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Identifying Thematic Patterns of Autonomy Shifts and Team Boundary Work for Long Duration Spaceflight Multiteam Missions

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IDENTIFYING THEMATIC PATTERNS OF AUTONOMY SHIFTS AND TEAM BOUNDARY WORK FOR LONG DURATION SPACEFLIGHT MULTITEAM MISSIONS

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ABSTRACT

As long duration exploration missions (LDEMs) become the norm for spaceflight, it is important to understand the factors that may influence how astronaut crews and ground control teams work together. Although there are numerous efforts underway to continue to push boundaries in space exploration, much of the existing work to examine teamwork is designed to primarily address intrateam issues, not considering how inter-team factors may predict team and mission performance. Given the potential future challenges and uncertainties of LDEMs, the National Aeronautics and Space Administration (NASA) has identified a need for risk-mitigating spaceflight multiteam system (SFMTS) interventions designed to resolve or prevent inadequate cooperation, coordination, communication, and psychosocial adaptation, both within and between component teams. This study serves to begin to break apart the specifics of how shifting inter-team autonomy is exhibited within teams (i.e., crew claiming, mission control granting) in space and what team boundary work (i.e., buffering) looks like in SFMTSs. Regarding inter-team autonomy shifts, we saw that the majority (65%) of the 100 critical incidents coded exhibited this shift. Further, most of these autonomy shifts were triggered by the space crew claiming its autonomy from Mission Control. Almost half (46%) of the critical incidents exhibited an inter-team autonomy shift triggered by “crew claiming”. Additionally, our findings focused around team boundary work showed that multiple types of team boundary work were often exhibited per critical incident. Buffering and Reinforcement were identified as the top team boundary work types, followed closely by Reinforcement and Spanning. The results show that very rarely is only one type of team-boundary work shown when there is an inter-team autonomy shift. The current team boundary work patterns found indicate the types of functional boundary work needed for inter-team autonomy shifts in complex spaceflight multiteam systems. These patterns were derived using the critical incident method and are descriptive of behaviors that could be used as the basis of team boundary and inter-team autonomy shift training for SFMTSs in LDEM. Implications of the findings from this study and future directions are further discussed.

DEDICATION

This work is dedicated to my parents, Mariana Salazar and Richard Alvarado, and my sister, Luciana Alvarado for always loving and supporting me. Without their enormous sacrifice and courage of moving to this country eighteen years ago, I likely would never have pursued a graduate degree nor been exposed to the opportunities that continue to shape my individual growth.

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INTRODUCTION

As National Aeronautics and Space Administration (NASA) prepares for *Return to the Moon 2024* (Gohd, 2019) and subsequent long duration exploration missions (LDEMs), efforts will be heavily implemented via spaceflight multiteam systems (SFMTSs), made up of multiple, interdependent *component teams* working towards mission success while physically apart from one another (Mathieu, Marks, & Zaccaro, 2001). To further clarify, multiteam systems (MTS) have been described as “two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals” (Mathieu et al., 2001, p. 290). Multiteam contexts are tasks that require a higher level of analysis than the individual and team, but a level lower than the organization and possibly extending across boundaries of multiple organizations (Mathieu et al., 2001). Tasks performed by MTSs create uniquely challenging situations as they often require coordination of efforts from multiple component teams that are often previously unacquainted. Further, MTSs often require a collective effort bringing together multiple areas of expertise found in the individual teams to tackle challenges in new, unconventional ways (Lanaj, Hollenbeck, Ilgen, Barnes, & Harmon, 2013; Marks & Luvison, 2012).

The efforts of SFMTSs, when properly coordinated, can achieve unprecedented advances in spaceflight, yet they are at an incredible risk for major collaboration breakdowns (Vessey, 2014, p. 135-153). Significant challenges relevant for team risk include social isolation, physical confinement, communication delays between crew and ground, as well as a long duration, and a high consequence environment. Each of these conditions affect the coordination, cooperation and overall performance of the team. Teams in space are isolated from Earth, and sometimes may also experience some limited psychological isolation (Landon, Vessey, & Barrett, 2016). However, real-time communication technologies (e.g., communication loops with Mission Control Center (MCC), Internet Protocol (IP) phone) and other video and instant messaging technologies (e.g., email, video messaging, internet) ensure current space crews such as those on the International Space Station (ISS) remain connected to colleagues, professional support, and friends and family on Earth (Khasawneh, Rogers, Bertrand, Madathil, & Gramopadhye, 2019; Landon et al., 2016).

Thus far, space vehicles have been designed to be primarily controlled from the ground making MCC the leaders of all spaceflight missions, whereby the crew acts solely through the leadership direction of MCC (Landon et al., 2016; Rogers, Khasawneh, Bertrand, & Madathil, 2017). This arrangement depends heavily on effective coordination across the SFMTS, especially during emergency situations. While this structure has worked thus far, in future LDEMs communication delays due to the distance of the spaceship as it travels away from Earth, will eliminate real-time communication between crew and ground teams (Mesmer-Magnus, Carter, Asencio, & DeChurch, 2016; Rogers, Khasawneh, Bertrand, & Chalil Madathil, 2019). Such communication constraints will inevitably require greater spaceflight crew autonomy from MCC, however little is known about the changing levels of autonomy and the impact of autonomy on the team over long duration. In this vein, autonomy becomes a potential risk factor for the MTS. For the context of SFMTSs, autonomy is defined as the "conditions, constraints, and limits that influence the degree of discretion by the astronaut or crew over choices, actions, and support in accordance with standard operating procedures" (Rubino & Keeton, 2010, pg. 20). SFMTS autonomy increases will likely modify training needs and necessitate mission planning that accounts for higher involvement from the crew, in terms of procedures, structure, and even crew composition (Rubino & Keeton, 2010).

To date, there have been no studies of autonomous crews in spaceflight for long duration missions specifically (Landon et al., 2016). However, a recent related study involving ISS crew members explored the impact of communication delays of roughly one hour with MCC on performance and well-being (Palinkas et al., 2013). In this study, autonomy was positively associated with crew and team performance, as well as crew well-being. However, autonomy was not found to mediate the relationship between communication delays and outcomes, suggesting communication delays and autonomy have a unique influence on performance and health outcomes. Additionally, the Astronaut Journals Project (Stuster, 2010) identified outside communications with MCC as the second-most stated category, suggesting the importance of well-established communication systems in the SFMTS. For example, ISS members communicate daily with personnel in MCC at the Johnson Space Center in Houston, Texas as well as with payload communicators (PAYCOMs) located at the Marshall Spaceflight Center in Huntsville, Alabama.

The current teaming and communication challenges experienced in SFMTSs are not caused directly by communication system issues, but rather by interpersonal frustrations between the parties communicating with each other. It is important to acknowledge that LDEMs will lack the ability of instant communication between ground and space crew, thus possibly complicating the interpersonal frustrations even more. Moreover, it is likely that the intricacy of future LDEMs will require increased crew discretion, less troublesome procedures, and general flexibility to perform tasks (Krikalev, Kalery, & Sorokin, 2010). These would grant the astronaut crew more autonomy from MCC, but with this freedom comes an increased responsibility and self-reliability for dealing with not only day-to-day tasks but also emergency situations that may come up. Thus, communication, goal, and leadership structures will probably need to shift, resulting in successive changes in how these MTSs and their component teams will work together (Zaccaro, Marks, & DeChurch, 2012).

Given these changes, there is a need to understand how the different component teams must be prepared in terms of having the right attitudes, behaviors, and cognitions in place - at both the team and system levels - in order to be prepared for such autonomy shifts. We must focus on understanding the effects not only on the crew but on the system in order to develop appropriate countermeasures. Therefore, this research effort seeks to advance our understanding of autonomy shifts and boundary spanning processes in space in order to provide practicable countermeasures NASA can take in preparation for LDEMs.

The study of SFMTS in LDEMs is challenging at best due to the nature of such teams and the relative frequency with which such teams exist. Therefore, this study employs historiometry - a "collection of methods in which archival data concerning historic individuals and events are subjected to quantitative analyses in order to test nomothetic hypotheses about human thought, feeling, and action" (Simonton, 1998, p. 269). MTSs are particularly advantageous to explore with historiometry, as they are often well-documented as a source of success or failure in complex events (e.g., DeChurch, Burke, Shuffler, Lyons, Doty, & Salas, 2011). Specifically, this study seeks to utilize this approach to abductively uncover thematic patterns in prior SFMTS critical incidents that outline when and how autonomy shifts are likely to occur for SFMTSs and inter-team boundary spanning processes that are critical for responding effectively as a system when autonomy shifts occur.

The Role of Multiteam Systems in Spaceflight

For the purpose of this work, it is important to ensure clarity around MTSs in spaceflight. The SFMTS is comprised of multiple connections beyond the simple crew/ground MTS, including a network of Mission Control teams within teams, and extending across multiple agencies (e.g., NASA, International Space Agencies, ESA) and specializations (e.g., astronauts, flight controllers, engineers). For example, the International Space Station can be thought of as a long duration MTS, whereby mission controls for different international agencies (e.g., NASA, Russian Federal Space Agency) must work together to ensure the crew is supported during missions. In addition to coordinating with their crew members on the ISS, the mission control centers must also coordinate with one another, and may have additional component teams that must coordinate as MTSs to handle issues or needs as they arise. Another example of a MTS operating in spaceflight could be a launch MTS, whereby different component teams are responsible for planning and preparing the crew and space vehicle for launch. This can involve engineering teams for the vehicle, psychological and health support teams for the crew, and a leadership team for the actual lead up to countdown and launch.

Further, based on interviews with NASA personnel conducted by various researchers (e.g., Burke & Feitosa, 2015; DeChurch & Mesmer-Magnus, 2015; Shuffler, Jiménez-Rodríguez, & Kramer, 2015), there are four types of SFMTSs which represent the structural features likely to play key roles in influencing relational states within and across teams (depicted in Figure 1). These MTS types vary in terms of the degree to which differences in disciplines, shared context, uncertainty and/or culture will shape team and interteam relations. In this vein, one can see how space crew isolation from the SFMTS has several implications on team performance.

To further understand the challenges faced by SFMTSs, it is important to mention that previous astronauts have noted systematic issues in regards to the ground and crew relations stating “I continue to be amazed by the degree to which the ground has gotten into the habit of taking action and not informing the crew”, “I still get frustrated by the degree to which we get left out of the loop. This has been a perpetual problem in the ISS crew world”, and “the ground too often fails to consider the crew when making decisions and taking action (Stuster, 2010, p. 31).” This type of divide between crewmember and ground will be particularly challenging for LDEMs whereby immediate and frequent communication will no longer be an option. Despite the previous complaints regarding ground and crew relations, there is still a deep gratitude and connection between these component teams, and it would be irresponsible to leave out comments regarding this effect. Previous astronauts have noted their appreciation for MCC by stating "I am surely glad the ground is watching our backs. That really makes me feel better (Struster, 2010, p. 18)". Thus, we can see that the spaceflight MTS is a complex system that requires a multi-faceted approach to understanding the many factors that influence it. We must acknowledge that the heavy dependency from crews on MCC won't be possible during LDEMs, as ground will not be able to provide immediate assistance. Therefore, the extended communication delays will necessitate the need for positive system relations between crew and ground prior to space flight and the capacity to manage autonomy shifts without negatively impacting team performance.

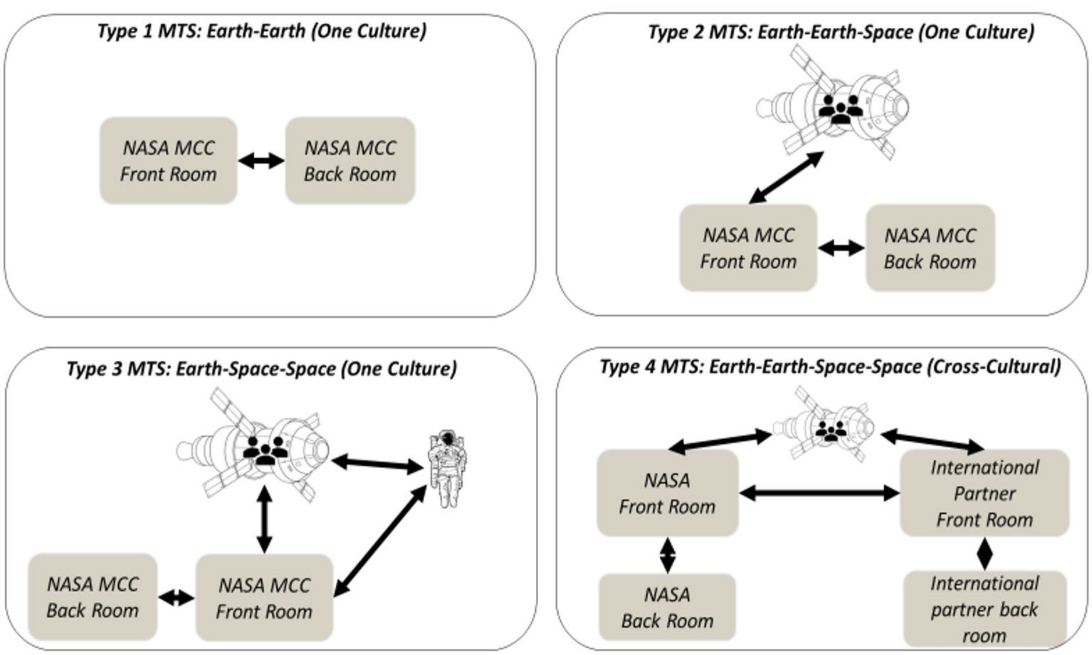

Figure 1. *Four types of SFMTSs (Shuffler et al., 2015).*

Autonomy Shifts & Communication Delays in LDEM SFMTSs

Communication is one of the most vital aspects to interactions among individuals, teams, and MTSs. A literature review by Shuffler, Jiménez-Rodriguez, and Kramer (2015) on MTSs points to communication as being particularly critical to MTS effectiveness. In this review, communication was shown as a construct that has received significant empirical/theoretical attention in being an important inter-& intra-team mediator for functional/dysfunctional behavior processes in MTSs (see Figure 2). Further, an operational assessment previously conducted by Shuffler and colleagues (2015) notes interviewees discussed the importance of inter and intra-team communication, especially regarding the anticipated communication delays. Interviewees noted, "we expect there to be a greater number of disconnects and misunderstandings between ground and crew". LDEMs will experience greater delays than ever before in communication, demanding increased autonomy for the astronaut crew that may have profound unprecedented effects on the MTS performance.

Indeed, the anticipated autonomy shifts will have a profound effect on multiple aspects of the team including managing day-to-day activities, such as making decisions or solving various problems that may arise (Khasawneh, Ponathil, Firat Ozkan, & Chalil Madathil, 2018; Leach, Wall, Rogelberg, & Jackson, 2005). Increases in autonomy have shown to have positive effects, having an impact on multiple outcomes such as improved performance and satisfaction (Thompson & Prottas, 2006; Leach, et al, 2005). Thus, we can expect benefits in LDEM MTSs due to the anticipated autonomy shifts. For example, the flexibility and autonomy the astronaut crew will be given is something that has been missing in current missions and a factor in causing annoyance/problems between space crews and ground.

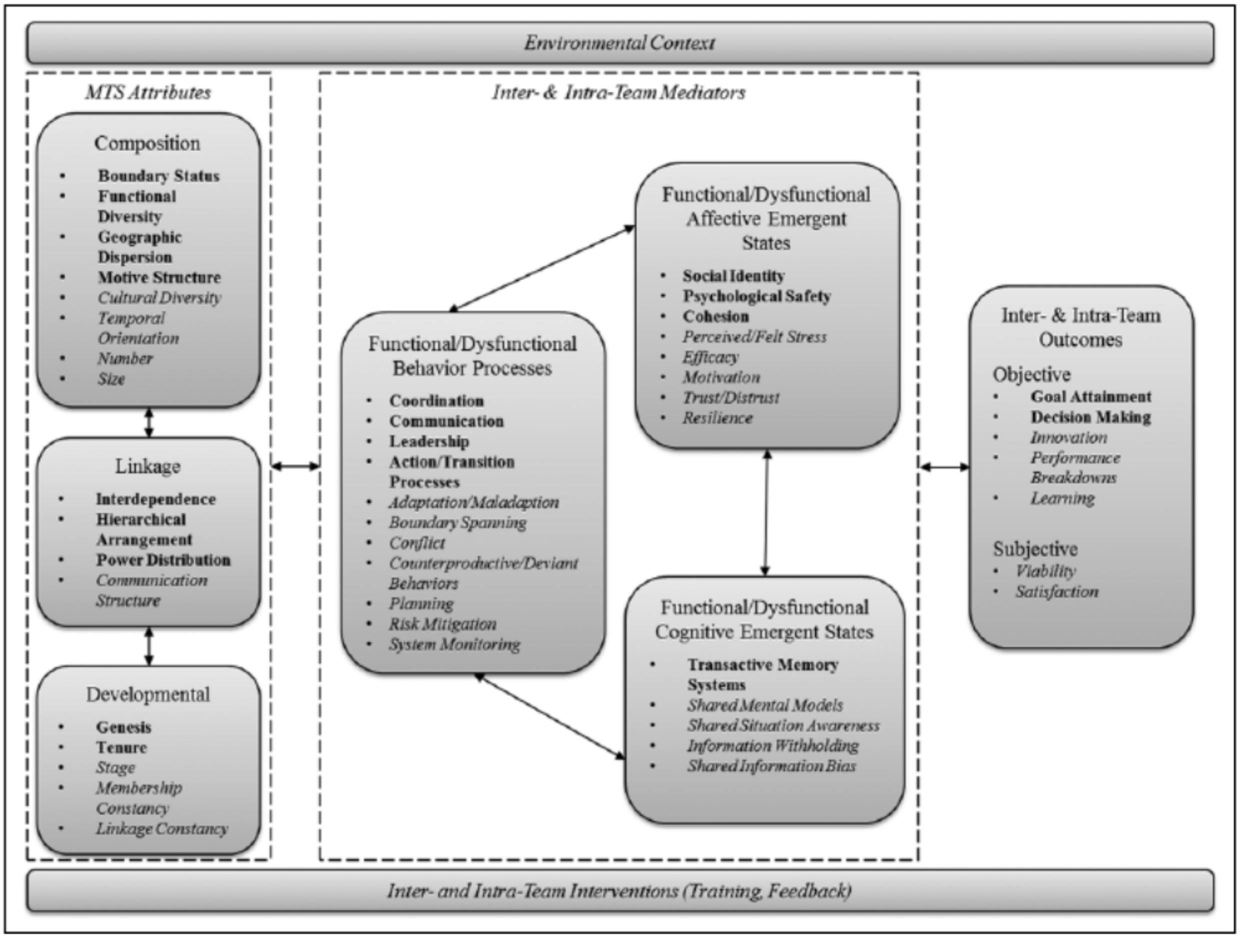

Figure 2. *Summary of multiteam systems research framework.*
Note: Bold items represent constructs with significant empirical & theoretical attention, while italicized are constructs in need of future research/theory (Shuffler, et al., 2015).

Stuster (2010) noted that the space crew is aware that good relations with ground personnel can contribute to effective task performance, but this has led to a tradition called "praise inflation", in which the spaceflight crew partakes in giving out profuse complements, even when not deserved, and a general avoidance of criticizing the ground personnel for deficiencies, real and perceived. Further, it seems that at least a portion of the ground personnel are more sensitive to certain remarks than the crew in space, a condition known to cause hypersensitivity and exaggeration of trivial issues. Thus, rather than facilitating the relationships between ground and on-orbit personnel, praise inflation and hypersensitivity are a source of annoyance to most crew and ground members.

Further, while mission success and performance is always the first priority for spaceflight missions, it is just as important, especially in LDEMs, to consider how increases in autonomy influence intermediate outcomes, such as team cohesion (Man & Lam, 2003), motivation (Langfred & Moye, 2004; Spector, 1986) and inter-team trust (Langfred, 2005). LDEMs involve many unique stressors due to the nature of spaceflight (Vessey, 2014), thus increases in team autonomy in these difficult situations may subsequently reduce the stress of the situation. Karasek (1979, 1998) suggests that stress increases when demands are high, as is particularly accurate in LDEMs, and when there is little control or autonomy over the situation. In this vein, one method for reducing high levels of stress experienced in LDEMs would be to increase the autonomy of the component teams, particularly of the spaceflight crew itself.

While research shows hopeful promise in the benefits autonomy can bring to performance, we must remember that an autonomous spaceflight crew has not been known to exist thus far. Therefore, autonomy shifts pose novel risks for MTSs that should be carefully considered. It has been established that due to the distance from Earth on LDEMs, communication delays between ground and crew are expected, thereby reducing the level of interdependence between teams in the MTS and increasing the level of autonomy teams will experience. Vessey (2014) suggested that communication delays will hinder effective coordination between component teams, reducing the quality of teamwork between teams and restricting the ability of the MTS to successfully complete their mission. Further, these delays in communication will also limit the amount of support (e.g. informational, social) ground control can provide to the spaceflight crew (Kanas et al., 2007) during routine tasks but also novel or emergency tasks alike. This will force the spaceflight crew to adapt to the limited inter-team communication and the shifting inter-team autonomy.

With this in mind, the current research seeks to uncover thematic patterns of autonomous crew behavior throughout critical incidents in prior SFMTs to further our understanding of what situations/contexts look like that either required an autonomous shift in the crew (e.g., communication issues) or in which the crew simply engaged in autonomous behavior and what the outcomes were. Thus, this research seeks to address the following research questions:

RQ 1: How is shifting inter-team autonomy exhibited within the space crew in SFMTSs?

Team Boundary Work

It is not enough to solely uncover the context and outcomes related to inter-team autonomy shifts; instead it is necessary to uncover the behaviors and processes enacted during inter-team autonomy shifts. Recently, research has started to acknowledge team boundary work as an important component for SFMTS effectiveness (Pendergraft, Carter, Tseng, Landon, Slack, & Shuffler, 2019). Team boundary work has been defined by Faraj and Yan (2009) as the activities that a team engages in to establish and maintain boundaries that are open enough to allow information and resources in, yet established enough to avoid uncertainty about who is on the team and who is held accountable for its collective outcomes.

Accordingly, team boundary work can be thought of as work done by members of the component team that involves acquiring information and resources while also managing relationships with external stakeholders and protecting internal team resources (e.g., team members' time and energy) from competing demands (Reagans & Zuckerman, 2001). To further clarify this concept, research regarding boundary spanning has identified three distinct types of boundary work: boundary spanning, boundary buffering, and boundary reinforcement (Davison & Hollenbeck, 2012; Faraj & Yan, 2009). The following section summarizes each type of boundary work and articulates the research questions I seek to answer specifically in terms of understanding boundary work in SFMTS.

Boundary Spanning

Boundary spanning has been defined as a strategy of engagement, in which a focal team undertakes actions to reach out into its environment in order to acquire important resources and support. Druskat and Wheeler (2003) reported that undertaking boundary spanning actions strongly affects team performance. Through boundary spanning, teams reach out to secure necessary resources and support in order to accomplish the team goal, while also developing relationships with stakeholders and promoting the team's work. Boundary spanning is an important activity that helps the team accomplish its objectives, thereby contributing to MTS performance as a whole (Davison & Hollenbeck, 2012; Agnisarman, Khasawneh, Ponathil, Lopes, & Madathil, 2018).

Boundary Buffering

Unlike boundary spanning, boundary buffering is a strategy of disengagement, in which a team closes itself off from the environment. A team buffers in order to protect itself from external disturbances and uncertainties, consequently enhancing the possibility of successful performance within (Lynn, 2005). Further, researchers have suggested that buffering may be undertaken either in response to or in anticipation of disruptive factors within the environment. It is important to note that evidence of buffering has shown to involve both formal strategies and procedures as well as informal codes and norms for deflecting these external disturbances and outside pressure or interference within the environment (Faraj & Yan, 2009). Boundary buffering strengthens the team's boundaries against external disturbances and protects its members by creating an internal atmosphere free from unnecessary disruptive factors, thereby contributing to team performance.

Boundary Reinforcement

Boundary reinforcement is a less studied type of boundary work in comparison to buffering and spanning. This type of boundary work refers to the ways in which a team internally sets and reclaims its boundaries by increasing member awareness of boundaries and enhancing team identity. Thus, boundary reinforcement is inward-facing work that is focused on factors internal to the team. Through boundary reinforcement, teams can maintain members focused on carrying out the team's task, possibly increasing team identification and commitment and enhancing individual and collective learning and creativity (Lovelace, Shapiro, & Weingart, 2001), thus contributing to team performance.

Boundary Work in LDEM SFMTSs

Due to the unique nature of LDEMs, it is important to take into account environmental factors that may influence team boundary work. Previous research suggests that team boundary work may be context dependent and task specific (Ancona & Caldwell, 1990). For instance, a team in an uncertain environment may engage in boundary buffering and reinforcement more heavily than it engages in spanning in order to reduce environmental demands impending performance (Faraj & Yan, 2009). LDEMs in space rely on the coordinated efforts of the SFMTS that crosses organizational, geographic, cultural and temporal boundaries (Anania et al., 2017). Thus, as team boundary work can be influenced by the situation and context a team operates in and as boundary work processes can be developed and reinforced prior to and during SFMTS missions, this study seeks to answer the following research questions:

RQ2: When faced with shifting inter-team autonomy, *what* team boundary work types (e.g., spanning, buffering, reinforcement) have been utilized, and what is their impact on SFMTS outcomes?

RQ3: When faced with shifting inter-team autonomy, *how* are SFMTSs boundary work types (e.g., spanning, buffering, reinforcement) implemented?

METHOD

Historiometry

Given the challenges that LDEMs and spaceflight contexts pose in terms of securing adequate data collection opportunities, the present research study utilizes historiometric analysis (HMA) to investigate the constructs of interest using archival sources, in line with others who have studied these contexts (DeChurch et al., 2011). The HMA method has been present in the social sciences for more than a century and is generally defined as the systematic analysis of the content of past events through review and coding of previously published media documenting historical events and persons, such as biographies, periodicals, and written histories (Crayne & Hunter, 2018). This method is particularly useful for organizational sciences, because it allows researchers to convert historical content into numerical data that may be further analyzed statistically.

Crayne and Hunter (2018) argue that the usefulness of HMA is further amplified when unique or rare data samples, context and situational specifics, and/or longitudinal data are examined--all of which is the case for SFMTSs. Additionally, in a recent study on team leadership using HMA, Burke, Shuffler and Wiese (2018) note that historiometry is especially useful when exploring relatively new constructs which have not been thoroughly examined or understood (such as LDEMs), and also suggest that HMA benefits from the "contextual richness of the data and the corresponding external validity" (p. 8). Specifically, recent studies have relied on inductive, qualitative methods to review topics of group-level impacts on leadership, MTSs, team leadership, and team adaptation (Mumford et al., 2008; DeChurch et al., 2011; Randall, Resick, & DeChurch, 2011; Burke et al., 2018). Qualitative methods that are inductive in their approach begin with data instead of hypotheses and involve the constant comparison of results to new data in order to refine ideas before an explanatory theory is developed (Brown & Glaser, 1978). Thus, this research utilized this approach and leveraged actual historical data from prior SFMTS critical incidents to successfully provide translatable, actionable results needed for developing the risk-mitigating interventions NASA desires.

Critical Incident Technique

Modeling upon similar historiometric studies of MTSs (e.g., DeChurch, et al., 2011), the present study also employs the critical incident (CI) technique in order to ensure systematic extraction of relevant information from the archival data sources. The CI technique is defined as "a method for obtaining specific, behaviorally focused descriptions of work or other activities" (Bownas & Bernardin, 1988, p. 1120). SFMTS CIs are specific events that have occurred in prior SFMTSs and are focused on observable behaviors, contain descriptive information about the situational context, and conclude with outcomes clearly tied to behaviors described in the SFMTS incident. Following the extraction of critical incidents, subject-matter experts (SMEs) sort CIs into emergent set of themes and then confer to reach a consensus on themes identified, and finally an additional set of raters re-categorizes the same CIs to identify the percentage of agreement between the raters and evaluate viability of the thematic schemas and categories (DeChurch, et al, 2011).

PROCEDURE

In a recent review, Crayne and Hunter (2018) outline the details of the HMA process, broken down into key steps and sub-step actions that should be taken (see Appendix A for steps as detailed by Crayne and Hunter (2018)). These were followed as summarized below.

Historiometric Analysis

Definition of Constructs and Research Questions

The constructs and research questions were defined as outlined and discussed above. This research seeks to identify thematic patterns in crew autonomy behaviors and boundary spanning work in previous SFMTSs. Specifically, the constructs of focus are in relation to the boundary work displayed in each critical incident extracted. That is, this research is not simply looking at thematic behavioral patterns in which autonomy is displayed in the SFMTSs, but rather, it is specifically looking at the situation or context that initiated inter-team autonomy shifts, the type of boundary work (boundary spanning, boundary buffering, and/or boundary reinforcement) the team performs during a critical incident and the outcomes associated with such.

Investigative Piloting

A preliminary list of sources was created, drawing on recommendations from NASA subject matter experts (SMEs) as well as the resources listed on the official NASA.gov website. These identified sources varied in their format and intended audience and included government reports, mission logs from websites maintained by NASA, and interviews from NASA's oral history projects. Investigative piloting was conducted by evaluating sources based on the presence or absence of discrete episodes involving SFMTSs and using them to guide the identification of additional sources. Where episodes that involved descriptions of SFMTS collaboration were found, further searches were conducted as needed to uncover additional contextual documentation pertaining to the event. This stage of investigative piloting also served to inform decisions on how this information might be coded to determine the types of boundary work teams may engage in during autonomy shifts.

Decision of Data Structure

A format for gathering critical incidents was chosen (see Appendix B). This format follows the guidelines set forth for critical incidents by Flanagan (1954) by having critical incidents include context, content, and consequences related to the phenomena of interest. However, this format was tailored to the specific needs of this study such that each critical incident includes the following components: spaceflight mission, relevant contextual information; a description of the event/trigger initiating the critical incident; a description of communication between ground and space crew or a description of autonomy shifts during the critical incident (actions taken by crew or ground); a description of the outcomes of the team's actions; a summary of the critical incident; and a list of specific sources used to draft it.

Prototyping and Codebook Drafting

The coding of the type of boundary work and situations/contexts leading to inter-team autonomy shifts was primarily driven by an abductive approach. A codebook was developed for the delineation of boundary work types. This codebook was based on the work done by Faraj and Yan (2009) to delineate boundary work types and examples of them (please see Appendix C). The boundary work types were updated as definitions were modified for the multi-team spaceflight context (see Appendix E). Further, a codebook for inter-team autonomy shift trigger types was also developed (please see Appendix D). Additionally, a prototype of a critical incident was developed in order to be used for training.

Data Sources and Collection Refinement

The sources from which data was collected have been finalized to include published and publicly available work detailing descriptions of SFMTS. A preliminary search for documents yielded a total of 108 initial sources (see Table 1). The criteria for choosing these sources followed recommendations by Parry, Mumford, Bower and Watts (2014).

Table 1. *Summary of resources included for SFMTS historiometric analysis*

Source Type	Count
Nasa Oral Histories	30
Official NASA or government reports	11
New articles, NASA articles, and mission archives	26
Other NASA documents	13

Over 200 critical incidents were pulled from the source material. A summary table is provided below with the total number of incidents pulled detailing the number of critical incidents per mission (Table 2). Of those 254 critical incidents, 100 were selected by the author for use in the current historiometric analysis based on appropriate content such as in-flight or in-space context, as opposed to critical incidents describing incidents prior to or post-flight. Table 3 shows the 100 incidents by spaceflight mission used for historiometric analysis with their respective outcomes.

Table 2. *Count of overall critical incidents by spaceflight mission name*

Mission Name	Grand Total
Apollo Missions	121
Gemini Missions	96
Mercury-Atlas Missions	18
Shuttle-MIR Missions	18
Skylab Missions	1
Total	**254**

Table 3. *Count of critical incidents by spaceflight mission name used for current historiometric analysis*

Mission Name	Count of CIs per Outcome		Grand Total
	Successful	Unsuccessful	
Apollo 10	26	2	28
Apollo 12	9	1	10
Apollo 16	12	1	13
Apollo 16	1	-	1
Apollo 17	3	-	3
Apollo 8	6	-	6
Apollo 9	3	-	3
Gemini 10	6	-	6
Gemini 11	4	-	4
Gemini 12	4	1	5
Gemini 5	4	2	6
Gemini 8	4		4
Gemini 9	-	2	2
Mercury-Atlas 7	-	1	1
Mercury-Atlas 9	3	-	3
Shuttle-mir mission STS-60	1	-	1
Shuttle-mir Mission sts-86	3	-	3
Skylab 4	1	-	1
Grand Total	**90**	**10**	**100**

Coder Training

Coders included a total of eleven subject matter experts (SMEs), arranged into two sets: one set (six SMEs) extracted critical incidents from the source material (extraction team) and a second set (five SMEs) was responsible for the actual coding of the extracted critical incidents (coding team). The extraction team consisted of six research assistants, all of whom were undergraduate psychology students trained on teaming/MTS research and familiarized with the goals and objectives of the research.

Critical Incident Extraction

The extraction team was thoroughly trained on the critical incident technique, in terms of the specific format developed and used for this study. This training consisted of learning about the critical incident technique as well as how to apply it within the context of this study, in terms of identifying critical incidents that describe cases of 1) autonomy shifts and 2) inter-team boundary work. Members of the extraction team were involved in practice rounds where they each assembled sets of critical incidents and received iterative feedback as to the quality of the incident pulled. This process continued until the lead research (author) was satisfied with the quality of the extracted incidents, in that all extracted incidents from training materials contained the needed elements in the right amount of detail and were being pulled in a similar manner across the individual coders.

Critical Incident Thematic Coding

Following the appropriate steps in the critical incident techniques, a group of three SMEs individually sorted the CIs into a set of emergent themes. In order to reduce rater bias, the group of SMEs performing the coding of CIs was distinct from the group extracting the CIs. Once individual coding was completed, consensus around themes was determined. SMEs consulted with each other until full consensus was reached regarding the identified themes.

The training of the coding team involved a slightly different process than that of the extraction team. These three coders were selected as they each have relatively extensive experience in coding of teamwork behaviors across several similar contexts. Furthermore, they had a thorough understanding of teamwork, MTSs, and boundary work processes. This combined with the emergent nature of the coding led to the members of the coding team to not require formal training. Instead, they were guided by their prior knowledge in the area, as well as the use of the codebook created discussed above (see Appendix C, D & E).

Retranslation of Critical Incidents into Thematic Coding Categories

Finally, a different group of two SMEs individually sorted the same CIs. The purpose of this final group of raters was to retranslate the CIs in order to identify inter-rater reliability and evaluate the viability of themes identified. SMEs consulted with each other until full consensus was reached regarding the identified themes.

Protocol Execution and Managing Coder Fatigue

Execution began with the pulling of critical incidents from the source material by the trained coders. Each critical incident was built from the chosen material by paraphrasing and creating summaries of the events and behaviors displayed by the spaceflight team. After each critical incident was pulled from the source material, it went through a quality control review by the author to ensure all relevant information was pulled from the original source material. As previously mentioned, 100 critical incidents were chosen to go through the coding exercise. These incidents were chosen by the author as appropriate critical incidents for coding team boundary work within SFMTSs.

The critical incidents were then used by coders to identify the boundary work type as either team boundary spanning work, team boundary buffering work, or team boundary reinforcement work and to specify the situation/context of each CI, implementation processes of boundary work, and outcome associated with each CI. First round and second round (back-translation) coders went through critical incidents by mission. That is, coders coded all critical incidents for a single spaceflight mission at a time. This served to ensure that coders had the maximum available context when coding each critical incident, as well as minimized cognitive load and coder fatigue. At the conclusion of coding, the coding team met for consensus meetings to resolve any discrepancies in coding.

Data Analysis Approach

To examine Research Question 1, the coding of how shifting inter-team autonomy was exhibited for each CI was examined to determine the factors that lead to shifting inter-team autonomy in SFMTSs. To analyze this data, three main factors that we believed were three main possible ways for shifting inter-team autonomy to be exhibited were created as coding options. These three factors were Crew Claiming, MCC Granting, and Environmental Factors – please see Appendix C for definitions. After being coded the themes were ranked to provide further insights into factors which most commonly lead to inter-team autonomy shifts. The same process was executed to examine Research

Questions 2 and 3 focusing on the specific objective of each research question. Research Question 2 examined the type(s) of team boundary work exhibited in the presence of inter-team autonomy shifts with their respective outcomes, and Research Question 3 took a more in depth-look at how these team boundary work types were put in place to identify if there was a specific order to them. These were the recommended and most appropriate analyses for this type of work, as similar processes have previously been implemented in similar studies (e.g., DeChurch et al., 2011; Pendergraft et al., 2019).

To conduct these analyses, this study utilized the definitions of team boundary work types provided by Faraj and Yan (2009) as a basis, but modifications to the definitions were made due to the unique environment SFMTSs are in. For example, team boundary buffering for this study was defined as the disengagement of one team from the MTS or its environment, similarly to how Farj and Yan (2009) defined it. However, we went one step further to specifically identify team boundary buffering as any critical incident that involved the space crew deliberately not reaching out to MCC. The difference here is that in a more common environment, a team not reaching out to another for help may not necessarily indicate buffering. However, because protocol suggests the space crew reach out to MCC when any issues arise, not reaching out to MCC during an incident was considered buffering boundary work. Further modifications and additions were made to the team boundary work types (please see appendix D and E).

RESULTS

Inter-team Autonomy Shifts

RQ1: How is shifting inter-team autonomy exhibited within the space crew in SFMTSs?

The results of the analyses depicted within the methods section yielded several interesting findings. One of the primary questions of interest was focused on identifying the way in which inter-team autonomy shifts took place by the space crew within SFMTSs. In this vein, we focused on three primary ways in which autonomy may be triggered: Crew Claiming, MCC Granting and Environmental Factors.

Results of the thematic analysis indicated all three triggers played a factor in the way inter-team autonomy shifts were seen within the SFMTSs, specifically focused on an autonomous space crew. More than half (65%) of the 100 critical incidents coded demonstrated an inter-team autonomy shift (see Table 4). Not surprisingly, since most space vehicles have been designed to be primarily controlled from the ground making MCC the leaders of all spaceflight missions (Landon et al., 2016) our results showed that MCC Granting was the lowest autonomy shift trigger. Crew Claiming was the highest trigger for inter-team autonomy shifts showing an autonomous space crew within the SFMTS.

Table 4. *Percentage (%) type of trigger by observed inter-team autonomy shift in space crew*

Type of Team Autonomy Shift Trigger (%)	Inter-Team Autonomy Shift? (%)		Grand Total (%)
	No	Yes	
Crew Claiming	-	46	46
MCC Granting	1	21	22
Environmental Factors		5	5
No Shift	27	-	27
Grand Total (%)	**28**	**72**	**100**

Team Boundary Work Patterns

RQ2: When faced with shifting inter-team autonomy, what team boundary work types have been utilized, and what is their impact on SFMTS outcomes?

A second area of interest pertained to the type of team boundary work exhibited within the SFMTS when an autonomy shift takes place, and the respective outcomes. Findings show that multiple types of team boundary work were often exhibited per critical incident. Due to the exploratory nature of this study, coders were not limited to choosing solely one type of team boundary work, thus the results show different emerging types of team boundary work exhibited during inter-team autonomy shifts. It is important to note that during the analysis, critical incidents were coded for boundary-work type even if they did not exhibit an autonomy-shift in order to better understand team boundary work in SFMTSs (table 5). However, the focus of RQ2 was on identifying themes or patterns in team boundary work type when an inter-team autonomy shift was exhibited. Buffering and Reinforcement were identified as the top team boundary work types, followed closely by

Reinforcement & Spanning. The results show that very rarely is only one type of team-boundary work shown when there is an inter-team autonomy shift (see table 6).

Table 5. *Count of team boundary work types by witnessed autonomy in space crews*

	Inter-Team Autonomy Shift?		
Boundary-work Type	No	Yes	Grand Total
All 3	-	13	13
Buffering	-	2	2
Buffering Reinforcement	-	24	24
Reinforcement	2	3	5
Reinforcement, Spanning	2	22	24
Spanning	31	-	31
Spanning, Buffering,	-	1	1
Grand Total	**35**	**65**	**100**

Table 6. *Top three team boundary work types for inter-team autonomy shifts within SFMTSs.*

Team boundary work type(s)	**Rank order**	**% of critical incidents supporting rank (%)**
Buffering & Reinforcement	1	37
Reinforcement & Spanning	2	34
Buffering, Reinforcement & Spanning	3	20

Table 7. *Ranked team boundary work type for CI exhibiting inter-team autonomy shifts per outcome*

Boundary Work Type	Outcome of CI with Inter-team autonomy shift		Total (%)
	Successful (%)	Unsuccessful (%)	
Buffering & Reinforcement	33.33	-	33.33
Reinforcement & Spanning	29.17	1.39	30.56
All 3 - Buffering, Reinforcement & Spanning	13.89	4.17	18.06
Spanning	8.33	1.39	9.72
Reinforcement	2.78	1.39	4.17
Buffering	2.78	-	2.78
Spanning & Buffering	-	1.39	1.39
Total % of inter-team autonomy shifts (%)	**90.28**	**9.72**	**100**

In addition, when looking at the outcomes of the coded critical incidents the results showed that most incidents which exhibited inter-team autonomy shifts ended in a successful outcome, with buffering and reinforcement together being the highest team-boundary work types to end in successful outcomes (see table 7). This finding is addressed further in the discussion portion.

Team Boundary Work Processes

RQ3: When faced with shifting inter-team autonomy, how are SFMTSs boundary work types (e.g., spanning, buffering, reinforcement) implemented?

Further, investigating the structural process of team boundary work when inter-team autonomy shifts were exhibited was the focus of Research Question 3. The analysis showed that when buffering and reinforcement took place within a single incident, they all started with buffering followed by reinforcement making up 33% of critical incidents exhibiting inter-team autonomy shifts. All the critical incidents that exhibited buffering and reinforcement within one incident were successful, leading us to see these boundary work types together as the most effective in terms of success. Furthermore, reinforcement and spanning were the second highest boundary work types exhibited within a single critical incident making up almost 31% of the inter-team autonomy shift critical incidents. There were four different ways these boundary work types were implemented regarding the boundary-work process, that is we identified four different ways of the order in which reinforcement and spanning were exhibited. Table 8 shows these findings in more detail. Lastly, the third highest types of boundary work exhibited within one critical incident was made up of all three types of team boundary work: buffering, reinforcement and spanning. Cis that exhibited all three types of team boundary work made up 18% of the critical incidents exhibiting inter-team autonomy shifts. It was in these scenarios where we saw the highest number of unsuccessful CIs making up 4% of the critical incidents coded for inter-team autonomy shifts. This finding is interesting as it begins to point out that perhaps when all three team boundary work types are exhibited there is too much chaos or disturbance, leading to unsuccessful management of issues by the multiteam system.

Table 8. *Top 3 boundary work types with boundary work processes and outcomes*

Team boundary work type(s) for coded inter-team autonomy shift(s) CIs	Boundary Work Process	Outcome		Total (%)
		Successful (%)	Unsuccessful (%)	
Buffering & Reinforcement	Buffering --> Reinforcement	33.33	-	33.33
Total (%)		**33.33**		**33.33**
Reinforcement & Spanning	Reinforcement --> Spanning	9.72	1.39	11.11
	Reinforcement --> Spanning --> Reinforcement	2.78	-	2.78
	Spanning --> Reinforcement	15.28	-	15.28
	Spanning --> Reinforcement --> Spanning	1.39		1.39
Total (%)		**29.17**	**1.39**	**30.56**
Buffering, Reinforcement & Spanning	Buffering --> Reinforcement --> Spanning	8.33	1.39	9.72
	Buffering --> Reinforcement --> Spanning --> Reinforcement	1.39	-	1.39
	Spanning --> Buffering --> Reinforcement	1.39	2.78	4.17
	Spanning --> Reinforcement --> Buffering	1.39	-	1.39
	Spanning --> Reinforcement --> Buffering --> Spanning	1.39	-	1.39
Total (%)		**13.89**	**4.17**	**18.06**

Additional Themes

Through the coding exercise additional themes surfaced that should be mentioned. Although this study found that autonomy shifts have been exhibited frequently in past missions, making up 65% of our coded incidents, the relinquishing of autonomy by the space crew was an additional theme that came up during the coding exercise. These incidents involved the space crew having autonomy and then for one reason or another relinquishing the autonomy back to MCC. In some instances, the space crew was seen claiming its own autonomy and attempting to manage the issues by themselves but once they realized they would not be able to resolve the issue on their own they relinquished autonomy and asked for help or guidance from MCC. Other times environmental factors led to the space crew gaining autonomy, in these instances the space crew would either try to manage the issue on their own or not try at all from the start, but in the end would always wait until they could come back in contact with MCC to ask for help. We can see there is an eagerness and confidence exhibited by the space crew in wanting autonomy from MCC, but the relinquishing of autonomy leads us to believe that there are still more steps that need to be taken to prepare the space crew to be successful when autonomous. Lastly, the theme of the space crew relinquishing autonomy was only seen when the space crew claimed its autonomy or received autonomy by environmental factors, it was not seen when MCC granted autonomy to the space crew. Table 9 and 10 detail these themes.

Table 9. *Additional themes identified in autonomy shifts triggered by crew claiming*

Additional Themes	CIs with Autonomy Shifts Total (%)
Space crew relinquishing autonomy	24
Weak reinforcement	12
Grand Total (%)	**36**

Table 10. *Percentage of relinquishing autonomy critical incidents with outcomes*

Autonomy Shift Trigger Type	Relinquishing Autonomy		CIs with Autonomy Shifts (%)
	Successful (%)	Unsuccessful (%)	
Crew Claiming	6	2	**8**
Environmental Focus	14	2	**16**
Grand Total (%)	**20**	**4**	**24**

DISCUSSION

Overall, designing valid interventions for SFMTSs is inevitably challenging: our knowledge of how SFMTSs optimally function is limited, and access to those familiar with these environments is equally difficult. However, historiometric approaches enable us to translate from our past, in order to be proactive and reactive for future SFMTS success. This study seeks to continue to comprehensively and inductively identify specific SFMTS contexts involving inter-team autonomy shifts and boundary work processes, focusing on functional and dysfunctional outcomes.

Regarding trigger types for inter-team autonomy shifts, we saw that the majority (65%) of the 100 critical incidents coded exhibited this shift. This is a good sign for future missions that expect to have a greater number of autonomy shifts, as through our analysis we can confirm that SFMTSs have already been dealing with them. Further, digging deeper into this finding, we see that many of these autonomy shifts were triggered by the space crew claiming its autonomy from Mission Control. Almost half (46%) of the critical incidents exhibited an inter-team autonomy shift triggered by “crew claiming”. This is a key takeaway as it suggests and further confirms the eagerness and confidence from space crews within their team unit to take charge and be less reliant on MCC. This may also be a good sign for future missions expecting a more autonomous space crew.

While “crew claiming” was a popular inter-team autonomy shift trigger, a pattern witnessed within crew claiming emerged in the form of the relinquishing of autonomy by the space crew. That is, shortly after the space crew claimed its autonomy, they relinquished it back to MCC. As we see that space crews desire to be more autonomous from MCC, the next steps may be to ensure that they have the appropriate tools and training in order to be successful when autonomous. In other words, how can we diminish this theme of "relinquishing autonomy"? More research around this specific theme is needed, but countermeasures can begin to be developed to mitigate this from happening on LDEMs.

Moreover, this study served in an exploratory manner to begin to identify themes and patterns in team boundary work during autonomy shifts in SFMTSs. Lastly, two additional themes (shown in Table 9) emerged from this study that were coded as the relinquishing of autonomy by the space crew and the observation of a different type of reinforcement which the coders identified as weak reinforcement. While this study shows us interesting findings, there remains a great amount of work to be done to truly solidify our understanding on team boundary work in SFMTSs.

Although future research is needed to further validate the current team boundary work patterns and inter-team autonomy shift trigger types, the overall themes and content created from this study have several practical implications for NASA. The team boundary work patterns found indicate the types of functional boundary work for inter-team autonomy shifts in complex spaceflight multiteam systems that occur most often and the outcomes historically tied to them. From these patterns of descriptive behaviors countermeasures and training can begin to be developed.

Similarly, these patterns could be used to develop team performance and feedback tools that reflect these important foci of functional team boundary work throughout inter-team autonomy shifts in SFMTSs. As spaceflight multiteam contexts are complex, informationally rich, and time-limited, the development of automated feedback tools will gather and feed information back to teams regarding such team boundary work behaviors as information flow within, between, and across teams in the system would be a particularly valuable practical application.

Limitations

While this study contributes to theory on team boundary work, several limitations need to be considered. First, the emphasis on context-rich cases, and inductive theory-generative approach makes our findings highly specific to the context in which we are interested (i.e., spaceflight multiteam systems), which comes at the expense of the inability to fully generalize the findings to other multiteam systems. Thus, the types of teams studied form boundary conditions for the results. It could be expected that the results presented herein apply to extreme teams as defined by Bell, Brown, Colaneri, and Outland (2018): those who (a) complete their tasks in performance environments with one or more contextual features that are atypical in level (e.g., extreme time pressure) or kind (e.g., confinement, danger) and (b) for which ineffective performance has serious consequences. That is, the findings may hold for astronauts, military personnel, wildland firefighters, or other teams with high skill levels who operate in intense, dynamic contexts under the pressure of extreme consequences, often life or death. However, they may be most applicable to extreme teams who are predominantly intact in their membership and where members have a high level of task-based experience.

Another limitation of this study is that its sample of critical incidents considered happened to be made up of overwhelmingly successful outcomes. Thus, as mentioned in the results, our findings showed that most team boundary work witnessed when inter-team autonomy shifts were triggered led to successful outcomes, but this may simply be due to the number of critical incidents with successful outcomes in our sample. That is, many of the documents used to develop incidents were focused upon near disasters and ways to improve these systems. It could be possible that different processes may exist for incidents with less successful outcomes.

Furthermore, the way in which a critical incident is structured can oftentimes affect the way that it is coded. Specifically, when coding incidents, the length of critical incidents is an interesting point to keep in mind. There were times when one critical incident could have been broken into two unique critical incidents, thus possibly changing the outcome that was coded as successful. This is an interesting matter to keep in mind for future similar studies and may be a way to mitigate the issue of having an overly large sample size of successful or unsuccessful critical incidents.

Lastly, while the proposed study intended to study inter-team autonomy shifts, the findings suggest that what took place may best be referred to as changes in autonomy. It is important to point this out because inter-team autonomy shifts seem to refer more directly to moments where autonomy is continuously changing. This was not the case in most of our critical incidents. What was witnessed was moments when the crew became autonomous or dependent on MCC. At most we saw shifts in the relinquishing of autonomy by the space crew, but this was not a back and forth of autonomy levels. Thus, perhaps it is needed to fully understand what we mean when we refer to inter-team autonomy shifts, as thus far it is loosely defined. More work is needed in this area.

Implications and Future Directions

The aim of this study was to inductively generate aspects of team boundary work and inter-team autonomy shift triggers important to spaceflight multiteam systems for long duration exploration missions. While there is clearly some correspondence between the theories used as basis points for this study and its findings, there are also unique notable differences which represent fruitful targets for future empirical studies of team boundary work within such contexts. Future research is needed that further explores these patterns and autonomy shift triggers in SFMTSs.

Although the team boundary work patterns, and autonomy shift triggers provide an interesting starting point for empirical work of team boundary work in MTSs, these patterns and triggers need to be examined in terms of their effect on system level outcomes. In other words, we need to further understand whether the identified patterns have a causal outcome on the multiteam system or act as mediators.

Further, the themes identified were derived using the critical incident method and are descriptive of behaviors that could be used as the basis of team and boundary spanner training for LDEMs. As NASA prepares for LDEMs, boundary spanner roles – those who connect or span the boundaries between distinct teams and support the development of team cognition – have been a topic of interest for SFMTSs (Anania et al., 2017). That is, understanding the type of boundary work and processes can help to further identify appropriate trainings for these roles. Additionally, this work aimed to identify autonomy-shift trigger types focused on the space crew. It would be interesting to instead identify specific individual roles that triggered these autonomy shifts and include those findings into boundary spanner leadership training.

Conclusion

As focus on the importance of team and multi-team systems research continues, the importance of team boundary work and inter-team autonomy shifts continues as well. This study serves to begin to break apart the specifics of how shifting inter-team autonomy is exhibited within teams (i.e., crew claiming, mission control granting) in space and what team boundary work (i.e., buffering) looks like in SFMTSs. Though this study works within a specific type of team (i.e. spaceflight teams) in a specific context (i.e. space), it may well have implications for other types of extreme teams. Furthermore, this study may serve as a springboard for further research to continue to investigate the specifics of these processes as well as continue to examine them through other, varied methods.

APPENDICES

Appendix A

Crayne and Hunter's (2018) Steps and Substeps for Historiometric Analysis

Steps	Substeps
1. Definition of constructs and research questions	a. Develop theory and hypotheses through extensive literature review
	b. Operationalize constructs of interest through theory and / or the use of previously validated construct measures
2. Investigative piloting	a. Primary investigator engages in a "proof of concept" exploration of the research landscape via case analysis
	b. Acquire a small set of potential narratives and use them to demonstrate that phenomena of interest are likely to be identified in such content
3. Decision of data structure	a. Determine how the how the data captured through content analysis should be structured
	b. Establish how constructs or relationships of interest are best captured - choose an "event-based" or "chapter-based" perspective
	c. Determine whether the study is to approach data from a within-subjects or between-subjects design, or some combination
	d. Identify a method for capturing criterion variables
4. Prototyping and codebook drafting	a. Develop a codebook that reflects the intended data structure and identifies predictor, control, and outcome variables
	b. Engage the research team in piloting to establish operational benchmarks, which examples for low, medium, and high levels of target constructs and phenomena
5. Data source and collection refinement	a. Use the coding strategy established during codebook development and information collected during piloting to identify and acquire data sources

	b. Review the selected content and make assessments of potential author biases, information completeness, sourcing, and consistency
6. Event / chapter selection and dissemination	a. Research team reviews the research materials and identifies content that is likely to be relevant to the research effort and eliminate content which is irrelevant
	b. Develop a plan for disseminating the selected content to the research team, and for storing any research materials
7. Coder training	a. Familiarize the rating team with the goals and objectives of the research, as well as the codebook
	b. Conduct pilot tests to develop socialized mental models within the team, whereby team members engage in discussion over materials to come to mutual agreement and consistency
	c. Engage in meetings with the rating team in order to maintain consistent perspectives on the materials and processes, as well as address specific questions or concerns
8. Protocol execution and managing coder fatigue	a. Establish a coding framework so that coders know how to progress through research materials and record data efficiently
	b. Organize materials such that coders are not constantly grouped together
	c. Remain vigilant for signals of coder fatigue or judgmental lapses. Check in with coding team directly, as well as look for statistical indicators of inconsistency
9. Data analysis	a. Organize final dataset and conduct statistical analyses necessary for hypothesis testing
	a. Assess the results of statistical analyses as

10. Integrating quantitative values with qualitative data	they relate to both predictions and existing theory and research b. Look for opportunities to illustrate findings or support theory through the story-telling ability of the narratives c. Consider revisiting data sources in search of theoretically sound moderators, informing future research

Appendix B

Coded Critical Incident Example

Mission	Gemini 9
CI #	G9-4
CI Narrative/ Summary	The astronaut conducting the EVA (Cernan) on the third day of the Mission realized it would be unsafe for him to continue with his tasks. His heart rate was increasing, he was sweating to the point that his visor was fogged up, and the stiffness of his spacesuit limited his mobility. After contacting Mission Control, he was told to take a break. However, he wanted to continue the EVA and began to connect himself to the Applied Meteorology Unit. Another astronaut (Stafford) ordered him to return to the shuttle. Stafford had to physically help Cernan back into the spacecraft since Cernan was in physical pain from the space suit pressure. Cernan attempted to remove a mirror from the side of the spacecraft, which resulted in his visor becoming completely fogged up. He and Stafford were able to re-pressurize the cabin, but the EVA was discontinued for the time being. After this incident, the AMU was never used again on Gemini.
Outcome	*Unsuccessful*
Autonomy Shift Trigger Type	*Crew Claiming*
Boundary Work Type(s)	*Buffering, Spanning & Reinforcement*
Order of Boundary Work	*Spanning → Buffering → Reinforcement*
Source(s)	Cernan, Eugene; Davis, & Donald A. (2013). "13" (Kindle)| The Last Man on the Moon: Astronaut Eugene Cernan and America's Race in Space (Unabridged. ed.). New York: St. Martin's Press. ISBN 9781429971782

Appendix C

Codebook: Interteam Autonomy Shift Trigger Types

Inter-Team Autonomy Shift Trigger Type	Definition
Crew Claiming	Space crew claims autonomy from MCC. Generally, the behaviors witnessed will show a clear action where the space crew is working alone within their own component team.
MCC Granting	Autonomy is given to the space crew by MCC either by clear direction from MCC to the space crew with orders to handle the incident by themselves or through recommendations on actions to take, leaving the space crew to make the final decision.
Environmental Factors	Environmental factors outside of any component team's control (e.g., communication issues, orbital distances) cause the autonomy shift.
No Shift	No autonomy shift is witnessed during the critical incident. Typically, will involve heavy spanning or sole reinforcement boundary work.

Appendix D

Codebook: Faraj and Yan (2009) Team Boundary Work Definitions

Team Boundary Work	Definitions by Faraj & Yan (2009)
Spanning	Strategy of engagement, in which a focal team undertakes actions to reach out into its environment in order to acquire important resources and support.
Buffering	Strategy of disengagement, in which a team closes itself off from the environment. Protects itself from external disturbances and uncertainties.
Reinforcement	A team internally sets and reclaims its boundaries by increasing member awareness of boundaries and enhancing team identity.

Appendix E

Codebook: Team Boundary Work Expanded Definitions

Team Boundary Work	Definition by Faraj & Yan (2009)	Expanded Definition
Spanning	Strategy of engagement, in which a focal team undertakes actions to reach out into its environment in order to acquire important resources and support.	Space crew reaches out to MC (or environment) for help, and/ or is open enough to receive information/help from MC.
Buffering	Strategy of disengagement, in which a team closes itself off from the environment. Protects itself from external disturbances and uncertainties.	Space crew chooses NOT to go to MC for help/guidance/information. NOT engaging in the first place.
Reinforcement	A team internally sets and reclaims its boundaries by increasing member awareness of boundaries and enhancing team identity.	Space crew works together to come up with an idea or solution by themselves, relying on internal team members and their knowledge to come up with a solution. Additionally, performing their expected duties without engagement from MC.

Appendix F

Inter-team Autonomy Shift Trigger Type Examples

Autonomy Shift Trigger Type	Critical Incident Coded Example
Crew Claiming	The Skylab 4 astronauts were unhappy with the way the ground control team micromanaged their work schedules. The crew complained repeatedly that they were overworked and never allowed to make their own decisions on when to do tasks. Halfway through their 84-day mission, the crew told Houston not to bother calling; they were taking the day off and would not answer the radio. The next day, after serious discussions, Houston agreed to modify their approach. Rather than detailed timelines with each minute scheduled, crewmembers would receive a daily list of tasks to be accomplished, which they could personally organize in the most effective sequence.
MCC Granting	After five long days of being on the space shuttle mission control let the space crew decide if they wanted to sleep in after completing the first part of their mission. Before deciding what to do the space crew reviewed a list of tasks, they had to do the following day to make sure sleeping in was the appropriate option. After talking about it with all the crew members they decided to let mission control know that they would be sleeping in the next day.
Environmental Factors	During Apollo 16, the lunar module (LM) and command module (CM) were separated with two and one astronauts in each, respectively. Suddenly, the CM begins shaking with a gimbal oscillating out of control. None of the astronauts can contact Mission Control (MC) as their orbit location prevents contact. The CM astronaut asks the LM astronauts for suggestions, but they have none, and revert to the flight rules. Unable to gain proper operation of the CM, the astronauts decide to rendezvous the LM and CM. The astronauts aboard the two separate ships begin communicating their location, and start referencing stars to help guide each other until they can rendezvous and finally gain control of the CM.
No Shift	As the space crew was completing the five tests that needed to be done before re-entry the crew noticed they didn't know how to fully complete the final test. The space crew asked mission control on how to navigate the final test that needed to be done before re-entry. Mission control informed them that they would need to go counterclockwise on their switch back around when completing final test. Then when finished with that they would need to go onto the next non exit skip pattern. The space crew followed the instructions from mission control and the outcome of this critical incident was a success.

Appendix G

Team Boundary Work Expanded Definitions Example

Team Boundary Work	Critical Incident Coded Example
Spanning	The space crew had just completed tracking landmarks when mission control contacted them about the fuel cells for the flight back home. Mission control (MC) had constructed a new fuel cell plan where they were going to leave it offline in an open circuit. They wanted the space crew to turn the fuel cell in-line heaters off and monitor the temperature. MC told the space crew they had to make sure the temperature stayed between 390 and 410. This would allow them to go as long as 50 hours without purging. MC acted created this solution for the space crew to use the fuel more wisely to get back home, which resulted in a positive outcome.
Buffering	The space crew members identified that they were having a serious problem with waste escaping the waste compartment. First, they thought that the waste compartment was full, and this was causing the waste to overflow, however they realized this was not the issue, rather that the suction was not working properly and waste was simply floating to the top and flowing out. The crew decided they would have to stick their hand deep into the waste compartment to ensure that they're waste would not come up. A crew member was either chosen as the unlucky individual to have to do this or an individual volunteered, it is unclear how the individual was chosen. However, the space crew did not attempt to reach mission control for help with this issue. Pushing the waste deep into the waste compartment fixed the issue.
Reinforcement	As the space crew was traveling, they realized something was wrong with the heater. According to procedures, the space crew should communicate this to mission control but were unable to because their location in space did not permit them to communicate with mission control. One of the space crew members asked why they didn't tell mission control earlier when they were in contact with them, but other members mentioned that the heater light had not come on until after they had lost communication with mission control. The space crew began to attempt to fix the heater themselves. They thought it was an exhaust temperature issue but also thought it could be the pump package. They went through all the circuit breaker buttons but could not fix the heater. The space crew decided to wait until they got back in contact with mission control to fix the heater with their help. It is unclear from the transcripts if the space crew were able to fix the heater in the end with mission control's help, but they were unable to fix it themselves.

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