Cockpit Team Coordination Skills: The Role of Monitoring and Backup

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ABSTRACT

Successful flight crew team performance in today's advanced technology cockpits is essential for mission accomplishment and contingent on crewmembers monitoring each other and providing the appropriate backup (Kontogiannis & Malakis, 2009; Tullo, 2010). Flight crew monitoring can serve as the last line of defense against aviation accidents and monitoring failures are evident in many recent accidents (Dismukes & Berman, 2010; FAA, 2017). In our study, thirty U.S. Coast Guard cockpit flight crews flew automated and non-automated instrument takeoffs as both pilot flying and pilot monitoring in the Coast Guard's MH-65 Operational Flight Trainer. We explored the effects of shared situational awareness, aviation experience, and level of cockpit automation on monitoring and backup performance. Instructor pilots observed the interaction of the cockpit flight crews to evaluate the level of monitoring and backup during the nighttime overwater instrument takeoffs. Based on the study's findings, the U.S. Coast Guard is redefining monitoring and backup in aircraft cockpits, defining critical behaviors for effective cockpit automation management, and changing how Coast Guard pilots are trained and evaluated to successfully perform in advanced technology multi-piloted cockpits.

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U.S. COAST GUARD AVIATION MISHAPS

Aviation is an essential operational capability of the U.S. Coast Guard for the safety, security, and stewardship of U.S. maritime interests. The primary mission of Coast Guard flight crews is operational response to search and rescue, law and treaties enforcement, marine environmental protection, and military readiness. However, Coast Guard aircraft accidents reduce operational effectiveness, cost lives, and damage valuable equipment. In 2010, the Coast Guard experienced five Class A flight mishaps resulting in loss of lives and costing the organization $124,860,386. These five Class A flight mishaps represented the highest annual Class A flight mishap cost ever experienced by the Coast Guard.

Leadership Response

In the summer of 2010, after a seven-month period involving four of the five Class A flight mishaps, Coast Guard leaders chartered a comprehensive review of Coast Guard aviation operations with the goal of enhancing flight safety, improving operational effectiveness, and identifying mishap reduction opportunities. The focus of the effort was not individual mishap investigations but an overarching review attempting to identify underlying common contributory factors existing in Coast Guard aviation. After the yearlong multifaceted review, the findings identified aviation deficiencies directly relating to human factors. A human factor finding in the review was the degradation of risk management and crew resource management practices among cockpit flight crews. In aviation, human error, and specifically crew resource management failures, is not a recent trend (Dismukes, & Berman, 2010; Prince & Salas, 1993).

Human Error in the Cockpit

Since the early days of powered flight, the interface between human and machine has proven to be the most challenging aspect of flight (Hobbs, 2004). Despite increased safety through technology and aviation system improvements, human error remains the primary cause of aviation accidents and loss of life (Dismukes, Berman, & Loulopoulos, 2007; Flin, O'Conner, & Crichton, 2008; Wiegmann & Shappell, 2003). Some argue that improvements to aircraft materials, aviation engineering techniques, and weather reporting procedures have not increased human error in aviation per se, but instead have brought the role of human error in aircraft accidents into greater prominence (Fraher, 2011; Reason, 2008). Human error in aviation, specifically in the cockpit environment, is traditionally labeled "pilot error" which often leads to a dangerous, single-minded view that focuses the blame solely on the pilot who committed the error rather than constructing the underlying causes of error (Dekker, 2006). According to Dismukes et al. (2007), aircraft accidents involve "a complex interaction of inherent human performance characteristics with task demands, environmental events and conditions, and social and organizational factors" (p. 300).

CREW RESOURCE MANAGEMENT

Crew Resource Management (CRM) was introduced in commercial aviation in the 1980s to mitigate the impact of human error by improving cockpit team performance (Dahlstrom & Dekker, 2010). The advent of CRM in aviation introduced social psychology and management principles into the cockpit environment and shifted the emphasis from traditional "stick and rudder" skills to managing team processes in the cockpit (Harris, 2011; Helmreich & Foushee, 2010). Aviation CRM training was embraced by U.S. military services in the 1990s as a result of research suggesting that enhancing flight crew coordination and communications improves mission effectiveness and flight safety (See Prince & Salas, 1993 and O'Conner, Hahn, & Nullmerer, 2010, for a review of U.S. military aviation CRM programs).

Shared Mental Models

CRM is a common instructional strategy for team training and effective CRM consists of the following:

- Shared understanding of the situation, the nature of the problem, the cause of the problem, the meaning of available cues, and what is likely to happen in the future, with or without action by the teams members;
- Shared understanding of the goal or desired outcome;
- Shared understanding of the solution strategy; what will be done, by whom, when, and why? (Dekker 2006; Orasanu, Martin, & Davison, 2001; Salas, Wilson, Burke, Wightman, & Howse, 2006)

Scientists now recognize that cognition is a phenomenon where individuals construct their reality cooperatively in a social environment. A shared cognitive construct among team members is called a shared mental model (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). Mathieu, Heffner, Goodwin, Cannon-Bowers, and Salas (2005) define a shared mental model as an "organized understanding or mental representation of knowledge that is shared by team members" (p. 38). Teams working in high workload dynamic environments use shared mental models to coordinate and adapt to changing demands and anticipate the needs of other team members when timely, error-free, and clear information is critical (Entin & Serfaty, 1999; Flin et al. 2008). Shared mental models allow teams the flexibility to shift knowledge structures accurately in response to novel situations in high-intensity, complex, stressful situations (Espevik, Johnsen, & Eid, 2011; Wildman et al., 2012). In aviation, shared mental models form the foundation for flight crew coordination (Grote, Kolbe, Zala-Mezo, Bienefeld-Seall, & Kunzle, 2010; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Sperling & Pritchett, 2011).

Team Monitoring and Backup

A shared mental model is a necessary precursor to effective backup behavior because it helps a team member decide when to provide backup and what assistance is needed (Salas, Rosen, Burke, Goodwin, & Fiore, 2006). Burke, Stagl, Salas, Pierce, & Kendall (2006) define monitoring as a "cognitive action in which team members regularly observe the actions of their teammates and watch for mistakes, slips, lapses, errors, and performance discrepancies" (p. 1195). Feedback to other team members can be verbal suggestions and/or corrective behaviors, with the goal of assisting the team member in getting his or her performance back on track (Dickinson & McIntyre, 1997).

When flying, pilots monitor the aircraft's course, configuration, and systems and, in multi-piloted aircraft cockpits, each other (Dismukes & Berman, 2010; Potter, Blickensderfer, & Boquet (2014). Cockpit flight crewmembers use monitoring and backup to render assistance and compensate for lapses in judgment or oversight made by the other flight crewmembers and possibly as the last barrier against accidents (FAA, 2017). Prince, Salas, Brannick, and Prince (2010) suggest that pilot experience level may affect monitoring and back up interactions in multi-piloted cockpits. Citing accident reports by aviation safety organizations, Dismukes and Berman (2010) state that lapses in monitoring have played a role in many aviation accidents and suggest that since monitoring is often occurring concurrently with other tasks (e.g., communicating, tuning, setting), pilots mistakenly believe that monitoring is secondary to those other tasks. Aviation analyses show that most of the human errors detected in aviation are detected by crewmembers not making the errors and that pilot monitoring is a valuable source in detecting mistakes of other team members (Kontogiannis & Malakis, 2009, p. 694). Tullo (2010) argues that pilots should practice and evaluate the skill of monitoring which will de-emphasize individual cockpit performance and increase the focus on team performance. Like advanced aircraft systems with multiple redundancies for added protection and increased safety, pilot monitoring and backup in multi-piloted aircraft provides a human redundancy that increases cockpit team effectiveness and flight safety.

Monitoring and Backup and Cockpit Automation

Cockpit automation is the execution of a task, function, or service by an automated system such as an autopilot, a flight director system, or a flight management system. Pilots use cockpit automation because it provides more precise flying by managing aircraft navigation, manipulating aircraft flight controls and engine power, and aircraft systems monitoring (Reising, Liggett, & Munns, 1999). There is growing empirical evidence on the negative effects of cockpit automation on human-monitoring performance (Casner & Schooler, 2014; Comstock & Arnegard, 1992; Mouloua, Hancock, Jones, & Vincenzi, 2010). According to Dismukes & Berman (2010), flight crews tend to monitor aircraft flight instruments less when aircraft are controlled by highly reliable cockpit automated systems.

The crash of Air France Flight 447 in the Atlantic Ocean while en route from Rio de Janeiro to Paris represents a salient example of negative effects of advanced cockpit automation and the flight crew's inability to monitor the aircraft and each other at the same time. According to Langewiesche (2014), the pilot monitoring became so distracted with interpreting cockpit automation indications that he abandoned his primary role of monitoring the actions of the pilot flying. Both pilots attempted to control the aircraft simultaneously further blurring predefined pilot flying and pilot monitoring roles and responsibilities. The pilots' confusion with the cockpit automation led to basic communication and coordination difficulties at a time when the Air France cockpit flight crew needed them the most. The interplay of cockpit automation and CRM was not fully understood until after the recovery of the aircraft flight data recorders and crash investigation.

Based on the Coast Guard Class A aircraft mishaps and the current literature on cockpit team coordination skills, we focused our research on how certain factors affect monitoring and backup within Coast Guard cockpit flight crews. As research has shown, shared mental models can affect how cockpit flight crews perform as a team, especially in dynamic environments requiring high workload (Entin & Serfaty, 1999; Flin et al. 2008). We decided to study this relationship between shared mental models and monitoring and backup behaviors during overwater instrument takeoffs at night. This represents a typical Coast Guard operational scenario and requires cockpit flight crews to perform a maneuver requiring high levels of team coordination and communication. As seen in the study's conceptual framework (Figure 1), we were interested in identifying 1) the existence of a shared mental model among cockpit flight crews before the instrument takeoff and 2) the shared mental model's effect on cockpit flight crew monitoring and backup.

Coast Guard aircraft are now equipped with advanced technology cockpits with increased automation capabilities. Similar to commercial aviation, the "glass cockpit" represents a major shift in the pilot-aircraft interface and requires increased levels of cockpit flight crew coordination and communication to safely operate the aircraft. Since recent literature points to negative effects of cockpit automation on monitoring and backup performance (e.g., Casner & Schooler, 2014), we were also interested in how cockpit automation levels influence monitoring and backup. Finally, we were interested to see if flight crew aviation experience level, quantified in total flight time, plays a role in how cockpit flight crew members monitor and backup each other. The oval depicted in Figure 1 represents our interest in the combined interaction effect of cockpit automation level, shared mental model, and flight crew experience level on cockpit flight crew monitoring and backup. The study variables were significant in providing clarity to cockpit team coordination practices currently occurring in Coast Guard cockpits.

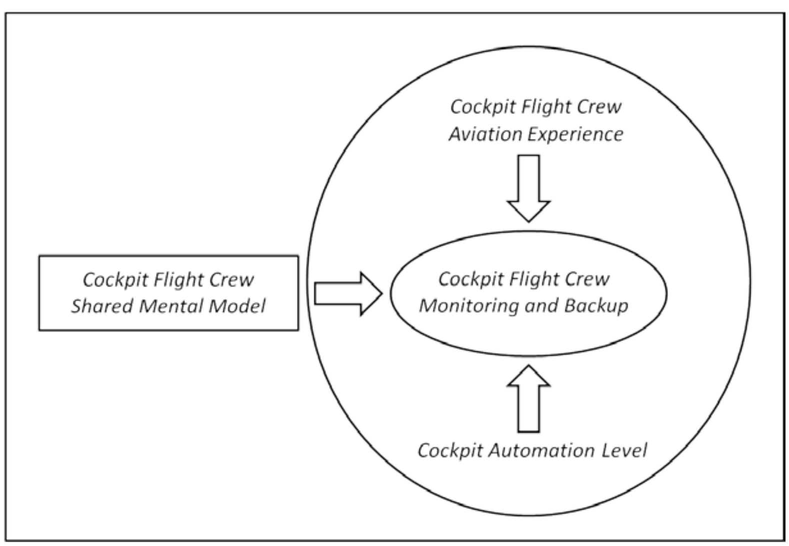

Figure 1. Conceptual Framework of the Study's Variables

METHOD

Participants

The MH-65 Coast Guard pilot population consists of 430 duty-standing pilots throughout the United States. Due to time and resource restraints, data was collected from a convenience sample of 30 two-pilot cockpit flight crews attending their annual proficiency training at the Aviation Training Center in Mobile, Alabama. The sample size closely matches the number of teams utilized in past shared mental model research (e.g., Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu et al., 2005). The pilots ranged in designation from Copilot to Aircraft Commander and all 30 participating flight crews consisted of at least one Aircraft Commander. The average total flight hours per cockpit flight crew (M = 4652, SD = 1872) is typical for operational Coast Guard multi-piloted cockpits.

Operational Measures of Variables

Aviation Experience

To gauge the overall experience and maturity level of the participating cockpit flight crews, we calculated total flight time for each cockpit flight crew based on the number of flight hours each pilot reported while completing a Shared Mental Model Instrument.

Shared Mental Model

Using the methodology found in Marks, Zaccara, & Mathieu (2000), Matheiu et al. (2000), and Mathieu et al. (2005) we determined a shared mental model score for each cockpit flight crew indicating the level of mental model sharedness about automated and non-automated instrument takeoffs. Pilots rated the relationship of seven critical instrument takeoff tasks using a scale from one (not related) to five (very related). For example, pilots indicated how related conducting a level off checklist is to achieving a desired level off altitude. Pilots' relatedness ratings were then compared to determine the level of shared mental model among the flight crew pilots.

Cockpit Automation

To determine the effect of cockpit automation on monitoring and backup, flight crews completed two types of instrument takeoffs (automated and non-automated). Pilots fly instrument takeoffs using cockpit flight instruments when visibility is poor and insufficient references exist for visual takeoffs. An automated instrument takeoff transitions the aircraft from hovering to a climb using the cockpit automation to fly the aircraft. During a non-automated instrument takeoff, the pilot "manually" flies the aircraft from hovering to a climb. Both types of instrument takeoffs are acceptable methods for safely climbing the aircraft in low visibility conditions.

Monitoring and Backup

A Monitoring/Backup Instrument was developed to determine the level of monitoring and backup occurring between flight crews during instrument takeoffs. Using a Likert-type scale raning from one (not at all) to five (to a very great extent), cockpit flight crews were judged on specific monitoring and backup behavior markers. For example, the pilots were judged on how often they corrected each others' errors when necessary or asked to do so.

Procedure

We met with each cockpit flight crew to explain the research study's objectives and to distribute an informed consent form. After each pilot signed the consent form, they received the Shared Mental Model Instrument. We explained the purpose of the instrument and asked that each pilot complete the instrument individually. The instrument was also used to collect each pilot's flight experience in hours and record the pilot's designation.

Using a repeated measures design, cockpit flight crews were recorded while they flew four instrument takeoffs (two automated and two non-automated). Each pilot flew an automated instrument takeoff and a non-automated instrument takeoff as the pilot flying and then functioned as the pilot monitoring while the other pilot flew an automated and non-automated instrument takeoff. The order of instrument takeoff type and pilot role (i.e., flying or monitoring) was counterbalanced using a Latin square design. The design allowed both pilots to be measured as pilot monitoring during both types of instrument takeoffs. The cockpit flight crews were unaware that the instrument takeoffs were being specifically observed for monitoring and backup behaviors.

Later in the week, two instructor pilots individually viewed the recorded instrument takeoffs and completed the Monitoring/Backup Instrument for the four instrument takeoffs performed by each cockpit flight crew. The two instructor pilots had over 15,000 combined flight hours in the Coast Guard and are experts in multi-piloted cockpit coordination and CRM principles. The instructor pilots viewed the instrument takeoffs at a training debriefing station. The debriefing station provides over-the-shoulder video playback of the cockpit, cockpit audio, and instrument panel playback. They observed each cockpit flight crew interaction during the instrument takeoff maneuvers as many times as necessary to observe and judge all monitoring and backup behaviors. Monitoring and backup scores were aggregated according to instrument takeoff type to produce one automated monitoring and backup score and one non-automated monitoring and backup score for each flight crew.

RESULTS

A series of planned comparisons were conducted to evaluate the relationships between each independent variable and monitoring and backup scores. We also conducted a repeated-measures ANCOVA to investigate a possible interaction effect between aviation experience level, shared mental model score, and cockpit automation level on monitoring and backup. The results are organized by variable and presented below.

Cockpit Automation

A planned comparison paired *t*-test showed that cockpit automation level affected pilot monitoring and backup, $t(29) = 2.576$, $p = .015$, $\eta^2 = .186$. Specifically, we found that flight crews had higher levels of monitoring and backup during non-automated instrument takeoffs ($M = 51.07$, $SD = 12.30$) than during automated instrument takeoffs ($M = 44.37$, $SD = 13.92$). These results show that highly reliable cockpit automated systems may lead to lower monitoring and backup performance.

Aviation Experience

Two correlations were conducted to evaluate the relationship between flight crew aviation experience level and monitoring and backup behaviors during automated and non-automated instrument takeoffs. The correlations between aviation experience and automated ($r(28) = -.065$, $p = .734$) and non-automated ($r(28) = .005$, $p = .979$) monitoring and backup scores were not statistically significant.

Shared Mental Models

Two correlations were conducted to evaluate the relationship between shared mental model and monitoring and backup behaviors during automated and non-automated instrument takeoffs. The correlations between shared mental models and automated ($r(28) = .26$, $p = .160$) and non-automated ($r(28) = .14$, $p = .463$) monitoring and backup scores were not statistically significant.

Interaction between Aviation Experience, Shared Mental Models, and Cockpit Automation Level

A repeated-measures ANCOVA was conducted to evaluate a possible interaction effect between flight crew aviation experience level (quantitative IV), shared mental model (quantitative IV), and cockpit automation (categorical IV) on monitoring and backup. We found that the interaction effect was not statistically significant, $F(1, 26) = 1.199$, $p = .284$.

DISCUSSION

The purpose of the study was to evaluate the effects of cockpit flight crew aviation experience, shared mental model, and cockpit automation level on monitoring and backup behaviors during instrument takeoffs. Interestingly, flight crew aviation experience and level of shared mental model for cockpit flight crews were not significantly related to monitoring and backup behavior. We expected to find a positive relationship between total flight time and monitoring and backup with more experienced flight crews being more likely to perform monitoring and backup behaviors as appropriate. However, we found that there was not a significant relationship between the two variables suggesting that Coast Guard pilots of all experience levels can exhibit appropriate levels of monitoring and backup and that cockpit team coordination skills should be developed and practiced throughout pilots' aviation careers.

We also found that higher levels of shared mental model among cockpit flight crews did not necessarily predict better monitoring and backup performance. This suggests that monitoring and backup behaviors occur among cockpit flight crews with both high and low levels of mental model sharedness. However, we did not test the validity of the shared mental model instrument and it is important to consider the sensitivity level of the instrument as a possible limitation of the study. Future research should consider using more sensitive measures of shared mental model (e.g., Pathfinder's knowledge structure assessment or UCINET's social network analysis [Mathieu et al., 2005]) for measuring shared mental models. The shared mental model instrument used in this research may not have been sensitive enough to detect shared mental model variance among and between cockpit flight crewmembers.

The monitoring and backup instrument also indicated some inaccuracy in how behaviors were scored during instrument takeoffs. It became apparent during data collection that the scoring instrument was not functioning as it was originally designed. Several of the behavior markers were dependent upon the pilot flying making a procedural error or mistake. If these mistakes did not occur, then the monitoring and backup behaviors were unobservable and the scale did not account for these scoring discrepancies. Even though additional training was held for the two instructor pilots to mitigate the instrument discrepancy, the interrater reliability of the instrument was poor for both automated (Pearson's $r = .44$) and non-automated (Pearson's $r = .29$) instrument takeoffs. Future research should include an instrument that adjusts scores based on the number of opportunities for monitoring and backup behaviors within each unique instrument takeoff team performance.

The most notable finding from this research was that level of automation in the cockpit influences how well cockpit flight crews monitor and backup each other. Our finding is consistent with the growing body of empirical evidence that shows how cockpit automation can negatively affect monitoring performance (e.g., Casner & Schooler, 2014; Mouloua, Hancock, Jones, & Vincenzi, 2010). This relationship is likely due to a perceived lower probability of error when using aircraft automated systems (Dismukes & Berman, 2010). As cockpit automation levels increase, the cockpit flight crew cognitive workload increases with the additional tasks of monitoring and controlling the automation (Hamilton, 2010). This theory is misaligned with how the Coast Guard has traditionally described the relationship between automation and workload. Coast Guard policy has presented automation management in a way that shows an inverse relationship between automation level and workload (i.e., as automation level increases, workload decreases). However, our research results and literature indicate a much more complicated relationship between automation, monitoring, and cockpit workload. Coast Guard policy needs to reflect that cockpit automation requires the same and possibly increased levels of workload, monitoring, and backup behaviors. Also, Coast Guard CRM training should address the requirement for increased levels of crew coordination, specifically increased levels of monitoring and backup between the cockpit flight crew. Taken together, the literature and the results of this research have influenced several major changes to Coast Guard aviation training, operational procedures, and policy.

ORGANIZATIONAL IMPACT

Redefining Monitoring and Backup in Coast Guard Cockpits

Precisely defining the roles pilot flying and pilot monitoring during the instrument takeoff maneuver was necessary to evaluate the cockpit team coordination. However, it became apparent during the study that standard operating procedures for the MH-65 aircraft, as well as other Coast Guard aircraft, lack comprehensive monitoring and backup performances during many critical aircraft maneuvers. Coast Guard aircraft flight manuals provide monitoring and backup performances with some critical maneuvers which increase crew coordination and communication as necessary and appropriate, e.g. instrument approaches, but the Coast Guard lacks a comprehensive systematic approach when defining successful cockpit team monitoring and backup and building those behaviors into standard operating procedures.

Behavior Markers

Behavioral markers represent a prescribed set of behaviors leading to a performance and have been used to observe cockpit flight crew CRM skills in commercial and military aviation (Flin & Martin, 2001; Fowlkes, Lane, Salas, Franz, & Oser, 1994). Cockpit flight crew behavior markers clarify and standardize pilot flying and pilot monitoring duties and allow direct observation of required cockpit communication and coordination tasks during critical maneuvers. Since research indicated a link between cockpit automation and monitoring and backup, we established behavior markers for training and evaluation of cockpit automation management in Coast Guard pilots (see Table 1). These behavior markers are similar to the automation behavior markers recently established by the Royal Canadian Air Force for operating their advanced technology cockpits (Lutat & Swah, 2013)

Table 1

Automation Management Behavior Markers

Automation	Automation Errors	Flight Displays	Flight Modes
Employ automation level that is appropriate for flight conditions and flight phase.	Identify and announce errors.	Select optimal display page and scale to enhance situation awareness.	Anticipate mode changes.
Monitor flight path.	Assume flight controls, if necessary.	Avoid cluttered display.	Announce mode changes.
Anticipate flight path changes.	Debrief error after resolution.		Verify mode changes.
Avoid automation fixation.			
Continually monitor to detect errors, avoid surprises, and maintain situational awareness.			

Using the automation management behavior markers to employ the aircraft automated flight system ensures cockpit flight crew's 1) continual awareness of the aircraft's desired flight path versus the actual flight path, 2) correct and timely interpretation of aircraft system information and parameters, and 3) correct and timely interpretation of automated flight information.

Aircraft Initial Training

Co-pilot training in Coast Guard multi-piloted aircraft traditionally focuses on aircraft systems and pilot flying skills, which lays the foundation for future higher levels of responsibilities within the aircraft cockpit. The training primarily focuses on operating aircraft flight controls and cockpit automation and managing aircraft systems, but on many occasions, lacks the pilot monitoring and team coordination training necessary for successful cockpit team performance. For example, a visual approach is predominantly trained as a pilot flying task. However, in the multi-piloted cockpits, both pilot flying and pilot monitoring duties occur during a visual approach maneuver: the pilot flying manipulates the aircraft controls or cockpit automation, and the pilot monitoring provides backup to the maneuver and other non-flying duties (e.g., radio communications, aircraft configuration checks, flight instrument and aircraft systems scanning). Precisely defining pilot flying and pilot monitoring duties during critical phases of flight enhances flight safety by further clarifying the role of each team member.

In light of recent commercial aviation accidents (Asiana Airlines Flight 214 and Colgan Air Flight 3407), industry, government, and labor organizations representatives collaborated to examine ways of improving monitoring and backup in commercial airline cockpits. Recommendations included monitoring practices, monitoring procedures and policies, cockpit automation monitoring, and the training and evaluating of monitoring skills. The working group found that pilot monitoring requirements increased in phases of flight when the time to detect and correct flight path errors is short and potential consequences of poor monitoring are the most severe (Flight Safety Foundation, 2014).

Using the critical phases of flight identified in the Flight Safety Foundation report (2014) and critical flight phases defined in current Coast Guard crew coordination policy, we conducted a job task analysis for pilot monitoring cockpit performances. The job task analysis generated pilot monitoring performances in Coast Guard multi-piloted aircraft in the following critical phases or maneuvers: 1) aircraft flight path, 2) taxi, 3) takeoff, 4) visual approach, 5) landing, 6) instrument takeoff, 7) instrument approach, 8) instrument missed approach, and 9) aircraft emergencies. Pilot monitoring tasks are now directly linked with each pilot flying task providing an orchestrated crew coordination procedure for each critical phase of flight or maneuver.

Development of MH-65E Standard Operating Procedures

The Coast Guard is modernizing its rotary-wing aircraft with the Rockwell Collins Common Avionics Architecture System (CAAS) advanced technology glass cockpit. The change in cockpit layout requires an entirely new interface protocol with revised crew coordination and automation management procedures. The drastic change in pilot's instrument panel scan, as well as the newly increased role of cockpit automation, has significant impacts to flight safety. To mitigate the risks associated with transitioning to an advance cockpit interface, we are using the pilot monitoring job task analysis output to design orchestrated crew coordination standard operating procedures for the MH-65E advanced technology cockpit.

Even though our current research focused on crew coordination in rotary-wing aircraft, our findings may generalize to fixed-wing advanced technology cockpits. As a result of industry involvement during standard operating procedures (SOP) design, many pilot monitoring duties have been defined in the Coast's Guard HC-130J and HC-27J communities. However, further clarity is warranted. Plans include pilot monitoring analyses for Coast Guard fixed-wing aircraft to build upon existing cockpit crew coordination practices. These analyses, along with further studies on defining successful monitoring and backup in aircraft cockpits and critical behaviors for effective cockpit automation management, are in development.

We are encouraged by the FAA's recent update to the SOP Advisory Circular (FAA, 2017). The update describes effective pilot monitoring duties and their role in cockpit automation. The FAA's recommendation to define, train, and integrate pilot monitoring duties into SOPs is a step in the right direction. Going forward, military and commercial aviation should work together to better understand the value of automation behavior markers and pilot monitoring performances on cockpit team effectiveness and flight safety in today's advanced technology multi-piloted cockpits.

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