiences during long-duration spaceflight missions. Specifically, participants were asked to describe their experiences relating to team coordination, communication, cohesion, performance, leadership, and stress during long-duration missions. In addition, they were asked to describe characteristics of the individuals, the tasks, and of the physical, social, and organizational environments encountered during such missions.

Each interview was transcribed into a Microsoft Word document utilizing a naturalistic approach and all identifying information was omitted. Content analysis techniques involving both meaning condensation and meaning categorization were utilized in order to derive core themes from the transcribed interview data files. An initial coding scheme was developed based upon focal constructs of the research project and core competencies identified by the NASA Missions Operations Directorate International Training Control Board (ITCB) Human Behavior and Performance (HBP) Training Working Group was supplemented with additional coding categories derived based upon other constructs described by interviewees.

Results

Five unique team task characteristics specific to LDSF crews were identified based upon the subject matter expert interviews. These are detailed in Table 2. Ten team competency requirements believed to be affected by these unique task characteristics are identified in Table 3. Team competencies reflect the constellation of knowledge, skills, and attitudes required for effective team performance that should be included in training efforts designed to optimize LDSF team performance. We organized the team competencies affected by unique characteristics of the LDSF task environment using a taxonomy that differentiates training requirements as to whether they are specific or generic with respect to the teammates and tasks performed (see Table 1). These groupings have implications with respect to the degree to which each competency can be addressed through training prior to or during an LDSF mission. Finally, for each competency, we identify research questions that need to be answered in order to inform the development of training for LDSF crews (see Table 3).

Conclusions

Results from this team task analysis detailed factors that should be considered when determining the generalizability of team training strategies developed for other types of teams that operate in high-risk environments. It also identified questions for future research to address in order to best meet the unique training needs of LDSF crews. Finally, we identified opportunities to address each of the targeted competencies through off-site (prior to mission) and on-site (during a mission) training strategies (see Table 4).

Table 1. Cannon-Bowers et al., (1995) Taxonomy of Team Competencies

	Teammate Generic	**Teammate Specific**
Task Generic	*Transportable team competencies:* Generalizable to new teams and tasks.	*Team specific competencies:* Generalizable to new tasks performed with the same team, but not to other teams.
Task Specific	*Task specific competencies:* Generalizable to new teams performing tasks members might have performed previously, but not to new tasks.	*Team specific & task specific competencies:* Not generalizable to new teams or new tasks.

Table 2. Unique Work Characteristics of Long-Duration Spaceflight Crews

Task Characteristic	**ISS Crews**	**Extreme Long-duration Missions (e.g., Mission to Mars Crews)**	**Aircrews**	**Air Traffic Control Teams**	**Command and Control Teams**
Variability in Task Interdependency	Perform tasks that vary on a continuum of interdependency, including a substantial proportion of time performing completely independent tasks	Will perform tasks that vary on a continuum of interdependency, probably fewer independent tasks	Primarily reciprocal interdependency, no significant independent tasks	Sequential and reciprocal interdependency, no significant independent tasks	Primarily reciprocal interdependency, few if any independent tasks
Variability In Task Tempo and Task Type	Experience significant variability in task tempo, and both predictable and unpredictable variability in task type	Experience significant variability in task tempo and both predictable and unpredictable variability in task type	Yes, but to a much lesser degree than LDSF crews	Yes, but to a much lesser degree than LDSF crews	Yes, but to a much lesser degree than LDSF crews
Variability in Teammate Familiarity	Experience substantial crew turnover every 3-6 months and often have little or no familiarity with new teammates	Will experience turnover of ground crewmembers only, will likely be familiar with one another prior to mission	Experience frequent (often daily) turnover with little or no prior teammate familiarity	Frequently utilize replacement members from same facility.	Experience limited turnover during missions and more substantial turnover between missions

Task Characteristic	ISS Crews	Extreme Long-duration Missions (e.g., Mission to Mars Crews)	Aircrews	Air Traffic Control Teams	Command and Control Teams
Team Composition/ Diversity	Experience substantial diversity with respect to culture, nationality, gender, expertise, and personality	Experience substantial diversity with respect to culture, nationality, gender, expertise, and personality	Experience diversity but within a smaller crew. Little diversity in nationality.	Experience diversity, but little diversity in nationality.	Experience diversity, but no diversity in nationality
Isolation and Confinement	Live and work together for long periods of time with small group of individuals	Live and work together for long periods of time with small group of individuals	Do not live together	Do not live together	Live and work together, but with a much larger group of individuals.

Table 3. LDSF Training Needs and Associated Research Questions

Type of Training Requirement	**Competencies**	**Research Questions**
Task-generic Teammate-generic	Collective Orientation Information Exchange Supporting Behavior Skill Adaptability/Flexibility Skill Team Leadership Skill Emotion Regulation Skill	○ *Research Question #1:* Can we identify specific coordination problems associated with shifting from a small to a large team and vice versa? And, do these problems vary as a function of task interdependency? ○ *Research Question #2:* Can we identify specific coordination problems associated with shifting from a fast paced to a slower paced task tempo and vice versa? And, do these problems vary as a function of task interdependency? ○ *Research Question #3:* Can we identify specific coordination problems associated with shifting from an independent to an interdependent team task and vice versa? ○ *Research Question #4:* Can we identify specific coordination problems associated with team diversity on specific traits (e.g., conscientiousness, extraversion)? And, do these problems vary as a function of task interdependency? ○ *Research Question #5:* Can we identify specific coordination problems associated with team diversity on specific dimensions of culture?

Type of Training Requirement	Competencies	Research Questions
Task-specific Teammate-generic	Inter-positional Knowledge	○ *Research Question #6:* What are the possible positive and negative effects of members holding inter-positional knowledge about one another's independent tasks?
Task-specific Teammate-specific	Shared Role Expectations	○ *Research Question #7:* How can teams be trained to come to consensus on role expectations while still encouraging productive discussion of competing alternatives
Team-specific Task-generic	Knowledge about Teammates Team Cohesion	○ *Research Question #8:* Can we identify consistent patterns of decay with respect to team cohesion over time? ○ *Research Question #9:* Can we anticipate decrements in team cohesion on the basis of team composition with respect to personality or culture? ○ *Research Question #10:* Can we anticipate decrements in team cohesion on the basis of critical team events? ○ *Research Question #11:* Does the effectiveness of various strategies for developing and maintaining team cohesion depend on the degree to which deficiencies in cohesion are systemic or limited to a component or individual on a team?

Table 4. Training Guidelines for Task-specific/Generic, Team-specific/Generic Team Competencies

Type of Training Requirement	**Competencies**	**Training Guidelines**	
		Off-Site Training	**On-Site Training**
Task-generic Teammate-generic	Collective Orientation Information Exchange Adaptability/Flexibility Supporting Behavior Team Leadership Skill Emotion Regulation Skill	• Self-paced Computer-based training • Behavior Role Modeling • Simulation	• Guided self-reflection
Task-specific Teammate-generic	Inter-positional Knowledge	• Informational Cross-training • Positional Modeling Cross-training • Positional Rotation Cross-training • Simulation-based training • Behavior role-modeling • Classroom seminars • Computer-based training • Semi-structured online chats	• Structured Team Debriefing Strategies • On-site Coaching • Demonstration • Semi-structured online chats • Computer-based training
Task-specific Teammate-specific	Shared Role Expectations	• Simulation • Semi-structured Online Chats • Structured Team Debriefing Strategies	• Structured Team Debriefing Strategies

Type of Training Requirement	Competencies	Training Guidelines	
		Off-Site Training	On-Site Training
Task-generic Teammate-specific	Knowledge about Teammates Team Cohesion	• Team Building Exercises • Simulation • Structured Team Debriefing Strategies • Semi-structured online chats	• Team Building Exercises • Guided Self-Reflection Strategies • Structured Team Debriefing Strategies[3]

1.0 Purpose and Background

Team training needs analysis is a systematic process by which the primary needs of an organization and the individuals within it are identified in order to determine the objectives of a training program, to identify likely training candidates, and to understand the organizational factors that may moderate training effectiveness. The purpose of the current report is to describe the methods and results from the first component of a team training needs analysis conducted for long-duration spaceflight (LDSF) crews: the analysis of coordination requirements associated with the team task itself.

As such, this report is the first in a series of three dedicated to (a) identifying characteristics of the team tasks that LDSF crewmembers will be responsible for completing, and the team competencies that are required to perform those tasks effectively (i.e., task analysis); (b) identifying characteristics of the individuals who serve as members of LDSF teams that may impact training needs and the effectiveness of various potential training strategies (i.e., person analysis); and (c) identifying characteristics of the organizational environment which are likely to facilitate or hinder efforts to train the team competencies identified (i.e., organizational analysis). The present report describes the first of these three components (i.e., team task analysis). First, we describe the literature review that guided our team task analysis approach. Next, we detail the methods utilized, including the semi-structured interviews conducted with National Aeronautics and Space Administration (NASA) astronauts with LDSF experience. We then identify five task characteristics associated with LDSF crews that were derived from transcripts of the interviews conducted that are both unique to this type of team relative to other teams operating in high-risk environments and are expected to impact team training requirements. Next, we identify the specific team competency requirements that should be impacted by these unique characteristics and discuss the manner in which they are expected to be affected. Finally, we identify research questions that should be answered in order to inform the development of strategies designed to address these unique team training needs.

The information gleaned from our subject matter expert (SME) interviews will be used to develop a more thorough understanding of the team task environment faced by crews who have experienced LDSF missions to date on both the International Space Station (ISS) and MIR. Although long-duration missions such as a possible mission to Mars are not clearly defined at this point, we speculate based on what is known to date regarding task characteristics that are likely to differ.

To that end, the following sections of this report detail the training needs analysis process. Next, an overview of task-related factors known to impact team training effectiveness (i.e., moderators of training) derived from a review of existing literature is presented. This overview provides insight into important task factors that may impact the generalizability of team training results from other team types that operate in high-risk environments (e.g., aircrews, air traffic control [ATC] teams, and military command-and-control teams).

1.1 Training Needs Analysis Defined

As mentioned above, training needs analysis refers to the process by which the primary needs of an organization and the individuals within it are identified in order to determine the objectives of a training program. This analytical process is a vital first step in the development and implementation of any training program because it identifies critical design and implementation factors. It is necessary in order to identify relevant criteria for evaluating training effectiveness. The training needs analysis process has three key components: *task analysis (i.e. what to train)*, *person analysis (i.e. who to train)*, and *organizational analysis (i.e. how to train)* (McGhee & Thayer, 1961).

The goal of *task analysis* is to determine the specific learning objectives of the training program. Through task analysis, the activities and job operations that trainees will ultimately need to perform and the conditions under which these tasks are performed are identified. Task analysis focuses on identifying primary job tasks and functions, as well as the essential knowledge, skills, and abilities (KSAs) required for successful completion (McGhee & Thayer, 1961). In essence, task analysis provides a thorough description of the work that the training program should be able to prepare individuals and/or teams to accomplish. *Person analysis* is dedicated to (a) identifying individuals within the organization in need of training, (b) determining the knowledge, skills, and attitudes in need of development, and (c) identifying training strategies most likely to be effective given the trainees' motivational and cognitive states (McGhee & Thayer). *Organizational analysis* is dedicated to determining the nature of the environment in which the training program will be offered. It involves collecting information regarding opportunities and boundary conditions that are likely to influence the effectiveness of training (Goldstein, 1991). For example, a critical component of organizational analysis is determining the degree to which trainees will be formally or informally reinforced (or punished) for transferring trained KSAs into their daily work. Organizational analysis also identifies training resources and time constraints/schedules that may limit the feasibility of various training options.

A primary objective of training needs analysis, whether team-oriented or individual-oriented, is to determine the degree to which existing training strategies or components of those strategies are likely to be effective in a new context. Specifically, the term *inter-organizational* validity has been used to refer to the degree to which a training program can be expected to yield similar results in a new organizational environment relative to the initial environment in which its validity had been demonstrated (Goldstein & Ford, 2002). Inter-organizational analyses are critical in determining how to adapt validated training strategies so that they remain effective if applied in new task, trainee, and organizational system contexts.

Inter-organizational validity is determined by identifying similarities and differences in tasks, trainee characteristics, and the organizational environment between the original context in which a training strategy has been previously validated (e.g., U.S. Navy submarine missions) and the new context in which the training strategy may be applied (i.e., long-duration spaceflight missions). Differences are then compared to known moderators of training effectiveness—those aspects of the task, trainees, or organizational context that have been empirically shown to enhance (or inhibit) training effectiveness in the existing literature. This analysis results in modifications of the original training to better fit the new context, or a determination that the training strategy is inappropriate for the new context. Through this analysis process, the aspects of the task, trainees, and organizational

environment (or the configuration of these) unique to the new context are revealed. Hypotheses can then be developed regarding new training strategies that are hypothetically most capable of addressing such unique needs. In sum, training needs analysis is a critical component of the foundation upon which any training development and evaluation effort is based.

With respect to the assessment of inter-organizational validity in the current report, a critical characteristic of long-duration spaceflight missions is that such operations represent a *high-risk system*. High-risk systems are defined as those that: (a) operate regularly with the potential to create catastrophe (e.g., loss of life, environmental damage), (b) consist of highly interdependent subsystems that often combine in a non-linear fashion; and (c) are tightly coupled (Perrow, 1999). We, therefore, identified three types of teams which also operate within high-risk systems, and for whom extensive empirical team training research exists: (a) ATC teams, (b) aircrews, and (c) military command-and-control teams (e.g., U.S. Naval Submarine crews). The goal of the present effort is to develop a better understanding of the similarities and differences that exist between long-duration spaceflight crews and these three types of teams. This information will allow us to leverage substantial prior investments that have been made in developing team training designed to optimize team performance and cohesion (e.g., Cannon-Bowers & Salas, 1998; Salas, Burke, Bowers, & Wilson, 2001; Smith-Jentsch, Baker, Salas, & Cannon-Bowers, 2001), and to efficiently focus current research and development efforts based on more in-depth understanding of unique features of long-duration spaceflight crews. To this end, we begin by describing potential moderators of team training needs in Section 3. In this section, we cover several key characteristics that have the potential to impact the training needs of various teams.

As noted above, the current paper details the first component of the training needs analysis for long-duration spaceflight, task analysis. Two subsequent white papers will detail the results of our person- and organization-focused analyses. Prior to detailing our research methodology, we first summarize the existent research upon which the semi-structured SME interviews were based. Specifically, we synthesize literature relevant to the comparison of team tasks and associated coordination demands that have been previously linked to team training needs and effectiveness.

2.0 Moderators of Team Training Effectiveness: Review of the Existing Literature

Effective teams successfully engage in both *taskwork* (i.e., efforts focused on accomplishing the required tasks) and *teamwork* (i.e., efforts aimed at operating cohesively as a unit; Glickman, Zimmer, Montero, Guerette, Campbell, Morgan, & Salas, 1987; Mclntyre & Salas, 1995; Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986). To adequately determine the nature of the teamwork and taskwork competencies required for any given team's success, a team task analysis is necessary. Team task analysis (TTA), as the name implies, refers to a systematic assessment of a team's task(s); however, a comprehensive team task analysis goes beyond analysis of *tasks* to include assessment of *teamwork* requirements (i.e., competencies or knowledge, skills/abilities, and attitudes – KSAs) as well (Baker, Salas, & Cannon-Bowers, 1998). According to Baker and colleagues, the results of TTA provide the necessary foundation for team resource management functions such as team design, performance management, and training.

Team task analysis methods have traditionally been derived from the job analysis literature, specifically the task analysis component. Goldstein (1993) defined task analysis as a tool designed to inform the development of objectives regarding performance of relevant activities required for successful execution of a job. However, translation of these individual-level analysis techniques to the team level has not always produced optimal results. Often, individual-level techniques fail to capture necessary internal and external factors that determine the foundation of team tasks (Sweezey, Owens, Bergondy, & Salas, 1998). Additionally, the techniques tend to focus on the taskwork component, giving little or no attention to teamwork (Burke, 2005).

Team tasks can vary on a number of dimensions (e.g., interdependence, size). These team task characteristics can affect training needs in at least three ways. First, team task characteristics can affect which competencies are most important to train. For instance, prior research has found that the relationship between team cohesion and team performance is stronger for teams with greater interdependence (Barrick, Bradley, Kristof-Brown & Colbert, 2007). Second, team task characteristics can affect the manner in which team competencies are operationally defined. For instance, mutual performance monitoring may look different in a physically distributed environment. Third, team task characteristics affect the degree to which particular training strategies are likely to result in performance benefits. For instance, team training tends to be more effective for teams with stable membership (Salas, Diaz Granados et al., 2008). The following sections of this report summarize the literature with respect to the major categories of team task characteristics that have been found to moderate team training needs and effectiveness.

2.1 Task-related Moderators

2.1.1 Task Interdependence

A number of prior authors have put forth taxonomies, which attempt to differentiate various levels and types of task interdependencies. Thomas (1967) and Van de Ven et al. (1976) defined a four-level hierarchy of task interdependence based upon the degree to which tasks require exchange and

coordination of information, effort, and other resources. The lowest level of interdependence, *pooled interdependence*, requires all team members to contribute toward group output. However, there is minimal to no need for direct interaction among team members. In this case, group performance is truly operationalized as the sum of individual parts. Coordination requirements are minimal because group members usually have similar roles and training, and each team member may complete an entire task independently. *Sequential interdependence* requires that team members complete their actions consecutively. Like a manufacturing assembly line, one team member's output becomes the input utilized by the next team member. While team members must interact, the flow of work is unidirectional; meaning that sub-tasks must be performed in a prescribed order. Differentiated roles enable each team member to contribute to team outcomes at a very specific point in this prescribed order. *Reciprocal interdependence* describes tasks characterized by a two-way workflow that require coordinated interactions among team members. That is, team member A's outputs become team member B's inputs and vice versa. Role differentiation, expertise heterogeneity, and flexible task strategies require team members to coordinate both effort and resources. Furthermore, the role structure is often externally defined—meaning that it is important to have all of the roles filled with the correct expertise. However, task performance is not necessarily highly contingent on *who* fills these roles (Saavedra, Early, Van Dyne, 1993). The highest level, *intensive team interdependence* (Tesluck et al., 1997), is characterized by a simultaneous, multi-directional workflow among team members. These tasks are characterized by a high degree of team autonomy, with team roles, task strategies, and methods organically defined by team members themselves.

Task interdependence has been shown to influence the magnitude of the relationships between cognitive, behavioral, and affective team constructs and team performance effectiveness (e.g., Saavedra et al., 1993). In other words, task interdependence determines, in part, how strong the need is to train particular team competencies for different types of teams. For instance, task interdependence has been shown to strengthen the relationship between cohesion and performance such that the performance of highly interdependent teams is most strongly and positively influenced by team cohesion (Beal, Cohen, Burke, McLendon, 2003). As such, training strategies that facilitate team cohesion would be expected to have a more positive impact on team performance for highly interdependent teams than for less interdependent teams.

Task interdependence has also been found to affect the impact of various training strategies on performance improvement. For example, Saavedra and colleagues (1993) found that for more highly interdependent tasks, teams were most effective when goals and feedback were focused at the team level, instead of on individual team members. However, for less interdependent tasks (e.g. pooled), individual goals and individual feedback were related to higher levels of team performance. Thus, a critical component of any team training needs analysis should be to determine the nature of the interdependence that exists for the targeted team types.

2.1.2 Task Variability

Another characteristic of team tasks that has been shown to moderate team training effectiveness is the degree to which the team's tasks are variable over time. Task variability influences the effectiveness of team training strategies in at least three ways. First, the return on investment (ROI) for training task-specific knowledge, skills, and attitudes is limited by the length of time in which teams will perform those tasks before switching to other tasks. As an example, consider organizations specializing in software technology and compare them to the airline industry. There

will be a much greater ROI when training aircrews how to fly commercial jetliners as compared to training software engineers simply because the life times of the products with which they work vary considerably. Planes tend to last for decades, and while advances in modern avionics technology have evolved (i.e., the transition from analogue instrument panels to "glass cockpit" aircraft), the coordination demands required to fly a specific type of airplane have been well researched (e.g., Prince, Chidester, Bowers, & Cannon-Bowers, 1992; Bowers, Morgan, Salas, & Prince, 1993) and have not changed dramatically over the years. In contrast, the programming languages and hardware components that require task-specific knowledge for software engineers have changed dramatically, and training on any one of them given to software engineers today may already be obsolescent by tomorrow.

Second, it follows that training which fosters flexibility and adaptive transfer will be effective to the extent that a team's tasks are highly unstable. Adaptive transfer involves "the use of one's existing knowledge base to generate a solution to a completely new problem" (Ivancic & Hesketh, 2000, p. 1968). Adaptive transfer for teams requires that members are capable of using their collective knowledge stores to generate solutions to new problems. Prior research has repeatedly demonstrated that training strategies, which optimize transfer to similar tasks, hinder adaptive transfer and vice versa (e.g., Aguinis & Kraiger, 2009; Ely, 2009). This has important implications for training designed to prepare teams that are expected to face highly variable tasks that cannot be anticipated ahead of time.

Third, teams that operate in task environments characterized by a mixture of stable and variable tasks, or those in which task stability is interrupted by sudden task changes, may also require training that facilitates their ability to shift from one task type to another effectively and efficiently. This notion is based on theory and research suggesting that when teams perform the same task for an extended period of time, they develop interaction patterns that tend to persist even when those patterns are no longer effective or efficient (e.g., Harrison, Mohommed, McGrath, Florey, & Vanderstoep, 2003; Kelly, 1988; Kelly, Futoron, & McGrath, 1990; McGrath & Kelly, 1986). Ancona and Chong (1999) referred to this as social entrainment. Social entrainment is said to occur when team members synchronize their actions to one another and also to external pacers (e.g., time constraints, task completion deadlines, and other situational demands). When teams are repeatedly faced with tasks that have the same characteristics, their coordination patterns become strongly entrained. This allows these teams to be more efficient and productive at performing those tasks over time than teams whose patterns are not strongly entrained (Kelly, 1988). However, strongly entrained teams that experience changes in the characteristics of their tasks can be at a major disadvantage if prior coordination patterns persist even in the face of changes made to the task (e.g., Gersick & Hackman, 1990). For example, it has been shown that the performance of highly entrained teams declines when their tasks require them to shift from a divisional to a functional structure (Moon, Hollenbeck, Ilgen, West, Ellis, Humphrey, & Porter, 2000). The temporal order of task types has been shown to matter as well, with certain temporal orders being more problematic than others. This is illustrated by the fact that, in the relevant studies, a shift from a functional structure to a divisional structure was less problematic (Moon et al., 2000). Finally, it is important to note that changes in the way a task is performed can occur even when the task itself does not change. For example, when a team increases in size, it may opt to divide tasks in a manner that capitalizes on specialization with respect to team member inputs. However, for the members who had performed that task earlier in a less specialized manner due to the constraints of small team size, prior

coordination patterns may persist. In sum, a key component of any team training needs analysis should be to determine the degree to which team tasks vary as well as how they vary both over time and in response to environmental stimuli.

2.1.3 Teammate Variability

Just as teams differ with respect to the tasks they perform, they also differ in the stability or variability of team membership. Further, these two dimensions are orthogonal such that a team may have stable membership combined with either stable or variable tasks. The reverse is also true. A team may have stable tasks with either variable or stable membership. The degree to which team membership is stable over time has also been studied as a moderator of team training effectiveness. Each time membership changes, members must engage in the process of team development anew.

Given the unique characteristics of the ISS with respect to training and crew changeover, particular attention needs to be paid to theories of team development. One specific model that may be informative in addressing the similarities and differences between ISS crews and more traditional teams is a theory of team development, which describes a set of partially overlapping phases that teams move through as they work together (Kozlowski, Gully, Nason, & Smith, 1999). This theory specifies four unique phases for team development: (1) team formation; (2) task compilation; (3) role compilation; and (4) team compilation. This model argues for soft transitions between phases; thus, no discrete and formal shift that is pre-defined. Whereas the term "stage" implies a discrete and fairly fixed or stepwise process, the term "phase" is meant to describe the more transitional nature of this activity. As such, it is intended to capture the idea that there are varied modal frequencies for these team processes across phases, that is, more of a "continuous series of phases, with partial overlap at transitions. Discontinuities occur at the transitions, but the shifts are not necessarily abrupt" (Kozlowski et al., 1999, p. 248). Thus, while there will be overlap of these processes across phases, the quantity of occurrence of particular teamwork processes will vary dependent upon the phase of problem solving. What needs to be explored with regard to LDSF is the developmental trajectory of space crews and how discontinuities in crews arising from abrupt changeovers will alter these phases. This is heightened by the fact that they work in close proximity for extended periods.

It has been demonstrated that team members who have worked together longer, report more positive attitudes toward one another, hold greater shared knowledge about one another's unique expertise, and demonstrate a greater willingness to engage in effective teamwork behaviors such as requesting and accepting backup when needed (Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009). When membership is highly variable, teammates have less time to develop positive knowledge and attitudes toward one another. Cannon-Bowers, Tannenbaum, Salas, and Volpe, (1995) described these as *team-specific* competencies. Unlike *team-generic* competencies (i.e. collective orientation, belief in the importance of teamwork, and communication skills), team-specific competencies are not transportable by an individual to any group of teammates he/she must work with. Instead, team-specific competencies must be redeveloped each time membership changes. As such, these competencies are not typically mentioned in job/task analyses, given their traditional focus on selection, rather than training. Whereas team-generic competencies could be assessed and used for selection, team-specific competencies, like team cohesion, are not meaningful without a particular group of teammates as a referent. Individuals themselves are not "cohesive." Instead, they feel cohesive toward certain teammates and not toward others.

With respect to team-specific knowledge, prior theory and research has shown that team performance is enhanced when members understand and agree upon one another's unique expertise, abilities, and preferences for task accomplishment (e.g., Austin, 2003). This knowledge is expected to make social information searches more effective and efficient (Moreland, Argote, & Krishnan, 1996). The term "transactive memory" has been used to describe the differentiated knowledge held by team or group members coupled with an understanding of the manner in which that knowledge is distributed within the team. A team activates its Transactive Memory System (TMS) when members cooperatively encode, store, retrieve, and communicate unique information on the basis of their transactive memories (Hollingshead, 2001; Wegner, 1987). Each time partial turnover occurs, a team's TMS is disrupted. Thus, in team task environments characterized by highly variable membership, tools and strategies for accelerating the development of TMSs are expected to facilitate coordination, and ultimately performance effectiveness. However, interventions such as off-site team building retreats, that have been shown to facilitate team-specific attitudes and knowledge in past research, are often impractical for these teams since the benefits of such training would be limited only to the length of time the teams they serve in remain intact. Consistent with this notion, Salas, Diaz Granados and colleagues (2008) found that formal off-site team training strategies had a greater impact on the performance of intact teams than on the performance of *ad hoc* (i.e., newly formed) teams.

2.1.4 Team Composition / Diversity

Membership variability can also affect team coordination by shifting the proportion of members holding certain demographic, personality, or cultural characteristics. Such variation in team composition can influence relational patterns within a team in ways that disrupt team functioning. This is most likely to occur when the pool of potential members used to replenish teams following turnover is highly heterogeneous. For instance, given similar levels of unfamiliarity, team coordination is likely to be more strongly affected by turnover if a team goes from being all male to being half male and half female, than it would be if its gender composition remained similar (Jackson, Brett, Sessa, Cooper, Julin, & Peyronnin, 1991). Harrison and Klein (2007) argued that team diversity is "the distribution of differences among the members of a unit with respect to a common attribute X, such as tenure, ethnicity, conscientiousness, task attitude, or pay," (p. 1199). For instance, teams can be described on a continuum with respect to similarity (homogeneous) or distinctness (heterogeneous) on a variety of different variables. Harrison, Price, and Bell (1998) explained diversity in teams in terms of surface and deep levels. According to Harrison and colleagues, surface-level diversity reflects the easily observed, biological characteristics that manifest in physical features (i.e., age, gender). Deep-level diversity, in contrast, is conceptualized as differences in members' attitudes and values. As compared to the easily visible surface-level characteristics, deep-level diversity is only identifiable through verbal and nonverbal behavior patterns evidenced over extended interactions. Yet, these deep-level variables are important to team performance. For example, research indicates that similarity in attitudes/values resulted in higher levels of cohesion (Terborg, Castore, & DeNinno, 1976).

In sum, membership variability not only increases the need for training team-specific knowledge and attitudes, it also influences the type of training strategies that are likely to result in the greatest return on investment. Thus, an important goal of any team training needs analysis should be to

determine the degree to which team membership is variable and the degree to which team-level composition, with respect to key demographic, personality, and cultural factors, varies.

2.2 Summary

The research summarized in the previous sections of this report was intended to communicate to readers the theoretical and empirical base that was drawn upon while developing our structured interview protocol and in interpreting the qualitative data generated by the interviews themselves. We identified three types of teams which, like LDSF crews, operate in high-risk environments and which appear to share several task, teammate, and organizational characteristics: ATC teams, aircrews, and military command and control teams (e.g., submarine crews). Each of these team types function within a 'high-risk system.' Specifically, (1) errors made by these teams have the potential to create a catastrophe, (e.g., loss of life, environmental damage); (2) the teams themselves work within highly interdependent multi-team systems; and (3) these multi-team systems are “tightly coupled, such that perturbations are transmitted rapidly between subsystems with little attenuation” (Perrow, p. 89).

In the following sections of this report, we detail our interview methodology. Then, we report the major themes extracted from the interviews and make comparisons to the three referent team task types just mentioned. In the final section of the report, we identify team-training requirements that are affected by these unique LDSF work characteristics, offer research questions and recommendations for the development, prioritization and evaluation of tools and strategies designed to facilitate team performance for LDSF crews.

3.0 Subject Matter Expert Interviews

3.1 Method

3.1.1 Sample

The sample comprised twelve NASA astronauts who had experienced at least one long-duration spaceflight mission (i.e., a mission three months or longer) at the time of their participation in the study. There was a mixture of male and female interviewees. The average age of the participants was 50 years. The sample was both ethnically and culturally diverse (exact diversity demographics have been omitted for anonymity purposes). Eight of the participants were born in countries other than the United States. Out of the twelve participants, four had completed Master's degrees and eight had completed Doctoral degrees. The disciplines in which the degrees were earned varied among the participants. In addition, four of the twelve participants had prior military experience.

The rank, tenure, and spaceflight experience of the participants also varied substantially. At the time of the study, the participants were classified as mission specialists, flight engineers, and/or commanders with NASA. The average amount of time each participant had been working at NASA as an astronaut averaged fifteen years. In addition, the amount of time that each of the participants had spent in spaceflight averaged 223 days. The length of their longest single spaceflight averaged 163 days and the total number of missions averaged to 3 (at the time of the study).

Interviewees were selected based on their long-duration spaceflight experience, their potential to provide a diverse perspective, as well as their availability. All participants were informed of the purpose of the study, notified of any risks and benefits associated with their participation, and were asked to provide informed consent. Further, all participants were treated in accordance with the guidelines set forth by the University of Central Florida's Office of Research and Commercialization and with those set forth by NASA's Committee for the Protection of Human Subjects.

3.1.2 Procedure

Interviews were conducted at Johnson Space Center (JSC), Houston, Texas. Semi-structured interviews were conducted over the course of five days during the months of February and June of 2010. Each astronaut participated in one or more interviews lasting anywhere from 30 to 90 minutes. Most astronauts participated in one interview that lasted approximately 60 minutes. During the interviews, two principal interviewers asked a series of open-ended questions designed to elicit information regarding the participants' experiences during long-duration spaceflight missions. Specifically, participants were asked to describe their experiences relating to team coordination, communication, cohesion, performance, leadership, and stress during long-duration missions. In addition, they were asked to describe characteristics of the individuals, the tasks, and of the physical, social, and organizational environments encountered during such missions. With the consent of the participants, all interviews were audio recorded for subsequent transcription and coding. In order to preserve confidentiality, the audio recordings were each assigned a unique participant identification number, and signed consent forms were stored separately from recordings, transcriptions, and coding

files. Additionally, all names used by interviewees in describing their experiences were omitted from the transcripts.

3.1.3 Transcription and Coding

Each interview was transcribed into a Microsoft Word document utilizing a naturalistic approach in which each utterance is captured in as much detail as possible (Oliver, Serovich, Mason, 2005). For example, grammar and interview noise (e.g., pauses, laughs, coughing) were recorded verbatim. Content analysis techniques (Bachiochi & Weiner, 2004; Krippendorff, 2004; Potter & Levine-Donnerstein, 1999) were utilized to derive core themes from the transcribed interview data files. In general, content analysis focuses on two phases: meaning condensation and meaning categorization. An initial coding scheme was developed based upon focal constructs of the research project and core competencies identified as necessary for astronaut candidates (top-down approach) identified by the NASA Missions Operations Directorate ITCB HBP Training Working Group (Bessone et al., 2008; Schmidt, 2008). However, additional coding categories were also derived based upon other constructs described by interviewees (bottom-up approach). A sampling of coded items appears in Appendix A. The complete coding file is available upon request.

3.2 Results

Content analyses of the structured interviews identified five team task characteristics associated with LDSF crews that differ in various degrees from those associated with our three types of referent teams. In the following sections we describe these characteristics and detail the manner in which they are unique from the characteristics faced by ATC teams, aircrews, military command-and-control teams (see Table 2 for a summary).

3.2.1 LDSF Team Task Characteristic 1: Variation in Task Interdependency

Members of LDSF crews perform tasks that vary significantly in their level of interdependency and include a significant number of tasks that are completely independent.

> *"For those two weeks, we were installing [deleted for confidentiality] … We worked together and had coordinated tasks. So we were very much a team."*
>
> *"10-20 percent [of our tasks] were interdependent… the majority certainly were independent."*
>
> *"…in the station, you are really kind of spread out most of the time, so it's not as much of a team dynamic when you are working. As I said, 75% of the time it's on your own."*

Compared to the highly interdependent tasks completed during short-duration shuttle missions, a common task characteristic identified by interviewees was that the majority of their time on the ISS involved working independently. A smaller number of pre-planned and highly critical tasks (e.g., extravehicular activities), however, required high levels of

reciprocal interdependency. Themes extracted from these initial interviews suggested that for many tasks on ISS missions to date (e.g., experiments, some technical glitches), collaborative problem solving regarding unplanned events/accidents is a low frequency, often-disjunctive task. Interviewees noted that in most circumstances one crewmember can correctly identify a problem and/or a solution. However, it was also noted that this single team member may be working closely with mission control staff. In these instances, the task of a single spaceflight team member (or small sub-team) may be more tightly coupled with mission control, than the actions of their fellow flight crewmembers. In sum, tasks completed as part of LDSF missions to date vary across the interdependency continuum, from completely independent to highly interdependent. On the basis of our initial interviews and on our review of relevant documentation, we expect that this unique work characteristic will also exist for crews on the other extreme long-duration missions such as the possible mission to Mars. However, a number of the astronauts interviewed noted that vehicle space limitations will likely reduce the degree to which the LDSF crew on a mission to Mars will bring independent projects with them.

The majority of the tasks performed by *military CIC teams*, *ATC teams*, and *aircrews* involve high levels of interdependency (i.e., sequential, reciprocal, intensive). Moreover, it is extremely rare for members of these teams to spend a significant amount of time performing tasks that are completely independent from the rest of the team. As a result, fluctuations in workload and stress are more synchronized for members of *aircrews* and of *CIC teams*. Members of *ATC teams* often experience increases in workload and stress on an individual basis, however, their physical proximity and interdependence makes it much more likely that one team members' stress will be noticed by and will affect other members. Thus, shifting between periods of almost complete independence and periods of extreme interdependence is a characteristic of LDSF teams that is unique.

3.2.2 LDSF Team Task Characteristic 2: Variability in Task Type and Tempo

LDSF crews experience high variability in both the type of tasks they perform over time and the tempo of task operations.

> *"A long-duration mission is very different… you have to make this transition from dynamic crew working together in a cohesive way, to a crew working efficiently, in orbit, with less schedule pressure and lack of ability to postpone events that you miss." "And so that means the crew now has to really shift gears. Once you're docked at the space station, now you've gone from… airplane mode to camper mode for sure."*

> *"…those first few weeks [on the ISS] are pretty laid back, in terms of tempo compared to space shuttle."*

> *"That transition from dynamic operations where everyone's a crew, extraordinarily well trained and prepared sitting on a launch pad and launching, and everyone works, speaks in turns … no one is out of turn, everyone knows their role and there's a huge efficiency. Up to the point where they start to get*

out of their seats and break out… fold out chairs, and start acting like in a galley. At that point it starts to turn into a camper and then things are unpredictable."

Interviewees discussed the variability in tempo of operations while on the ISS and the likelihood of even greater task tempo variability on a mission to Mars. For example, astronauts on a mission to Mars will likely have extended periods of boredom as they travel extremely long distances, but then will have to shift gears and engage in intense or highly focused activity in emergency situations or for scheduled experiments.

Each of the astronauts we interviewed also reported a wide variety of tasks they performed, ranging from routine maintenance to complex problem solving. Many of these problem-solving tasks could not be anticipated, nor trained, for prior to a mission. Finally, the astronauts noted that in past missions, changes in crew size during periods of crew turnover have required adaptation with respect to the manner in which tasks were performed.

Aircrews, and to a lesser degree, command and control teams and ATC teams, experience some degree of variability in task tempo. However, the variability in tempo described by the astronauts we interviewed appears to be much more significant. Similarly, aircrews, command and control teams, and ATC teams all face unexpected problem solving tasks. However, such novel problem solving tasks appear to occur with lesser frequency relative to the procedural tasks performed. Finally, *command-and-control teams* on *submarines* also have to deal with issues of crowding and competition for personal space and resources. However, these factors are a constant. In other words, crew size never changes. *Aircrews* often operate with 2 to 3 members but, again, this crew size tends to remain constant as well. *ATC teams* vary in size as a function of the level of traffic experienced by a particular tower. Within a tower facility, however, team size is typically very stable. Therefore, a unique feature of past long-duration missions on the ISS is the fact that astronauts had to adapt to variations in team size and the resulting changes in the manner that tasks are divided and performed over time. Although team training strategies have been tested on teams of variable sizes, little is known about team training for teams whose size changes over time. As such, coordination among both arriving and departing crewmembers during periods of crew changeover represents a unique challenge for ISS team training.

3.2.3 LDSF Team Task Characteristic 3: Variation in Teammate Familiarity

LDSF crews working on the ISS may have little or no significant prior training and/or familiarity with some of their teammates.

"We've been transitioning from this backup flow to this single flow to launch scenario, which is much shorter and the biggest impact I see is the crewmembers don't know their crewmembers nearly as well"

"Right now the current plan for the foreseeable future would be a crew of 3 onboard, another crew of 3 overlapping with them will arrive, when they depart, another crew of 3. So every crew of 3 will have two different other crews of 3"

"Each of those transitions is a little taxing"

"In a 2 and a half year training flow, this crew of 6 might be in the same country 2 weeks, in 2 and a half years…"

"[T]hey have 6 months…training with the prime crew. And in that 6 months they might spend 5 or 6 weeks together... and that's not enough time to understand the cultural nuances and the personality nuances of the different crewmembers…"

"…people and personalities that you're familiar with and you know how they work and then that totally changes. It's not like it gradually changes. It entirely changes when the hatch closes."

The twelve astronauts we interviewed reported that crew membership on the ISS changes every 3 to 6 months as new members arrive to relieve existing members. According to these interviewees, familiarity with new crewmembers varies substantially, with some having never met face-to-face prior to working together, some having extensive experiences together resulting from training or prior missions, and others having met in training or meetings for short periods of time, but maybe weeks, months, or even years prior to the mission. Conversely, the crew on a mission to Mars will almost certainly have extensive training together prior to their departure. However, it is unclear whether all flight crewmembers will have the opportunity to train with the specific ground crewmembers involved in a given mission.

Although many other types of teams experience variable team membership, the specific nature of membership variability that exists on the ISS is unique. For example, a*ircrew* members often have little or no familiarity with their crewmembers prior to a flight. However, they do not typically remain an intact crew for more than a day or two. Thus, the return on investment for teammate-specific training is typically not considered high enough. As a result, aircrew cockpit resource management training focuses almost exclusively on teammate-generic competencies. By contrast, many *ATC teams* have much more stable membership. Thus, it has been recommended that ATC team training incorporate strategies specifically designed to foster teammate-specific attitudes and knowledge (Smith-Jentsch, Baker, Salas, & Cannon-Bowers, 2001). Like ISS team members, members of *ATC teams* are trained to perform all major positions in the control tower yet they differ widely in their prior experiences with particular task problems. When task expertise is highly overlapping, the need to understand members' unique expertise is not as obvious nor is the identification of experts as clear. It has been shown in an ATC environment that in such cases, agreement regarding relative expertise is positively associated with the willingness to ask for or to accept backup from other members (Smith-Jentsch, et al., 2009). Similarly, the astronauts we interviewed noted that they often had little familiarity with one another's unique expertise and that this limited their ability to utilize one another effectively during problem solving and high workload periods when backup was needed.

Military CIC teams (e.g., *submarine teams)* experience limited turnover in membership during a deployment and undergo extensive training together prior to a deployment.

However, they often experience substantial turnover between deployments. These teams have the opportunity to undergo training focused on developing teammate familiarity and associated competencies prior to a mission. By contrast, *ISS crews* often have limited or no opportunities to do so prior to a mission. Thus, training strategies aimed at improving teammate familiarity for these crews should be flexible enough to be effectively utilized during missions.

3.2.4 LDSF Team Task Characteristic 4: Team Diversity

Members of LDSF teams must adapt to significant team- and multi-team-level diversity.

> *"I think it makes a difference whether or not there are multiple people with the same background or the same language…. It made a big difference on board to me whether I was with two Russians or two Americans and a Russian; it was a completely different environment for me. I didn't realize until the second half, what I had been missing in terms of the closeness of camaraderie...it makes a difference in terms of comfort level."*

> *"When I was there with two Russians, I was the odd one out since the language of communication on board was Russian, and so I would not always be the most vocal person around the dinner table, but I would try and stay engaged, [but] sometimes I wouldn't be [because] I couldn't follow and couldn't put up the effort sometimes."*

> *"Whether we want to admit it or not, we have tasks that are done on what we call the US segment and tasks that are done on the Russian segment. And always the lead guy is from that segment. There is a pretty clear correlation…if something is going to be done on this segment it's going to be the lead from that segment plus the other person from that segment."*

> *"The United States and Russia have a very different way of handling mistakes. Russian mistakes are counted on the ground and they're pay is actually docked by mistakes. So, not admitting to a mistake is financially [motivated]…"*

> *"I definitely think personality is going to play a huge role in the success of a particular mission." "There is a tone with every crew…For example. [Name] and [Name] did not have the same sense of humor as each other; one likes to goof off more, and one's more serious, and depending on how outgoing they are that mix can be completely different."*

LDSF crews are quite diverse with respect to culture, nationality, gender, and personality. Moreover, the particular diversity of an LDSF crew on the ISS changes with each partial turnover of ground and/or flight crew personnel. This influences team climate (e.g., formal, informal) as well as roles and information exchange patterns (e.g., interpersonal coalitions) within the team and multi-team system. Moreover, members of the in-group (most represented culture or interpersonally closest to the commander) may find themselves in the out-group after partial turnover has occurred. To the degree that climate arises from an interaction among team members, variation in team composition should influence team-level climate even in a situation in which the leader does not change. The pool of replacement

members that is drawn from to fill positions on the ISS is quite heterogeneous with respect to gender and national culture. Team-level composition within the crew on a mission to Mars, or other extreme long-duration missions will not vary, unless one or more members become incapacitated. However, the composition of ground crews will vary over time.

Certainly, membership turnover within *ATC teams*, *aircrews*, and *CIC teams* does not affect the cultural composition of these teams to the degree that it does for ISS teams given that the pool of replacement members is homogeneous in terms of national culture and language. Differences in gender composition do exist for *ATCs*, *aircrews*, and some *CIC teams*. However, submarine teams, who must live and work in close quarters similar to the ISS, consist to date of only male members. Thus, for these teams, crew turnover does not change the gender composition of the team. By comparison then, ISS teams are unique in the degree to which membership instability affects not simply familiarity with individual team members but also development of social factions associated with national culture.

Prior research has demonstrated the manner in which team composition with respect to variance in personality as well as the management style of team leaders can affect team functioning (e.g., Bell, 2007; Smith-Jentsch, Salas, & Brannick, 2001). Specifically, results have shown that individuals' willingness to engage in effective teamwork behaviors and to transfer what they have learned in team training is dependent upon the relative personality of other team members and the style of the leader to whom they are assigned. This has been identified as a challenge in prior research on *aircrews* and *ATC teams* as well. However, to date, there are no validated training strategies designed to give team members the skills to adapt to changes in team composition associated with personality and/or leadership.

3.2.5 LDSF Team Task Characteristic 5: Intense Isolation and Confinement

LDSF flight crews must live and work for long periods of time in a confined and isolated environment with a small number of crewmembers.

> *"The difference between the ground team and the crew team is that the ground team can disconnect themselves from the operation for a significant period of time."*
>
> *"… a 2 person crew on the space station is a, is a pretty unique thing. Um… it has its challenges from a levity point of view." "With a 2 person crew, it's hard to make jokes that make you both laugh without it being forced."*
>
> *"…tighter spaces, you'll have, say, I'm taking a wild guess here, four people, crammed into a vehicle that's much smaller than the space station. So it will be tight quarters."*
>
> *"You know it's sort of just like being married [laughing]. Dating is great but then when you start to throw your shoes around or you don't clean the toilet ever, people start getting tired of you. It's the same type of thing on here, just being conscious of your stuff, and where it is and what it's doing. That's the thing that I emphasized and you know we joke around because up in the office*

you can see who has a clean desk and who has got the messy desks and just you know that crewmembers going to be like that that crewmembers going to be like that…

"Say a year in a vehicle the size of a van for a year, I mean I've done it in a Soyuz for two days but I think that could be kinda tough. I think the complete lack of privacy would get bothersome after a while. Think it would be nice if the vehicle were designed so that everybody had a little bit of personal space, like a coffin space bunk with a curtain you could draw so at least have a little bit of privacy, I think that would be important to me. And maybe that's not possible, maybe we can't afford that, I don't know"

The crew on a mission to Mars expedition will live and work in a confined and isolated environment with a small number of teammates for an unprecedented amount of time. They will be limited to asynchronous communication with others outside of their crew given technology limitations and the extreme distance. Moreover, they will have to live with the knowledge that there is no option for them to return home prematurely. This level of extended isolation will exacerbate any potential conflicts among crewmembers as a function of personality or cultural differences. Each of the astronauts we interviewed noted the presence of such conflicts on the ISS.

Members of *aircrews* and *ATC teams* generally do not live together and, thus, experience breaks from interacting with one another. *Military CIC* teams, however, do live and work together. Submarine teams, in particular, live together in isolation for extended periods. A key difference, however, is that the size of a typical submarine crew is much larger than the size of a typical LDSF crew and the space they are confined to is much larger as well. Thus, LDSF crews are unique with respect to the fact that any face-to-face social interaction is restricted to a small number of individuals. This increases the likelihood that interpersonal conflicts will arise and when they do, members have limited opportunities to escape dealing with those conflicts. This is a unique characteristic of LDSF crews that will greatly affect the importance of certain competencies that members need in order to function effectively.

3.3. Summary

Overall, five team task characteristics unique to LDSF crews and expected to impact team training requirements based on prior research were identified: variation in task interdependence, variability in task tempo and type, variation in teammate familiarity, variation in team composition/diversity, and extended isolation/confinement. The following section specifies the expected impact of these characteristics on the team competencies (i.e., knowledge, skills, and attitudes) that LDSF crewmembers will need to develop during training in order to perform effectively during such missions.

4.0 Recommended Directions for Training Research and Development

The previous section of this report detailed five unique work characteristics associated with LDSF crews (see Table 2). In the present section of the report, we discuss the manner in which each of these unique work characteristics are likely to require team members to possess certain competencies (see Table 3), and therefore, affect the team training needs of LDSF crews. It follows that the inter-organizational validity of training developed to address these competencies for other types of teams will likely be limited by these factors. In some cases, this may require modifications to be made to existing training in order to maximize its utility, and in other cases, entirely new training content and strategies may be required. In the final sections of our report, we detail the manner in which the unique characteristics of LDSF crews should impact team competency requirements. We also identify a number of directions for future research that could inform the development of new training specifically tailored for the unique work characteristics faced by LDSF crews (see Table 3). Finally, we discuss the manner in which each of the competencies might be addressed through on-site (during a mission) and off-site (prior to a mission) training (see Table 4). In this regard, we organize our discussion by grouping the team training requirements according to the Cannon-Bowers et al. (1995), framework. This framework differentiates team competencies based on whether they are task-generic or task-specific, and whether they are teammate-generic or teammate-specific (see Table 1).

Table 1. Cannon-Bowers et al., (1995) Taxonomy of Team Competencies

	Teammate Generic	**Teammate Specific**
Task Generic	Transportable team competencies: Generalizable to new teams and tasks.	Team specific competencies: Generalizable to new tasks performed with the same team, but not to other teams.
Task Specific	Task specific competencies: Generalizable to new teams performing tasks members might have performed previously, but not to new tasks.	Team specific and task specific competencies: Not generalizable to new teams or new tasks.

4.1 Team Competency Needs Affected by Unique LDSF Team Task Characteristics

4.1.1 Task-generic, Teammate-generic Training Requirements

4.1.1.1 Collective orientation

> *"I look at the group as not only the ones on board but [also] the guys on the ground."*
>
> *"Most crews, to foster good climate, will at least eat one meal a day together as a crew, and make it kind of a social thing."*

The significant amount of time LDSF crewmembers spend performing independent tasks is likely to reduce their states of *collective orientation* during certain portions of their mission. Collective orientation has been defined as a team member's predisposition to engage in interdependent behavior; that is, collectively oriented team members "pool information, share resources, and check errors" and thus, benefit from interacting with others (Driskell & Salas, 1992, p. 279). Collective orientation has traditionally been viewed as an individual difference variable and thus a team- and task-generic competency that can be transported to new situations with new crewmembers. However, prior research has also demonstrated that collective orientation can be affected by situational factors. For instance, Smith-Jentsch, Zeisig, Cannon-Bowers, and Salas (1997) found that ATCs who worked at facilities where the tower and the radar facilities were physically separated had lower collective orientation than did those where the two facilities were located in the same building. Additionally, Driskell and Salas (1992) found that collective orientation was lowered when team members were under high workload/stress. ISS members spend a significant amount of time performing individualized tasks physically out of one another's view. This is also likely to be true of crews on a potential mission to Mars. Moreover, both ISS crews and crews on a Mars mission must regularly coordinate with members of various mission control crews (1) from whom they are physically separated, (2) whom they may have never had face-to-face contact with and (3) whom they often experience delayed communications with. In essence, members of these physically separated, yet mutually dependent teams may be more or less strangers working under conditions that require the utmost trust and deference to expertise. When team members lose their collective orientation, they fail to consider others who may potentially provide them backup and assistance. They may also fail to consider the manner in which their actions could negatively affect another crewmember. Finally, they are unlikely to notice situations in which they could potentially provide or request backup and assistance.

The astronauts we interviewed indicated that maintaining and/or regaining a state of *collective orientation* was currently an unmet team training need. To be effective for LDSF crews given their unique team task characteristics, training strategies designed to address this need should include on-site methods that can be employed to address fluctuations in the level of interdependence among team members.

4.1.1.2 Information exchange

> *"My crew invented a procedure to put [the loss of power] right. It was never written down and never blessed by the Russian control center as a technique. And it was never really debriefed either. They never really had any time to ask us "What was it that you did?" So when the new crew arrives, and the old crew has left, this thing happens again. And now the new crew has no experience with this problem."*
>
> *"And, in that time we were just hearing from the station commander of the day which was (name). He was saying "Look we need to at least get together for an hour and discuss what each other's expectations are for food. You know do we*

want to have a meal every day together do we want to… you know… just discuss who wants to sleep where?"

"And this way, (Through indirect handover procedure where the old and new crews overlap for about 3 months) you are learning over the course of several months from the other guy whenever it comes up, it's like "hey, how do you do this?" "Why is this?" you know… "Am I doing this wrong?" "Why is this so hard?" you know, you can learn from the guy that's been there longer."

Effective *information exchange* occurs when members can anticipate one another's needs for information and pass that information without having to be asked for it (Smith-Jentsch, et al., 1998). It also involves knowing whom to seek different types of information from and fully utilizing all those potential sources of information. Finally, information exchange involves providing big picture summaries to ensure the team's shared situation awareness. When team members lose collective orientation they are likely to miss opportunities to seek and to pass relevant information. Therefore, the fact that LDSF crewmembers spend a substantial amount of time performing independent tasks is likely to affect their information exchange processes. Training designed to support information exchange for LDSF crews will need to incorporate specific instruction on how to know *what* information to pass team members regarding one's independent tasks and *when* to pass that information. Moreover, training designed to support information exchange should include instruction that helps astronauts identify what information to share about their unique expertise that is unfamiliar to their teammates and when to do so. Finally, training for information exchange should provide guidance that assists LDSF members in identifying situations when they need to seek or share information regarding role expectations or task strategies that may be specific to their culture, nationality, or training that could otherwise cause conflict when interacting within a diverse team.

4.1.1.3 Supporting behavior

"Sometimes we're scheduled for tasks together, sometimes we're scheduled independently. And on days that we're scheduled independently, some are more heavily tasked, or have hard tasks, or have things that are more intense let's say than others."

"Some people were incredibly busy and others were very bored." "A couple of crewmembers had almost nothing to do. And they read book after book after book…other crewmembers had an enormous amount of stuff to do."

"I felt totally inhibited in going to ask (name) to help me, to break him out of what he was doing…And I just, you know, cursed myself, It was a terrible situation to be in, where I've not even thought to ask [for help]."

"We had an electrical failure on board that caused us to lose com with the ground for a matter of hours... So, we worked through this thing and all I can tell you was we were double-checking, triple-checking every step we took because if you get off this path you are basically starting over, so it was a big

deal. But I would point to that as a bright spot in terms of interaction, crew cohesion and all that…"

Effective *supporting behavior* involves monitoring teammates for errors, pointing out those errors, and/or correcting those errors when they occur (Smith-Jentsch et al., 1998). Additionally, it involves providing and requesting backup from one another by shifting workload as needed. The fact that ISS members frequently vary with respect to their level of workload means that they often have the opportunity to provide such backup. However, if they do not pick up on the cues that another team member needs backup, such opportunities will be missed. High task interdependence provides numerous opportunities to notice that another member is overloaded. However, when members perform tasks independently, teammates must make explicit efforts to seek information about one another's level of stress/workload. Our analysis revealed that a unique aspect of this competency for LDSF crews is that members spend a significant amount of time performing highly independent tasks. This is also likely to be true for crews on other extreme long-duration missions. Thus, training designed to facilitate supporting behavior for LDSF crews should incorporate instruction on monitoring and providing support to teammates during periods when they are performing independent as well as inter-dependent tasks.

4.1.1.4 Flexibility/Adaptability

"That transition from non time critical ops to dynamic operations is a key transition for any team, and it's one that I think needs to be formally recognized as a transition that should be practiced and briefed"

"I believe that the greatest danger is this pitfall where a crew member, where a crew can make a mistake, because they didn't transition from the laid back to the dynamic ops."

"When you come to a dynamic operation, where you have irreversible, physical events, events that have very, very, very costly, consequences, and possibly safety ones, the great danger is that you wake up after a month of same routine every day the task list of doing (name)'s experiment and then suddenly, this day, you now have to do the spacewalk and you just don't ramp up fast enough in terms of attention to detail, and crispness of the time line."

Flexibility/adaptability skill has been defined as the ability to alter a course of action or team repertoire in response to changing conditions (Salas, Sims, & Burke, 2005). Results from our interviews suggest that members of ISS crews perform highly variable tasks. First, tasks vary in unpredictable ways as ISS teams react to unanticipated problems such as equipment malfunctions and even accidents. Second, planned tasks vary widely in terms of their level of interdependence and tempo. Finally, the manner in which planned tasks are performed varies over time as a function of changes in team size. Thus, adaptability and flexibility is a crucial team competency for LDSF crews. Research on social entrainment suggests that specific breakdowns in team coordination can be anticipated when shifting from one type of task structure to another. As such, training could be developed that specifically prepares LDSF members for such breakdowns. For instance, a large team can benefit from a division

of labor that is highly specialized. This training would be team-generic but task-specific. Other strategies could be developed to address adaptability to unexpected events and such training would be both task- and team-generic. This team training need will also exist for crews on a mission to Mars.

Through our analysis, we have noted that there are certain re-occurring changes in situational demands that long-duration spaceflight crews must adapt to. These are changes in tempo/pace, changes in team size, and changes in task interdependency. As a result, we recommend that training be developed to train crewmembers to anticipate and effectively adapt to these specific changes.

LDSF crewmembers also must adapt to other members that vary in diverse ways with respect to nationality, culture, gender, personality, and expertise. If specific types of conflicts can be anticipated with respect to specific types of team diversity, LDSF members could be trained to expect such conflicts and to modify their strategies for interacting within such crews as a result. Thus, adaptability training for LDSF crews should emphasize both task-focused adaptation as well as interpersonal-focused adaption.

4.1.1.5 Team leadership skills

> *"It is important to share and pick up tips. You need to be receptive to that. Someone who's been up there for a long time has had a chance to work with something. There are nuances of how to make it work better"*
>
> *"You are learning over the course of several months from the other guy "hey, how do you do this?" "Why is this?" "Am I doing this wrong?" "Why is this so hard?" you know, you can learn from the guy that's been there longer."*
>
> *And I look at them and say "Well I know what to do." And I am a "nobody" in the technical leadership chain of this crew. And so they look at me and go "We're not going to do that." "That was an awkward situation…"*
>
> *"There is a tone with every crew" "It all depends on who the commanders are, because the commanders can set the tone completely…and that's very personality dependent."*

As we have mentioned earlier in this report, ISS crews face many situations that could not be anticipated and trained prior to their missions. This requires them to innovate and to develop new solutions to solve those problems. This new knowledge developed by the team members needs to be shared with one another so that the team can make best use of it as a resource. In this respect, member variability and task variability jointly present a challenge for ISS crews such that members possessing unique knowledge leave and new members not possessing that knowledge enter with little time for the transfer of this knowledge. Members of a mission to Mars crew will not experience this turnover. However, they will be isolated for a much longer period of time and will experience situations that are likely to be far more novel than do ISS crews. As such, it will be critical that they effectively mentor and coach

one another. This means that members must all possess *team leadership skills* so that they can share in the responsibility for developing and guiding their team.

Moreover, prior research has shown that team diversity can have both positive and negative effects on team performance and that this depends on the leadership style of the team leader. Specifically, teams with leaders demonstrating transformational leadership behaviors seem to be able to harness the benefits of team diversity more effectively than teams with a leader who does not demonstrate those behaviors (Shin & Zhou, 2007). The four primary behaviors that transformational leaders engage in are (a) inspirational motivation (i.e., articulating a vision that is appealing and inspiring to followers), (b) idealized influence (i.e., behaving in admirable ways that cause followers to identify with the leader), (c) intellectual stimulation (i.e., challenging assumptions, takes risks, and solicits followers' ideas), and (d) individualized consideration (attending to each follower's needs, acting as a mentor or coach to the follower, listening to the follower's concerns and needs; Judge & Piccolo, 2004). Given the fact that ISS crews experience substantial changes in member diversity on surface features over time, we consider it of critical importance that commanders as well as all members are trained in team leadership skills associated with a transformational leadership style.

4.1.1.6 Emotion regulation

> *"You have to be extraordinarily tolerant and understanding of the room to which people can move in."*
>
> *"One of my crew, um, came up relatively late in the mission, was not an efficient worker he knew how to get his stuff done, and you know, he's a very low key kind of guy. He would take a nap during the day and he'd just sleep in his Kaiota with the door open, which is the sleep station with his door open…" [And another member] would get very perturbed by him." [I told him] "he is getting his job done, just let it go". "But he couldn't let it go…"*
>
> *"I think if a crew can address an irritation immediately, it's so far ahead, of those that, don't say something right up front. The first time something bothers you, then you have to deal with it... But if something really gets your goat, and it could just be you're weak, it's just your weakness, your idiosyncrasy, you need to communicate that it's getting your goat." "Some people are not very good at it."*
>
> *"I think when you have, uh, sort of a, call it a conflict, or something like that, um… it's rare that, well, I don't know what's rare, what's, you know, common, it doesn't, for me anyway, it's rare that you sort of discuss it, you say, "Ok, now I get it" and then all the emotion associated with it just dissipates. I mean it takes hours or days, something like that, for it to go away…"*

Emotion regulation skills refer to the ability of individuals to influence which emotions they have, when they have these emotions, and how they experience and express the emotions

(Gross, 1998). The astronauts we interviewed noted the propensity for experiencing negative emotions as a function of conflicts arising from differences in personality and/or culture. Moreover, they noted that the fact that ISS members live and work together in isolation can exacerbate these negative emotions.

Prior research on the relationship between work and non-work mood and satisfaction has demonstrated that negative affect arising from interactions in either realm of life spills over and causes negative mood and dissatisfaction in the other realm of one's life (Heller & Watson, 2005). In this way, discord resulting from diversity in member personalities is likely to have a spiraling effect, becoming more and more troublesome over time unless crewmembers find a way to resolve such conflict. This represents, in our view, a significant team training need for LDSF crews. Each of the astronauts we interviewed described having to adjust to changes in team composition with respect to personality after partial crew turnover has occurred. Moreover, the astronauts described the manner in which these shifts in team composition influenced the climate within the crew and ultimately the level of cohesion and/or conflict between crewmembers.

Recent research on emotion regulation suggests that individuals can be trained to change their cognitions about situations and therefore avoid negative emotions rather than experiencing the emotions and attempting to suppress them and that this improves cognitive performance (Keith & Frese, 2005). Specifically, emotion regulation training that focuses on "deep acting" involves instructing trainees to restructure their cognitions about situations and the motives of others (Grove & Fisk, 1989). The fact that ISS crews live in isolation with their teammates for long periods of time makes it likely that diversity in personality and in culture will serve as primary root causes for interpersonal conflicts. Thus, training for emotion regulation would likely be most effective if it incorporated specific information about various personality types and cultures to assist members in restructuring their cognitions regarding the motives and methods of other teammates as a means of preventing negative emotions regarding their behavior whenever possible.

4.1.2 Task-specific, Teammate-generic Training Requirements

4.1.2.1 Inter-positional knowledge

> *"Because of this segmented operations [sic], we kind of divided up and as a result of that, I think there've been some areas where we don't have that insight as much as we should. We're pushing to get the commanders enough information that they will understand the big picture on the Russian segment. We are trying to get the Russian commanders enough information to know what's going on, on the U.S. segment so that they know what's going on there."*

> *"One of my crewmembers went and installed it [new hardware] and plugged it in where the procedure told him to plug it in, but in order to do that, he flipped a switch off which the other socket was a Russian payload"*

Inter-positional knowledge is a task-specific, team-generic knowledge competency involving members' understanding of the unique tasks being performed by those holding positions or roles other than their own. The fact that astronauts are cross-trained on many of the core and reoccurring safety-related tasks on the ISS means that they possess high levels of *inter-positional knowledge* regarding those tasks and the manner in which they are interdependent. However, the astronauts we interviewed noted that they typically had very little, if any, information about one another's independent projects. At least two potential problems arise from this. First, it was noted that crewmembers occasionally unintentionally interfere with one another's goal progress. Second, opportunities to assist one another are not capitalized upon. Based on our interviews, it appears that *inter-positional knowledge regarding one another's independent tasks* represents a currently unmet ISS team training need that is also likely to become a team training need for other extreme long-duration missions.

4.1.3 Task-specific, Teammate-specific Training Requirements

4.1.3.1 Shared role expectations

> *"The crew that came up to take me home didn't have any expectations of what my role would be…so that role is being developed on the fly while you're doing an activity."*
>
> *"So arriving on the MIR to a 2 person crew, Russian crew, with a third person who I was replacing, a NASA astronaut, I had no knowledge of how they ran their crew. I didn't even know if my role was going to be an operational one as a crew member or as a guest researcher."*
>
> *"When you're starting to form the team I think it's important that everybody should have a meeting or briefing, and sit there with the team, and talk about everybody's culture and where they rub or where they don't rub so that people are aware, as you're getting to know each other, what those biases or what those, you know, ingrained attitudes are so that you can recognize when you run into one in training that'll really help communication."*

The limited amount of time ISS members spend training together prior to performing as a team results in a deficiency with respect to team- and task-specific knowledge. Specifically, each of the astronauts we interviewed described the lack of *shared role expectations* among crewmembers after partial turnover has occurred. *Shared role expectations* are agreed upon plans regarding the manner in which a specific group of teammates chooses to perform a task and to divide responsibility among themselves with regard to those tasks. *Shared role expectations* enable teams to respond more quickly and to perform tasks more efficiently due to the reduced need for explicit coordination during task execution.

Team diversity with respect to culture, nationality, gender, expertise, and personality is likely to create significant diversity in LDSF members' role expectations as well. Training designed to assist LDSF members in developing shared role expectations will need to provide strategies for identifying or anticipating these differences and in negotiating a shared

understanding in this respect. Given that members may have limited time to train together prior to a mission, strategies for achieving shared role expectations during a mission will be needed.

4.1.4 Task-generic, Teammate-specific Training Requirements

4.1.4.1 Team cohesion

> *"I think that our first allegiance is almost always to each other, us crewmembers. Then, it's to our control centers."*
>
> *"I look at the group as not only the ones on board but the ones the guys on the ground. You have to have them have trust in us and us to have trust in them to know that what they told me to do…[I may not know why but I] just go and do it."*
>
> *"[On adopting an attitude of] Ok, do your thing and we'll do our thing," [that is] not good for crew cohesiveness."*
>
> *"[Of factions within the team based on nationality] "They're getting this and we aren't getting that" and "why can't we just share, we are all just one station"...*

Members of long-duration spaceflight crews must work together in isolation for long periods of time. This means that they must rely on one another for their own survival and for the success of the mission as a whole. This requires that members possess a sense of team cohesion. Team cohesion has been defined as a dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its instrumental objectives and/or satisfaction of group members' needs (Carron & Brawley, 2000; Beal et al. (2003). Team cohesion is an affective psychological state that emerges from the experiences and interactions that occur among team members. It is comprised of interpersonal attraction among team members, a shared commitment to team tasks, and feelings of team pride (Barrick et al., 2007; Beal, Cohen, Burke, & McLendon, 2003). Many challenges exist for LDSF crews in pursuit of strong and positive team cohesion. Among these are that they are multi-cultural, spend a significant amount of time performing independent tasks, and must live and work together without breaks for a long period of time. As they rely on ground crews as well, it is important that ground and spaceflight crews feel a sense of team cohesion toward one another.

When viewed in terms of the unique work characteristics identified in the present analysis, training for the maintenance of team cohesion over time must incorporate content that specifically addresses how to do so in light of these challenges.

4.1.4.2 Knowledge about teammates

> *"Say you are on a fire scenario. You have the ability through a laptop to open a circuit breaker while the other two are down in another module potentially with*

smoke and have a mask on. …you are not going to willy-nilly decide who [should play what] role." "You are going to want to use all the resources you have… [For example,] …"you would probably be best person to get on the laptop [because] you speak the clearest Russian."

"That idea of just getting together and talking about what do you think my capabilities are or I think your capabilities are this, I would be happy to know you're the one that should be doing that…."

Astronauts on the ISS have highly overlapping expertise on most of the tasks that are critical to their safety. However, they vary substantially with respect to the unique types of problems they have encountered during previous missions. They also differ with respect to their fluency in different languages. Thus, while they are interchangeable in many respects (i.e., regarding critical roles and preplanned tasks), they are not interchangeable in terms of their ability to solve unique and unexpected problems. With each partial turnover of team membership, members must develop team- and task-specific knowledge about their new teammates' unique expertise, preferences, and work habits. The astronauts we interviewed reported that the development of such knowledge about teammate characteristics represented a currently unmet ISS team training need. The crew of a mission to Mars expedition will certainly have extensive time training together prior to their mission. Knowledge of teammate characteristics should be among the learning objectives for such training. Moreover, a mission to Mars crew will almost certainly experience ground crew turnover during their mission, thus knowledge about ground crewmembers' unique expertise and other characteristics should be addressed over time as well.

As we have noted earlier in this report, shared and accurate knowledge about teammate characteristics enable TMS to function (Hollingshead, 2001; Wegner, 1987). A TMS is a set of individual memory systems in combination with the communication that takes place between individuals (Wegner, 1987). Moreover, it is the collective knowledge within the team and the awareness of where the knowledge is held. Thus, each time partial turnover occurs, a team's TMS is disrupted potentially resulting in errors and inefficiencies. One day, a particular astronaut may be the most knowledgeable about a particular type of equipment but after a crew change, a new member may be the most knowledgeable. The remaining members of the prior crew may not revisit this issue thinking that they know who to go to for questions regarding that piece of equipment. Thus, training designed to foster knowledge about teammates' expertise for the ISS will need to incorporate on-site strategies that can be used during periods of membership turnover. Moreover, given that the need for different types of expertise will vary over time and will often be unpredictable during a mission to Mars, on-site strategies for updating and detailing teammate-specific knowledge in light of new problems should also be relevant for this context as well.

4.2 Candidate Training Strategies

4.2.1 Task-generic, Teammate-generic Competencies

The previous section highlighted team competency requirements that are affected by the unique work characteristics existing for LDSF crews. Of these, the following would be considered task- and team-generic: (1) Collective Orientation, (2) Information Exchange, (3) Adaptability/ Flexibility, (4) Supporting Behavior, (5) Team Leadership Skill, and (6) Emotion Regulation Skills. The following sections of this report discuss appropriate methods for training these competencies.

4.2.1.1. Off-site training

Team competencies that are both task-generic and team-generic are ideal candidates for off-site training prior to a mission. Such competencies are relevant, regardless of changes to mission goals or crew membership. Task- and team-generic competencies do not require the training of intact teams. In fact, some of the training for these competencies can be accomplished through *self-paced computer-based training, behavior role-modeling, and simulation*. For instance, multi-media computer-based simulation whereby an individual responds to video-based characters has been shown to significantly improve conflict resolution and emotion regulation skills (Potocnik, Smith-Jentsch, Garcia, & Yarbrough, 2010; Feldman, Smith-Jentsch, & Afek, 2008). Other skills are best trained in a group environment, yet this training does not necessarily require individuals to train with members of the crew they will ultimately work with. For instance, prior research has demonstrated that individuals trained in team leadership skills using behavioral role-modeling and simulation-based training were able to effectively transport those skills to other intact team environments (Smith-Jentsch, 2008).

4.2.1.2. On-site training

Prior research has demonstrated the negative effects of physical separation and high workload/stress on team members' states of collective orientation and emotion regulation skills. Thus, it is likely that collective orientation and emotion regulation will have to be re-trained over time on-site to account for the long-term effects of physical separation, stress, and extended periods of task independence. Prior research has demonstrated the validity of indirect/un-obtrusive measures of collective orientation and emotion regulation. For instance, Driskell and Salas, (1992) asked team members simply to describe tasks or situations and evaluated their use of "we" and "us" versus "I" and "they" to determine their state of collective orientation. Such measures could be automated using word search programs or even speech recognition software and could serve as tools for identifying decrements in collective orientation states. Strategies for *guided self-reflection* can then be used to aid individuals in adjusting their collective orientation states and emotion regulation skills.

As we have noted earlier in this report, time constraints appear to hinder the transfer of expertise among ISS crewmembers, particularly during periods of member turnover. Thus,

whereas off-site training is best suited for imparting the communication skills necessary for effective leadership as well as conflict resolution and emotion regulation, on-site tools and strategies such as structured team debriefing methods will likely be necessary to ensure that members recognize and utilize opportunities to engage in such behaviors.

4.2.1.3 Research questions supporting team training development

Prior research has demonstrated the effectiveness of various strategies for training adaptability in teams and individuals (e.g., Ford et al., 1998; Chen, Thomas, & Wallace, 2005; Kozlowski et al., 2001). Research on social entrainment suggests that team coordination can breakdown in predictable ways when teams become accustomed to a certain task structure and are suddenly required to adopt a different task structure. Moreover, this research suggests that the problems associated with such transitions differ as a function of the direction of the change. There is some evidence, however, that suggests teams can be trained to modify their strategies in adaptive ways (Salas, Nichols, & Driskell, 2007). However, this prior research did not specifically address coordination breakdowns associated with the particular dimensions upon which ISS crew tasks regularly vary (i.e., team size, tempo, task interdependency). Thus, research designed to address the following research questions is recommended in order to develop the content for such training.

- *Research Question #1: Can we identify specific coordination problems associated with shifting from a small to a large team and vice versa? Do these problems vary as a function of task interdependency?*

- *Research Question #2: Can we identify specific coordination problems associated with shifting from a fast paced to a slower paced task tempo and vice versa? And, do these problems vary as a function of task interdependency?*

- *Research Question #3: Can we identify specific coordination problems associated with shifting from an independent to an interdependent team task and vice versa?*

Prior research has begun to demonstrate performance decrements with respect to team diversity (Bell, 2007). However, in order to develop training content that would address conflict resolution and team leadership skills that are specifically tailored to address particular configurations of team personality or particular configurations of cultural composition additional research is needed.

- *Research Question #4: Can we identify specific coordination problems associated with team diversity on specific traits (e.g., conscientiousness, extraversion)? And, do these problems vary as a function of task interdependency?*

- *Research Question #5: Can we identify specific coordination problems associated with team diversity on specific cultural dimensions?*

4.2.2 Task-specific, Teammate-generic Competencies

One of the team competencies highlighted through our team task analysis as unique and critical for training needs for ISS and extreme long-duration missions crews can be classified as task-specific and team-generic. This is *inter-positional knowledge*.

4.2.2.1. Off-site training

Off-site training to promote inter-positional knowledge does not require that the specific members who will comprise a particular team be identified. It does, however, require that the tasks to be performed have been defined well in advance of the mission. Prior research has demonstrated that cross-training is an effective means of promoting inter-positional knowledge (Volpe, Cannon-Bowers, Salas, & Spector, 1996). Three levels of cross-training were defined: *informational cross-training*, *positional modeling*, and *positional rotation* (Blickensderfer, Cannon-Bowers, & Salas, 1998). It has been suggested that the level of cross-training needed for a given type of team is dependent on the level of task interdependency and the degree to which members are physically separated from one another.

Informational cross-training involves providing information to teammates regarding the manner in which their tasks' goals and procedures can potentially facilitate or hinder one another. *Positional modeling* goes further by actually demonstrating the performance of tasks performed by teammates working different positions. Finally, *positional rotation* involves allowing members to actually practice performing one another's tasks. To the degree that it is desired for members to have the capability to replace one another in the performance of a task, *positional rotation* is recommended. In the context of a long-duration spaceflight mission, this would include tasks critical for safety that must be performed by someone. Therefore, if a crewmember responsible for one of those tasks is incapacitated another member can perform the task satisfactorily. By contrast, for independent discretionary tasks, the primary goal for inter-positional knowledge is to prevent interference among team members. An example of this may be the independent experiments that are performed by individual members. In the event a team member is unable to perform this task, other team members are not held responsible for completing the task. For such tasks, *informational cross-training* is most appropriate. Finally, when members will not necessarily serve as replacements, but perform highly interdependent tasks, *positional modeling* is recommended. This is particularly true when members are physically separated and thus do not otherwise have the opportunity to observe one another performing inter-positional tasks. Off-site methods of delivering cross-training include *simulation-based training, behavior role-modeling*, and *classroom seminars*. For tasks that are relatively stable across missions, *computer-based training* could be developed and administered remotely. For tasks that vary with each mission (e.g., experiments), *classroom-based training* and/or *semi-structured online chats* could be used.

4.2.2.2 On-site training

It is likely that off-site training alone will not be sufficient for addressing the need for LDSF crews to possess inter-positional knowledge for at least two reasons. First, the details

regarding experiments to be performed independently by crewmembers from various nations appear to change frequently, making off-site training in advance of a mission insufficient or impractical. Second, given the length of time that crew on extreme long-duration missions will be gone, it is likely impractical to expect that members can acquire and maintain all of the inter-positional knowledge that will be relevant to them during the course of the mission solely through off-site training. As a result, on-site methods such as *structured debriefing methods*, *on-site coaching*, and *demonstration* are likely to be necessary. With respect to the development of inter-positional knowledge regarding ground crew tasks, *semi-structured online chats* and *multi-media computer-based training* that can be delivered at a distance are also candidate methods.

4.2.2.3 Research questions supporting team training strategy development

- *Research Question #6: What are the critical aspects of members' independent tasks that need to be understood by other team members?*

4.2.3 Task-specific, Teammate-specific Competencies

One of the team competencies highlighted through our team task analysis as unique and critical training needs for ISS and extreme long duration mission crews would be considered both task- and team-specific. Below we discuss examples of how the training need for this competency, *shared role expectations*, can be filled through off-site and on-site training.

4.2.3.1. Off-site training

Off-site training to promote shared task expectations requires that the membership of a crew for a particular mission and the tasks associated with that mission are specified in sufficient detail well in advance of a mission. In situations when this is the case and when members of these intact teams can be brought together for training in the same location, *simulation-based training* accompanied by *structured debriefing techniques* have been shown to be highly effective strategies for enhancing task- and team-specific knowledge (Smith, Cannon-Bowers, Tannenbaum, & Salas, 2008). When teammates cannot be physically brought together for training, such training can be accomplished through technologies such as video-teleconferencing or electronic chat. For instance, we have argued earlier that members of ISS crews often lack inter-positional knowledge regarding one another's independent tasks, which appear to primarily involve experiments that each is responsible for conducting. Given the limited amount of shared training time and the likelihood that the timing of these opportunities will not coincide with the finalization of information about experiments, *semi-structured online chats* between crewmembers are likely the most efficient method of training inter-positional knowledge regarding independent tasks in advance of a mission.

4.2.3.2 On-site training

Task goals and plans appear to change frequently for members of ISS crews. Moreover, time constraints may prevent off-site training for task- and team-specific knowledge. Therefore, on-site training strategies will be critical components of team training for ISS crews. This will certainly be the case for crewmembers on other extreme long-duration missions, such as a mission to Mars due to the sheer length of the mission. The same strategies used to train

task- and team-specific knowledge off-site can be applied for training on-site. The use of simulation will depend of course on the availability of such technology on-site. However, *structured debriefing methods* can be easily employed on-site for the spaceflight crews themselves and for training that includes both the space and ground crews.

4.2.3.3. Research questions supporting strategy development

Although prior research has demonstrated positive relationships between shared role expectations and team performance, it has also been demonstrated that the quality of the task strategies and expectations that team members agree upon moderates this relationship. Thus, team training strategies designed to foster shared role expectations must incorporate features that prevent teams from over-emphasizing agreement to the extent that dissenting opinions are not expressed. Thus, the development of strategies for developing shared role expectations would benefit from additional research which investigates the following question.

- *Research Question #7: How can teams be trained to come to consensus on role expectations while still encouraging productive discussion of competing alternatives?*

4.2.4 Task-generic, Teammate-specific Competencies

Of the team competencies highlighted through our team task analysis as unique and critical training needs for ISS and mission to Mars crews, the following would be considered task-generic but team-specific: (1) *Knowledge about teammates* and (2) *Team cohesion*.

4.2.4.1. Off-site training methods

Off-site training for task-generic and team-specific competencies requires that intact crews have been defined, but not necessarily that their mission/tasks have all been specified. This training can include *team building exercises* involving any sort of tasks that are likely to enable members to develop familiarity with one another's personalities, habits, preferences, personal goals, and unique expertise. They can also be used to develop positive team-specific attitudes such as cohesion. *Simulation-based training* accompanied by *structured debriefing methods* can also be used to accomplish these training goals. In the event that crewmembers are not able to train in the same physical location, *semi-structured online group chats* and other forms of distance communication may be used to train these same competencies.

4.2.4.2 On-site training strategies and methods

Due to the expected variation in team cohesion over time as various events and conflicts arise, indirect measures of team cohesion should be used to monitor this competency on a periodic basis. Similarly, as partial turnover in membership occurs, on-site measures of knowledge about teammates' unique characteristics can be used to focus on-site training strategies. Such measures should include members of ground crews as well. Analyses of these data should determine whether any deficiencies noted are systemic or are limited to either sub-components or individuals within the team. This will allow for tailored on-site training interventions. *Team building exercises, guided self-reflection strategies (*in the case

where an individual is experiencing low cohesion), and *structured debriefing methods* are examples of techniques that can be used alone or in combination to remedy problems noted.

4.2.4.3 Research questions supporting strategy development

Recent research has demonstrated that individuals demonstrate predictable patterns of increased and decreased job satisfaction over time that are associated with beginning and ending jobs (Boswell, Boudreau, & Tichy, 2005). It may be that team members also demonstrate predictable patterns of increased and decreased team cohesion as a function of changes or duration of team membership (e.g., the so-called "honeymoon" and "hangover" effects). The timing of desired measurements for team cohesion could facilitate effective intervention if research were conducted to address the following questions.

- *Research Question #8: Can we identify consistent patterns of decay with respect to team cohesion over time?*
- *Research Question #9: Can we anticipate decrements in team cohesion on the basis of team composition with respect to personality or culture?*
- *Research Question #10: Can we anticipate decrements in team cohesion on the basis of critical team events?*
- *Research Question #11: Does the effectiveness of various strategies for developing and maintaining team cohesion depend on the degree to which deficiencies in cohesion are systemic or limited to a component or individual on a team?*

4.3 Summary

The preceding section of this report detailed a number of team training needs that are expected to be influenced by the unique team task characteristics of LDSF crews. Specifically, we have discussed the manner in which specific attitude, knowledge, and skill competencies will need to be defined and trained differently due to the unique task environment faced on the ISS and for a planned mission to Mars. Finally, we have noted directions for future research that should inform the development of such team training strategies and discussed the degree to which each of the training needs can be fulfilled through either on-site or off-site training.

Table 2. **Unique Work Characteristics of Long-Duration Spaceflight Crews**

Task Characteristic	**ISS Crews**	**Extreme Long-Duration Missions (e.g., Mission to Mars Crews)**	**Aircrews**	**Air Traffic Control Teams**	**Command and Control Teams**
Variability in Task Interdependency	Perform tasks that vary on a continuum of interdependency, including a substantial proportion of time performing completely independent tasks	Will perform tasks that vary on a continuum of interdependency, probably fewer independent tasks	Primarily reciprocal interdependency, no significant independent tasks	Sequential and reciprocal interdependency, no significant independent tasks	Primarily reciprocal interdependency, few if any independent tasks
Variability In Task Tempo and Task Type	Experience significant variability in task tempo, and both predictable and unpredictable variability in task type.	Experience significant variability in task tempo and both predictable and unpredictable variability in task type.	Yes, but to a much lesser degree than LDSF crews	Yes, but to a much lesser degree than LDSF crews	Yes, but to a much lesser degree than LDSF crews
Variability in Teammate Familiarity	Experience substantial crew turnover every 3-6 months and often have little or no familiarity with new teammates.	Will experience turnover of ground crewmembers only, will likely be familiar with one another prior to mission	Experience frequent (often daily) turnover with little or no prior teammate familiarity	Frequently utilize replacement members from same facility.	Experience limited turnover during missions and more substantial turnover between missions.

Table 2. **Unique Work Characteristics of Long-Duration Spaceflight Crews**

Task Characteristic	**ISS Crews**	**Extreme Long-Duration Missions (e.g., Mission to Mars Crews)**	**Aircrews**	**Air Traffic Control Teams**	**Command and Control Teams**
Team Composition/ Diversity	Experience substantial diversity with respect to culture, nationality, gender, expertise, and personality.	Experience substantial diversity with respect to culture, nationality, gender, expertise, and personality.	Experience diversity but within a smaller crew. Little diversity in nationality.	Experience diversity, but little diversity in nationality.	Experience diversity, but no diversity in nationality.
Isolation and Confinement	Live and work together for long periods of time with small group of individuals	Live and work together for long periods of time with small group of individuals	Do not live together	Do not live together	Live and work together, but with a much larger group of individuals.

Table 3. LDSF Training Needs and Associated Research Questions

Type of Training Requirement	Competencies	Research Questions
Task-generic Teammate-generic	Collective Orientation Information Exchange Supporting Behavior Skill Adaptability/Flexibility Skill Team Leadership Skill Emotion Regulation Skill	○ *Research Question #1:* Can we identify specific coordination problems associated with shifting from a small to a large team and vice versa? And, do these problems vary as a function of task interdependency? ○ *Research Question #2:* Can we identify specific coordination problems associated with shifting from a fast paced to a slower paced task tempo and vice versa? And, do these problems vary as a function of task interdependency? ○ *Research Question #3:* Can we identify specific coordination problems associated with shifting from an independent to an interdependent team task and vice versa? ○ *Research Question #4:* Can we identify specific coordination problems associated with team diversity on specific traits (e.g., conscientiousness, extraversion)? And, do these problems vary as a function of task interdependency? ○ *Research Question #5:* Can we identify specific coordination problems associated with team diversity on specific dimensions of culture?

Type of Training Requirement	Competencies	Research Questions
Task-specific Teammate-generic	Inter-positional Knowledge	○ *Research Question #6:* What are the possible positive and negative effects of members holding inter-positional knowledge about one another's independent tasks?
Task-specific Teammate-specific	Shared Role Expectations	○ *Research Question #7:* How can teams be trained to come to consensus on role expectations while still encouraging productive discussion of competing alternatives
Team-specific Task-generic	Knowledge about Teammates Team Cohesion	○ *Research Question #8:* Can we identify consistent patterns of decay with respect to team cohesion over time? ○ *Research Question #9:* Can we anticipate decrements in team cohesion on the basis of team composition with respect to personality or culture? ○ *Research Question #10:* Can we anticipate decrements in team cohesion on the basis of critical team events? ○ *Research Question #11:* Does the effectiveness of various strategies for developing and maintaining team cohesion depend on the degree to which deficiencies in cohesion are systemic or limited to a component or individual on a team?

Table 4. Training Guidelines for Task-specific/Generic, Team-specific/Generic Team Competencies

Type of Training Requirement	**Competencies**	**Training Guidelines**	
		Off-Site Training	**On-Site Training**
Task-generic Teammate-generic	Collective Orientation Information Exchange Adaptability/Flexibility Supporting Behavior Team Leadership Skill Emotion Regulation Skill	• Self-paced Computer-based training • Behavior Role Modeling • Simulation	• Guided self-reflection
Task-specific Teammate-generic	Inter-positional Knowledge	• Informational Cross-training • Positional Modeling Cross-training • Positional Rotation Cross-training • Simulation-based training • Behavior role-modeling • Classroom seminars • Computer-based training • Semi-structured online chats	• Structured Team Debriefing Strategies • On-site Coaching • Demonstration • Semi-structured online chats • Computer-based training
Task-specific Teammate-specific	Shared Role Expectations	• Simulation • Semi-structured Online Chats • Structured Team Debriefing Strategies	• Structured Team Debriefing Strategies
Task-generic Teammate-specific	Knowledge about Teammates Team Cohesion	• Team Building Exercises • Simulation • Structured Team Debriefing Strategies • Semi-structured online chats	• Team Building Exercises • Guided Self-Reflection Strategies • Structured Team Debriefing Strategies

5.0 Conclusions and Next Steps

Results of the task analysis component of the team training needs analysis identified five unique task characteristics of LDSF missions that are expected to impact the importance of team competency requirements, the manner in which those competencies are defined for the purpose of training, and the degree to which on-site and off-site training is appropriate. These task characteristics include: variation in task interdependence, variability in task tempo and task type, variability in teammate familiarity, team composition/diversity, and isolation/confinement. Based upon these characteristics, ten team competencies were identified. Team competencies reflect the constellation of knowledge, skills, and attitudes required for effective team performance that should be included in training efforts designed to optimize LDSF team performance. These competencies were categorized along two dimensions: (1) the degree to which the competency was *team generic* or *team specific* (i.e., degree that the competency is transportable across teams) and (2) the degree to which the competency was *task generic* or *task specific* (i.e., transportable across tasks). For each type of team competency, we identified potential training methods and research questions that need to be answered in order to support the development of training for LDSF crews (see Table 3 and 4).

This report will be followed by two additional reports which focus more specifically on trainee characteristics and environment/organizational characteristics (e.g. hierarchical structure, leadership structure) that are known moderators of training effectiveness. In combination, these three reports are designed to identify core training needs for LDSF, map team competencies to these needs, and identify training strategies and methods relevant for developing these team competencies. Selected training methods and strategies identified in these reports will be tested in future field and laboratory studies.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2015	Technical Memorandum

4. TITLE AND SUBTITLE
Training "The Right Stuff": An Assessment of Team Training Needs For Long-Duration Spaceflight Crews

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS
S-1205

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-2015-218589

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/Unlimited
Available from the NASA Center for AeroSpace Information (CASI)
7115 Standard
Hanover, MD 21076-1320 Category: 53

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This report describes a team training needs analysis dedicated to identifying characteristics of the task environment Long Duration Space Flight (LDSF) crews face that are both unique to this type of team and are expected to have a significant impact on team competency requirements and the strategies used to address those training needs. The current report is organized into four sections. First, we synthesize literature indicating the major categories of team task characteristics that have been shown to moderate team training requirements and effectiveness. Second, we describe the methods used to interview twelve National Aeronautics and Space Administration (NASA) astronauts during the months of February and June 2010. Third, we identify five task characteristics associated with LDSF crews that were derived from transcripts of the interviews conducted that are both unique to this type of team relative to other teams operating in high risk environments and are expected to impact team training requirements. Fourth, we identify the specific team competency requirements that should be impacted by these unique characteristics. Finally, we identify research questions that should be answered in order to inform the development of strategies designed to address these unique team training needs.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
training analysis; astronaut training; training evaluation; space flight training psychological factors; personnel development; analysis; analyzing; psychology; astronaut performance	62	

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