

## Emergency Response Coordination in Space

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### Abstract

Spaceflight is a dangerous, complex endeavor. A network of high-performing technical experts plans and trains for any conceivable emergency, but unforeseen events inevitably occur. During EVA 23 (i.e., an extravehicular activity, or spacewalk) outside the International Space Station, an astronaut nearly drowned in his spacesuit. The astronaut crew in space worked with the network of experts on the ground in Mission Control to save his life. In addition, NASA engaged in a comprehensive investigation to gather and apply lessons learned from this network so that it does not happen again. The acute emergency response and longer-term approach to growing from lessons learned are discussed through this example to highlight how networks may be called upon in times of crisis to save the day and make permanent, positive changes.

### Key Words

Team, multiteam system, spaceflight, emergency, coordination, networks

## Emergency Response Coordination in Space

Human space flight is an unforgiving environment in which seemingly minor issues may have significant repercussions. The International Space Station (ISS) is a prime example of the complexity of NASA's operations. As one of the most intricate structures ever built by humans, it represents a pinnacle of technological achievement, operational complexity, and international collaboration. Its maintenance and functioning require precise coordination across various disciplines and countries. At NASA, that responsibility falls to NASA's Flight Operations Directorate (FOD). FOD encompasses Mission Control and the astronaut corps, as well as a network of trainers, engineers, and other operations experts. FOD's mission is "to select and protect our astronauts and to plan, train and fly human space flight and aviation missions" (Houston & Heflin, 2015). In other words, crew safety is foremost in everything that is done in this extreme, high-consequence setting.

Teamwork is critical to achieving mission goals and is one of the FOD's Foundations of Flight Operations, along with discipline, competence, confidence, responsibility, toughness, and vigilance (Dempsey, 2017). The spaceflight crew is one team in a large network of multiple teams that comprise the spaceflight multiteam system. Many of the other operations teams in this network are part of Mission Control, which is staffed with dozens of expert flight controllers who possess deep knowledge of every technical system on the ISS and other space transport vehicles (McTigue et al., 2021).

The effective functioning of the network of teams enabling spaceflight and exploration requires extensive training of all people involved prior to missions. Astronauts and flight controllers are highly skilled and educated in technical domains. They spend much of their careers engaged in training to maintain a high degree of technical skill over time. They are also trained in teamwork skills (Landon et al., 2018). Specifically, both groups are trained on Space Flight Resource Management skills, including team task coordination, communication, risk assessment, supporting behavior, and leadership/followership. Astronauts are also trained on Expeditionary Skills, which approaches behavioral health and performance competencies more broadly than a task-oriented focus because the astronauts live together in a dangerous environment. Expeditionary Skills include self-care, team care, communication, leadership/followership, teamwork, and group living skills (Landon et al., 2018; Landon et al., 2024). Astronauts practice these skills for years in many different scenarios before they fly. They often have well-established relationships with their crewmates prior to a mission and build working and interpersonal relationships with members of Mission Control. The ISS is arguably the most complex object humanity has ever built, with numerous potential failure points, which has led to a tradition of extensive contingency planning and training. Astronauts and flight controllers practice emergency response and other time-pressured scenarios to enable later performance, allowing them to practice stress management in those situations. They train to function as an elite network of teams.

Another aspect of the FOD Foundations of Flight Operations is “to be aware that, suddenly and unexpectedly, we may find ourselves in a role where our performance has ultimate consequences” (Dempsey, 2017). There are inevitably mishaps, incidents, and accidents in such a complex environment, and one such incident is that of EVA 23. Extravehicular activities (EVAs), also known as spacewalks, usually involve a pair of astronauts exiting the orbiting vehicle (e.g., the ISS) to install or fix equipment on the vehicle’s exterior or to deploy equipment into orbit. Astronauts don individual spacesuits containing life support systems with oxygen for breathing, protection from debris and the harsh ultraviolet light from the sun, pressurization against the vacuum of space, and a communications system, among other features. The suit is climate-controlled via a Liquid Cooling and Ventilation Garment that requires water for cooling and various tubes, lines, and connectors to move the water through the system. Some EVAs are several hours in length, making rehydration necessary; therefore, the suit has an in-suit drink bag with a tube projecting up into the helmet to allow the astronaut to drink while suited. Astronauts also wear an absorbent garment similar to an adult diaper to manage waste. These details regarding water in the suit are relevant because the EVA 23 incident occurred due to a leak of water into the helmet, threatening the life of the astronaut in the suit and requiring the activation of a network of experts within this multiteam system to respond to the acute and long-term threats.

The EVA 23 incident was classified as a High Visibility Close Call: that is, it was an event in which there is no injury and minor equipment or property damage but which had the potential to cause more severe injury to a crewmember, equipment, or loss of mission, characterized by a high degree of programmatic impact and public interest (NASA, 2013). The review of this incident revealed two key approaches to coordination in the network of teams activated during this incident. First, EVA 23 required acute team problem-solving, decision-making, and coordination to save a crewmember’s life in a time-pressured situation. As water leaked into his helmet, European Space Agency astronaut Luca Parmitano worked with his team in space and on the ground to quickly address the situation. Second, the investigation and follow-up actions at NASA required more comprehensive identification of root causes and recommended changes to avoid such dangerous situations in the future. NASA leveraged the deep knowledge in the network of FOD personnel and beyond to understand the sequence of events leading up to the emergency situation on EVA 23, how that response was adequate (or not), and what lessons could be learned. The process took multiple months of detailed analysis. This case describes how the network of individuals and teams were activated to respond to the crisis and to conduct the after action review and investigation that would enable the functioning of this network of teams in the future. Similar underlying processes were used in each of the two responses, such as information gathering and risk assessment across a multidisciplinary network of teams, but the tempo of each situation presented different challenges for teams and leaders.

In such a high-stakes environment, robust network strategies across the multiteam system become indispensable. These strategies are not just about technological networks enabling the ISS to function as a physical system, they are also about the human networks consisting of the complex web of interactions and collaborations among various teams and individuals. Effective

network strategies—undergirded by intense training— ensure crucial information is relayed accurately and swiftly, decisions are made based on comprehensive data, and all team members are synchronized in their actions and responses. Communication in mission-critical operations is about clarity, timeliness, and reliability. At NASA, this involves not just speaking and listening but also understanding and interpreting complex data and signals. NASA has developed sophisticated communication channels for spaceflight and has built an equally sophisticated network of experts who are resilient and capable of operating in the challenging environment of space.

## **NASA's Approach to Activating Networks to Support Multiteam System Functioning**

### **Phase 1: EVA 23 Emergency Response**

On July 16, 2013, European astronaut Luca Parmitano and NASA astronaut Chris Cassidy exited the ISS in their spacesuits to perform an EVA (NASA, 2013). Years of EVA training and other extreme environment resilience and problem-solving training had prepared the astronauts well. Inside the ISS were their crewmates, monitoring and assisting with the EVA as needed. Flight controllers in the Mission Control Center at NASA's Johnson Space Center in Houston, Texas, monitored and supported the EVA from the ground. EVAs are one of the most critical and dangerous tasks because the astronauts exit the ISS, so a dedicated EVA team is on duty to assist the astronauts in space and other personnel in Mission Control, such as the flight director and the capsule communicator (CAPCOM). The flight director is the conductor of the Mission Control multiteam orchestra, leading the mission from the ground and coordinating directly with the flight controllers in the multidisciplinary "front room." CAPCOM is the conduit through which Mission Control talks to the astronauts in space. In other words, the flight director and CAPCOM are key boundary spanners in the network of Mission Control teams. Other "back room" and mission evaluation support teams coordinate with their discipline's personnel in the front room. Flight controllers are trained in communication protocols, team skills, and procedure execution, in addition to being experts in their particular technical discipline or system. The amount of expert and skilled personnel supporting any given EVA is extremely high. Each person in the network of teams also learns how their particular position and team fit into the network, facilitating swift and effective response in a crisis as each individual fulfills the duty of their role.

The EVA started as planned (Hansen, 2022; NASA, 2013; Robertson & Kothakonda, 2018). However, at minute 38, Parmitano experienced a "CO2 sensor bad" alarm, indicating that something was wrong with his carbon dioxide suit sensor. This alarm might happen if the sensor is damp, but it typically occurs at the end of the EVA as water vapor or moisture builds up over a few hours. In other words, the dozens of experts on the ground in Mission Control did not make the connection that the sensor might already be exposed to a concerning level of moisture. At minute 44, Parmitano reported water on the back of his head. He continued to work, updating Mission Control as he felt the water increasing in the helmet. The other EVA astronaut, Cassidy, confirmed that water increasingly leaking into Parmitano's helmet, but they could not identify its

origin. Each statement back and forth between the astronauts and Mission Control was verbally acknowledged with words such as “copy” or longer answers, confirming that the information was successfully pushed to other people. Problem-solving in real-time, providing each other with unique pieces of information, Parmitano and Mission Control continued to discuss the nature of the water: whether it was getting worse, where it might be coming from, if he might be sweating profusely, etc. They hypothesized that the water was coming from the drink bag due to an incorrect assumption of a similar situation from the last EVA. Subsequently, Parmitano decided to drink the remaining contents. The discussion on the space-to-ground communication loop could be heard by personnel across the multiteam system so that all Mission Control teams heard real-time updates from the astronauts, an efficient method of updating the entire network of critical information at the same time. Large screens at the front of the main Mission Control room display data to all discipline consoles, and each discipline has several computer screens at their desk with data and information from the ISS and between individuals within the same discipline. This broadcasting of information enables Mission Control to quickly take action and pass relevant information up through their respective channels to the flight director in a timely fashion.

Eventually, Parmitano stated that the water continued increasing and was clinging to his head (Hansen, 2022; NASA, 2013; Robertson & Kothakonda, 2018). Crew safety is paramount, and making it difficult to see, the decision was made within Mission Control to end the EVA and direct him back to the airlock and reenter the ISS. Immediately, Mission Control and the IV crew prepared to aid Parmitano upon reentry. The teams were already thinking about the next steps necessary for ensuring his safety and were pre-positioning supplies and personnel in the ISS. As Parmitano made his way to the airlock, there was no communication between Parmitano and Mission Control, but the situation continued to escalate: water was in his eyes and ears, clinging to his mouth and nose, making it difficult to communicate and breathe. His communication system failed. Astronaut Cassidy observed his EVA partner moving back to the airlock, noticed from Parmitano’s movements that something was wrong, and decided to return to the airlock as quickly as possible to be in a position to help Parmitano when he arrived. This supporting behavior later proved important as Cassidy was with Parmitano to help communicate by feel. Around this time, the sun set, plunging the ISS into darkness. Parmitano, being the resilient and well-trained astronaut that he is, remained calm, using the tether attached to his suit as a guide to pull himself back to the airlock.

Once inside the airlock with the hatch closed, re-pressurization began with air feeding into the airlock (Hansen, 2022; NASA, 2013; Robertson & Kothakonda, 2018). Mission Control’s attempts to communicate with Parmitano were met with silence due to the failed communication system, but Cassidy’s presence allowed him to visually confirm that Parmitano was okay and provided status updates to Mission Control. These discoveries of changing conditions were tested quickly, and this network of teams adjusted decisively to new courses of action. Again, their extensive training on these types of situations was key. The time-pressured nature of the situation forced rapid assessments, passing of information, and decision-making. However, the time pressure prohibited a full assessment of the situation (e.g., investigating the

CO2 alarm, discussing the temperature of the water to identify the source, understanding the severity of the increasing water earlier in the EVA), which may have prevented the situation from escalating to the extent that it did. Luckily, Parmitano made it back inside the ISS, where his cosmonaut crewmates were able to remove his helmet and clean the water from his head. Extensive training and preparation enabled this network of teams to support Parmitano's safe return to the ISS.

## **Phase 2: Post-EVA Problem-Solving**

The response to the EVA 23 mishap began almost immediately after Parmitano was safe (on the following day) and continued for several days. The crewmembers took pictures of the helmet with the water; calculations determined it was almost 1.5 liters (Hansen, 2022; NASA, 2013). The crew performed other inspections to collect data, including checking the suit for holes and damage that might be the source of the leak and performing the water leak troubleshooting steps. Information was passed down to Mission Control experts for further analysis. Mission Control created new procedures for testing various aspects of the suit, which the crew in space executed. Unfortunately, some of the testing procedures were not fully validated on the ground and exposed the crew to a potential fire hazard. Personnel later reported that they perceived time pressure to perform these tests before they were validated to maximize on-orbit crew time. Fire is one of the three major safety emergencies on the ISS, in addition to toxic chemical leaks and depressurization. Thus, as the crew focused on understanding the EVA 23 mishap, their focus on other potential threats was reduced, nearly causing further harm. In a multiteam system such as this, one team is reliant on another team for expertise. For the network of teams to operate effectively, teams must trust each other. Indeed, trust between high-performing teams in a multi-discipline, complex environment is generally a positive that supports performance. The high degree of trust between the space-to-ground teams is built on years of successful mission support. However, the trusting team is also vulnerable to mistakes made by the team they are depending on. Errors may cascade across the network. In this case, trust of the Mission Control team led the crew to engage in what was unknowingly a potentially dangerous action.

## **Phase 3: Comprehensive Mishap Investigation**

NASA's final method to diagnose problems and take corrective actions is through comprehensive mishap investigations. The Mishap Investigation Board was directed to begin its investigation just over two weeks after EVA 23 (NASA, 2013). The chief engineer for the ISS, Chris Hansen, led the investigation. He holds technical expertise and was well-positioned to identify which individuals and teams were needed to understand the mishap thoroughly. He assembled a team of experts to gather information from the crew and Mission Control personnel, to identify relevant documents about the hardware and previous related incidents, and to interview a wide range of personnel and experts. The loop communications from that day were transcribed for later analysis. The Mishap Investigation Board also employed the Department of Defense Human Factors Analysis and Classification System (HFACS) process with the help of human factors experts. HFACS is a best practice developed by the Department of Defense

specifically to identify hazards and risks in the context of human error, which may have contributed to or caused each event leading to the mishap. Notably, it examines issues that go beyond the technical causes and also includes acts, preconditions, supervision, and organizational influences with related categories and subcategories.

This detailed investigation identified several precursor events that led to the EVA 23 mishap. For example, during EVA 22, one week before EVA 23, Parmitano experienced water in his helmet. It was less water than EVA 23, and it was noted at the time as coming from an unknown source, with speculation that it might have originated from the drink bag (Hansen, 2022; NASA, 2013). During the EVA 22 debrief, a flight controller asked Parmitano if he had consumed much of the water in the drink bag (Hansen, 2022). Mission Control thought Parmitano responded, “I didn’t drink at all,” but he actually said, “I didn’t drink it all.” Mission Control assumed the water must have come from a full drink bag and decided not to conduct a follow-up investigation. This discussion also took place during a shift handover (the time during which the group of flight controllers supporting EVA 22 had mostly left or were preparing to leave). Thus, there was a communication breakdown across the network due to misunderstandings and inadequate attention, which led to false assumptions. This investigation also discovered that there was time pressure to perform EVA 23 only a week after EVA 22, which is a quicker tempo than is typical. There were other instances of a CO<sub>2</sub> alarm and water in the helmet documented in the past, but because they did not result in a major mishap, the network of teams had normalized their occurrence. This “normalization of deviance” (Vaughn, 1996) from accepted standard performance allowed complacency to take root. Eventually, the investigation determined the EVA 23 mishap was caused by a buildup of inorganic material blocking small holes in the water separator, resulting in water spilling into the vent loop (Hansen, 2022; NASA, 2013). It was not the drink bag. NASA personnel were not familiar with this particular failure; thus, this network of teams was not adequately prepared to identify and respond appropriately.

The comprehensive analysis was documented in a report (NASA, 2013) so lessons learned are available for the future and to explicitly outline a set of recommendations to prevent such an incident from occurring again. These recommendations contain technical improvements, but, importantly, also held individual, team, and organizational changes that could be made to enhance the system around the technical and safety decisions. For example, findings included “Organizational influences led to an acceptance of risk by workers below the [ISS] Program management level” and “The team possessed insufficient knowledge about possible water leaks originating in the vent loop and areas upstream; however this lack of knowledge was due to insufficient training.” The findings were extensive, as were the 49 recommendations stemming from the findings. The recommendations were written as action statements, directing NASA specifically on how it “should” take action to remedy the situation for the future safety of the crew. Recommendations were also identified as root versus proximate versus intermediate causes versus contributing factors or simply observations. The Mishap Investigation Board delivered their report to NASA leaders, who directed action to be taken on the recommendations. FOD

personnel took accountability and enacted those recommendations. Over ten years later, there has not been a similar water-in-the-helmet mishap.

### **General Discussion**

Learning lessons through adversity is not desired, but the resulting changes are often a positive redirection that may be felt years later. To benefit from adversity, organizations must be willing to look inward with a critical perspective and be willing to learn. A detailed analysis may uncover concerns that are not obvious with a more cursory review. This may be especially true in organizations with extremely complex task work and structure, such as NASA's spaceflight multiteam system. The example of EVA 23, a high visibility close call that did not result in crew injury, can also serve to highlight the incredible safety record of astronauts on the ISS. The ISS has been in continuous operation since 2000 with few severe injuries. Most recorded injuries are minor and have not affected mission success, even during grueling EVAs (Chappell et al., 2017). This record is noteworthy given that even seemingly small annoyances like a water leak can have fatal consequences in such an extreme environment.

This mishap also highlights how NASA effectively activates a network of high-performing teams in different ways. The initial response required quick application of deep knowledge, quickly coordinated through key boundary spanners to the astronauts executing the hands-on response on the ISS. Long before a mission, the network of systems experts, EVA experts, and expert trainers develop procedures for every task and train the astronauts in those procedures. Behavioral health experts also train the astronauts in stress management and team skills. Each EVA is planned to the detail, timed, and rehearsed by all involved. Flight controllers have also received technical training and team skills training and practice emergency response during simulations. Protocols for communication and information flow are practiced every day on the job. In other words, the complex network among individuals and teams is well-established and experienced when off-nominal situations occur. This training enabled a quick and effective response. Although this particular failure was unknown, the network sprang into action and saved the astronaut's life. In the succeeding investigation, the Mishap Investigation Board drew upon the knowledge of the diverse network of teams to diagnose the root causes and recommend changes. They were also able to prompt self-reflection on how the network of teams made errors in the leadup to the mishap and during the post-mishap suit testing. Technical organizations that fail to look at the human side of the organization will fail to address challenges fully in the future. NASA personnel are willing to look at all aspects of a problem and enact best practices (e.g., HFACS), which support that broader perspective.

### **Lessons Learned**

#### **Lesson One: Prepare for the Worst**

Organizations that need networks of teams to function at their best must prepare for the worst. NASA is particularly adept at predicting contingency scenarios or situations in which things go wrong. Experts are constantly trying to anticipate all the different ways something

could fail and building response procedures accordingly. Redundancies are built into the systems to avoid single points of failure and, when possible, to have workarounds that are easily accessible when needed. Information about every system is well-documented, updated, and posted on internal shared information sites so that all can access the latest knowledge. Personnel are taught to refer to these shared sites regularly and update them accordingly. A consistent aspect of working in Mission Control is participating in training simulations in which all manner of problems occur. It provides flight controllers, astronauts, and other support personnel opportunities to practice decision-making, team skills such as communication and supporting behaviors, and stress management in time-pressure, (simulated) high-consequence situations. Overcoming challenges is simply a part of the job because lives may be at stake in a real emergency. Everyone must be prepared to respond without panic and have easily accessible, accurate information when needed. In unforeseen circumstances, the existing knowledge and troubleshooting processes can be leveraged to address the situations rapidly.

## Lesson Two: Train (Don't Just Hope) for the Best

NASA selects for excellence during the hiring process; a high degree of competence is expected throughout one's career. However, NASA is also very specialized in that the systems and the spaceflight environment hold totally unique challenges. The NASA experts must undergo a large amount of training even if they are highly qualified. For example, astronauts already have prestigious careers, advanced degrees, and an extremely high degree of resilience when they begin their job at NASA, but they must still undergo a two-year training program to learn about space, the ISS, and other vehicle systems; how NASA functions across its network of teams (both domestic and international); and how they can function in their individual role within that established multiteam system. They undergo refresher training many times during their careers and receive specialized training once they are assigned to a particular mission. Mission Control is partly successful because of the culture of excellence—personnel are competent in their areas and can be trusted to do their jobs well. Individuals on a team may swap in and out due to shiftwork schedules and be working with many other individuals, but the common model of technical skills, team skills, and an approach to problem-solving allows for those teams to maintain performance. Organizations should not assume that elite individuals do not need onboarding and training or that they can be ignored when making training assignments. Practice prevents skill decay. This applies to both technical as well as leadership and teamwork skills. Individuals on a team acting independently are not as effective as a team or a network of teams working together in complex environments such as spaceflight.

## Lesson Three: Slow is Fast

Astronauts often use the phrase “slow is fast” in reference to working in a microgravity environment in which the normal way of moving is not possible. Moving slow avoids errors that might cause rework and delays. This phrase is also applicable to situations like EVA 23. Before EVA 23, water was observed leaking into the helmet during EVA 22 but was incorrectly

assumed to be coming from the drink bag. Time pressure partly drove the desire to conduct EVA 23 before a full investigation was performed. Taking time to do this investigation may have uncovered the cause before the mishap. The post-EVA testing that created a fire risk might also have been avoided if not for the time pressure to understand the problem when the crew had on-orbit time and before the test was validated. There were opportunities to act “slow” in considering the problems, which would have saved time and prevented a close call later. Later, NASA did take more time to slow down and engage in the comprehensive mishap investigation, leveraging the full knowledge of NASA experts. Organizations would be wise to allow time to act “slow”, planning for review and adequate testing before moving forward.

## Lesson Four: Allow Time to Look Within

Different types of pressure (e.g., time, political, cost) may cause organizations to avoid a comprehensive and ongoing approach to learning. Environments may not be as dangerous as spaceflight, lowering motivation to self-reflect and improve if the consequences do not seem as high. However, understanding how an organization’s systems and processes could be improved can be leveraged to meet the unique goals of that organization. It may also uncover unexpected areas for improvement. NASA invites outside experts to participate in major accident investigations; famously, Dr. Richard Feynman contributed to the Challenger investigation. Organizations may find use in leveraging the network of experts outside the organization for a fresh perspective. Identifying which aspects of a network are most appropriate for different conditions (e.g., NASA leverages the EVA team in real-time operations only during EVAs, and they use the rest of their time to plan EVAs and improve systems) is also something that could prove quite important for organizational leaders to understand.

### **Summary of Advice for Organizations:**

In summary, I offer the following advice for organizations aiming to utilize networks of teams to operate in complex, high-consequence, and goal-directed work:

- *Prepare for the worst:* Document institutional knowledge in an accessible, centralized location that teams throughout the network can access. Prepare for inevitable stress.
- *Train (do not just hope) for the best:* Train everyone to excellence. Even excellent performers need a refresh.
- *Slow is fast:* Take time to plan and test properly. Do not assume.
- *Allow time to look within:* Do not miss potential lessons learned by finding reasons to avoid self-reflection.

### **Questions to Consider Before Starting Your Project:**

- Which individuals and teams in a network are needed to plan and execute the project?

- Has everyone in the network received training to operate successfully in that network?
- Have we considered what could go wrong and how to respond? How will we react if an event occurs that we never anticipated?
- Have we reserved enough time for planning, execution, and follow-up debriefs or investigations of how the network of individuals and teams functioned?

### **Final Thoughts**

Spaceflight is only possible when a network of teams works together effectively. The complexity of every small action is a feat of engineering and science, as well as a feat of teamwork and leadership. Individuals must be well-trained to perform, and leaders must understand where and how to pull on that diverse wealth of knowledge distributed throughout this network of individuals and teams efficiently and effectively. Individuals and teams at all levels should also feel comfortable pushing information when their particular expertise is needed. Practicing the coordination, communication, and flow of information required before emergencies happen avoided a tragedy on EVA 23. The extensive review conducted by NASA identified communication distortion and perceived time pressure to conduct EVA 23 as contributing to the mishap in the first place. To ensure multiple teams function as a high-performing network, leaders should focus on all parts of the planning and execution process, including making time for each part of the process to be fully completed. Importantly, this leadership occurs on every team throughout the network, not just at the flight director level. Everyone can take ownership of how they are prepared to respond to adversity.

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