

A System Theoretic Safety Analysis of U.S. Coast Guard Aviation Mishap involving CG-6505

by

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Abstract

During a 22-month period, between 2008 and 2010, the U.S. Coast Guard experienced seven Class-A aviation mishaps resulting in the loss of 14 Coast Guard aviators and seven Coast Guard aircraft. This represents the highest Class-A aviation mishap rate the Coast Guard has experienced in 30 years. Following each Class-A mishap, the Coast Guard conducted Mishap Analysis Boards (MAB) in accordance with Coast Guard aviation policy. A MAB involves a detailed investigation and report on the causal and contributing factors of a specific mishap and is conducted in accordance with the Department of Defense Human Factors Analysis and Classification System (DOD HFACS) which is based on the ‘Swiss Cheese’ accident causal analysis model. Individual MAB results did not identify common causal or contributing factors that may be causing systemic failures within the aviation safety system. Subsequently, the Coast Guard completed a more system-focused safety analysis known as the Aviation Safety Assessment Action Plan (ASAAP) comprised of five components: 1) Operational Hazard Analysis; 2) Aviation Safety Survey; 3) Aviation Leadership Improvement Study; 4) Independent Data Analysis Study; and 5) Industry Benchmarking Study. ASAAP recently concluded “complacency in the cockpit and chain of command as the leading environmental factor in the rash of serious aviation mishaps.” Although the ASAAP study examined Coast Guard aviation more holistically than individual MABs, it did not apply systems theory and systems engineering approaches.

This thesis applies Dr. Leveson’s Systems Theoretic Accident Model and Processes (STAMP) model to identify, evaluate, eliminate, and control system hazards through analysis, design, and management procedures, in order to more fully examine the Coast Guard’s aviation system for potential systemic sources of safety hazards. The case study used in this thesis is the September 2008 mishap, involving a Coast Guard helicopter (CG-6505) conducting hoist training with a Coast Guard small boat, which resulted in the loss of the helicopter and its four-person crew. The analysis identified enhancements to Coast Guard aviation system controls that were not expressly identified as part of the MAB and ASAAP study. These findings will complement the Coast Guard’s MAB and ASAAP results to better understand and eliminate systemic Coast Guard aviation safety hazards with the aim of preventing future mishaps. Finally, by comparing the results of the STAMP analysis and the MAB, this thesis attempts to answer the question, ‘is the STAMP model better than the ‘Swiss Cheese’ model in identifying causes to the accidents?’

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Executive Summary of Findings

On September 4, 2008, a Coast Guard HH-65 helicopter (CG-6505) and a 47-foot Coast Guard small boat (CG-47317), both stationed near Honolulu, Hawaii, were conducting hoisting training at approximately 8 p.m. local time when the helicopter's hoist became snagged on the small boat's engine room dewatering standpipe. The helicopter eventually crashed and all four people on board (pilot, co-pilot, flight mechanic, and crewman) were killed. Per standard procedures and policy, the Coast Guard performed a detailed investigation (Mishap Analysis Board (MAB)) of the CG-6505 mishap which detailed accident causes, contributing factors, and recommendations to address these issues.

In order to more fully examine the Coast Guard's aviation system for potential sources of safety hazards, this thesis performs a Causal Analysis based on STAMP (CAST) on the CG-6505 mishap. The findings of this CAST analysis identified several inadequacies with respect to control/feedback within the Coast Guard's Aviation System which contributed to the hazards that led to the CG-6505 mishap. Furthermore, this CAST analysis includes multiple recommended enhancements to the Coast Guard aviation system that were not expressly identified as part of the Coast Guard's aforementioned MAB and subsequent system-wide assessment (Aviation Safety Assessment Action Plan (ASAAP)). These findings, summarized below, are meant to augment the Coast Guard's MAB and ASAAP results to more fully understand and eliminate systemic Coast Guard aviation safety hazards with the aim of preventing future mishaps.

- Additional warning signals to assist pilots in positioning the aircraft at a safe distance above receiving platforms (e.g., small boat) during night missions. – Considering the risk/routine nature of pilot overcontrol/overtorque during nighttime hoisting operations, the Coast Guard should take action to review state of the market/art capabilities to provide more information to the pilot/aircrew to reduce the risk of overcontrol/overtorque. This could result in additional sensors/warning indicators to assist the pilot in positioning/holding the aircraft at a safe/stable distance above the receiving platform (e.g., small boat).

- Additional warning signals to alert pilot to snagged hoist condition and additional communications capabilities between air/boat crews – The Coast Guard should take action to add a sensor system to the hoist to inform the pilot/crew when the hoist is entangled and/or overloaded. Additionally, the Coast Guard should pursue acquisition of capabilities or implementation of tactics, techniques, and procedures to enable direct communications between the aircrew and boat crew. Both of these steps will improve the aircrew’s ability to detect hoist entanglements and quickly implement “hoist fouled/damaged” emergency procedures.
- Enhanced hoist training - Considering the high-risk nature of night time hoisting operations, the Coast Guard should consider adding night time hoisting operations, including fouling (entanglement) procedures, to its simulator training curriculum.
- Improved reporting of standardization visit and Search and Rescue (SAR) check results - To improve accountability and transparency (e.g., control and feedback), it is recommended that the Coast Guard require the Pilots Under Instruction (PUIs), and the PUI’s Operations Officer’s and Commanding Officer’s, in addition to the Aviation Training Center Instructor Pilot’s signature on the Procedures Checklist form.
- Enhanced standardized ditching training – The Coast Guard should include ditching procedures as a line-item on the Standardization Visit Procedures Checklist. Additionally, each pilot/air crewman should be required to demonstrate proficiency in executing ditching procedures and making determinations when ditching the aircraft is warranted.
- Increased emphasis on paramount importance of life safety over preservation of aircraft – To address gaps in current ditching capabilities and cultural barriers to ditching, the Coast Guard should take the following actions:
 - Improve HH-65 capabilities (e.g., additional lighting) to enable safe nighttime ditching.
 - Modify training, doctrine, and policy (e.g., Coast Guard Air Operations Manual) to more clearly emphasize crew safety over aircraft preservation.
 - In order to improve operational safety and effectiveness, it is recommended that the Coast Guard work with the Department of Homeland Security, Office of

Management and Budget, and Congress to procure an attrition reserve aircraft inventory proportionally similar to that of the other branches of the Armed Forces.

- Implement a Capabilities Management System: To address the general lack of control and feedback in the management of existing capabilities (e.g., HH-65) the Coast Guard should:
 - Develop a database and process to catalogue all of its capabilities at the system (e.g., platform – HH-65, 47-ft MLB) and subsystem (e.g., hoist system, hover lighting, hoist deck, etc.) levels. This Capabilities Catalogue should include details regarding the capability of the system/subsystem and any unfulfilled requirements/gaps documented with respect to system/subsystem inadequacies. Additionally, and perhaps most importantly, considering hazards/accidents occur most often due to component interaction, this database should “tag” interfacing subsystems (e.g., hoist system correlated to 47-foot MLB hoist deck) to more systematically ensure Coast Guard capability managers take a systems view in the execution of their duties.
 - Develop a virtual interactive “capabilities management community” forum where the various entities with capability management responsibilities (e.g., Office of Aviation Forces, Aviation Safety Division, Aviation Training Center, FORCECOM, Acquisition Directorate, and Coast Guard operational units (air stations/sectors/small boat stations)) can “come together” regularly to discuss capability management and operational safety hazard issues. Furthermore, each of these communities should be provided access to populate the Capabilities Catalogue database to assist in identifying capability requirements, gaps, recommendations, interfaces, hazards, etc. Providing a forum for continuous and collaborative discussion and facilitating formal and open communication of capability requirements and gaps via a shared database is expected to spur user-centered innovation and improve communication and coordination of capabilities requirements, in turn improving system safety.
 - Periodically review minor mishaps to identify trends and identify safety-related capability gaps.

- Considering the importance of robust operational capabilities to the Coast Guard's ability to safely and effectively execute its missions, it is recommended that the Coast Guard hold itself accountable to the prescribed annual Operational Analysis process and shift oversight from the Office of Management and Budget, the Department of Homeland Security, and the Coast Guard Acquisition Directorate to an entity with the Coast Guard Office of Aviation Forces' chain of command.
- Increased sponsor/user involvement in major system design/development/sustainment: During the design and development of new capabilities or major upgrades and analysis of existing capabilities, the project sponsor (e.g., Office of Aviation Forces) and the user group (e.g., aviation operators) should be heavily involved. This involvement should extend beyond the specific platform manager/user base to include platform managers/users from other similar capabilities and interfacing capabilities. For example, rather than limiting involvement in the HH-65 modernization program to just the HH-65 platform manager and HH-65 operators, representatives from the HH-60 community and Small Boat Forces community should also be involved.
- Increased industry involvement in major system sustainment: Similarly, the Coast Guard should increase industry involvement during major modernization programs and demonstrations (e.g., Operational Analysis) of existing capabilities to ensure appropriate state of the market technologies and industry best practices are adopted at the sub-system level. This could be done by including a panel of industry representatives to observe/advise during Operational Analyses and Program Implementation Reviews.
- Enhanced/standardized Crew Resource Management/Operational Risk Management training: Considering the recurring nature of inadequate Crew Resource Management and Operational Risk Management in Coast Guard aviation mishaps, the Coast Guard should take action to more systemically address inadequacies in these programs. Crew Resource Management training should be standardized across the Coast Guard and be included in annual Aviation Training Center Standardization Visits and the Division of Aviation Safety's (CG-1131) Safety Standardization Visits. Unit level training should comply with standardized training procedures. Furthermore, it is recommended that the Coast Guard leverage the establishment of FORCECOM to develop a Coast Guard-wide

standardized Crew Resource Management and Operational Risk Management readiness program to better deliver training and improve Service-wide proficiency in these critical operational skill sets. Establishing a centrally managed, standardized program overseen by experts in training development and delivery will raise leadership awareness, heighten priority, and improve the effectiveness of these programs. Finally, rather than approaching Operational Risk Management from purely a general approach, the Aviation Safety Division should catalogue specific risks and mitigating tactics, techniques, and procedures associated with specific routine and emergency operations and capabilities. Used in conjunction with the previously recommended cataloguing of system capabilities and associated gaps, these two databases could be powerful tools in identifying operational hazards and associated mitigation strategies.

Chapter 1: Introduction

During the past several years, the U.S. Coast Guard has experienced an alarmingly high mishap rate in its aviation program. In addition to conducting its standard event-chain based investigations following each major mishap, the Coast Guard completed a broader, system-wide investigation in an attempt to identify common causal and contributing system factors. While these efforts identified several causal and contributing factors, they did not take a systems approach to safety. The purpose of this thesis is to apply a systems theory and systems engineering approach – Systems Theoretic Accident Model and Processes (STAMP) - to accident causality in order to identify, evaluate, eliminate, and control the system hazards that are causing/contributing to this unprecedented major mishap rate.

Motivation

During a 22-month period, between 2008 and 2010, the U.S. Coast Guard experienced seven Class-A aviation mishaps¹ resulting in the loss of 14 Coast Guard aviators and seven Coast Guard aircraft. This represents the highest Class-A aviation mishap rate the Coast Guard has experienced in 30 years [28]. Following each Class-A mishap, the Coast Guard conducted Mishap Analysis Boards (MAB) in accordance with Coast Guard aviation policy [30]. A MAB involves a detailed investigation and report on the causal and contributing factors of a specific mishap and is conducted in accordance with the Department of Defense Human Factors Analysis and Classification System (DOD HFACS) which is based on the ‘Swiss Cheese’ accident causal analysis model [10]. Individual MAB results did not identify common causal or contributing factors that may be causing systemic failures within the aviation safety system. Subsequently, the Coast Guard completed a more system-based safety analysis known as the Aviation Safety Assessment Action Plan (ASAAP) comprised of five components: 1) Operational Hazard Analysis; 2) Aviation Safety Survey; 3) Aviation Leadership Improvement Study; 4) Independent Data Analysis Study; and 5) Industry Benchmarking Study. ASAAP recently concluded “complacency in the cockpit and chain of command as the leading environmental factor in the rash of serious aviation mishaps.” [24]. Although the ASAAP study examined

¹ A Class-A Mishap is the most severe level of mishap in the Coast Guard, resulting in either fatality or permanent disability of personnel, or \$1 million in damage or loss of a Coast Guard asset (Coast Guard Safety and Environmental Health Manual, 2007)

Coast Guard aviation more holistically than individual MABs, it did not apply a systems theory/systems engineering approach.

What is perhaps most alarming about these seven major mishaps is that all but one occurred during either training or non-operational transit rather than during a Search and Rescue or other Coast Guard operations which are frequently conducted under harrowing conditions/circumstances. Although, following the period of increased Coast Guard aviation mishaps the Coast Guard aviation program was major mishap free for over 18 months, aviation safety remains a critical issue for the Coast Guard from both a mission performance and resource management perspective. For example, just recently, on February 28, 2012, the Coast Guard incurred another Class A mishap when a HH-65 helicopter (CG-6535) crashed into Mobile Bay, AL, killing all four Coast Guard members on board [3]. Because the Coast Guard is still conducting its formal investigation, not many details regarding the specific causes of the accident have been released to the public at the time of this writing, however, the Coast Guard has confirmed that the aircraft, “had departed the Aviation Training Center in Mobile on a training mission.” [2].

The Coast Guard’s loss of eight aircraft due to training/transit-related mishaps over a period of 3.5 years results in a 6% reduction in rotary wing fleet size. Considering the Coast Guard does not maintain an attrition reserve inventory, these losses directly translate to reduced Coast Guard operational capacity (e.g., Coast Guard is unable to meet mission requirements). More importantly, these mishaps have tragically and unnecessarily taken the lives of 18 Coast Guard members. Continued adverse impacts to Coast Guard mission capacity and loss of life of Coast Guardsmen as witnessed over the last few years is unsustainable in terms of Coast Guard mission execution and the health and safety of the Coast Guard aviation community.

Although the Coast Guard has completed detailed investigations into each accident, identified several causal and contributing factors and implemented associated recommended actions to reduce hazards, major mishaps continue to occur. *The main goal of this thesis is to perform a STAMP analysis on a Coast Guard aviation mishap to identify, evaluate, eliminate, and control system hazards through analysis, design, and management procedures employed by the Coast*

Guard as part of the performance of their aviation missions in order to improve Coast Guard aviation safety. The case study used in this thesis is the September 2008 mishap, involving a Coast Guard helicopter (CG-6505) conducting hoist training with a Coast Guard small boat, which resulted in the loss of the helicopter and its four-person crew. The analysis identified enhancements to Coast Guard aviation system controls that were not expressly identified as part of the MAB and ASAAP study. These findings will complement the Coast Guard's MAB and ASAAP results to better understand and eliminate systemic Coast Guard aviation safety hazards with the aim of preventing future mishaps.

Research Question

As with all major aviation mishaps, following the CG-6505 accident on September 4, 2008, in accordance with Coast Guard aviation safety policy [8], the Coast Guard completed a MAB to investigate the causality of the accident. The Coast Guard conducts MABs in accordance with the DOD HFACS, which is built upon James Reason's 'Swiss Cheese' causality model and concept of active failures and latent failure/conditions [8, 10, 21]. In most traditional causality models including the 'Swiss Cheese' model, accidents are considered to be caused by chains of failure events, each failure directly causing the next one in the chain [15]. While the DOD HFACS goes beyond simply investigating causes of the proximate events leading to an accident, it is still an event chain-based model, which assumes accidents occur when unlikely events randomly coincide to result in hazardous conditions. Furthermore, the 'Swiss Cheese' model presents causality in a linear fashion, lending to operator blame and linear probabilistic risk assessment, which often results in an understated risk picture. The concern is that this perspective on accident causality fails to recognize the migration of systems over time to states of high risk due to organizational factors, and/or engineering and management decisions that stem from common cause systemic factors (e.g., cost cutting measures, poor safety culture, complacency, system design flaws, etc.).

Conversely, the STAMP method is based on systems theory and expands accident analysis beyond proximal events, component failures, and human errors. It provides a more systematic way to model accidents through a structured step-by-step process that involves modeling the entire system in the form of a hierarchical structure and then analyzing control loops within that

structure. Through this approach the STAMP method enables identification of what went wrong with the system's development, operation, or organization that prevented proper control of external disturbances, component failures, or dysfunctional interactions among system components.

By comparing the results of this STAMP analysis and the CG-6505 MAB, this thesis attempts to answer the question, 'is the STAMP model better than the 'Swiss Cheese' model in identifying causes to the accidents?'

Organization

This thesis report begins with a literature review of various accident causality models. Specifically, Chapter 2 includes a brief explanation of traditional event chain-based causality models and associated shortcomings, an overview of James Reason's 'Swiss Cheese' model and associated limitations, a discussion regarding the Coast Guard's MAB process which is based on the 'Swiss Cheese' model, an overview of system-based approaches to accident causality, a detailed description of STAMP, and a step-by-step explanation of the STAMP-based accident causality model (CAST). Chapter 3 provides a summary of the proximal event chain of events leading up to and including the mishap of CG-6505 based on the Coast Guard's MAB. An overview of the Coast Guard's CG-6505 MAB findings, including causal factors, contributing factors, and recommendations, is included in Chapter 4. Chapter 5, the heart of this thesis, provides a full CAST analysis of the CG-6505 mishap, including identification of system hazards and safety constraints, development of the hierarchical safety control structure, in-depth analysis of the control/feedback loops throughout the structure, and recommendations to improve the Coast Guard's aviation system. A detailed comparison of CAST and MAB findings is provided in Chapter 6. The thesis concludes with Chapter 7, which recommends Coast Guard implementation of the CAST recommendations and adoption of the STAMP/CAST methodology by the Coast Guard.

Chapter 2: Literature Review

This section of this thesis begins with the shortcomings of traditional chain-of-event causality models, including a detailed discussion of James Reason’s ‘Swiss Cheese’ accident causality model. Then systems theory and System Theoretic Accident Modeling and Process (STAMP)—a new accident causality model [18] is discussed. Next, an explanation regarding why it is appropriate to apply CAST (Causal Analysis based on STAMP) to a Coast Guard aviation accident in light of Coast Guard safety objectives is provided.

Event Chain-Based Models:

In most traditional causality models, accidents are considered to be caused by chains of failure events, each failure directly causing the next one in the chain [15]. These models explain accidents in terms of multiple events, sequenced as a forward chain over time and almost always involve component failure, human error, or energy-related events [19]. Furthermore, these models generally form the basis for most safety-engineering and reliability engineering analyses, including Fault Tree Analysis (FTA), Probability Risk Assessment (PRA), Event/Decision Trees, and/or Failure Mode Affects and Criticality Analysis (FMECA) [17].

The Trouble with Traditional Event Chain-Based (Non-Systems Approach) Causality Models

According to Dr. Nancy Leveson, there are several reasons why simple event chain-based models are no longer adequate for the more complex socio-technical systems (e.g., Coast Guard aviation system) that are in use today [16]:

- 1) Confusion of reliability with safety – most traditional causality models make the mistake of assuming that safety is increased by increasing system or component reliability. In complex socio-technical systems, component interaction, rather than component failure more often results in a hazardous scenario.
- 2) Event Chain-based Causation – most traditional models develop a chain of directly related events to understand accidents and assess risks. Oftentimes in the case of complex systems, indirect events, inadequate system controls, and/or organizational factors are critical to understanding accidents and associated system safety risks.

- 3) Limitations of Probabilistic Risk Assessment – typically there is a strong desire to quantify risk when conducting safety assessments in conjunction with system design and development. Event chain-based causation involves event trees and chains that lend to probabilistic calculations. However, when dealing with complex socio-technical systems, this is often impossible to do accurately. For example, in a complex system, it is practically impossible to factor in all interfacing and indirect/contributing factors in event chain analysis. Furthermore, event chains often treat initiating events as mutually exclusive, resulting in risk assessments that grossly understate system level risks, especially when considering systems that migrate to an increasingly unsafe condition over time due to systemic factors.
- 4) Role of Operators in Accidents – most event chain-based causation analysis terminates when a human operator is attributed with committing an error, often characterized as non-compliance with a documented process or procedure. These event chain-based analyses often commit hindsight bias – judging a person for what they should have done/not done, failing to obtain a missing a piece of information, and/or estimating the consequences and failing to take action to prevent them – and fail to consider the reasons that caused the operator to commit the “error.”
- 5) Role of Software in Accidents – event chain-based models typically treat software in terms of reliability rather than examining how human, hardware, and environmental interactions with software could result in a hazardous scenario.
- 6) Static Versus Dynamic Views of Systems – most event chain-based models attribute major accidents to the chance simultaneous occurrence of random events. This approach fails to recognize that systems are not static and often, over time, migrate toward a more hazardous state as system safety controls are relaxed/not enforced.

‘Swiss Cheese’ Model Overview

James Reason’s ‘Swiss Cheese’ model is an accident causality model built upon a concept of active failures and latent failures/conditions. According to Reason, active failures are the actions or inactions of operators that are believed to cause the mishap. These are the traditional “errors” that serve as last acts committed by individuals, typically front-line operators (e.g., pilots, control room crews) that often immediately result in accidents. Conversely, according to Reason, latent

failures/conditions are errors that exist within the organization or elsewhere in the supervisory chain of command that affect the sequence of events ultimately resulting in an accident [21].

Reason's 'Swiss Cheese' model describes how active and latent failures/conditions may occur simultaneously within complex operations to create hazardous conditions ultimately resulting in an accident. Therefore, the 'Swiss Cheese' model calls for accident investigation to look beyond active failures to examine latent failures and conditions to better understand causal and contributing factors. That said, whether active or latent, Reason's 'Swiss Cheese' model is principally concerned with human contribution to systems accidents, "because accident analyses reveal that human factors dominate the risks to complex installations. Even what appear at first sight to be simple equipment breakdowns can usually be traced to some prior human failure." [21]. In order to more systematically approach accident causality in terms of both active failures and latent failures/conditions, the 'Swiss Cheese' model categorizes human factor contributions occurring in the following forms, originating from top-level management and propagating through the various layers of a system including line management, operators, and system defenses [21]:

- a. Fallible decisions (latent failures) – erroneous decisions made by top-level managers/designers/management.
- b. Line management deficiencies (latent failures) – line management deficiencies (e.g., training deficiencies) typically resulting from fallible decisions.
- c. Preconditions for unsafe acts (latent failures) – latent states that create the potential for a wide variety of unsafe acts (e.g., failing to wear personal safety equipment).
- d. Unsafe acts (active failures) – an error (slip, lapse, or mistake) or violation committed in the presence of a hazard.
- e. Inadequate defenses (active and latent failures) – Lack of system defenses (e.g., safeguards preventing direct contact with dangerous materials) creating a window of accident opportunity.

Within the "Swiss Cheese" model, and as depicted in Figure 2.1 below, a complex interaction and conjunction of latent failures and unsafe acts creates a trajectory of accident opportunity that penetrates several defensive systems. According to Reason, "the chances of such a trajectory of

opportunity finding loopholes in all of the defenses at any one time is very small indeed.” [21]. As is discussed further below, this is only true if all the failures are independent and occur truly randomly. In the case of systemic causes, failures are not independent, and do not occur randomly.

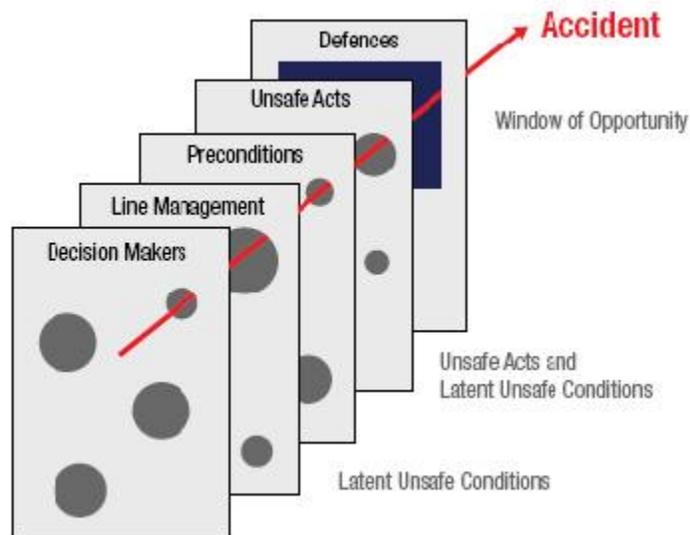


Figure 2.1 Swiss Cheese Model [22]

Limitations of the ‘Swiss Cheese’ Model

While the ‘Swiss Cheese’ model goes beyond simply investigating causes of the proximate events leading to an accident (which is typical of most event chain-based causation analyses), it does have its limitations. For one, it is still an event chain-based model, which assumes accidents occur when unlikely events randomly coincide to result in hazardous conditions. According to Dr. Nancy Leveson, although this is compelling because it is easy to understand, unfortunately it also oversimplifies the causality [18]. In fact, failures resulting from systemic causes are not independent, and do not occur randomly. Furthermore, the ‘Swiss Cheese’ model presents causality in a linear fashion, leading to linear probabilistic risk assessment, which often results in an understated risk picture. For example, Reason states that in general, in the context of the defense in depth provided by multiple layers of Swiss cheese (e.g., barriers), “the chances of such a trajectory of opportunity finding loopholes in all the defenses at any one time is very small indeed.” [21]. This type of thinking can lead to the addition of barrier-type solutions after

completion of initial system design, which often results in significant additional costs and unintended consequences across system interfaces.

This perspective on accident causality fails to recognize the migration of systems over time to states of high risk due to organizational factors, and/or engineering and management decisions that stem from common cause systemic factors (e.g., cost cutting measures, poor safety culture, complacency, system design flaws, etc.). In other words, most accidents in complex systems involve multiple low-probability events occurring in the worst possible combination. The ‘Swiss Cheese’ model presents these as independent (and somewhat linear) events with low probability, leading to the multiplication of these individual probabilities resulting in an egregiously low probability for overall system risk. In reality, the events are dependent and likely related to common systemic factors that do not appear in the event chain [18].

Finally, while the ‘Swiss Cheese’ model provides a taxonomy for characterizing human errors at all levels of the system in question, it is limited to the event chain leading up to the accident. Unlike systems theory-based accident causality models such as STAMP, the ‘Swiss Cheese’ model does not provide a comprehensive, systematic methodology for determining accident causality.

Coast Guard Mishap Analysis Board and DOD HFACS

The Coast Guard’s aviation mishap investigation process (Mishap Analysis Board (MAB)) involves a detailed investigation and report on the causal and contributing factors of a specific mishap and is conducted in accordance with Department of Defense Human Factors Analysis and Classification System (DOD HFACS). The Coast Guard’s MAB process consists of selecting a panel of experts from the Coast Guard’s aviation capabilities, operations, safety, and engineering communities to carry out a causality investigation in accordance with the DOD HFACS process as documented in DOD Instruction (DODI) 6055.7 - Accident Investigation, Reporting, and Record Keeping and the DOD HFACS Guide. The DOD HFACS process is based on James Reason’s ‘Swiss Cheese’ model [8, 10].

According to DOD HFACS, “Analysis indicates that human error is identified as a causal factor in 80 to 90 percent of mishaps, and is present but not causal in another 50 to 60 percent of all mishaps, and is therefore the single greatest mishap hazard. Yet, simply writing off mishaps to "operator error" is a simplistic, if not naïve, approach to mishap causation and hazard identification. Further, it is well established that mishaps are rarely attributed to a single cause, or in most instances, even a single individual. Rather, mishaps are the end result of myriad latent failures or conditions that precede active failures... What makes Reason's model particularly useful in mishap investigation is that it forces investigators to address latent failures and conditions within the causal sequence of events. For instance, latent failures or conditions such as fatigue, complacency, illness, and the physical/technological environment all affect performance but can be overlooked by investigators with even the best of intentions. These particular latent failures and conditions are described within the context of Reason's model as Preconditions for Unsafe Acts.” [10].

Consistent with above, the DOD HFACS requires the MAB investigative team to analyze the incident in terms of four main tiers of failures/conditions:

- a. Acts – factors that are most closely tied to the mishap, and can be described as active failures or actions committed by the operator that result in human error or an unsafe situation.
- b. Preconditions – factors in a mishap such as conditions of the operators, environmental or personnel factors that affect practices, conditions, or actions of individuals and result in human error or an unsafe situation
- c. Supervision – factors that involve the supervisory chain of command that contribute to an accident including inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations.
- d. Organizational Influences – factors in a mishap if the communications, actions, omissions or policies of upper-level management directly or indirectly affect supervisory practices, conditions or actions of the operator(s) and result in system failure, human error or an unsafe situation.

Figure 2.2 provides the DOD HFACS taxonomy of these four failure/condition tiers including sub-categories for each.

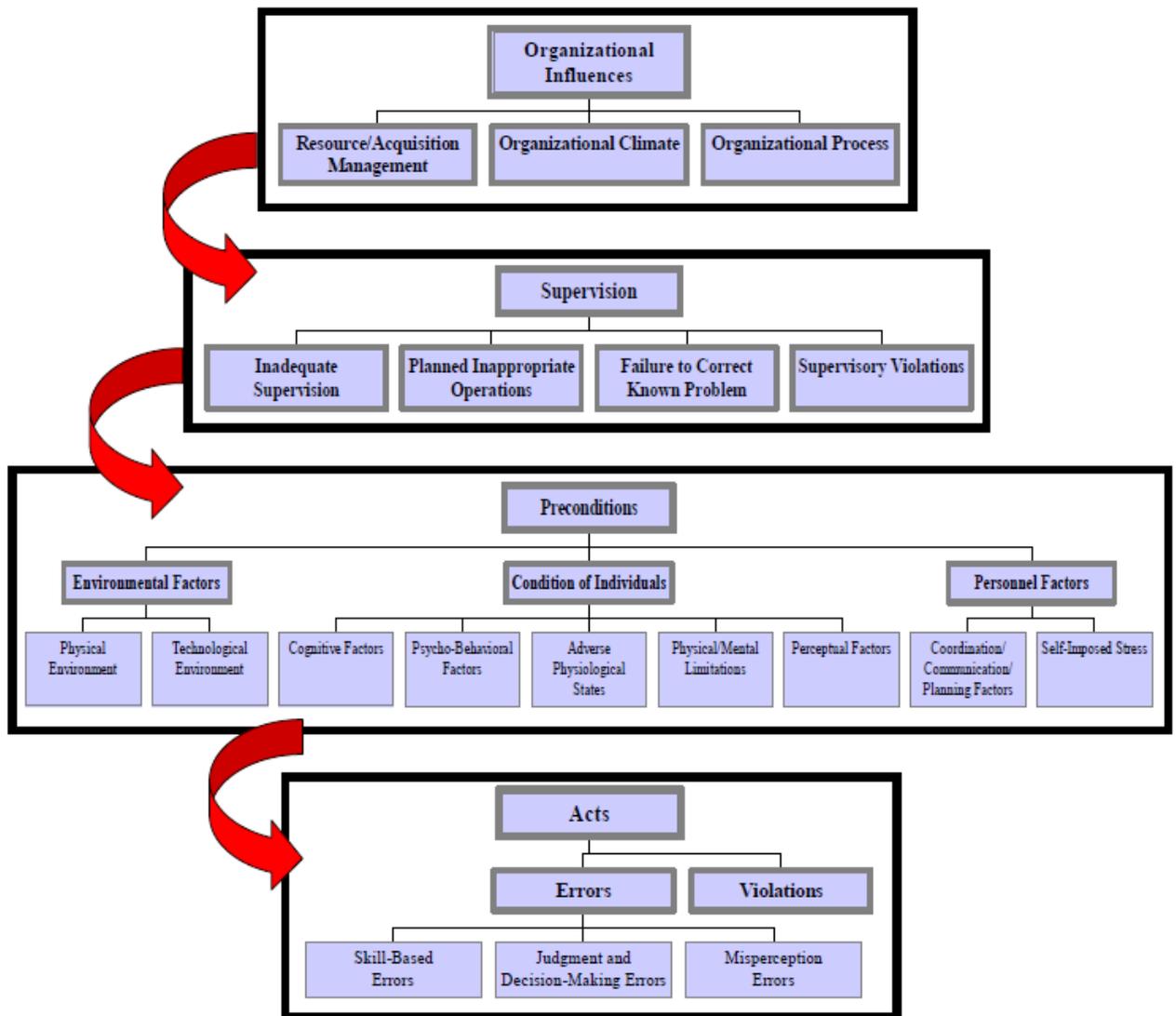


Figure 2.2: DOD HFACS Taxonomy of Failure Modes [10]

The MAB Process:

Per the DOD HFACS, the Coast Guard MAB must gather human factors evidence. To do so, the MAB typically starts with the event outcome and creates a time line documenting each step that leads up to the event. As the MAB probes backwards, it must determine whether a material/equipment event (e.g., part failed) occurred or an individual committed or failed to commit an act that resulted in the outcome event. At each step the MAB must document who

committed the act, then utilize the above taxonomy to further classify the act into one of six possible Skill-Based Errors (e.g., procedural error, over-control), one of six Judgment and Decision-Making Errors (e.g., risk assessment, task misprioritization), Procedural Error (due to misperception), or one of three Violations (e.g., lack of discipline).

Once the MAB has classified the act, it then must look closer to identify the associated latent errors. This is done by evaluating the preconditions that resulted in the unsafe act. To do this, the MAB reviews each of the categories and sub categories in this tier of the DOD HFACS and identifies or eliminates the various preconditions that lead to the act. For example, Figure 2.3 lists the possible preconditions that are related to environmental factors. Per the DOD HFACS, environmental factors are associated with physical (e.g., weather, climate, etc.) and technological (e.g., cockpit design factors, automation) preconditions. Each of the sub-categories listed in Figure 2.3 is defined in the DOD HFACS [10].

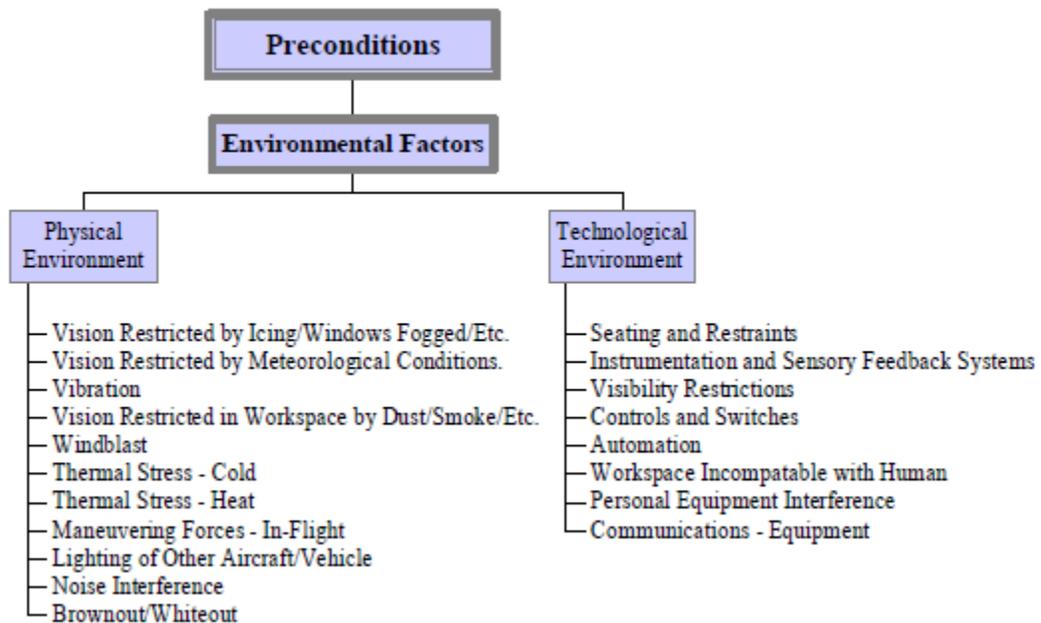


Figure 2.3: DOD HFACS Taxonomy of Preconditions – Environmental Factors [10]

Once the MAB has fully identified and documented all preconditions for the associated act, a similar process is followed for supervisory and organizational failure conditions. An excerpt of

the DOD HFACS guide containing all of the failure conditions and sub-categories is provided in Appendix B.

Systems Approach to Safety

Safety approaches based on systems theory address the aforementioned limitations associated with event chain models by looking beyond simple event chains and considering accidents as arising from the interactions among system components rather than single causal variables or factors [16]. Instead of focusing on unsafe acts, conditions, or component failures, classic system safety approaches apply systems theory and systems engineering principles to examine what went wrong with the system's development, operation, or organization to allow the accident to take place. Systems safety approaches adhere to a set of fundamental systems theory and engineering assumptions and principles [18]:

- 1) Systems can be viewed as hierarchies of components, where components interact to deliver system performance. Each of the lower levels (components) of a system is controlled by upper levels within the hierarchy.
- 2) Some properties of systems, in this case safety, are emergent. That is, safety emerges from the collective interaction of the social and technical system components, including hardware, software, and human interaction. Therefore, in order to adequately examine system safety, it must be viewed in the context of the social and technical system as a whole.
- 3) Individual component behavior (including events or actions) cannot be understood without considering the components' role, interfaces and interaction within the entire system.
- 4) Emergent properties like safety are controlled or enforced by a set of constraints (control laws) imposed upon system components in order to control their behavior.
- 5) Control in open systems (a system of interrelated components that are influenced by inputs from and outputs to their environment) requires communication via feedback loops of information and control [4].
- 6) In order to control a process, four conditions are required: a) Goal Condition – the controller must have a goal; b) Action Condition – the controller must be able to

influence the state of the system; c) Observability Condition – the controller must be able to determine the state of the system; and d) Model Condition – the controller must possess a model of how the system works [1].

Therefore, in applying a systems approach to safety, the goal is to control the behavior of the system by enforcing the safety constraints in its design and operation. In order to do this, controls must be established. These controls can come in various forms, including human or automated controls, physical design, processes (e.g., manufacturing processes, maintenance procedures, etc.), and/or social controls (e.g., management, government, regulation, cultural, individual, etc) [18].

STAMP Overview

The STAMP accident model, created by Dr. Nancy Leveson, is based on the aforementioned system safety theory and principles. Therefore, the STAMP model attributes accident causation to when external disturbances, component failures, or dysfunctional interactions among system components are not adequately handled by the control system, that is, they result from inadequate control or enforcement of safety-related constraints on the development, design, and operation of the system. According to Dr. Leveson, “Safety then can be viewed as a control problem, and safety is managed by a control structure embedded in an adaptive socio-technical system.” [4].

Therefore, through the application of STAMP, determining the cause of an accident requires identifying the ineffective or missing control action(s) and understanding why it was ineffective or missing. Accident prevention efforts must then be focused on designing and implementing controls that will enforce required system safety constraints [18]. STAMP analyzes system constraints, control loops, process models, and levels of control to identify inadequate control structures leading to safety hazards and preventive measures to resolve potential/existing hazards [7]. The three basic constructs that underlie STAMP – safety constraints, hierarchical safety control structures, and process models – are discussed in greater detail below:

- 1) Safety Constraints – Those constraints placed on a system that, if enforced, will prevent unsafe events or conditions (e.g., hazards). Safety constraints are an important concept to understand within the STAMP construct because the events leading to losses/accidents occur because safety constraints were not successfully enforced. Within the STAMP accident model, these safety constraints are enforced through system safety controls. Recall from the above discussion, controls can come in the form of human, automated, physical design, processes, and/or social controls. For example, in a subway system, a system safety constraint may be that the train door must be closed while the train is moving. The associated control(s) could be approached in several ways including but not limited to a human train operator ensuring the door is closed (active control) or a mechanical interlock preventing the train from moving if the door is open (passive control) [18].

- 2) Hierarchical Safety Control Structures – In the STAMP accident model, consistent with systems theory, systems are viewed as hierarchical structures. Through the development of a hierarchical safety control structure, STAMP analysis provides a comprehensive, systematic methodology for determining accident causality. Within the hierarchical structure, each level enforces safety constraints on the activity associated with the level below. Control processes occur between levels of the hierarchy to control the activities and behavior at the lower levels in the hierarchy. Therefore, constraints at a higher level control lower-level behavior via associated control processes. If these control processes *do not provide adequate control*, the safety constraints will be violated via behavior in the lower-level components, resulting in a hazardous condition and potentially leading to an accident. According to the STAMP accident model, inadequate control can occur at each level of the hierarchical control structure from:
 - a. Missing constraints (unassigned responsibility for safety);
 - b. Inadequate safety control commands;
 - c. Commands that were not executed correctly at a lower level; or
 - d. Inadequately communicated or processed feedback about constraint enforcement.

For example, consider a subway system where the operator of the train controls the position of the subway train through an electro-mechanical control in the pilot house of the train engine car. Inadequate control could result from the operator not being assigned the responsibility of closing the subway door before moving the train (missing constraint), the operator failing to issue a command to close the door via the electro-mechanical switch before moving the train (inadequate safety control commands), an electro-mechanical failure preventing the door from closing (commands that were not executed correctly at a lower level), or a faulty (or lack of) indicator of the door position (inadequately communicated or processed feedback about constraint enforcement).

Per the STAMP accident causality model, and as depicted in Figure 2.4, effective communication channels are needed both downward (reference channel) and upward (measuring channel) between the various levels of the hierarchical safety control structure, in order to adequately enforce safety constraints. The reference channel enables communication of the control commands (e.g., goals, policies, constraints) to the lower levels. Similarly, the measuring channel enables communication of feedback necessary for the controlling level to understand how effectively the constraints are being satisfied and to adapt future control commands to more effectively satisfy the constraints, as necessary [18].

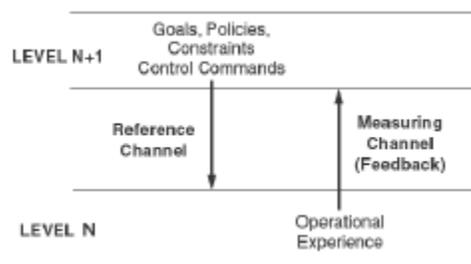


Figure 2.4 – Hierarchical Safety Control Structure Communications Channels [18]

- 3) Process Models – just as process models are an important element of control theory, they are also a very important part of the STAMP accident model. Consistent with the

systems/control theory discussed above, the four specific STAMP model conditions that must exist to control a process are [1, 18]:

- a. Goal – the safety constraints that must be enforced by each controller in the hierarchical safety control structure;
- b. Action Condition – implemented via the reference (downward) control channel;
- c. Observability Condition – conducted via the measuring/feedback (upward) communication channel; and
- d. Model Condition – The controller’s model of the process being controlled.

Without an accurate process model (e.g., model condition), the controller cannot effectively control the process. It is important to note that the controller can be human or automated and the process model can be mental or logic-based, respectively. Regardless of type, the process model must incorporate the same key pieces of information: the relationship among system variables (control laws), the current state of the variables, and the methods by which the process can change the state of the system/variables. The controller leverages this process model to determine which control actions are required in order to enforce safety constraints and avoid hazardous conditions [18].

Extending our subway example, let us now assume there is a controller that automatically opens the door when the train comes to a stop and shuts the door after a certain amount of time. The process model for the train motion controller would be that if the train operator gives the command to move the train, the controller would first check the status of the door. If the feedback indicates the door is open, a command would be issued to shut the door. Once the feedback indicates the door is open, the control command to move would be given to the engine/transmission/brake system to allow the train to move.

In summary, accidents in STAMP are the result of a complex set of system interactions that result in behavior violating the safety constraints. The safety constraints are enforced by control loops between the levels of the hierarchical system safety control structure that are in place during system design, development, and operation. The STAMP accident causality model attributes accidents to the occurrence of one or more of the following conditions [18]:

- a. The safety constraints were not enforced by the controller:
 - i. The control actions necessary to enforce the associated safety constraint were missing/not provided;
 - ii. The control actions necessary to enforce the associated safety constraint were provided at the wrong time (too late/early) or stopped too soon; or
 - iii. Unsafe control actions were provided.
- b. Appropriate control actions were provided but not followed.

Why STAMP for Coast Guard Accident Analysis?

As stated previously, the Coast Guard conducted a detailed investigation of the CG-6505 mishap that occurred on September 4, 2008. The investigation, which will be reviewed in detail in subsequent sections of this thesis, concluded December 2, 2009 and found several causal and contributing factors. A subsequent, more system-level assessment known as ASAAP found several systemic issues contributing to hazards across the Coast Guard aviation system. While both of these investigatory efforts were done thoroughly and collectively identified broader systemic issues within the aviation system, they did not involve a scientific, systems-based approach to identifying hazards and therefore may not provide a complete picture regarding accident causality. That is, unlike with the STAMP accident model, they did not apply systems theory, control theory, and systems engineering principles in a systematic fashion to identify missing/inadequate controls leading to unsafe conditions within the aviation system.

There are several advantages to taking a scientific, systems-based approach that leverages control theory and systems engineering principles to investigate accident causality, all of which directly correlate to a complex socio-technical system such as Coast Guard aviation. For example, benefits of the STAMP based approach to accident causality determination include [18]:

- a. STAMP expands accident analysis beyond proximal events, component failures and human errors. It includes the entire socio-technical system including organizational, societal, and cultural factors as well as system design, system component interaction, and human interaction.

- b. STAMP provides a more scientific way to model accidents through a structured step-by-step process that involves modeling the entire system in the form of a hierarchical structure and then analyzing control loops within that structure. This approach produces a better and less subjective understanding of why the accident occurred and how to prevent future ones.
- c. STAMP shifts the emphasis in the role of humans in accidents from errors (e.g., deviations from standard operating procedures) to focus on internal and external factors that influence human behavior to better understand what caused humans to act in the manner they did.
- d. STAMP encourages a shift in emphasis from the ‘what’ caused the accident to ‘why’ the events occurred that resulted in hazardous conditions. This tends to shift the posture of the analysis from blame to correction and prevention.
- e. STAMP focuses on the processes (e.g., control processes) involved in the accidents in addition to the events and conditions present during and the preceding the accident.
- f. STAMP assists in identifying operational metrics to assist in analyzing performance data to identify leading indicators that a system is migrating to a less safe posture.

STAMP/CAST Process

This section provides a brief overview of the STAMP based accident causality procedures known as CAST (Causal Analysis based on Stamp). A full CAST analysis of the CG-6505 mishap is performed in accordance with the process described below in subsequent sections of this thesis.

“The use of CAST does not lead to identifying single causal factors or variables. Instead it provides the ability to examine the entire socio-technical system design to identify the weaknesses in the existing safety control structure and to identify changes that will not simply eliminate symptoms but potentially all the causal factors, including the systemic ones.” [18].

To accomplish this, CAST develops the socio-technical safety control structure for the system being analyzed and identifies the safety constraints that were violated at each level of the structure and why. The specific steps of CAST as developed by Dr. Leveson are [18]:

1. Identify the system(s) and hazard(s) involved in the accident.
2. Identify the system safety constraints and system requirements associated with that hazard(s).
3. Document the safety control structure in place to control the hazard and enforce the safety constraints. The safety control structure includes each system component's roles, responsibilities, controls provided or created pursuant to their responsibilities, and the associated feedback.
4. Determine the proximate events leading to the accident.
5. Analyze the accident at the physical system level (e.g., in the case of CG-6505, the helicopter, pilots, aircrew, small boat, and boat crew). Identify the contribution of the physical and operational controls, physical failures, dysfunctional interactions, communication and coordination flaws, and unhandled disturbances to the events. Determine why the physical controls in place were not adequate in preventing the hazard.
6. Moving up the levels of the safety control structure, determine how and why each successive higher level contributed to the inadequate control at the lower level. This step involves the bulk of the analysis and must include the following:
 - a. For each system safety constraint, determine whether the responsibility for enforcing it was assigned to a component in the safety control structure and if a component(s) did not exercise adequate control to ensure their assigned safety constraints were enforced in the components below them.
 - b. Develop an understanding of all human decisions or flawed control actions in terms of: the information available to the decision maker, required information not available, behavior-shaping mechanisms (e.g., the context and influences on the decision-making process), the value structures underlying the decision, and any flaws in the process models of those making the decisions and why those flaws existed.
7. Analyze overall communications and coordination contributors to the accident.
8. Determine if there were any changes to the system hierarchical safety control structure over time that migrated the system to a less safe posture and contributed to the accident.
9. Develop recommendations.

STAMP vs. ‘Swiss Cheese’ Accident Causality Models

The above discussion highlights several theoretical advantages of the STAMP model (e.g., systems-based accident causality model) over the ‘Swiss Cheese’ (e.g., event chain-based accident causality model). However, in order to answer the central research question of this thesis – *Is the STAMP model better than the Swiss Cheese model in identifying causes to the accidents?* - it will be instructive from a pragmatic sense to compare the results of the STAMP-CAST analysis conducted herein to the Coast Guard’s MAB results. This comparison is included in subsequent sections of this thesis.

Chapter 3: Case Study Accident Description – Proximal Event

Chain

The accident took place on September 4, 2008 and involved a Coast Guard HH-65 helicopter (CG-6505) and a 47-foot Coast Guard small boat (CG-47317), both stationed near Barbers Point, Hawaii. The helicopter and small boat were conducting hoisting training at approximately 8 p.m. local time when the helicopter's hoist became snagged on one of the small boat's engine room dewatering standpipe. The helicopter eventually crashed and all four people on board (pilot, co-pilot, flight mechanic, and crewman) were killed. Figures 3.1 and 3.2 show a typical HH-65 and HH-65 hoisting operations, respectively. The proximal event chain is listed below and is based on the Coast Guard's Mishap Analysis Board (MAB) Final Report on the CG-6505 mishap (See Appendix A for the Final Decision Letter from the Vice Commandant of the Coast Guard regarding the CG-6505 MAB) [28]:

- a. At 2011 Hawaii-Aleutian Standard Time (HST) on September 4, 2008, Air Station Barbers Point Coast Guard Helicopter 6505 (CG-6505) was taking part in a night hoisting training evolution with Station Honolulu Motor Life Boat 47317 (CG-47317) approximately six miles south of Honolulu, HI. CG-6505 was carrying four people: two pilots, and two aircrew (one flight mechanic and one rescue swimmer). CG-47317 had four people onboard: one coxswain, one crewmember, one engineer, and one break-in crewmember.
- b. CG-6505 maneuvered overhead CG-47327 conducting delivery of the helicopter basket to the small boat via hoist cable.
- c. CG-6505 descended toward the deck of CG-47317.
- d. CG-47317 rose on a sea swell upward toward CG-6505.
- e. This relative motion rapidly closed the distance between CG-6505 and CG-47317, causing slack to build up in the hoist cable.
- f. The hoist cable entangled on the CG-47317 engine room dewatering standpipe on the aft buoyancy chamber's forward face.
- g. As CG-6505 maneuvered to regain altitude and CG-47317 rode down the sea swell, all slack in the hoist cable was consumed and the hoist cable became taught.

- h. The cable pulled the helicopter down in a rapid roll to the right (the hoist is mounted right of the helicopter's longitudinal centerline).
- i. The force of the helicopter caused the cable to part at the point of entanglement (e.g., at the dewatering standpipe).
- j. The release of downward force caused the helicopter to rapidly roll to the left with extreme yaw (rotation about vertical axis) to the left.
- k. During the extreme rolls and yaw, the main rotor blades contacted the hoist boom assembly, disrupting the finely-tuned motion of the rotating helicopter rotor blades and creating a significant out of balance condition as indicated by severe vibrations that existed for the remainder of the flight.
- l. Also during the extreme rolls and yaw, the main gearbox suspension system (e.g., transmission connecting the engines to the main rotor assembly) suffered damage due to overtorque and tensile loading/unloading from the hoist cable.
- m. The pilots and aircrew of CG-6505 recovered from the extreme rolls and yaw and began flying the aircraft from CG-47317 toward Coast Guard Air Station Honolulu.
- n. CG-6505 made several "mayday" calls that were heard by CG-47317, Coast Guard Sector Honolulu, and Honolulu International Airport Air Traffic Control Tower.
- o. Approximately three minutes into CG-6505's flight toward Coast Guard Air Station Honolulu, the rotor system failed, the aircraft departed controlled flight at approximately 500 feet above the water and at a speed of 40 knots, and then crashed into the water.
- p. Nearby Coast Guard assets, as well as other state and local agency assets, responded to the scene to attempt to provide assistance. All four members of CG-6505 were killed in the crash. Most of the aircraft was eventually recovered, but was not reusable.



Figure 3.1 - Coast Guard (CG) HH-65 Helicopter



Figure 3.2 - CG HH-65 Helicopter Conducting Hoisting Operations with a CG 47-foot Small Boat

Chapter 4 - Coast Guard 6505 Mishap Accident Board Investigation and Findings

Following the mishap of CG-6505 on September 4, 2008, in accordance with Coast Guard aviation safety policy, the Coast Guard completed a Mishap Analysis Board (MAB) to investigate the causality of the accident [8]. The final report on the CG-6505 MAB is included as Appendix A to this thesis. As described in detail in Chapter 2, a MAB involves a detailed investigation and report on the causal and contributing factors of a specific mishap and is conducted in accordance with the Department of Defense Human Factors Analysis and Classification System (DOD HFACS) [8, 10]. This section of this thesis summarizes the findings of the Coast Guard MAB investigation and report.

CG-6505 Mishap Accident Board Findings

The accident report found three (3) main “causal factors/actions” (linear events) that led to the accident (loss of the aircraft and personnel casualties). Each causal factor had related “pre-conditions” and “supervisory/organizational issues” that contributed. Causal factors and associated contributing factors are detailed below. A copy of the CG-6505 MAB Final Report Letter is included as Appendix A.

Causal & Contributing Factors:

- Causal Factor #1: Pilot Procedural Error – The aircraft hovered too close to the deck of the small boat while conducting hoisting operations. The pilot then “overtorqued” the aircraft in reaction to being too close to the deck of the small boat.

Related Contributing Factors:

- Poor visibility due to darkness
 - Pilot misperception of operational conditions
-
- Causal Factor #2: Pilot Procedural Error – Because the aircraft was too close to the small boat, there was too much slack in the hoist cable. This enabled the cable to become fouled (e.g., entangled) on the engine room dewatering pipe extending from the aft buoyancy

chamber of the small boat. The pilot/crew failed to recognize that the cable was entangled and failed to enact the “hoist cable fouled/damaged” emergency procedures. Failure to enact these procedures, combined with the aforementioned “overcontrol/overtorque” error resulted in substantial torquing of the aircraft/hoist mechanism which parted the hoist cable and induced an extreme attitude adjustment (e.g., extreme rolling left and right and yawing left) during which the main gear box (drive connecting the engines to the rotor) was damaged and the hoist cable made contact with the rotor blades.

Related Contributing Factors:

- Poor visibility due to darkness
 - Lack of hoist cable sensors/feedback
 - Lack of system safety approach to CG asset design/acquisition.
-
- Causal Factor #3: Pilot Procedural Error – Failure to execute aircraft ditching procedures. Rather than attempting to safely ditch the aircraft in the water, the pilots attempted to return to the air station. About 3 minutes after the hoist fouling, the aircraft crashed into the water, killing all on board. The investigation states that the pilot should have initiated ditching procedures immediately upon regaining control of the aircraft. Note: The term “ditching” refers to a series of maneuvers that the pilot and aircrew take to abandon a damaged aircraft (e.g., controlled crash) in flight in order to safely egress from the aircraft prior to catastrophic failure/uncontrolled crash.

Related Contributing Factors:

- Poor visibility due to darkness – crew’s inability to see water surface and/or visibly assess damage may have dissuaded decision to ditch aircraft.
- Loud vibration – The loud noise in the cockpit and aft section of the aircraft due to the excessive vibration may have impeded situational awareness, crew communications, etc.
- Channelized attention – The aircrew’s attention became too channelized on maintaining the aircraft versus analyzing the situation and taking appropriate action.

- Cultural instinct – There is a cultural imperative in the Coast Guard aviation community to “bring the crew and aircraft home” which may have influenced the decision not to ditch the aircraft.
- Crew Team Leadership – The conversation recorded by the aircraft audio data recorder indicated poor Crew Resource Management (CRM) post hoist cable parting. Specifically, the investigation cited poor communications, lack of assertiveness, and failure to follow procedures.
- Organizational Training Issues – The investigation cited a lack of emphasis on ditching in pilot/crew development and training. Also, there is no requirement for pilots/crews to demonstrate proficiency with respect to ditching and ditching simulation training does not provide a realistic environment.

General Contributing Factors: The MAB identified several general contributing factors not necessarily associated with a single specific causal factor:

- Inadequate Hoist Cable Shear Control – Initial review found that the hoist cable shear control may not be optimally located to allow for easy pilot/crew shearing of the hoist upon entanglement.
- Inadequate Platform-to-Platform Communication – The investigation cited the inability of the boat crew to communicate effectively with aircrew as a contributing factor to the hoist becoming entangled and the aircrew’s failure to initiate hoist fouled/damaged procedures.
- Inadequate Maintenance Procedures of Main Gear Box Elastomeric Stops – The investigation revealed that maintenance and condition of the dampening elements between the airframe and the main gear box (main gear box elements damaged during extreme attitude adjustments) were not being monitored/tracked. Further analysis demonstrated that the dampening elements were in good condition and did not contribute to the accident.

MAB Recommendations: The Coast Guard’s CG-6505 MAB documented several recommendations, listed below, to address the aforementioned causal and contributing factors.

According to Coast Guard officials, these recommendations have been implemented [14]. However, more must be done to improve the safety of the Coast Guard aviation system, as evidenced by the recent crash of another Coast Guard HH-65 helicopter (CG-6535) while conducting training in Mobile, AL on February 28, 2012 [2].

- Install and evaluate “dynamic overload (slipping clutch) hoist system” on the HH-65 (similar to other Coast Guard helicopter types (e.g., HH-60)).
- Conduct system safety analysis of all Coast Guard hoist systems and replace hoists as necessary.
- Replace all main gear box elastomeric stops across the HH-65 fleet. Determine the useful service life of elastomeric stops and establish maintenance procedures.
- Create and mandate use of a protective shroud to cover the 47317 engine room dewatering standpipe on the aft buoyancy chamber’s forward face during hoisting operations.
- Evaluate requirements of system safety integration into Coast Guard asset/acquisition design procedures.
- Increase frequency and realism of aircraft ditching procedures in pilot/crew training and qualification. Increase emphasis during simulator training and include ditching decisions in annual Standardization Visits.
- Conduct a formal Operational Hazard Assessment of helicopter hoisting operations with small boats.
- Update operating and training manuals accordingly.

Chapter 5: CAST ANALYSIS – CG-6505 MISHAP

This section reports a complete CAST analysis of the CG-6505 accident in accordance with the CAST process described in Chapter 2. The nine steps of CAST are [18]:

1. Identify the system(s) and hazard(s) involved in the accident.
2. Identify the system safety constraints and system requirements associated with that hazard(s).
3. Document the safety control structure in place to control the hazard and enforce the safety constraints. The safety control structure includes each system component's roles, responsibilities, controls provided or created pursuant to their responsibilities, and the associated feedback.
4. Determine the proximate events leading to the accident.
5. Analyze the accident at the physical system level (e.g., in the case of CG-6505, the helicopter, pilots, aircrew, small boat, and boat crew). Identify the contribution of the physical and operational controls, physical failures, dysfunctional interactions, communication and coordination flaws, and unhandled disturbances to the events. Determine why the physical controls in place were not adequate in preventing the hazard.
6. Moving up the levels of the safety control structure, determine how and why each successive higher level contributed to the inadequate control at the lower level. This step involves the bulk of the analysis and must include the following:
 - a. For each system safety constraint, determine whether the responsibility for enforcing it was assigned to a component in the safety control structure and if a component(s) did not exercise adequate control to ensure their assigned safety constraints were enforced in the components below them.
 - b. Develop an understanding of all human decisions or flawed control actions in terms of: the information available to the decision maker, required information not available, behavior-shaping mechanisms (e.g., the context and influences on the decision-making process), the value structures underlying the decision, and any flaws in the process models of those making the decisions and why those flaws existed.

7. Analyze overall communications and coordination contributors to the accident.
8. Determine if there were any changes to the system hierarchical safety control structure over time that migrated the system to a less safe posture and contributed to the accident.
9. Develop recommendations.

Step 1 - System Definition & Hazards

System Definition:

The system being analyzed is the Coast Guard Aviation System. For the purposes of this analysis, the Coast Guard Aviation System is organized into two interfacing elements:

1. Development – responsible for development of Coast Guard aviation requirements, capabilities, tactics, training, and procedures.
2. Operations – responsible for conducting operations using Coast Guard aviation capabilities.

System Hazards:

Based on the proximal event chain, the hazardous conditions that immediately yielded the catastrophic accident were initiated when the aircraft approached too closely to the small boat during hoisting resulting in excessive slack in the hoist cable and an overcontrol/overtorque action from the pilot. The hoist cable then became entangled on a protruding pipe (engine room dewatering standpipe) on the small boat. While this entanglement was facilitated by the excessive slack in the hoist cable, hoist cable entanglement can occur without the presence of excessive slack and therefore, is itself a system hazard. Once the hoist cable was entangled, actions were not/could not be followed to avoid damaging the aircraft. Finally, after the pilots regained control of the aircraft post-hoist parting, continued flight of the severely damaged aircraft (as opposed to ditching) placed the crew in a hazardous condition. Therefore, the four system level hazards associated with this accident are:

1. Pilot positions aircraft too close to small boat.
2. Helicopter hoist gets entangled on small boat.
3. An entangled hoist causes damage to the aircraft.
4. Pilot/aircrew continues to fly aircraft after damage.

Step 2 – System Safety Constraints and System Requirements

System Safety Constraints:

The system level constraints required to address (e.g., prevent) the aforementioned hazards are:

1. The pilot must not position aircraft too close to small boat.
2. The hoist must not become entangled on the small boat.
3. The aircrew/pilot must be able to disconnect/disentangle the hoist without causing damage to the aircraft.
4. The pilot/aircrew must abandon the aircraft after severe damage to the aircraft.

System Requirements:

The system requirements necessary to prevent the aforementioned hazards and enable safe execution of roles and responsibilities are:

1. The pilot must not position the aircraft too close to small boat.
2. Feedback must be provided to the pilot/aircrew to inform the pilot of distance from the small boat during hoisting operations.
3. The hoist must not become entangled on the small boat.
4. Snag/entanglement hazards must be eliminated on the small boat.
5. The aircrew/pilot must be able to disconnect/disentangle the hoist without causing damage to the aircraft.
6. The hoist must be able to automatically pay out to avoid causing damage to the aircraft.

A mapping of system hazards to system-level safety design requirements is provided in Table 5.1.

	Hazards	Safety Design Constraints
1	Pilot positions aircraft too close to small boat.	The pilot must not position aircraft too close to small boat. Feedback must be provided to the pilot/aircrew to inform the pilot of distance from the small boat during hoisting operations.
2	Helicopter hoist gets entangled on small boat.	The hoist must not become entangled on the small boat. Snag/entanglement hazards must be eliminated on the small boat.
3	An entangled hoist causes damage to the aircraft.	The aircrew/pilot must be able to disconnect/disentangle the hoist without causing damage to the aircraft. The hoist must be able to automatically pay out to avoid causing damage to the aircraft.
4	Pilot/aircrew continues to fly aircraft after damage.	The pilot/aircrew must abandon aircraft after severe damage to the aircraft.

Table 5.1 – System Hazards and Safety Design Constraints

Step 3 - Hierarchical System Safety Control Structure

The hierarchical system safety control structure for the Coast Guard helicopter accident is provided in Figures 5.1, 5.2, and 5.3. Figure 5.1 provides an overview of both the System Development and System Operations elements of the overall system. The red arrows (numbered 1-4) in Figure 5.1 indicate how the two elements of the system are interlinked. Figures 5.2 and 5.3 provide a detailed control structure for the System Development and System Operations elements, respectively. A brief overview of system roles, responsibilities, and interfaces follows. Detailed descriptions of roles and responsibilities of each element within the system are provided later in the CAST analysis.

Overview of System Hierarchical Control Structure Roles, Responsibilities, and Interfaces:

System Development – With regard to System Development, the Coast Guard’s Office of Aviation Forces (CG-711) fulfills the roles of Platform Manager and Project Sponsor. In these capacities, CG-711 manages all of the Coast Guard’s aviation capabilities (e.g., fixed wing aircraft, rotary wing aircraft, etc.). They work with Coast Guard operators (e.g., Air Stations) to understand capability requirements and to ensure the capabilities (e.g., aircraft and associated sub-systems) meet the operational needs. If the operational needs are not being met, CG-711 works with the Air Stations (and interfacing capabilities such as small boat stations and the Coast Guard’s Office of Boat Forces (equivalent of CG-711 for small boat oversight – not pictured in the Safety Control Structure) to understand and document Coast Guard aviation operational capability requirements. CG-711 then works with the Coast Guard’s Acquisition Directorate to upgrade existing capabilities or acquire new capabilities in order to meet unsatisfied operational requirements. CG-711 works with the Coast Guard’s Chief Financial Officer to obtain project funding and the Coast Guard’s Acquisition Directorate manages the major system acquisition project (e.g., upgrade existing aircraft or procure new aircraft) per the direction/guidance of CG-711. The Coast Guard’s Aviation Safety Division audits/oversees the aviation program, works with the various system elements (e.g., CG-711, Air Stations, Acquisition Directorate) to improve aviation safety, and reports to the Coast Guard’s Human Resources Directorate.

System Operations – The Coast Guard Sector Honolulu is the Operational Command that directs and coordinates Coast Guard operations in the coastal regions surrounding Hawaii. Coast Guard Air Station Barbers Point and Coast Guard Small Boat Station Honolulu are operational units that report directly to Coast Guard Sector Honolulu. Coast Guard Air Station Barbers Point provides aircraft, pilots, and aircrews to conduct operations as directed by Coast Guard Sector Honolulu. The CG-6505 aircraft, pilot and crew were assigned to Coast Guard Air Station Barbers Point. Similarly, Coast Guard Small Boat Station Honolulu provides small boats to conduct operations as directed by Coast Guard Sector Honolulu. The CG-47317 small boat and boat crew were assigned to Coast Guard Small Boat Station Honolulu. The Coast Guard’s Office of Aviation Forces (CG-711) provides operational policy to the Coast Guard aviation community (e.g., Coast Guard Air Stations) and works with Coast Guard Forces Command and Coast Guard Aviation Training Center to establish aviation tactics, techniques, and procedures. Coast Guard Forces Command oversees the operational readiness (e.g., training, certification, material condition) of all Coast Guard operational units and establishes standardized Coast Guard-wide tactics, techniques, and procedures. The Coast Guard’s Aviation Training Center develops and conducts standardized aviation training for pilots and establishes standardized aviation tactics, techniques, and procedures. Finally, the Aviation Safety Division conducts Standardization Visits (e.g., audits) to ensure standardized tactics, techniques, procedures and policies are being followed by operational aviation units (e.g., Coast Guard Air Stations).

System Development – System Operations Inter-linkages – As shown by the red arrows in Figure 5.1, there are four major linkages across the Systems Development and Systems Operations elements of the Coast Guard’s aviation system. Each are briefly described below:

1. Office of Aviation Forces (CG-711) – From a system development perspective, CG-711 establishes aviation operational capability requirements manages existing capabilities and directs design, development, and procurement of upgrades to existing and acquisitions of new capabilities in order to meet operational requirements. From a system operation perspective, CG-711 directs operational policy and works with FORCECOM and Aviation Training Center to establish aviation tactics, techniques, and procedures.

2. Aviation Safety Division (CG-1311) – CG-1131 works with CG-711, Coast Guard Air Stations, and the Coast Guard Acquisition Directorate to ensure safety requirements are accounted for within aviation capabilities. CG-1131 audits Coast Guard operations to ensure they are conducted in accordance with standardized tactics, techniques, procedures, and aviation policies.
3. Coast Guard Air Stations – From a system development perspective, Coast Guard Air Stations identify capability shortfalls and/or suggest capability enhancements to CG-711 in order to meet operational requirements. From a system operations perspective, in general, Coast Guard Air Stations carry out operations per the direction of Coast Guard Sectors.
4. Coast Guard Small Boats – As an interfacing capability, Coast Guard small boat design is an input to the development of Coast Guard aviation systems. Additionally, the small boats play an integral role in conducting Coast Guard operations.

CONTROL STRUCTURE – System Development & Ops (Overview)

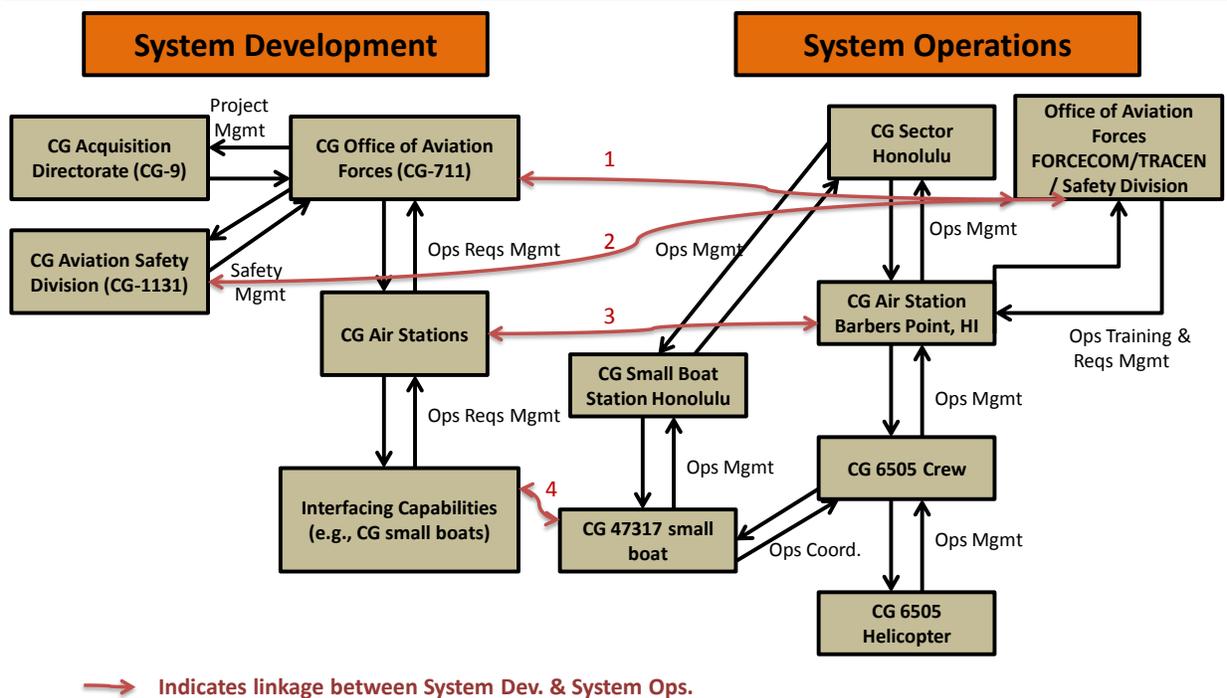


Figure 5.1 – CG-6505 Hierarchical Control Structure (Overview)

CONTROL STRUCTURE – System Development (Detailed View)

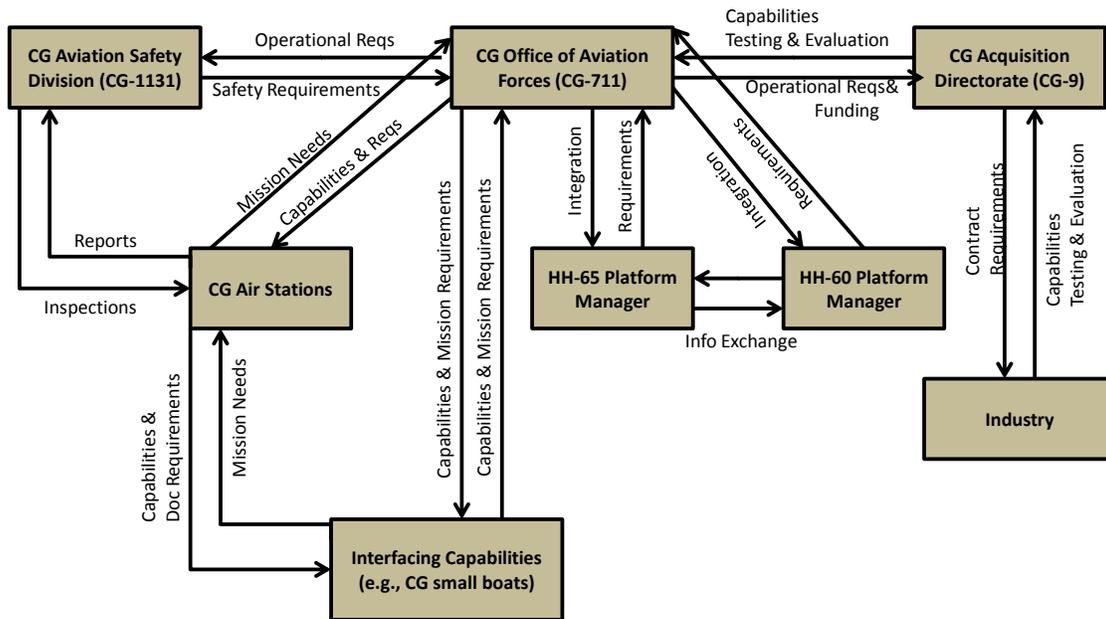


Figure 5.2 – CG-6505 Hierarchical Control Structure (System Development Detailed View)

CONTROL STRUCTURE – System Operations (Detailed View)

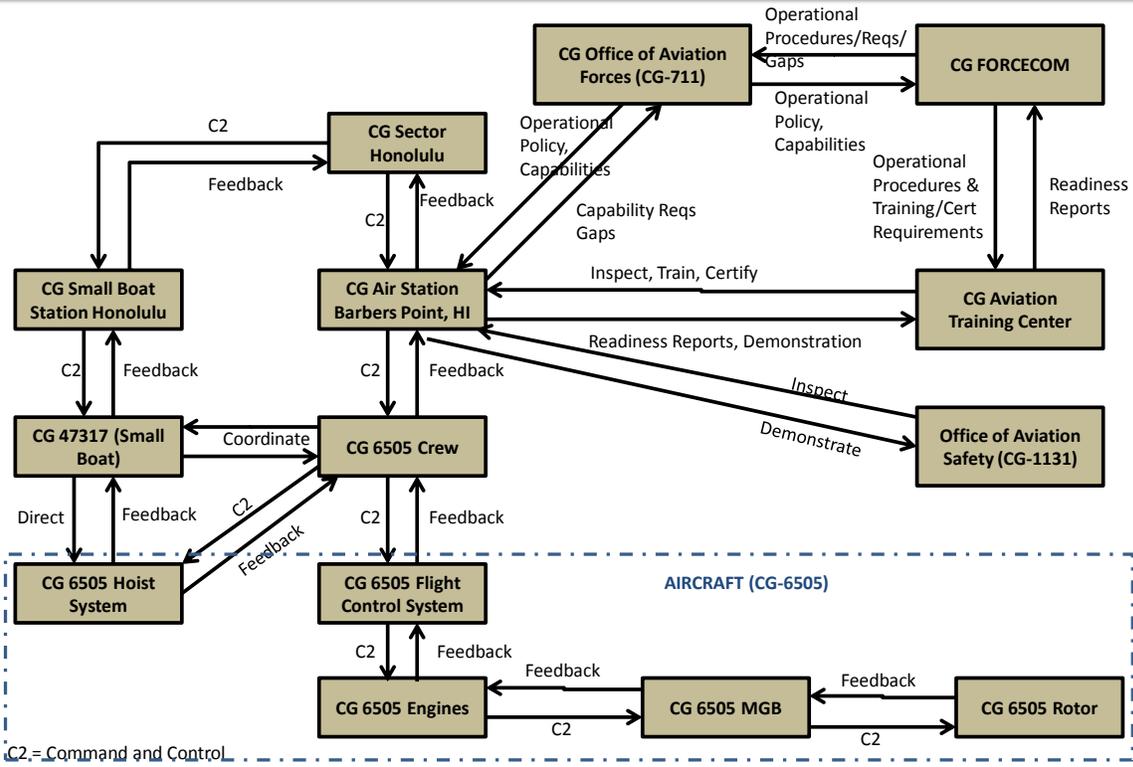


Figure 5.3 – CG-6505 Hierarchical Control Structure (System Operations Detailed View)

Step 4 – Proximal Event Chain

The proximal event chain is contained in Chapter 3 of this thesis and is based on the Coast Guard's Mishap Analysis Board (MAB) Final Report on the CG-6505 mishap (See Appendix A for the Final Decision Letter (Final Report) from the Vice Commandant of the Coast Guard regarding the CG-6505 MAB).

Step 5 - Analyzing the Physical Process

Physical System (Helicopter and Small Boat) Safety Controls:

In this part of CAST, the physical system (e.g., CG-6505 (helicopter – dashed blue box in Figure 5.3) and CG-47317 (small boat)) is analyzed with the purpose of identifying the physical and operational controls and any potential physical failures, dysfunctional interactions and communication, or unhandled external disturbances that contributed to the events. The goal is to determine why the physical controls in place during the time of the accident were ineffective in preventing the hazard [18].

Figure 5.4 provides a summary of the safety requirements and constraints violated within the physical system, the emergency and safety equipment available to the crew, the physical failures and inadequate controls, and the physical contextual factors. Several items within the physical system analysis warrant additional discussion:

Inadequate Capabilities to Prevent the Helicopter from Getting Too Close to the Small Boat:

Based on discussions with Coast Guard aviation program management personnel [14], pilots use multiple sources of data; however, rely primarily on the radar altimeter, to avoid approaching too close to the small boat during night time hoisting operations. Furthermore, based on information gathered during these interviews with Coast Guard aviation program management personnel and the Final Decision Letter from the CG-6505 MAB, pilot overcontrol/overtorque (e.g., too closely approaching the small boat and too rapidly/forcefully correcting) is a fairly common occurrence during night time hoisting operations. It is acknowledged that the Coast Guard must routinely perform high risk operations in the normal course of its mission execution, including night time hoisting operations. However, given the routine occurrence of night time hoisting operations, and the fairly common occurrence of overcontrol/overtorque, rather than simply accepting the high-risk nature of this routine operation, the Coast Guard should pursue additional capabilities (e.g., equipment/sensors), tactics, and procedures to better prevent exposing pilots/aircrew to hazards associated with approaching too close to the small boat during night time hoisting operations. Based on discussions with Coast Guard aviation program managers, it appears the

Coast Guard has not documented any capability requirements to assist in mitigating the risks associated with nighttime hoisting operations, including the addition of feedback mechanisms/sensors to inform the pilot that he/she is approaching too close to the small boat. This raises a couple of questions: Why have these requirements not been generated/documentated? Why is the risk associated with night time hoisting operations accepted by the Coast Guard?

Inadequate Hoist System: Analysis of the physical system reveals as many as three inadequacies within the hoist system at the time of the CG-6505 mishap: 1) Lack of a dynamic slip clutch does not allow for the hoist to pay out (e.g., release more cable to relieve downward force on the aircraft) in the event the hoist is entangled/overloaded; 2) The hoist system has a shear mechanism on the pilot's collective (part of cockpit controls) and the flight mechanic's control panel. However, there is no shear control on the hoist pendent which would facilitate shearing of the hoist during remote operation; and 3) There is no sensor/feedback system (other than visual) indicating to the pilot or aircrew that the hoist is entangled. *Furthermore, there is no record of identification of these inadequacies or action to fix them on behalf of the Coast Guard.* Why did these inadequacies go unnoticed and/or why was no action taken to address them over 24 years of operation (the HH-65 helicopters were acquired from 1981 – 1984 [13], at least 24 years before the CG-6505 mishap)? This is especially puzzling in the case of the lacking dynamic slip clutch hoist capability, considering the Coast Guard's other helicopter platform (HH-60), which satisfies a similar mission profile to the HH-65, was equipped with the dynamic slip clutch hoist capability at the time of the accident. Why, over the course of 18 years of operation of a dynamic hoist clutch on the HH-60 (the HH-60 helicopters were acquired in 1990 [13], 18 years before the CG-6505 mishap), was the requirement for a similar hoist capability for the HH-65 not identified?

Inadequate Ditching Capabilities and Competencies: The Coast Guard MAB investigation characterizes the pilot's decision to not ditch the aircraft as a procedural error that was a causal factor in the mishap. Poor visibility (inability to see the ditching surface) along with inadequate training (e.g., pilot/aircrew competencies) and cultural issues were cited as contributing factors. With respect to capabilities, it appears lack of adequate lighting resulted in poor visibility of the "ditching surface." Based on interviews with aviation program management personnel, existing

lighting has limited effectiveness with respect to ditching procedures. Each pilot station has a controllable hover light, which is not powerful enough to provide enough visibility for ditching. There is a 3rd light mounted on the aft of the aircraft operated by the flight mechanic to aid in search missions. The third light is powerful but the beam is too focused to assist in ditching operations. According to Coast Guard aviation program managers, there is no requirement on record for improved lighting for night time operations/ditching. Why was this capability requirement not identified? Why is training on ditching procedures not adequately emphasized? What can be done to improve this training? What is the source of the cultural barriers to ditching aircraft in the Coast Guard? What can/should be done to overcome these barriers?

Inadequate Feedback to Pilot/Aircrew: Analysis of the physical system indicates a general lack of feedback to the pilot/aircrew. Although some of these have been cited individually with respect to their associated physical components, it is worth mentioning them again as a systemic issue. Rather than providing the pilot with sensor/feedback systems to more objectively indicate hazardous conditions (e.g., hoist entangled, approaching too close to the small boat, severe damage to the rotor/main gear box), the system relies on the pilot's auditory and visual cues to identify hazardous conditions, despite routine operations where visual abilities are impaired (e.g., night time operations). Why has the requirement for additional sensors/feedback gone unnoticed/undocumented?

Hoist Entanglement Hazard on the Coast Guard's 47-foot Small Boat: The configuration/design of CG-47317 (small boat), particularly the protruding engine room dewatering standpipe above deck, resulted in a significant hoist entanglement hazard. Considering the 47-foot small boat routinely conducts hoisting operations with Coast Guard helicopters, why was this boat designed this way? Why was this hazard never noticed/documented/corrected during the 11 years of operation with Coast Guard helicopters (note the Coast Guard 47-foot small boat was acquired in 1997 [13], eleven years before the CG-6505 mishap)?

Inadequate Communications Capabilities: Analysis of the physical system reveals a lack of ability of the boat crew to communicate directly with the air crew. This lack of communications capability was also documented as a contributing factor in the Coast Guard's MAB. (Note: the

boat coxswain (driver) can communicate with the pilot and aircrew via radio. However, the boat crew's ability to communicate with the coxswain is limited due to noise from the helicopter). In the case of an emergency condition, such as an entangled hoist cable, time is exceptionally critical and the ability of the boat crew, who may be the only operators able to see the entanglement, to communicate directly with the pilots/aircrew could help reduce/avoid hazardous conditions. Why has this communications gap gone unnoticed, undocumented, or unaddressed? What can be done (e.g., capabilities, tactics, procedures) to enable the boat crew to communicate directly with the pilots/aircrew?

At this point in the analysis, it is helpful in addressing the central research question of this thesis - *is the STAMP model better than the Swiss Cheese model in identifying causes to the accidents?* - to quickly compare the effectiveness of STAMP vs. the Coast Guard's current process (MAB and ASAAP) in identifying physical system inadequacies that contributed to the CG-6505 mishap. The below table provides a summary of this comparison:

Physical Inadequacy	STAMP	MAB/ASAAP
1. Insufficient capabilities to prevent pilot from getting too close to small boat	Yes	Yes
2. Inadequate hoist capabilities (dynamic slip, shear, sensor)	Yes	Yes
3. Inadequate lighting/ditching capabilities.	Yes	No
4. Inadequate feedback to pilot/crew regarding damage to aircraft.	Yes	No
5. Hazardous small boat configuration (deck protrusion).	Yes	Yes
6. Inadequate boat crew to aircrew comms.	Yes	Yes

7. Inadequate capabilities management.	Further Analysis Needed	No
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This quick comparative analysis suggests that the STAMP analysis more comprehensively examines the physical system for control/feedback inadequacies than the Coast Guard’s current practices as the STAMP analysis highlighted two physical system inadequacies (e.g., inadequate lighting/ditching capabilities, inadequate feedback to pilot/crew regarding damage to aircraft) that the MAB/ASAAP did not identify. STAMP’s systems thinking approach, which examines the physical system from a control/feedback perspective and examines the physical elements as a system, yields more complete results. *Furthermore, and perhaps most importantly, the STAMP analysis, highlights the need to more closely examine the Coast Guard’s capabilities management system.* For example, the STAMP analysis raises many questions about the capabilities management system, including:

- Were these physical inadequacies identified prior to the mishap?
- If so, what was done about them?
- If not, why?

As we will see further in this STAMP analysis, answers to these questions highlight critical control/feedback inadequacies in the Coast Guard’s capability management process that must be addressed to remove hazards in the current control structure.

Safety Requirements and Constraints Violated:

- Prevent helicopter from getting too close to the small boat
- Prevent the helicopter hoist from getting entangled
- Provide ability to shear hoist in the event it gets entangled
- Provide protection to helicopter in the event the hoist becomes entangled
- Provide indicators (alarms) of hazardous conditions (e.g., helicopter too close to the small boat, hoist entangled, damage to main gear box, etc.)

Emergency and Safety Equipment (Controls):

- Hoist system shear capability
- Night Vision Goggles
- Communications system (VHF radio communications between boat coxswain and helicopter pilot)
- Protective equipment for flight crew
- Search lights

Failures and Inadequate Controls:

- Inadequate protection against the helicopter approaching too close to the small boat during night time hoisting operations
- Inadequate indicators of hazardous conditions:
 - Inadequate indicator that helicopter is too close to small boat.
 - Inadequate indicator that the hoist is entangled.
 - Inadequate indicator that the helicopter has sustained significant damage (e.g., main gear box).
- Inadequate protection to prevent hoist from becoming entangled (deck protrusion on small boat).
- Inadequate hoist capabilities (no dynamic clutch; inadequate shear capability) to prevent aircraft from being damaged post-hoist entanglement.
- Inadequate communications capabilities/tactics between boat crew and air crew
- Lack of adequate lighting for night vision

Physical Contextual Factors:

- CG-6505 was one of four HH-65 helicopters attached to Coast Guard Air Station Barbers Point. Each of the helicopters is flown by various pilots/aircrews, however, all HH-65 helicopters have identical capabilities/configuration.
- HH-65 helicopters routinely perform hoisting operations and training with 47-foot Coast Guard small boats identical to the small boat (CG-47317) involved in the accident.

Figure 5.4 – CG-6505 Physical Plant Level Analysis

Step 6 - Analyzing the Higher Levels of the Safety Control Structure

Following completion of the analysis of the physical plant and identification of physical control inadequacies, the next step is to examine the higher levels of the hierarchical safety control structure to attempt to understand why those physical control inadequacies occurred. In order to do this, consistent with the CAST procedures previously outlined, this section of the thesis report analyzes each relevant component of the safety control structure, starting with the lowest physical controls and working upward to the higher level program management elements. By proceeding with analysis all the way up the safety control structure to the program management levels, we are able to develop an understanding of the reasons for the physical system inadequacies and why the operators at the lower levels acted in the way they did [18].

CG-6505 (Helicopter) Crew

Per the Safety Control Structure (Figure 5.3), the CG-6505 Crew controlled the aircraft primarily by commanding and controlling the flight control system and the hoist system. The CG-6505 Crew received feedback from both the flight control system and hoist system via various sensors/gauges and visual/auditory observation. Additionally, the CG-6505 Crew coordinated operations with CG-47317 (small boat) via communication.

Figure 5.5 summarizes the CG-6505's safety related responsibilities, operational context, unsafe decisions and control actions, and process model flaws. As the operators of the aircraft, this is the component of the safety control structure with the most direct/proximate safety-related responsibilities. Some of these key responsibilities include preventing the aircraft from getting too close to the small boat, preventing the hoist from getting entangled, preventing damage to the aircraft post-hoist entanglement, and ditching the aircraft upon suffering severe damage. As listed in Figure 5.5, the crew took several unsafe control actions. Analysis of these actions results in the identification of the following control/feedback inadequacies at the CG-6505 Crew level:

Control/Feedback Inadequacies

- Inadequate Control/Feedback – Pilot and Flight Control System in Hover/Approach – CG-6505 pilot was not able to adequately control the aircraft flight control system in descent to hover for night time hoisting operations at a safe distance from the small boat.
- Inadequate Control – Aircrew Control of Entangled Hoist – CG-6505 pilot/aircrew was not able to adequately control the hoist system to prevent damage to the aircraft post-hoist entanglement. Hoist unable to pay out cable (e.g., dynamic clutch) and shear capabilities inadequate (no remote shear capability at hoist pendant).
- Inadequate Control/Feedback – Aircrew to Boat Crew communication and coordination – Inability for CG-6505 crew and CG-47317 crew to communicate/coordinate operations may have contributed to damage to aircraft post hoist-entanglement.

To address these control/feedback inadequacies, this CAST analysis recommends the following actions be taken:

- Considering the risk/routine nature of pilot overcontrol/overtorque during nighttime hoisting operations, the Coast Guard should take action to review state of the market/art capabilities to provide more information to the pilot/aircrew to reduce the risk of overcontrol/overtorque. This could take the form of additional sensors/warning indicators to assist the pilot in positioning/holding the aircraft at a safe/stable distance above the receiving platform (e.g., small boat). Furthermore, adding an overload/entanglement sensor on the hoist system and improving communications to allow for direct coordination between the air crew and the receiving crew (e.g., boat crew) will also likely improve the safety and efficiency of nighttime hoisting operations.
- This CAST analysis concurs with the Coast Guard’s action to replace the existing HH-65 hoist system with a dynamic slip clutch system.

In addition to these control/feedback inadequacies at the CG-6505 Crew level, there were several unsafe decisions and control actions and process model flaws that warrant further examination at higher levels in the safety control structure:

- Pilot/Aircrew failed to ditch aircraft after aircraft was severely damaged.
- Inaccurate assessment of risk of entangling hoist on small boat deck fittings.

- Belief that routine pilot overcontrol (approaching too close to the small boat) and overtorque (exceeding the safe torque limits of the aircraft to correct for mis-positioning of aircraft) during night training/operations is acceptable.

Safety-Related Responsibilities

- Prevent helicopter from getting too close to the small boat
- Prevent the helicopter hoist from getting entangled
- Must follow standard flight procedures
 - Must shear hoist or pay out hoist cable in the event of entanglement (e.g., prevent damage to aircraft post-hoist entanglement).
 - Must abandon aircraft after aircraft sustains major damage (e.g., continued safe flight is threatened)
- Pilot must direct aircrew in executing roles and responsibilities during routine and emergency operations.

Context

- Conducting training operations at night (low visibility) with lack of sensor feedbacks to assist in determining distances (e.g., lights, night vision goggles, sensors, communications, etc.)
- Coast Guard aviation resources fully employed to meet operational needs. Aircraft inventory does not include spare aircraft to backfill in the event of a crash/severe damage to an aircraft.
- Loud vibration (hard to communicate) after helicopter sustains damage.
- Ditching procedures are not emphasized as part of aviation standardization and certification. Therefore, pilots/aircrew not proficient in aircraft ditching procedures. Training procedures do not simulate real event scenario.

Unsafe Decisions and Control Actions

- Pilot maneuvered aircraft too close to the small boat during the fourth hoisting evolution.
- Pilot over-torqued the aircraft to quickly correct for approaching too close to the small boat.
 - Resulted in causing extreme forces on the aircraft causing severe rolls, snapping of the hoist cable, and damage to the aircraft.
 - Prevented pilot/aircrew from being able to initiate hoist fouled/damaged procedures (e.g., shear cable or pay out cable).
- Pilot/Aircrew failed to ditch aircraft after aircraft was severely damaged. Instead they attempted to fly back to Air Station.

Process Model Flaws

- Incorrect assessment of how close the helicopter is to the boat due to lack of visual feedback.
- Inaccurate assessment of risk of entangling hoist on small boat deck fittings.
- Belief that routine pilot over-control (approaching too close to the small boat) and over-torque (exceeding the safe torque limits of the aircraft to correct for mis-positioning of aircraft) during night training/operations is acceptable.

Figure 5.5 – CG-6505 Crew Level Analysis

Coast Guard Air Station Barbers Point

Per the Safety Control Structure (Figure 5.3), Coast Guard Air Station Barbers Point provided control over the CG-6505 Crew by executing command and control in the form of verbal and written communications, approval of flight plans, providing required training, and ensuring proper qualifications and certifications. The Air Station received feedback from the CG-6505 crew via verbal communications in flight, and through personnel training, certification, and qualification records. Additionally, per the Safety Control Structure (Figure 5.2), Coast Guard Air Station Barbers Point provided control over interfacing capabilities (e.g., small boats) via documenting capability requirements. The Air Station received feedback from the interfacing capabilities in the form of mission needs (e.g., unsatisfied requirements/gaps) with respect to aviation/hoist operations.

Figure 5.6 summarizes Coast Guard Air Station Barbers Point's safety related responsibilities, operational context, unsafe decisions and control actions, and process model flaws. Of the several safety responsibilities listed in Figure 5.6, failure of the Air Station to perform three key safety related responsibilities resulted in several unsafe decisions and control actions.

First among these key responsibilities is unit level training. As a Coast Guard aviation unit, Coast Guard Air Station Barbers Point is charged with establishing and conducting unit-level operational safety training to pilots/aircrew in accordance with Coast Guard aviation training requirements promulgated by Aviation Training Center [30]. These training requirements include both Crew Resource Management (e.g., operational risk management) and ditching training. Crew Resource Management training is provided annually to all pilots by the Aviation Training Center and to the crew by the Aviation Technical Training Center. Throughout the course of the year, Crew Resource Management Training is the responsibility of the Air Station unit Flight Safety Officer. The Flight Safety Officer is typically a collateral duty and the requirements for unit level Crew Resource Management training are not standardized by Aviation Training Center. Additionally, there is no requirement for unit level ditching training, however, Aviation Training Center expects the Air Stations to maintain ditching proficiencies. The Coast Guard investigation cited the crew for poor Crew Resource Management during the accident (contributing factor to not initiating ditching procedures) and a general under emphasis

of ditching procedures and lack of ditching proficiency across the Coast Guard, suggesting that these responsibilities were not carried out adequately at the Air Station.

The second key responsibility that was not properly performed is the responsibility of all Coast Guard Air Stations to identify helicopter operational requirements and associated gaps and communicating those requirements/gaps to the Coast Guard Office of Aviation Forces. Several capability gaps (see Figure 5.6) that were never documented/pursued that contributed to the CG-6505 mishap suggest that Coast Guard Air Stations (including Coast Guard Air Station Barbers Point) were deficient in performing this role. However, further analysis as part of the STAMP process suggests that the responsibility to identify capability requirements is diffused across multiple entities including the Coast Guard Air Stations, Aviation Training Center, and Office of Aviation Forces. This diffused responsibility may have resulted in the Air Station deferring to other entities within the safety control structure to identify required capabilities.

Finally, the third key responsibility that was not properly performed was the Air Station's responsibility to provide leadership and oversight of the aircrews. The MAB report cites a cultural force across the Coast Guard compelling pilots to return to the base with the aircraft, even if it means placing the crews in danger, as a contributing factor in the mishap [28]. This stems from a lack of leadership emphasis on the imperative to ditch an aircraft whenever there is severe damage to an aircraft or the crew's safety is jeopardized by continued flight. As we will see in subsequent sections of this report, this lack of leadership emphasis on the importance of ditching a damaged aircraft is not limited to just the Air Station level, but occurs throughout the safety control structure.

This analysis results in the identification of the following control/feedback inadequacies at the Coast Guard Air Station Barbers Point level:

Control/Feedback Inadequacies

- Inadequate Control/Feedback – Air Station Capabilities Management – Coast Guard Air Station Barbers Point inadequately determined/documentated capability requirements/gaps.

- Inadequate Control/Feedback – Air Station Oversight of Crew Resource Management Training – Coast Guard Air Station Barbers Point inadequately trained crew in Crew Resource Management and ditching procedures and unable to provide accurate assessments of pilot/crew associated proficiencies.
- Inadequate Control – Air Station Emphasis on Preserving Life Safety – Coast Guard Air Station Barbers Point inadequately emphasized importance of ditching the aircraft to preserve life safety of crew.

Safety-Related Responsibilities

- Approve flights and coordinate/provide command and control of helicopter operations and training.
- Establish and conduct unit-level operational safety training to pilots/aircrew in accordance with Coast Guard aviation training requirements promulgated by Aviation Training Center.
- Ensure all pilots/aircrew have completed required training and qualifications.
- Perform required maintenance on aircraft to ensure safe operations.
- Identify helicopter operational requirements and associated gaps. Communicate requirements/gaps to Coast Guard Office of Aviation Forces.
- Provide leadership and oversight to pilots and aircrew.

Context

- The Air Station pilots and aircrew were up to date on training and qualification requirements, however, consistent with Coast Guard-wide Aviation Training and Qualification requirements, did not emphasize ditching procedures.
- All required maintenance had been performed on the aircraft located at the Air Station.
- Air Station Barbers Point operates only the HH-65 model helicopter. Considering they do not operate the HH-60 model, they were likely not aware of the dynamic hoist clutch assembly system capability.
- The responsibility to identify capability requirements is diffused across multiple entities including the Coast Guard Air Stations, Aviation Training Center, and Office of Aviation Forces.
- Local training of Operational Risk Management and Crew Resource Management techniques is the responsibility of the unit Flight Safety Officer, which is a collateral duty for one of the pilots stationed at the Air Station.

Figure 5.6 (1 of 2) – Coast Guard Air Station Barbers Point Level Analysis

Unsafe Decisions and Control Actions

- Did not identify requirement for HH-65 dynamic hoist clutch assembly to allow for system overloading (e.g., similar to HH-60 dynamic hoist clutch assembly).
- Did not identify requirement (capability shortfall) for sensor system on HH-65 hoist system to indicate system overload.
- Did not identify requirement (capability shortfall) to aid in nighttime hover/approaches to avoid common pilot overcontrol/overtorque errors during nighttime hoisting operations.
- Did not emphasize aircraft ditching procedures in unit level pilot and aircrew training/certification.
- Did not identify requirement for capabilities necessary to safely conduct nighttime ditching operations (lack of sufficient lighting to see surface).
- Failed to establish proficiency in Crew Resource Management.

Process Model Flaws

- Inaccurate assessment of risk of entangling hoist.
- General acceptance of high risk associated with nighttime hoisting operations.
- Cultural imperative to return to the Air Station with both the crew and the aircraft.

Figure 5.6 (2 of 2) – Coast Guard Air Station Barbers Point Level Analysis

Coast Guard Aviation Training Center (Mobile, AL)

Per the Safety Control Structure (Figure 5.3) and the safety related responsibilities listed in Figure 5.7, Coast Guard Aviation Training Center provides control over Coast Guard Air Station Barbers Point (and all other Coast Guard Air Stations), through establishment of standardized operating tactics, training, and procedures in conjunction with its parent command - Forces Readiness Command (FORCECOM) – and through inspection, training, and certification of all pilots and air crewman. Coast Guard Aviation Training Center completed this control action by working with the Coast Guard’s Office of Aviation Forces to maintain the Coast Guard Flight Operations Manual [23] and conducting annual week-long refresher training at the Aviation Training Center in Mobile, AL for all aviation personnel on a rotating basis. Furthermore, Aviation Training Center personnel visited each Coast Guard Air Station once a year to conduct Aviation Standardization Visits where they would interview and fly with a portion of the pilots and air crewman to ensure standardized tactics, techniques, and procedures were understood and being used by the air station personnel. Aviation Training Center would receive feedback from each Coast Guard air station, including Air Station Barbers Point, in the form of “readiness reports” (reports that stated level of qualification and training status for personnel attached to the unit) and observation during annual in-house training and Standardization Visits [14, 26].

In addition, in accordance with the Safety Control Structure (Figure 5.3) Aviation Training Center currently reports to Coast Guard Force Readiness Command (FORCECOM). FORCECOM provides control over Aviation Training Center through establishment and documentation of standardized operational tactics, techniques, and procedures. Aviation Training Center provides feedback to FORCECOM by closely coordinating with FORCECOM during the development of standardized operational tactics, training, and procedures and by providing periodic consolidated aviation fleet readiness reports. Note: At the time of the CG-6505 mishap, the Coast Guard had recently established FORCECOM and was in the process of shifting control of the Aviation Training Center from Coast Guard Headquarters Office of Aviation Forces to FORCECOM [14, 26].

Figure 5.7 summarizes Coast Guard Aviation Training Center’s safety related responsibilities, operational context, unsafe decisions and control actions, and process model flaws at the time of

the CG-6505 mishap. Figure 5.7 lists several inadequacies related to Aviation Training Center's performance in standardizing certain key tactics, techniques, and procedures; and identifying critical capability gaps:

Standardized Tactics, Training, and Procedures

The Coast Guard's MAB revealed that training on ditching procedures was not adequately provided across the Coast Guard, resulting in a contributing factor to the CG-6505 Crew's decision not to ditch the aircraft after sustaining severe damage to the rotor and main gear box. Specifically, the Coast Guard MAB pointed to a lack of "realism" in the training provided by the Aviation Training Center (presumably simulator training provided annually at the Aviation Training Center). By digging into this further through the STAMP/CAST process (e.g., identifying control and feedback mechanisms for developing pilot/air crew ditching competencies and proficiency), it was discovered that ditching procedures are not a required element of the Standardization Visits and there is no record that ditching procedures were discussed during the Aviation Training Center Standardization Visit to Coast Guard Air Station Barbers Point in 2007. Appendix C provides a sample Standardization Visit Procedures Checklist. As can be seen from the score card, although demonstration of three Emergency Procedures (EPs) is required, demonstration of ditching procedures is not specifically required. Considering annual Standardization Visits are the only time where dedicated instructor pilots (e.g., Aviation Training Center instructor pilots) observe Air Station personnel in an in-flight environment, it is recommended that ditching procedures be added to Standardization requirements and included in the overall pilot evaluation score card. Furthermore, the only required signature on the Standardization Visit Procedures Checklist is that of the Aviation Training Center Instructor Pilot. The Pilot Under Inspection (PUI) nor the PUI's Commanding Officer or Operations Officer are required to sign the form. To improve accountability and transparency (e.g., control and feedback), it is recommended that the Coast Guard require the PUIs, and the PUI's Operations Officer's and Commanding Officer's, in addition to the Aviation Training Center Instructor Pilot's signature on the Procedures Checklist form.

Similarly, unit level Search and Rescue (SAR) Procedures Checks (periodic unit level review of pilots) do not require demonstration of proficiency of ditching procedures or the PUI's or PUI's

Operations Officer's or Commanding Officer's signatures on the form. Note: A copy of a SAR Procedures Checklist is included in Appendix D. Considering the importance of ditching proficiency to the safety of the air crew, it is recommended that ditching procedures also be added to the SAR Procedures Check List and the Coast Guard require the PUI and the PUI's Operations Officer and Commanding Officer sign the form following inspection/check.

Additionally, although Aviation Training Center included hoisting operations and fouling (e.g., hoist entanglement) procedures in its annual Standardization Visits, they are not included in the annual simulator training conducted at Aviation Training Center. Considering the high-risk nature of night time hoisting operations, the Coast Guard should consider adding night time hoisting operations and fouling procedures to its simulator training curriculum.

Finally, the Coast Guard MAB report cites a cultural force across the Coast Guard compelling pilots to return to their base with the aircraft, even if it means placing the crews in danger as a contributing factor in the mishap [28]. This stems from a lack of leadership, training, and operational policy emphasis regarding the imperative to ditch an aircraft whenever there is severe damage or the crew's safety is jeopardized by continued flight. As the "owner" of operational tactics, training, and procedures, Aviation Training Center is a key contributor to this unsafe posture and must play an active role in overcoming the cultural barrier to ditching aircraft after sustaining severe damage. It is recommended that Aviation Training Center, FORCECOM, the Office of Aviation Forces (CG-711), and the Aviation Safety Division (CG-1131) work together to collectively emphasize the importance of ditching following severe damage through the following actions:

- Improve ditching training through increased training and evaluation of pilots/crew in operational environments (e.g., Standardization Visit) and increased emphasis of importance.
- Update policies to reflect safety of crew being paramount to safety/sustainment of aircraft. For example, the Coast Guard's Air Operations Manual includes the following statements that appear to emphasize the safety/sustainment of the aircraft on par with the safety of the crew [23]:

“The safety of the aircrew *and aircraft* must always be one of the primary considerations integrated into the fabric of aviation mission planning and execution.”

“The fundamental reasons for a comprehensive aviation safety program are the well being of personnel and the *preservation of limited resources*.”

“Tools like crew utilization standards are not designed to hinder operational commanders in mission planning or execution; rather, they are designed to minimize injury and *damage and to preserve limited capital and personnel resources for future use*.”

Although it is difficult to attribute causation of the Coast Guard’s aviation community’s cultural aversion to ditching to policy statements like the ones listed above, it is clear that these statements treat crew and aircraft safety as equals. Therefore, to help overcome the Coast Guard’s cultural barriers with respect to ditching, it is recommended that these statements be adjusted to clearly state the safety of the crew as paramount to the aircraft, including removal of statements referring to limited capital resources.

- Unlike other military services (e.g., U.S. Air Force, U.S. Navy), the Coast Guard does not have an “attrition reserve” (sometimes referred to as a “crash spare” inventory) for its aircraft inventory. Attrition reserve is defined by the Department of Defense as, “aircraft procured for the specific purpose of replacing the anticipated losses of aircraft due to peacetime and/or wartime attrition.” [5]. Operating without an attrition reserve, all of the Coast Guard’s aircraft are fully employed either in operations, training, or maintenance at any given time. If an aircraft is lost in a mishap, this results in a direct reduction in flight time available to perform Coast Guard missions. Following the loss of an aircraft, the Coast Guard will consider requesting funding to replace the aircraft.

At a minimum, this will take two years to receive funding and procure the aircraft, and typically comes at the cost of another planned procurement. Some aircraft are never replaced, largely due to constrained budgets. For example, the Coast Guard has not yet replaced the CG-6505 airframe lost in 2008 despite a significant gap in available versus required flight hours [33]. Other military branches have attrition reserve inventories, representing as much as 15 percent of overall inventory depending upon aircraft type and mission, where aircraft are immediately available to replace lost aircraft [6, 9]. Based on discussions with aviation program management personnel [14], although there is no proof that the lack of an attrition reserve inventory influences pilot/aircrew behavior, it is plausible that the inability to replace lost aircraft (e.g., lack of crash spare inventory) could be contributing to the cultural barriers to ditching aircraft following mishaps resulting in severe damage to the aircraft. In order to improve operational safety and effectiveness, it is recommended that the Coast Guard work with the Department of Homeland Security, Office of Management and Budget, and Congress to procure a crash spare inventory proportionally similar to that of the other branches of the Armed Forces based on aircraft type and mission profile.

Based on the above analysis/discussion, the following control/feedback inadequacies involving Aviation Training Center existed at the time of the CG-6505 mishap:

Control/Feedback Inadequacies

- Inadequate Control/Feedback – Lack of Standardized Ditching Training – Lack of standardized training (observation and reporting) of ditching procedures.
- Inadequate Control – Lack of emphasis on Ditching & Paramount Importance of Life Safety – Lack of emphasis on importance of ditching an aircraft following severe damage.
- Inadequate Control/Feedback – Lack of Standardized Night-Time Hoist Training – Lack of standardized simulator training (observation and reporting) of night-time hoist and fouling procedures.

Note: The above discussion regarding recommendations to modify Coast Guard aviation policy [23] to clarify the ultimate importance of crew safety and to procure an attrition reserve to counter the cultural barriers to ditching relate primarily to responsibilities that fall under the Coast Guard Office of Aviation Forces. Therefore, inadequacies in control/feedback related to these issues are not included in this section (Aviation Training Center) of the thesis. Instead, this discussion is referenced in the subsequent analysis of the Office of Aviation Forces along with documentation of associated control/feedback inadequacies.

Safety-Related Responsibilities (Interviews, ATC web page)

- Develop and promulgate standardized flight procedures.
- Provide core training for rotary wing and fixed wing pilots, rescue swimmers and aircrews for air stations Coast Guard wide. Provide all Coast Guard pilots with initial training and annual proficiency refresher training held at the Aviation Training Center.
- Conduct annual aviation Standardization Visits at all operational aviation units to evaluate adherence to these procedures.
 - Examine the air station's training program;
 - Ensure desired skills and standards are taught by designated instructors;
 - Review aviator proficiency under actual conditions; and
 - Provide refresher training opportunities.
- Serve as the Coast Guard's aviation training, techniques, and procedures development center.
 - Identify helicopter operational requirements and associated gaps. Communicate requirements/gaps to Coast Guard Office of Aviation Forces.
- Identify capabilities requirements to improve safety/efficiency of tactics, techniques, and procedures.

Context

- All pilots and aircrew on CG-6505 attended required training at Aviation Training Center (ATC) within the last year.
- The last Standardization Visit that ATC performed at Air Station Barbers Point preceding this accident was in 2007 (within prescribed timeframes).
- Review and testing of ditching procedures is not part of the annual Standardization Visit requirements, however, it is often discussed informally as part of the visit. Ditching procedures are covered in a simulator setting at the annual training conducted at ATC.
- Review and testing of hoist damaged/fouled procedures is part of the annual Standardization Visit requirements. However, hoist training is not part of the annual simulator training held at the ATC.

Figure 5.7 (1 of 2) – Coast Guard Aviation Training Center Level Analysis

Unsafe Decisions and Control Actions

- ATC did not adequately train pilots on ditching procedures. Ditching procedures are not a required element of the Standardization Visits and there is no record that ditching procedures were discussed during the ATC Standardization Visit to Coast Guard Air Station Barbers Point in 2007. Furthermore, review of the annual ditching simulator training conducted at ATC found that it did not provide an adequate/realistic training environment for personnel receiving training.
- ATC did not adequately emphasize the importance of ditching an aircraft to preserve crew safety following a mishap that results in severe damage to the aircraft.

Process Model Flaws

- Inaccurate assessment of risk of entangling hoist.
- Inaccurate assessment of aviation community's proficiency with respect to aircraft ditching procedures.
- General acceptance of risk associated with nighttime hoisting operations. Belief that routine pilot over-control (approaching too close to the small boat) and over-torque (exceeding the safe torque limits of the aircraft to correct for mis-positioning of aircraft) during night training/operations is acceptable.

Figure 5.7 (2 of 2) – Coast Guard Aviation Training Center Level Analysis

Coast Guard Force Readiness Command (FORCECOM) – Norfolk, VA

FORCECOM was officially established in 2009 to, “enhance readiness using enterprise-wide analysis and standardized doctrine, training, tactics, techniques, and procedures to best allocate forces for sustainable mission execution.” [32]. During 2008, preceding the CG-6505 mishap, the Coast Guard was in the process of establishing FORCECOM and transitioning oversight and management of Aviation Training Center from the Office of Aviation Forces to FORCECOM. While this transition certainly created a distraction to those charged with programmatic management and oversight of the Coast Guard’s aviation program (e.g., Office of Aviation Forces, Aviation Training Center, Aviation Safety Division, and air stations), this did not significantly contribute to the CG-6505 mishap.

Note: Although FORCECOM was not formally established at the time of the CG-6505 mishap, many of its elements were established/functioning at least informally. For the purpose of this analysis and to maximize the potential for lessons learned that are applicable to the Coast Guard’s current organizational structure, this analysis includes FORCECOM as a functioning entity at the time of the mishap.

Considering FORCECOM provides oversight and management of Aviation Training Center, and is charged with performing many of the same roles and responsibilities with respect to training, tactics, and procedures, albeit at the service-level, vice community-level (e.g., aviation community), many of the safety related responsibilities, context, unsafe decisions and control actions, and process model flaws listed in Figure 5.8 are very similar to those listed for the Aviation Training Center (Figure 5.7). However, the role of Service-wide readiness provider was initiated with the establishment of FORCECOM and creates several opportunities and some challenges for the Coast Guard in terms of reducing hazards in the aviation community moving forward. Considering other elements of FORCECOM’s influence on aviation safety are covered in the Aviation Training Center level analysis, the remainder of this discussion is focused on this unique Service-wide readiness manager role of FORCECOM.

A key opportunity created by the establishment of FORCECOM is to standardize training and execution of tactics, techniques, and procedures associated with programs that cut across various

communities. For example, Crew Resource Management and Operational Risk Management tactics, techniques, and procedures within the aviation community, are managed by the Aviation Safety Division. However, many of the Crew Resource Management and Operational Risk Management tactics, techniques, and procedures are similar regardless of community. That is, with respect to Crew Resource Management and Operational Risk Management, what works for aviators, generally works for ship operators, small boat operators, marine safety specialists, etc. Currently, these programs are being managed at the community level resulting in lack of standardization, unnecessary overhead and program management redundancy, and perhaps conflicting approaches across the Coast Guard. Furthermore, as shown in the analysis documented in the Aviation Safety Division section of this thesis, because the Aviation Safety Division relies on several sources for the training (e.g., Aviation Training Center, Aviation Technical Training Center, and Air Station Flight Safety Officers), there is a lack of standardization with respect to Crew Resource Management and Operational Risk Management training even within the aviation community.

Because poor Crew Resource Management was cited in the Coast Guard's CG-6505 MAB as a contributing cause to the CG-6505 mishap (decision not to ditch aircraft following severe damage) [28] and it is identified as at least a contributing cause in most recent Coast Guard aviation mishaps (ASAAP), it is recommended that the Coast Guard leverage the establishment of FORCECOM to develop a Coast Guard-wide standardized Crew Resource Management and Operational Risk Management readiness program to better deliver training and improve Service-wide proficiency in these critical operational skill sets. Establishing a centrally managed, standardized program overseen by experts in training development and delivery is expected to raise leadership awareness, heighten priority, and improve the effectiveness of these programs.

Similarly, establishment of FORCECOM provides an opportunity to better manage training, tactics, techniques, and procedures across platforms (e.g., helicopters and small boats). For example, the Coast Guard's CG-6505 MAB report identifies the inability of the boat crew and aircrew to communicate directly as a general contributing cause to the mishap. Additionally, the CG-6505 MAB report cites the design of the small boat (e.g., protruding dewatering standpipe) as a contributing factor to the entanglement of the hoist. It is possible that synthesized

management of training, tactics, techniques, and procedures, as offered by FORCECOM, could enable early identification of cross-platform safety hazards such as these and allow for preventive mitigation in the future. To address such issues, as part of its recommendations, the Coast Guard's CG-6505 MAB report calls for, "[evaluation of] requirements of system safety integration into Coast Guard asset/acquisition design procedures." Consistent with the above discussion, it is recommended that FORCECOM be included in the process to integrate system safety into Coast Guard asset/acquisition design procedures.

As alluded to previously, there are challenges associated with the establishment of FORCECOM. For example, creation of FORCECOM not only removes Aviation Training Center from the Office of Aviation Forces chain of command, it also places a management and oversight layer above the Aviation Training Center. While splitting the capability requirements managers (e.g., Office of Aviation Forces) from the training, tactics, and procedures managers (e.g., Aviation Training Center) creates a healthy tension within the capabilities management organization, it could hinder communications between Aviation Training Center and the Office of Aviation Forces if not managed adeptly. The Coast Guard should take care to ensure the Office of Aviation Forces and Aviation Training Center continue to coordinate closely (informally and formally) regarding development of capabilities requirements, training, tactics, techniques, and procedures.

Similar to the Aviation Training Center, the following control/feedback inadequacies are noted with respect to FORCECOM's current role as the Service-wide readiness provider as they relate to the CG-6505 mishap:

Control/Feedback Inadequacies

- Inadequate Control/Feedback – Lack of Standardized Ditching Training – Lack of standardized training (observation and reporting) of ditching procedures.
- Inadequate Control – Lack of emphasis on Ditching & Paramount Importance of Life Safety – Lack of emphasis on importance of ditching an aircraft following severe damage.

- Inadequate Control/Feedback – Lack of Standardized Training – Lack of standardized management (e.g., development and implementation) of Crew Resource Management and Operational Risk Management training, tactics, techniques, and procedures.

Safety-Related Responsibilities

- Optimize Coast Guard force readiness through establishing and implementing standardized training, tactics, techniques, and procedures and measuring compliance with readiness requirements.
- Provide oversight and management of Aviation Training Center in the execution of their duties.
 - Establish standardized operational tactics, techniques and procedures that grow out of field innovations, best practices and lessons learned.
 - Establish standardized operational policies and training to ensure force interoperability and readiness.
 - Conduct coordinated and standardized inspections and assessments, followed by analysis, that contribute to operational readiness.

Context

- At the time of the accident, FORCECOM was just being established and ATC was being transitioned from CG-711's oversight to FORCECOM.
- Standardized operational tactics, techniques, and procedures were in place at the time of the accident, including Coast Guard Air Operations Manual, Coast Guard Shipboard Aviation Operations Manual, etc.
- Lack of integration in management across aviation platforms and system-wide perspective in hazards analysis.
- The responsibility to identify capability requirements is diffused across multiple entities including the Coast Guard Air Stations, FORCECOM, ATC, and Office of Aviation Forces.
- Lack of standardized/centralized Operational Risk Management and Crew Resource Management training program across Coast Guard Aviation/Coast Guard overall (Diffused across ATC, Aviation Technical Training Center, and unit FSOs)

Figure 5.8 (1 of 2) – Coast Guard FORCECOM Level Analysis

Unsafe Decisions and Control Actions

- FORCECOM did not integrate hoisting operational tactics, training, and procedures to ensure interoperability across all Coast Guard operational platforms. Resulted in hoist entanglement hazard (protruding dewatering pipe) on the deck of the Coast Guard's 47-foot small boat fleet.
- FORCECOM did not provide boat crew with ability (e.g., capabilities, tactics, techniques, and/or procedures) to communicate with aircrew during helicopter/hoisting operations.
- Inadequate Operational Risk Management and Crew Resource Management training program.
- FORCECOM did not emphasize ditching procedures during its previous annual Standardization Visit to Air Station Barbers Point.
- FORCECOM did not emphasize hoist fouled/damaged emergency procedures during its previous annual Standardization Visit to Air Station Barbers Point.

Process Model Flaws

- Inaccurate assessment of the need for the boat crew (in addition to the boat coxswain) to be able to communicate with the helicopter aircrew during hoisting operations.
- Inaccurate assessment of risk of entangling hoist.
- Inaccurate assessment of aviation community's proficiency with respect to aircraft ditching procedures.
- General acceptance of risk associated with nighttime hoisting operations. Belief that routine pilot over-control (approaching too close to the small boat) and over-torque (exceeding the safe torque limits of the aircraft to correct for mis-positioning of aircraft) during night training/operations is acceptable.

Figure 5.8 (2 of 2) – Coast Guard FORCECOM Level Analysis

Coast Guard Office of Aviation Forces – CG Headquarters, Washington, DC

The Coast Guard Headquarters Office of Aviation Forces (CG-711) is perhaps the center of gravity of the Coast Guard aviation program with control and feedback linkages to multiple entities on both the System Operation and System Development sides of the hierarchical system Safety Control Structure. The Office of Aviation Forces' roles and responsibilities include providing the Coast Guard aviation community (e.g., Coast Guard Sectors and Air Stations) with capabilities in the form of resources, doctrine, oversight, and training programs to support safe and effective execution of Coast Guard missions.

For example, per the System Operation Safety Control Structure (Figure 5.3) and the safety related responsibilities listed in Figure 5.9, the Office of Aviation Forces provides control over the aviation operational community (e.g., air stations, FORCECOM (and Aviation Training Center indirectly)) by providing operational policy [23] and capabilities (e.g., helicopters) to the fleet. Feedback is provided to the Office of Aviation Forces from the air stations, and FORCECOM/Aviation Training Center in the form of capability gaps, ideally via annual Operational Analysis assessments.

From a System Development perspective (Figure 5.2), as the Coast Guard's Aviation Capabilities Program Manager, the Office of Aviation Forces maintains the following control/feedback linkages:

- Coast Guard Air Stations – The Office of Aviation Forces provides Coast Guard Air Stations with aviation capabilities to meet their mission needs. The Air Stations provide feedback to the Office of Aviation Forces in the form of mission needs/capability gaps.
- Interfacing Capabilities – The Office of Aviation Forces has a similar control/feedback relationship with interfacing capabilities (e.g., small boats) as described above for Air Stations. In the case of Coast Guard-owned/operated small boats, the Office of Aviation Forces coordinates this control/feedback with the Coast Guard's Office of Boat Forces. Note: The Coast Guard's Office of Boat Forces has similar responsibilities with respect to boat forces management to that of the Coast Guard's Office of Aviation Forces' responsibilities for aviation forces management.

- Aviation Safety Division – The Office of Aviation Forces provides feedback to the Aviation Safety Division in the form of operational requirements. The Aviation Safety Division exercises control/provides feedback via establishing safety requirements and guidance for the development of capability, training, tactics, techniques, and procedures.
- Coast Guard Acquisition Directorate – The Office of Aviation Forces provides control through establishing capability requirements and providing acquisition funding to the Coast Guard Acquisition Directorate. The Acquisition Directorate provides feedback by provisioning required capabilities and conducting testing and evaluation.
- HH-65 and HH-60 Platform Managers – Within the Office of Aviation Forces, there are two distinct helicopter Platform Managers, one for each the HH-65 and HH-60 platforms, to assist the office in carrying out its capability management roles and responsibilities with respect to helicopters. In addition to supervisory control, the Office exercises control over the individual Platform Managers by integrating/standardizing requirements when operationally feasible. Feedback is provided by the Platform Managers to the Office through documentation of operational capability requirements. The two Platform Managers coordinate with each other via informal information exchange.

As the Coast Guard’s aviation capabilities program manager, the following discussion and recommendations regarding aviation capability management and operational policy inadequacies most directly apply to the Office of Aviation Forces. That said, the Office of Aviation Forces must work with other entities within the aviation capabilities management organization (e.g., Aviation Training Center, FORCECOM, Aviation Safety Division) to best/fully address these deficiencies.

Aviation Operational Capability Requirements Management Deficiencies

As listed in Figure 5.9, the Office of Aviation Forces, in conjunction with the Aviation Training Center, FORCECOM, Coast Guard air stations, and Aviation Safety Division did not identify/document several capability requirements, including a dynamic hoist clutch assembly, hoist entanglement sensor system, night time hover/hoisting assistance capabilities, night time

ditching capabilities, and boat crew to air crew communications capabilities (see Physical System Analysis Section for additional details regarding these capability shortfalls). While these capability shortfalls become much more obvious post-mishap, what is also obvious through the STAMP/CAST analysis process is that the Coast Guard's Capabilities Management Organization (in the case of aviation this includes Office of Aviation Forces, FORCECOM, Aviation Training Center, and Aviation Safety Division) is not conducting formal periodic reviews of existing capabilities to identify capability gaps due to changes in mission requirements, equipment obsolescence, state-of-the-market changes, or identification of new/modified safety hazard analyses.

In fact, despite the Coast Guard having a policy to conduct such an Operational Analysis on existing capabilities on an annual basis, the Coast Guard has *never* performed such a capability requirement review in the 24 years that it has operated the HH-65 helicopter.

Per the Coast Guard's Major Systems Acquisition Manual [31],

“Operational Analysis (OA) is used to assess an asset/system's ability to continue to effectively perform its missions in a cost effective manner. The analysis is required by the Office of Management and Budget (OMB) and the Department of Homeland Security (DHS) and is to be done by the sponsor (the Office of Aviation Forces in the case of the HH-65 platform) on an annual basis. By definition, OA is a method of examining the current performance of a steady-state operation (typically an asset or service in the Support Phase) and measuring that performance against an established set of cost, schedule, and performance parameters. The analysis should demonstrate a thorough examination of the need for the asset or service, the performance being achieved by the asset or service, the advisability of continuing the asset or service, and alternative methods of achieving the same results.”

Furthermore, according to OMB policy [20],

“Operational analysis may indicate a need to redesign or modify an asset if previously undetected faults in the design, construction, or installation are

discovered during the course of operations; if operational or maintenance costs are higher than anticipated; or if the asset fails to meet program requirements.”

According to aviation program management personnel, it is during these OAs where the Coast Guard would identify a requirement for a new/modified capability, tactic, technique, or procedure on an existing asset in order to more effectively or safely perform a mission [14]. The failure to perform an OA over the 24-year lifetime of the HH-65 airframe begins to explain why the Coast Guard aviation capabilities management organization did not identify the need for a dynamic hoist clutch until after the CG-6505 mishap. Considering that a dynamic hoist clutch was “state of the market” technology in 1990 and came with the aircraft as standard equipment when the Coast Guard acquired the HH-60 helicopter platform (medium range helicopter with similar mission profile to the HH-65 short range helicopter) from Sikorsky that same year [11], it is likely that an OA performed on the HH-65 post-1990 would have resulted in at least identification of a potential upgrade in hoist capability for improved operational effectiveness/safety, if not replacement of the HH-65 hoist system. Note: The requirement for an annual OA has been in place since at least 2006 per the Coast Guard Major Systems Acquisition Manual, COMDTINST M500.10, however, has been referenced in Coast Guard Acquisition Policy since at least 1992 [31, 34].

Based on discussions with Coast Guard aviation program management personnel, the reason OAs are not being performed is because OMB and DHS have not held Coast Guard’s “feet to the fire) (e.g., OMB and DHS have not held the Coast Guard accountable to the requirement and have not provided adequate control over the OA process). It is interesting to note that the Coast Guard’s Major Systems Acquisition Manual, the policy document that requires the OA, although being a Commandant (Service Chief) Policy, falls under the oversight and control of the Coast Guard’s Acquisition Directorate. None of the operational capability program management entities (e.g., Office of Aviation Forces, FORCECOM, Aviation Training Center, Aviation Safety Division) report to/fall under the control of the Acquisition Directorate. This fracture in capability management oversight responsibilities results in missing/inadequate control and feedback over and within the operational capability requirements management process.

Considering the importance of robust operational capabilities to the Coast Guard’s ability to

safely and effectively execute its missions, it is recommended that the Coast Guard hold itself accountable to the prescribed annual OA process and shift oversight from the OMB, DHS, and the Acquisition Directorate to an entity within the Office of Aviation Forces' chain of command.

Furthermore, it appears that, in the absence of OAs, the Coast Guard's Office of Aviation Forces is relying on the reporting of capability-related mishaps in existing Coast Guard computer databases (e.g., ALMIS) to identify safety-related capability needs. However, considering that 19 hoisting entanglements (14 of which involved HH-65 helicopters) were recorded in ALMIS between the years of 1992 and 2007 [14] and no action was taken to upgrade the hoist system (e.g., upgrading to a dynamic slip clutch capability as installed on the HH-60 platform), indicates the current capabilities management system is not effective in capturing safety-related capability requirements.

Additionally, the fact that the HH-60 operated for 18 years with a dynamic hoist clutch while the HH-65 operated without this needed capability indicates an inadequacy in control/feedback specific to the Office of Aviation Forces' ability to integrate requirements/capabilities/hazard management across platforms. It is recommended that the Office of Aviation Forces more formally document, integrate, and standardize, where possible, individual platform capabilities.

Recommended Aviation Policy & Capability Changes to Counter Cultural Impediments to Ditching:

As discussed in detail in the Aviation Training Center section of this CAST analysis, current operational aviation policies and lack of an attrition reserve inventory of aircraft may be contributing to the Coast Guard's cultural barriers preventing ditching of aircraft following sustaining major damage in order to preserve the safety of the pilot/crew. Considering the Office of Aviation Forces is the Coast Guard's program manager for the Coast Guard Air Operations Manual and sponsor for the acquisition of new aviation capabilities, it is recommended that the Office of Aviation Forces lead the revision of operational aviation policies to clearly state the paramount importance of crew safety over aircraft survivability and to acquire additional aircraft commensurate with similar Department of Defense best practices.

Based on the above analysis, the following inadequacies regarding control/feedback within the Coast Guard's Capabilities Management Organization, specifically the Office of Aviation Forces, are identified:

- Inadequate Control/Feedback – Lack of Periodic Capabilities Review/Communication – Lack of formal periodic capability gap assessment (e.g., OA) required/performed. Lack of oversight/control over OA requirements. Lack of systematic approach (e.g., STAMP-based process analysis - STPA) to OA. Lack of ability to identify/track capability requirements and related safety hazards.
- Inadequate Control/Feedback – Lack of Integrated Capability Management – Lack of formal integration/standardization of helicopter operational capabilities across platforms.
- Inadequate Control – Inadequate Aviation Operational Policy – Lack of clear guidance regarding paramount importance of crew safety (over aircraft survivability).
- Inadequate Control – Insufficient Aviation Capacity – Lack of attrition reserve to sustain operational requirements despite the attrition of aircraft due to peacetime and/or wartime mishaps/losses.

Figures 5.9 and 5.10 summarize the safety related responsibilities, context, unsafe decisions and control actions, and process model flaws of the Office of Aviation Forces and the HH-65/60 Platform Managers, respectively.

Safety-Related Responsibilities

- Provide the Coast Guard aviation community (e.g., Coast Guard Sectors and Air Stations) with capabilities in the form of resources, doctrine, oversight, and training programs to support safe and effective mission execution:
 - Ensure proper funding and resources are provided to all Coast Guard aviation units.
 - Oversee/manage all short and long-term aviation specific projects.
 - Manage all operational Coast Guard Aviation helicopter platforms (e.g., HH-65 Dolphin and HH-60 Jayhawk). Identify capability requirements for each individual platform and integrate capability requirements across platforms as appropriate.
- Provide the Coast Guard aviation community (e.g., Coast Guard Sectors and Air Stations) with operational policy to govern Coast Guard aviation operations.

Context

- The Office of Aviation Forces works with Coast Guard operational commanders (Sector and Air Station Commands) mission Program Managers, Aviation Training Center, FORCECOM, and the Aviation Safety Division to develop and validate aviation capability requirements.
- The Office of Aviation Forces provides funding and aviation capability requirements to the Coast Guard Acquisition Directorate to initiate Coast Guard aviation major system acquisitions.
- The Office of Aviation Forces works closely with the Acquisition Directorate throughout acquisition programs, ultimately accepting new capabilities upon validation that they meet the operational requirements through successful Operational Testing and Evaluation (OT&E).

Figure 5.9 (1 of 2) – Coast Guard Office of Aviation Forces Level Analysis

Unsafe Decisions and Control Actions

- Installed (accepted) and operated different hoist systems on HH-65 and HH-60 helicopter platforms despite similar mission profile.
 - Installed (accepted) and operated hoist system without dynamic clutch assembly on HH-65.
 - Did not identify requirement for dynamic clutch assembly on HH-65.
- Did not identify requirement (capability shortfall) for sensor system on HH-65 hoist system to indicate system overload.
- Did not identify requirement (capability shortfall) to aid in nighttime hover/approaches to avoid common pilot overcontrol/overtorque errors during nighttime hoisting operations.
- Did not identify requirement (capability shortfall) to aid in nighttime ditching operations.
- Did not identify requirement (capability shortfall) to aid in boat crew to air crew direct communications.
- Issued policy that did not clearly state the paramount importance of pilot/crew safety over that of sustaining the aircraft (e.g., personnel resources over capital resources).
- Did not adequately provision aircraft inventory to sustain required level of operations due to lack of attrition reserves.

Process Model Flaws

- Inaccurate assessment of nighttime hoisting operation capability requirements:
 - Failure to understand need for hoist sensing system (sense overload)
 - Failure to understand need for aircrew to communicate with boat crew directly
 - Failure to understand need to eliminate pilot tendency to overcontrol (approach too close to small boat).
 - Failure to understand need for improved visibility during nighttime emergencies to facilitate ditching.
- In accurate assessment of impact on Coast Guard aviators' operational tendencies/behavior resulting from strong central/policy emphasis on importance of protecting aircraft due to limited capital resources and lack of attrition reserves in the Coast Guard's aviation inventory.
- Inaccurate process model of small boat capabilities (due to lack of integration in management across aviation platforms and system-wide perspective in hazards analysis).

Figure 5.9 (2 of 2) – Coast Guard Office of Aviation Forces Level Analysis

Safety-Related Responsibilities

- As part of the Office of Aviation Forces, assist the Office in providing the Coast Guard aviation community (e.g., Coast Guard Sectors and Air Stations) with HH-65 and HH-60 helicopter capabilities in the form of resources, doctrine, oversight, and training programs to support safe and effective mission execution:
 - Manage the HH-65 and HH-60 helicopter platforms. Identify capability requirements for each helicopter and integrate capability requirements across platforms as appropriate.
 - Oversee/manage all short and long-term HH-65- and HH-60-specific projects.

Context

- Generally accepting of risks associated with nighttime hoist operations.
- Insufficient coordination and communication across HH-65 and HH-60 platform managers resulted in reduced integration in management across aviation platforms and system-wide perspective in hazards analysis.

Unsafe Decisions and Control Actions

- Installed (accepted) different hoist systems on HH-65 and HH-60 helicopter platforms despite similar mission profile.
 - Installed (accepted) hoist system without dynamic clutch assembly on HH-65.
- Did not identify requirement (capability shortfall) for sensor system on HH-65 hoist system to indicate system overload.
- Did not identify requirement (capability shortfall) to aid in nighttime hover/approaches to avoid common pilot overcontrol/overtorque errors during nighttime hoisting operations.
- Did not identify requirement (capability shortfall) to aid in nighttime ditching procedures.

Process Model Flaws

- Inaccurate assessment of nighttime hoisting operation capability requirements:
 - Failure to understand need for hoist sensing system (sense overload)
 - Failure to understand need for aircrew to communicate with boat crew directly
 - Failure to understand need to eliminate pilot tendency to overcontrol (approach too close to small boat).
 - Failure to understand need for improved visibility during nighttime emergencies to facilitate ditching.
- Over-emphasis on importance of protecting aircraft (on par with safety of crew).

Figure 5.10 – Coast Guard HH-65/HH-60 Platform Manager Level Analysis

Coast Guard Small Boat Station Honolulu and CG-47317 Boat Crew

Coast Guard Small Boat Station Honolulu played a minor/insignificant role in the causation of the mishap of CG-6505. The Small Boat Station's primary role per the Safety Control Structure (Figure 5.3) was to provide command and control over the small boat operations and obtain feedback from the small boat via communications. The other significant responsibility of the Small Boat Station was to ensure the required personnel were on board and qualified. The Coast Guard MAB found that the Small Boat Station performed all required duties adequately [28]. This CAST analysis concludes the same. With respect to the CG-47317, they failed to prevent the hoist from becoming entangled on the small boat, however, there was likely nothing they could do to prevent this given the circumstances/capabilities provided to them. As stated previously, they were unable to communicate to the helicopter aircrew that the hoist was entangled in time to prevent damage to the helicopter. This was due to the rapid nature of the operation and the lack of communications capabilities to allow direct communications between the aircrew and boat crew. This capability management control inadequacy was addressed in previous sections of this report. The Small Boat Station's and Boat Crew's safety related responsibilities, context, unsafe decisions and control actions, and process model flaws are summarized in Figure 5.11.

Safety-Related Responsibilities

- Approve, coordinate, and provide command and control over small boat operations (e.g., CG- training operations).
- Conduct training operations with Coast Guard Air Station Barbers Point safely.
- Ensure hoist does not become entangled during hoist operations.

Context

- Coast Guard Small Boat Station Honolulu routinely conducts training operations (e.g. multiple times per week) with helicopters from Coast Guard Air Station Barbers Point.
- Coast Guard Small Boat Station Honolulu approved Coast Guard Small Boat CG-47317 to conduct training operations with Coast Guard helicopter CG-6505 on the evening of the accident.
- Coast Guard Small Boat Station Honolulu boat crew had completed all required training and were compliant with all fatigue standards.

Unsafe Decisions and Control Actions

- Boat crew unable to communicate directly with pilot/aircrew when hoist became entangled on small boat aft buoyancy chamber dewatering pipe.

Process Model Flaws

- None.

Figure 5.11 – Coast Guard Small Boat Station Honolulu & CG-47317 Boat Crew Level Analysis

Coast Guard Sector Honolulu

Similar to Coast Guard Small Boat Station Honolulu, Coast Guard Sector Honolulu played a minor/insignificant role in the causation of the mishap of CG-6505. The Sector's primary role per the Safety Control Structure (Figure 5.3) was to provide command and control over the Small Boat Station Honolulu and Air Station Barbers Point operations and obtain feedback from each via communications. The other significant responsibility of the Sector was to ensure the required personnel were onboard the small boat and aircraft and possessed the proper qualifications. The Coast Guard MAB found that Coast Guard Sector Honolulu performed all required duties adequately [28]. This CAST analysis concludes the same. The Sector's safety related responsibilities, context, unsafe decisions and control actions, and process model flaws are summarized in Figure 5.12.

<p>Safety-Related Responsibilities</p> <ul style="list-style-type: none">• Approve, coordinate, and provide command and control over operations conducted by Coast Guard Air Station Barbers Point and Coast Guard Small Boat Station Honolulu.• Ensure Coast Guard Air Station Barbers Point satisfies training and qualification requirements. <p>Context</p> <ul style="list-style-type: none">• Coast Guard Sector Honolulu approved the training operations between Coast Guard Air Station Barbers Point and Coast Guard Small Boat Station Honolulu on the evening of the accident. <p>Unsafe Decisions and Control Actions</p> <ul style="list-style-type: none">• None. <p>Process Model Flaws</p> <ul style="list-style-type: none">• None.

Figure 5.12 – Coast Guard Sector Honolulu Level Analysis

Interfacing Capabilities – Coast Guard Office of Boat Forces

The Coast Guard routinely conducts operations with various types of assets, including Coast Guard small boats, Coast Guard cutters (larger ships), and assets from other Federal, state, and local industries. Since this accident involved a Coast Guard Small Boat, the following analysis is from the perspective of Coast Guard small boat capability managers (Coast Guard Office of Boat Forces), however, could be applied universally to examine management of all interfacing capabilities.

Per the Safety Control Structure (Figure 5.3), the Office of Aviation Forces coordinates with the Office of Boat Forces by passing down aviation capability requirements and aligning that with similar information provided by the Office of Boat Forces. As cited in the Coast Guard CG-6505 MAB [28], this coordination/control/feedback process was not performed adequately resulting in the Coast Guard's 47-foot small boat design including a protruding dewatering standpipe which caused a significant safety hazard which contributed to the mishap.

Additionally, the Coast Guard MAB also cited the inability of the boat crew to communicate directly with the aircrew as a contributing factor to the mishap. The Coast Guard MAB final report included the following recommendations associated with management of interfacing capabilities [28]:

- Create and mandate use of a protective shroud to cover the 47-foot small boat engine room dewatering standpipe on the aft buoyancy chamber's forward face during hoisting operations.
- Evaluate requirements of system safety integration into Coast Guard asset/acquisition design procedures.
- Conduct a formal Operational Hazard Assessment of helicopter hoisting operations with small boats.
- Update operating and training manuals accordingly.

This CAST analysis concurs with these MAB recommendations. Additionally, it is recommended that the Coast Guard interfacing capability program managers (e.g., Office of Boat Forces) be included in the process to integrate system safety into Coast Guard asset/acquisition design procedures. Note: This is a common problem in interfacing organizations. In this case,

the Office of Aviation Forces (and as a result the entire Capabilities Management Organization) had an incorrect process model regarding Coast Guard 47-foot small boat capabilities. This process model inaccuracy can be best corrected in a sustained manner by requiring review of interfacing capabilities (e.g., small boat capabilities) along with review of helicopter capabilities.

It is worth mentioning that the above recommendations address inadequacies in the design/development of capabilities. Execution of the aforementioned periodic coordinated Operational Analysis process may have detected these capability shortfalls post-design/procurement and is critical to adopt in conjunction with design/development-related recommendations to address overall systemic capability management control/feedback inadequacies.

Figure 5.13 summarizes the Office of Boat Forces' (Interfacing Capabilities) safety related responsibilities, context, unsafe decisions and control actions, and process model flaws.

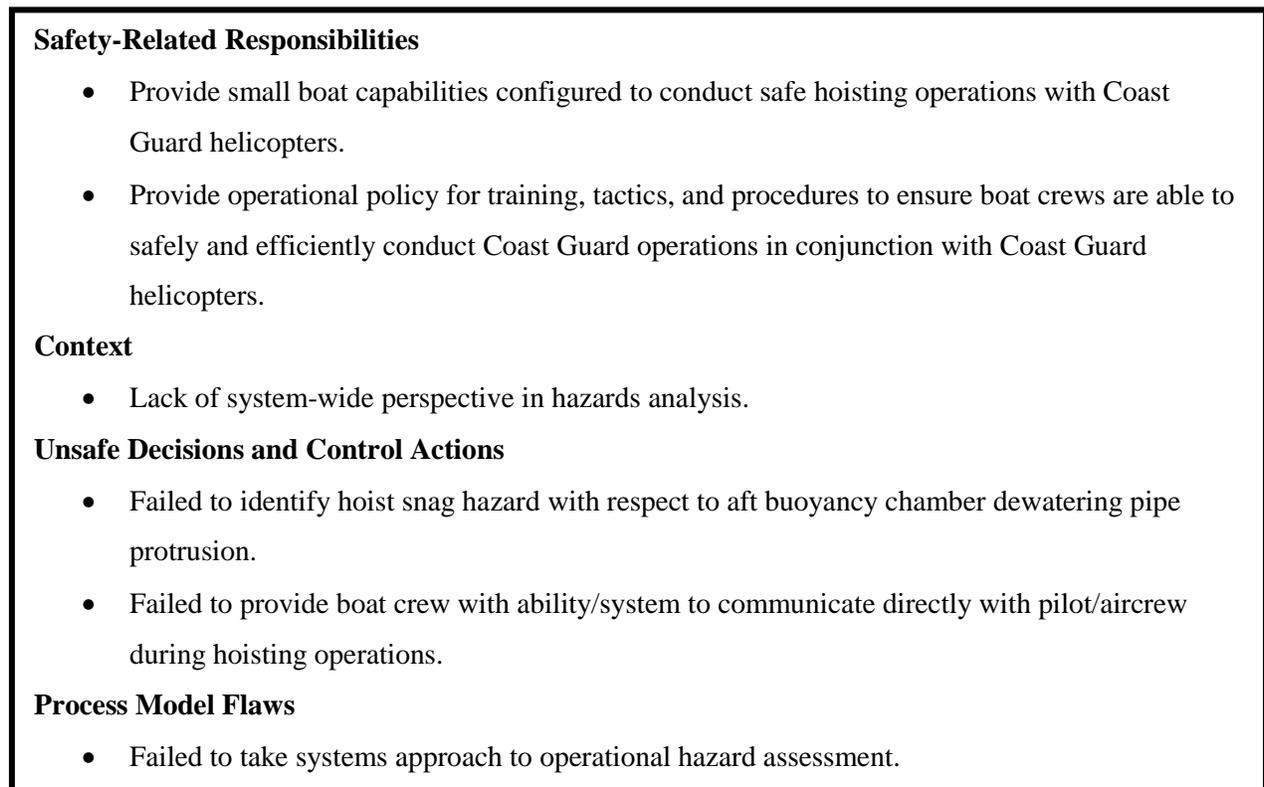


Figure 5.13 – Interfacing Capabilities Level Analysis

Coast Guard Acquisition Directorate – CG Headquarters, Washington, DC

Per the system development Safety Control Structure (Figure 5.2), the Acquisition Directorate receives control from the Office of Aviation Forces in the form of operational capability performance requirements and associated funding to acquire those capabilities. The Acquisition Directorate provides feedback to the Office of Aviation Forces in the form of acquired capabilities, and testing and evaluation to demonstrate operational effectiveness (e.g., satisfaction of performance requirements) of those capabilities. Furthermore, the Acquisition Directorate exercises control over industry (e.g., capability designers, developers, and manufacturers) in the form of contractual requirements. Industry then provides feedback to the Acquisition Directorate through provisioning designs, capabilities, and testing and evaluation.

It is worth mentioning that the Coast Guard's Acquisition Directorate, established originally in 1986, significantly revamped into its current form in 2006 as part of fairly recent comprehensive reform of its acquisition processes and organizational structure to address documented deficiencies in the Coast Guard's overall acquisition process [12, 14, 27]. These reformed processes and organization were not in place at the time of the acquisition events in question. For example, the HH-65 was originally acquired in 1981-1984 and the scoping effort for the modernization of the aircraft (e.g., upgrading engines, avionics, navigation, and weapons systems) was largely done in the early 2000s [25]. Additionally, the design and original procurement of the 47-foot motor lifeboat occurred from 1988-1997 [13]. Many of the unsafe decisions and control actions described below that were performed during these acquisition events were due to inadequate controls/feedback that have been addressed through the Coast Guard's recent acquisition reform efforts. That said, the acquisition processes in place at the time of these acquisitions did not have adequate control/feedback mechanisms in place to prevent hazards. It is from this perspective that the following analysis is based on.

The Coast Guard CG-6505 MAB final report concludes that with respect to the acquisition of the HH-65 helicopter and the 47-foot motor life boat, there were two factors in the acquisition and design process that influenced the outcome of the incident [28]:

- With respect to the hoist assembly, the MAB report concludes, “When the HH-65 was purchased in the 1980s, there was no service requirement to conduct a formal system

safety and hazard analysis. This requirement has been established with the incorporation of the [Major Systems Acquisition Manual], but is not yet a mature and well defined process in application. In this case, the hoist assembly as integrated into the HH-65 at the time of acquisition had latent hazards that were not envisioned, documented or experienced until this incident.”

- With respect to the motor life boat, the MAB report concludes, “A snag hazard on the motor life boat (the dewatering standpipe) contributed to the mishap in that it is located in the primary hoist training area and was not specifically identified as a potential hazard. Multiple snag hazards exist on all boats; the significance of the dewatering standpipe is that its presence in the hoist area was not widely known by aircrews.”

To address these deficiencies, the MAB recommends that the Acquisition Directorate, along with various sponsor offices (e.g., Office of Aviation Forces), “shall evaluate the current organizational requirements of system safety integration as applied to acquisition decisions at all levels and prepare a report on any identifiable gaps with solutions to the Vice Commandant within six months of release of this report.” [28].

This STAMP/CAST analysis certainly concurs with these findings and recommendation regarding a lack of system level approach to safety within the acquisition system at the time of the acquisition of the HH-65 and 47-foot Motor Life Boat fleet. However, close examination of the Safety Control Structure and associated control/feedback processes reveals specific control/feedback inadequacies within the acquisition system that may persist today despite the recent acquisition reforms:

- Inadequate Control/Feedback – Sponsor/User involvement in design/development:
During the modernization of the HH-65 airframe over the eight years preceding the CG-6505 mishap (2001-2008), the Coast Guard affected major upgrades to the HH-65 platform, including replacing existing engines with more powerful variants and upgrading the avionics system. It is noteworthy that during this timeframe, the HH-60 helicopter was operating with a dynamic slip clutch hoist assembly. Had the HH-60 platform manager or HH-60 pilots/flight mechanics been consulted during this modernization, the requirement to upgrade the hoist assembly may have been identified.

Furthermore, had helicopter pilots/flight mechanics/boat crewman been consulted during the design and development of the 47-foot motor life boat, the dewatering standpipe design may have been altered to mitigate the associated hoist snag hazards.

- Inadequate Control/Feedback – Sponsor capability and requirements cataloguing: Based on discussions with aviation program management personnel, in the years preceding the CG-6505 mishap, the Coast Guard did not maintain a systematic process for documenting existing system and sub-system capabilities and operational capability gaps. In fact, according to Coast Guard databases, 19 hoisting entanglements (14 of which involved HH-65 helicopters) were recorded between the years of 1992 and 2007, several of which resulted in the parting of hoist cables and significant forces applied to the airframes involved [14]. However, as there was no action taken to address this recurring safety hazard. A systematic process for documenting existing system and sub-system capabilities, related safety hazards, and operational capability gaps would facilitate comparative analysis of capabilities across platforms (e.g., identifying differences in hoist capabilities between HH-65s and HH-60s) and ensure all capability shortfalls are addressed, or at least documented and considered, during asset modernization scoping.
- Inadequate Control/Feedback – Coast Guard Acquisition Directorate and Industry: During initial acquisition of the HH-65, there is no record of discussion with industry regarding state of the market hoist systems. At the time of the acquisition from Eurocopter, it is not clear whether or not Sikorsky was installing dynamic slip clutch hoist systems on their aircraft as standard equipment. (Note: Coast Guard aviation capability managers were able to determine that Sikorsky was installing dynamic slip clutch hoist systems as standard equipment as far back as 1990, however, were not able to determine if this was the case during the early 1980s when the HH-65 was acquired). Regardless, maintaining a robust dialogue with industry will enhance the Coast Guard's ability to understand the state of the market with respect to operational capabilities.
- Inadequate Control/Feedback – Periodic Operational Assessment: As mentioned previously, the Coast Guard's failure to perform periodic OAs resulted in inadequate control/feedback with respect to maintain safe/efficient capabilities. Specifically, failure to perform OAs on HH-65s and 47-foot small boats (from a systems perspective) allowed

the Coast Guard's hoisting operations to migrate to an unsafe state over time. That is, with the delivery of the 47-foot small boat, a new (greater) hoist snag hazard (dewatering standpipe) was introduced to the system. However, according to the MAB report, this hazard was not well-known within the aviation community. Conducting periodic OAs, including operational hazard assessments, would have likely identified the increased snag hazard, increased awareness of the hazard within the aviation community, and may have resulted in mitigating actions prior to the CG-6505 mishap.

Based on the above analysis, the following specific actions are recommended to be included as part of the MAB report's recommendation to "evaluate the current organizational requirements of system safety integration as applied to acquisition decisions at all levels." [28]. Note: These recommendations have been developed in light of the Coast Guard's recent acquisition reforms:

- **Improved capability and requirements cataloging:** As part of the effort to enhance their system safety approach to acquisitions and capability management, the Coast Guard should undertake an effort to catalogue all of its capabilities at the system (e.g., platform – HH-65, 47-ft MLB) and subsystem (e.g., hoist system, hover lighting, hoist deck, etc.) levels. This cataloging should include details regarding the capability of the system/subsystem, any unfulfilled requirements/gaps documented with respect to system/subsystem inadequacies, and, perhaps most importantly, "tagging" of interfacing subsystems (e.g., hoist system correlated to 47-foot MLB hoist deck). This database should be updated continuously, or at a minimum following completion of OAs and periodically to capture safety-related capability needs documented in operational/mishap databases such as ALMIS. Furthermore, the database should be consulted when identifying potential capability acquisition or major maintenance efforts. By maintaining a database that tracks capabilities, gaps, and interfaces at the sub-system level, the Coast Guard will be able to better manage capability acquisition, operation, and maintenance from a systems perspective, thereby reducing safety hazards and system failures that often occur at the seams (e.g., system/subsystem interfaces).
- **Improved Sponsor/User Involvement in Design/Development:** During the design and development of new capabilities or major upgrades of existing capabilities, the project sponsor (e.g., Office of Aviation Forces) and the user group (e.g., aviation operators)

should be heavily involved. This involvement should extend beyond the specific platform manager/user base to include platform managers/users from other similar capabilities and interfacing capabilities. For example, rather than limiting involvement in the HH-65 modernization program to just the HH-65 platform manager and HH-65 operators, representatives from the HH-60 community and Small Boat Forces community should also be involved.

- Increased Industry Involvement during Design/Development/Demonstration: Similarly, the Coast Guard should increase industry involvement during design and development associated with new acquisitions and major modernization programs and demonstration of existing capabilities (e.g., OAs) to ensure appropriate state of the market technologies and industry best practices are adopted at the sub-system level. This could be done by:
 - Requiring proposals related to key subsystems during the contractor down-selection process
 - Including a panel of industry representatives to observe/advise during OAs
- Initiate Periodic Operational Analysis: Finally, as recommended previously, the Coast Guard should conduct periodic OAs to systematically identify and document capability gaps and emerging hazards. These OAs should include involvement of all interfacing capabilities.

Figure 5.14 summarizes the Coast Guard Acquisition Directorate's safety related responsibilities, context, unsafe decisions and control actions, and process model flaws.

Safety-Related Responsibilities

- Acquire capabilities (e.g., HH-65 helicopter, 47-foot Motor Life Boat) to meet user (Coast Guard operators) and customer (Project Sponsors (e.g., Office of Aviation Forces, Office of Boat Forces)) operational capability requirements.

Context

- The Coast Guard's Acquisition Directorate had not been established at the time of the acquisition of the HH-65 helicopter fleet (1980-85), nor at the time of the design of the 47-foot motor life boat fleet (1988-1990).
- In the early 2000s, the Coast Guard initiated a project, ultimately managed by the Coast Guard's Acquisition Directorate, to modernize the H-65 helicopter. This modernization included, among such things as installing more powerful engines, upgrading avionics, installing Airborne Use of Force (e.g., weapons/armament), and upgrading navigation systems. The re-engining effort was completed in 2004 and the Airborne Use of Force was completed in 2011. Upgrades to avionics and navigation systems are ongoing. The modernization project did not include modifications to the hoist system or other capability gaps previously cited in this report.
- CG-6505 performed in accordance with all applicable performance requirements.

Unsafe Decisions and Control Actions

- The acquisition process in place at the time installed (accepted) different hoist systems on HH-65 and HH-60 helicopter platforms despite similar mission profile.
 - Installed (accepted) hoist system without dynamic slip clutch assembly on HH-65.
- The acquisition process in place at the time did not identify a hoist entanglement hazard on the 47-foot Coast Guard motor life boat fleet during acquisition of the 47-foot motor life boat or during OT&E of the HH-65 helicopter post-re-engining.
- The acquisition process accepted operational requirements from the customer regarding the modernized HH-65 without conducting benchmarking of similar capabilities in Coast Guard portfolio (e.g., HH-60).

Process Model Flaws

- Coast Guard acquisition process did not incorporate a system safety approach.
 - Failed to take a systems approach to identifying operational hazards/deficiencies during acquisition of the 47-foot motor life boat and the modernized HH-65 helicopter.

Figure 5.14 – Coast Guard Acquisition Directorate Level Analysis

Coast Guard Aviation Safety Division – CG Headquarters, Washington, DC

Per the system development Safety Control Structure (Figure 5.2) and the safety related responsibilities listed in Figure 5.13, the Coast Guard's Aviation Safety Division provides control over Coast Guard Air Station Barbers Point (and all other Coast Guard Air Stations), through establishment of safety-related standardization inspections where they administratively review the air stations to ensure they are conducting all required training and following standardized policies. The Aviation Safety Division receives feedback from the air stations through observation during inspections and periodic reporting. Additionally, the Aviation Safety Division provides control over and receives feedback from the Coast Guard's Office of Aviation Forces through coordination of operational safety requirements and guidelines in conjunction with the design and development of capabilities, training, tactics, techniques, and procedures [25].

A key duty of the Aviation Safety Division is program management of the Crew Resource Management and Operational Risk Management programs within the aviation community.

- Operational Risk Management – A continuous, systematic process of identifying and controlling risks in all activities according to a set of pre-conceived parameters by applying appropriate management policies and procedures. This process includes detecting hazards, assessing risks, and implementing and monitoring risk controls to support effective, risk-based decision-making [29].
- Crew Resource Management – A management system which makes optimum use of all available resources - equipment, procedures and people - to promote safety and enhance the efficiency of operations [35].

As alluded to in the FORCECOM section of this analysis, poor Crew Resource Management was cited as a contributing cause to the CG-6505 mishap (decision not to ditch aircraft following severe damage [28]) and it is identified as at least a contributing cause in most recent Coast Guard aviation mishaps [24]. The recurring nature of this contributing factor suggests a systemic problem in the Crew Resource Management training program. Closer examination of the program revealed that the Aviation Safety Division relies on several sources of training (e.g.,

Aviation Training Center, Aviation Technical Training Center, and Air Station Flight Safety Officers) to develop and monitor aviation community proficiency with Crew Resource Management and Operational Risk Management techniques [14]. Because most of the training is provided by Air Station Flight Safety Officers as part of a collateral duty, this training is often conducted in an ad hoc manner and control/feedback associated with these programs is not adequate. Furthermore, the Operational Risk Management program focuses only on general risk assessment and management tactics. It does not include a process for identifying and documenting specific risks and mitigation strategies associated with specific routine or emergency operational scenarios.

Additionally, based on review of the Coast Guard's CG-6505 MAB final report [28] and discussions with aviation program management personnel [14], there appears to be general acknowledgment and acceptance of the risk of conducting nighttime hoisting operations across the Coast Guard aviation community, including the Aviation Safety Division. For example, statements in the MAB final report and during interviews allude to the routine nature of pilot overcontrol/overtorque during such operations. As we saw in the CG-6505 mishap, this overcontrol/overtorque can be deadly in combination with another hazard (e.g., hoist entanglement). In an event chain-based model, the likelihood of a hoist entanglement in conjunction with overcontrol/overtorque would likely be very low. However, in the case of the Coast Guard's aviation program, it is not so low due to the dependency that exists between the two events during nighttime hoisting evolutions. Therefore, it is apparent that overtime, the Coast Guard's aviation system migrated to an unsafe state as overcontrol/overtorque pilot errors during nighttime hoisting became common place, the Coast Guard operated a helicopter without dynamic slip clutch capability, and the Coast Guard introduced a 47-foot Motor Life Boat with a severe hoist snag hazard. As the Aviation Safety Division did not recognize these hazards, it is apparent that they did not exercise adequate control/feedback with respect to identifying operational risks and associated mitigation plans.

Finally, the Aviation Safety Division must be involved, if not lead the effort to overcome cultural and psychological forces across the Coast Guard compelling pilots to attempt to return to the base with a damaged aircraft, even if it means placing the crews in danger. As discussed in the

Aviation Training Center and Office of Aviation Forces section of this report, this stems from a lack of leadership, training, and operational policy emphasis regarding the imperative to ditch the aircraft whenever there is severe damage to an aircraft or the crew's safety is jeopardized by continued flight. As the "owner" of aviation safety, the Aviation Safety Division is a key contributor to this unsafe posture and must play an active role in overcoming the cultural barrier to ditching aircraft after sustaining severe damage.

Based on the above analysis/discussion, the following control/feedback inadequacies involving the Aviation Safety Division existed at the time of the CG-6505 mishap:

Control/Feedback Inadequacies

- Inadequate Control/Feedback – Lack of Standardized CRM/ORM Training: Lack of standardized training (observation and reporting) of Crew Resource Management and Operational Risk Management programs through use of multiple training delivery sources, collateral duty program, and limited programmatic guidance.
- Inadequate Control/Feedback – Lack of Safety Advocacy to Address Known Risks: Rather than advocating correction/mitigation, the Aviation Safety Division generally accepted known aviation operational risks (e.g., nighttime hoisting operations).
- Inadequate Control - Lack of Emphasis of Safety of Life Over Preservation of Aircraft: Lack of emphasis on importance of ditching an aircraft following severe damage.

Based on these control/feedback inadequacies, the following actions are recommended:

- To improve Crew Resource Management and Operational Risk Management proficiencies across the Coast Guard, it is recommended that the Coast Guard consider leveraging FORCECOM to develop standardized delivery modes, tactics, techniques, and procedures for Crew Resource Management and Operational Risk Management training. This training should be conducted by personnel dedicated to the field of Crew Resource Management and Operational Risk Management rather than taken on at the local level as a collateral duty. Furthermore, rather than approaching Operational Risk Management from purely a general approach, the Aviation Safety Division should catalogue specific

risks and mitigating tactics, techniques, and procedures associated with specific routine and emergency operations and capabilities. Used in conjunction with the previously recommended cataloging of system capabilities and associated gaps, these two databases could be powerful tools in identifying operational hazards and associated mitigation strategies via tactics, techniques, procedures, training, policies, and/or capability enhancements.

- To improve operational safety, it is recommended that, rather than accepting certain routine operations as being high risk (e.g., nighttime hoisting), the Aviation Safety Division formally request the Office of Aviation Forces and FORCECOM/Aviation Training Center to investigate methods to mitigate the risks. These formal requests should be documented and monitored by the Office of Aviation Forces in the capabilities catalogue and by the Aviation Safety Division in the Operational Risk Management catalogue.
- As discussed previously, it is recommended that Aviation Training Center, FORCECOM, the Office of Aviation Forces, and the Aviation Safety Division work together to collectively emphasize the importance of ditching following severe aircraft damage through increased training, updating policies, and establishing a crash spare inventory as elaborated on in the Aviation Training Center section of this analysis.

Figure 5.15 summarizes the Coast Guard Acquisition Directorate's safety related responsibilities, context, unsafe decisions and control actions, and process model flaws.

Safety-Related Responsibilities

- The Coast Guard Aviation Safety Division's mission is to:
 - Foster a culture that promotes aviation professionalism;
 - Support successful completion of aviation operations;
 - Increase operational efficiency;
 - Maximize loss control.
- Serves as the program manager for the following programs and initiatives:
 - Operational Risk Management and Crew Resource Management.
 - Flight/Aviation Safety Officer Program – Program to train and certify aviators in operational risk management, crew resource management, occupational safety, and other risk management and safety techniques to act as safety advocates and ensure safe operations at Coast Guard aviation units.
 - Aviation Standardization – Policy development, inspection, and audit to ensure all Coast Guard aviation units are operating and maintaining aircraft in accordance with Coast Guard-wide policies and directives.
 - Mishap Analysis and Reporting – Policy development for conducting aviation mishap analysis and reporting.

Context

- Decentralized and non-standard approach to Operational Risk Management and Crew Resource Management led to complacency/lack of proficiency.
- Operational Risk Management efforts solely focused on general risk assessment and management. It did not include identification of specific risks and mitigation strategies associated with routine or emergency operations.

Figure 5.15 (1 of 2) – Coast Guard Aviation Safety Division Level Analysis

Unsafe Decisions and Control Actions

- Did not achieve proficiency in pilots/aircrews with respect to Operational Risk Management, Crew Resource Management, and aircraft ditching procedures.
- Did not identify specific risks and mitigation strategies associated with routine or emergency flight procedures.

Process Model Flaws

- Generally accepted risks associated with nighttime hoisting operations:
 - Failure to understand need for hoist sensing system (sense overload)
 - Failure to understand need for aircrew to communicate with boat crew directly
 - Failure to understand need to eliminate pilot tendency to overcontrol (approach too close to small boat).
- Failure to recognize importance of proficiency with respect to aircraft ditching procedures.
- Inaccurate assessment of aviation forces' proficiency with respect to Operational Risk Management and Crew Resource Management.
- Failed to recognize importance of cataloguing risks/mitigation strategies associated with specific flight operations.

Figure 5.15 (2 of 2) – Coast Guard Aviation Safety Division Level Analysis

Step 7 – Examination of Overall Communication & Coordination

In this part of the STAMP/CAST process, overall communications and coordination are examined to identify instances where coordination and communication between controllers resulted in significant sources of hazards and/or contributed to/caused the CG-6505 accident to occur.

This analysis revealed the area of capabilities management as significantly lacking in terms of communications and coordination. This issue has been discussed previously in Step 6 of this analysis from a component level perspective. The following discussion is from the system perspective.

This analysis revealed that capabilities management responsibilities, with respect to aviation capabilities, although primarily owned by the Coast Guard's Office of Aviation Forces, are diffused to several entities across the Coast Guard, including operators (e.g., air stations and sectors), Aviation Training Center, FORCECOM, Aviation Safety Division and the Acquisition Directorate. While this diffusion complicates management of capabilities, it is necessary to holistically address capability requirements, gaps, and associated hazards as each entity offers a unique perspective. Furthermore, as recommended previously, in addition to the aforementioned participants, program managers and users of interfacing capabilities should also participate in the capability management process. With all of these players, communication and coordination of capability requirements becomes challenging. As we saw in the case of CG-6505, the requirements for a dynamic slip clutch hoist system, improved approach/hover capabilities for nighttime hoisting, improved ditching capabilities, and improved boat crew to aircrew communications capabilities were never requested/documented despite similar capabilities existing on similar platforms and well-know/documented risks associated with current capabilities.

It was previously recommended (see Step 6 – Acquisition Directorate section) that the Coast Guard should develop a database and process to catalogue all of its capabilities at the system (e.g., platform – HH-65, 47-ft MLB) and subsystem (e.g., hoist system, hover lighting, hoist

deck, etc.) levels. This cataloguing should include details regarding the capability of the system/subsystem, any unfulfilled requirements/gaps documented with respect to system/subsystem inadequacies, and, perhaps most importantly, “tagging” of interfacing subsystems (e.g., hoist system correlated to 47-foot MLB hoist deck).

While this step is critical to improving capabilities management within the Coast Guard, this alone will not address the communication and coordination challenges presented by diffused capability roles and responsibilities. Therefore, to address these issues, it is recommended that the Coast Guard develop a virtual interactive “capabilities management community” forum where these different entities can “come together” regularly to discuss capability management and operational safety hazard issues. Furthermore, each of these communities should be provided access to populate the Capabilities Catalogue database to assist in identifying capability requirements, gaps, recommendations, interfaces, hazards, etc. Providing a forum for continuous and collaborative discussion and facilitating formal and open communication of capability requirements and gaps via a shared database is expected to spur user-centered innovation [36] and improve communication and coordination of capabilities requirements, in turn improving system safety.

Step 8 – Dynamics and Migration to a High Risk State

According to Dr. Leveson, most major accidents result from a migration of the system toward reduced safety margins over time [18]. The mishap of CG-6505 was no exception. Nighttime hoisting operations are acknowledged to be a challenging (e.g., high-risk) operation that commonly involved pilot overcontrol/overtorque “procedural errors.” [14, 28]. Since its introduction to service in 1985, the Coast Guard had been conducting nighttime hoisting operations with a fleet of HH-65 helicopters without a dynamic slip clutch assembly. As we saw in the CG-6505 mishap, pilot overcontrol/overtorque can be deadly in combination with a hoist entanglement. In an event chain-based model, the likelihood of a hoist entanglement in conjunction with overcontrol/overtorque would likely be very low. However, in the case of the Coast Guard’s aviation program, it is not so low due to the dependency that exists between the two events during nighttime hoisting evolutions. Additionally, in 1997, the Coast Guard introduced a 47-foot Motor Life Boat with a significant hoist entanglement hazard due to a protruding dewatering standpipe. This hazard was known in the small boat community, but not in the aviation community.

Therefore, it is apparent that overtime, the Coast Guard’s aviation system migrated to an unsafe state as overcontrol/overtorque pilot errors during nighttime hoisting became common place, the Coast Guard operated a helicopter without dynamic slip clutch capability, and the Coast Guard introduced a 47-foot Motor Life Boat with a severe hoist snag hazard.

It is expected that previous recommendations made in this report with respect to more integrated, system-based management of capabilities requirements, in particular conducting periodic OAs, improved communications and coordination amongst the capabilities management community, and enhanced documentation of capabilities requirements and gaps, will improve system safety within the aviation community.

Step 9 – Recommendations

In summary, STAMP/CAST analysis identified the following major control and feedback inadequacies in the Coast Guard Aviation hierarchical system Safety Control Structure:

- Inadequate Control/Feedback – Pilot and Flight Control System in Hover/Approach – The physical system does not provide adequate feedback and controls to the pilot to assist the pilot in safely executing nighttime hoisting operations. The pilot relies heavily on limited visuals and the altimeter to ensure the approach/hover is conducted at a safe distance. Considering the frequent occurrence of overcontrol / overtorque in this scenario, improved control is needed.
- Inadequate Control/Feedback – Lack of Control/Feedback of Hoist System and Lack of Communications between Air/Boat Crews – Due to inadequacies in the hoist system (e.g., lack of dynamic slip clutch, sub-optimal location of shear control for remote hoisting operations) and communications (e.g., inability of boat crew to communicate directly with air crew resulting in sub-optimal control/feedback), CG-6505/CG-47317 were not able to adequately control the hoist system to prevent entanglement and damage to the aircraft post-hoist entanglement. Additionally, lack of sensors on the hoist system resulted in inadequate feedback to the air crew regarding entangled status.
- Inadequate Control/Feedback – Lack of Standardized Ditching Training – Lack of standardized training (observation and reporting) of ditching procedures.
- Inadequate Control/Feedback – Inadequate Reporting of Standardization Visit and SAR Checks - The only required signature on the Standardization Visit Procedures Checklist is that of the Aviation Training Center Instructor Pilot. Additionally, the only required signature on the SAR Procedures Checklist is the unit's instructor pilot. Failure to require the PUI and the PUI's Commanding Officer and Operations Officer to sign these forms results in inadequate accountability and transparency (e.g., control and feedback) with respect to pilot/aircrew proficiency and potential hazards/operational risks.
- Inadequate Control – Lack of emphasis on Ditching & Paramount Importance of Life Safety – Lack of emphasis on importance of ditching an aircraft following severe damage. Contributed to lack of control over cultural resistance to ditching. Lack of clear

policies and sufficient attrition reserve aircraft may be contributing to cultural barriers to ditching damaged aircraft to preserve crew safety.

- Inadequate Control/Feedback – Capabilities Management System: General lack of control and feedback in the management of existing capabilities (e.g., HH-65):
 - Inadequate Control/Feedback – Lack of Periodic Capabilities Review/Communication – Lack of formal periodic capability gap assessment (e.g., Operational Analysis) required/performed. Lack of review of minor mishaps to identify safety-related capability gaps.
 - Inadequate Control/Feedback – Lack of Integrated Capability Management – Lack of formal integration/standardization of helicopter operational capabilities across platforms.
 - Inadequate Control/Feedback – Sponsor capability and requirements cataloguing: Lack of systematic process for documenting existing system and sub-system capabilities and operational capability gaps.
 - Inadequate Control/Feedback – Lack of Safety Advocacy to Address Known Risks: Rather than advocating correction/mitigation, the Aviation Safety Division generally accepted known aviation operational risks (e.g., nighttime hoisting operations).
- Inadequate Control/Feedback – Sponsor/User involvement in design/development: Insufficient sponsor and user involvement, including like platforms and interfacing capabilities during acquisition and modernization efforts.
- Inadequate Control/Feedback – Coast Guard Acquisition Directorate and Industry: Insufficient involvement with industry regarding state of the market capabilities and procedures.
- Inadequate Control/Feedback – Lack of Standardized CRM/ORM Training: Lack of standardized training (observation and reporting) of Crew Resource Management and Operational Risk Management programs through use of multiple training delivery sources, collateral duty program, and limited programmatic guidance. Lack of identification/cataloguing of operational risks and mitigating actions specific to operational procedures/conditions.

To address these control and feedback inadequacies the following actions, in addition to those recommended by the Coast Guard CG-6505 MAB, are recommended for Coast Guard implementation:

- Additional warning signals to assist pilots in positioning the aircraft at a safe distance above receiving platforms (e.g., small boat) during night missions. – Considering the risk/routine nature of pilot overcontrol/overtorque during nighttime hoisting operations, the Coast Guard should take action to review state of the market/art capabilities to provide more information to the pilot/aircrew to reduce the risk of overcontrol/overtorque. This could result in additional sensors/warning indicators to assist the pilot in positioning/holding the aircraft at a safe/stable distance above the receiving platform (e.g., small boat).
- Additional warning signals to alert pilot to snagged hoist condition and additional communications capabilities between air/boat crews – The Coast Guard should take action to add a sensor system to the hoist to inform the pilot/crew when the hoist is entangled and/or overloaded. Additionally, the Coast Guard should pursue acquisition of capabilities or implementation of tactics, techniques, and procedures to enable direct communications between the aircrew and boat crew. Both of these steps will improve the aircrew’s ability to detect hoist entanglements and quickly implement “hoist fouled/damaged” emergency procedures.
- Enhanced hoist training - Considering the high-risk nature of night time hoisting operations, the Coast Guard should consider adding night time hoisting operations, including fouling (entanglement) procedures, to its simulator training curriculum.
- Improved reporting of standardization visit and Search and Rescue (SAR) check results - To improve accountability and transparency (e.g., control and feedback), it is recommended that the Coast Guard require the Pilots Under Instruction (PUIs), and the PUI’s Operations Officer’s and Commanding Officer’s, in addition to the Aviation Training Center Instructor Pilot’s signature on the Procedures Checklist form.
- Enhanced standardized ditching training – The Coast Guard should include ditching procedures as a line-item on the Standardization Visit Procedures Checklist.

Additionally, each pilot/air crewman should be required to demonstrate proficiency in executing ditching procedures and making determinations when ditching the aircraft is warranted.

- Increased emphasis on paramount importance of life safety over preservation of aircraft – To address gaps in current ditching capabilities and cultural barriers to ditching, the Coast Guard should take the following actions:
 - Improve HH-65 capabilities (e.g., additional lighting) to enable safe nighttime ditching.
 - Modify training, doctrine, and policy (e.g., Coast Guard Air Operations Manual) to more clearly emphasize crew safety over aircraft preservation.
 - In order to improve operational safety and effectiveness, it is recommended that the Coast Guard work with the Department of Homeland Security, Office of Management and Budget, and Congress to procure an attrition reserve aircraft inventory proportionally similar to that of the other branches of the Armed Forces.
- Implement a Capabilities Management System: To address the general lack of control and feedback in the management of existing capabilities (e.g., HH-65) the Coast Guard should:
 - Develop a database and process to catalogue all of its capabilities at the system (e.g., platform – HH-65, 47-ft MLB) and subsystem (e.g., hoist system, hover lighting, hoist deck, etc.) levels. This Capabilities Catalogue should include details regarding the capability of the system/subsystem and any unfulfilled requirements/gaps documented with respect to system/subsystem inadequacies. Additionally, and perhaps most importantly, considering hazards/accidents occur most often due to component interaction, this database should “tag” interfacing subsystems (e.g., hoist system correlated to 47-foot MLB hoist deck) to more systematically ensure Coast Guard capability managers take a systems view in the execution of their duties.
 - Develop a virtual interactive “capabilities management community” forum where the various entities with capability management responsibilities (e.g., Office of Aviation Forces, Aviation Safety Division, Aviation Training Center,

FORCECOM, Acquisition Directorate, and Coast Guard operational units (air stations/sectors/small boat stations)) can “come together” regularly to discuss capability management and operational safety hazard issues. Furthermore, each of these communities should be provided access to populate the Capabilities Catalogue database to assist in identifying capability requirements, gaps, recommendations, interfaces, hazards, etc. Providing a forum for continuous and collaborative discussion and facilitating formal and open communication of capability requirements and gaps via a shared database is expected to spur user-centered innovation and improve communication and coordination of capabilities requirements, in turn improving system safety.

- Periodically review minor mishaps to identify trends and identify safety-related capability gaps.
- Considering the importance of robust operational capabilities to the Coast Guard’s ability to safely and effectively execute its missions, it is recommended that the Coast Guard hold itself accountable to the prescribed annual Operational Analysis process and shift oversight from the Office of Management and Budget, the Department of Homeland Security, and the Coast Guard Acquisition Directorate to an entity with the Coast Guard Office of Aviation Forces’ chain of command.
- Increased sponsor/user involvement in major system design/development/sustainment: During the design and development of new capabilities or major upgrades and analysis of existing capabilities, the project sponsor (e.g., Office of Aviation Forces) and the user group (e.g., aviation operators) should be heavily involved. This involvement should extend beyond the specific platform manager/user base to include platform managers/users from other similar capabilities and interfacing capabilities. For example, rather than limiting involvement in the HH-65 modernization program to just the HH-65 platform manager and HH-65 operators, representatives from the HH-60 community and Small Boat Forces community should also be involved.
- Increased industry involvement in major system sustainment: Similarly, the Coast Guard should increase industry involvement during major modernization programs and demonstrations (e.g., Operational Analysis) of existing capabilities to ensure appropriate state of the market technologies and industry best practices are adopted at the sub-system

level. This could be done by including a panel of industry representatives to observe/advise during Operational Analyses and Program Implementation Reviews.

- Enhanced/standardized Crew Resource Management/Operational Risk Management training: Considering the recurring nature of inadequate Crew Resource Management and Operational Risk Management in Coast Guard aviation mishaps, the Coast Guard should take action to more systemically address inadequacies in these programs. Crew Resource Management training should be standardized across the Coast Guard and be included in annual Aviation Training Center Standardization Visits and the Division of Aviation Safety's (CG-1131) Safety Standardization Visits. Unit level training should comply with standardized training procedures. Furthermore, it is recommended that the Coast Guard leverage the establishment of FORCECOM to develop a Coast Guard-wide standardized Crew Resource Management and Operational Risk Management readiness program to better deliver training and improve Service-wide proficiency in these critical operational skill sets. Establishing a centrally managed, standardized program overseen by experts in training development and delivery will raise leadership awareness, heighten priority, and improve the effectiveness of these programs. Finally, rather than approaching Operational Risk Management from purely a general approach, the Aviation Safety Division should catalogue specific risks and mitigating tactics, techniques, and procedures associated with specific routine and emergency operations and capabilities. Used in conjunction with the previously recommended cataloguing of system capabilities and associated gaps, these two databases could be powerful tools in identifying operational hazards and associated mitigation strategies.

By way of example, Figure 5.16 (below) provides a graphical depiction of the inadequacies in the controls/feedback in Coast Guard capabilities management, as indicated by red lines. The inadequacies exist within the Office of Aviation Forces and between the Office of Aviation Forces and Coast Guard Air Station Barbers Point, Interfacing Capabilities, Aviation Training Center, FORCECOM, and the Aviation Safety Division and led to omissions in capabilities management that at least contributed to the CG-6505 mishap.

Chapter 6: Discussion – CAST vs. MAB Findings

This section is focused on answering the central research question of this thesis; *Is the STAMP model better than the Swiss Cheese model in identifying causes to the accidents?* The following discussion compares the findings of the CAST analysis contained in this thesis to the findings of the MAB report completed by the Coast Guard in December 2009. Specifically, Table 6.1 (below) summarizes the major issues/inadequacies identified by the two analyses, discusses the related findings and recommendations of each of the CAST and MAB analyses, and provides a brief explanation as to what led to any differences in findings/recommendations between the two analyses. Red highlighted text indicates where the MAB findings were either deficient or not as comprehensive as compared to the associated CAST findings.

Issue	CAST Findings	MAB Findings	Comments
Common occurrence of overcontrol/overtorque in nighttime hoisting ops	Lack of pilot control/feedback addressed through recommendation to enhance nighttime approach/hover capabilities.	Faulted pilot in case of CG-6505 and does not address systemic factors. Generally accepts risk.	By analyzing the issue via a systems approach, the CAST process facilitates identification of system control/feedback inadequacies rather than simply faulting the operator.
Lack of feedback to pilot regarding status of hoist	Identified lack of feedback and recommended inclusion of overload/entanglement sensor and addressing lack of direct communications between aircrew and boat crew through improved tactics, techniques, procedures, or capabilities.	Identified lack of feedback and recommended inclusion of overload/entanglement sensor. Identified lack of communications between air crew and boat crew but did not recommend correction.	Very similar findings in CAST and MAB.
Inadequate reporting of Standardization Visit and SAR Check results	Identified issue and recommended modification to require the pilot under instruction and his/her chain of command (e.g.,	No discussion on Standardization or SAR Check procedures.	Through development of the Hierarchical Safety Control Structure and analysis of the control and feedback

	operations officer, commanding officer) sign the inspection sheet.		loops between the Division of Aviation Safety, Aviation Training Center, and the Air Stations, CAST highlighted the inadequacies with the current Standardization practices.
Lack of emphasis on ditching and paramount importance of life safety	Identified capabilities (e.g., lighting), training, policy, and procurement strategies to address inadequacies in ditching competencies and organizational barriers to ditching.	Recommended increased emphasis/improved training and mentioned cultural barriers, however, did not address more systemic factors.	CAST hierarchical safety control structure enable investigator to follow thread from pilot level (e.g., reluctance to ditch) up through Office of Aviation Forces level to identify unclear policies and lack of resources as contributing factors.
Inadequate capabilities management system	Identified general lack of process/procedures for documenting existing capabilities, interfacing capabilities, capability gaps, and failure to perform required annual Operational Analysis on existing capabilities to enable discovery of cost and performance shortfalls. Concurred with MAB findings to replace HH-65 hoist system and mandate use of protective shroud over dewatering stand pipe on 47-foot small boats.	Identified issues with HH-65 hoist system in place at the time of mishap and recommended fleet-wide replacement. Recommended fleet wide analysis of hoist systems. Recommended creation and use of protective shroud over dewatering stand pipe. Also recommended Operational Hazards Assessment of hoisting operations. <u>Did not examine systemic issues resulting in failure to identify capability gap.</u>	CAST systems-based approach enabled broader examination of systemic factors. Identified factors preventing the Coast Guard from monitoring existing capabilities for hazards and identifying capability needs/gaps. Identified failure to perform existing controls including its own Operational Analysis policy.
Inadequate sponsor/user involvement in design and development of new capabilities and evaluation of existing	CAST recommends including sponsor/user representatives from interfacing capabilities in addition to capability of	Recommends standing up a team to evaluate requirements of system safety integration into Coast Guard	The CAST hierarchical safety control structure highlights the interfacing capabilities and

capabilities.	interest in the design & development of new capabilities and evaluation of existing capabilities.	asset/acquisition design procedures.	organizational elements enabling a specific recommendation to address the system safety issues identified in both the MAB and CAST analyses.
Lack of industry involvement in acquisition and sustainment of capabilities	Recommends including industry in design, development, and sustainment of capabilities.	Not addressed in MAB.	Development of the CAST hierarchical safety control structure highlighted the Acquisition Directorate's interface with industry and their understanding of state of the market technologies.
Inadequate Crew Resource Management (CRM) and Operational Risk Management (ORM) training/guidance	Recommends leveraging new organizational element to standardize CRM/ORM across Coast Guard and taking advantage of aviation community expertise to catalogue specific operational risks and mitigating strategies	Poor CRM cited as a contributing factor in MAB, but no recommendations to improve CRM. ORM not addressed in MAB.	CAST analysis of higher levels of the organizational structure enabled identification of contributing factors to poor CRM proficiency including lack of standardized approach to CRM/ORM.

Table 6.1 – CAST vs. MAB Findings – Comparative Analysis

Review of the analysis contained in Table 6.1 indicates that in eight of the nine major control/feedback inadequacies identified by either of the CAST and/or MAB analyses, the CAST findings and recommendations were more comprehensive and more systemically-focused than the related MAB findings and recommendations. In other words, although the MAB analysis looked beyond proximal events leading up to the loss of CG-6505, in general, the CAST analysis better identified the systemic inadequacies in system controls/feedback that enabled existence of hazardous conditions in the aviation development and operations system that ultimately resulted

in the CG-6505 mishap. Because the CAST analysis yielded inadequate controls/feedback within the higher levels of the aviation development and operations system, the CAST analysis recommendations better target the systemic causal factors rather than more symptomatically-targeted recommendations identified by the MAB. It is this author's opinion that the principle reasons the CAST analysis provides superior results over the MAB 'Swiss Cheese'-based analysis is the development of the hierarchical Safety Control Structure and consideration of the control/feedback loops between each level of the control structure. Development of the hierarchical Safety Control Structure facilitates consideration of a broader, system-level view of the mishap while consideration of control/feedback loops enables identification of inadequacies resulting in hazards experienced by lower levels of the system structure (e.g., operators).

For example, consider the issue regarding inadequacies in the Coast Guard's aviation capabilities management. The MAB recommended that the HH-65 hoist system be replaced with a dynamic clutch capability, a shroud be created and used to cover the protruding dewatering stand pipe on the 47-foot small boat, and an operational hazards assessment be conducted on helicopter hoisting operations. These somewhat obvious recommendations target the specific issues (e.g., symptoms of more systemic issues) illuminated by the CG-6505 mishap. What is missing in the MAB analysis is the deeper analysis that asks, 'why were these capability gaps not identified sooner?' To answer this question, one must progress higher up the organization beyond the helicopter crew and air station to the program management level (e.g., Office of Aviation Forces, Acquisition Directorate, FORCECOM, Aviation Training Center, etc.). The CAST analysis does this. Through examination of the control/feedback loops throughout the hierarchical Safety Control Structure from the CG-6505 (e.g., operator) level all the way up to the Office of Aviation Forces (program management) level, a deeper understanding of the causes of the system hazards emerges. As was seen in Figure 5.16, inadequacies in the controls/feedback, as indicated by red lines, within the Office of Aviation Forces and between the Office of Aviation Forces and Coast Guard Air Station Barbers Point, Interfacing Capabilities, Aviation Training Center, FORCECOM, and the Division of Aviation Safety led to omissions in capabilities management that at least contributed to the CG-6505 mishap. Identification of these inadequacies led to the following important insights, findings, and recommendations that were not included in the MAB report:

- There is no central repository cataloguing all system and sub-system level capabilities and associated interfaces. Development of a Capabilities Catalogue, including details regarding the system/subsystem capabilities, system interfaces, unfulfilled requirements/gaps will enable Coast Guard capability managers to more systematically ensure operational capabilities enable safe and efficient mission execution.
- The Coast Guard is struggling to identify and document capability enhancements to continuously improve (e.g., safer, more efficient) existing capabilities. Development of a capabilities management community forum where the various entities with capability management responsibilities (e.g., Office of Aviation Forces, Aviation Safety Division, Aviation Training Center, FORCECOM, Acquisition Directorate, and Coast Guard operational units (air stations/sectors/small boat stations) can virtually “come together” regularly to exchange ideas regarding capability management and operational safety hazard issues will spur user-centered innovation and improve communication and coordination of capabilities requirements, in turn improving system safety.
- The Coast Guard is not currently performing annual Operational Analysis on existing capabilities as required by Coast Guard and Office of Management and Budget policies. Completion of Operational Analysis is key to identifying operational hazards such as routine overcontrol/overtorque during nighttime hoisting operations, small boat deck protrusions, or lack of dynamic hoist clutch capabilities.

Chapter 7: Conclusion

During a 22-month period, between 2008 and 2010, the U.S. Coast Guard experienced seven Class-A aviation mishaps resulting in the loss of 14 Coast Guard aviators and seven Coast Guard aircraft. This represents the highest Class-A aviation mishap rate the Coast Guard has experienced in 30 years [28]. Following each Class-A mishap, the Coast Guard conducted a Mishap Analysis Board (MAB), which leverages the ‘Swiss Cheese’ accident causality model in accordance with Coast Guard aviation policy [30]. Individual MAB results did not identify common causal or contributing factors that may be causing systemic failures within the aviation safety system. Subsequently, the Coast Guard completed a more system-based safety analysis known as the Aviation Safety Assessment Action Plan (ASAAP) which recently concluded “complacency in the cockpit and chain of command as the leading environmental factor in the rash of serious aviation mishaps.” [24]. Although the ASAAP study examined Coast Guard aviation more holistically than individual MABs, it did not apply systems theory and systems engineering approaches. Aviation safety remains a critical issue for the Coast Guard from both a mission performance and resource management perspective. For example, just recently, on February 28, 2012, the Coast Guard incurred another Class A mishap when a HH-65 helicopter (CG-6535) crashed into Mobile Bay, AL, killing all four Coast Guard members on board [3].

The goal of this thesis was to examine one of these aviation mishaps (CG-6505 crash during nighttime hoist training operations in Honolulu, HI on September 4, 2008) using the STAMP accident causality model to:

- Perform a STAMP analysis on a Coast Guard aviation mishap to identify, evaluate, eliminate, and control system hazards through analysis, design, and management procedures employed by the Coast Guard as part of the performance of their aviation missions in order to improve Coast Guard aviation safety.
- Determine if the STAMP model is better than the ‘Swiss Cheese’ (e.g., Coast Guard MAB) model at identifying causes to accidents.

The STAMP/CAST analysis contained herein identified several important system control/feedback inadequacies, and associated recommendations to resolve these inadequacies within the Coast Guard's aviation system that were not documented in the Coast Guard MAB's findings and recommendations. These findings and recommendations exclusive to the STAMP/CAST analysis include elements related to system capability deficiencies; capabilities management processes and procedures; and operational policy, standardization, certification and inspection; etc. In fact, of the nine major system control/feedback inadequacies identified by the STAMP/CAST analysis as contributing to/causing system safety hazards, eight of the related findings and recommendations were significantly more comprehensive and more systemically-focused than related MAB findings and recommendations.

Based on the analysis contained herein, this thesis concludes:

- The Coast Guard should implement all nine of the recommendations contained in Step 9 of the CAST analysis (see Chapter 5 of this thesis) in order to address systemic issues resulting in system hazards that contributed to the mishap of CG-6505. Considering these recommendations address systemic issues, it is likely that implementation of these recommendations will address at least a portion of the systemic issues contributing to the Coast Guard's overall elevated aviation mishap rate.
- The STAMP/CAST model is better than the 'Swiss Cheese' model at identifying accident causality.
- The Coast Guard should adopt the STAMP/CAST model as part of its current MAB process to more comprehensively investigate accident causality and identify/implement systemically-focused corrective actions.

Appendix A – Final Report on CG-6505 Mishap Analysis Board

U.S. Department of
Homeland Security

United States
Coast Guard



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5100

DEC 02 2009

MEMORANDUM

From: *D. P. Pekoske*
D. P. Pekoske, VADM
COMDT (CG-09)

To: Distribution

Subj: FINAL DECISION LETTER ON COAST GUARD AIR STATION BARBERS POINT
CLASS "A" AVIATION FLIGHT MISHAP INVOLVING HH-65C CGNR 6505 ON
04 SEP 2008

Ref: (a) Safety and Environmental Health Manual, COMDTINST M5100.47
(b) Department of Defense Human Factors Analysis and Classification System (DoD
HFACS): A mishap investigation and data analysis tool

1. SYNOPSIS. At 2011 Hawaii-Aleutian Standard Time (HST) on September 4th 2008, Air Station Barbers Point Coast Guard Helicopter Number (CGNR) 6505 was taking part in a night hoisting training evolution with Station Honolulu Motor Life Boat (MLB) 47317 approximately six miles south of Honolulu, HI. CGNR 6505 was carrying 4 people: two pilots, one flight mechanic (FM) and one rescue swimmer (RS). CG 47317 had four people onboard: one coxswain, one crewmember/ break-in coxswain, one engineer and one break-in crewmember.

CGNR 6505 was in the recovery phase of a hoist following a standard delivery of the rescue basket with trail line to the "dead in the water" (DIW) MLB when the mishap occurred. As the helicopter maneuvered overhead it descended as the MLB rose on a swell. The relative motion created excess slack in the hoist cable. Despite the efforts of the attending MLB crewmen, the excess cable entangled on the MLB engine room dewatering standpipe on the aft buoyancy chamber's forward face. As the MLB rode down the swell and the helicopter maneuvered to regain altitude, the cable became taut, physically pulled the helicopter down to the right, and then parted under extreme tension at the engine room dewatering standpipe.

The cable parting induced an unusual attitude (rapid right and left roll with extreme yaw to the left), during which the main rotor blades contacted the hoist boom assembly. This disrupted the normal finely-tuned motion of the rotating helicopter rotor blades (up and down / forward and aft) and created a significant out of balance condition resulting in severe vibrations that existed for the remainder of the flight. The main gearbox suspension system was also compromised resulting from a severe overtorque and attendant system degradation from the forces of tensional loading (as the hoist cable became taut) and instantaneous unloading (as the hoist cable parted).

Despite the severe vibrations, the aircrew recovered from the unusual attitude, and in the process, flew away from the water. They also made several "MAYDAY" calls that were overheard by the MLB crew, Sector Honolulu and Honolulu International Airport Air Traffic Control Tower (ATC).

Approximately three minutes later, after gaining altitude and moving closer to shore, the damage to the airframe caused in the hover was compounded by deterioration of components of

the rotor system, compromising the airworthiness of the helicopter. The aircraft departed controlled flight at approximately 500 feet and 40 kts and impacted the surface.

2. CLASSIFICATION. Per reference (a), this is a Class "A" mishap due to the four fatalities and loss of the aircraft.

3. CAUSAL FACTORS. The factors that contributed to this accident are listed in chronological order using the descriptors from reference (b), and organized into three main acts that occurred or should have occurred during the incident. (ACT A: Overcontrol/Overtorque that resulted in the fouled cable, ACT B: Procedural error to not clear the fouled cable, ACT C: Procedural error to not execute the ditching procedure.) Each section starts with the individual act and is followed by the existing preconditions, supervisory influences, and organizational influences that affected them.

a. Act: Overcontrol: Just prior to the hoist cable snag, the aircrew experienced a momentary misperception of the relative distance between the helicopter and MLB. This resulted in a minor overcontrol (overtorque) that was the Pilot at the Control's (PAC's) response to either the aircraft entering a slight descent, the stern of the MLB rising up on the crest of a swell, or more likely a combination of the two. The variance in altitude and aircrew response was not unusual for a standard hoisting evolution, however it led to a scenario where enough slack rapidly built up between the helicopter and vessel for the hoist cable to become wrapped around the MLB's aft dewatering standpipe.

(1) Precondition: Vision restricted by Darkness: Darkness makes routine tasks more challenging. In this case it contributed in some part to the position keeping of the aircraft and snag event because all of the members involved were operating in an environment with limited visual cues. The PAC was also practicing the planned (and necessary) skill set of hoisting without the aid of Night Vision Goggles (NVGs), which further reduced the visual cues available. Finally, the environmental conditions that evening included a surf advisory of 6-8 feet, winds from the East/Northeast (070 degrees) and reported seas of 1-2 feet. The aircraft was pointed into the wind which placed the PAC on the side of the aircraft where terrain features (lights from shore) would not have been seen and therefore offered no relief from the reduction in visual cues. The conditions existing at the time of this incident were demanding but well within normal training parameters.

(2) Precondition: Misperception of Operational Conditions: The assessment of operational conditions during any hoisting evolution is a dynamic process requiring innumerable inputs, corrections and re-corrections. The rate of small corrections is so great and the control input so miniscule that hoisting itself can almost be considered a nonstop series of changing perceptions and/or misperceptions that are acted upon and corrected. From all of the evidence gathered, this description accurately matches the profile of the mishap aircraft in the seconds prior to the overtorque and snag. Even though the movement of the aircraft wasn't far out of the range of a standard hoisting evolution, it was enough to allow the combined relative positions of the aircraft and

small boat to converge and create sufficient slack in the hoist cable so that it collected on deck and became wrapped around the aft dewatering standpipe.

- b. Act: Procedural Error: Although precursors to the event occurred in rapid succession, had the aircrew realized the cable was snagged, they should have initiated the "Hoist Cable Fouled/Damaged" emergency procedure. This would have prompted the PAC to reduce the distance between the helicopter and MLB, the FM to pay out more cable, or either of them to shear the hoist cable before it reached the severity of the ultimate overload. In this case the environmental conditions, relatively short span of time, design of the hoist system, and design of the surface platforms used in hoist training hindered them from taking action quickly enough to influence the final outcome.
- (1) Precondition: Vision restricted by Darkness: The FM is expected to keep track of several things during any hoist evolution: aircraft position relative to the vessel, obstructions and altitude, the rescue device, personnel in the hoist area, and the condition and location of the hoist cable. In relative terms, the last task of keeping track of the entire length of hoist cable with certainty at night is far more difficult. In this case, boat crew members observed slack in the hoist cable in the aft buoyancy chamber, but given the lack of visual cues, it is likely that the FM lost sight of the cable and failed to recognize the excess slack or that it had become snagged.
 - (2) Precondition: Instrumentation and Sensory Feedback Systems: Hoisting in the H-65 is predominately a visual maneuver augmented by tactile feedback through the FM's hand on the hoist cable and through the aircrew's perception of the physical shift of the aircraft's attitude as a heavy load is picked up. While either of these feedback cues could have potentially alerted the aircrew to a dangerous situation, neither is quantifiable or adequate as the primary backups to the visual sense in a short time span.
 - (3) Organizational Influence: Acquisition Policies / Design Process: In this case, there were two factors in the acquisition and design process that influenced the outcome of the incident. The first is the design integration of the hoist system on the H-65 and the second is the systems safety design of Coast Guard small boats.
 1. Hoist Assembly: When the H-65 was purchased in the 1980s, there was no service requirement to conduct a formal system safety and hazard analysis. This requirement has been established with the incorporation of the Major Systems Acquisition Manual (MSAM), COMDTINST M5000.10A, but is not yet a mature and well defined process in application. In this case, the hoist assembly as integrated into the H-65 at the time of acquisition had latent hazards that were not envisioned, documented or experienced until this incident. The H-65 hoist assembly safely performed countless hoists over decades of service, but it is now known that under certain conditions, it is capable of transferring loads onto the aircraft that are well in excess of the airframe limitations. It is also attached to the airframe in a location where,

under unusual attitude scenarios, it can physically contact the main rotor blades.

2. Small Boat Platforms: A snag hazard on the MLB (the dewatering standpipe) contributed to the mishap in that it is located in the primary hoist training area and was not specifically identified as a potential hazard. Multiple snag hazards exist on all boats; the significance of the dewatering standpipe is that its presence in the hoist area was not widely known by aircrews.
- (4) Organizational Influence: Program and Policy Risk Assessment: The current Coast Guard model of reporting hazards and developing mitigation strategies through engineering solutions, modifications to operational procedures, and focused training and education is sound and has successfully prevented mishaps or reduced the severity of mishaps in countless situations. The identification of organizational risk assessment as a factor in this case is a sobering reminder that in the world of complex systems and competing demands, improvement is always possible. In this case, there were opportunities for further analysis and risk assessment that may have exposed some of the latent hazards associated with this hoist assembly and/or routine methods of employment. As previously mentioned regarding the hoist assembly itself, one of those opportunities was at the time of purchase. For the assessment of operational hazards on vessels used in training, had more thorough formal dynamic interface tests been conducted between the two platforms (or for all other routine training platform combinations), then the specific snag hazard underneath the aft buoyancy chamber on the MLB could have been identified.
- c. Act: Procedural Error: It was determined that the aircraft damage to the gearbox and main rotor system (and associated severe vibrations) occurred immediately after the aircraft was recovered from the unusual attitude induced by the cable parting. The aircrew flew for approximately three minutes after the damage occurred without any crewmember directly articulating symptoms (vibrations) or causes (rotor blade/airframe damage), or clearly initiating any specific emergency procedure or discussing which landing criteria should be applied. While there might be plausible environmental, mental, cultural and preconditioned training responses that can explain their actions, it is also reasonable to have expected the aircrew in this case to diagnose the vibrations as severe enough to warrant ditching.
 - (1) Precondition: Vibration: The out of balance condition caused by the rotor system contacting the hoist boom created severe vibrations that impeded situational awareness, crew coordination, internal communications, initiation of emergency procedures, and the ability of the aircrew to complete basic duties such as manipulation of switches and flight controls.
 - (2) Precondition: Vision restricted by Darkness: During the unusual attitude recovery the aircrew lost sight of their only reliable visual reference, the MLB. While visual reference with a surface asset is not required to maintain a hover at night, the

degraded visual cues caused by darkness combined with the vibrations and traumatic nature of the unusual attitude recovery are plausible factors that contributed to the aircraft's observed flight profile away from the water. The same factors also explain the absence of ditching procedures as events progressed due to the difficulty of executing a survivable approach to the water with a degraded aircraft and severe vibrations.

- (3) Precondition: Channelized Attention: The H-65 flight manual states in the beginning of the emergency procedure section that regardless of the nature and severity of the emergency the overriding consideration is to: "Maintain Aircraft Control, Analyze the Situation, and Take Appropriate Action." The initial recovery from the unusual attitude following the cable parting was highly commendable and clearly placed the aircrew in the "Maintain Aircraft Control" mindset. However, once the aircrew gained control of the aircraft, there was no indication, from internal communications, that they progressed into the analysis phase. This channelized attention on flying the aircraft, combined with the shock and induced stress of the initial incident, the unusual attitude following the cable parting, and the severe vibrations, distracted the aircrew from effectively completing the analysis phase in sufficient time to affect the outcome.
- (4) Precondition: Response Set: After the unusual attitude recovery, despite a degraded communications environment, there was little to no discussion among the aircrew regarding what they were seeing or their intentions. Through their actions and the flight profile, it can be inferred that they were potentially responding in a predisposed and conditioned manner to do two things: first to fly out (get away from the water) and second to continue to a landing site (not ditch and get to the beach). For the fly out portion of the event, the flight profile matches the recovery steps from the unusual attitude recovery to gain airspeed with the instrument reference of the nose and wings level on the horizon. This profile is also further supported by the ingrained response in the H-65 community to fly out from a partial power loss (engine failure) scenario. For the second portion of the event, the continued flight toward land with significant airframe damage and severe vibrations, it can be inferred that the aircrew was influenced by a cultural instinct to "bring the aircraft and crew home." In this aspect, their potential confidence in the airframe and perception that they could possibly make it the last few miles, despite the vibrations, likely kept them from descending and ditching the aircraft.
- (5) Precondition: Crew / Team Leadership: Prior to the hoist cable parting, the aircrew was the perfect model of standardization and effective communications. Following the event however, there was a clear breakdown in several aspects of Crew Resource Management (CRM) that significantly impacted the aircrew's ability to take the appropriate action. In an environment of severe vibration and distracting visual and aural warnings, the absence of assertiveness by any member of the crew and lack of procedural adherence to challenge and reply protocol led to a situation where the aircrew was operating independently with regard to actions and communications and

not cross-checking each other's performance. Neither pilot communicated an intention to continue flying toward land or solicited the aircrew for a description of what had occurred or was occurring in the back of the aircraft to aid the decision making process. The FM did not report the cable snag, its parting, or any aircraft damage that he might have witnessed as the rotor blades contacted the hoist boom assembly. It is also probable that the FM and/or RS witnessed, heard or felt the departure of the hoist boom assembly since it was determined to have departed shortly after the initial damage. Communicating any critical information could have helped the aircrew collectively diagnose and focus on the severity of the situation. Later in the sequence of events there were calls from the FM and RS to conduct certain steps from the ditching emergency procedure, but they were not acknowledged nor were they clear requests to initiate a ditching scenario.

- (6) Organizational Influence: Organizational Training Issues / Programs: Although aircrews are exposed to ditching scenarios in annual simulator sessions, they are not required to demonstrate proficiency in these procedures during search and rescue procedures check-flights conducted during annual standardization visits. In addition, due to lack of simulator fidelity, ditching scenarios are rarely practiced to and beyond the point of water landing. If these scenarios were practiced and evaluated more routinely and with greater realism, the aircrew might have responded more quickly to their symptoms and carried through with what was likely the best option at the time, to ditch the aircraft shortly after the damage occurred.

4. ADDITIONAL FINDINGS. The following items were not determined to be directly causal to this incident, but were so closely related to the incident that they are listed here for continual process improvement and mishap prevention in similar situations.
- a. Precondition: Controls and Switches: There was no indication that anyone attempted to shear the hoist cable, but the investigation revealed that there is potential room for improvement in the design and location of the shear switches for quick access. Shear switches are located on the pilot's collective (covered thumb switch) and the flight mechanic's hoist control panel. There is no shear switch on the hoist pendent, used for remote hoist operation. Although no determination has been made that the design and location of the switches are sub-optimal or that they were a factor in the mishap, a human factors review of this system will be conducted.
 - b. Precondition: Communicating Critical Information: While it might not have changed the outcome of this incident due to the compressed period of time, boat crewmembers on Coast Guard platforms have limited means of transmitting critical information, either through verbal means (radio) or visual hand or light signals to the aircrew. In this case, a boat crewmember on the MLB tending the basket saw the cable get snagged, but was not able to convey the hazard to anyone in a timely manner.
 - c. Organizational Influence: Procedural Guidance / Publications: While there was no clear indication that any of the aircrew were executing published emergency procedures, several

were noted in the course of the investigation as needing further review for clarity and emphasis of content. They include the "Hoist Cable Fouled/Damaged," "Rotor Blade Damage," "Abnormal Vibration," and "Ditching (Power On)" emergency procedures.

- d. Organizational Influence: Attrition Policies: The engineering investigation revealed that the elastomeric stops (dampening elements in the suspension system between the main gearbox and the aircraft) have no determined service life and are not tracked. The only inspection currently performed on these parts is visual, which has been determined by independent engineering analysis to be insufficient in determining internal damage caused by overloading or fatigue.
5. CORRECTIVE ACTIONS COMPLETED. The following actions have been initiated or completed since the incident.
 - a. The Aircraft Control Configuration Board (ACCB) has approved the installation and evaluation of a prototype hoist system on an H-65 that incorporates a dynamic overload (slipping clutch) system. The evaluation is expected to be completed in the spring of 2010.
 - b. COMDT (CG-41) has mandated the replacement of all H-65 laminated elastomeric stops during the Programmed Depot Maintenance (PDM) schedule. Service life remains to be determined.
 - c. A protective shroud has been created and mandated for use on the stern of the 47' MLB for all DIW training maneuvers. The shroud mitigates the specific snag hazard evident in this incident and others on this class of vessel. The requirement for shroud use for H60 hoist operations has been rescinded, because the hoist clutch on the H60 releases tension if the cable is stressed beyond normal limits. The use of the shroud shall remain in effect for H65 hoist operations as an interim measure pending analysis of a similar feature for the H65.
 6. CORRECTIVE ACTIONS TO BE COMPLETED. The following items shall be accomplished through a reprioritization of existing resources or by using the resource proposal process.
 - a. COMDT (CG-1, CG-4, CG-6, CG-7 and CG-9) shall evaluate the current organizational requirements of system safety integration as applied to acquisition decisions at all levels and prepare a report on any identifiable gaps with solutions to CG-09 within six months of release of this report.
 - b. COMDT (CG-711) shall coordinate with all stakeholders to fund a formal system safety hazard analysis of the hoist assemblies on the H-65 and H-60. This is consistent with the requirements of the Major System Acquisitions Manual (MSAM), COMDTINST M5000.10A for systems purchased today, and shall be retro-actively applied in this case to both hoist systems based on the latent hazards identified in this report. COMDT (CG-711) shall also ensure that the results of this analysis are used to document a more detailed list of system requirements in the next version or update to the Operational Requirements

Documents (ORD) of both platforms. At a minimum, the analysis shall address the following discussion items from this incident:

- (1) Element of cable strength in relation to other cable requirements (chaffing, bending, etc.).
 - (2) Overall design factor of the hoist cable strength and the effect it has on other airframe limitations.
 - (3) Design of the current hoist boom on the H-65 since it is physically possible to contact the main rotor blades in certain flight regimes.
 - (4) Potential engineering solutions that could mitigate latent hazards inherent to the hoist system (e.g., a cable with a lower design factor, a slipping clutch/ drag mechanism, a sensor system that would alert the crew of an overload condition, an automatic shear function that would prevent an extreme overload).
 - (5) Human factors engineering solutions in the design of the FM's shear switch to facilitate the location and identification through readily identifiable covers. Also consideration of an improved option for the left seat pilot to assist in shearing when needed.
- c. ATC Mobile shall increase the realism and frequency of aircrew exposure to situations requiring analysis that would ultimately lead to ditching at sea. In aircrew simulator training, greater emphasis shall be placed on continuing the scenario to and beyond water landing. In addition, scenarios requiring a ditching decision shall be incorporated into annual unit standardization visits. Training scenarios should also incorporate the CRM discussions addressed in this report to punctuate the importance of solid crew coordination in all operations, but especially in highly complex and abnormal scenarios.
- d. COMDT (CG-711) shall coordinate with all stakeholders to conduct a formal COMDT (CG-113) Operational Hazard Assessment of each Coast Guard rotary wing asset working with routine small boat hoist training platforms (Coast Guard, contract or other agency vessels). The results shall be captured in a separate document, similar to the Navy's Shipboard Aviation Facilities Resume, to be a single reference point for aircrew and small boat crews for identifying and discussing hazards associated with their operations. If engineering or procedural processes are identified as deficient, then the appropriate change request or engineering modification form shall be initiated.
- e. COMDT (CG-41) shall assess the materiel condition of the main gearbox (MGB) suspension system and its dynamic components for service life implications. The overload of the main gearbox suspension system was well outside of design parameters as a direct result of the forces imparted during the incident. This investigation also revealed that more information needs to be obtained on the life limits of MGB components. Since the initiative to document these concerns is already underway via the Supportability Analysis Plan (SAP), COMDT

(CG-41) shall ensure that it includes at a minimum the following discussion items from this incident:

- (1) Potential incorporation of service life limits and updated examination criteria for the laminated elastomeric stops.
 - (2) Validation of the current C-channel design.
 - (3) Development of limits or tolerances permissible for the MGB base plate mechanical stops to make contact with the airframe stops as well as the laminated stop outboard ends being allowed to make contact with the stop supports or C-channels during flight.
 - (4) Potential updates to inspect the entire MGB suspension and drive shaft couplings when discovering any premature wear of the laminated stops or high speed flex couplings.
 - (5) Potential incorporation of more detailed inspections following a MGB overtorque/snagged hoist cable/hard landing or other events which could trigger an abnormal unloading of the MRH or imbalance of the engine drive shaft.
- f. The appropriate policy and staff offices from CG FORCECOM, COMDT (CG-711, CG-731, and CG-41) shall ensure the following manuals, syllabi and training requirements are implemented:
- (1) Analyze, develop and improve standardized "Boat-to-Helicopter" hand signals to be published in the Boat Crew Seamanship Manual and both rotary wing flight manuals. At a minimum, consideration should be given to the following routine communication scenarios: "Ready for pickup," "Cable snag," and "Abort hoist."
 - (2) Incorporate bold face (memory) steps into a new "Aircraft Ditching from a Hover" Emergency Procedure (EP) for the H-65 Flight Manual. It shall be short and conducive to memorized actions under extreme stress. One of the listed symptoms shall be "Severe vibrations of unknown origin." The current EP, "Aircraft Ditching from Forward Flight," shall continue to be used under a more deliberative ditching decision scenario.
 - (3) Re-write the "Abnormal Vibration" EP from the H-65 Flight Manual to include severity of vibrations in the symptoms section and to provide a definition of severe vibrations. The EP shall also be written from the most extreme scenario where severe vibrations would result in bold faced steps to land or ditch immediately to the benign scenario where diagnosis could occur with a different landing criteria applied.
 - (4) Include the more specific descriptors of abnormal vibrations from the Maintenance Manuals and Maintenance Procedure Cards (MPCs) in the H-65 Flight Manual abnormal vibrations section.
 - (5) Re-write the "Fouled Cable" EP from the H-65 Flight Manual to model the H-60 flight

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BARBERS POINT CLASS "A" AVIATION FLIGHT MISHAP
INVOLVING HH-65C CGNR 6505 ON 04 SEP 2008

manual in addressing the severity of "potential injury or danger imminent" in the beginning of the EP as a bold face item.

- (6) Update the Air Operations Manual, COMDTINST 3700.1 (series) and the Boat Operations and Training Manual to include an initial and recurrent requirement for rotary wing aircrew and surface forces to conduct asset familiarization on platforms routinely encountered in each unit's operations. Aircrew and boatcrew members shall receive the training within three months of reporting to a new operational unit and periodically thereafter at appropriate intervals.
- (7) Update the Flight Mechanic (FM) initial flight syllabus and re-qualification flights to incorporate fouled cable EPs that result in a scenario simulating shear procedures.
- (8) Evaluate the feasibility of integrating enlisted aircrew into simulator training to improve proficiency in crew resource management during normal and emergency procedures scenarios.

#

Dist: COMDT (CG-01, CG-DCO, CG-7, CG-711, CG-731, CG-5, CG-6, CG-4, CG-41, CG-1,
CG-11, CG-113, CG-1121, CG-9)
CG PACAREA (P)
CG LANTAREA (A)
CG FORCECOM (FC-5)
CGD FOURTEEN (d)
CGAS BARBERS POINT

Appendix B – DOD HFACs Human Error Failure Conditions and sub-categories

An excerpt of the DOD HFACS guide containing all of the failure conditions and sub-categories is provided below.

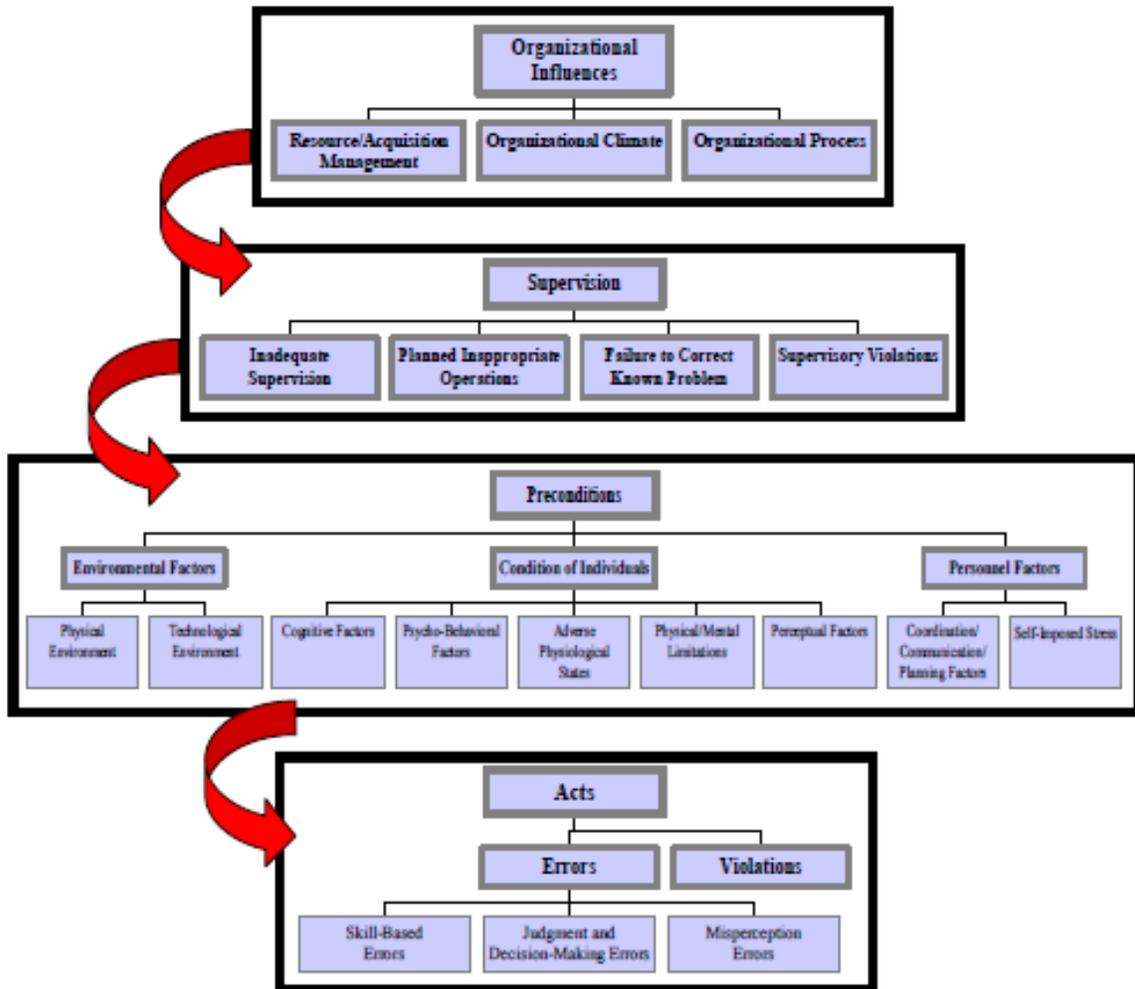


Figure 2. DOD HFACS Model

Note In the electronic version of this document each of the HFACS Model boxes are hyper-linked to more in-depth descriptions

1. Acts

Acts are those factors that are most closely tied to the mishap, and can be described as active failures or actions committed by the operator that result in human error or unsafe situation. We have identified these active failures or actions as *Errors and Violations* (see Figure 3).

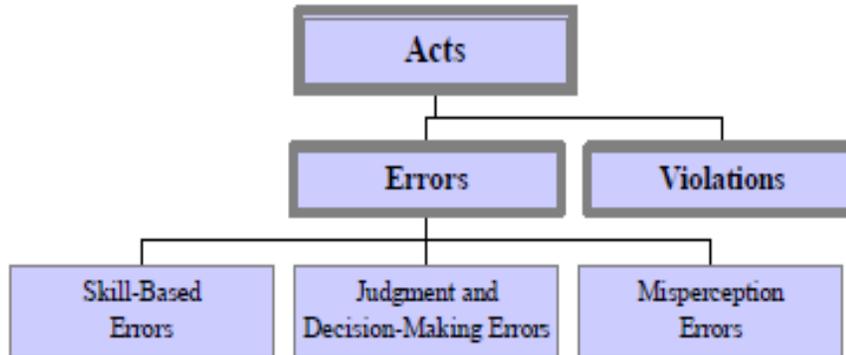


Figure 3. Categories of Acts of Operators

Errors: Errors are factors in a mishap when mental or physical activities of the operator fail to achieve their intended outcome as a result of skill-based, perceptual, or judgment and decision making errors, leading to an unsafe situation. Errors are unintended. We classified Errors into three types: *Skill-Based*, *Judgment and Decision Making*, and *Misperception Errors*. Using this error analysis process, the investigator must first determine if an individual or team committed an active failure. If so, the investigator must then decide if an error or violation occurred. Once this is done, the investigator can further define the error.

Skill-based Errors: Skill based errors are factors in a mishap when errors occur in the operator's execution of a routine, highly practiced task relating to procedure, training or proficiency and result in an unsafe situation. Skill-based Errors are unintended behaviors. (Table 1)

Judgment and Decision Making Errors: Judgment and Decision making errors are factors in a mishap when behavior or actions of the individual proceed as intended yet the chosen plan proves inadequate to achieve the desired end-state and results in an unsafe situation (Table 1).

Misperception Errors: Misperception errors are factors in a mishap when misperception of an object, threat or situation (such as visual, auditory, proprioceptive, or vestibular illusions, cognitive or attention failures) results in human error (Table 1).

Violations: Violations are factors in a mishap when the actions of the operator represent willful disregard for rules and instructions and lead to an unsafe situation. Unlike errors, violations are deliberate. (Table 1)

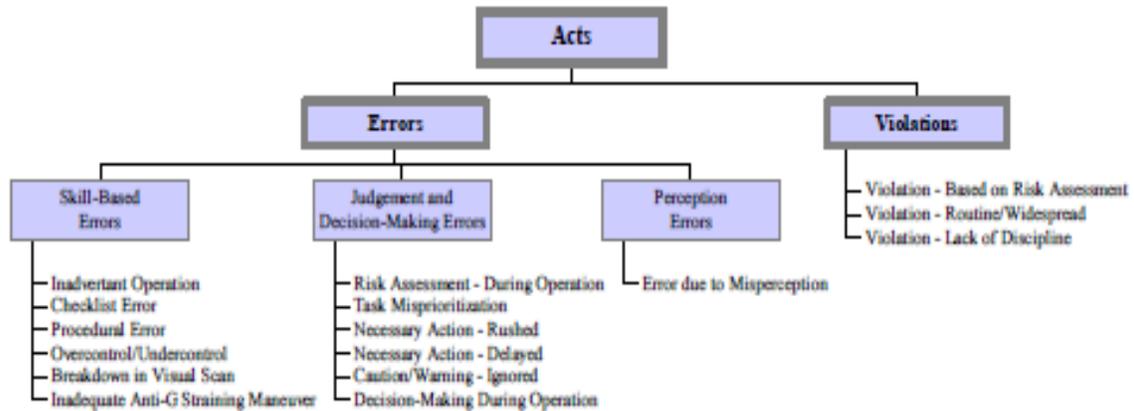


Table 1 Acts

2. Preconditions

Preconditions are factors in a mishap if active and/or latent preconditions such as conditions of the operators, environmental or personnel factors affect practices, conditions or actions of individuals and result in human error or an unsafe situation (Figure 4). In this error analysis model preconditions include *Environmental Factors*, *Condition of the Individuals* and *Personnel Factors*.

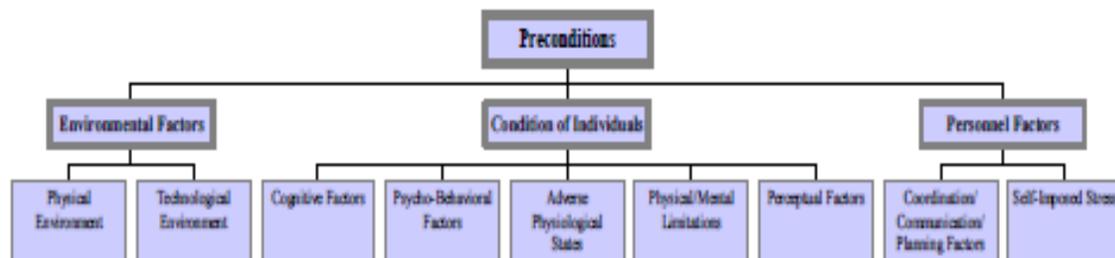


Figure 4. Categories of Preconditions for Unsafe Acts

Environmental Factors: Environmental factors are factors in a mishap if *physical* or *technological* factors affect practices, conditions and actions of individual and result in human error or an unsafe situation. Environmental factors include:

Physical Environment: Physical environment are factors in a mishap if environmental phenomena such as weather, climate, white-out or dust-out conditions affect the actions of individuals and result in human error or an unsafe situation. (Table 2)

Technological Environment: Technological environment are factors in a mishap when cockpit/vehicle/workspace design factors or automation affect the actions of individuals and result in human error or an unsafe situation. (Table 2)

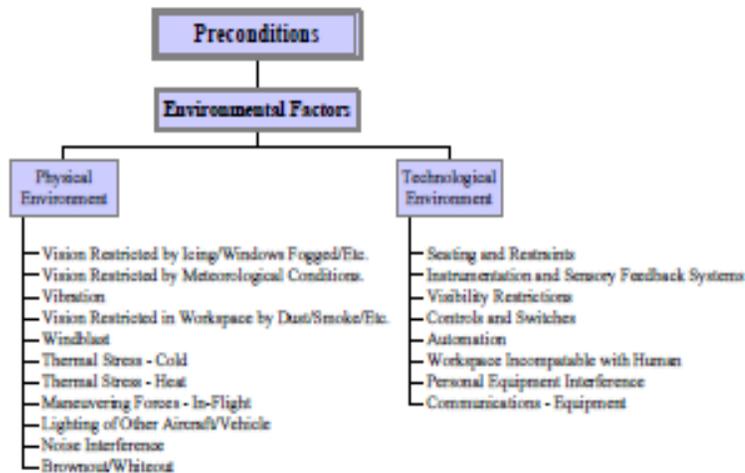


Table 2. Environmental Factors:

Condition of the Individual: Condition of the individual are factors in a mishap if cognitive, psycho-behavioral, adverse physical state, or physical/mental limitations affect practices, conditions or actions of individuals and result in human error or an unsafe situation. Condition of the Individuals include:

Cognitive Factors: Cognitive factors are factors in a mishap if cognitive or attention management conditions affect the perception or performance of individuals and result in human error or an unsafe situation. (Table 3)

Psycho-Behavioral Factors: Psycho-Behavioral factors are factors when an individual's personality traits, psychosocial problems, psychological disorders or inappropriate motivation creates an unsafe situation. (Table 3)

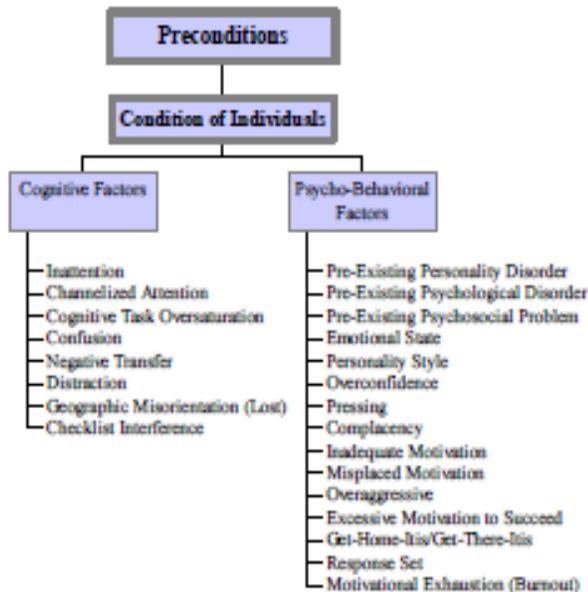


Table 3. Conditions of the individual (part 1)

Adverse Physiological States: Adverse physiological states are factors when an individual experiences a physiologic event that compromises human performance and this decreases performance resulting in an unsafe situation. (Table 4)

Physical/Mental Limitations: Physical/mental limitations are factors in a mishap when an individual lacks the physical or mental capabilities to cope with a situation, and this insufficiency causes an unsafe situation. This often, *but not always*, indicates an individual who does not possess the physical or mental capabilities expected in order to perform the required duties safely. (Table 4)

Perceptual Factors: Perceptual factors are factors in a mishap when misperception of an object, threat or situation (visual, auditory, proprioceptive, or vestibular conditions) creates an unsafe situation. If investigators identify spatial disorientation (SD) in a mishap the preceding causal illusion should also be identified. Vice versa, if an illusion is identified as a factor in a mishap then the investigator should identify the resultant type of SD. (Table 4)

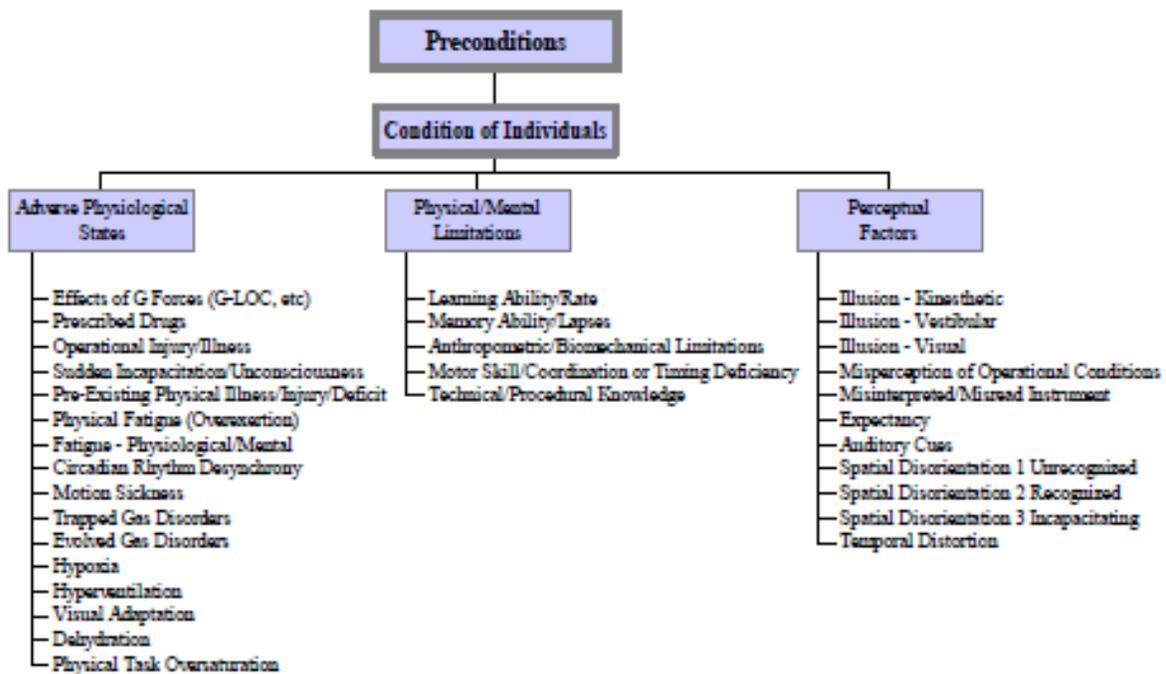


Table 4. Conditions of the individual (part 2)

Personnel Factors: Personnel factors are factors in a mishap if self-imposed stressors or crew resource management affects practices, conditions or actions of individuals, and result in human error or an unsafe situation. Personnel factors include:

Coordination / Communication / Planning: Coordination / communication / planning are factors in a mishap where interactions among individuals, crews, and teams involved with the preparation and execution of a mission that resulted in human error or an unsafe situation

Self-Imposed Stress: Self-imposed stress are factors in a mishap if the operator demonstrates disregard for rules and instructions that govern the individuals readiness to perform, or exhibits poor judgment when it comes to readiness and results in human error or an unsafe situation. These are often violations of established rules that are in place to protect people from themselves and a subsequent unsafe condition. One example of self-imposed stress is drinking alcohol prior to operating a motor vehicle.

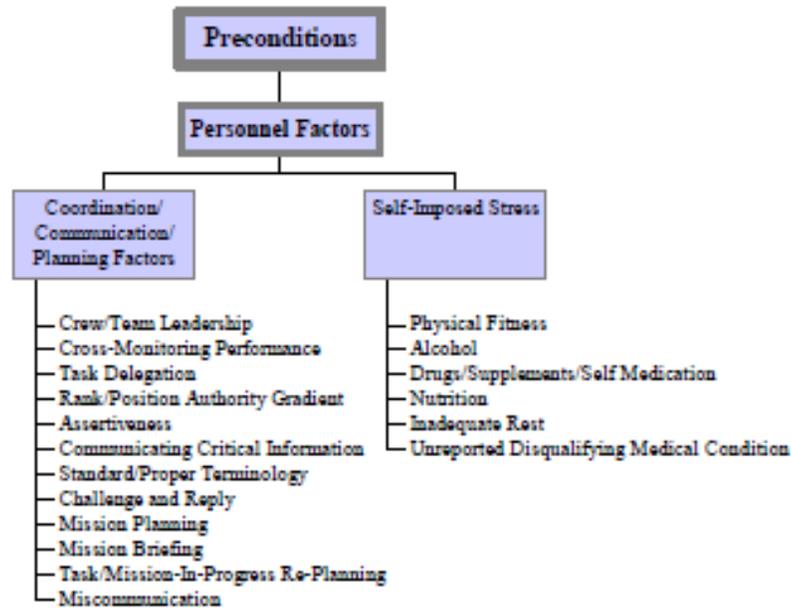


Table 5. Personnel Factors

3. Supervision

The Human Factors Working Group has determined that a mishap event can often be traced back to the supervisory chain of command. As such, there are four major categories of Unsafe Supervision: *Inadequate Supervision*, *Planned Inappropriate Operations*, *Failed to Correct a Known Problem*, and *Supervisory Violations* (see Figure 5).

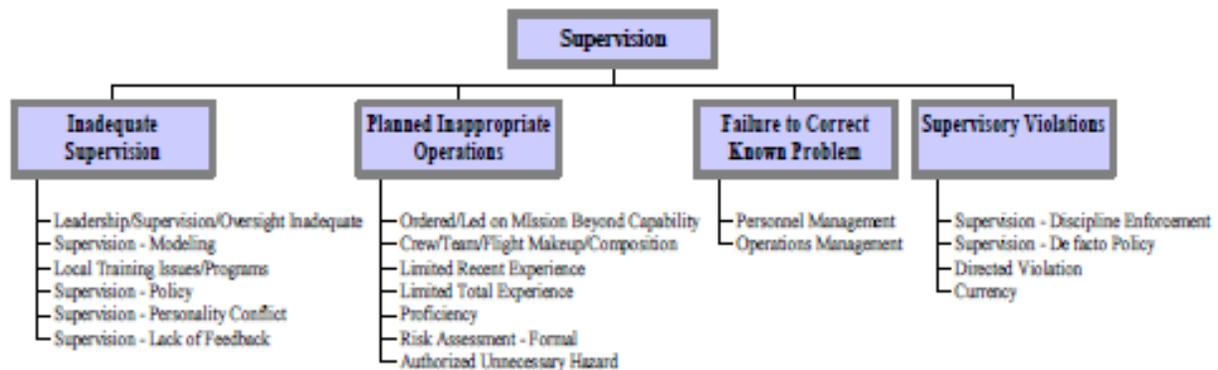


Figure 5 / Table 6. Categories of Unsafe Supervision

Inadequate Supervision: The role of supervisors is to provide their personnel with the opportunity to succeed. To do this, supervisors must provide guidance, training opportunities, leadership, motivation, and the proper role model, regardless of their supervisory level. Unfortunately, this is not always the case. It is easy to imagine a situation where adequate CRM training was not provided to an operator or team member. Conceivably, the operator's coordination skills would be compromised, and if put into a non-routine situation (e.g., emergency), would be at risk for errors that might lead to a mishap. Therefore, the category Inadequate Supervision accounts for those times when supervision proves inappropriate, improper, or may not occur at all (see Table 6). Inadequate Supervision is a factor in a mishap when supervision proves inappropriate or improper and fails to identify a hazard, recognize and control risk, provide guidance, training and/or oversight and results in human error or an unsafe situation.

Planned Inappropriate Operations: Occasionally, the operational tempo or schedule is planned such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such Planned Inappropriate Operations, though arguably unavoidable during emergency situations, are not acceptable during normal operations. Included in this category are issues of crew pairing and improper manning. For example, it is not surprising to anyone that problems can arise when two individuals with marginal skills are paired together. During a period of downsizing and/or increased levels of operational commitment, it is often more difficult to manage crews. However, pairing weak or inexperienced operators together on the most difficult missions may not be prudent (see Table 6). Planned Inappropriate Operations is a factor in a mishap when supervision fails to adequately assess the hazards associated with an operation and allows for unnecessary risk. It is also a factor when supervision allows non-proficient or inexperienced personnel to attempt missions beyond their capability or when crew or flight makeup is inappropriate for the task or mission.

Failure to Correct a Known Problem: Failed to Correct a Known Problem refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue uncorrected. For example, the failure to consistently correct or discipline inappropriate behavior certainly fosters an unsafe atmosphere and poor command climate (see Table 6). Failure to Correct Known Problem is a factor in a mishap when supervision fails to correct known deficiencies in documents, processes or procedures, or fails to correct inappropriate or unsafe actions of individuals, and this lack of supervisory action creates an unsafe situation.

Supervisory Violations: Supervisory Violations, on the other hand, are reserved for those instances when supervisors willfully disregard existing rules and regulations. For instance, permitting an individual to operate an aircraft without current qualifications is a flagrant violation that invariably sets the stage for the tragic sequence of events that predictably follow (see Table 6). Supervisory Violations is a factor in a mishap when supervision, while managing organizational assets, willfully disregards instructions, guidance, rules, or operating instructions and this lack of supervisory responsibility creates an unsafe situation.

4. Organizational Influences

Fallible decisions of upper-level management directly effect supervisory practices, as well as the conditions and actions of operators. These latent conditions generally involve issues related to *Resource/Acquisition Management*, *Organizational Climate*, and *Organizational Processes* (see Figure 6). Organizational Influences are factors in a mishap if the communications, actions, omissions or policies of upper-level management directly or indirectly affect supervisory practices, conditions or actions of the operator(s) and result in system failure, human error or an unsafe situation.

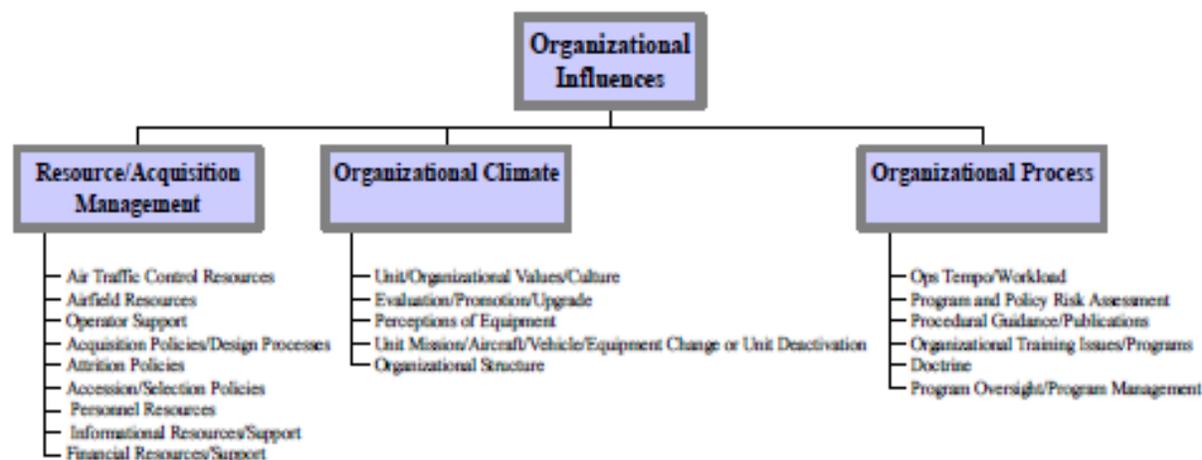


Figure 6 / Table 7. Categories of Organizational Influences

Resource / Acquisition Management: This category refers to the management, allocation, and maintenance of organizational resources—human, monetary, and equipment/facilities. The term “human” refers to the management of operators, staff, and maintenance personnel. Issues that directly influence safety include selection (including background checks), training, and staffing/manning. “Monetary” issues refer to the management of nonhuman resources, primarily monetary resources. For example, excessive cost cutting and lack of funding for proper equipment have adverse effects on operator performance and safety. Finally, “equipment/facilities” refers to issues related to equipment design, including the purchasing of unsuitable equipment, inadequate design of workspaces, and failures to correct known design flaws. Management should ensure that human-factors engineering principles are known and utilized and that existing specifications for equipment and workspace design are identified and met (see Table 7). Resource / Acquisition Management is a factor in a mishap if resource management and/or acquisition processes or policies, directly or indirectly, influence system safety and results in poor error management or creates an unsafe situation.

Organizational Climate: Organizational Climate refers to a broad class of organizational variables that influence worker performance. It can be defined as the situational consistencies in the organization's treatment of individuals. In general, Organizational Climate is the prevailing atmosphere or environment within the organization. Within the present classification system, climate is broken down into three categories—structure, policies, and culture. The term “structure” refers to the formal component of the organization. The “form and shape” of an organization are reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Organizations with maladaptive structures (i.e., those that do not optimally match to their operational environment or are unwilling to change) will be more prone to mishaps. “Policies” refer to a course or method of action that guides present and future decisions. Policies may refer to hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, use of safety equipment, etc. When these policies are ill-defined, adversarial, or conflicting, safety may be reduced. Finally, “culture” refers to the unspoken or unofficial rules, values, attitudes, beliefs, and customs of an organization (“The way things really get done around here.”). Other issues related to culture include organizational justice, psychological contracts, organizational citizenship behavior, *esprit de corps*, and union/management relations. All these issues affect attitudes about safety and the value of a safe working environment (see Table 7). Organizational Climate is a factor in a mishap if organizational variables including environment, structure, policies, and culture influence individual actions and results in human error or an unsafe situation.

Organizational Processes: This category refers to the formal process by which “things get done” in the organization. It is subdivided into three broad categories—operations, procedures, and oversight. The term “operations” refers to the characteristics or conditions of work that have been established by management. These characteristics include operational tempo, time pressures, production quotas, incentive systems, and schedules. When set up inappropriately, these working conditions can be detrimental to safety. “Procedures” are the official or formal procedures as to how the job is to be done. Examples include performance standards, objectives, documentation, and instructions about procedures. All of these, if inadequate, can negatively impact employee supervision, performance, and safety. Finally, “oversight” refers to monitoring and checking of resources, climate, and processes to ensure a safe and productive work environment. Issues here relate to organizational self-study, risk management, and the establishment and use of safety programs (see Table 7). Organizational Processes is a factor in a mishap if organizational processes such as operations, procedures, operational risk management and oversight negatively influence individual, supervisory, and/or organizational performance and results in unrecognized hazards and/or uncontrolled risk and leads to human error or an unsafe situation.

Appendix C – Aviation Training Center Standardization Visit Procedures Checklist

MH-65 STAN PROCEDURES CHECK

Pilot:			Qual Level:		Unit:	Evaluator: <input type="checkbox"/> - "X" if ATC IP	Date: 14 MAR 12
			<input type="checkbox"/> IP	<input type="checkbox"/> AC			Date STAN Exam Completed:
			<input checked="" type="checkbox"/> P	<input type="checkbox"/> CR			
Flight information: (include any general comments, including time/route of flight, weather/sea conditions, malfunctions and limitations, etc.)							
REQUIRED STD		UNSAT	SATISFACTORY		EVALUATED MANEUVER / PROCEDURE * Indicates optional item ** ATC IP Only	COMMENTS Place "X" in corresponding blocks to left of maneuver/procedure. Comments required for other than "STD" marks.	
CP	FP AC IP		TRAIN TO STD	STD			
PREFLIGHT DISCUSSION							
S	S			X	TODD Card	Aerodynamics: Unable to explain blow-back/flap-back. IP explained the dissymmetry of lift and how this leads to blow-back. PUI admitted to poor knowledge and lack of preparation for aero.	
S	S			X	Flight Crew Inspection		
K	K	X			Aerodynamics <small>(plus Normal Flight Manual Ch. 11.4)</small>	Autorotations: PUI was asked the Visual Autorotation Procedure and could only verbalize the 'turn towards landing area step'. PUI admitted not studying autorotations at all.	
K	K				Status Page		
K	K			X	Unusual Attitudes	Any System: IP asked the PUI to pick a system. PUI was not prepared to brief any of the systems and admitted an overall poor systems knowledge.	
K	K	X			Autorotations		
K	K	X			Any System	GROUND/TAXI OPS	
S	S				CHECKLISTS		
S	S				BASIC AIRWORK	TAKEOFFS	
I	S				Hover		
I	S				No Hover	Any System: IP asked the PUI to pick a system. PUI was not prepared to brief any of the systems and admitted an overall poor systems knowledge.	
I	S				Running		
I	S				PATTERN/TRANSITION POINT	APPROACHES & LANDINGS	
I	S				Hover		
I	S				No Hover	AFCS OFF TAKEOFF & LANDING	
I	S				Running		
I	S				Elevated Pad/Pinnacle Approach*	TAIL ROTOR MALFUNCTIONS	
I	S				AFCS OFF TAKEOFF & LANDING		
I	S				TAIL ROTOR MALFUNCTIONS	SINGLE ENGINES	
I	S				Running Landing		
I	S				Landings	LOW HOVER SINGLE ENGINES	
I	S				Continued Speed		
I	S				Minimum Speed	HIGH HOVER SINGLE ENGINES	
D	D				Minimum Speed Waveoff w/NR Droop to 320 RPM**		
I	S				LOW HOVER SINGLE ENGINES	Landback	
I	S				HIGH HOVER SINGLE ENGINES		
I	S				Landback	SAFETY PILOT DUTIES	
I	S				Continued Flight		
S	S				SAFETY PILOT DUTIES	IP DUTIES (IP only)	
S	S				IP DUTIES (IP only)		
EMERGENCY PROCEDURES							
I	S				EP 1		
I	S				EP 2		
I	S				EP 3		
I	S				EP 4*		

CRM EVALUATION: (Communication, Flight Discipline & Leadership), Risk Management, Situational Awareness, etc.)	
Was CRM performance Satisfactory? (check one) <input type="checkbox"/> Yes <input type="checkbox"/> No	
Feedback & Recommendations:	Did pilot meet required performance level? (check one) <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
The brief was unsatisfactory for an AC Stan Check and as a result this ride is a fail. PUI is struggling to keep up with aviation duties in conjunction with collateral job and family life, which was very evident during the brief. Recommend FEB immediately discuss the way forward.	
Evaluator's Signature and Date (required): COOPER,JOEL F.1364991122	Unit CO/OPS Signature (optional): [Redacted]

Page 2 – Standardization Visit Procedures Checklist

Appendix D – Unit Level Search and Rescue Procedures Checklist

MH-65 SAR PROCEDURES CHECK

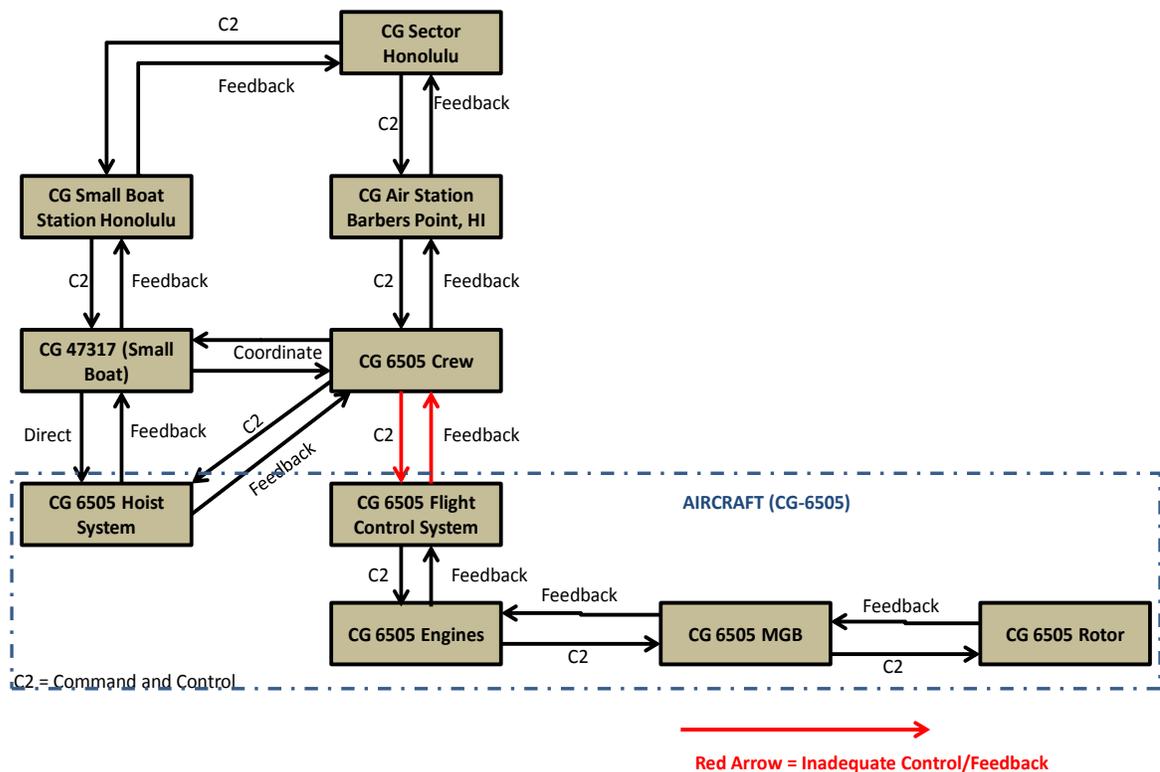
Pilot:		Qual Level: <input type="checkbox"/> IP <input type="checkbox"/> AC <input type="checkbox"/> FP <input type="checkbox"/> CP		Unit:	Evaluator: <input type="checkbox"/> - %* if ATC IP	Date:	
Flight Information: (Include any general comments, including route of flight, weather/sea conditions, malfunctions and limitations, etc.)							
REQUIRED STD	CP	FP AC IP	UNSAT	SATISFACTORY		EVALUATED MANEUVER / PROCEDURE * Indicates optional item	COMMENTS Place %* in corresponding blocks to left of maneuver/procedure. Comments required for other than "STD" marks.
				TRAIN TO STD	STD		
						PREFLIGHT	
	S	S				TODD Card	
	S	S				Flight Crew Inspection	
	K	K				Weather Phenomena	
	K	K				RADALT Bug Use	
						FMS & FDS	
	I	S				CDU Operations	
	I	S				Search Patterns	
	I	S				FDS Use	
	I	S				Radar Use	
						INSTRUMENT PROCEDURES	
	I	S				CATCH or MATCH	
	I	S				ITO (Coupled or Uncoupled)	
						VESSEL HOISTS	
	P	S				Vessel/Crew Briefing	
	P	S				Underway w/o Trail Line	
	P	S				Underway w/ Trail Line	
	P	S				DIW w/ Trail Line	
						RESCUE SWIMMER OPS	
	P	S				Deployments	
	P	S				Direct Deployments	
	P	S				Recoveries	
	P	S				* Harness Deployment w/ Trail Line	
	S	S				CHECKLISTS	
						EPS (Min. of 3)	
	I	S				EP 1:	
	I	S				EP 2:	
	I	S				EP 3:	
CRM EVALUATION: (Communication, Flight Discipline & Leadership), Risk Management, Situational Awareness, etc.)							
Was CRM performance Satisfactory? (check one) <input type="checkbox"/> Yes <input type="checkbox"/> No							
Feedback & Recommendations: Did pilot meet required performance level? (check one) <input type="checkbox"/> Yes <input type="checkbox"/> No							
Evaluator's Signature and Date (required):				Unit CO-OPS Signature (optional):			

Appendix E – Inadequate Control/Feedback Diagrams

This appendix summarizes the system safety control/feedback inadequacies identified through completion of the CAST analysis contained herein this thesis. A brief narrative description and graphical depiction is provided for each control/feedback inadequacy.

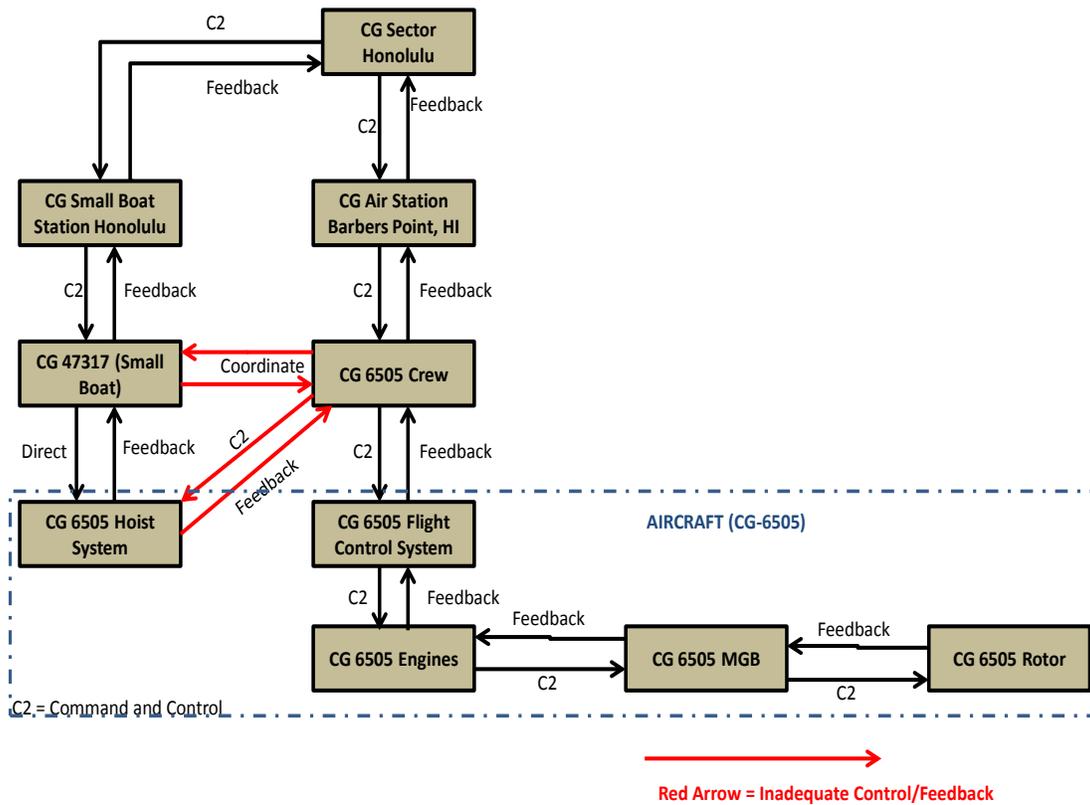
Inadequate Control/Feedback – Pilot and Flight Control System in Hover/Approach – The physical system does not provide adequate feedback and controls to the pilot to assist the pilot in safely executing nighttime hoisting operations. The pilot relies heavily on limited visuals and the altimeter to ensure the approach/hover is conducted at a safe distance. Considering the frequent occurrence of overcontrol / overtorque in this scenario, improved control is needed.

Pilot & Flight Control System in Hover – Control/Feedback Inadequacies



Inadequate Control/Feedback – Lack of Control/Feedback of Hoist System and Lack of Communications between Air/Boat Crews – Due to inadequacies in the hoist system (e.g., lack of dynamic slip clutch, sub-optimal location of shear control for remote hoisting operations) and communications (e.g., inability of boat crew to communicate directly with air crew resulting in sub-optimal control/feedback), CG-6505/CG-47317 were not able to adequately control the hoist system to prevent entanglement and damage to the aircraft post-hoist entanglement. Additionally, lack of sensors on the hoist system resulted in inadequate feedback to the air crew regarding entangled status.

Hoisting Operations – Control/Feedback Inadequacies

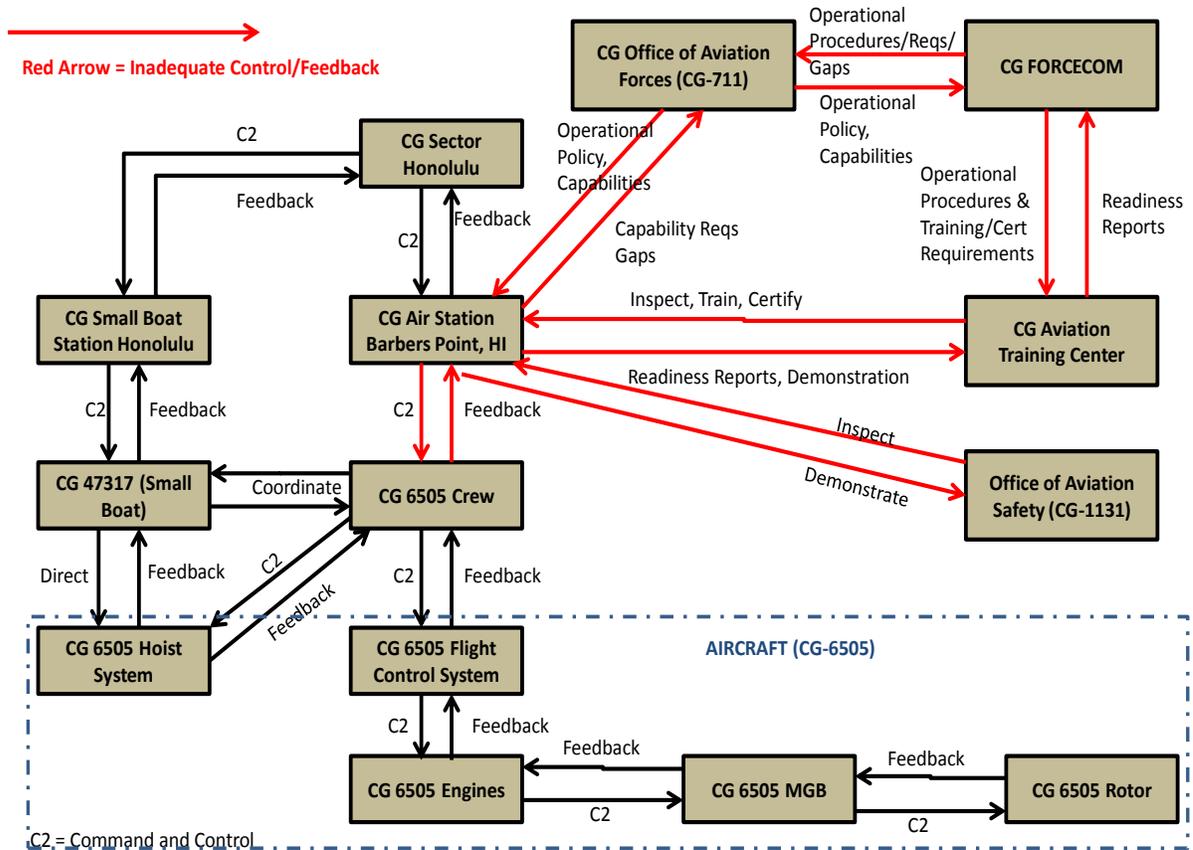


Inadequate Control/Feedback – Lack of Standardized Ditching Training – Lack of standardized training (observation and reporting) of ditching procedures.

Inadequate Control – Lack of emphasis on Ditching & Paramount Importance of Life Safety
 – Lack of emphasis on importance of ditching an aircraft following severe damage.

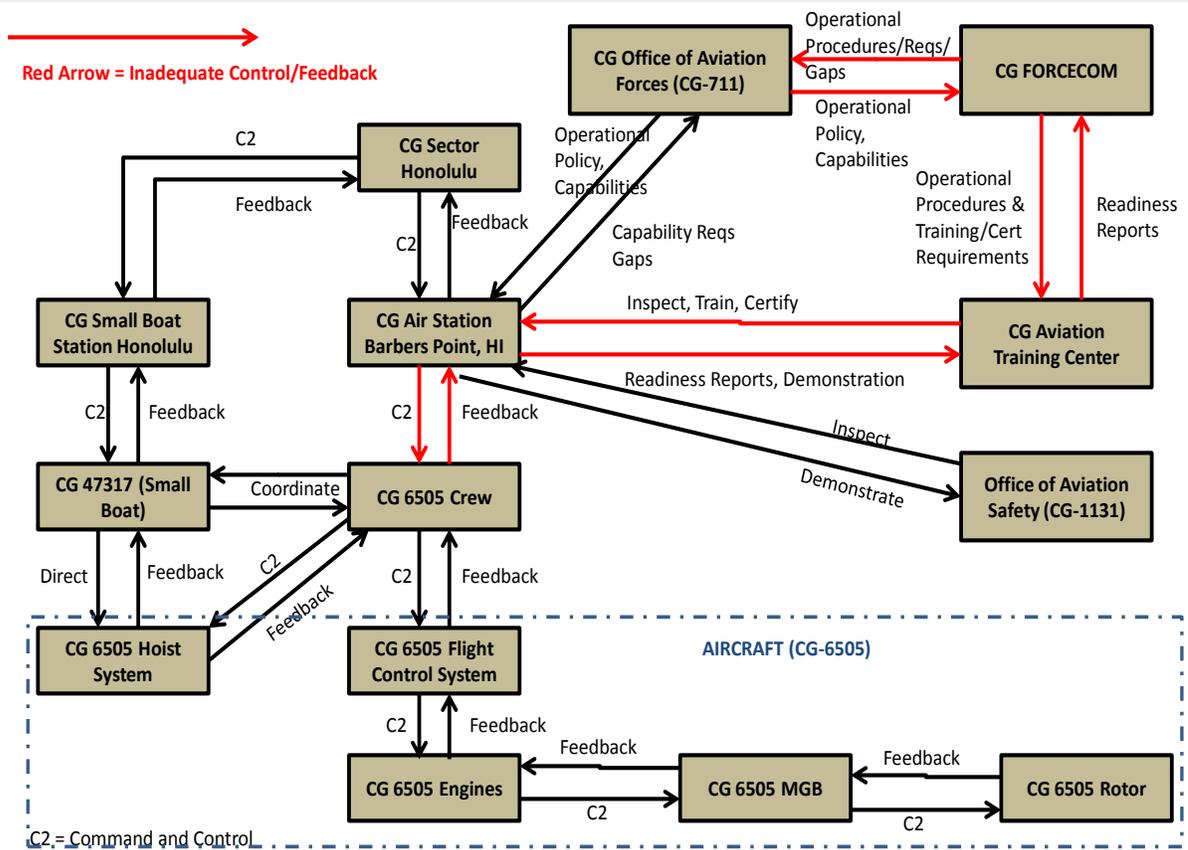
Contributed to lack of control over cultural resistance to ditching. Lack of clear policies and sufficient attrition reserve aircraft may be contributing to cultural barriers to ditching damaged aircraft to preserve crew safety.

Ditching Procedures & Life Safety Emphasis – Control/Feedback Inadequacies



Inadequate Control/Feedback – Inadequate Reporting of Standardization Visit and SAR Checks - The only required signature on the Standardization Visit Procedures Checklist is that of the Aviation Training Center Instructor Pilot. Additionally, the only required signature on the SAR Procedures Checklist is the unit’s instructor pilot. Failure to require the PUI and the PUI’s Commanding Officer and Operations Officer to sign these forms results in inadequate accountability and transparency (e.g., control and feedback) with respect to pilot/aircrew proficiency and potential hazards/operational risks.

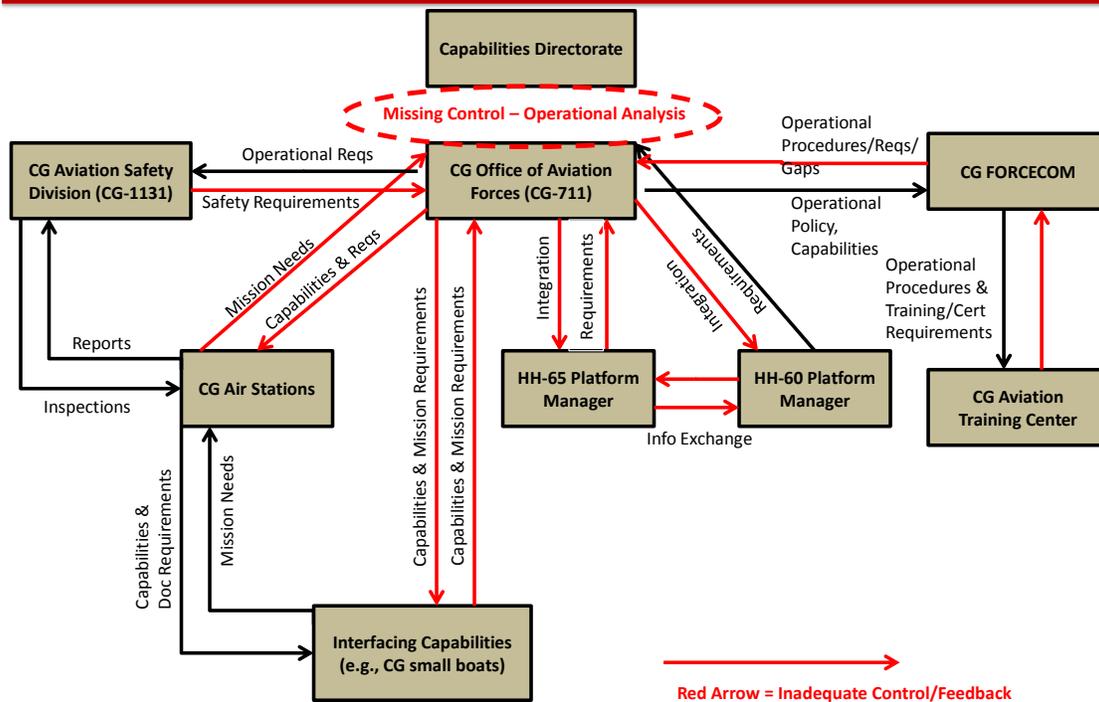
Standardization Visit & SAR Checks – Control/Feedback Inadequacies



Inadequate Control/Feedback – Capabilities Management System: General lack of control and feedback in the management of existing capabilities (e.g., HH-65):

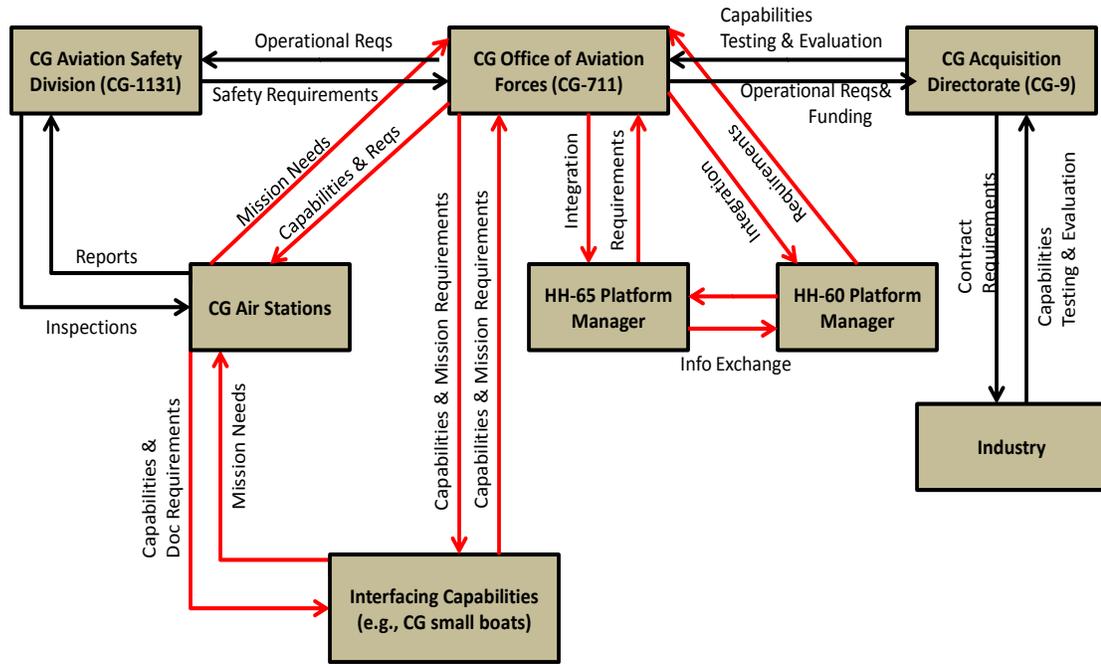
- Inadequate Control/Feedback – Lack of Periodic Capabilities Review/Communication – Lack of formal periodic capability gap assessment (e.g., Operational Analysis) required/performed.
- Inadequate Control/Feedback – Lack of Integrated Capability Management – Lack of formal integration/standardization of helicopter operational capabilities across platforms.
- Inadequate Control/Feedback – Sponsor capability and requirements cataloging: Lack of systematic process for documenting existing system and sub-system capabilities and operational capability gaps.
- Inadequate Control/Feedback – Lack of Safety Advocacy to Address Known Risks: Rather than advocating correction/mitigation, the Aviation Safety Division generally accepted known aviation operational risks (e.g., nighttime hoisting operations).

Capabilities Management – Control/Feedback Inadequacies



Inadequate Control/Feedback – Sponsor/User involvement in design/development: Lack of sponsor and user involvement, including like platforms and interfacing capabilities during acquisition and modernization efforts.

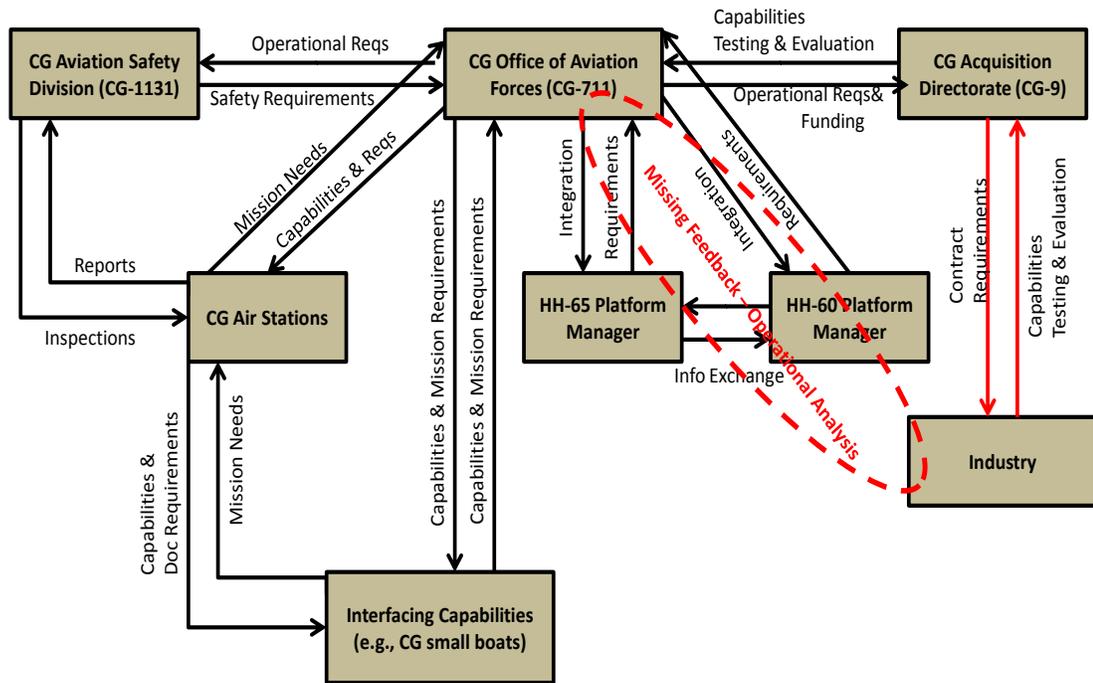
Sponsor/User Involvement in Design & Development – Control/Feedback Inadequacies



→
Red Arrow = Inadequate Control/Feedback

Inadequate Control/Feedback – Coast Guard Acquisition Directorate and Industry: Lack of involvement with industry regarding state of the market capabilities and procedures.

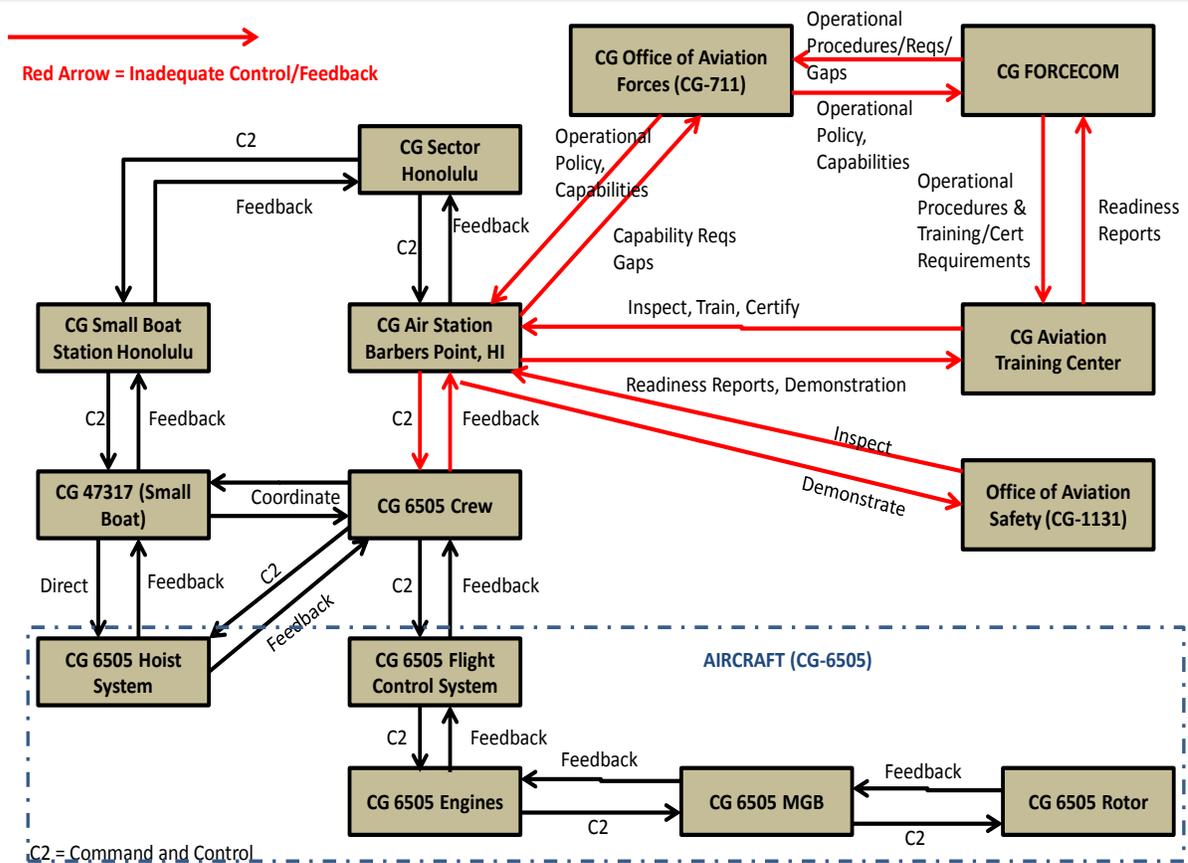
Industry Involvement – Control/Feedback Inadequacies



→
Red Arrow = Inadequate Control/Feedback

Inadequate Control/Feedback – Lack of Standardized CRM/ORM Training: Lack of standardized training (observation and reporting) of Crew Resource Management and Operational Risk Management programs through use of multiple training delivery sources, collateral duty program, and limited programmatic guidance. Lack of identifying/cataloguing operational risks and mitigating actions specific to operational procedures/conditions.

CRM / ORM Training – Control/Feedback Inadequacies



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