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The Role of Shared Mental Models in Team Coordination Crew Resource Management Skills of Mutual Performance Monitoring and Backup Behaviors

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The University of Southern Mississippi

THE ROLE OF SHARED MENTAL MODELS IN TEAM COORDINATION CREW
RESOURCE MANAGEMENT SKILLS OF MUTUAL PERFORMANCE
MONITORING AND BACKUP BEHAVIORS

by

Alan Reid Martinez

Abstract of a Dissertation
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

May 2015

ABSTRACT

THE ROLE OF SHARED MENTAL MODELS IN TEAM COORDINATION CREW RESOURCE MANAGEMENT SKILLS OF MUTUAL PERFORMANCE MONITORING AND BACKUP BEHAVIORS

by Alan Reid Martinez

May 2015

The purpose of Crew Resource Management (CRM) is to improve flight crew coordination in multipiloted cockpits and in turn increase aviation flight safety. One aspect of CRM team coordination is the ability for flight crews to monitor each other properly and provide the appropriate backup if necessary. The author explores the role of shared mental models among Coast Guard rotary wing cockpit flight crews and their influence on monitoring and backup behaviors during nighttime overwater flight maneuvers. Using the Coast Guard's MH-65 Operational Flight Trainer located at the Coast Guard Aviation Training Center in Mobile, Alabama, cockpit flight crews flew automated and manual instrument takeoff (ITO) maneuvers. Coast Guard CRM subject matter experts observed the interaction of the cockpit flight crews judging the level of mutual performance monitoring and backup behaviors during the ITO maneuvers. Using a repeated measures design, the researcher investigated the relationship and interaction between ITO maneuver shared mental model, type of ITO maneuver, and pilot flight time on cockpit flight crew monitoring and backup behaviors. Findings indicate a significant relationship between cockpit automation and levels of mutual performance monitoring and backup behaviors in cockpit flight crews.

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A Dissertation
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for the Degree of Doctor of Philosophy

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May 2015

DEDICATION

This research is dedicated to U.S. Coast Guard flight crews who daily put themselves in harm's way to protect the maritime interests of the United States and save those in distress at sea. I admire their professionalism and competence and count it an honor to have served and worked alongside them for many years. The research is also dedicated to those who have given their lives flying in the high-risk environment of nighttime overwater operations. Only those who have been there truly understand the demanding aspects of night flying in reduced visibility with no visible horizon. I have lost several close friends to this demanding environment, and on a more personal note, my brother Ronald L. Martinez was lost at sea in a nighttime overwater helicopter accident 31 years ago. My hope is that this research will help continue to increase the flight crew coordination effectiveness and operational flight safety of the brave souls whose job requires them to operate in this high-risk environment.

ACKNOWLEDGMENTS

I sincerely thank my dissertation committee chair, Dr. Cyndi Gaudet. Her ability to live in my technical aviation world while walking me through my Ph.D. journey is truly amazing. I also give a special thanks to my entire dissertation committee. Dr. Heather Annulis, thank you for your valuable input and encouragement, and yes, I have another question. Dr. Dale Lunsford, I knew I was making progress when we discussed my statistical analysis and I understood what you were saying. Dr. Patti Phillips, you made the Human Capital Development program highly relevant to my aviation world, and I appreciate your positive attitude and constant encouragement. Dr. Randy Johnson, it seems just yesterday we were serving together at a Coast Guard Air Station. I appreciate your insight and advice regarding pursuing an advanced degree. Your aviation technical expertise and academic savvy are contagious, and I appreciate your continued support. Once again, I am extremely grateful to share the journey with all of you.

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LIST OF ABBREVIATIONS

<i>ATC</i>	Aviation Training Center
<i>CRM</i>	Crew Resource Management
<i>FAA</i>	Federal Aviation Administration
<i>HFACS</i>	Human Factors Analysis and Classification System
<i>ITO</i>	Instrument Takeoff
<i>NTSB</i>	National Transportation Safety Board
<i>OFT</i>	Operational Flight Trainer
<i>SME</i>	Subject Matter Expert

CHAPTER I

INTRODUCTION

Aviation is an essential operational capability of the U.S. Coast Guard for the safety, security, and stewardship of U.S. maritime interests (U.S. Coast Guard, 2014b, 2014c). Coast Guard flight crews operate at Coast Guard Air Stations across the country flying multi-mission aircraft supporting the missions of the Coast Guard. The primary missions of Coast Guard flight crews is operational response to search and rescue, law and treaties enforcement, marine environmental protection, and military readiness (U.S. Coast Guard, 2013). 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 (U.S. Coast Guard, 2010a). These five Class A flight mishaps represented the highest annual Class A flight mishap cost ever experienced by the Coast Guard (U.S. Coast Guard, 2010a). Coast Guard aviation leaders responded by calling for a comprehensive safety review of all aspects of aviation operations (M. Emerson, personal communication, July 28, 2010). The primary focus of the review was identifying aviation operational deficiencies and possible areas for flight safety improvement. One outcome of the safety review was the evaluation and refocus of the Crew Resource Management (CRM) program for Coast Guard flight crews (U.S. Coast Guard, 2010a). A few years earlier, then Commanding Officer of the Coast Guard Aviation Training Center expressed concern to aviation program managers about the current Coast Guard CRM program, believing that CRM training had become a mere

“check in the box” for Coast Guard flight crews and called for a comprehensive training upgrade (D. R. Callahan, personal communication, June 19, 2007).

Crew Resource Management (CRM)

According to Harris (2011), aviation is a sociotechnical system consisting of complex interactions between humans and technology. Aviation CRM is a management process encouraging the optimal use of human resources in today’s aircraft cockpits.

According to Helmreich, Merritt, and Wilhelm (1999), CRM represents human performance and its limitations in the cockpit. The U.S. Coast Guard (2014a) defines CRM as “the effective use of all available resources for flight crews to assure a safe and efficient operation, reducing error, avoiding stress, and increasing efficiency” (p. 20-3).

Aviation CRM attempts to combat human error among flight crews by training and improving non-technical skills such as communication, coordination, and teamwork (Flin, O’Conner, & Crichton, 2008; Kanki, Helmreich, & Anca, 2010; Wiener, Kanki, & Helmreich, 1993). Beginning in the 1970s in response to several commercial airline accidents exposing poor crew communication and coordination, CRM is now prevalent in many high-risk, dynamic team environments and organizations (Fraher, 2011; Helmreich et al., 1999). In aviation, the primary purpose of CRM is increasing flight safety by improving teamwork effectiveness of flight crews (Aguinis & Kraiger, 2009). Reason (1997) argues that aviation CRM has proven successful in improving flight crew performance through situational awareness sharing, enhanced leadership, and better crew communication.

CRM Training

The focus of CRM training is to prevent aviation accidents by improving and optimizing individual and crew performance (Federal Aviation Administration [FAA], 2004; U.S. Coast Guard, 2014a). The FAA (2004) further defines CRM training essentials and the role of flight crews with the following stated guidelines:

1. CRM training is most effective within a training program centered on clear, comprehensive [Standard Operating Procedures] SOPs;
2. CRM training should focus on the functioning of crewmembers as teams, not as a collection of technically competent individuals;
3. CRM training should instruct crewmembers how to behave in ways that foster crew effectiveness;
4. CRM training should provide opportunities for crewmembers to practice the skills necessary to be effective team leaders and team members;
5. CRM training exercises should include all crewmembers functioning in the same roles (e.g. captain, first officer, and/or flight engineer, flight attendants) that they normally perform in flight;
6. CRM training should include effective team behaviors during normal routine operations. (p. 6)

Human Error in the Cockpit

Aviation CRM training also focuses on improving cognitive and psychosocial skills of flight crewmembers (Kanki et al., 2010), which primarily manifest through teamwork processes (Wiener et al., 1993). Advocates of CRM believe that improving

cockpit flight crews' interpersonal and cognitive teamwork processes can directly increase flight safety and reduce the number of accidents attributed to human error (FAA, 2004; Foushee, 1984; Lauber, 1987; Oser, Salas, Merket, Walwanis, & Bergondy, 2000). In fact, reducing the accidents caused by human error is the major thrust of recent CRM error management initiatives and human factors accident analyses (Helmreich & Merritt, 2000; Helmreich, Wilhelm, Klinect, & Merritt, 2001; Wiegmann & Shappell, 2001, 2003). Although new viewpoints now exist about the role of CRM training, reducing cockpit human errors and aircraft accidents through CRM training remains a prevailing view among human factor researchers and aviation safety experts today (Flin et al., 2008; O'Conner & O'Dea, 2007; U.S. Coast Guard, 2009a; Wiegmann & Shappell, 2003).

However, others believe aircraft accidents are not caused by unreliable and irresponsible flight crews committing errors but occur because complex systems are basically unsafe and represent competing values in a resource-constrained world (Dekker, 2002, 2003; Perrow, 1999). Researchers now argue that human resilience, flexibility, and adaptability create safety in complex systems (Cook, O'Conner, Render, & Woods, 2004; Dekker, 2002, 2003, 2006; Reason, 2008). According to Reason (2008), the human contribution of individual and collective mindfulness is required in complex and dynamic environments where human and technical failures are unavoidable. Fraher (2011) believes that teams operating in high-risk dynamic environments must evolve and adapt to changing workplace conditions and further suggests that today's advanced technologies require teams with increased communication, improved coordination, and shared mental modeling.

Shared Mental Models

Effective crew performance coordination requires shared mental models among flight crewmembers (FAA, 2003), and research shows shared mental models enhance crew coordination (Grote, Kolbe, Zala-Mezo, Bienefeld-Seall, & Kunzle, 2010; Krieger, 2005; Sperling & Pritchett, 2011). A positive relationship exists among shared mental models, team processes, and performance (Marks, Sabella, Burke, & Zaccaro, 2002; Marks, Zaccaro, & Mathieu, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Rentsch & Klimoski, 2001; Smith-Jentsch, Mathieu, & Kraiger, 2005; Waller, Gupta, & Giambatista, 2004; Zou & Lee, 2010). Teams operating in high-risk environments, such as aircraft cockpits, must cultivate a shared mindfulness which ensures a proactive approach to safety and sustained vigilance (Fraher, 2011; Krieger, 2005). Cockpit flight crews align expectations and increase safety by using shared mental models tools such as standardized phraseology, standardized operating procedures, and pre-established verbal communication (U.S. Coast Guard, 2013).

Mutual Performance Monitoring and Backup Behaviors

Shared mental models enhance team effectiveness by providing the underpinning for mutual performance monitoring and backup behaviors decisions (Salas, Rosen, Burke, Goodwin, & Fiore, 2006). Through shared mental models, team members decide if, when, and what type of monitoring and backup is appropriate and required. Monitoring and backup behaviors are team coordination processes which increase the awareness of other team members' actions and cause members to pay attention and recognize when appropriate corrections and feedback are necessary (Wilson, Salas,

Priest, & Andrews, 2007). According to Sumwalt, Thomas, and Dismukes (2003), pilots use monitoring and cross checking to increase flight safety. Since the goal of CRM training in aircraft multipiloted cockpits is to increase flight safety by improving flight crew coordination, Sumwalt et al. (2003) argue that monitoring and backup skills need to be the next focus of aviation CRM training.

Pilot Monitoring and Cockpit Automation

Cockpit flight crews also use mental models when monitoring aircraft automation and establish expectations of the behavior of those automation systems (Bjorklund, Alfredson, & Dekker, 2006; Sarter, Woods, & Billings, 1997). However, researchers believe that flight crew monitoring performance decreases when aircraft are controlled by highly reliable cockpit automated systems such as autopilot, flight director system, and flight management system (Mouloua, Hancock, Jones, & Vincenzi, 2010). Cockpit automation is associated with poorer human-monitoring performance (Casner & Schooler, 2014; Comstock & Arnegard, 1992; Davies & Parasuraman, 1982; Dismukes & Berman, 2010). According to Mouloua et al. (2010), cockpit automation impacts human-monitoring performance and monitoring strategies based on flight crew shared mental models (Mouloua et al., 2010).

Shared Mental Models in Coast Guard Aviation

Coast Guard aviation now recognizes the significance of shared mental models among cockpit flight crews. Interim Change 5 of the *MH-65 Aircraft Flight Manual* released in April of 2013 updates procedures associated with helicopter overwater ITOs and specifically addresses the role of shared mental models with the following guidance: “Following the completion of hover operations, the [pilot at the controls] shall give a

departure brief prior to commencing a coupled or manual ITO to ensure a shared mental model amongst all crewmembers” (U.S. Coast Guard, 2010b, p. 2-19). Interim Change 5 also defined pilot flying and safety pilot responsibilities during aircraft-automated coupled ITOs and pilot flying manual ITOs. The goal of the updated procedures is to increase cockpit flight crew effectiveness by establishing standard pilot flying actions and safety pilot verbal calls and monitoring duties during both types of ITOs. However, the value or influence of shared mental models in Coast Guard cockpits and their role in mutual performance monitoring and backup behaviors during cockpit automated and non-automated critical flight phases is unclear.

Statement of the Problem

Coast Guard CRM training attempts to reduce human error and increase flight safety by improving flight crew coordination. However, recent Coast Guard aircraft mishaps costing lives and millions of dollars, coupled with the new views that human resiliency, flexibility, adaptability, and shared mental models create safety by improving flight crew coordination and performance, highlight the need for a clearer understanding of the role of shared mental models and cockpit automation on mutual performance monitoring and backup behaviors in Coast Guard cockpits.

Purpose of the Study

The purpose of the study is to examine the effect of the ITO maneuver shared mental model among Coast Guard aircraft cockpit flight crews, ITO type (coupled or manual), and cockpit flight crew total flight time on mutual performance monitoring and backup behaviors.

Research Objectives (RO)

The research objectives of the study are as follows:

- RO1: Describe the demographics of the study population according to pilot designation/qualification and cockpit flight crew total flight time experience.
- RO2: Determine the level of mental model sharedness in MH-65 aircraft cockpit flight crews of ITO maneuver critical team tasks.
- RO3: Determine the relationship between the ITO maneuver shared mental model score and observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.
- RO4: Compare the type of ITO (coupled or manual) on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.
- RO5: Determine the relationship between flight crew total flight time and observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.
- RO6: Determine the combined interaction effect of the ITO maneuver shared mental model score, ITO type, and flight crew total flight time on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.

Conceptual Framework

Figure 1 provides the conceptual framework for depicting the existence of cockpit flight crew ITO shared mental model (RO2) and its relationship with mutual performance monitoring and backup behaviors (RO3). The ITO type (coupled or manual) and cockpit

crew total pilot time may also influence mutual performance monitoring and backup behaviors (RO4 and RO5). The combined interaction effect of the ITO shared mental model, ITO type, and cockpit flight crew total flight time on mutual performance monitoring and backup behaviors is shown in RO6.

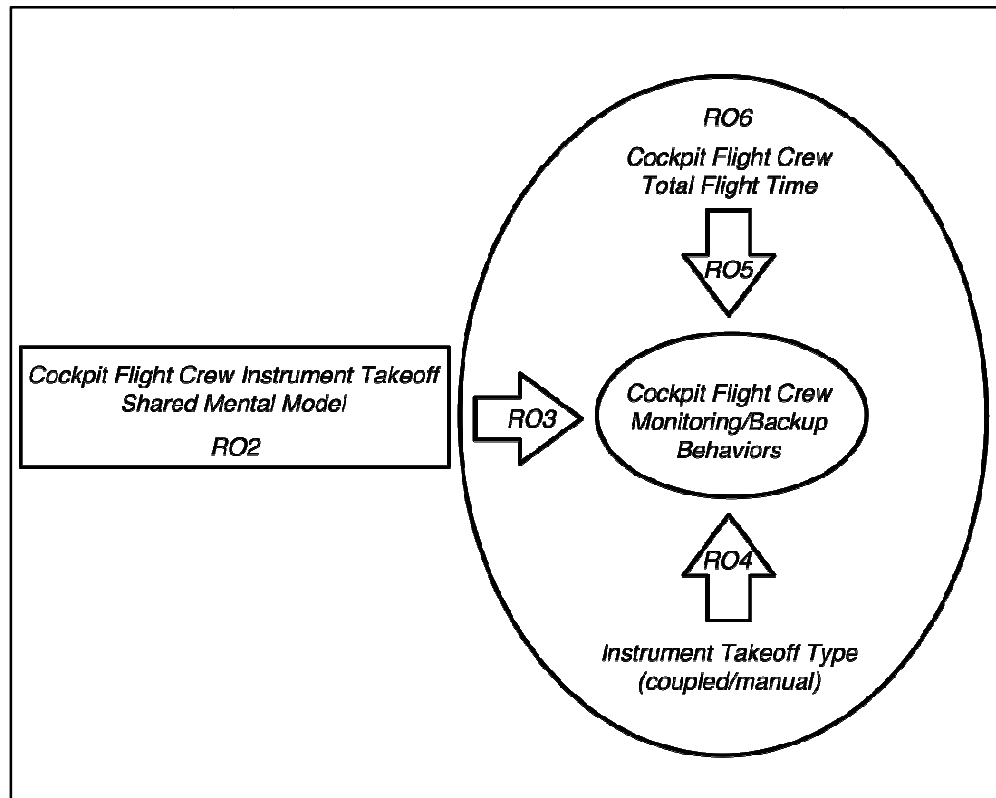


Figure 1. Conceptual Framework of the Study's Research Objectives and Variables.

Data collection will consist of a Shared Mental Model Instrument (RO1, RO2), and a Monitoring/Backup Behaviors Instrument (RO3, RO4, RO5, RO6) for observing MH-65 aircraft cockpit flight crewmember behaviors during ITO maneuvers in the MH-65D Operational Flight Trainer located at the Coast Guard Aviation Training Center (ATC) in Mobile, Alabama. A complete description of the instruments, data collection, and ITO maneuver scenario are found in the study's methodology chapter.

Significance of the Study

From a human capital standpoint, the selection, training, and proficiency of Coast Guard pilots directly affects the success of Coast Guard aviation operational missions. The ability of Coast Guard flight crew to operate in extreme and hazardous environments in a highly professional and safe manner protects flight crews and saves lives.

The significance of the study is the expected applicability to other Coast Guard rotary-wing and fixed wing aircraft cockpits beyond the MH-65. Though the aircraft equipment and models may differ, cockpit flight crew procedures and protocol in Coast Guard multipiloted aircraft is highly similar to that of other aircraft. Research insights are immediately available and applicable to all Coast Guard cockpit flight crew. Military CRM, specifically CRM in Coast Guard cockpits, have concentrated on skills identified twenty years ago. To stay current, CRM in the Coast Guard must evolve as research clarifies new aspects of cockpit flight crew coordination.

Assumptions

Because the MH-65 pilots participating in the study are attending their normal recurrent training at ATC Mobile, it is assumed that they accurately represent the population of duty-standing pilots assigned to Coast Guard Air Stations at the seventeen operational units across the United States and Puerto Rico. A second assumption is that participants taking part in the study are under no perceived pressure to participate and will perform in a manner similar to their normal cockpit protocol and performance abilities. Thirdly, the study participants are expected to answer the survey questions truthfully and without bias. Finally, the researcher assumed the methods used for determining crew pairing shared mental models found in early team process and

performance literature are valid (Marks et al., 2000, 2002; Mathieu et al., 2005; Mathieu et al., 2000; Smith-Jentsch et al., 2005), and that the Monitoring/Backup Behaviors Instrument aligns with methods found in Salas, Sims, & Burke (2005) and Wilson et al. (2007).

Limitations and Delimitations of the Study

The researcher was not involved in the selection of the pilots attending the ATC Mobile training course, and therefore pilots may not truly represent the total MH-65 pilot population. To narrow the scope of research, the study was limited to the MH-65 aircraft community and did not include the other four Coast Guard operational aircraft (MH-60T, HC-144A, HC-130H, HC-130J). All pilots participating in the study are designated in aircraft model type and currently meet proficiency standards defined in the Coast Guard Air Operations Manual (U.S. Coast Guard, 2013). Also, the CRM experts using the measurement instrument to analyze mutual performance monitoring and backup behaviors during the ITO maneuvers may view the behaviors differently and therefore affect interrater reliability.

Definition of Key Terms

The following provides further clarity to key terms used within the aviation industry:

1. *Advisory Circular* – A document distributed by the Federal Aviation Administration to guide and inform those involved in the aviation industry. Though not regulatory in nature, Advisory Circulars provide direction and information on specific topics and may require implementing by the Federal Aviation Administration (Houston, n.d.).

2. *Autopilot* – “Those units and components that furnish a means of automatically controlling the aircraft” (Jeppesen, 2012, p. 34)

3. *Aviation human factors* – Human capabilities and limitations in the aviation environment and the study of influences that enhance safety and performance of those operating in the aviation system (Koonce, 1979).

4. *Backup behaviors* – “Ability to anticipate other team members’ needs through accurate knowledge about their responsibilities. This includes the ability to shift workload among members to achieve balance during high periods of workload or pressure” (Salas et al., 2005, p. 560).

5. *Briefing* – “Verbal conference conducted between the pilots before the beginning of certain phase of workload that will be requiring coordination and therefore an agreed-upon plan; for example, before takeoff, or before starting an approach to the destination airport” (Dismukes, Berman, & Loulopoulos, 2007, p. 313). The specific items of briefings are normally defined in varies aviation operations standard operating procedures.

6. *Cockpit automation* – The execution of a task, function, or service by an automated system such as a flight management system, flight director system, and autopilot to control navigation, engine power, and system monitoring of the aircraft (Dismukes et al., 2007; Mouloua et al., 2010).

7. *Cockpit flight crew* – Members of a cockpit team who hold pilot designations and perform in-flight duties relating to the operation of a multipiloted aircraft.

8. *Coupled ITO* – An instrument takeoff using the aircraft’s flight director system and automatic flight control system to transition aircraft from a hover to a climb out profile (U.S. Coast Guard, 2010b).

9. *Designation* – “Certification that a pilot or aircrew member has met training and experience requirements to operate an aircraft day or night, cross-country, in all weather conditions for which the aircraft is certified” (U.S. Coast Guard, 2013, Glossary-6).

10. *Federal Aviation Administration (FAA)* – “The government agency that regulates flight operations and safety aspects of commercial aviation in the United States” (Dismukes et al., 2007, p. 317).

11. *Flight Director System* – “A form of automatic flight control in which all of the information is displayed to the pilot rather than being used to actuate control servos” (Jeppesen, 2012, p. 136). A flight director system can be “coupled” to the aircraft’s flight controls and provide a means of automatically controlling the aircraft.

12. *Flight Safety Officer* – A specific billet at aviation commands responsible for advising and assisting the unit’s Commanding Officer in issues relating to aviation safety and risk management processes. Interchangeable with the term *Aviation Safety Officer*.

13. *Hindsight bias* – A human tendency to evaluate past events in light of what is now known about the event. This bias can cause a person to oversimplify an event and assume things blatantly obvious about the event after the fact were obvious during the event. (Dismukes et al., 2007).

14. *Human Factors Analysis and Classification System (HFACS)* – An analysis tool originally developed for the U.S. Navy and Marine Corps for determining human

casual factors in aviation accidents. The human casual factor classifications are based on Reason's (1990a, 1997) Swiss Cheese Model (Wiegmann & Shappell, 2003).

15. *Instrument takeoff (ITO)* – A maneuver utilized when ambient conditions cause reduced visibility, e.g. precipitation, low ceiling, or lack of visible horizon, and helicopter induced restrictions to visibility such as blowing dust or water caused by the rotor downwash. ITOs are invaluable aids when taking off at night and toward and over water or deserted areas (U.S. Coast Guard, 2010b; U.S. Navy, 2009).

16. *Manual ITO* – An instrument takeoff which the pilot flying, also known as [pilot at the controls], manipulates the flight controls to transition from a hover to a climb out profile (U.S. Coast Guard, 2010b).

17. *Mutual performance monitoring* – “The ability to develop common understandings of the team environment and apply appropriate task strategies to accurately monitor teammate performance” (Salas et al., 2005).

18. *National Transportation Safety Board (NTSB)* – “U.S. government agency responsible for investigating and determining the probable cause of civil aviation accidents” (Dismukes et al., 2007, p. 324).

19. *Operational Flight Trainer (OFT)* – A flight simulation device representing aircraft flight and system characteristics used to train individual pilots or cockpit flight crews (Moroney & Moroney (2010). Interchangeable with the term flight simulator.

20. *Operational Risk Management (ORM)* – “A continuous, systematic process for identifying and controlling risks. The process includes detecting hazards, assessing risks, and implementing and monitoring risk controls to support effective, risk-based decision making” (U. S. Coast Guard, 2002).

21. *Pilot at the controls* – “The pilot operating the flight controls (cyclic, collective, and pedals)...The [pilot at the controls] is responsible for movement and maneuvering of the aircraft via control inputs with reference to either visual or instrument information.” (U.S. Coast Guard, 2010b, p. 4-1). Interchangeable with the term pilot flying.

22. *Pilot flying* – The pilot who is controlling the aircraft in flight by manipulating the flight controls, thrust or power control levers, and flight management system (Dismukes et al., 2007).

23. *Pilot in command* – The pilot, in a multipiloted aircraft, who has been delegated to take charge of the aircraft and be accountable for a specific flight or mission. Normally, the pilot in command is normally the pilot in the aircraft who holds the highest designation and qualification in aircraft type. “The [pilot in command] is responsible for the safe, orderly, efficient and effective performance of the aircraft, aircrew and passengers during the entire mission” (U.S. Coast Guard, 2013, p. 2-6).

24. *Pilot monitoring* – Pilot responsible for monitoring the actions of the pilot flying, aircraft systems, and radio communications. (Dismukes et. al., 2007; U.S. Coast Guard, 2013) Interchangeable with the term safety pilot and pilot not at the controls.

Safety pilot –

During dual pilot operation of the aircraft, the safety pilot is the pilot not operating the flight controls. The safety pilot provides backup to the pilot operating the aircraft controls by performing cockpit duties such as checklists, briefings, communications, and cockpit automation tasks. In general, the safety pilot should handle any cockpit duty that may potentially distract the [pilot at the

controls] from concentration on flight control operation with reference to visual or instrument information. During critical phases of flight, the safety pilot shall monitor the flight controls as much as practicable. The safety pilot should have his/her hands near the primary flight controls to allow monitoring of the [pilot at the controls'] flight control inputs and be prepared to assist in aircraft control or to take over the flight controls if the situation dictates. (U.S. Coast Guard, 2010b, p. 4-1)

25. *Shared mental models* – “An organizing knowledge structure of the relationships among the task the team is engaged in and how the team members will interact” (Salas et al., 2005, p. 561). Shared mental models provide a common understanding between team members and allows them to anticipate what is required by the other team members (Stout, Cannon-Bowers, Salas, & Milanovich, 1999).

26. *Sociotechnical system* – A system consisting of complex interactions between personnel and the technology in the workplace and includes societal infrastructures and behavior in the organization. “Sociotechnical systems contain people, equipment and organizational structures...linked by functional processes and social processes which are informal but which may serve to either facilitate or hinder the functional processes” (Harris, 2011, p. 7).

27. *Threat and error management* – Assuming that human error is inevitable, threat and error management is a three layer error defense countermeasure strategy including 1) avoiding error, 2) trapping errors before they are occur, and 3) managing the effects of errors that occur and are not trapped (Helmreich et al., 1999).

28. *Total pilot time* – “Time spent at a flight control position (in an authorized aircraft or simulator) by Coast Guard aviators and student pilots who are assigned duty involving flying” (U.S. Coast Guard, 2013, Glossary-17).

Chapter Summary

Aviation CRM is an accepted practice in the industry for increasing flight crew effectiveness by improving teamwork processes. Understanding the role of shared mental models among flight crews and their impact on mutual performance monitoring and backup behaviors can lead to clearer CRM instructional strategies and training outcomes. Chapter II of this study shows recent Coast Guard aircraft accidents, views on human error in complex systems, and the history of CRM in commercial and military aviation. New views of human error and recent research of teamwork processes associated with shared mental models shed new light on the role of team coordination CRM skills of mutual performance monitoring and backup behaviors and their ability to improve cockpit flight crew performance in multipiloted aircraft.

CHAPTER II

REVIEW OF RELATED LITERATURE

This section first reviews the recent increase in Coast Guard aircraft accidents and resulting impact to CRM training. Aviation CRM was initially a response to human error in the cockpit and the failure of flight crew coordination and communication in commercial and military aircraft cockpits. A more recent understanding of human error in the cockpit includes the role of organizations in aircraft accidents which suggests a more systemic view of aircraft accidents (Reason, 1990a, 1997, 2008) and inevitability of human error in complex sociotechnical systems (Cook et al., 2004; Dekker, 2006; Perrow, 1999). Teamwork processes significantly influence the effectiveness of teams in highly dynamic work environments such as aircraft cockpits (Marks, Mathieu, & Zaccaro, 2001; Mathieu, Maynard, Rapp, & Gilson, 2008), and shared mental models among flight crews lead to improved teamwork process of pilot monitoring and backup behaviors (Grote et al., 2010; Krieger, 2005; Mathieu et al., 2000; Sperling & Pritchett, 2011).

Coast Guard Aviation

Aircraft are a primary asset in the execution of Coast Guard missions and Maritime Domain Awareness (Maritime Security Policy Coordinating Committee, 2005; U.S. Coast Guard, 2013). The Coast Guard has utilized aircraft to enhance search, rescue, and law enforcement maritime operations for nearly a hundred years. With close ties to naval aviation and following a similar developmental path (U. S. Coast Guard Aviation Association, 2003-2006), Coast Guard aviation provides a major operational capability to the Coast Guard by operating nearly two hundred rotary-wing and fixed-

wing aircraft in the U.S. maritime environment. However, aircraft mishaps (accidents) reduce operational effectiveness, cost lives, and damage and destroy valuable assets.

Department of Defense Services and Coast Guard Aviation Accidents

Table 1 shows a comparison between Class A flight mishap rate averages of Department of Defense services and Coast Guard since 2000 (see Appendix A for flight mishap classifications).

Table 1

Department of Defense and Coast Guard Class A flight Annual Mishap Rates 2000-2012 and Twelve-Year Average¹

Fiscal Year	Coast Guard	Air Force	Army	Navy	Marine Corps
2000	0	1.1	0.6	1.85	2.69
2001	1.93	1.2	1.0	1.25	1.3
2002	0	1.45	2.5	1.8	3.89
2003	0	1.2	2.65	2.2	2.91
2004	0	1.1	2.1	1.1	5.18
2005	0.87	1.5	2.4	1.5	2.5
2006	1.81	0.9	1.7	1.6	1.9
2007	0.84	1.3	1.0	1.0	2.05
2008	0.86	1.25	1.2	1.5	2.26
2009	0	0.8	2.06	1.15	1.41
2010	4.26	0.71	1.68	0.75	1.46
2011	0	0.76	1.1	0.95	2.44
2012	0.88	1.01	1.7	0.98	2.17
Average	0.88	1.12	1.67	1.36	2.47

¹ Class A flight mishaps per 100,000 flight hours is an aviation industry standard enabling the normalizing of standard safety data across multiple aviation operations and organizations.

As seen in Table 1, the Coast Guard average annual rate remained below other services. However, in fiscal year 2010 the Coast Guard experienced five Class A flight mishaps costing the organization \$124,860,386 (U.S. Coast Guard, 2010a). These five Class A flight mishaps represent the highest annual Class A flight mishap cost ever experienced by the Coast Guard (U.S. Coast Guard, 2010a). As shown in Table 1 and Figure 2, the five Class A flight mishaps resulted in an annual mishap rate of 4.26 per 100,000 flight hours (U.S. Coast Guard, 2010a).

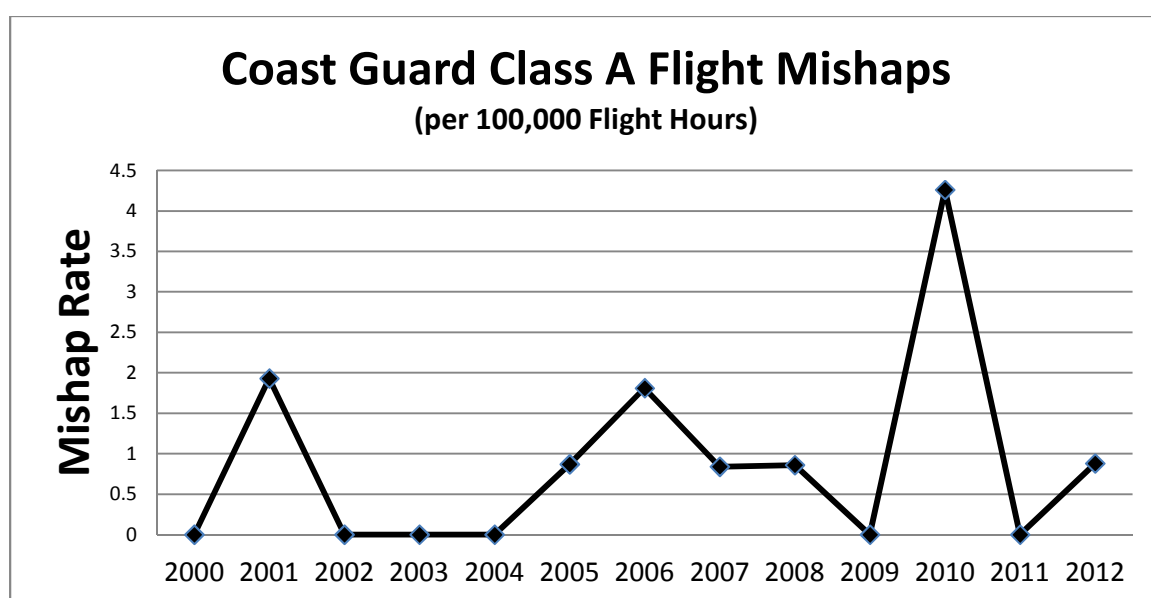


Figure 2. Coast Guard Class A Flight Mishap Rate Fiscal Year 2000-2012

With the exception of the U. S. Marine Corps 2004 annual mishap rate of 5.18, the Coast Guard's Class A flight mishap rate of 4.26 in 2010 is higher than all Department of Defense aviation counterparts for the period from FY00 to FY12 (see Table 1). Until 2010, the Coast Guard averaged one Class A flight mishap a year for nearly 30 years, and the last time the Coast Guard experienced more than two Class A flight mishaps in a single year was 1982 (U.S. Coast Guard, 2010a). The five Class A mishaps in 2010 ended a traditionally stable mishap rate and flight safety record and

prompted a comprehensive review of all aspects of Coast Guard aviation (U.S. Coast Guard , 2010a).

Aviation Safety Assessment Action Plan

In May of 2010, after a seven-month period involving four of the Class A flight mishaps, Coast Guard leaders chartered the Aviation Safety Assessment Action Plan (M. Emerson, personal communication, July 28, 2010). The Aviation Safety Assessment Action Plan was 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 present in the Coast Guard aviation environment” (U.S. Coast Guard, 2010a, p. 3). Coast Guard leaders were interested in exploring subtle negative influences possibly undermining the aviation culture environment. The Aviation Safety Assessment Action Plan consisted of five distinct analysis components: (a) an operational hazard analysis, (b) an aviation data collection and safety survey, (c) aviation leadership improvement focus group, (d) an independent data analysis and process assessment study, and (e) Coast Guard aviation association industry benchmarking study (U.S. Coast Guard, 2010a).

After the yearlong multifaceted review, the findings identified five overarching Coast Guard aviation deficiencies (J. P. Currier, personal communication, October 15, 2011), with four of the deficiencies directly relating to human factors. One specific human factor finding was the degradation of ORM and CRM practices. According to the U.S. Coast Guard (2012), CRM is “the effective use of all available resources – human

resources, hardware, and information – with the goal of optimizing human performance and reducing human error in the aviation environment” (p. 9). The major tenets of Coast Guard CRM are flight discipline, leadership, risk management, decision making, situational awareness, communications, and assertiveness (U.S. Coast Guard, n.d.-a). Though Coast Guard CRM has been in place since the early 1990s, the Aviation Safety Assessment Action Plan found problems in CRM training delivery methods and less than optimum targeting of training audiences (U.S. Coast Guard, 2010a). The plan’s findings resulted in several CRM training improvement initiatives. A memorandum from then Commanding Officer of ATC Mobile outlined two actions taken in response to CRM findings: first, specific unit-based CRM discussions and review of human factors aircraft mishap as part of the annual standardization visit to Coast Guard Air Stations, and second, a written assessment of CRM skills on all pilot evaluation check flights (S. C. Truhlar, personal communication, September 1, 2010). The unit-based CRM discussion and associated mishap review allowed CRM training to be tailored specifically to the unit’s aircraft, daily flying environment, and mission, and the CRM written assessment provided feedback on individual pilot CRM strengths and documented areas for improvement (T. D. Jones, personal communication, November 10, 2010; S. C. Truhlar, personal communication, September 1, 2010)

Though changes were made to Coast Guard CRM training as a result of the Aviation Safety Assessment Action Plan findings, senior leader support and commitment to CRM tenets and training remained high. Vice Admiral (VADM) J.P. Carrier, Vice Commandant of the Coast Guard and highest ranking Coast Guard aviator, strongly

emphasized the role of CRM and teamwork among flight crewmembers during an interview about Coast Guard flight crew proficiency and initiative:

Everyone in the [flight] crew has a part to play in the success of that mission.

And our principles, including CRM, are such that everyone has a voice. If you're not comfortable, you're duty-bound to speak up. Clearly, the aircraft commander makes the final call, but we all have a role and voice. On a crewed aircraft, we fly best as a team. (Johnson, 2013, p. 9)

Considering the recent findings and recommendations of the Aviation Safety Assessment Action Plan, a review of Coast Guard mishaps shows that human error, and specifically CRM failures, is not a recent trend.

Human Error in Coast Guard Aviation

Aviation human factors mishap data helps deconstruct system failures and enables a more thorough identification of hazards (U.S. Coast Guard, 2012). A review of Coast Guard Class A aviation mishaps for the past 20 years indicates human factors a central causal factor contributing to at least nineteen of the twenty-four Class A mishaps (79%; B. A. Potter, personal communication, March 1, 2013). This 79% closely aligns with the 60-80% human error accidents percentage normally cited in other military and commercial aviation mishap analysis (e.g., Flin et al., 2008; O'Conner & O'Dea, 2007; Wiegman & Shappell, 2003). Coast Guard aviation safety leaders suggest that human error in aviation mishaps is as high as 85% and is the most common cause factor in Coast Guard aviation mishaps (U.S. Coast Guard, 2009a). In fact, human error in Coast Guard cockpits led to the recent adoption of the Department of Defense Human Factors Analysis and Classification System (HFACS) for mishap analysis (U.S. Coast Guard,

2010a) The Department of Defense HFACS framework allows a better understanding of the underlying human factor causes in aviation accidents (Gibb & Olson, 2008). See Charnon (2012) for a complete review of HFACS and its use in Coast Guard aviation mishap trend analysis following the 2003 organizational move from Department of Transportation to the Department of Homeland Security.

Further review of Coast Guard Class A flight mishaps shows that 18 mishap reports directly cited or inferred a breakdown or lack of CRM among flight crewmembers. (B. A. Potter, personal communication, March 1, 2013). A review of the eight most recent Coast Guard Class A flight mishap administrative investigations (FY06-FY12) reveals that seven of the mishaps contain specific CRM failures (Allen, 2009; Brice-O'Hara, 2012; Currier, 2013; Neffenger, 2012 & 2013; Pearson, 2009; Salerno, 2012). Despite training CRM tenets to flight crews, CRM failures continue to occur in Coast Guard cockpits.

U.S. Navy and Marine Corps aviation, a comparable maritime service to the U.S. Coast Guard, experienced similar CRM-related failure rates among cockpit flight crews. The U.S. Navy and Marine Corps' seven CRM critical skills are similar to the Coast Guard's: (a) mission analysis, (b) leadership, (c) risk management, (d) decision making, (e) situational awareness, (f) adaptability/flexibility, (g) communications, and (f) assertiveness (U.S. Navy, 2011). Examining Naval Aviation Class A mishaps, Jones (2009) found 69% of rotary wing and tactical jet aircraft accidents from 1997 to 2007 listed CRM failure as one of the accident causal factor.

However, Wilson-Donnelly and Shappell (2004) found a mismatch between the training of CRM tenets and CRM failures in the U.S. Navy and Marine Corps. Analyzing

U.S. Navy and Marine Corps accidents between 1990 and 2000, Wilson-Donnelly and Shappell found six major CRM failure groupings: (a) failure to conduct adequate briefing, (b) failure to utilize resources, (c) lack of communication, (d) miscommunication, (e) failure to monitor, and (f) failure to backup/assist. Wilson-Donnelly and Shappell believe the six major CRM failure groupings indicate a misalignment between the CRM critical skills taught to flight crews and the type of CRM failures actually occurring in U.S. Navy and Marine Corps cockpits. An analysis of the seven Coast Guard Flight A flight mishaps containing specific CRM failures show at least one of the six Wilson-Donnelly and Shappell CRM failure groupings occurring in all mishaps. More interesting is the fact that failing to backup and assist other flight crewmembers occurred in six mishaps, suggesting a misalignment between Coast Guard CRM training and actual cockpit CRM failures similar to the U.S. Navy and Marine Corps finding by Wilson-Donnelly and Shappell (2004).

Human Error

Human error is the failure to achieve desired consequences or planned actions leading to unintended consequences and accidents (Maurino, Reason, Johnston, & Lee, 1995; Reason, 1990a). Major accidents in complex systems such as nuclear power plants, marine and rail transport, chemical process plants, off-shore oil platforms, and commercial aviation can be linked to human error (Reason, 1990b). Humans performing in cognitively demanding real world situations often find themselves facing complex and uncertain situations (Cook et al., 2004). Well-known accidents, e.g. Three Mile Island; Chernobyl; Challenger; Exxon Valdez; and more recently, the 2009 Air France Flight #447 en route from Rio de Janeiro to Paris, represent catastrophic accidents involving

human failures in complex technologies and sociotechnical systems (Reason, 1990a; Zolli, 2012). A review of 37 significant safety operating events at commercial nuclear power plants show human error contributed significantly to nearly all events (Gertman et al., 2001). The health care system is at least a decade behind to other high-risk industries in basic safety, and human error results in as many as 98,000 deaths each year exceeding that of motor-vehicle accidents, breast cancer, and AIDS (National Research Council, 2000). Human error costs hospitals nationwide \$17 billion to \$29 billion per year (National Research Council, 2000). According to Davies (2001), the medical community is slow to recognize the universal role of human error and is continually pressured to perform without error.

From 1960s to the 1990s, human error in hazardous systems increased fourfold and now represents approximately 80-90% of all major accidents (Maurino et al., 1995; Reason, 1997). According to Flin et al. (2008), errors in human non-technical skills have played a major role in serious nuclear power plant incidents such as Three Mile Island and Chernobyl. Since 1979, human error has occurred in 14 of the major maritime, military, police, healthcare, petrochemical, transport and aviation accidents (Flin et al., 2008). Of those 14 major industry accidents, teamwork and team coordination failures were major contributors in seven of the accidents (Flin et al., 2008). However, Reason (1997) cautions using the broad label of *human error* since it may misrepresent how and why accidents actually occurred and fails to acknowledge the human contribution to safety by those frontline professionals operating in complex organizational systems. Hollnagel (2012) further argues that neither simple nor complex linear thinking is insufficient for understanding sequences of causes and effects in accidents and suggests

that recent accidents like the Challenger explosion and Chernobyl meltdown emphasize the need to recognize non-technical aspects of sociotechnical systems.

Simple Cause and Effect Linear Sequencing of Human Error

A simple cause and effect linear sequencing perspective promotes the view that human error is an aspect of human performance that is substandard or flawed (Woods, Dekker, Cook, Johannesen, & Sarter, 2010). Simply stated, the label of human error in accident analysis infers that 1) human performance immediately prior the accident was flawed, and 2) inadequate human performance directly attributed to the accident (Woods et al., 2010). According to Woods et al., the common belief is that human performance is distinctly separate from the represented system, and errors occur either within the human side or within the represented system. Separating the human from the system enforces the idea that human error is correctable by changing the behaviors of individuals operating within the system (Woods et al., 2010). With simple linear cause and effect perspective, human error is avoidable and a product of human cognition defects (Maurino, 1999; Reason, 2008). Eliminating the error (cause) will eliminate the accident (effect).

According to Reason (2008), believing that human error is avoidable promotes a human-as-hazard perspective. Human-as-hazard advocates believe that highly trained frontline professionals have a moral obligation to care and avoid making errors (Reason, 2008) and that human errors are a result of carelessness; inattention; distraction; or the lack of skill, vigilance, or conscientiousness (Dismukes et al., 2007). The human-as-hazard perspective or “bad apple theory” fosters the view that humans are the dominant

contributor to accidents and that “complex systems would be fine, were it not for the erratic behavior of some unreliable people (bad apples) in it” (Dekker, 2006, p. 1).

Complex Cause and Effect Linear Sequencing of Human Error

According to Dismukes et al. (2007), accidents usually involve human performance characteristics and their complex interaction with task demands, environment condition and events, and social and organizational influences. Reason (1990a) argues that social and organizational factors lead to accidents because of weaknesses or gaps in a complex system. Reason’s (1990a, 1997) Swiss Cheese Model portrays the sequence of holes in organizational defenses attributed to active failures and latent conditions which eventually line up, allowing an accident trajectory through the layers of defense.

According to Wiegman and Shappell (2003), Reason’s Swiss Cheese Model provides the unifying theoretical framework for integrating all human error perspectives but argue that the Swiss Cheese Model is too theoretical in nature and “as a result, analysts, investigators, and other safety professionals have had a difficult time applying Reason’s [(1990a, 1997)] model to the real world” (p. 50). Wiegman and Shappell (2003) believe the Swiss Cheese Model is primarily descriptive and argue that their HFACS provides the analytical tool for accident investigation and determining human error latent conditions and active failures. However, Wilson et al. (2007) believe that despite human error classification frameworks such as HFACS, labeling human error as a root cause of an accident is “too broad and leaves much to one’s imagination as to what really occurred” (p. 246). Similarly, Diehl (1997) argues that human error is easy to classify but extremely difficult to predict and even more difficult to correct.

According to Hollnagel (2012), determining human error resulting from technological, psychological, environmental, and organizational influences represents complex sequence-of-events linear thinking implying both order and cause and effect. Using sequence-of-events linear thinking for determining human error in accident investigations does little to explain the complex nature of systems in which accidents occur. Sequence-of-events cause and effect investigations promote the human-as-hazard view by attributing accident causes to human mistakes, deficient supervision, ineffective leadership, lack of appropriate rules and procedures, or some deficiencies in human or represented system performance (Woods et al., 2010). According to Hollnagel, simple and complex sequence-of-events linear thinking investigations attempt to identify human error actions in accidents based on future outcomes yet to be determined when the human error action occurred. Sequence-of-events linear thinking fosters hindsight bias which fosters a cause-consequence equivalence (Dekker, 2006). Dekker further argues that hindsight bias turns convoluted complexity into a simple, linear story and oversimplifies the events which actually occurred and destroys the ability to look objectively at past events judged as human error.

Complexity of Sociotechnical Theoretical Perspective of Human Error

Today's sociotechnical systems are highly complex and involve the interaction of humans and technology to deliver results from the human-machine collaboration. Sociotechnical systems contain people and equipment and operate within social systems of organizational goals, policies, and procedures (Harris, 2011; Qureshi, 2008). Sociotechnical systems also contain legal, political, cultural, and environment components (Qureshi, 2008). According to Dekker (2006), human error in sociotechnical

systems is an “inevitable by-product of the pursuit of success in an imperfect, unstable, resource-constrained world” (p. 65). Dekker (2006) believes that complex sociotechnical systems do not exist to be safe, but on the contrary, they exist to make money, render a service, or provide a product. Accidents in complex sociotechnical systems such as nuclear power plants, marine and rail transport, chemical process plants, and commercial aviation are inevitable because those systems are high-risk and intrinsically hazardous (Cook et al., 2004; Perrow, 1999). Because sociotechnical systems are highly complex and intrinsically hazardous, accidents normally represent failures in adapting to systems’ complexity and interactions instead of human performance failures (Hollnagel, 2012).

Researchers suggest humans create safety in sociotechnical systems (Cook et al., 2004; Dekker, 2006; Reason, 1997, 2008). Cook et al. (2004) argue that in sociotechnical systems, humans continuously create safety by adapting to changing conditions moment to moment. Reason (2008) identifies the ability to adapt to changing conditions as human variability and argues for its necessity for safeguarding imperfect systems in an uncertain and dynamic world. Safety is created predominantly by human resilience and flexibility (Dekker, 2006). According to Hollnagel (2012), sociotechnical systems are enhanced by the ability of humans to respond, monitor, learn, and anticipate. Opposed to having safety, humans *do* safety in sociotechnical systems. Humans do safety by continually assessing and revising performance that is sensitive to the possibility of failure and by knowing and monitoring risk boundaries (Woods et al., 2010). Humans create safety because, unlike computers, they are equipped to make rational decisions in novel situations when information is incomplete, contradicting, ambiguous, and even missing (Dismukes, 2009). Reason (2008) defines the human

contribution to creating safety in complex, intrinsically unsafe sociotechnical systems as the “human-as-hero” perspective and argues that frontline professionals (e.g. nuclear power plant operators, commercial pilots) often represent the last line of defense against major accidents.

Human Error in Aviation

Since the early days of powered flight, the human-machine interface has proven to be the most challenging aspects of human 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 (Wiegmann & Shappell, 2003; Dismukes et al., 2007; Flin et al., 2008). From 1959 to 1980, flight crew error was the primary cause of 76% of aircraft accidents among the worldwide commercial jet fleet, and from 1981 to 1990, flight crew error was the primary cause of 70.5% of aircraft accidents among the worldwide commercial jet fleet (Weener, 1992). However, during the same period of time, aircraft malfunctions were responsible for only 11% of all commercial aviation accidents (Weener, 1992).

According to Darby (2006), from 1996 to 2005, 55% of all aircraft accidents were caused by crew error. Darby is quick to note that the recent reduction of crew error in aircraft accidents is likely due to changes in weather reporting, Air Traffic Control, and aircraft maintenance reporting procedures. 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). Hobbs (2004) argues that human error in aviation is not a recent phenomenon. Analyzing Australian

Transport Safety Bureau data of aircraft accidents in the early 20th century, the author found that pilot error contributed to nearly 70% of accidents. Hobbs argues human error has been a flight safety issue since the early days of aviation. Whether human error is a recent phenomenon or existing since the early days of aviation, Wells (2001) believes that human error by cockpit flight crews represents the single greatest threat to flight safety in today's commercial aviation.

Human error in aviation, specifically in the cockpit environment, is traditionally labeled "pilot error." However, according to Diehl (1997), the term *pilot error* focuses the blame of the accident instead of identifying and finding solutions to the problem. Dekker (2006) believes assigning human error to aircraft mishaps 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. 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).

Human error in aviation exists because, like other complex sociotechnical systems, the aviation system is inherently unsafe and represents a continual contradiction between operational efficiency and safety (Dekker, 2006). There is a natural tendency to believe the aviation system is inherently safe and that the people operating in the system are unreliable and subject to deviations causing aircraft accidents (Pelegri, 2013). Dismukes et al. (2007) suggest that inappropriate actions or omissions by flight crews are many times cited as probable causes only because of their proximity to aircraft accident final events.

Human Error in Flight Crew Non-technical Skills

In the 1970s, aviation psychologists and accident investigators at the NASA-Ames Research Center began exploring broader human factors issues associated with flight operations (Helmreich & Foushee, 2010). Based on simple linear thinking cause and effect accident investigations, flight crew human factors data seem to point to inadequacies in non-technical skills such as team communication, coordination, workload management, situational awareness, task allocation, and resource utilization for safe flight operations. At the same time, a series of fatal commercial airline accidents caused by the lack of communication, coordination, and backup behavior between the aircraft flight crews accentuated the need for pilot training that is more non-technical and psychosocial in nature.

In 1978, United Airlines Flight #173 experienced a total breakdown of situational awareness and communication near Portland, Oregon, when flight crewmembers failed to comprehend a critical fuel state and successfully communicate their concern with the captain (Kanki, 2010; NTSB, 1979). The aircraft crashed after running out of fuel in flight (NTSB, 1979). Four years later, a lack of flight crew communication, coupled with improper engine anti-icing procedures before takeoff and weather departure delays, resulted in Air Florida Flight #90 crashing into the Potomac River immediately after takeoff from Washington National Airport (NTSB, 1982). In fact, when the aircraft was stalling, an aerodynamic condition where the aircraft wings fail to produce enough lift required to maintain flight, the pilots failed to verbalize anything prompting a stall recovery response even though both were fully qualified in stall recovery procedures (Kanki & Smith, 2001).

Six years later in 1988, Delta Airlines Flight #1141 crashed on takeoff after failing to follow checklist procedures and configuring the aircraft flaps for takeoff (NTSB, 1989). The accident investigation revealed that the first officer became distracted with an extended social conversation with an on-board flight attendant during taxi prior to takeoff (NTSB, 1989). Though the captain did not extensively participate in the conversation, he failed to “control the group processes and did not establish work priorities or demonstrate a concern for operational duties” required for safe flight (Helmreich & Foushee, 2010, p. 23).

Foushee (1984) notes that crew redundancy in an aviation multipiloted cockpit is necessary to improve the safety margin, but argues this safety margin diminishes when captains fail to heed the warnings of other crewmembers and when crewmembers fail to provide the necessary and timely backup. Citing a NASA study by Cooper, White, and Lauber, Foushee (1984) agrees with the hazards of crew performance processes breakdowns and suggests that crew coordination factors should receive more aviation research and training attention.

A NASA research project originally designed to investigate individual pilot vigilance, workload, and response to stress providentially brought a new clarity to the reoccurring team communication and coordination failures among flight crew (Ruffell Smith, 1979). According to Helmreich and Foushee (2010), Ruffell Smith’s flight crew interaction study demonstrates the operational significance of crew interactions. The primary conclusion of the study is that human errors are a result of breakdowns in crew coordination rather than shortfalls in pilot technical knowledge and skills. Poor cockpit

leadership directly affects the timely exchange of critical information during periods of work overload and task saturation (Helmreich & Foushee, 2010).

Because of the NASA study, the accident investigators began looking at human error in team processes and team effectiveness among flight crews using linear sequence-of-event accident investigation methodology. Flight safety was now focusing on understanding and promoting team communication and coordination processes in multipiloted cockpits. Foushee (1984) suggests an early challenge in cockpits was shifting from “The Right Stuff” traditional pilot mentality of self-reliant, macho, and decisive, characterized by the Tom Wolfe novel, to a professional pilot culture stressing cockpit team effectiveness (Wolfe, 1979).

Crew Resource Management

Early attempts to improve flight team processes was initially called Cockpit Resource Management with roots dating back to a 1979 NASA conference exploring the causes of commercial airline accidents (Orlady & Foushee, 1987). Helmreich et al. (1999) believe that many of the commercial air carriers attending the conference left “committed to developing new training programs to enhance the interpersonal aspects of flight operations” (p. 19). Lauber (1987), a NTSB researcher present at the 1979 NASA conference, defined Cockpit Resource Management as “the effective utilization of all available resources—hardware, software, and liveware—to achieve safe, efficient flight operations” (p. 9). Liveware refers to the flight crewmembers performing cockpit team functions. Cockpit Resource Management became a systematic approach to improving aviation safety by training flight crews on leadership, human performance, communication, and cooperation (Dahlstrom & Dekker, 2010). According to Harris

(2011), the advent of CRM introduced social psychology and management to the cockpit environment. The cockpit work environment shifted from traditional "stick and rudder" skills to a managing the flight crew in a highly automated aircraft environment (Helmreich & Foushee, 2010). Flight crew management included complex human capital skills such as judgment, problem solving, social relationships, personality, motivation, communication, and coordination.

According to Salas, Wilson, Burke, Wightman, and Howse (2006a), CRM is a common instructional strategy for team training. Citing Orasanu, Martin, and Davison (2001), Dekker (2006) believes that effective CRM contains 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? (p. 129)

History of CRM Training

Early CRM training was in response to the human as hazard theoretical perspective of human error and focused on improving flight crew attitudes, leadership, and communications using psychological testing and interpersonal behavior training (Helmreich et al., 1999; Maurino & Murray, 2010). The goal of CRM training was changing attitudes toward cockpit group interaction and flight crew management. Therefore, early CRM training programs were intended to correct communication errors

such as the lack of assertiveness by copilots and dictatorial personalities of captains (Helmreich et al., 1999).

The NTSB made its first direct reference to CRM in accident report recommendations after the 1978 United Airlines flight #173 crash near Portland, Oregon (NTSB, 1979). The NTSB recommendations specifically asked the FAA to urge all air carriers to instruct their crewmembers on flight deck resource management principles with “particular emphasis on the merits of participative management for captains and assertiveness training for other cockpit crewmembers” (NTSB, 1979, p. 30). Over the next few years, NTSB accident investigation reports continued to recommend applying the findings of CRM research to commercial pilot training programs in an effort to reduce cockpit human error.

By the mid-1980s, commercial airlines embraced CRM and incorporated team communication and coordination principles into their pilot training programs. A jointly sponsored NASA/U.S. Air Force Military Airlift Command CRM conference in 1987 validated the spread of the CRM training throughout commercial and military aviation (Orlady & Foushee, 1987). Cockpit crew team building, briefing strategies, situation awareness, the management of crew stress, and crew decision-making principles were becoming part of CRM training. (Helmreich et al., 1999; Maurino & Murray, 2010). The new emphasis on cockpit group dynamics and team-oriented training led to the renaming of CRM to Crew Resource Management...a label that still exists today. According to Maurino and Murray, early CRM efforts purposefully maintained a clear separation between aviation technical skills, i.e. flying the aircraft, and flight crew non-technical skills, i.e. assertiveness.

Beginning in the early 1990s, CRM non-technical skills were integrated with flight crew technical training (FAA, 1991). This integration, coupled with the introduction of electro-optical instrument displays (glass cockpits), led to CRM training components focusing on small team cognitive applications, human performance, and the human-machine interface (Maurino & Murray, 2010). According to Maurino and Murray, a major step forward in CRM non-technical and technical training integration was an underlying paradigm shift in aviation safety from reactive to proactive and the integration of vigilance and human reliability.

In 1993, the FAA published initial guidance on developing, implementing, reinforcing, and assessing CRM training. Distributed as Advisory Circular 120-51 and nearly ten years after the introduction of CRM, the circular was the FAA's first attempt to define how CRM programs play a role in air carrier training and operations (Farrow, 2010; Wilson, Guthrie, Salas, & Howse, 2010). Advisory Circular 120-51 (1993) states the mission of CRM training is to "prevent aviation accidents by improving crew performance through better crew coordination" (p. 4), and suggests CRM curriculum topics of communication processes, decision making, and team building. However, the theoretical basis for FAA CRM guidance was optimizing human performance by reducing human error.

By the late 1990s, CRM training began reflecting influence of management actions or inactions, organizational synergy, flight crew interaction, and shared mental models (Maurino & Murray, 2010). By the end of the 20th century, researchers began questioning the intended results of CRM training. Helmreich et al. (1999) suggest that on the surface, CRM training seems to resolve the problems of human error by making it an

fundamental part of all flight training but argue that the initial overarching rationale of reducing crew-based human error had been lost. Early CRM training efforts attempted to train specific flight crew behaviors for increasing flight safety, but the focus of early CRM generations was imperfect by attempting to eliminate human error (Maurino, 1999; Helmreich et al., 1999).

Threat and Error Management

Human error is ubiquitous and inevitable and a result of the natural limitations of human performance in complex systems and forms the basis for threat and error management introduced to CRM training in the late 1990s (Helmreich et al., 1999). The goal of CRM threat and error management is the trapping and mitigating of errors within the aviation system before they become consequential (Helmreich & Merritt, 2000). Advocates of threat and error management believe that flight crew CRM behaviors should evaluate external and internal threats then determine corrective actions (Helmreich et al., 2001). The management of threats and errors provides a contextual framework that defines CRM skills as error countermeasures (Maurino & Murray, 2010). Kontogiannis and Malakis (2009) recognize that elimination of human error is difficult to achieve and that many times errors are associated with adverse consequences in complex situations involving high workload and high stress decision making. Therefore, the essence of CRM threat and error management is not the prevention of human error but the stopping of adverse consequences through the detection and correction of errors (Kontogiannis & Malakis, 2009). Although many commercial and military aviation CRM programs have incorporated threat and error management, Fraher (2011) argues that threat and error

management programs are ineffective in helping flight crews innovate, increase situation awareness, develop shared mental models, and enhance cockpit teamwork.

Human Error Theoretical Perspective for CRM Training

From the beginning, the goal of CRM in aviation was increasing team effectiveness by eliminating communication and coordination errors among cockpit flight crews. Originally created to increase communication between non-assertive copilots and captains with strong personalities and leadership styles, flight crew CRM training programs evolved to include other non-technical skills such as situational awareness, risk management, and decision-making. By 2000, CRM training incorporated threat and error management attempting to recognize the inevitability of human error in the cockpit. Threat and error management remains prevalent in aviation CRM training programs today.

CRM in U.S. Military Aviation

Aviation CRM training in the U.S. military is a direct result of commercial aviation CRM programs starting a decade earlier (O'Conner, Hahn, & Nullmeyer, 2010). By 1989, and following commercial carrier CRM training models, each service (Army, Air Force, Navy and Marine Corps) had at least one CRM program among various squadrons and aviation units (Prince & Salas, 1993). Prince and Salas believe that CRM may have developed more slowly within the military than in commercial aviation because of the lack of aviation human error evidence, the organizational makeup of each service, the variety of missions and training requirements of each service, and the absence of public pressure associated with the loss of multiple lives with commercial carrier wide-body aircraft. Though many of the military services initially labeled their CRM as

aircrew coordination training, the overall purpose was similar to commercial aviation efforts (Prince & Salas, 1993).

Cavanaugh and Williams (1987) believe that CRM principles are applicable to both military and commercial cockpit flight crews. However, Cavanaugh and Williams suggest that significant differences exist between military and commercial cockpit flight crews and caution against applying generic CRM training solutions to both. Cavanaugh and Williams sum these significant differences into six main categories: 1) impact of military rank; 2) purpose of the aviation mission; 3) crew qualifications differences with commercial aviation flight crews; 4) crew lifestyle and aviation job requirements; 5) absence of union and employee/employer relationships; and 6) other differences including training, crew communication, and flight crew protocol. Prince and Salas (1993) believe that the differences between commercial and military aviation identified by Cavanaugh and Williams (1987) fall under three general categories: (a) task (aviation mission requirement, flying conditions, and equipment); (b) people (flight crew makeup and experience); and (c) organization (military cockpit and organization structure differences).

O'Conner et al. (2010) suggest that factors such as mission timing constraints, multiple unit coordination, and pilot workload represent stark differences between commercial air carriers and military operations. O'Conner et al. (2010) argue that CRM-related mishaps occur three times more often in military aviation than in commercial aviation and that the focus on mission accomplishment, the frequent changing jobs and military assignments, and the non-homogenous nature of the military aviation units, create "CRM programmatic challenges" not prevalent in commercial aviation (p. 447).

Despite differences between military and commercial aviation, U.S. military services embraced CRM training when research suggested that enhancing flight crew coordination and communications improves mission effectiveness and flight safety (See Prince & Salas, 1993 and O’Conner et al., 2010 for a review of U.S. Air Force, U.S. Army, U.S. Navy and Marine Corps CRM programs).

CRM in U.S. Coast Guard Aviation

Aviation CRM training is required for all Coast Guard flight crews (U.S. Coast Guard, 2013). Coast Guard flight crews receive CRM training prior to aircraft flight training. The goal of the training is improving the performance of individuals and teamwork with the following objectives:

1. Determining and analyzing personality traits as they relate to aircrew interaction and problem solving.
2. Improving interpersonal skills and crew communications.
3. Developing and improving participation as an individual and crewmember in a positive and assertive manner.
4. Developing and enhancing individual and crew situational awareness skills.
5. Identifying hazardous trends and attitudes through analysis of past human error mishaps.
6. Presenting a risk management methodology that can help individuals and crews identify error producing conditions and prevent or mitigate hazardous situations.
7. Use and management of advanced cockpit technology and automation.

8. Recognition of the effects of illness, medications, diet, fatigue, and other self-imposed stressors on in-flight performance.

(U.S. Coast Guard, 2014a, p. 20-3)

Initial CRM training occurs at ATC Mobile for Coast Guard pilots attending their Coast Guard aircraft qualification course. Refresher CRM training occurs annually at Coast Guard Air Stations for pilots who have completed initial CRM training (U.S. Coast Guard, 2013).

History of Coast Guard CRM Training

Coast Guard CRM training has similar roots to CRM training in other military services. In fact, Lieutenant Commander R. Wharton, representing Coast Guard aviation safety, attended the 1979 joint NASA/MAC conference in San Francisco (Orlady & Foushee, 1987). Coast Guard CRM training began in the early 1990s focusing on team communication and coordination skills for multipiloted aircraft using a training program commercially contracted by the U.S. Army (Prince & Salas, 1993). It was the Coast Guard's first attempt to leverage commercially available CRM material and training. However, one major concern was non-Coast Guard aspects of the training and a need for Coast Guard-focused specific training. In 1994, Coast Guard aviation safety began building an "in-house" CRM training solution using Coast Guard aviation instructors (T. M. McGuire, personal communication, April 26, 2013). By the late 1990s, training on foundational CRM skills was mandated for all Coast Guard pilots and aircrew. By 1998, Coast Guard Flight Safety Officers assigned to local aviation units were trained and authorized to teach CRM training. At first, Coast Guard CRM training was required within three years after becoming a flight crewmember, allowing aviation units training

flexibility and the opportunity for new flight crewmembers to obtain operational experience prior to CRM training.

Initially, the goal of Coast Guard CRM training was the optimal team performance in a complex multiple task environment through the training of four basic principles: (a) situational awareness; (b) communications; (c) assertiveness; and (d) risk management. Aviation instructors also taught common obstructions to the four basic principles, known as roadblocks, attempting to improve flight crew team effectiveness. Roadblocks to CRM are negative, ingrained habits, and personal attitudes of flight crewmembers such as “odd man out,” “hidden agenda,” and “hazardous attitudes” (U.S. Coast Guard, n.d.-a). The four basic principles and roadblocks represented the core of Coast Guard CRM training throughout the 1990s. Aspects of error management (Helmreich et al., 2001) based on the Swiss cheese model (Reason, 1990a, 1997) were incorporated by 2002 in an attempt to align Coast Guard CRM training with emerging research in cockpit human error. Coast Guard flight crew training focused on error management, the four basic CRM principles, and common roadblocks to effective CRM in the aircraft.

Coast Guard Enhanced CRM

In 2007, Coast Guard aviation safety and training representatives participated in a CRM symposium jointly hosted by Embry-Riddle Aeronautical University (ERAU); aircraft manufacturer Bombardier; and Frasca, the makers of flight training equipment for airlines and various flight schools and military organizations, (C. Bonner, personal communication, January 30, 2013). Called ERAU: CRM Vectors 2007, the two-fold objective of the symposium was identifying the current generation of CRM theory and

practice and predicting the future of CRM training (Beneigh & Hubbard, 2007). One of the major defined themes was the training and evaluation of CRM. It was from the ERAU: CRM Vectors 2007 conference that the Coast Guard began exploring the feasibility of a comprehensive revision of its CRM training program. Concerns had grown that CRM training in the Coast Guard had become “a mere check in the box” without utilizing the latest design, development, implementation and evaluation techniques (D. R. Callahan, personal communication, June 19, 2007).

By 2008, the Coast Guard out-sourced the revamping of its CRM training for pilots and flight crews. Known as “Enhanced CRM”, the curriculum incorporates the latest CRM principles and concepts of University of Central Florida Institute for Simulation and Training, ERAU, the European Joint Aviation Authority, and Helmreich’s University of Texas Aerospace Crew Resource Project (D. R. Callahan, personal communication, June 19, 2007).

Major components of Enhanced CRM are the concepts of airmanship and flight discipline (Kern, 1997, 1998). Airmanship consists of three fundamental principles: skill, proficiency, and discipline. Total airmanship “blends technical and tactical expertise, [pilot] proficiency, and the variety of human factors to smoothly and effectively integrate the capabilities of the pilot and the machine” (Kern, 1998, p. 8). Kern (1997) suggests that total airmanship improves situation awareness, reduces human error, and increases operational effectiveness.

Using an airmanship model, Kern (1998) identifies the personal accountability and reliability foundation of flight discipline and the interconnectedness of pilot skill, proficiency, and required expertise leading to situational awareness and judgment.

Kern's (1997, 1998) airmanship and flight discipline constructs attempt to improve aviation safety by improving aviation compliance and accident prevention at the individual professional pilot level. Kern (1998) argues that the organizational system or training approach used in the traditional CRM has not produced the desired results of reducing human error. Moreover, an individual approach of personal accountability and mental readiness is needed to "identify and predict their own personal error patterns [which are] based on their unique lives and circumstances" (Kern, 2008, p. 147).

Identifying the conditions leading to errors and violations, Kern (2008) further argues that flight crews must learn to identify their personal error-producing conditions and work offensively to mitigate and ultimately reduce and/or prevent them. Enhanced CRM maintains that aircraft accidents are avoidable by reducing the number of individual human errors (U. S. Coast Guard, n.d.-b).

Summary of Coast Guard CRM

Coast Guard CRM has followed the developmental path of both commercial and military aviation efforts and in the beginning used the same contractor outsourcing support for flight crew training as the U.S. Army (T. M. McGuire, personal communication, April 26, 2013). The basic principles of situational awareness, communications, assertiveness, leadership, risk management, and decision-making have remained Coast Guard CRM tenets since their introduction in the early 1990s. Threat and error management was introduced in the early 2000s, and flight crews were taught to evaluate external and internal threats and determine corrective actions (Helmreich et al., 1999; Helmreich et al., 2001; Helmreich & Merritt, 2000). The recent overhaul of the CRM training with Kern's (1997, 1998) airmanship model is an attempt to improve flight

crew situational awareness; reduce errors; and increase operational effectiveness by using flight discipline, skills, and proficiency with a thorough knowledge of one's self, aircraft, team environment, and risk. However, Coast Guard Enhanced CRM training continues to align with the theoretical perspective that human error can be reduced and possibly eliminated.

CRM Skills

Researchers (Flin & Martin, 2001; Helmreich & Foushee, 1993) suggest CRM skills commonly follow two primary clusters: social skills and cognitive skills. Social skills represent the interaction between pilots and/or crew through communication and coordination. Cognitive tasks are the individual tasks that flight crewmembers use to operate in the aviation environment and deal with how the pilot thinks and processes information. Cognitive CRM skills include monitoring, crosschecking, problem solving, and making decisions.

Early CRM training focused on increasing flight crew communication and coordination. Lauber (1987) credits American Airlines as the first to identify CRM skills for flight crews: (a) delegation of tasks and assignment of responsibilities, (b) establishment of priorities, (c) monitoring and crosschecking, (d) use of information, (e) problem assessment and the avoidance of preoccupation, (f) communications, and (g) leadership. Flight crew skills identified by early CRM training developers seem to address the initial human error failures of lack of assertiveness by copilots and dictatorial personalities by captains.

By the early 1990s, researchers were identifying CRM critical skills and expanding on American Airlines' initial CRM skills list. Table 2 shows the skills suggested by researchers which became the foundation for most aviation CRM training.

Table 2

Studies Defining Crew Resource Management Critical Skills

Orlady & Foushee (1987)	Helmreich & Foushee (1993)	Prince & Salas (1993)
Communication	Communication	Communication
Problem-solving Decision-making Judgment	Decision tasks	Decision making
Leadership/Followership	Team formation	Leadership
Interpersonal skills	Management tasks	Assertiveness
Situation Awareness	Situation Awareness	Situation Awareness
Critique	Workload management tasks	Mission Analysis
Stress management		Adaptability

Similar to commercial aviation, the U.S. Army, Navy, and Air Force researchers began defining CRM critical skills in the early 1990s (O'Conner et al., 2010). According to O'Conner et al., United States military CRM training focuses on skills relevant to military flight operation demands, and those defined skills have become the groundwork for military services throughout the world.

Though the CRM critical skills are highly similar, each program is unique to requirements for the particular service. Table 3 shows the CRM critical skills currently trained for the U.S. Navy, Army, Air Force, and Coast Guard.

Table 3

CRM Critical Skills in U.S. Military Services

U.S. Navy	U.S. Army	U.S. Air Force	U.S. Coast Guard
Communication	Communication	Communication	Communication
Decision making	Decision making	Risk Management	Decision making
Leadership	Team leadership	Task Management	Cockpit Hazards
Assertiveness	Assertiveness	Crew/Flight Coordination	Assertiveness
Situation Awareness	Situation Awareness	Situation Awareness	Situation Awareness
Mission Analysis	Pre-mission planning	Mission Analysis	Risk Management
Adaptability			Cockpit Automation
			Flight Physiology

Though CRM training is well rooted in United States military aviation training today, with the exception of aspects of threat and error management (Helmreich et al., 1999; Helmreich & Merritt, 2000), the critical skills identified in the early 1990s are still taught to military aviators. Military CRM experts believe that identified CRM critical skills have remained relatively unchanged since the beginning (R. G. Hahn, personal communication, October 6, 2013).

Teamwork

Teamwork is a major contributor to business organizational goals and process improvement (Swanson & Holton, 2009). According to Salas (2005), 80% of today's workers are part of some type of work team within their organization. Industry

globalization, emerging technology and safety issues demand that teams operate effectively in competitive environments (Salas, 2005). In addition, high-risk complex environments require flexibility and responsiveness among individual experts/specialists operating in teams (Flin et al., 2008).

As sociotechnical systems become increasingly complex and produce conditions for human error, teamwork within the system and the role of each team member is essential (Fraher, 2011). Researchers investigating the role of individual skills on team performance believe that individual task proficiencies alone are not sufficient to ensure effectiveness team performance (Delise, Gorman, Brooks, Rentsch, & Steele-Johnson, 2010; Salas, Bowers, & Cannon-Bowers, 1995; Stout, Salas, & Carson, 1994). Successful team performance requires a specific set of knowledge, skills, and attitudes (KSAs) at the team level for successful mission completion (Oser, et al., 2000). Delise et al. (2010) argue that team members must develop teamwork skills including understanding the unique roles performed by each member of the team and the interdependencies of those roles.

Team Processes

Wilson et al. (2007) believe that teamwork skills are cyclical in nature and act as processes, outcomes, and processes again. Wilson et al. further suggest, “what serves as an outcome of one variable may serve as an input to another” (p. 247). Marks et al. (2001) describe teamwork skills as processes in which team members’ interdependent actions change inputs to outcomes through verbal, cognitive, and behavioral activities. Team processes are important because they define how team contributions transform into performance outcomes (Mathieu et al., 2008). Team processes describe the types of

interaction that take place among the team's members (Marks et al., 2001). Researchers (Flin et al., 2008; Wilson et al., 2007) believe that communication is a teamwork process. Verbal communication is the primary way team processes manifest (Fraher, 2011; Helmreich & Foushee, 2010). According to Flin et al., safety, productivity, quality, and job satisfaction are examples of team outcomes.

Team CRM processes

According to Flin et al. (2008), CRM training is a team-based strategy for helping individuals be more effective in team processes. Salas et al. (2006a) believe that pilot training of team-based processes must go beyond individual skills and include how to use those team-based processes to improve team performance and safety. Researchers (Flin et al., 2008; Kanki et al., 2010; Salas et al., 2006a) agree with earlier defined CRM teamwork processes of communication, leadership, decision-making, mission analysis/planning, and assertiveness but now recognize the team process of shared situation awareness through shared mental models and the team process of monitoring and backup behaviors.

Mental Models

Contemporary human-machine systems research has explored the role of individual mental models in human behavior and performance. Realizing the nontransparent *black box* understanding of human mental models, Rouse and Morris (1985) propose, "mental models are the mechanisms whereby humans are able to generate descriptions of system purpose and form explanations of system functioning and observed system states, and predictions of future system states" (p. 7). Agreeing with Rouse and Morris, Burns (2000) argues that mental models are adaptive belief constructs

that are used to describe, explain and forecast situations. Rouse and Morris (1985) believe that the successful search for mental models can result in substantial impacts to system design and training.

Active mental models are important because they shape how we act toward people or situations and affect what we see, and proper use of mental models can make the difference between success and failure (Senge, 1990). In management, proper mental models help organizations make good strategic business decisions which can achieve and enhance their competitive advantage. Marsick and Watkins (1994) state that mental models are “deeply held cognitive, value-based, feeling-fraught frameworks people use to interpret situations they encounter [and that] people may or may not be aware of the models they use, let alone learn to test them” (p. 356). Marsick and Watkins further argue that new mental models are needed for today’s business environment for work teams to innovate and retain the competitive edge.

A mental model is a symbolic portrayal of conceptual information that exists within memory (Salas et al., 1995). Mental models allow individuals to draw inferences, understand phenomena, and dictate action decisions (Mathieu et al., 2000). Mental models construct expectations for the future by describing, explaining, and predicting events (Marks et al., 2000; Mathieu et al., 2000). Senge (1990) suggests that Schon’s (1983) reflective practice, i.e., the art of reflecting on one’s thinking, is a pragmatic example of a mental model. Langan-Fox, Anglim, and Wilson (2004) describe mental models as simulations “run to produce qualitative and quantitative inferences, [which] underpin our understanding of a system, and allow us to describe, predict, and explain behavior of a system” (p. 334). Researchers (Bjorklund, Alfredson, & Dekker, 2006;

Sarter, Woods, & Billings, 1997) believe that in aviation, cockpit flight crewmembers use mental models for scanning cockpit instruments, monitoring aircraft automation, and establishing accurate expectations of the behavior of aircraft systems.

Shared Mental Models

Scientists now recognize that cognition is a social phenomenon and that individuals construct their reality cooperatively in a social environment (Klimoski & Mohammed, 1994). A shared cognition construct among team members is the shared mental model (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). Mathieu et al. (2005) define a shared mental model as an “organized understanding or mental representation of knowledge that is shared by team members” (p. 38). The shared mental model construct is also known as team member schema agreement (Rentsch & Klimoski, 2001), shared cognition (Cannon-Bowers & Salas, 2001), team mental model (Klimoski & Mohammed, 1994; Mohammed, Ferzandi, & Hamilton, 2010), team mutual awareness (MacMillan, Paley, Entin, & Entin, 2005), shared situation model (Orasanu, 1990, 2010), shared mindfulness (Krieger, 2005), and shared situational awareness (Salas et al., 2006b).

Team members must explain and forecast the actions of other team members and use shared mental models to do so (Cannon-Bowers, Salas, & Converse, 1990; Cannon-Bowers et al., 1993). Scientists believe there is a positive relationship between shared mental models and team processes and performance (e.g., Marks et al., 2002; Marks et al., 2000; Mathieu et al., 2000; Mathieu et al., 2005; Rentsch & Klimoski, 2001; Smith-Jentsch et al., 2005; Waller et al., 2004; Zou & Lee, 2010). Developing shared mental models can improve the team’s ability to coordinate efforts, adapt to changing situations,

and predict the needs of other team members (Flin et al., 2008). Shared mental models help team members share an understanding of the situation, and a common understanding of task responsibilities and task information requirements (Stout et al., 1999). Shared mental models create an environment in which team members anticipate and foresee the needs of the other team members (Orasanu, 1994; Salas, Wilson, Burke, Wightman, & Howse, 2006b; Stout et al., 1999). Wilson et al. (2007) argue that team coordination breakdowns and teams not sharing a common understanding of the situation lead to errors and missed steps or procedures. On the other hand, team coordination mechanisms fostering shared cognition reduce the risk of errors and maintain or improve performance (Wilson et al., 2007).

In training, developing accurate mental models improves performance outcomes. According to Johnson, Khalil, and Spector (2008), greater shared mental models translate into greater team capabilities, and team communication mediates the process of developing shared mental models. Scientists found that in the naturalistic team setting of FAA Air Traffic Control towers, shared mental models facilitate teamwork (Smith-Jentsch et al., 2005; Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009).

So what is “Shared” in Shared Mental Models?

Klimoski and Mohammed (1994) argue that the term *shared* in team mental models “can refer to a cognitive representation that is identical among team members (e.g. common knowledge), a distributed configuration of representations (no overlap), or to a configuration of overlapping representations among group members” (p. 421). According to Mathieu et al. (2005), mental model “sharedness” is the consistency between individual member mental models and models with other team members.

Mathieu et al. (2005) argue, “there is no ‘team model’ per se,” only individual mental models that are shared in a team (p. 38). Sharedness is not aggregating individuals’ models to a team model but instead a merging that represents individuals sharing a common knowledge structures.

Mohammed et al. (2010) believe that the organization of shared knowledge structures among team members remains at the core of the shared mental model construct and point to various terms used to describe sharedness including similarity, convergence, agreement, consensus, commonality, compatibility, overlap, and consistency. Cannon-Bowers et al. (1993) believe that most of time what is shared regarding team mental models is task dependent. However, during dynamic situations requiring high levels of flexibility and adaptability, what is common among team members is each team member’s function to the team task (Cannon-Bowers et al., 1993).

Research supports the existence of both task and team shared mental models (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994; Mathieu et al., 2005; Mathieu et al., 2000). Task mental models represent *what* needs to be accomplished and include work goals and performance requirements whereas team mental models are *how* the work is accomplished among the team (Marks et al., 2001; Mohammed et al., 2010). Though team mental models focus on the team member’s interpersonal interaction requirements, task work mental models relate to team processes and team performance outcomes (Lim & Klein, 2006; Mathieu et al., 2005).

Mohammed et al. (2010) argue that task and team mental model categories may be too generic to describe content-specific knowledge requirements adequately. Recent team research on military helicopter flight crews indicates that team shared mental

models are best explained as complementing each other. Sperling and Pritchett (2011) argue,

the measure of a shared mental model is not whether each team member's mental model is similar to each other's, but rather whether each one's mental model corresponds to the individuals' tasks and collectively are complementary, with each team member knowing which information is known by the other team member should he or she need to seek it, and which information is needed from them to other team members and when. (p. 395)

Whether shared mental models between team members are described as similar, common, task-related, team-related, or complementary, the critical inference is that teams possess shared mental models that lead to common expectations and allow team members to anticipate the needs of other team members and respond when appropriate and necessary.

Shared Mental Models in High Tempo and Dynamic Environments

Flin et al. (2008) believe that teams working under high levels of workload and in dynamic environments are able to coordinate and adapt to changing demands using shared mental models. Entin and Serfaty (1999) suggest that high-performing teams use shared mental models to anticipate the situation developments and the needs of other team members when timely, error-free, and clear information is critical. Entin and Serfaty (1999) further state that effective teams use implicit coordination strategies during high-stress situations and that "shared mental models are useful constructs to explain the anticipatory behavior of team members in the absence of scarcity of communications" (p. 313). Accurate mental representations are critical to a team's

ability to adapt and respond to changing situations in highly complex, hazardous, and stressful situations (Salas et al., 2008; Wildman et al., 2012). According to Espevik, Johnsen, and Eid (2011), shared mental models allow teams the flexibility to shift knowledge structures accurately in response to novel situations in high-intensity situations.

The Tactical Decision Making Under Stress (TADMUS) research program members, commencing after the 1998 downing of an Iranian commercial aircraft by *U.S.S. Vincennes*, attempted to address team coordination and decision making under the high operational tempos, short decision times, and ambiguous information conditions (Espevik, Johnsen, Eid, & Thayer, 2006). By comparing errors between expert and novice teams, TADMUS researchers found that high sharing mental model teams (a) are more accurate in predicting actions of teammates, (b) require less overt planning, (c) spend less time communicating, (d) make fewer requests for repeat information, (e) have better sequencing of activities, and (f) are more resilient to the effects of stress (Espevik et al., 2006). The findings of the multi-year, multi-million dollar TADMUS research program led to advances in team training interventions such as mental model training (Beaubien, Baker, & Holtzman, 2003).

Team Adaptability and Communication through Shared Mental Models

In highly dynamic environments, shared mental models provide a common framework for teams to respond and adapt to situations requiring unfamiliar and unexpected performance (Marks et al., 2000). Martin-Milham and Fiore (2005) believe a critical component of shared cognition is the team's ability both "assess risk and the time available for decisions and...to construct a mental picture of the operational

environment” (p. 55-1). Burke, Stagl, Salas, Pierce, & Kendall (2006) offer that team adaptability is not possible without shared mental models because “members do not have compatible views of equipment, tasks, and team member roles and responsibilities, which allow members to adapt proactively” (p. 1194).

Flin et al. (2008) suggest that teams use the process of communication to develop shared mental models when operating in situations that require team decision-making. In a low-fidelity tank simulation study of 79 three-member tank platoon teams formed by undergraduates of a large mid-Atlantic university, Marks et al. (2000) found that leader briefings influenced the development of team shared mental models which in turn positively affected team communication processes and team performance. Salas, Rosen, et al. (2006) suggest that expert teams hold shared mental models allowing them to anticipate the needs of each other and coordinate their actions without overt communication.

Shared Mental Models in Aircraft Cockpits

Grote et al. (2010) believe cockpit crew effectiveness increases when using adaptive coordination based on actions or responses emerging from shared mental models. Orasanu’s (1990) seminal research explores cockpit team communication and the role of shared mental models and planning. Orasanu (1990) found that during increased workloads, cockpit crewmembers increase the amount of information while cockpit team leaders reduce the number of requests for information, thus suggesting a type of implicit coordination with the use of accurate shared mental models. Burke et al. (2006) state that implicit coordination “requires that [team] members draw from their shared mental models to anticipate and meet the needs of their teammates without being

asked” (p. 1197). Krieger (2005) believes that communication and interpersonal interaction are significant factors in human error in aviation and suggests that shared mindfulness among flight crew is necessary in improving team effectiveness. Suggesting a communicative interaction that is conjointly-achieved, Krieger (2005) found that shared mindfulness allows cockpit team members to actively attend to, respond to, and perceive information and make decisions.

Flight crew coordination and performance in the cockpit are two central concepts in CRM, and the foundation for effective crew coordination and performance among flight crewmembers is shared mental models (FAA, 2003). Researchers (Grote et al., 2010; Krieger, 2005; Mathieu et al., 2000; Sperling & Pritchett, 2011) believe that shared mental models can enhance crew coordination in the multipiloted cockpits. Endsley (2010) further recognizes the link between shared mental models in flight crew performance by suggesting that the CRM crew behaviors improve situation awareness indirectly through the development of shared mental models. According to Robertson & Endsley (1995), flight crewmembers use a crew briefing and prior planning to establish shared mental models. Those shared mental models allow flight crewmembers to predict how others will act, thus forming the basis for Level 3 situational awareness (projection of future status) and producing more efficient cockpit crews.

Shared mental models in Coast Guard aviation

The Coast Guard recently began introducing the concept of shared mental models in aircraft cockpits. The author of Commandant Instruction M3710.1G, *Air Operations Manual* provides guidance on the use of standard phraseology and notes that flight crews should "announce any changes in speed, altitude, flight path, configuration,

or any other changes that affect the crew's shared mental model" (U.S. Coast Guard, 2013, p. 4-2). The Air Operations Manual further outlines standard phraseology for pilot flying and pilot monitoring during critical phases of flight, e.g. takeoffs, landings, to promote effective communication and reduce flight crew workload. Coast Guard Office of Aviation Forces, Fixed Wing & Sensors Division Chief iterates the importance of shared mental models in Coast Guard cockpits: shared mental models shape how flight crews think and interact and represent an aspect of cockpit flight discipline. If Coast Guard flight crews are not thinking the same thing when interacting in the cockpit, there is a problem (P. Beavis, personal communication, August 10, 2013).

Monitoring and Backup Behaviors

According to Salas, Rosen et al. (2006), shared cognition, in the form of compatible [shared] mental models, as well as mutual performance monitoring are necessary precursors to effective team processes, such as back-up behavior, because they form the foundation for decisions of when a team member must step in to provide backup, who should step in, and what assistance is needed. (p. 443)

Burke et al. (2006) define mutual performance 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 in an effort to catch and correct them in a timely manner” (p. 1195). Marks et al. (2001) suggest that team members provide monitoring and backup behavior by (a) providing verbal feedback or coaching, (b) supporting in carrying out actions, or (c) assuming and completing a task for a team member. Feedback to other team members can be verbal suggestions and/or corrective

behaviors, but the ultimate goal is assisting the team member in getting his or her performance back on track (Dickinson & McIntyre, 1997). According to Marks et al. (2002), mutual performance monitoring and backup are empirically derived team coordination skills which significantly contribute to team shared cognition and manifest through observable behaviors.

Marks et al. (2002) state that backup behavior is an important teamwork process and define it as assisting team members in performing of tasks and recognize the criticality of backup behavior during challenging, highly interdependent, time-critical situations in which mistakes can jeopardize team success. Porter, Hollenbeck, Ilgen, Ellis, and West (2003) have defined backup behaviors in the following way:

The discretionary provision of resources and task-related effort to another member of one's team that is intended to help that team member obtain the goals as defined by his or her role when it is apparent that the team member is failing to reach those goals. (p. 391)

Porter et al. argue that effective backup behaviors require that team members to have an understanding of each other's responsibilities and be both willing and able to provide and seek support when needed. Furthermore, researchers (Smith-Jentsch et al., 2009) suggest that team members with more experience working together request and accept more backup from each other and that requesting and accepting backup increases with teammates' familiarity. Wilson et al. (2010) suggest that teams reduce the risk of errors and maintain performance with the following mechanisms:

1. share knowledge of the team, task and environment;
2. ask for assistance or assist others when overloaded;

3. monitor each other's performance to identify deficiencies and provide assistance; and
4. maintain vigilance so as to adapt as the situation deems necessary. (p. 249)

Salas et al. (2005) believe that monitoring and backup behaviors are closely associated with the shared mental models and suggest the following team research propositions:

1. "Mutual performance monitoring affects team effectiveness through effective backup behavior" (p. 576).
2. "Effective mutual performance monitoring will only occur in teams with adequate shared mental models and a climate of trust" (p. 577).
3. "Effective backup behavior requires the existence of adequate shared mental models and mutual performance monitoring" (p. 580).

Monitoring and Backup Behavior among Flight Crewmembers

In multipiloted aircraft, mutual monitoring of the other pilot's actions and tasks is essential for team coordination and effectiveness (Tullo, 2010). Marks et al. (2001) believe that cockpit flight crewmembers use monitoring and backup behavior and render assistance when and if required to assist each other. Marks et al. (2001) suggest that monitoring and backup behavior compensates for lapses in judgment or oversight made by the other flight crewmembers. When flying, pilots monitor the aircraft's course, configuration, and systems and in multipiloted aircraft cockpits, each other (Dismukes & Berman, 2010). Potter, Blickensderfer, and Boquet (2014) believe that pilot monitoring is a cognitive strategy involving scanning and processing of both aircraft systems and the actions of the other pilot to determine the allocation of attention resources to areas of need.

The concept of pilot monitoring is redefining the primary role differences between the pilot manipulating (or managing in the case of autopilot and flight director systems) the aircraft flight controls and the pilot not flying. 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). Pilots monitoring each other in multipiloted cockpits is essential to flight safety and serve as the final defense against cockpit threats and errors (Potter et al., 2014).

The FAA (2003) revised *Advisory Standard Operating Procedures for Flight Deck Crewmembers* recognizing the primary role of the non-flying pilot, acknowledging that “it makes better sense to characterize pilots by what they *are* doing rather than by what they are not doing,” and further suggesting that pilot monitoring is now widely accepted as a more accurate term to describe that pilot not flying (p. 1). The FAA (2003) identifies the division of duties and responsibilities of pilot flying and pilot monitoring and monitoring/cross-checking as flight deck discipline and states, “effective monitoring and cross-checking can be the last barrier or line of defense against accidents because detecting an error or unsafe situation may break the chain of events leading to an accident” (Appendix 19, p. 1).

Commercial and military aviation organizations recognize the role of monitoring as a primary and shared responsibility of flight crewmembers and, following the FAA's guidance, now label the pilot not actually flying the aircraft as pilot monitoring. Tullo (2010) argues that pilots should practice and evaluate the skill of monitoring. Tullo further argues that when pilot training occurs in multipiloted aircraft, the emphasis of the pilot not flying is monitoring. Tullo believes doing so will reinforce the primary role of the pilot monitoring and *de-emphasize* individual performance, thus focusing it on the team performance.

Monitoring and Backup Behavior 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. Cockpit automation can manage aircraft navigation, manipulate aircraft flight controls and engine power, and monitor aircraft systems (Dismukes et al., 2007; Mouloua et al., 2010). Pilots use cockpit automation for more precise flying and aircraft systems monitoring than flying without automation (Reising, Liggett, & Munns, 1999 ; Wiener, 1988). Mouloua et al. (2010) point to growing empirical evidence on the negative effects of cockpit automation. According to Mouloua et al., when aircraft are controlled by highly reliable cockpit automated systems such as autopilot, flight director system, and flight management system, a pilot's ability to monitor the aircraft is affected. Researchers found that cockpit automation can lead to poor human-monitoring performance (Casner & Schooler, 2014; Comstock & Arnegard, 1992; Davies & Parasuraman, 1982; Dismukes & Berman, 2010). Dismukes et al. (2007) suggest that degraded pilot monitoring abilities associated with cockpit automation are rooted in basic

human cognitive vulnerabilities. Tesmer (2010) believes the biggest downside to cockpit automation is its inability to discern the flight crew intent. Tesmer argues that cockpit automation tasks must verbalize, verify, and monitor between pilots in multipiloted cockpits to increase automation awareness.

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 the pilot flying became so distracted with interpreting cockpit automation indications that he abandoned his primary role of monitoring the actions of the pilot flying. Cockpit automation also caused both pilots to control the aircraft simultaneously without knowing the flight control inputs of the other pilot, further confusing predefined pilot flying and pilot monitoring roles and responsibilities. Langewiesche (2014) believes 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. Langewiesche (2014) believes that the Air France crash "stands out as the most perplexing and significant airline accident of modern times" (p. 258).

Monitoring and Backup Behavior in Coast Guard Cockpits

Following the commercial aviation industry, the Coast Guard aviation leaders recognize pilot monitoring and backup behaviors and are clarifying the focus of the pilot not operating the aircraft flight controls. Recent air operations policy guidance now utilizes the term *pilot monitoring* interchangeably with legacy terms such as *safety pilot*

(U.S. Coast Guard, 2013). Fixed-wing aircraft communities in the Coast Guard (e.g. HC-144, HC-130J) use the term *pilot monitoring*. The HC-144A *Aircraft Flight Manual* specifically states that the “duties of the [pilot flying] and [pilot monitoring] shall be divided to provide the highest levels of situational awareness and...CRM” (U.S. Coast Guard, 2011b, p. 2A-4). Coast Guard rotary-wing aircraft communities define the role of pilot monitoring and emphasize that the pilots monitoring should provide backup to the pilot flying (U.S. Coast Guard, 2009a; U.S. Coast Guard, 2010b). For both fixed wing and rotary wing aircraft, the Coast Guard *Air Operations Manual* defines pilot monitoring communication protocol when using cockpit automation equipment (U.S. Coast Guard, 2013). In Coast Guard multipiloted cockpits, the overall goal of the pilot not flying is to monitor the completion of all procedures and to provide back up to the other member of the flight crew (U.S. Coast Guard, 2013).

Chapter Summary

The Coast Guard continues to look for ways to operate aircraft safely and effectively but recent aircraft accidents require a fresh look at flight safety in Coast Guard aviation. Concerns by aviation leadership about the use of and effectiveness of CRM among flight crews led to changes in delivery method and evaluation, but human error continues in Coast Guard cockpits. However, human error in the cockpit is not new in aviation. Commercial and military CRM training is a direct result of efforts to reduce human error in the cockpit and improve coordination and communication among cockpit crewmembers. As new research in the psychosocial aspects of flight crew interaction continues to influence the focus of CRM, new CRM skills are emerging. Teamwork skills and outcomes indicate the role and impact of shared cognition among flight

crewmembers. Similar to advanced aircraft systems with multiple redundancies for added protection for increase safety, multipiloted aircraft provide a *human redundancy* designed to provide mutual performance monitoring and backup behaviors between pilots, increasing cockpit team effectiveness. Coast Guard CRM must move toward leveraging multipiloted human redundancy behaviors and training team skills that both create and enhance safety in multipiloted cockpits.

CHAPTER III

METHODOLOGY

Commercial and military aviation CRM attempts to increase flight crew effectiveness by improving cockpit teamwork processes. Recent Coast Guard aircraft mishaps costing lives and millions of dollars indicate a need for a better understanding of shared mental models and their role in cockpit flight crew team coordination CRM skills. The purpose of the study was to examine the effect of the ITO maneuver shared mental model among Coast Guard aircraft cockpit flight crews, ITO type (coupled or manual), and cockpit flight crew total flight time on ITO maneuver mutual performance monitoring and backup behaviors. In this chapter, the researcher describes the study's population and sample, research design including study variables, researcher-designed instruments used in the study, internal and external validity threats, Institutional Review Board approval procedures, and data collection procedures.

Research Objectives (RO)

The research objectives of the study are as follows:

- RO1: Describe the demographics of the study population according to pilot designation/qualification and cockpit flight crew total flight time experience.
- RO2: Determine the level of mental model sharedness in MH-65 aircraft cockpit flight crews of ITO maneuver critical team tasks.
- RO3: Determine the relationship between the ITO maneuver shared mental model score and observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.

- RO4: Compare the type of instrument takeoff (coupled or manual) on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.
- RO5: Determine the relationship between flight crew total flight time and observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.
- RO6: Determine the combined interaction effect of the ITO maneuver shared mental model score, ITO type, and flight crew total flight time on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews.

Population and Sample

The population of the study was Coast Guard pilots who fly the MH-65 aircraft. Approximately 430 pilots fly the MH-65 at 19 Coast Guard Air Stations across the country (K. Barres, personal communication October 15, 2013). The MH-65 pilots have completed initial military flight training and are currently trained to fly the MH-65 aircraft. The pilots are assigned specific designations based on training and aviation experience as one of the following (ranked from lowest to highest): 1) copilot, 2) first pilot, and 3) aircraft commander. According to U.S. Coast Guard (2013), each pilot designation represents specific roles and responsibilities within the aircraft cockpit and certifies the pilot has gained a specific level of training and experience to safely fly the aircraft in day and night during all weather conditions.

The copilot designation is for pilots initially trained in the MH-65 aircraft who have demonstrated aircraft systems and emergency procedures knowledge,

communications and security procedures, Federal Aviation Regulations, and FAA policies and procedures. The copilot designation is for pilots holding a military pilot rating (military aviator) but lack Coast Guard mission and operational experience (U.S. Coast Guard, 2013). The first pilot and aircraft commander designations are for pilots who possess higher levels of aircraft experience and Coast Guard operational experience and can function as pilot in command. Pilots functioning as pilot in command are ultimately responsible for the safe, orderly, efficient, and effective performance of the flight and mission completion (U.S. Coast Guard, 2013). Though both first pilot and aircraft commander designations can function as pilot in command, the aircraft commander designation is for pilots who have demonstrated higher levels of aviation judgment, flight discipline, aircrew supervision, and the use of cockpit CRM principles.

In addition to the three pilot designations, some pilots are also qualified as instructor pilots, allowing them to perform formal instruction, evaluation, and standardization (U.S. Coast Guard, 2013). The instructor pilot qualification is in addition to the aircraft commander designation and normally given to pilots who are highly competent aircraft commanders. All instructor pilots are aircraft commanders, but not all aircraft commanders are instructor pilots. Coast Guard instructor pilots must demonstrate personal characteristics such as superior judgment, patience, discretion, a desire to instruct, and the ability to inspire confidence and win respect (U.S. Coast Guard, 2013). Coast Guard instructor pilots are individually-selected and represent the highest level of aviation experience and maturity among pilots. Instructor pilots are responsible for the training and evaluation of all MH-65 pilots and the mentoring of less experienced pilots in aviation decision making, judgment, leadership, and Coast Guard CRM tenets.

Population Sample

According to Fink (2003), a convenience sample consists of individuals who are willing to participate and easily available for sampling. Pilots attending their MH-65 Proficiency Simulator Course at ATC Mobile were invited to participate in the study. The MH-65 Proficiency Simulator Course is a weeklong training course required by all MH-65 pilots on a 15-month recurrent cycle. The course provides a mechanism for FAA-required pilot instrument checks and flight scenarios emphasizing aircraft emergency procedures and critical flight maneuvers (*Federal Aviation Regulations/Aeronautical Information Manual*, 2013; U.S. Coast Guard, 2013). The MH-65 Proficiency Simulator Course consists of both ground school and Operational Flight Trainer (OFT) events. As seen in Table 4, there are four separate OFT events in a week-long Proficiency Simulator Course (ranked in event order): 1) Emergency Procedures 1, 2) Instrument Check 1, 3) Instrument Check 2, and 4) Emergency Procedures 2. Instrument check OFT events assess pilot instrument flight planning knowledge and abilities and in-flight instrument procedures. The emergency procedures OFT events evaluate aircraft systems and emergency procedural knowledge.

Table 4

MH-65 Proficiency Simulator Course OFT Events

OFT event 1	OFT event 2	OFT event 3	OFT event 4
Emergency Procedures 1	Instrument Check 1	Instrument Check 2	Emergency Procedures 2

Pilots attending the Proficiency Simulator Course are divided into two-pilot cockpit flight crews and remain paired together for all four OFT events. Cockpit flight crew pairing

promotes crew familiarity and allows the assessment of CRM skills between the two pilots during the course. The study used the cockpit flight crews established by the MH-65 Proficiency Simulator Course schedulers.

Research Design

A cross-sectional, descriptive, nonexperimental repeated measures design was used in this study (Shadish, Cook, & Campbell, 2002). Data was collected during an eleven-week period from June to August 2014 corresponding with MH-65 Proficiency Simulator Course convenings. The availability of MH-65 instructor pilots at ATC Mobile during summer transfer season and the maintenance upgrade of the MH-65 OFT limited the data collection period to approximately three months. Thirty-three cockpit flight crews participated, and all cockpit flight crews asked agreed to participate. Thirty-three cockpit flight crews participating closely matches the number of teams utilized in past shared mental model research (Marks et al., 2002; Marks et al., 2002; Mathieu et al., 2005; Mathieu et al., 2005).

Instrument Takeoffs (ITOs)

The study consisted of cockpit flight crews flying ITOs (two per pilot) in the MH-65 OFT. Pilots fly ITOs using cockpit flight instruments when visibility is poor and insufficient references exist for visual takeoffs (U.S. Coast Guard, 2010b). According to the *MH-65 Aircraft Flight Manual* (U.S. Coast Guard, 2010b), two types of ITOs, coupled and manual, are available for use by MH-65 cockpit flight crews during low visibility conditions. A coupled ITO transitions the aircraft from hovering to a climb using the flight director automated system. During a manual ITO, the pilot “manually” flies the aircraft from hovering to a climb. The coupled ITO relies primarily on the

cockpit automation to fly the aircraft. Both types of ITOs are acceptable methods for safely climbing the helicopter away from the water in low visibility conditions following overwater hover operations.

In May of 2012, a Coast Guard Transition Flight Working Group convened to review rotary wing procedures associated with critical phases of low overwater helicopter operations (D. Waters, personal communication, April 19, 2013). Several recommendations made by the Coast Guard Transition Flight Working Group were implemented to enhance safety and increase operational effectiveness of their helicopter flight crews. Interim Change 5 of the MH-65 Aircraft Flight Manual, released in April of 2013, modified the procedures for coupled and manual ITOs, thereby enhancing safety during low overwater helicopter operations. Safely flying the helicopter in low visibility conditions following overwater hover operations remained the primary purpose of coupled and manual ITOs, and the description of the maneuvers remained relatively unchanged. However, Interim Change 5 standardized coupled and manual ITO briefing items, delineated more specifically pilot flying duties and safety pilot duties, and standardized cockpit flight crew verbal communication during the ITO maneuvers (see Figure 3). The modified procedures were designed to increase cockpit flight crew coordination by establishing specific guidelines on monitoring and backup behaviors of the safety pilot during the ITO maneuvers. The coupled and manual ITO were chosen by the researcher because of the critical nature of low overwater helicopter operations and the importance of proper mutual performance monitoring and backup behaviors by the cockpit flight crews during ITO maneuvers.

COUPLED INSTRUMENT TAKEOFF

The PAC's departure brief is initiated by the FM during execution of Rescue Check Part 3.

PAC – Brief type of ITO, desired heading and level off altitude, in feet, and any other pertinent information (i.e. desired FD modes, MFD page).

SP/FM – Acknowledge.

PAC – "Commencing Coupled ITO."

SP – "Go Around engaged."

SP – "Three positive rates of climb." (RADALT, BARALT, IVSI)

SP – "Approaching ___ feet." (50 feet prior to the briefed altitude.)

PAC or SP – Request or offer FD modes, if desired.

PAC or SP – "ITO complete. Commence (or Commencing) Level Off Checks."

With the AFCS engaged and coupled to the flight director, establish a hover and check for normal indications. Smoothly increase collective to establish a climb, while setting a wings level, nose on the horizon, accelerating attitude. This attitude will provide the airspeed necessary to preclude a descending, nose low takeoff profile.

Activate Go-Around (GA) at no less than 25 feet, ensuring cyclic is in a trimmed condition and avoiding fly-through. The helicopter will level and accelerate to 40 KIAS. At 40 KIAS it will establish a 700 fpm climb and accelerate to 70 KIAS. Once established in this climb, select noncollective modes of the flight director such as indicated airspeed (IAS) and HDG SEL or NAV. With the GA mode selected, the collective synchronize (C-SYNC) function is the same as during IAS-VS operations.

MANUAL INSTRUMENT TAKEOFF

The PAC's departure brief is initiated by the FM during execution of Rescue Check Part 3.

PAC – Brief type of ITO, desired heading and level off altitude, in feet, and any other pertinent information (i.e. desired FD modes, MFD page).

SP/FM – Acknowledge.

PAC – "Commencing Manual ITO."

SP – "Three positive rates of climb." (RADALT, BARALT, IVSI)

SP – "40 KIAS, 5 degrees nose down."

SP – "Approaching ___ feet." (50 feet prior to the briefed altitude.)

PAC or SP – Request or offer FD modes, if desired.

PAC or SP – "ITO complete. Commence (or Commencing) Level Off Checks."

A manually executed ITO may be accomplished whenever the PIC desires. From a hover, check for normal indications. Disengage all FDS modes and smoothly increase collective to establish a climb, while setting a wings level and nose on the horizon attitude. Monitor RADALT and vertical speed for positive climb indications. After a climbing acceleration to 40 KIAS, lower the nose five degrees and continue accelerating until achieving a 70 to 80 KIAS climb profile. Once established, continue with a normal climb and engage noncollective FDS modes as required

Figure 3. MH-65 Aircraft Coupled and Manual Instrument Takeoff (ITO) Procedures Coupled and Manual Instrument Takeoff Procedures describing the maneuvers and specific Pilot at the Controls and Safety Pilot cockpit tasks. Adapted from "Flight Manual USCG Series HH-65C Helicopter, CGTO 1H-65C-1 (Interim Change 5)." Washington, DC: Author. pp. 2-19, 20. Copyright 2010 by the U.S. Coast Guard. Adapted with permission.

Research Design

In this repeated measures design study, cockpit flight crews flew four ITO maneuvers (two coupled and two manual) in their Emergency Procedures 2 OFT event of the MH-65 Proficiency Simulator Course. According to Sprinthall (2012), a repeated measures design allows the study subjects to be measured more than once, therefore creating a within-subjects design. To determine the mutual performance monitoring and backup behaviors between the two pilots during the climb away from the water in low

visibility conditions, each pilot flew a coupled ITO and a manual ITO and then functioned as safety pilot while the other pilot flew a coupled ITO and a manual ITO. Pilots monitor aircraft systems and each other when operating the aircraft (Dismukes & Berman, 2010; Marks et al., 2001; Potter et al., 2014; Tullo, 2010). A repeated measures design was used to allow both pilots to be measured on monitoring and backing up as the pilot flying and pilot monitoring during the ITOs.

Research Variables

There were three independent variables and one dependent variable used in the study. The three independent variables were the ITO maneuver shared mental model score, type of ITO being flown, and cockpit flight crew total flight time. The dependent variable was the ITO maneuver monitoring/backup behavior score. The following is a discussion of each variable and its purpose in the study.

ITO Maneuver Shared Mental Model Score

According to Stout et al. (1999), a shared mental model is a coordinating mechanism for effective teamwork. Shared mental models can enhance crew coordination and situational awareness in multipiloted cockpits (Endsley, 2010; Grote et al., 2010; Krieger, 2005; Mathieu et al., 2000; Sperling & Pritchett, 2011). Marks et al. (2000) classified the sharedness levels of mental models in cockpit flight crews as a similarity index score. Mathieu et al. (2005) and Mathieu et al. (2000) classified the sharedness levels of mental models in cockpit flight crews as a centrality index score. The sharedness score of Marks et al. (2000), Mathieu et al. (2005), and Mathieu et al. (2000) indicated the influence of the shared mental model on cockpit flight crew performance.

Using the methodology found in Marks et al. (2000), Mathieu et al. (2005), and Matheiu et al. (2000), the researcher determined a shared mental model score for each cockpit flight crew indicating the level of mental model sharedness of the ITO maneuvers. To determine the effect of flight crew shared mental model on mutual performance monitoring and backup behaviors, the study used the cockpit flight crew shared mental model score as an interval variable.

ITO Type (coupled or manual)

A coupled ITO transitions the aircraft to a climbout profile using a cockpit automated system while the manual ITO involves the pilot “manually” hand-flying the ITO flight climbout profile. Though both types of ITOs are designed to establish a climbout profile when transitioning to forward flight following overwater hover operations, the coupled ITO relies primarily on aircraft cockpit automation to fly the maneuver. According to Dismukes & Berman (2010), flight crews monitor aircraft flight instruments less when aircraft are controlled by highly reliable cockpit automated systems when the probability for error is lower. However, it is unclear whether pilot monitoring and backup of cockpit automation is similar to pilot monitoring and backup of the other pilot in multipiloted cockpits. To determine the effect of cockpit automation on mutual performance monitoring and backup behaviors between MH-65 cockpit flight crews, the study used ITO type (coupled or manual) as a nominal (categorical) variable.

Cockpit Flight Crew Total Flight Time

Flin et al. (2008) believe that level of experience, technical expertise, and familiarity with situations influence decision-making. According to Prince, Salas, Brannick, and Prince (2010), the interaction of pilots in multipiloted cockpits changes

based on the experience level of the individual pilots. A pilot's aviation judgment and decision making increase with flying experience and maturity. The Coast Guard recognizes that more experienced pilots, e.g. instructor pilots and aircraft commanders, should possess higher degrees of judgment, flight discipline, and CRM skills (U.S. Coast Guard, 2013).

In aviation, one indicator of experience and maturity is pilot total hours. In both commercial and military aviation, total pilot time is an industry-standard indication for flight experience, aviation discipline, maturity, and decision-making. Total pilot time is used as a discriminator in pilot hiring decisions. However, total pilot time as an experience indicator varies among aviation industry sectors, e.g. general aviation or airline transport aviation. Wiggins and Bollwerk (2006) classify a general aviation novice pilot as having accumulated less than 1,000 flight hours and an expert pilot as having more than 1,000 flight hours. Studying the role of flight hours and cockpit flight crew performance, Todd and Thomas (2012) classify airline transport first officers with less than 1,500 flight hours as low time pilots and first officers with more than 1,500 flight hours as high time pilots. Airline captains with less than 5,000 flight hours are considered low flight time captains, and captains with more than 5,000 are high time captains (Todd & Thomas, 2012).

Coast Guard pilots are normally initially designated in aircraft type with as little as 200 total flight hours. The designations of first pilot and aircraft commander require a minimum of 500 and 700 total flight hours, respectively (U.S. Coast Guard, 2013). The Coast Guard Air Operations Manual encourages Coast Guard pilots to accumulate 20-25 flight hours per month to maintain aviation proficiency and to reduce operational risks

(U.S. Coast Guard, 2013). Coast Guard first pilots and aircraft commanders are required to fly a minimum of 96 flight hours a year (U.S. Coast Guard, 2013) but normally can acquire 200 to 400 flight hours a year. According to Prince et al. (2010), cockpit flight crews communicate differently based on each pilot's experience and maturity. However, it is unclear whether cockpit flight crew aviation experience and maturity level, quantified in total flight time, affects cockpit flight crew mutual performance monitoring and backup behaviors. To gauge the overall experience and maturity level of the participating cockpit flight crews, the researcher combined the total flight hours of each cockpit flight crew (two pilots) to create a cockpit total flight time interval variable.

Mutual Performance Monitoring and Backup Behavior Score

Research shows that monitoring is the act of observing behaviors and actions of other team members, thus allowing team members to identify mistakes and lapses in behaviors and actions (Salas et al., 2005; Wilson et al., 2007). Backup behaviors occur when team members help each other perform their roles, and research indicates the positive effect between backup behaviors and team performance (Porter et al., 2003). Derived from the team performance process analysis found in earlier shared mental model research (Mathieu et al., 2005; Mathieu et al., 2005; Marks et al., 2002; Marks et al., 2002), the levels of mutual performance monitoring and backup behaviors of each cockpit flight crew ITO maneuvers were judged to create a mutual performance monitoring and backup behaviors score interval variable for each MH-65 cockpit flight crew.

Instrumentation

Two researcher-designed data collection instruments were used in the study: 1) Shared Mental Model Instrument, and 2) Monitoring/Backup Behavior Instrument. The purpose of the Shared Mental Model Instrument was to determine the level of sharedness of cockpit flight crews' mental model regarding the coupled and manual ITO maneuvers and to create a shared mental model score for each cockpit flight crew for later comparison with ITO maneuver mutual performance monitoring and backup behaviors. The purpose of the Monitoring/Backup Behavior Instrument was to determine the level of mutual performance monitoring and backup behaviors occurring between each cockpit flight crew during the coupled and manual ITOs and to create a coupled and manual ITO score.

Shared Mental Model Instrument Development Background

The researcher-designed Shared Mental Model Instrument was derived from earlier shared mental model instruments found in Marks et al. (2002), Mathieu et al. (2005) and Mathieu et al. (2000) which identified critical team tasks across flight crew team positions necessary for mission success. Mathieu et al. (2005) and Mathieu et al. (2000) identified critical team tasks of a two-person team flight crew flying an F-16 flight simulator on a military mission (see Table 5). Marks et al. (2002) identified critical team tasks of a three-person flight crew (pilot, gunner, and radar specialist) operating an Apache attack helicopter flight simulator in battlefield attack missions (see Table 5). In Mathieu et al. (2005) and Mathieu et al. (2000) as well as Marks et al. (2002), the critical team tasks characterize a shared mental model which helped team members

predict and describe who should do what at a particular point in time during the flight missions to complete the assigned mission.

Table 5

Critical Team Tasks Identified to Complete the Mission

Mathieu et al. (2005) Mathieu et al. (2000)	Marks et al. (2002)
Diving/climbing	Escape enemy attacks
Banking/turning	Follow waypoints
Choosing airspeed	Identify enemy
Selecting and shooting weapons	Position helicopter for targeting
Reading/interpreting radar	Adjust speed
Intercepting the enemy	Fire weapons
Escaping the enemy	Announce enemy approach
Dispensing chaff and flares	Adjust altitude
	Select target

After identifying the critical team tasks to successfully complete the mission, Mathieu et al. (2005), Mathieu et al. (2000), and Marks et al. (2002) asked each member of the flight crew to judge the relatedness of each team task to other identified team tasks and assign a number ranging from 1 (*not related*) to 9 (*very related*). The team member scores were fed into computer programs and compared to other team member scores to determine a similarity index (Marks et al., 2000) or centrality index (Mathieu et al., 2005; Mathieu et al., 2000) indicating a level of team mental model sharedness regarding critical team tasks.

Shared Mental Model Instrument

The researcher conducted a team task analysis, based on a methodology described in Burke (2005), of the MH-65 coupled and manual ITO procedures with an ATC Mobile

instructor pilot. The analysis resulted in seven critical team tasks for ITO maneuvers common to both the coupled and manual ITOs (see Table 6). The seven ITO maneuver critical team tasks were placed both vertically and horizontally in the Shared Mental Model Instrument, producing a grid-like format with empty boxes creating an intersection between two ITO maneuver team tasks (see Appendix B). The grid-like format allowed the recording of a related value between two ITO maneuver team tasks by each pilot of a cockpit flight crew.

Table 6

Critical Team Tasks Identified to Complete an ITO Maneuver

Coupled ITO	Manual ITO
Aligning maneuver expectations (Departure Brief)	Aligning maneuver expectations (Departure Brief)
Establishing pre-ITO aircraft configuration	Establishing pre-ITO aircraft configuration
Pilot at the controls & safety pilot verbal call outs	Pilot at the controls & safety pilot verbal call outs
Monitoring attitude, airspeed, & altitude	Monitoring attitude, airspeed, & altitude
Monitoring flight director for proper control inputs	Monitoring flight director for proper control inputs
Achieving desired level-off altitude	Achieving desired level-off altitude
Conducting level-off checklist	Conducting level-off checklist

Each pilot of the cockpit flight crew completed the Shared Mental Model Instrument by judging the relatedness of each critical team task to another task and choosing a value ranging from 1 (*not related*) to 5 (*very related*). The pilot recorded the value of the two critical team tasks in each box intersecting of two critical team tasks (see Appendix C for an example of a completed Shared Mental Model Instrument).

The researcher compared the critical team task values recorded on each pilot's Shared Mental Model Instrument and created a shared mental model score for each critical team task comparison. For example, if one pilot chose a value of 1, indicating a low related value between two critical team tasks, and the other pilot chose 5, indicating a high related value between two critical team tasks, the shared mental model score for this two tasks comparison equaled 4. The critical team tasks shared mental model scores were aggregated to produce a total shared mental score for each MH-65 cockpit flight crew. A low shared mental score represented a high level of mental model sharedness for the cockpit flight crew. The Shared Mental Model Instrument also captured study participant pilot designation and total flight time descriptive statistics.

Monitoring/Backup Behavior Instrument Background

For cockpit flight crews, observable behaviors are specific actions employing CRM skills in a given situation (FAA, 2006). The researcher-designed Monitoring/Backup Behavior Instrument was derived from past CRM behavioral marker instruments designed to capture and measure cockpit flight crew observable behaviors. According to Flin and Martin (2001), behavioral markers have been used to represent a prescribed set of behaviors leading to a performance aspect.

The Targeted Acceptable Responses to Generated Events or Tasks methodology was used to evaluate team CRM performance by identifying events that elicit behaviors of interest and then controlling the introduction of those events through an OFT in-flight scenario script (Fowlkes, Lane, Salas, Franz, & Oser, 1994). The goal of Targeted Acceptable Responses to Generated Events or Tasks is minimizing observer judgments of cockpit flight crew through the use of predefined set of acceptable behaviors (O'Conner,

Hormann, Flin, Lodge, Goeters, & JARTEL Group, 2002). Non-Technical Skills is a behavioral rating system to assess a pilot's CRM non-technical skills. The framework of Non-Technical Skills is intended to reduce ambiguities in evaluating pilot CRM skills (Flin, 2010). The basic usability and psychometric properties of Non-Technical Skills was tested within a consortium of European research centers and aviation companies. The test consisted of eight recorded OFT airline transport operational scenarios, each with a unique set of design references, reflecting pilot non-technical skills for behavior categories (O'Conner et al., 2002). Instructors rated cockpit flight crew behaviors in each scenario and judged predefined behaviors on a 5-point scale score form ranging from *very poor* to *very good* (Flin, 2010).

Monitoring/Backup Behavior Instrument

In order to determine the level of mutual performance monitoring and backup behaviors during the coupled and manual ITOs flown by the cockpit flight crews, the researcher-designed Monitoring/Backup Behavior Instrument established scenario-based predefined CRM behavior markers similar to Targeted Acceptable Responses to Generated Events or Tasks and Non-Technical Skills. The behavior markers were derived from mutual performance monitoring and backup statements and questions found in Salas et al. (2005) and Wilson et al. (2007; see Table 7) . The teamwork behavior markers of Salas et al. (2005) and Wilson et al. (2007) were contextualized to the roles and responsibilities of cockpit flight crews (pilot flying and pilot monitoring) during the coupled and manual ITO maneuvers and captured as five mutual performance monitoring and five backup behavior CRM behavior markers in the Monitoring/Backup Behavior Instrument (see Appendix D). Each ITO maneuver mutual performance monitoring and

backup behavior marker is scaled from 1 (*not at all*) to 5 (*to a very great extent*) in order to rate the level of mutual performance monitoring and backup behaviors of each cockpit flight crew. The Likert rating scale used in the Monitoring/Backup Behavior Instrument is similar to the rating scale found in Mathieu et al. (2005) and Mathieu et al. (2000).

Table 7

Teamwork Behavior Markers

Salas et al. (2005)	Wilson et al. (2007)
Mutual Performance Monitoring	Mutual Performance Monitoring
Identifying mistakes and lapses in other team members' actions.	Did team members observe the behaviors and actions of other team members?
Providing feedback regarding team member actions to facilitate self-correction.	Did team members recognize mistakes made recognize mistakes made by others? Were team members aware of their own and others' surroundings?
Backup Behavior	Backup Behavior
Recognition by potential backup providers that there is a workload distribution problem in the their team.	Did team members correct other team members errors?
Shifting of work responsibilities to underutilized team members.	Did team members provide and request assistance when needed?
Completion of the whole task or parts of tasks by other team members.	Did team members recognize when one performed exceptionally well?

Monitoring/Backup Behavior Observation Methodology

To determine the mutual performance monitoring and backup behaviors displayed by the cockpit flight crews during the coupled and manual ITOs, two CRM SMEs viewed the recorded ITO maneuvers on the Computer-Aided Debriefing Station and completed a Monitoring/Backup Behavior Instrument for each ITO maneuver (coupled and manual).

The two CRM SMEs are highly experienced Coast Guard instructor pilots with over 15,000 combined flight hours and experts in multipiloted cockpit coordination and CRM principles. The debriefing station used by the CRM SMEs is located in the pilots' debriefing room at ATC Mobile and allows for over-the-shoulder video/audio recording of the cockpit area and instrument panel and training event playback capability (see Figure 4). The debriefing room is normally used for recording MH-65 Proficiency Simulator Course OFT events. The CRM SMEs observing the recorded coupled and manual ITOs knew the purpose and research objectives of the study but were unaware of the shared mental model scoring of each cockpit flight crew while judging the mutual performance monitoring and backup behavior levels.



Figure 4. Computer-Aided Debriefing Station Screen.

Instrumentation by Research Objective and Study Variables

The two researcher-designed data collection instruments explored the six research objectives using the study's three independent variables and one dependent variable. The

Shared Mental Model Instrument was used for describing the demographics of the study population according to pilot designation/qualification and obtaining the cockpit flight crew total flight time experience (RO1). The Shared Mental Model Instrument also determined the level of mental model sharedness of MH-65 aircraft cockpit flight crews on ITO maneuver critical team tasks (RO2).

The Monitoring/Backup Behavior Instrument captured the MH-65 cockpit flight crews' observed levels of mutual performance monitoring and backup behaviors during the coupled and manual ITOs and determined the relationship of those behaviors and ITO maneuver shared mental model score (RO3), type of instrument takeoff (coupled or manual (RO4), and flight crew total flight time (RO5). The data collection instruments and their associated research objectives, independent variables, dependent variable, and statistical analysis are seen in Figure 5.

Research Objective	Data Collection	Variable	Variable	Statistical Analysis
1	Shared Mental Model Instrument	N/A	N/A	Descriptive/ Mean & SD
2	Shared Mental Model Instrument	N/A	N/A	Mean & SD
3	Monitoring/ Backup Behavior Instrument	Shared Mental Model score	Monitoring and Backup Behaviors	Correlation
4	Monitoring/ Backup Behavior Instrument	ITO type (coupled or manual) IV	Monitoring and Backup Behaviors DV	T-test
5	Monitoring/ Backup Behavior Instrument	Flight crew total flight hours	Monitoring and Backup Behaviors	Correlation
6	Monitoring/ Backup Behavior Instrument	SMM score ITO type Flight crew total flight hours IVs	Monitoring and Backup Behaviors DV	ANCOVA

Figure 5. Data Collection, Variables, and Statistical Analysis by Research Objective.

Instrument Validity and Reliability

According to Phillips and Phillips (2007), validity is the degree to which an instrument measures what it is designed to measure, and reliability is the consistency of the instrument over time. According to Hall and Brannick (2008), a major drawback when using humans as judges is that judges may disagree with each other and interpret differently what they observe. A validity threat to the study was interrater reliability between the CRM SMEs judging mutual performance monitoring and backup behaviors when completing the Monitoring/Backup Behavior Instruments on the recorded cockpit flight crew ITO maneuvers. To increase the study's construct validity, the CRM SME raters received a one-hour training session on the use of the Monitoring/Backup Behavior Instrument. The training included a review of mutual performance monitoring and backup statements and questions found in Salas et al. (2005) and Wilson et al. (2007) as well as a review of the five mutual performance monitoring and five backup behavior CRM behavior markers on the Monitoring/Backup Behavior Instrument.

Interrater reliability was tested between CRM SMEs judging mutual performance monitoring and backup behaviors. The Monitoring/Backup Behavior Instrument scores were tested using Pearson's product-moment correlation coefficient (r) to assess interrater reliability between the two CRM SMEs judging the mutual performance monitoring and backup behaviors. Pearson's r is possible for interrater reliability when raters produce raw scores (Huck, 2012) and is a popular statistic test for calculating the degree of consistency among independent raters (Multon, 2010). Pearson's r of .70 is an acceptable level of reliability (Multon, 2010). Pearson's r tests between the two CRM SMEs were .44 and .29 for coupled and manual Monitoring/Backup Behavior Instrument scores

respectively. A low Pearson's r interrater reliability score between the two CRM SMEs for coupled and manual scores possibly occurred as a result of the Monitoring/Backup Behavior Instrument mutual performance monitoring and backup behaviors scoring.

Additional threats to the CRM SME observations and the Monitoring/Backup Behavior Instrument included observer errors of leniency and central tendency (Pershing Warren, & Rowe, 2006). Errors of leniency occur when observers rate behaviors high regardless of performance, and errors of central tendency occur when observers rate all participants at the middle of the scale (Pershing et al., 2006). Defining flight crew monitoring and backup observable behaviors and Likert scale levels during the CRM SME training helped to decrease possible errors of leniency and central tendency. During the CRM SME training, the researcher reviewed examples of low, medium, and high levels of pilot monitoring behaviors and backup behaviors.

Monitoring/Backup Behavior Instrument Validity Threat

The 10 ITO maneuver mutual performance monitoring and backup behavior markers found on the Monitoring/Backup Behavior Instrument seen in Appendix D are based on the teamwork behavior markers found in Salas et al. (2005) and Wilson et al. (2007). According to Phillips (1997), behavior markers are used for observing the presence or absence and frequency of behaviors of study participants. The behaviors in this study were the mutual performance monitoring and backup behaviors of the cockpit flight crews during the coupled and manual ITOs. However, eight of the 10 ITO maneuver mutual performance monitoring and backup behavior markers on the Monitoring/Backup Behavior Instrument require either cockpit flight crew flight control mistakes, lapses in procedural steps, or ITO maneuver errors. If the flight crew did not

make a mistake, lapse, or error, the mutual performance monitoring and backup behavior became unmeasurable. For example, Behavior Marker 6 on the Monitoring/Backup Behavior Instrument could not be judged by CRM SME observers if a flight control error was not made by the pilot flying. In these instances, the CRM SMEs observing the recorded cockpit flight crew ITO maneuvers noted the behavior marker as “not applicable.” “Not applicable” behavior markers were removed from the total possible score in an attempt to reduce observation instrument inaccuracy and maintain Monitoring/Backup Behavior Instrument validity. Therefore, each completed Monitoring/Backup Behavior Instrument final score was calculated only on the behavior markers scored and not the 200 total possible points on the Monitoring/Backup Behavior Instrument.

Threats to Internal and External Validity

The researcher considered threats to internal and external validity (Shadish et al., 2002). The convenience sampling of 66 MH-65 pilots forming 33 MH-65 cockpit flight crews presented an internal validity threat to the study. Since a random sampling of all Coast Guard MH-65 pilots located across the United States and Puerto Rico was cost prohibitive, the convenience sample of 66 MH-65 pilots (33 MH-65 cockpit flight crews) attending their annual MH-65 Proficiency Simulator Course was deemed acceptable to the researcher. To moderate the convenience sampling validity threat of the study, the researcher reviewed the designation and experience level pairing of each cockpit flight crew to ensure the pairing closely matched that normally occurring in MH-65 aircraft cockpits at Coast Guard Air Stations. Cockpit flight crew designation pairings and experience levels are reported in Chapter IV.

The recent changes to the MH-65 Aircraft Flight Manual regarding coupled and manual ITO maneuvers represented a history threat to the study. Since all MH-65 cockpit flight crews had been trained and evaluated on the new ITO maneuver procedures, there was a reasonable expectation that flight crews were familiar and proficient in the ITO modified procedures. To increase internal validity, all participating flight crews were advised of the upcoming ITO maneuvers when signing their informed consent forms allowing them to review the ITO maneuver procedures prior to their Emergency Procedures 2 OFT event.

To reduce the testing effect of the ITO maneuver repeated measures data collection, the researcher used a Latin Square design to counterbalance the four recorded ITO maneuvers in the Emergency Procedures 2 OFT event. The repeated measures allowed both pilots to be measured in pilot flying and pilot monitoring roles. The Latin Square design determined ITO type, order of ITOs, and flight crew duties by seat position for each cockpit flight crew (see Appendix E). To ensure the four ITO maneuvers were conducted similarly for each cockpit flight crew, each ATC Mobile instructor pilot conducting the ITO maneuvers was given a job aid outlining the Latin Square design to be used for their particular Emergency Procedures 2 OFT event.

External validity refers to the ability to apply the study to other settings and populations (Sprinthall, 2012). The study's setting was in the Coast Guard's MH-65D OFT. According to Moroney and Moroney (2010), OFTs are a valid representation of aircraft flight and system characteristics. Commercial and military aviation use OFTs extensively for flight crew training and to create dynamic real-world situations to measure cockpit flight crew effectiveness and performance (Salas & Preist, 2005).

According to the Civil Aviation Authority (2006), OFTs allow crews to practice CRM behaviors under normal and emergency conditions. Fowlkes et al. (1994) used OFT in-flight scenarios to evaluate team CRM performance. Dismukes (2009) argues that full-mission flight simulation (OFTs) allow for ethnographic observation and laboratory experimentation when studying the expert performance of real world tasks. Given past CRM research using OFTs (Fowlkes et al., 1994; O'Conner et al., 2002; Potter et al., 2014), the researcher believes that this study's findings on cockpit flight crew mutual performance monitoring and backup behaviors may be applicable to monitoring and backup behaviors found in other Coast Guard and United States military multipiloted cockpits.

Institutional Review Board Approval

The researcher submitted the data collection instruments (Shared Mental Model Instrument and Monitoring/Backup Behavior Instrument), data collection plan, and study participant consent form to The University of Southern Mississippi Institutional Review Board (IRB) for human subject review and approval (The University of Southern Mississippi Institutional Review Board website, n.d). Following research approval by The University of Southern Mississippi (see Appendix F), similar human subjects research forms were submitted to the U.S. Coast Guard IRB for human subject review and approval (U.S. Coast Guard, 2011a). U.S. Coast Guard IRB approval was granted approximately one month later (Appendix G). Both IRB reviews were necessary to ensure the proposed research met the relevant federal and institutional standards and the ethical treatment and well-being of those participating in the study. The Coast Guard's IRB recognized the primary oversight of The University of Southern Mississippi's IRB.

Data Collection Procedures

Data collection began immediately following The University of Southern Mississippi and U.S. Coast Guard IRB approval. The MH-65 Proficiency Simulator Course convened each Monday and finished by Thursday or Friday of the same week. On the first day of the course, the researcher reviewed the designation/experience level pairing of each cockpit flight crew to ensure a minimum of one instructor pilot or aircraft commander was part of each cockpit flight crew ensuring normal cockpit flight crew representation. The number of cockpit flight crews available for the study varied from one to four cockpit flight crews per week.

The researcher met with each Proficiency Simulator Course cockpit flight crew member during the Emergency Procedures 1 OFT event, explaining the research study's objectives and distributing an IRB Informed Consent Form (Appendix H) to each pilot of the cockpit flight crew. After each pilot signed the research study's consent form and the researcher answered all questions about the study, each pilot received a Shared Mental Model Instrument. The researcher explained what the Shared Mental Model Instrument's purpose was and how to individually complete grid-like format by judging the relatedness of each critical team task to another task and choosing a related value ranging from 1 (*not related*) to 5 (*very related*). Each pilot acknowledged fully understanding how to complete the Shared Mental Model Instrument. The researcher informed the cockpit flight crewmembers to bring their completed Shared Mental Model Instruments to their Emergency Procedures 2 OFT event later in the week. The cockpit flight crews were also advised about the ITO maneuvers later that week during the Emergency Procedures 2 OFT event. At no point were the cockpit flight crews told that the coupled and manual

ITOs were being specifically observed for mutual performance monitoring and backup behaviors.

The Emergency Procedures 2 OFT event always occurred Thursday or Friday during the week of the Proficiency Simulator Course. The researcher met with each cockpit flight crew at the start of the Emergency Procedures 2 OFT event and collected a completed Shared Mental Model Instrument from each pilot. Prior to boarding the MH-65 OFT, the ATC Mobile instructor pilot conducting the Emergency Procedures 2 OFT event was given a job aid outlining the Latin Square design order for that particular cockpit flight crew. Additional information on the job aid included protocol for labeling the coupled and manual ITOs recordings by cockpit flight crew number for later viewing. Since the Emergency Procedures 2 OFT event contained other training maneuvers and instructional items, the ATC Mobile instructor pilot was given latitude on when to complete the coupled and manual ITOs during the OFT event. The researcher was not in the OFT during the Emergency Procedures 2 OFT event.

Within a week of the Emergency Procedures 2 OFT event, each CRM SME individually viewed the recorded ITO maneuvers on the debriefing station and completed a Monitoring/Backup Behavior Instrument for the two coupled and two manual ITOs performed by each cockpit flight crew. Though the four ITOs took approximately 20 minutes to complete during the Emergency Procedures 2 OFT event, completing of Monitoring/Backup Behavior Instruments while watching the four recorded ITOs took approximately 1 to 1.5 hours for each cockpit flight crew. The playback capability of the debriefing station allowed the CRM SMEs to observe each cockpit flight crew interaction during the ITO maneuvers as many times as necessary to observe and judge all mutual

performance monitoring and backup behaviors. Once both CRM SMEs had completed observing each cockpit flight crew's coupled and manual ITOs by judging their mutual performance monitoring and backup behaviors on each ITO maneuver, the researcher collected the eight completed Monitoring/Backup Behavior Instruments and combined them with the two completed Shared Mental Model Instruments to form a data collection package for each cockpit flight crew. The Proficiency Simulator Course data collection steps, associated data instruments, and event/instrument outputs are seen in Figure 6.

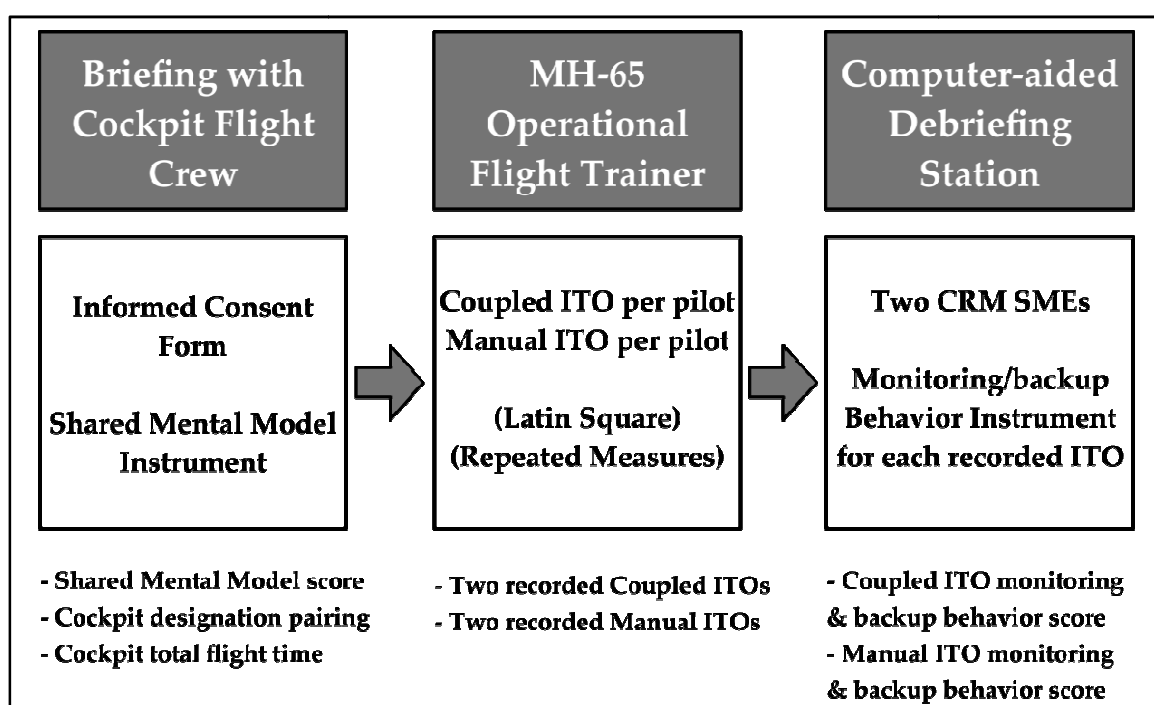


Figure 6. Proficiency Simulator Course Data Collection Steps.

Data Collection Preparation

The data collection package for each cockpit flight crew consisted of two individually completed Shared Mental Model Instruments and eight CRM SME completed Monitoring/Backup Behavior Instruments. Malfunctions with the MH-65 OFT prevented three of the participating cockpit flight crews from completing the coupled and manual ITOs. Therefore, complete data packages (two Shared Mental

Model Instruments and four Monitoring/Backup Behavior Instruments) were available for only 30 participating cockpit flight crews. In the following section, the researcher describes the data collection preparation steps for the researcher-designed instruments in preparation for data analysis.

Shared Mental Model Instrument Data

Participating MH-65 pilots completed a Shared Mental Model Instrument and gave it to the researcher prior to their involvement in the cockpit flight crew ITO maneuvers. The researcher calculated the shared mental model score for each cockpit flight crew. The data set for analysis contained 30 cockpit flight crew shared mental model scores. The Shared Mental Model Instruments also produced a pilot designation pairing, e.g. aircraft commander / first pilot, and cockpit total flight time descriptive statistics for each cockpit flight crew.

Monitoring/Backup Behavior Instrument Data

Each cockpit flight crew flew four ITO maneuvers (two coupled and two manual) during the Emergency Procedures 2 OFT event. Each pilot flew a coupled ITO and manual ITO and then functioned as safety pilot while the other pilot flew a coupled and manual ITO. The cockpit flight crew total data collection package consisted of four coupled ITO Monitoring/Backup Behavior Instruments (two per CRM SME observer) and four manual ITO Monitoring/Backup Behavior Instruments (two per CRM SME observer). The maximum number of points for each Monitoring/Backup Behavior Instrument was 50 with total possible points of 200 for each cockpit flight crew's four Monitoring/Backup Behavior Instruments.

Chapter Summary

The study's six research objectives were measured using a cross-sectional, descriptive, nonexperimental repeated measures methodology with MH-65 pilots attending their annual Proficiency Simulator Course. Using the MH-65 OFT located at ATC Mobile, cockpit flight crews flew coupled and manual ITO maneuvers to study the interaction effect of shared mental model levels, cockpit automation, and flight crew experience level on mutual performance monitoring and backup behaviors. Two researcher-designed data collection instruments were used to determine the level of mental model sharedness and level of monitoring and backup behaviors among the participating cockpit flight crews. The SMEs viewed the recorded ITO maneuvers and judged the levels of mutual performance monitoring and backup behaviors of the cockpit flight crews. The cockpit operational relevance of flight crew pairings and the counterbalancing ITO maneuver Latin Square observation design mitigated internal and external threats to the study. The following chapter describes the results of the study's data analysis.

CHAPTER IV

ANALYSIS OF DATA

The purpose of the study is to examine the effect of the ITO maneuver shared mental model among Coast Guard aircraft cockpit flight crews, ITO type (coupled or manual), and cockpit flight crew total flight time on mutual performance monitoring and backup behaviors. The researcher designed the Shared Mental Model Instrument and the Monitoring/Backup Behavior Instrument for specific data collection efforts. Each MH-65 pilot participating in the study completed the Shared Mental Model Instrument, and the data on the instrument helped determine the level of mental model sharedness between the cockpit flight crew regarding critical tasks associated with the coupled and manual ITO. By calculating the Shared Mental Model Instruments completed by pilots in each cockpit flight crew, the researcher created a shared mental model score. The researcher later compared the shared mental model score with mutual performance monitoring and backup behaviors performed by each cockpit flight crew during the ITOs. The researcher also used the Shared Mental Model Instrument to capture descriptive statistics of each cockpit flight crew (designation/qualification, total pilot flight time). The purpose of the Monitoring/Backup Behavior Instrument was to determine the level of mutual performance monitoring and backup behaviors occurring between each cockpit flight crew during the coupled and manual ITOs and to create a coupled and manual ITO mutual performance monitoring and backup behavior score for each cockpit flight crew. The Monitoring/Backup Behavior Instruments were completed by CRM SMEs observing the recording of each cockpit flight crew's ITO maneuvers and determined observed levels of mutual performance monitoring and backup behaviors of the cockpit flight

crews. The chapter presents the data analysis results for each of the six research objectives of the study.

Demographics

The demographics of the study participants were collected on the Shared Mental Model Instrument. Pilots self-reported designation/qualification and their total flight time. After completing the data collection preparation steps as described in the previous chapter, the researcher compiled the Shared Mental Model Instrument to produce a designation/qualification pairing descriptive statistic for each cockpit flight crew. Pilot total flight time on the Shared Mental Model Instrument was used for determining cockpit flight crew total flight time.

Research Objective One (ROI)

The purpose of RO1 was to show descriptive statistics of the sample population according to pilot designation/qualification (instructor pilot, aircraft commander, first pilot, copilot) and cockpit total flight time experience. All MH-65 pilot designations were represented in the population convenience sample ($N = 30$) of the cockpit flight crews. Each cockpit flight crew contained at least one pilot with either an instructor pilot or aircraft commander. Of the 30 cockpit flight crews, instructor pilots were part of 60% ($n = 18$) of the cockpit flight crews, and aircraft commanders were part of the remaining 40% ($n = 12$). The cockpit flight crew pairing in the sample population represented all normal designation pairings and experience levels normally found in Coast Guard cockpits. Table 8 shows the study's cockpit flight crews ranked by paired designation from the highest combined designation and qualification level to lowest in terms of

training, aviation experience, maturity, aviation decision making, Coast Guard operational experience, and multipiloted aircraft CRM experience.

Table 8

Descriptive Statistics of Cockpit Flight Crews

Cockpit Flight Crew by Paired Designation/Qualification		
Pilot 1	Pilot 2	N
instructor pilot	instructor pilot	2
instructor pilot	aircraft commander	8
instructor pilot	first pilot	4
instructor pilot	copilot	4
aircraft commander	aircraft commander	8
aircraft commander	first pilot	3
aircraft commander	copilot	1
Total Cockpit Flight Crews		30

Of the 30 cockpit flight crews participating in the study, only five paired designation/qualification contained copilots. The remaining 25 paired designation/qualification cockpit flight crews comprised of instructor pilots, aircraft commanders, or first pilots, thus representing higher levels of aircraft and Coast Guard operational experience and pilot in command competencies. Ten cockpit flight crews contained similar pilot designations, e.g. instructor pilot and instructor pilot, aircraft commander and aircraft commander. These particular cockpit flight crews represented a

cockpit flight crew designation/qualification setting in which both pilots held similar designation, qualification, and pilot in command abilities. In a multipiloted Coast Guard cockpit, the pilot functioning as the pilot in command normally provides leadership in the cockpit environment and is responsible for a safe execution of the flight. During the coupled and manual ITO maneuvers in the MH-65 OFT with cockpits containing similar pilot designation/qualifications, the pilot flying the aircraft assumed the role of pilot in command.

To gauge the overall experience and maturity level of the participating cockpit flight crews, the study combined the total flight hours of each cockpit flight crew (two pilots) to create a cockpit flight crew total flight time variable. Individual total flight time of each pilot was self-reported on the Shared Mental Model Instrument and combined with the other cockpit flight crewmember to establish a cockpit flight crew total flight time. Table 9 shows the minimum, maximum, mean, and SD for cockpit flight crew total flight time.

Table 9

Descriptive Statistics of Cockpit Flight Crew Total Flight Time

Variable	<i>N</i>	Min	Max	<i>Mean</i>	<i>SD</i>
Cockpit Flight Crew Total Flight Time	30	2005	9100	4652	1827

One of the four instructor pilot / copilot cockpit flight crew designation pairings had a minimum flight crew total flight time of 2005 with the instructor pilot having 1600 total flight hours and the copilot having 405 total flight hours. The cockpit flight crew pairing

having the maximum combined total flight hours of 9100 was a paired designation of aircraft commander and aircraft commander. The combined cockpit flight crew total time mean of 4652 showed normal levels of combined flight time experience for Coast Guard multipiloted cockpits.

Since the focus of the study was the combined experience level of the cockpit flight crew on ITO mutual performance monitoring and backup behaviors, the individual total flight time self-reported on the Shared Mental Model Instruments was not used as a study variable. However, the range of the individual total flight time of the pilot participants ranged from a copilot with 405 total flight hours to a 7500 flight hour aircraft commander. Four of the five copilots had less than 1000 hours of total flight time, a normal amount of time for Coast Guard Air Station duty-standing pilots holding a copilot designation.

Results

Data for the following research objectives were collected on the study's two researcher-designed data collection instruments. Research objective 2 shows the data analysis of cockpit flight crews' shared mental model scores. Research objectives 3, 4, 5, and 6 show the relationships and interactions of the study's three independent variables on observed levels of mutual performance monitoring and backup behaviors.

Research Objective Two (RO2)

The purpose of RO2 was to show the level of mental model sharedness between each MH-65 aircraft cockpit flight crew regarding the ITO maneuver. A shared mental model was determined by each pilot of a cockpit flight crew scoring the relatedness of seven critical team tasks. The Shared Mental Model Instruments of each cockpit flight

crew were aggregated to produce a shared mental model score. A lower shared mental model score represented a higher level of shared mental model regarding seven critical team tasks. Complete agreement between a cockpit flight crew regarding the relatedness of ITO maneuver critical team tasks would result in a score of zero (highest possible level of shared mental model) while complete disagreement of ITO maneuver critical team tasks would result in a score of 84 (lowest level possible level of shared mental model). The minimum shared mental model score of 14 was recorded for two cockpit flight crews with designation/qualification pairings of aircraft commander / first pilot and instructor pilot / copilot. The highest aggregated shared mental model score of 51 occurred between an aircraft commander / first pilot. Table 10 shows the minimum, maximum, mean and SD for cockpit flight crew shared mental model scores.

Table 10

Shared Mental Model Score

Variable	Min	Max	Mean	SD
Score	14	51	23.43	7.74

No cockpit flight crew showed total agreement on the relatedness of the seven critical team tasks (zero shared mental model score), but all cockpit flight crews shared mental model scores that fell within the lower two-thirds of possible scores, indicating a general agreement by the cockpit flight crews on the levels of relatedness of the seven critical team tasks of the ITO maneuvers. The cockpit flight crews shared mental model scores were associated with both high and low levels of cockpit flight crew total flight

time indicating the existence of shared mental models at all levels of cockpit flight crew experience and maturity.

Data Analysis of Cockpit Flight Crews Mutual Performance Monitoring and Backup Behaviors

Research objectives 3, 4, 5, and 6 show the relationships and interactions of the study's independent variables on observed levels of mutual performance monitoring and backup behaviors by cockpit flight crews during the ITO maneuvers flown in the MH-65 OFT. After completing the data collection preparation steps as described in the previous chapter, the researcher compiled the Monitoring/Backup Behavior Instruments to produce a coupled ITO mutual performance monitoring and backup behavior score and manual ITO mutual performance monitoring for each cockpit flight crew. The following data analysis shows the mutual performance monitoring and backup behavior scores by each research objective and independent variable. An alpha of .05 was used for all statistical tests.

Research Objective Three (RO3)

The purpose of RO3 was to show the relationship between a cockpit flight crew ITO maneuver shared mental model score and observed levels of mutual performance monitoring and backup behaviors during the ITO maneuvers. Since the shared mental model score and ITO mutual performance monitoring and backup behavior scores are quantitative in nature, the researcher used the Pearson's r to assess the linear relationship between the shared mental model score independent variable and coupled and manual ITO mutual performance monitoring and backup behaviors dependent variables (Green & Salkind, 2011). The correlation between cockpit flight crew shared mental model score

and coupled ITO mutual performance monitoring and backup behavior score was not significant, $r(28) = .26, p = .160$. The correlation between cockpit flight crew shared mental model and manual ITO mutual performance monitoring and backup behaviors was not significant, $r(28) = .14, p = .463$. The results indicate that for the 30 cockpit flight crews, there is no relationship between levels of mental model sharedness and observed levels of mutual performance monitoring and backup behaviors during the ITO maneuvers. Higher levels of mental model sharedness of the relatedness of ITO maneuver critical team tasks among cockpit flight crews may reflect in both higher levels and lower levels of coupled and manual ITO mutual performance monitoring and backup behaviors.

Research Objective Four (RO4)

The purpose of RO4 was to compare the type of instrument takeoff (coupled or manual) on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews. The type of ITO serves as the repeated measures design of the study which enabled both pilots of the two-pilot cockpit flight crew to be measured in pilot flying and pilot monitoring roles during the coupled and manual ITOs. It was important to measure mutual performance monitoring and backup behaviors for both the pilot flying and pilot monitoring during the ITO maneuver because in multipiloted cockpits, both pilots provide mutual performance monitoring and backup behaviors to each other simultaneously despite which pilot is actual flying the aircraft. A one sample t test was conducted to compare mutual performance monitoring and backup behaviors between the coupled and manual ITOs. According to Green & Salkind (2011), 30 scores provided a moderate sample size for the statistical test. With alpha level set at

.05, the test was statistically significant, $t(29) = 2.576$, $p < .015$, $M = 6.7$, $SD = 14.24$, indicating that for the 30 cockpit flight crews, mutual performance monitoring and backup behaviors changed between coupled and manual ITOs. Cockpit flight crewmembers show higher levels of mutual performance monitoring and backup behaviors when flying manual ITOs than coupled ITOs. Though both types of ITOs are designed to establish an instrument climbout profile when transitioning to forward flight following overwater hover operations, cockpit flight crews showed higher levels of mutual performance monitoring and backup behaviors when the pilot manually flew the aircraft as opposed to using embedded aircraft systems through cockpit automation. The cockpit flight crews monitored each other, but it is still unclear whether pilot monitoring of cockpit automation and pilot monitoring of the other pilot is similar. The data analysis of RO4 shows that cockpit automation may have affected the level and quality of mutual performance monitoring and backup behaviors between cockpit flight crews.

Research Objective Five (RO5)

The purpose of RO5 was to show the relationship between cockpit flight crew total flight time and observed levels and mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews. Using data collected from both the Shared Mental Model Instruments and the completed Monitoring/Backup Behavior Instruments, a Pearson's r tested the linear relationship between the quantitative variables of cockpit flight crew total flight time and coupled and manual ITO mutual performance monitoring and backup behavior scores. The statistical analysis for RO5 is similar to that found in RO3. The correlation between cockpit flight crew total flight time and coupled ITO mutual performance monitoring/backup behaviors was not significant, $r(28) = -.065$,

$p = .734$, and the correlation between cockpit flight crew total flight time and manual ITO mutual performance monitoring/backup behaviors was not significant, $r(28) = .005$, $p = .979$. The results indicate that for the 30 cockpit flight crews, there is no relationship between the higher levels cockpit flight total flight time and increased levels of mutual performance monitoring and backup behaviors during the coupled and manual ITO maneuvers. Higher cockpit flight crew total flight time did not increase or decrease observed levels of coupled and manual ITO mutual performance monitoring and backup behaviors. Cockpit flight crew total flight time varied from 2005 to 9100 total flight hours, and the coupled and manual ITO mutual performance monitoring and backup behaviors varied in both high and low time flight crews. The results indicate that aviation experience and maturity level, measured in pilot flight time, is not an indicator of potential levels of mutual performance monitoring and backup behaviors.

Research Objective Six (RO6)

The purpose of RO6 was to show the combined interaction effect of the ITO maneuver shared mental model score, ITO type (coupled or manual), and flight crew total flight time on observed levels of mutual performance monitoring and backup behaviors in MH-65 aircraft cockpit flight crews. Since cockpit flight crew shared mental models, cockpit automation, and the experience and maturity of the flight crew exist and are possibly interconnected in Coast Guard MH-65 multipiloted cockpits, a repeated measures ANCOVA was used to determine the combined interaction effect of the study's three independent variables: 1) ITO type (within-subjects nominal variable), 2) shared mental model (SMM) score (interval variable), and 3) flight crew total flight time (interval variable) on the dependent variable of observed mutual performance monitoring

and backup behaviors. The repeated measures design allowed for multiple observations of the ITO type within-subject factor. The between-subject independent variables were the shared mental model score and flight crew total flight time of the participating cockpit flight crews. Typically, in repeated measures analyses, the between-subject independent variables are categorical in nature and represent groupings. Both between-subject independent variables in the study were interval and did not fit the traditional repeated measures model analyses. Researchers argue that categorizing quantitative variables to conform to a particular statistical model or simplify collected data reduces the inherent variability of the measurements and can hide true variable relationships (Seaman & Allen, 2014; Taylor, 2011; B. Johnson, personal communication, October 21, 2014). Therefore, instead of categorizing the interval variables to conform to an ANOVA using repeated measures, both between-subject independent variables were measured as covariates to determine their combined interaction effect on the dependent variable of mutual performance monitoring and backup behaviors.

The statistical assumptions normally associated with ANCOVA, such as equal regression slopes and linear relationship between covariates and the dependent variable, were presumed outside the study's considerations since the ANCOVA statistical methodology was primarily used to preserve the quantitative independent variables as collected (Taylor, 2011). The researcher focused on the combined interaction effect and not the control of the study's quantitative independent variables. The assumption of sphericity was not required since the within-subject effect contained only two levels i.e. coupled and manual (Park, Cho, & Ki, 2009). The researcher measured the strength of the independent relationships using Pearson's correlation coefficient. The linear

relationships were low and not statistically significant ($p > .05$). However, the shared mental model score showed a stronger relationship than flight crew total flight time to the monitoring and backup behaviors.

The repeated measures ANCOVA includes all main effects and interaction effects, and the results indicated no statistically significant interaction of the shared mental model score, cockpit total flight time, and within-subjects effects of ITO type, $F(1, 26) = 1.199, p = .284$. (see Tables 11 and Table 12). The entire repeated measures ANCOVA SPSS output is included for clarification, but the research interest lay in the combined interaction effect of the study's three independent variables of ITO type, shared mental model score, and cockpit total flight time found on Table 11. The results indicate that interconnectedness and existence of cockpit flight crew shared mental models, cockpit automation, and the experience and maturity of the cockpit flight crew did not affect levels of coupled and manual ITO mutual performance monitoring and backup behaviors of Coast Guard cockpit flight crews.

Table 11

Analysis of Covariance Summary of Tests of Within-Subjects Contrasts

Variable	Type III Sum of Squares	df	Mean Square	F	p-value	Partial Eta Squared
ITO Type	208.764	1	208.764	1.998	.169	.071
ITO Type* Cockpit Total Flight Time	61.897	1	61.897	.592	.448	.022
ITO Type*SMM Score	189.157	1	189.157	1.810	.190	.065
ITO Type* SMM Score* Cockpit Total Flight Time	125.269	1	125.269	1.199	.284	.044
Error	2717.297	26	104.511			
Total	3302.384					

Table 12

Analysis of Covariance Summary of Tests of Between-Subjects Effects

Variable	Type III Sum of Squares	<i>df</i>	Mean Square	<i>F</i>	<i>p</i> -value	Partial Eta Squared
Intercept	1272.785	1	1262.785	5.038	.034	.162
Cockpit Total Flight Time	15.550	1	15.550	.062	.805	.002
Share Mental Model (SMM) Score	69.650	1	69.650	.278	.603	.011
SMM Score* Cockpit Total Flight Time	.044	1	.044	.000	.990	<.001
Error	6516.961	26	250.652			
Total	7864.99					

Chapter Summary

The purpose of the study was to examine the effect of the ITO maneuver shared mental model among Coast Guard aircraft cockpit flight crews, ITO type, and cockpit flight crew total flight time on ITO maneuver mutual performance monitoring and backup behaviors. Cockpit flight crews flew ITOs in the MH-65 OFT as part of their Proficiency Simulator Course at ATC Mobile. The ITOs were recorded, and later two CRM SMEs viewed them to judge the levels of ITO maneuver mutual performance monitoring and backup behaviors between the two-pilot flight crew. The results showed no statistically significant main effects or interaction effects of shared mental model score, ITO type, or cockpit flight time. However, the data indicated that cockpit automation, or the lack thereof, influenced cockpit flight crews' levels of mutual performance monitoring and backup behaviors when performing coupled and manual ITOs.

CHAPTER V

SUMMARY

The following chapter is a summary of the study's findings, conclusions, and recommendations. The researcher discusses conclusions and appropriate recommendations based on the data analysis findings while considering the study's limitations. The researcher makes recommendations for future research regarding the role of shared mental models and cockpit automation on mutual performance monitoring and backup behaviors in aircraft cockpits.

Summary of the Study

Aircraft cockpit flight crews use CRM to increase flight safety by strengthening teamwork performance (Aguinis & Kraiger, 2009). Researchers (Flin et al., 2008; O'Conner & O'Dea, 2007; U.S. Coast Guard, 2009b; Wiegmann & Shappell, 2003) suggest that CRM in multipiloted cockpits reduces human error, thereby increasing flight safety. Others (Cook et al., 2004; Dekker, 2002, 2003, 2006; Reason, 2008) argue that flight safety in mutipiloted cockpits increases not by reducing human error but by improving teamwork performance and introducing human elements of resiliency, flexibility, and adaptability into the inherently unsafe sociotechnical aviation system. Resiliency, flexibility, and adaptability among cockpit flight crews represent crew coordination and team processes and are based on the presence of cockpit flight crew shared mental models (Grote et al., 2010; Krieger, 2005; Sperling & Pritchett, 2011). Shared mental models provide the underpinning for mutual performance monitoring and backup behavior decisions among flight crewmembers (Salas, Rosen et al., 2006; Wilson et al., 2007).

The study's literature review shows recent Coast Guard aviation mishaps and the subsequent responses by the Coast Guard for reducing accidents by changing CRM training for cockpit flight crews. However, the Coast Guard's approach to reducing accidents is based on, and promotes, a cause-and-effect linear sequencing view of human error in the cockpit. The cause-and-effect linear sequencing view of human error in the cockpit fails to recognize the complexity of interrelated sociotechnical systems and the role humans play in those systems.

The training of CRM for cockpit flight crews began in the 1970s and continues today in both commercial and military aviation. Coast Guard CRM training for cockpit flight crews began in the early 1990s and continues today, focusing on both cognitive skills (e.g. decision making and situational awareness) and teamwork social skills (e.g. communication and assertiveness). However, research shows that teamwork processes for improving cockpit flight crew coordination rely on a shared cognition represented in shared mental models. Marks et al. (2000), Mathieu et al. (2005), and Mathieu et al. (2000) show shared mental models producing effective mutual performance monitoring and backup behaviors between the cockpit flight crewmembers.

To examine the effect of shared mental models on cockpit flight crew coordination, thirty MH-65 cockpit flight crews were evaluated on mutual performance monitoring and backup behaviors while flying critical night overwater ITOs in the MH-65 Operational Flight Trainer located at ATC Mobile. The researcher examined the relationships and interaction effects of cockpit flight crew shared mental model, cockpit automation, and pilot experience (measured in cockpit total flight time) on observed

levels of mutual performance monitoring and backup behaviors during the coupled and manual ITOs.

Findings, Conclusions, and Recommendations

The following findings and conclusions are from the data collected and subsequent statistical analysis and based on a study's research objectives. Each research objective indicates a specific finding followed by a specific conclusion derived from the finding. A recommendation follows each study finding and conclusion.

Coast Guard Aircraft Cockpit Flight Crews Shared Mental Models

Shared mental models are knowledge structures among team members describing the level of similarity, convergence, agreement, consensus, commonality, compatibility, and consistency of those knowledge structures (Mohammed et al., 2010). In highly dynamic environments of Coast Guard multipiloted cockpits during critical night overwater maneuvers, the shared agreement and consensus of crew mental models were task specific to coupled and manual ITO critical tasks for completing the ITO maneuver.

Finding. Shared mental models exist between Coast Guard MH-65 cockpit flight crews on critical team tasks associated with critical night overwater ITOs. The cockpit flight crew mental model is scoreable representing levels of sharedness regarding the critical team tasks of coupled and manual ITOs. Each MH-65 cockpit flight crew had a shared mental model score level indicating a general agreement by the cockpit flight crews on the levels of relatedness of the seven critical team tasks of the ITO maneuvers. The cockpit flight crews shared mental model scores were seen in both high and low levels of cockpit flight crew aviation experience and maturity.

Conclusion. Shared mental models exist in Coast Guard cockpits and that the level of mental model sharedness between cockpit flight crews is associated with specific cockpit tasks. Consistent with the findings of Marks et al. (2000), Mathieu et al. (2005), and Mathieu et al. (2000), cockpit flight crew mental model sharedness is a quantifiable score that can be determined by surveying cockpit flight crews on the specific cockpit flight crew tasks. A shared mental model among cockpit flight crews is necessary to perform successfully critical low overwater coupled and manual ITO maneuvers in the night environment. Standardized operating procedures and flight crew verbal communication, i.e. pilot briefing, establishes the cockpit flight crew shared mental model for the coupled and manual ITO maneuvers.

Recommendation. All critical flight maneuvers performed in the Coast Guard aircraft by cockpit flight crews, e.g. instrument takeoffs and approaches, visual takeoffs and landings, and nighttime low overwater operations, should have cockpit flight crew standardized operating procedures and preestablished verbal communication. Coast Guard cockpit flight crews should be continuously assessed on the ability to perform the standardized critical flight maneuvers both as the pilot flying and as pilot monitoring.

Coast Guard Aircraft Cockpit Flight Crew Shared Mental Models and Mutual

Performance Monitoring and Backup Behaviors

High-performing teams use shared mental models to anticipate the needs of other team members and provide timely, error-free exchange of information when necessary (Entin & Serfaty, 1999). Cockpit flight crewmembers increase crew coordination and improve flight safety by monitoring each other and providing backup when required. According to Kontogiannis & Malakis (2009) and Potter et al. (2014), mutual

performance monitoring and backup behaviors allow cockpit flight crewmembers to detect mistakes made by other crewmembers and serves as the final defense in cockpit human errors.

Finding. The study's finding did not show statistical significance for the relationship between the higher levels of mental model sharedness and increased levels of mutual performance monitoring and backup behaviors during the ITO maneuvers. The finding indicates cockpit shared mental models can be associated with both high and low levels of mutual performance monitoring and backup behaviors. More specifically, higher levels of mental model sharedness in the cockpit do not necessarily translate into increased levels of mutual performance monitoring and backup behaviors.

Conclusion. Coast Guard cockpit flight crewmembers act and create appropriate mutual performance monitoring and backup behaviors to improve crew coordination, thus producing safer cockpit flight crews regardless of levels of mental model sharedness. Though the purpose of the study was to determine the role of cockpit shared mental models in the team coordination skills of mutual performance monitoring and backup behaviors, the study shows that monitoring and backing up behaviors occur among Coast Guard cockpit flight crewmembers with both low and high levels of mental model sharedness.

Cockpit human error is inevitable in the complex sociotechnical aviation system which is inherently unsafe, and Coast Guard cockpit flight crews create flight safety by monitoring and backup behaviors despite shared mental model agreement levels. The key point here is that flight safety is not improved in Coast Guard multipiloted cockpits by eliminating human error or increasing mental model sharedness, but flight safety is

created when flight crews adapt, through human resiliency and flexibility, and determine proper monitoring and backup responses for a given situation. Furthermore, Coast Guard cockpit flight crews create flight safety by adapting and responding to changing situations in highly complex and hazardous flight environments with appropriate mutual performance monitoring and backup behaviors. Given the results of this study, it is unclear whether shared mental models positively influence or mediate mutual performance monitoring and backup behaviors when cockpit flight crews create flight safety.

Recommendation. Coast Guard aviation leadership should accept that aircraft accidents will continue to occur because of the inevitability of human error in the complex sociotechnical aviation system. Because of the inevitability of human error in Coast Guard cockpits, flight crews need to recognize they are responsible for creating safety in the cockpit through effective team coordination CRM skills of mutual performance monitoring and backup behaviors. Based on the findings of this research and related literature, this author recommends a stronger linkage between backup behaviors and mutual performance monitoring in CRM training for Coast Guard cockpit flight crews. Agreeing with Sumwalt et al. (2003), the researcher also recommends pilot monitoring skills as the next focus for cockpit flight crew CRM training. The training could be associated with flight discipline (i.e. defined crew duties, checklist use, standardized cockpit communication) providing further illumination of cockpit flight crew performances possibly related to mutual performance monitoring and backup behaviors.

Cockpit Automation and Cockpit Flight Crew Mutual Performance Monitoring and Backup Behaviors

Cockpit automation can lead to poor human-monitoring performance (Casner & Schooler, 2014; Comstock & Arnegard, 1992; Davies & Parasuraman, 1982; Dismukes & Berman, 2010). Pilot monitoring behaviors involve scanning and processing of both aircraft automated systems and the actions of the other pilot to determine the allocation of attention resources to areas of need (Potter et al., 2014). However, the management of cockpit automation by cockpit flight crews can be distracting to the point that they fail to monitor each other adequately at a time it's needed the most (Langewiesche, 2014).

Finding. Flight crews exhibited more backup and monitoring behaviors when performing manual ITOs than when performing coupled ITOs. Specifically, pilots increase monitoring/backup behaviors with lower levels of cockpit automation.

Conclusion. Cockpit automation affects the nature and level of mutual performance monitoring and backup behaviors occurring between cockpit flight crewmembers during the ITO maneuvers. Higher levels of cockpit automation leads to lower levels of mutual monitoring performance between cockpit flight crews. The researcher concludes that highly reliable cockpit automated systems lead to lower monitoring performance because of the perceived lower probability of error of the aircraft's automated system. Agreeing with Hamilton (2010), the researcher concludes that as cockpit automation levels increase, the cockpit flight crew workload increases attempting to understand, monitor, and control the automation. If cockpit automation fails, the cockpit workload further increases as pilots attempt to understand the failure and the impact of the failure.

The U.S. Coast Guard (2013) automation pyramid conceptual framework regarding the flight discipline of cockpit automation shows decreasing levels of workload and increasing levels of situational awareness with higher levels of cockpit automation (see Figure 7). The automation pyramid indicates that cockpit automation reduces cockpit workload and shows lower pilot monitoring requirements of cockpit automation and the other pilot. The Coast Guard's automation pyramid also indicates that the situational awareness of cockpit flight crews increases with higher levels of cockpit automation.

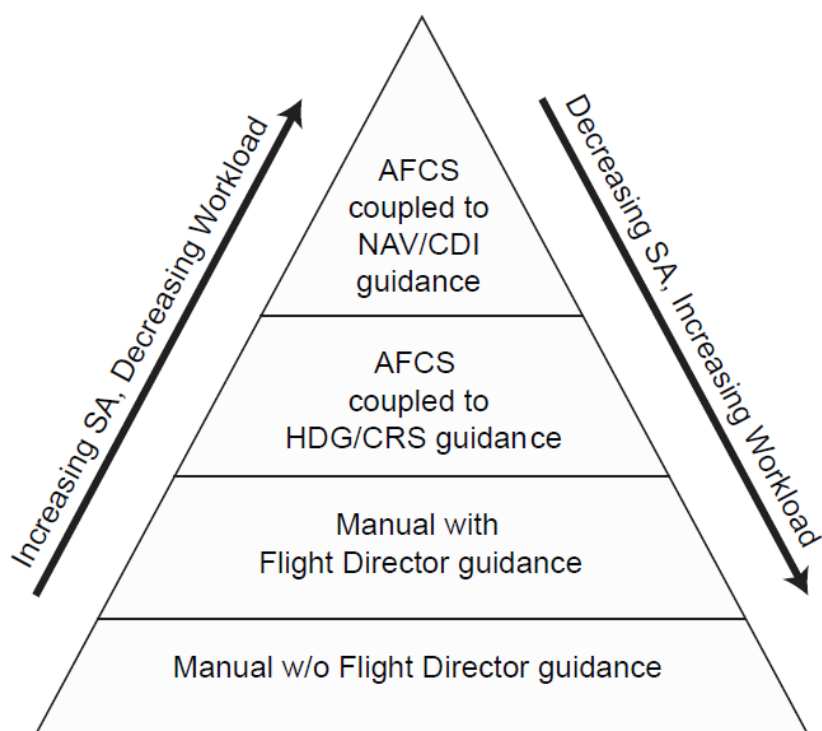


Figure 7. Coast Guard's Automation Pyramid depicting the relationship between situation awareness (SA) cockpit workload with different levels of cockpit automation. Adapted from "U.S. Coast Guard Air Operations Manual, COMDTINST 3710.1G." Washington, DC: Author. p. 4-5. Copyright 2013 by the U.S. Coast Guard. Adapted with permission.

According to Endsley (2010), the benefits of cockpit automation occur when the automated procedure plan aligns with the flight crew's plan. However, when cockpit

automation misaligns with the flight crew's plan, the flight crew becomes "outside-of-the loop" of the automation, in turn reducing the flight crew's situational awareness. The researcher agrees with the situational awareness impacts to cockpit flight crews caused by cockpit automation that Endsley sets forth.

Recommendation. Coast Guard cockpit flight crews need a better understanding of the relationship between cockpit automation and pilot workload and the potential impacts of cockpit automation to mutual performance monitoring and backup behaviors in the cockpit. Coast Guard policy on the use of cockpit automation should properly reflect increases of cockpit flight crew workload and monitoring behavior requirements with higher cockpit automation levels. Coast Guard pilots need to understand that cockpit automation requires the same and possibly increased levels of monitoring and backup behaviors compared to the automated system. Coast Guard CRM training should address the requirement for increased levels of crew coordination, specifically increasing levels of mutual performance monitoring and backup behaviors between the cockpit flight crew flight crew when using cockpit automation. Agreeing with Tesmer (2010), the researcher recommends that cockpit flight crews be taught to treat cockpit automation as the "dumbest crewmember of the flight crew" since the automation is unable to establish the true nature of the cockpit flight crew intent when utilized (p. 293).

Aviation Experience on Cockpit Flight Crew Mutual Performance Monitoring and Backup Behaviors

Team members with more experience working together request and accept more backup from each other, and team member backup behaviors increase with teammates'

familiarity (Smith-Jentsch et al., 2009). In multipiloted cockpits, the type and level of interaction and communication between the pilots is based on experience and maturity level of each pilot (Prince et al., 2010).

Finding. This study's did not show statistical significance for the relationship between the higher levels cockpit flight crew total flight time and increased levels of mutual performance monitoring and backup behaviors during the ITO maneuvers. The finding indicates aviation experience, expressed through pilot total flight time, is associated with both high and low levels of mutual performance monitoring and backup behaviors. In other words, higher total flight time does not necessarily translate into increased levels of mutual performance monitoring and backup behaviors.

Conclusion. Pilots with low aviation experience may perform monitoring and backup behaviors as well as highly experienced pilots, and experienced pilots do not necessarily perform higher levels of mutual performance monitoring and backup behaviors. Coast Guard cockpit flight crews of all aviation experience levels can exhibit appropriate levels of mutual performance monitoring and backup behaviors, implying that the team coordination CRM skills can be learned early in one's aviation career. Agreeing with Tullo (2010), the researcher concludes that mutual performance monitoring and backup behaviors need to be trained, practiced, and evaluated.

Recommendation. Behaviors are learned through observing and modeling of behaviors in others (Ormrod, 1995). The best way to teach mutual performance monitoring and backup behaviors is for an instructor pilot to model the appropriate behavior in the cockpit. Behavior role modeling is an effective tool for modeling mutual

performance monitoring and backup behaviors for Coast Guard cockpit flight crews, and that modeling must occur in the aircraft or OFT to be effective.

Shared Mental Model, Cockpit Automation, and Aviation Experience on Cockpit Crew Mutual Performance Monitoring and Backup Behaviors

Workload in the modern aircraft cockpits is divided into two groups: workload demands from within the cockpit and workload demands from outside the cockpit (Hamilton, 2010). In addition to normal aircraft flight cockpit workload demands, pilots must communicate, monitor, and back up the other pilot in multipiloted aircraft cockpits.

Finding. This study demonstrates no combined interaction effects between a cockpit flight crew shared mental model, cockpit automation, and pilot flight time on mutual performance monitoring and backup behaviors.

Conclusion. The interactions of shared mental models and aviation experience of cockpit flight crews, combined with cockpit automation tasks, have a minimal effect on each other.

Limitations of the Study

According to Sprinthall (2012), statistical research is empirical, inductive, and interpretable. The ability to infer from the study's findings may be diminished by four study limitations. The first limitation to the study is the sample population and size. The population of the study is the 430 Coast Guard pilots who fly the MH-65 aircraft. These pilots are located at Coast Guard units throughout the United States. Short of having all 430 pilots participate in the study, a random sample of study participants from the population would have provided the strongest ability for statistical inference. The researcher chose a convenience sample of MH-65 pilots attending their annual

Proficiency Simulator Course to reduce time and study costs. The Proficiency Simulator Course also allowed the use of the MH-65 Operational Flight Trainer located at ATC Mobile for data collection purposes. The convenience sample introduced a sample error to the study. Creating an abstract population for inferences purposes from a nonprobability sample ultimately reduced the sampling statistical power. Data collection from the 30 cockpit flight crews participating in the study represents 7% of the MH-65 pilot population. The 7% of the MH-65 pilot population fell short of the sample size needed to ensure an acceptable confidence level and corresponding margin of error. Therefore, the study findings may not reflect the shared mental models and monitoring and backup behaviors of the entire MH-65 pilot population.

The second limitation is the study's data collection instruments. The researcher-designed data collection instruments were designed to explore the study's six research objectives. The objective of the Shared Mental Model Instrument was determining the level of mental model sharedness between the MH-65 cockpit flight crewmembers about the seven ITO maneuver critical team tasks and producing a shared mental model score for each cockpit flight crew. Similar to methods found in Marks et al. (2002), Mathieu et al. (2005) and Mathieu et al. (2000), the data collection instrument listed critical team tasks for both cockpit flight crewmembers. The cockpit flight crews were asked to make judgments about the relatedness of the critical team tasks using a 5-point scale to determine the mental model sharedness between the cockpit flight crewmembers. The researcher calculated a shared mental model score by aggregating the combined related values of the Shared Mental Model Instrument of each cockpit flight crew. Conversely, Marks et al. (2002) determined the shared mental model score of a three-person Apache

gunship flight crew by feeding critical team task values into Pathfinder computer program and producing a similarity index. Mathieu et al.'s (2005) shared mental model score was calculated using UCINET network analysis program thereby producing a centrality index. The centrality index identified "network relationships underlying mental models in a fashion similar to...Pathfinder solutions" (Mathieu et al., 2005, p. 43). Marks et al. (2002) and Mathieu et al. (2005) used the computing power of Pathfinder's knowledge structure assessment and UCINET's social network analysis for mathematical shared mental model measurements. A limitation to this study is the shared mental model measurement methodology of manually calculating the shared mental model score (index) instead of using the analytic capabilities of computer software.

The two CRM SMEs observed the recorded coupled and manual ITOs and used the researcher-designed Monitoring/Backup Behavior Instrument to record levels of mutual performance monitoring and backup behaviors among cockpit flight crews. The instrument did not function as originally designed because many of the monitoring and backup behavior markers statements were written based on possible mistakes and procedural errors by the pilot flying and pilot monitoring. When mistakes and procedural errors did not occur, the monitoring and backup behavior marker was unobservable. This discrepancy became apparent to the researcher following university and Coast Guard IRB approval and during cockpit flight crew data collection. Even though additional training was held for the two CRM SMEs to mitigate the instrument discrepancy, a low Pearson's *r* interrater reliability score between the two CRM SMEs for coupled and manual scores possibly occurred as a result of the Monitoring/Backup Behavior Instrument mutual performance monitoring and backup behaviors scoring.

A third limitation is the statistical analysis of the data. The statistical analysis of the three independent variables and one dependent variable was based on the desired outcome of each research objective. Since the research objectives and data collection design drove the statistical tests, the between-subject quantitative variables were left intact and analyzed with a repeated measures ANCOVA. The researcher agrees that disregarding normal ANCOVA statistical assumptions to preserve the quantitative independent variables reduced the study's statistical validity but found disregarding statistical assumptions necessary when using the repeated measures design. Therefore, the shared mental model score and cockpit total flight time were treated as independent interval variables and not true study covariates.

The researcher's place of employment for the study's setting was the fourth limitation and may have influenced the study's results. While all cockpit flight crews asked to participate did so, the environment of the Coast Guard Aviation Training Center and the importance of the pilots' annual Proficiency Simulator Course may have swayed their decision to participate. The esprit de corps of the aviation profession and team nature of the pilot community may have duly impelled individual Coast Guard pilots to participate. Though audio and video recordings of the Proficiency Simulator Course instructional events are standard protocol, the recordings may have altered the interaction of cockpit flight crew and the level monitoring and backup behaviors displayed by the pilots. Pilots may have altered their normal verbal interaction and communication to enhance crew coordination behaviors for the recordings.

Recommendations for Further Research

While the results of the study provide insight into the influence of shared mental models and cockpit automation on cockpit flight crew monitoring and backup behaviors, the potential for further research exists. Based on the study's findings, the following are recommendations for future research:

1. While early attempts of CRM training focused on increasing assertiveness of copilots and reducing dictatorial personalities of pilots in command, today's cockpits are highly automated, and flight crews are normally taught during initial stages of training to work as a team. Flight disciplines such as standard operating procedures for cockpit flight crews, defined crew duties, and the use of cockpit checklist are embedded in today's cockpit team processes. However, research is necessary to clarify the role of shared mental models in team coordination CRM skills of mutual performance monitoring and backup behaviors and their tie to aviation flight discipline practices.
2. The critical CRM skills found in Orlady and Foushee (1987), Helmreich and Foushee (1993), and Prince and Salas (1993) may still be applicable today, but research is necessary to show how to translate those critical CRM skills identified 20 years ago into creating flight safety in today's highly automated cockpits.
3. Aviation CRM training rooted in human error elimination promotes only the cause and effect solution and is normally a result of post-accident aviation investigations fraught with hindsight bias and a cause-consequence human error view (Dekker, 2006). With new views on human error in inherently unsafe

complex systems, further research is necessary to understand humans' contribution to flight safety.

4. The safety data collection program Line Operations Safety Audit is an aviation industry attempt to identify successful CRM skills displayed by cockpit flight crews in the actual operational environment. A Line Operations Safety Audit evaluates cockpit flight crew performance in normal day-to-day operations identifying sociotechnical aviation system issues related to safety (Tesmer, 2010). A Continental Airlines Line Operations Safety Audit showed that cockpit flight crews with good CRM behaviors performed better in the complex sociotechnical aviation system than those with poor CRM behaviors (Tesmer, 2010). Human contribution to flight safety should be further explored through a similar-type analysis. The analysis would further illuminate successful CRM mutual performance monitoring and backup behaviors of frontline pilot professionals operating in the complex sociotechnical aviation system.
5. Other U.S. military services should replicate the current study in other aircraft types using full-mission OFTs. Since all military services of the United States use state-of-the-art full-mission OFTs for all initial and recurrent pilot training, the opportunity for replicating team coordination CRM skills research using full-mission OFTs is abundant.

Conclusion

Aviation CRM is now the most widely used strategy for team coordination training for cockpit flight crews, and it is utilized in the Coast Guard to improve each flight crew's ability to work as a team. The purpose of the study was to examine the

relationships and interaction of the ITO maneuver shared mental model, type of ITO, and cockpit flight crew total flight time on mutual performance monitoring and backup behaviors. Sumwalt et al. (2003) argue that monitoring and backup skills are the next focus of CRM training. The goal of the research is to help Coast Guard aviation leadership find ways to improve flight safety in the Coast Guard cockpits. Because Coast Guard flight crews must continuously operate in a sociotechnical aviation system that is complex, imperfect, ambiguous, and often contradicting, monitoring and backup skills must be the next focus of CRM training for Coast Guard flight crews.

For Coast Guard flight crews to operate effectively in extreme and hazardous environments such as night overwater ITO maneuvers, crews require high levels of coordination. However, instances of failing to monitor and backup are occurring in Coast Guard aircraft accidents. Just telling cockpit flight crews to monitor and backup more is not enough. A better understanding of the role of shared mental models in flight crew team coordination CRM skills of mutual performance monitoring and backup behaviors is necessary. Coast Guard flight crews must take advantage of the multipiloted human redundancy of mutual performance monitoring and backup behaviors.

A success example of cockpit crew flight discipline, shared mental model, pilot monitoring and backup behaviors, and ultimate cockpit team effectiveness is US Airways Flight #1549 emergency water landing in the frigid waters of the Hudson River on January 15, 2009 (Fraher, 2011). Following a bird strike and total failure of both engines, Captain Chesley “Sully” Sullenberger and First Officer Jeffrey Skiles safely glided the damaged commercial aircraft to an emergency water landing, saving all 150 passengers and five crew on board. Six months later, during the NTSB public hearing

regarding the US Air #1549 emergency water landing, Captain Sullenberger stressed the importance of CRM crew coordination monitoring and backup behaviors by saying, "I think it is that paying attention matters. That having awareness constantly matters. Continuing to build that mental model to build a team matters" (Langewiesche, 2009, p. 23). When high-risk situations happen to Coast Guard flight crews operating in the complex sociotechnical aviation system, Coast Guard cockpit flight crews need to be ready to react with high levels of crew coordination, similar to Captain Sullenberger and his crew, and create flight safety with shared mental models and critical monitoring and backup skills. Creating flight safety with monitoring and backup behaviors is the CRM human capital performance outcome that can save the lives of the brave flight crews operating in high-risk environments such as overwater operations at night.

APPENDIX A
FLIGHT MISHAP CLASS COST BREAKDOWN

FISCAL YEAR 2010 and Beyond	
Class A	\$2,000,000 or greater or death
Class B	\$500,000 to \$1,999,999 or serious injury
Class C	\$50,000 to \$499,999 or minor injury
Class D	Less than \$49,999
Class E	Engine damage only, regardless of cost
FISCAL YEAR 2002 to 2009	
Class A	\$1,000,000 or greater or death
Class B	\$200,000 to \$999,999 or serious injury
Class C	\$20,000 to \$199,999 or minor injury
Class D	Less than \$20,000
Class E	Engine damage only, regardless of cost
FISCAL YEAR 1989 to 2001	
Class A	\$1,000,000 or greater or death
Class B	\$200,000 to \$999,999 or serious injury
Class C	\$10,000 to \$199,999 or minor injury
Class D	Less than \$10,000

U.S. Coast Guard. (2010a). *FY10 Aviation Safety Report*. Retrieved from http://www.uscg.mil/hq/cg1/cg113/docs/Safety_Reports/FY10AviationSafetyRpt.pdf

APPENDIX B

SHARED MENTAL MODEL INSTRUMENT

Shared Mental Model Instrument

Your Pilot Designation: _____

Your Total Flight Time: _____

Background: The seven team tasks below are combined actions required by the cockpit flight crew to successfully complete the ITO maneuver. Research suggests that measuring the “relatedness” of each task to the other six tasks, then comparing the relatedness between cockpit crewmembers, helps determine the existence of a crew shared mental model (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005).

Directions: In your opinion, what is the relatedness of each task to the other six tasks? Assign a number from 1 (not related) to 5 (very related) and place in the box associated with each paired tasks. For example, how related are aligning maneuver expectations (Departure Brief) to establishing pre-ITO aircraft configuration?

		Aligning maneuver expectations (Departure Brief)	Establishing pre-ITO aircraft configuration	PAC & SP verbal call outs	Monitoring attitude, airspeed, & altitude	Monitoring FD for proper control inputs	Achieving desired level-off altitude
1	Aligning maneuver expectations (Departure Brief)						
2	Establishing pre-ITO aircraft configuration						
3	PAC & SP verbal call outs						
4	Monitoring attitude, airspeed, & altitude						
5	Monitoring FD for proper control inputs						
6	Achieving desired level-off altitude						
7	Conducting level-off checklist						
		Aligning maneuver expectations (Departure Brief)	Establishing pre-ITO aircraft configuration	PAC & SP verbal call outs	Monitoring attitude, airspeed, & altitude	Monitoring FD for proper control inputs	Achieving desired level-off altitude

APPENDIX C

COMPLETED SHARED MENTAL MODEL INSTRUMENT EXAMPLE

Shared Mental Model Instrument

Your Pilot Designation: ACYour Total Flight Time: 2000

Background: The seven team tasks below are combined actions required by the cockpit flight crew to successfully complete the ITO maneuver. Research suggests that measuring the "relatedness" of each task to the other six tasks, then comparing the relatedness between cockpit crewmembers, helps determine the existence of a crew shared mental model (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005).

Directions: In your opinion, what is the relatedness of each task to the other six tasks? Assign a number from 1 (not related) to 5 (very related) and place in the box associated with each paired tasks. For example, how related are aligning maneuver expectations (Departure Brief) to establishing pre-ITO aircraft configuration?

		Aligning maneuver expectations (Departure Brief)	Establishing pre-ITO aircraft configuration	PAC & SP verbal call outs	Monitoring attitude, airspeed, & altitude	Monitoring FD for proper control inputs	Achieving desired level-off altitude
1	Aligning maneuver expectations (Departure Brief)						
2	Establishing pre-ITO aircraft configuration	3					
3	PAC & SP verbal call outs	4	3				
4	Monitoring attitude, airspeed, & altitude	4	3	5			
5	Monitoring FD for proper control inputs	3	3	4	5		
6	Achieving desired level-off altitude	3	3	3	3	4	
7	Conducting level-off checklist	3	3	4	5	4	3
		Aligning maneuver expectations (Departure Brief)	Establishing pre-ITO aircraft configuration	PAC & SP verbal call outs	Monitoring attitude, airspeed, & altitude	Monitoring FD for proper control inputs	Achieving desired level-off altitude

APPENDIX D

MONITORING/BACKUP BEHAVIOR INSTRUMENT

Mutual Performance Monitoring Behaviors

1. The cockpit flight crew observed the behaviors and actions of each other.

(1) Not at all (2) (3) (4) (5) To a very great extent

2. The cockpit flight crew recognized aircraft flight control mistakes made by the PAC.

(1) Not at all (2) (3) (4) (5) To a very great extent

3. The cockpit flight crew recognized safety pilot/mutual performance monitoring mistakes made by the SP.

(1) Not at all (2) (3) (4) (5) To a very great extent

4. The SP identified lapses in PAC ITO procedural steps.

(1) Not at all (2) (3) (4) (5) To a very great extent

5. The PAC identified lapses in SP ITO procedural steps.

(1) Not at all (2) (3) (4) (5) To a very great extent

Backup Behaviors

6. The SP corrected PAC errors when necessary or when asked to do so

(1) Not at all (2) (3) (4) (5) To a very great extent

7. The PAC corrected SP errors when necessary or when asked to do so.

(1) Not at all (2) (3) (4) (5) To a very great extent

8. The SP completed ITO procedural tasks when the PAC failed to do so.

(1) Not at all (2) (3) (4) (5) To a very great extent

9. The PAC completed ITO procedural tasks when the SP failed to do so.

(1) Not at all (2) (3) (4) (5) To a very great extent

10. The cockpit crew recognized when the ITO was performed exceptionally well.

(1) Not at all (2) (3) (4) (5) To a very great extent

APPENDIX E

FOUR ITO MANEUVER LATIN SQUARE DESIGN

Design 1	
Left Seat Pilot	Right Seat Pilot
Coupled ITO	Safety Pilot
Safety Pilot	Manual ITO
Manual ITO	Safety Pilot
Safety Pilot	Coupled ITO
Design 2	
Left Seat Pilot	Right Seat Pilot
Safety Pilot	Manual ITO
Manual ITO	Safety Pilot
Safety Pilot	Coupled ITO
Coupled ITO	Safety Pilot
Design 3	
Left Seat Pilot	Right Seat Pilot
Manual ITO	Safety Pilot
Safety Pilot	Coupled ITO
Coupled ITO	Safety Pilot
Safety Pilot	Manual ITO
Design 4	
Left Seat Pilot	Right Seat Pilot
Safety Pilot	Coupled ITO
Coupled ITO	Safety Pilot
Safety Pilot	Manual ITO
Manual ITO	Safety Pilot

APPENDIX F

INSTITUTIONAL REVIEW BOARD NOTICE OF COMMITTEE ACTION

**INSTITUTIONAL REVIEW BOARD**

118 College Drive #5147 | Hattiesburg, MS 39406-0001

Phone: 601.266.5997 | Fax: 601.266.4377 | www.usm.edu/research/institutional-review-board**NOTICE OF COMMITTEE ACTION**

The project has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the "Adverse Effect Report Form".
- If approved, the maximum period of approval is limited to twelve months.
Projects that exceed this period must submit an application for renewal or continuation.

PROTOCOL NUMBER: 14050101

PROJECT TITLE: **The Role of Shared Mental Models in Team Coordination Crew Resource Management (CRM) Skills of Mutual Performance Monitoring and Backup Behaviors**PROJECT TYPE: **New Project**RESEARCHER(S): **Alan R. Martinez**COLLEGE/DIVISION: **College of Science and Technology**DEPARTMENT: **Human Capital Development**FUNDING AGENCY/SPONSOR: **N/A**IRB COMMITTEE ACTION: **Exempt Review Approval**PERIOD OF APPROVAL: **05/19/2014 to 05/18/2015**

Lawrence A. Hosman, Ph.D.
Institutional Review Board

APPENDIX G

U.S. COAST GUARD INSTITUTIONAL REVIEW BOARD APPROVAL



Commandant
United States Coast Guard

2703 Martin Luther King Jr. Ave. SE
STOP 7902
Washington, DC 20593-7902
Staff Symbol: CG-113
Phone: (202) 475-5182
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MEMORANDUM

JUN 16 2014

6500
16 Jun 2014

From: *Carlos A. Comperatore*
Carlos A. Comperatore, Ph.D.
Chair, Coast Guard Institutional Review Board

Reply to
Attn of:
Ms. Pik Kwan Ng
202.475.5204

To: Mr. Alan Martinez
USCG ATC Mobile

Subj: THE ROLE OF SHARED MENTAL MODELS IN TEAM COORDINATION CREW
RESOURCE MANAGEMENT (CRM) SKILLS OF MUTUAL PERFORMANCE
MONITORING AND BACKUP BEHAVIORS

Ref: (a) Title 45 CFR 46 – Protection of Human Subjects
(b) Coast Guard Human Research Protection Program, COMDTISNT M6500.1 (Series)

- 1) The Coast Guard Institutional Review Board (CGIRB) completed an expedited review of the subject protocol pursuant to reference (a) and (b).
- 2) The CGIRB recognizes the authority of the University of Southern Mississippi Institutional Review Board as having primary oversight of this study.
- 3) Exemption from further CGIRB oversight is granted with the understanding that no further changes or additions will be made to the study procedures, data collection instruments, and/or investigators involved in the conduct of this research. Any changes shall be submitted to the CGIRB for review and approval prior to beginning or continuing data collection.
- 4) Any unanticipated problems related to your use of human subjects in this protocol must be promptly reported to the CGIRB through its coordinator, Ms. Pik Kwan Ng.
- 5) Please notify the CGIRB coordinator upon completion of the study. Should you have any questions or concerns, do not hesitate to contact Ms. Ng via email at Pik.K.Ng@uscg.mil.

#

APPENDIX H
INFORMED CONSENT FORM



INSTITUTIONAL REVIEW BOARD
LONG FORM CONSENT

LONG FORM CONSENT PROCEDURES

This completed document must be signed by each potential research participant.

- The Project Information section of this form should be completed by the Principal Investigator before submitting this form for IRB approval.
- Signed copies of the long form consent should be provided to all participants.

Last Edited May 14th, 2014

Today's date:		
PROJECT INFORMATION		
Project Title: The Role of Shared Mental Models In Team Coordination Crew Resource Management (CRM) Skills of Mutual Performance Monitoring and Backup Behaviors		
Principal Investigator: Alan R. Martinez	Phone: (251) 544-7429	Email: alan.r.martinez2@uscg.mil
College: Science and Technology, Gulf Coast Campus	Department: Human Capital Development	
RESEARCH DESCRIPTION		
<p>1. Purpose:</p> <p>The purpose of this research is to explore the role of shared mental models and their effect on team coordination crew resource management (CRM) skills of mutual performance monitoring and backup behaviors. Interim Change 5 of the H-65 Aircraft Flight Manual released in April of 2013 updates the procedures for critical phases of low overwater helicopter operations. Change 5 specifically defined Pilot at Controls (PAC) and Safety Pilot (SP) responsibilities during coupled and manual instrument takeoff (ITOs). The goal of the updated ITO procedures is to increase cockpit flight crew effectiveness by establishing standard pilot flying (PF) actions and pilot monitoring (PM) verbal calls and actions during ITO maneuvers. Change 5 also includes a specific reference to cockpit flight crew shared mental models with the following statement: "Following the completion of hover operations, the PAC shall give a departure brief prior to commencing a coupled or manual ITO to ensure a shared mental model amongst all crewmembers" (MH-65 Aircraft Flight Manual, Page 2-19). Currently, the value and influence of flight crew shared mental models in Coast Guard cockpits and their role in mutual performance monitoring and backup behaviors is unclear. The results of this study can lead to a better understanding of cockpit flight crew CRM team coordination skills and possibly help further define Coast Guard CRM.</p> <p>2. Description of Study:</p> <p>The study's first data collection step involves determining the "sharedness" of a cockpit flight crew mental model using the Shared Mental Model Instrument. Derived from a team task analysis conducted by the researcher, the Shared Mental Model Instrument contains critical ITO maneuver team performances. Pilot participants will individually judge the relatedness of the critical ITO maneuver team performances. The researcher will then compare the two Shared Mental Model Instruments of a MH-65 Proficiency Simulator Course cockpit flight crew to determine that crew's shared mental model level. The Shared Mental Model Instrument takes approximately fifteen minutes to complete.</p> <p>The next data collection step occurs when H-65 Proficiency Simulator Course cockpit flight crew crews fly coupled and manual ITOs during the Emergency Procedures II event. MH-65 pilots will take turns functioning as Pilot at the Controls (PAC) and Safety Pilot (SP) during the ITOs. The ITO maneuvers will be recorded</p>		

using the Computer-Aided Briefing Station (CABS) for later viewing.

The final data collection step is viewing the recorded ITOs. CRM subject matter experts will observe and judge the flight crew coordination during the ITOs and complete one Monitoring/Backup Behaviors Instrument for the cockpit flight crew coupled ITOs and one Monitoring/Backup Behaviors Instrument for the manual ITOs.

The data recorded in the Shared Mental Model Instruments and Monitoring/Backup Behaviors Instruments will be statistically analyzed.

3. Benefits:

There are no monetary benefits to the participants associated with this study. Participating, or not participating, in the study does not affect MH-65 Proficiency Simulator Course performance evaluations. If you participate, you can withdraw at any time from the study with no negative consequences.

4. Risks:

There is the possibility that through other course documents, such as the daily flight schedule, weekly training schedule, and CABS recording voice identification could identify your involvement in this study. As a result, one possible risk is that others will know that you have participated in the study, and confidentiality may be compromised. The only inconvenience to participating pilots is completing the Shared Mental Model Instrument. Other human subject data collection efforts occur within the normal MH-65 Proficiency Simulator Course structure and should transparent to participating pilots.

5. Confidentiality:

The data collection methods used in this study is designed to provide the highest level confidentiality. You and the pilot you are paired with during your MH-65 Proficiency Simulator Course will remain anonymous in data collection procedures and referred to as Flight Crew #1, Flight Crew #2, etc. At no time will your name appear on the Shared Mental Model Instrument or Monitoring/Backup Behaviors Instrument for tracking purposes. However, there is a chance that other course documents, such as the daily flight schedule, weekly training schedule, and CABS recording voice identification could identify your involvement.

The recording of the Operational Flight Trainer Emergency Procedures II training event is in accordance with standard ATC Mobile debriefing protocol. The coupled and manual ITOs during the Emergency Procedures II training event will be specifically labeled Flight Crew #1, Flight Crew #2, etc. In order to associate those ITOs with the proper Shared Mental Model Instrument and Monitoring/Backup Behaviors Instruments.

The coupled and manual ITOs recorded during the Emergency Procedures II training event will be deleted 60 days after the completion of the study. The completed Shared Mental Model Instruments and Monitoring/Backup Behaviors Instruments will also be deleted 60 days after the completion of the study.

6. Alternative Procedures:

No alternative procedures required.

7. Participant's Assurance:

This project has been reviewed by the Institutional Review Board, which ensures that research projects involving human subjects follow federal regulations.

Any questions or concerns about rights as a research participant should be directed to the Manager of the IRB at 601-266-5997. Participation in this project is completely voluntary, and participants may withdraw from this study at any time without penalty, prejudice, or loss of benefits.

Any questions about the research should be directed to the Principal Investigator using the contact

Information provided in Project Information Section above.	
CONSENT TO PARTICIPATE IN RESEARCH	
Participant's Name: _____	
<p>Consent is hereby given to participate in this research project. All procedures and/or investigations to be followed and their purpose, including any experimental procedures, were explained. Information was given about all benefits, risks, inconveniences, or discomforts that might be expected.</p> <p>The opportunity to ask questions regarding the research and procedures was given. Participation in the project is completely voluntary, and participants may withdraw at any time without penalty, prejudice, or loss of benefits. All personal information is strictly confidential, and no names will be disclosed. Any new information that develops during the project will be provided if that information may affect the willingness to continue participation in the project.</p> <p>Questions concerning the research, at any time during or after the project, should be directed to the Principal Investigator with the contact information provided above. This project and this consent form have been reviewed by the Institutional Review Board, which ensures that research projects involving human subjects follow federal regulations. Any questions or concerns about rights as a research participant should be directed to the Chair of the Institutional Review Board, The University of Southern Mississippi, 118 College Drive #5147, Hattiesburg, MS 39406-0001, (601) 266-5997.</p>	
_____	_____
Research Participant	Person Explaining the Study
_____	_____
Date	Date

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