NASA's SPACE FLIGHT RESOURCE MANAGEMENT PROGRAM: A SUCCESSFUL HUMAN PERFORMANCE ERROR MANAGEMENT PROGRAM

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ABSTRACT

Space Flight Training Division Instructors at NASA's Johnson Space Center (JSC) have combined human performance related error research with lessons from operational communities to develop Space Flight Resource Management (SFRM), a successful human-error-management training program. The vision of the SFRM program is to fully integrate human factors and technical training to such a degree that the process becomes part and parcel to the way crews and flight controllers are trained. All aspects of the SFRM program are practical, skill-based, and operationally relevant. The cornerstone of this program rests in its ability to facilitate, develop and reinforce the individual and team performance of NASA's flight crews and Mission Control Center (MCC) flight controllers by establishing self-critiquing habit patterns. The SFRM program has emerged as part of an operational training philosophy, becoming the vehicle that has enabled Shuttle and International Space Station (ISS) flight crews and MCC flight controllers to effectively manage operational errors. This paper details the NASA SFRM program development and maturation. The successes, lessons learned, and recommendations have enormous implications to all manned space training. Moreover, these lessons can benefit other industries in that they directly apply to any team-oriented organization.

INTRODUCTION

Over the past three decades, advances in technology and automation have made it possible for the aviation and aerospace industries to greatly improve the mechanical reliability of aircraft and spacecraft. Refinements in design, manufacture, and repair have led to a steady decline in accidents due to mechanical failures. Foushee & Helmreich (1988) found that accidents and incidents due to human error have not shown the same declining trend. Seventy percent of aviation accidents are the result of human error where crew members failed to manage all available resources, many becoming preoccupied with distractions, then failing to properly manage the flight path or status of the aircraft. Many were the result of crews failing to manage the interface between one another or with other agencies that operate within their environment. The U.S. Space Program is not immune to the same errors that exist within the commercial aviation industry. Merritt & Helmreich (1996) report that the cockpit of jet transports, the space shuttle, and nuclear power plants are all settings where teams must interact with each other and with technology. Research into accidents and adverse incidents in these environments suggests that the majority involve human error, which tends to fall in the categories of team coordination, communication, leadership, and decision making (Helmreich, Kanki & Wiener, 1993).

In an attempt to reduce accidents caused by human error, the commercial aviation industry has developed Cockpit Resource Management (CRM) training for their members. In 1997 the Space Flight Training Division at NASA's Johnson Space Center developed Space Flight Resource Management (SFRM) training. The SFRM program trains many of the same topics that CRM teaches the commercial aviation industry, but adapts them specifically for space flight operations. The program's name was therefore changed from "crew" to "Space Flight" Resource Management in an attempt to stress to the entire organization that these issues are not unique to the flight crew, but are equally applicable to all members of the NASA team. The success of this program is a direct result of clear, focused, patient vision and implementation.

DISCUSSION

CRM Training: Review of Relevant Literature

The Evolution of CRM Training in Commercial Aviation

Over the past two decades, the commercial aviation industry has developed formal CRM training to help its members better manage operational errors. As each airline went to work to develop its own program, the academic research community studied many of these programs, and continually discovered and advocated ways to improve the effectiveness of this training. Helmreich (1998) reports that this collaborative effort has caused CRM training to evolve over the years.

Helmreich, Merritt & Wilhelm (1999) report that early CRM training implementations tended to rely too heavily on exercises unrelated to aviation, and were laced with irrelevant psychological terminology to communicate its core training concepts. Byrnes & Black (1993) attest that operational communities soon began to realize the need to operationalize CRM training. Helmreich et al, (1999) found that airlines began to integrate CRM and technical training, while shifting the focus from personality-based concepts to specific skills and behaviors that crews could use to interact more effectively.

In the last six years, the academic community became concerned that the original and overreaching rationale for CRM training, which is to reduce the frequency and severity of operational errors, had been lost. Merritt & Helmreich (1996) disclose that we must realize the limits of human performance; Human error is inevitable, what is needed is a strategy for

managing error. This realization brought about the notion of CRM training as an error management tool. Helmreich & Merritt (1998) defines error management at the crew level as:

> Actions taken to reduce the probability of errors occurring (error avoidance) or to deal with errors committed either by detecting and correcting them before they have an operational impact (error trapping) or to contain and reduce the severity of those that become consequential (error mitigation) (p. 2).

Components of a Successful CRM Program

Management support and organizational fit

Management's role in ensuring the success of a CRM training program cannot be overemphasized. Helmreich (1995) suggests that management plays a pivotal role in facilitating the organization's acceptance of CRM training by setting clear standards, and providing commitment and support. Successful management support is realized when management internalizes that "CRM training is not a single fix for human error. Rather, it is a part of an organization's commitment to error management that includes building and nurturing a safety culture" (Helmreich & Merritt, 1998, p. 2.). In order to keep CRM training relevant, it is required that the programs are tailored to fit the unique training needs of specific operating conditions, as well as the philosophies and characteristics of an organization (Helmreich, 1993).

Integration and Implementation

Helmreich (1993) reports that a comprehensive review of literature and research indicate an apparent need to fully integrate CRM and technical training into all aspects of training. The data clearly support that the interrelationship between CRM and technical components is highly correlated with technical performance. Helmreich et al. (1993) assert that to achieve the level of integration necessary to ensure successful CRM program implementation, the definition and evaluation of observable CRM behaviors must be as reliable and valid as that of technical maneuvers. Helmreich et al. (1993) recommend that management and program developers keep the following axioms in mind when developing and implementing a CRM program.

1. To be accepted, the practice of CRM concepts must be accorded the same status as adherence to technical standards that are continually observed and reinforced.

2. If CRM concepts are not reinforced, there is no point in committing resources to CRM training. CRM will not be treated with the same seriousness as technical issues.

3. CRM concepts cannot be reinforced if they cannot be reliably assessed. Instructors and evaluators must be trained and skilled in assessment and reinforcement of CRM practices.

Program evaluation

The topic of data collection in the arena of CRM is complex and carries with it a myriad of issues and concerns for many organizations. Nevertheless, evaluation data collection is a critical element of an effective CRM training program that must fit each organization's culture.

Proper program evaluation enables training departments to assess the effectiveness of the training delivered, and identify necessary corrections to existing curricula. The data also provide direction for continuing training (Helmreich, 1995).

Continuing Training and Reinforcement

Introductory CRM courses are designed to raise participants' level of awareness and positive attitudes toward practicing CRM skills. Continuing training sessions must not only give the opportunity to practice CRM skills, but also ensure that lessons are reinforced through effective facilitated debriefings. Therefore, additional advanced CRM training for instructors should include strategies for debriefing and reinforcing effective behaviors (Helmreich, 1993).

Space Flight Resource Management Program Development and Implementation

Program Charter and Vision

In February of 1997, NASA management conducted a detailed post flight analysis of a satellite deploy and found that several operational errors had occurred. To address the resultant training issues brought about by this analysis, the Space Flight Training Division turned to the newly chartered Space Flight Resource Management development team to develop and deliver formal CRM training for flight crews. From this mandate, the development team went to work on satisfying the training requirements. The development team realized from the start that the issues at hand were not mere isolated crew errors. Flight crews very rarely work in isolation from MCC personnel. For this reason, the development team changed the program name from "Crew" to "Space Flight" Resource Management in order to emphasize that what was at stake was not only a crew training issue, but also one that included every member of the NASA team.

Operational Insights

Members on the SFRM development team were fully aware of the research being done and recommendations being advocated by the academic community. What was not known was how successfully the operational communities, external to NASA, were implementing these recommendations. In order to gain this insight, the development team visited four major commercial air carriers, as well as two nuclear power companies. The primary objective was to discover first hand the following: 1) the nature and content of each organization's CRM program 2) through open dialogue, what was working within that program, and identify the specific reasons for success and 3) the mistakes companies made during their program development, including the specific reasons for each unsuccessful outcome.

SFRM Program Philosophy and Development

Although the ultimate vision of the development team was to bring SFRM training to all members of the NASA team, the initial development focused on addressing crew-training needs. Based on the academic and operational data gathered, the development team agreed that all SFRM training would be based on the following: error management philosophy, skill-based, operationally relevant, fully integrated within technical training, and continually reinforced. Reinforcement of SFRM skill usage proved to be the largest challenge. It was first realized that the experience base of the instructor corps, with respect to aviation related human factor issues and concepts of CRM in general, was very limited. Before the training department could deliver

effective training to the astronaut corps, baseline instruction for all instructors, with respect to the concepts of SFRM, was required.

Courseware Design and Instructor Training

Three classes were developed to address the instructor training needs. The SFRM Overview course was designed with two primary objectives in mind: 1) increase each participant's awareness of SFRM concepts and 2) standardize the vocabulary and application of SFRM training throughout the training division. Six categories, or performance elements, were chosen to frame the set of skills most applicable to the NASA organizational climate: Command, Leadership, Communication, Workload Management, Situational Awareness and Decision-Making. All of the SFRM classroom lessons were instructionally designed to limit lecture, and to stress facilitation of guided discussions. This approach encourages the highest level of student participation possible. To further enhance student participation, class sizes are limited to no more than 30 students, with a targeted optimum class size of 18-20. The instructor presents each performance element, then describes, in detail, the general concepts associated with the element. Next, the instructor facilitates a discussion of how these concepts apply operationally at NASA, and introduces each element's skill set. Ultimately, instructors are responsible for SFRM skill observation to the same level of expertise that they already possess within their technical disciplines. To address this training requirement, the development team used video clips from popular movies, carefully choosing those that were best suited for the space flight business. Each clip illustrates the active use of the SFRM element skills under discussion. After viewing each clip, students are asked to identify which of the skills are present, and how they are used within the video. The most common comment taken from student class critiques indicates that this approach made the SFRM concepts and skills come alive for the students, and fostered belief that with practice, they could actively observe SFRM and technical skills with equal proficiency.

As instructors near their technical certification, they take the second course, SFRM Applied Methods. The primary objective of this class is to sharpen and refine the student's SFRM skills observation using actual space flight missions and actual training sessions as examples. Not only does this approach bring operational relevance to the training, but it also serves to give students an understanding that as an instructor, their observations, coupled with sound, facilitative debrief skills, become the vehicle to reinforce SFRM training.

Once an instructor is assigned to a training team, a third course, SFRM Facilitation, is attended. This class provides instructors with the knowledge of how to fully integrate the SFRM training within the existing technical curriculum. Instructors evaluate actual training debriefs against a simple, yet ridged set of SFRM debrief criteria. Flight crews are expected to: 1) raise and initiate discussion of SFRM topics directly with each other, 2) critically analyze the training scenario and discuss the impact of the SFRM skills used on the scenario's outcome, 3) develop and implement specific actions to improve those skills deemed to be less than effective and, 4) identify and reinforce those skills that were particularly effective. While using more instructional methods to cover technical issues is appropriate, instructors discover that by taking a facilitative approach when debriefing SFRM topics, flight crews and flight controllers not only learn more from each training session, but also develop critical self-critiquing habit patterns. To this end, instructors are introduced to specific questioning strategies designed to facilitate an effective team-centered debrief.

Flight Crew SFRM Training

Every astronaut candidate (ASCAN) receives the SFRM Overview and Applied Methods classes as a part of their initial training curriculum. These classes occur during the first month of space training to stress the importance of the SFRM skills. How effective SFRM skill usage will enhance their individual and team performance is specifically stressed. There is an enormous difference between *knowledge of* SFRM concepts and skills and a *commitment to* the program's governing training philosophy. Each ASCAN is challenged to make a personal commitment to the SFRM program and its principles. To make such a commitment, each must demonstrate discipline, focus and resolve by incorporating SFRM during every training opportunity.

As flight crews are assigned to a specific mission and begin their training, the first official assigned crew activity is a SFRM Refresher class. The primary objective of this class is to give the mission commander a forum for establishing open communication and a positive crew climate among crewmembers. The class is divided into two parts, each stressing a particular objective. The first part addresses the relationship that each set of SFRM performance element skills has with the others. Using a multimedia approach, crews then listen to an audio recording of MCC communications, during an actual launch that addressed an in-flight anomaly. The crew then identifies and evaluates the effectiveness of the SFRM skills that were used by MCC controllers during this example. Specific emphasis is placed on assessing the communication skills used, and how those skills led to a heightened level of situational awareness among the entire MCC team. This discussion serves as a springboard where each crewmember then shares an example drawn from their experience of either effective or ineffective SFRM skill usage. To ensure that these discussions remain operationally relevant, the crewmembers are asked to elaborate on how each lesson learned may be applied in the course of the assigned crew training that they are about to undertake. In the second part of the class, the instructor explicitly defines and establishes expectations with regard to debriefing SFRM topics. It is not sufficient to discuss topics as a crew and critically analyze the effectiveness of their skill usage, only to state that they will remember not to make the same error in the future. Crews are reminded that in such cases, the training team will facilitate the discussion further. Crews will be challenged to develop and state strategies that will be exercised to correct those SFRM skills identified as being less than effective.

MCC Flight Controller SFRM Training

Concurrent with the start of flight crew SFRM training, the SFRM Development Team began to move toward its vision of providing error-management training to all members of the NASA team. Because flight crews use the direction and expertise of mission control as their primary external resource, bringing SFRM training to the flight control community was the next logical expansion of the SFRM program.

To baseline those flight controllers already fully certified and who have a basic understanding of CRM concepts, the SFRM Applied Methods for MCC course was developed. The primary objectives of this class are to operationalize the essential concepts behind the SFRM skills and to practice SFRM skill observation, assessment and debrief critique. This class is taught from a flight controller perspective, and combines the basic course content of the SFRM Overview with all of the actual space flight examples from the SFRM Applied Methods course. As a result of the overwhelming support and acceptance from NASA management, the flight control community has included SFRM training as a required course of instruction for all those seeking certification as a NASA Flight Controller. All new hires that aspire to become flight controllers attend both the SFRM Overview and Applied Methods classes.

Space Shuttle Maintenance SFRM Training

Word soon spread throughout the various NASA organizations of the success of the SFRM program. Looking for ways to ingrain CRM principals into the Space Shuttle vehicle maintenance processes, members from the Human Factors Engineering Group at the Kennedy Space Center (KSC) attended the SFRM classes. Members from the SFRM and KSC development teams then worked together to discover ways to bring the SFRM training to vehicle maintenance personnel. Currently, the KSC training group is providing a customized version of the SFRM Overview to newly hired shuttle maintenance personnel, with plans to develop customized versions of the Applied Methods and Facilitation courses.

Future SFRM Program Development

While the Space Shuttle SFRM training is well underway with the primary focus of SFRM reinforcement and debrief facilitation, International Space Station (ISS) instructors have now begun taking the SFRM Applied Methods and Facilitation classes. Presently, the SFRM development team is comprised of members of the Shuttle Guidance & Control/Propulsion group within the Space Flight Training Division. As the space flight examples were developed for the Applied Methods and Facilitation classes, these examples were chosen with an unintentional bias toward shuttle specific ascent/entry cases. Clear differences exist in operational philosophy between NASA's Space Shuttle Program and ISS Program. As the class composition began to be more heavily weighted toward ISS personnel, it became apparent that using shuttle specific examples with ISS personal as the target audience tended to be less effective. To maintain a better organizational fit between the courseware and the targeted student population, work is currently underway to identify and develop ISS specific examples for inclusion in the SFRM Applied Methods and Facilitation when teaching classes primarily consisting of ISS personnel.

The SFRM briefing given to assigned shuttle crews at the start of mission training has proven to be extremely effective, and has been overwhelmingly accepted by the astronaut corps. The SFRM development team judges that it would greatly enhance the training efforts toward the mission control community if a similar class were developed to benefit the flight controller community assigned to a specific mission. Flight controllers undergo two basic forms of training: generic, and flight specific integrated training. Generic training is primarily used for proficiency, procedure verification and certification. During flight specific integrated training, a mission control team is formed, which will support a specific shuttle mission. This team then begins to train with a specific shuttle flight crew. To afford NASA's Flight Directors the same benefit that Shuttle Commanders receive, the best placement of this class would be just prior to the flight specific integrated training.

Reasons for Program Success

One reason for SFRM program success is that a strong management commitment and support exists within the NASA organization. Another stems from the SFRM development team's understanding that CRM programs tailored to match the culture of an organization possess the greatest likelihood for success. Keeping in mind the solid research done by academia and the operational implementation from industries similar to space flight operations allowed the team to avoid replicating identified pitfalls and to capitalize on successful approaches. These approaches were in turn scrutinized to determine if inclusion into the SFRM course fit NASA's organizational culture. In many cases unique solutions were necessary, and the classroom instruction became highly interactive, skill-based, and operationally relevant with the concepts

presented and reinforced with specific space flight and aviation examples. The one reason judged to be most responsible for SFRM program success is reinforcement.

By raising the importance of SFRM training equal to that of technical training, and by providing consistent reinforcement through facilitated debriefs, SFRM has become part and parcel to the way flight crews and flight controllers are trained at NASA today. Crews and flight controllers are challenged to continually critique the effectiveness of their skills during every training event and actual operational mission. As a result, the SFRM program has emerged as a training program governed by an operational training philosophy, which enables Shuttle and ISS flight crews and MCC flight controllers to effectively manage operational errors.

RECOMMENDATIONS

The SFRM development team recommends the following for those engaged in CRM training development and implementation. First, take heed of the exceptional work that the academic community has done to advance the effectiveness of this training. Second, strive to make all aspects of classroom instruction operationally relevant to the student population. Students must clearly see how this training can and will be used in their *daily* work environment. The most effective way to bridge philosophy to actual operations is to find examples that come from ones own organization. Third, clearly articulate some simple expectations of the student with regard to debriefing. Ensure that instructors have the training to properly facilitate vs. instruct CRM issues. Fourth, debriefing CRM issues only during annual certifications is simply not often enough to affect the transfer of training desired. The goal must be to change the organizational culture to such an extent that debriefing/critiquing the effectiveness of CRM skills becomes a natural part of doing business. It must become part of the user's daily habit pattern. Fifth, be patient and open to corrections. If possible, steer away from spending an inordinate amount of energy gathering metrics to "prove" that the program is reaching some arbitrary numerical goal. Instead, program evaluation should first concentrate on the ways and frequency CRM topics are reinforced. In other words, first look at the trainers, then the trainees. Maintain a two-way line of communication between the program developers/instructors and the student population. The best feedback comes from an open dialogue with the end-users themselves, thus giving them a stake into the program's success.

The SFRM development team has been visited by a myriad of organizations, including commercial air carriers, FAA air traffic controllers, nuclear power generation plant controllers, fire fighters, medical personnel, the British and Australian Royal Air Forces, and several aerospace companies. The SFRM development team continues to look forward to many more collaborations that facilitate the development and implementation of the most effective error management training possible. In the case of manned space flight operations as well as many other industries, the success of our organization and the lives of those we train depend on our resolve and commitment to their safety.

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