Fiscal Year:	FY 2024	**Task Last Updated:**	FY 02/28/2024
PI Name:	Fischer, Ute Ph.D.		
Project Title:	Understanding Key Components of Successful Autonomous Space Missions		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Behavior and performance		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HFBP**:Human Factors & Behavioral Performance (IRP Rev H)		
Human Research Program Risks:	(1) **BMed**:Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders (2) **Team**:Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team		
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Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Comments:	NOTE: The NSSC also lists the PI as Ute Fischer-Loss (Ed., March 2025).		
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Start Date:	06/29/2016	**End Date:**	11/30/2023
No. of Post Docs:	0	**No. of PhD Degrees:**	1
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No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:	Whitmire, Alexandra	**Contact Phone:**	
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Key Personnel Changes/Previous PI:	May 2020 report: Dr. Tofighi withdrew as Co-Investigator from the project effective July 1, 2019.		

COI Name (Institution):	Mosier, Kathleen Ph.D. (Teamscape LLC)
Grant/Contract No.:	NNX16AM16G
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Performance Goal Text:	
Task Description:	Exploration space missions will require that space crews manage tasks more autonomously than in current operations, although they will continue to be part of the multi-team system (MTS) comprised of members in space and on the ground. The overall goal of the proposed research is to develop countermeasures that will enhance the ability of MTS members to maintain effective team performance and manage autonomous operations during Long Duration Exploration Missions (LDEMs). We will use NASA Life Sciences Data Archive (LSDA) data collected in space analogs and the International Space Station (ISS) to develop models of the individual- and team-level relationships between crew autonomy, emergent states, and team performance. Additionally, several simulations will be conducted in space analogs to assess the impact of different autonomy implementations on MTS performance in long-duration missions. Data from this study will be used to refine the individual- and team-level models, and to create a MTS-level model of the autonomy-performance relationship. Our approach is comprehensive in that we will examine different implementations and levels of autonomy, experience with interdependent and autonomous operations, individual and team process variables as well as varying task constraints. A set of products to support space and mission control teams during long-duration exploration missions will be delivered. These include: a validated model of factors related to team autonomy and team performance in LDEMs; recommendations for how team autonomy should be managed within a MTS during LDEMs, including countermeasures to mitigate potential negative effects; and recommendations for future research on autonomous team functioning.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Multiteam collaboration is not a unique feature of spaceflight operations but common to many organizations, as is the question of how best to implement task autonomy within a multiteam system. We therefore expect that our research findings not only generalize to other isolated and confined extreme (ICE) environments, such as Antarctica, but also apply to any organization that require the collaboration by different work units.
	BACKGROUND. Long-duration space exploration missions will inevitably require crew autonomy as a result of significant delays and disruption in space/ground communication. The introduction of crew autonomy will represent a significant operational shift from current practice and will necessitate the creation of a new sociotechnical system in which the roles and responsibilities of humans in space and humans on the ground have to be redefined (Kanas & Manzey, 2008; Manzey, 2004). Autonomy is generally defined as self-governance in terms of self-sufficiency and self-directedness; that is, self-reliance or independence of and freedom from outside interference. Incorporating crew autonomy into spaceflight will be challenging as crews will continue to be members of the space/ground multiteam system (MTS), which is rooted in the interdependence and collaboration of teams (Mathieu, Marks & Zaccaro, 2001). These potentially conflicting requirements produced by crew autonomy introduce a certain degree of tension within the MTS. The overall positive impact of task autonomy on individuals' motivation, satisfaction, and task performance has been well documented in laboratory and field research (Langfred & Moye, 2004; Roma Hursch, Hienz, Brinson, et al., 2013). On the other hand, studies in space analogs and the International Space Station (ISS) indicate that crew autonomy could potentially be disruptive to space/ground collaboration (Frank, Spirovska, McCann, Wang, et al., 2013; Kanas, Saylor, Harris, Neylan, et al., 2010). OBJECTIVE. The aims of this project were (1) to examine how crew autonomy affects the individual team members (crew and mission control personnel), as well as intra (crew)- and inter (MTS)-team states and processes, and (2) suggest recommendations for the implementation of autonomy that will be most supportive of MTS effectiveness, as well as (3) identify countermeasures to enhance the ability of space crews and ground personnel to collaborate effectively during autonomous space missions. METHODS. Data were collected in 10 space mission simulations conducted in two analog facilities: HERA (Human Exploration Research Analog) at NASA Johnson Space Center (JSC) and the Medical-Technical Ground-Based Experimental Complex in Moscow, Russia (SIRIUS). HERA Campaigns 5 and 6 (C5; C6) each involved four missions that were comparable in terms of duration (45 days), crew size (4 crewmembers per mission) and operational tasks but differed with respect to their operational design. HERA C5 missions mimicked current mission operations and served as control conditions to HERA C6 missions that included an autonomy manipulation. Mission control in HERA C5 included 12 members of the Flight Analog Group at JSC acting as HABCOMs (as the stand-ins for MCC); HERA C6 included 15 HABCOMs. SIRIUS 19 and 21 simulated lunar missions, with a duration of 4 and 8 months, respectively. Participants in S-19 were 6 crewmembers and 24 medical staff members representing MCC; 5 crewmembers and 23 medical staff participated in S-21. Both S-19 and S-21 involved high crew autonomy, with crew/MCC communication delayed by 5-min one way. Our research used a multi-pronged approach, comprising surveys, analysis of crew/MCC communication, and post-mission interviews with MTS members. Surveys at the MTS-level tapped crewmembers' and mission controllers' shared identity, their perception of cohesion among members of the space/ground MTS as well as the efficacy of the MTS. Simulations included several unexpected events/tasks that tested crewmembers' willingness to reach out to and cooperate with MCC. Task-related surveys concerned crewmembers' and mission controllers' evaluation of teamwork and task performance, and their ratings of the crew's and MCC staff's task contribution. Analyses of crew/MCC communication during tasks examined communication quantity, conversational control (i.e., who initiated communication on a topic), and the extent to which communications supported common ground between component teams. Post-mission interviews were conducted with crewmembers (HERA C6 and SIRIUS 21) and MCC (HERA C6) to gain insights into participants' views of autonomy, concerns they had, issues they encountered, and visions of how autonomy should be managed within the MTS. At the intra-team level, we used the SYMLOG (System for Multiple Level Observation of Groups) to assess the team dynamics of HERA and SIRIUS crews. Crewmembers rated each other with respect to behaviors that represent three

important dimensions of team interaction—positive/negative, dominant (active)/submissive (introverted) and task-oriented/expressive (joking) behavior (Parke, 1985). Based on their ratings, a group diagram was created, and statistics were calculated to characterize the crew's team dynamics and then to relate these team-level parameters to MTS variables.

Measures at the individual level assessed MTS team members' affect, workload, and stress. Data for HERA and SIRIUS crewmembers were provided by NASA JSC's HFBP group via a data-sharing agreement. MCC data were collected by us.

Task Progress:

RESULTS. It is clear from the data gathered in our research that autonomy does impact the space/ground MTS in significant ways and that problems and fault lines observed in remote collaboration may be exacerbated by crew autonomy (Ball & Evans, 2001; Gushin, Zaprisa, Kolinitchenko, et al., 1997; Kanas & Manzey, 2008; Stuster, 2010). Our data revealed that analog participants and their respective MCC personnel had differing concepts of what autonomy meant and differing expectations of their responsibilities and the parameters of their collaboration. This caused confusion about MTS roles as well as the boundaries of autonomy. Crews viewed autonomy in terms of self-sufficiency (SIRIUS 21) or self-directedness (HERA C6) and felt annoyed when their expectations were not met which, in turn, led to frustration and irritation targeted at MCC.

Crew autonomy was found to weaken cohesion among members of the space/ground MTS, and to lower confidence in the efficacy of their collaboration. Survey data showed that MTS members in autonomous missions reported less inter-team cohesion and efficacy than crew and MCC who worked under current operational conditions. Interview data, in addition, revealed that crewmembers considered reaching out to MCC for assistance as a last resort and an infringement on their autonomy. These findings are consistent with Shuffler and Carter's (2018) notion that "countervailing forces" such as empowering component teams may help them but to the detriment of MTS performance.

Our analyses indicated that crew autonomy may undermine common ground among members of the space/ground MTS. Both crewmembers and MCC stated in post-mission interviews that there would be less need for space/ground communication during autonomous missions, but component teams differed in their assessment of this development. While crewmembers portrayed it as a natural consequence of crew autonomy, MCC worried that less inter-team communication would deprive them of important mission updates and ultimately impair their ability to assist crews. Our analysis of crew/MCC communication in HERA C5 and C6 corroborated the interview data. We observed that the crew and MCC talked less during autonomous missions, and importantly, that autonomous crews delayed informing MCC about off-nominal events and failed to keep them apprised of their actions and procedures compared with control crews. Similar behaviors were noted for the SIRIUS crews. Additionally, SIRIUS crewmembers exercised more autonomy than HERA crews insofar as they ignored or questioned requests and in the case of SIRIUS 21, at times seemingly minimized the seriousness of off-nominal events.

In contrast to survey data that indicated decrements in MTS cohesion and efficacy, both crew and MCC emphasized in post-mission interviews that successful autonomous missions require a partnership between crew and MCC, built on trust, mutual respect, and interpersonal relationships. For crewmembers, this partnership implied that MCC would treat them as an equal team with different responsibilities, respond to requests in a timely fashion and provide accurate and clear information. For MCC salient aspects were that the crew would keep them informed about their actions and treat them as a resource. A theme shared by crewmembers and MCC was the acknowledgment that long-duration space missions will require trust and strong social cohesion, possibly friendship, between space and ground team members. These findings echo the view expressed by Roma and Bedwell (2017) that social cohesion, apart from task cohesion and technical competence, may become particularly critical to team effectiveness as exploration missions extend in duration.

Disconnects between component teams were evident regarding shared identity and task work. Crewmembers and MCC of autonomous and control missions alike tended to focus on members of their component team rather than the MTS as a source of shared identity. Likewise, crewmembers and MCC harbored different views about MCC's contribution to task performance, with crewmembers giving little credit to MCC. These kinds of disconnects between component teams could impact MTS functioning over the course of long-duration space missions, creating an in-group/out-group "us versus them" attitude that can be detrimental to MTS cohesion and performance (Verhoeven, Kramer, & Shuffler, 2022) and may lead to conflict and competition between the teams (Lanaj, Hollenbeck, Ilgen, Barnes & Harmon, 2013).

Related analyses at the intra-team showed that aspects of a crew's team dynamics—in particular, a positive team climate—were associated with MTS cohesion and efficacy, suggesting that processes at the level of the crew may influence processes within the space/ground MTS and vice versa, processes at the level of the MTS may impact processes within the crew. Post-mission interview data corroborated this latter point as crewmembers described how MCC behavior led to intra-crew conflict.

At the individual level our data indicate that MTS members' affective states—mood, workload, and stress—were less affected by crew autonomy per se but may be more impacted by mission duration. Higher negative affect was reported, and workload and stress increased over the course of the SIRIUS missions, in particular the 8-month mission.

CONCLUSIONS AND RECOMMENDATIONS. Together our survey and interview data, as well as communication analysis identified critical issues that countermeasures need to address to ensure MTS effectiveness during autonomous space missions. As others have stressed the preparation of crew and mission support personnel for space exploration will require that training goes beyond individual technical knowledge and skills or work processes centered on component teams, and instead will have to take place in an MTS context (Pendergraft, Carter, Trainer, Jones, et al., 2021; Salas, Tannenbaum, Kozlowski, Miller, et al., 2015; Shuffler & Carter, 2018; Verhoeven et al., 2022). The present research adds to this body of work by pinpointing specific issues (such as social cohesion and interpersonal relationships between MTS members) or behaviors (communication practices) that training should target.

Autonomous space missions will necessitate that we rethink how crew and MCC can maintain common ground on mission status and crew activities. Current communication procedures will need to be modified since their design presumes almost real-time space/ground communication and is centered on the information requirements of ground personnel in mission control. Instead, communication procedures for autonomous missions have to be consistent with crew autonomy and long communication delays. Existing communication protocols (Fischer & Mosier, 2021; Mosier & Fischer, 2021) designed to support crew/MCC interactions under time delay could provide a structural template, and information needs and communication norms could be developed participatively by stakeholders to ensure MTS member's compliance with communication requirements during missions (Asencio, Carter, DeChurch, Zaccaro, & Fiore, 2012). Furthermore, MCC should use communication styles in their interactions with crewmembers that reinforce their partnership. Possible approaches include team-centered communication (Fischer & Orasanu, 2000) or an autonomy-supportive communication style (Goemaere et al., 2018; 2019).

Delays in space/ground communication will severely disrupt if not eliminate an essential experience of synchronous remote communication, namely the sensation of connectedness and copresence; the perception that a remote partner is "real" and present in the "here and now" and that partners are psychologically connected despite their physical distance (Kreijns & Weidlich, 2022; Oh, Bailenson, & Welch, 2018). A novel communication tool—Braiding—was designed to alleviate this problem and could be used in scheduled conversations between MTS members, in particular, boundary spanners from component teams- to maintain interpersonal relationships and foster social cohesion.

Intelligent systems and shared technologies will be important enablers of crew autonomy. Both types of technologies support self-sufficient action by crewmembers without direct involvement of and interaction with ground personnel. However, by reducing crew reliance on ground support, these technologies also reduce opportunities for contact between space and ground teams and thus may undermine critical MTS components, in particular, social cohesion, interpersonal relationships, and team communication. It is therefore important that the implementation of intelligent technology is balanced with requirements—informational and affective—that arise from the fact that humans in space and humans on Earth will continue to work together as part of a MTS.

Bibliography Type:	Description: (Last Updated: 03/22/2024)
Abstracts for Journals and Proceedings	Fischer U, Mosier K, Mueller ST, Veinott E. "Differential impact on task and social cohesion measures during long-duration spaceflight simulations." 67th International Annual Meeting of the Human Factors and Ergonomics Society, Washington, DC, October 23-27, 2023. Abstracts. 67th International Annual Meeting of the Human Factors and Ergonomics Society, Washington, DC, October 23-27, 2023. , Oct-2023
Abstracts for Journals and Proceedings	Mueller ST, Veinott E, Fischer U, Mosier K. "Modeling teamwork over time: Findings from long duration spaceflight simulations." 14th International Applied Human Factors and Ergonomics Conference, San Francisco, California, July 20-24, 2023. Abstracts. 14th International Applied Human Factors and Ergonomics Conference, San Francisco, California, July 20-24, 2023. , Jul-2023
Abstracts for Journals and Proceedings	Fischer U, Mosier K, Mueller ST, Veinott E. "The impact of crew autonomy on the space/ground multiteam system." 2024 NASA Human Research Program Investigator's Workshop, Galveston, TX, February 13-16, 2024. Abstracts. 2024 NASA Human Research Program Investigator's Workshop, Galveston, TX, February 13-16, 2024. , Feb-2024