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

STAMP Workshop - 2013

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U.S. Coast Guard
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Agenda

- STAMP – System Safety applied to CG aviation
  - Why the research topic
    - Motivation, Objectives, Methodology
  - Overview of CG aviation mishap (CG-6505)
  - Overview of STAMP (System Safety Analysis Tool)
  - STAMP vs. CG Mishap Analysis methodology
  - STAMP Findings
  - Recommendations

Motivation

- Increased CG Aviation Mishap Rate
  - Seven Class A mishaps in 22-month period 2008-2010

- CG mishap investigations centered on human factors analysis.

- Individual CG mishap investigations did not find common contributing or causal factors resulting in systemic failures.
  - Aviation Safety Assessment Action Plan (ASAAP): "Complacency in cockpit"

Research Objectives

- Apply systems theory and systems engineering approaches to ID, evaluate, eliminate, and control *system hazards* through analysis, design, and management procedures.
  - STAMP – Systems Theoretic Accident Model and Processes
    - Dr. Nancy Leveson
- Focus on the systemic *sources*
- *Compare CG MAB to STAMP findings to determine if STAMP is a good tool for CG mishap investigation.*

Methodology

Apply STAMP to a single CG aviation mishap….

Mishap Summary – CG-6505

- ❑ Coast Guard HH-65 Helicopter (CG-6505) from Air Station Barbers Point, Oahu, Hawaii
- ❑ Experienced a mishap during training evolution with Coast Guard small boat
- ❑ All four (4) persons on board were lost (pilot, co-pilot, flight mechanic, and rescue swimmer)
- ❑ Date: September 4, 2008

Summary of Events Leading to Mishap:

- At 2011 (local time – Hawaii) on Sept 4, 2008, a Coast Guard helicopter (CG-6505) was conducting night time hoist training with CG Small Boat (CG-47317).
  - Hoist training consists of hovering over the deck of the boat and lowering and raising a basket with the helicopter hoist.
- During one of the hoist evolutions, the helicopter got closer to the deck of the small boat than the pilot intended.
- The pilot reacted by increasing altitude quickly.
- Simultaneously, the hoist cable entangled itself on a deck fitting (aft buoyancy chamber de-watering standpipe) of CG-47317.
- The entangled cable caused CG-6505 to roll hard left
- The cable parted and the CG-6505 rolled hard right
- Hard rolls caused damage to CG-6505's main gear box (interface between engines and rotors)
- CG-6505 flies away from CG-47317 heading toward the CG Air Station
- CG-6505 catches on fire and crashes into the water
- All four (4) people on board (pilot, co-pilot, flight mechanic, rescue swimmer) die on impact.

Coast Guard Mishap Analysis Board

- Conducted in accordance with Department of Defense Human Factors Analysis and Classification System (DOD HFACS).
- DOD HFACs based on Reason's 'Swiss Cheese' Model of active and latent failures

- DOD HFAC Categories:

***Active Failures**:*

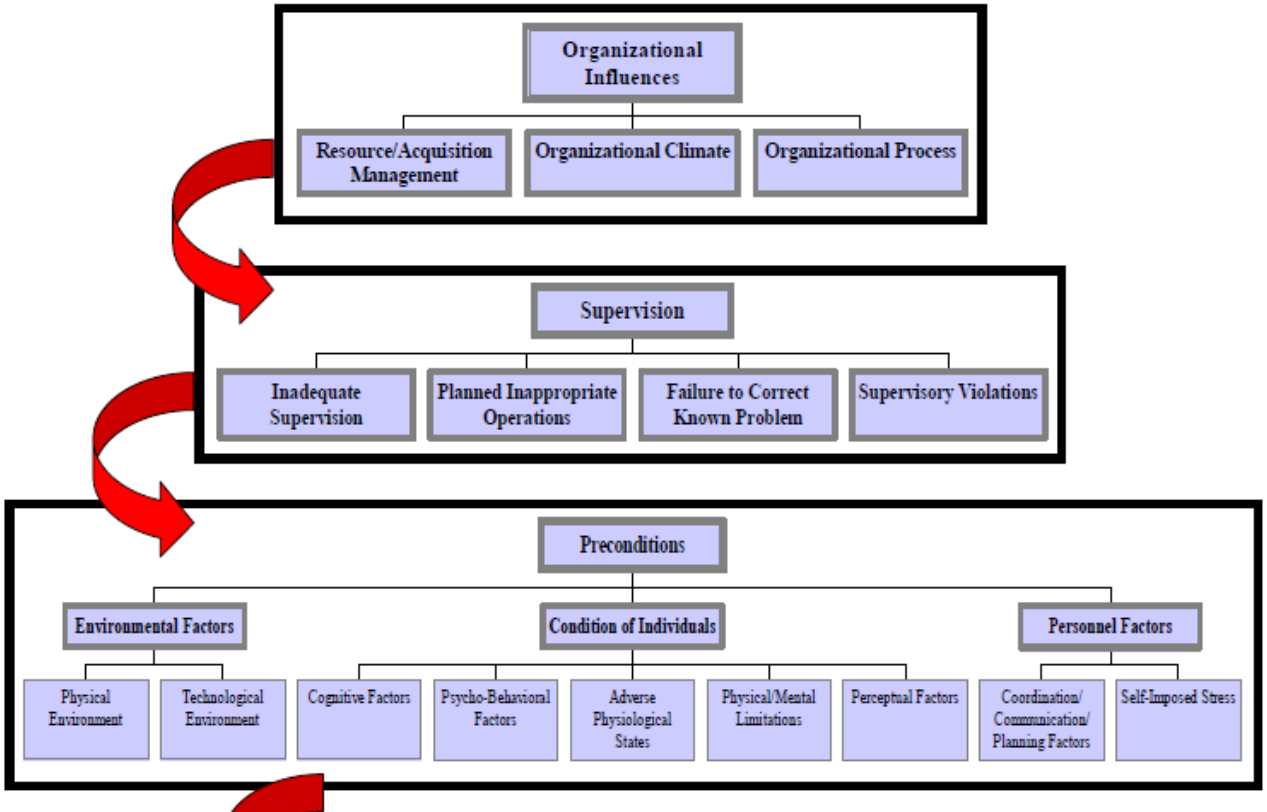
- **Acts** – factors that are most closely tied to the mishap, and can be described as *active failures* or ***actions committed by the operator*** that result in human error or an unsafe situation.

***Latent Failures**:*

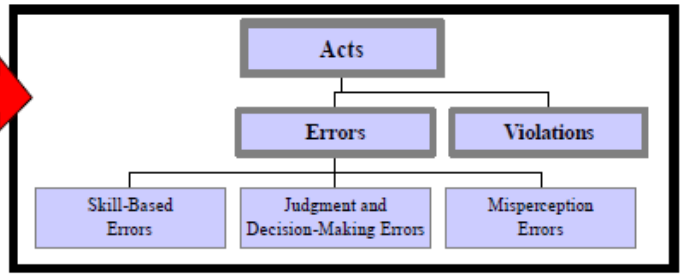
- **Preconditions** – factors in a mishap such as conditions of the operators, ***environmental or personnel factors*** that affect practices, conditions, or actions of individuals and result in human error or an unsafe situation
- **Supervision** – factors that involve the ***supervisory chain of command*** that contribute to an accident including inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations.
- **Organizational Influences** – ***Org lvl factors*** such as climate, resource mgmt.

DOD HFACS – ACTIVE & LATENT FAILURE CATEGORIES

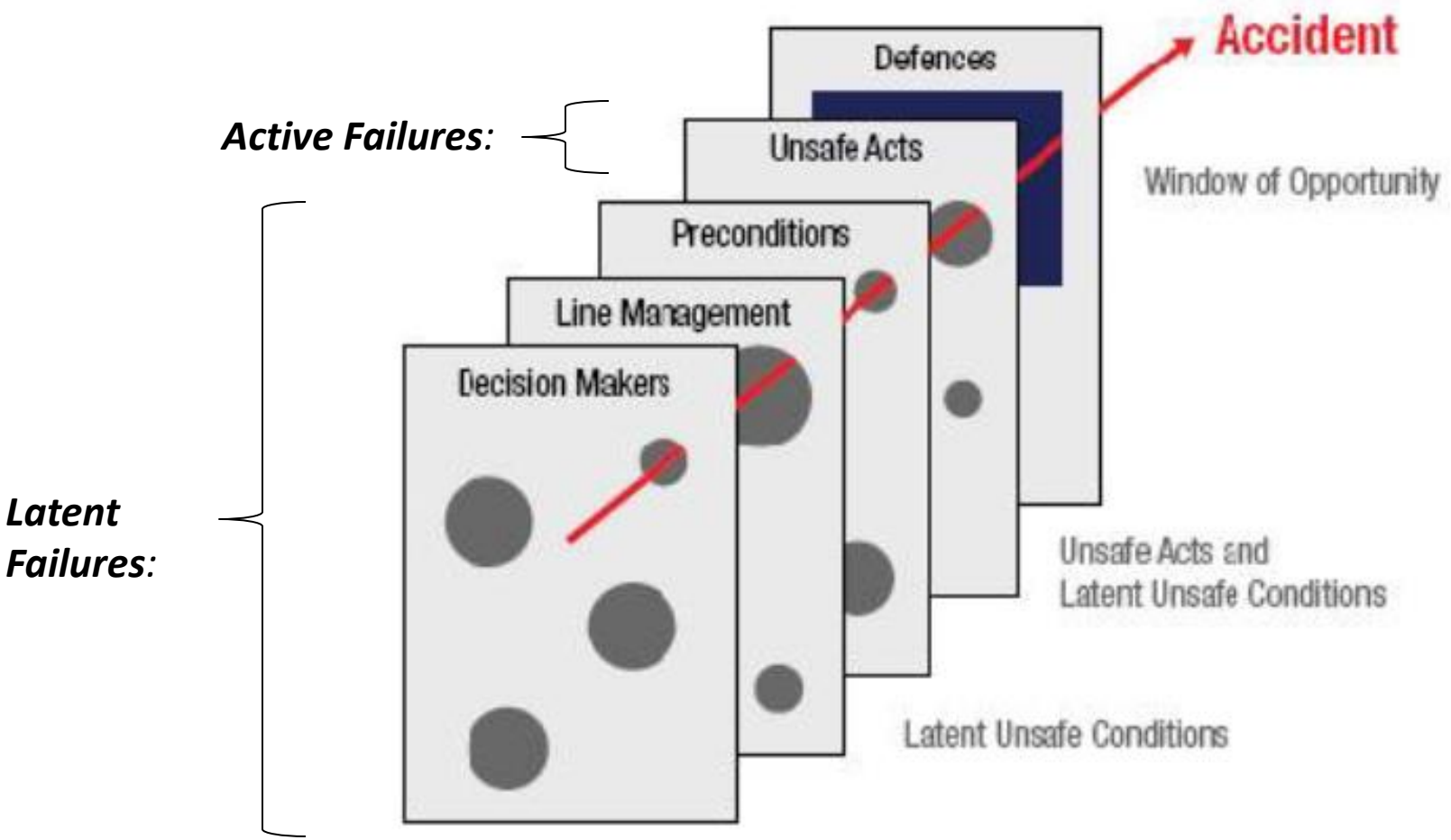
Latent Failures:



Active Failures:



DOD HFACS – ACTIVE & LATENT FAILURE CATEGORIES



Accident Report Identified Causes (1 of 4) – CG-6505

Summary of findings:

The accident report found three (3) main "causal factors/actions" to the accident. Each causal factor had related "pre-conditions" and "supervisory/organizational issues" that contributed. The following slides are organized accordingly.

Causal Factor #1:

- Pilot Over-Control and Over-Torque
  - Approached too close to CG-47317
  - Over adjusted to compensate – commanded aircraft to climb away too fast

Related Contributing Factors:

- Poor visibility due to darkness
- Pilot misperception of operational conditions

Accident Report Identified Causes (2 of 4) – CG-6505

Causal Factor #2:

- Pilot Procedural Error – Failure to initiate "Hoist Cable Fouled/Damaged emergency procedures
  - Failure to pay out cable
  - Failure to shear cable

Related Contributing Factors:

- Poor visibility due to darkness
- Lack of hoist cable sensors/feedback
- Lack of system safety approach to CG asset design/acquisition.

Accident Report Identified Causes (3 of 4) – CG-6505

Causal Factor #3:

- Pilot Procedural Error – Failure to initiate aircraft ditching emergency procedures
  - Failure to recognize/evaluate severe vibration post hoist cable parting
  - Failure to ditch aircraft

Related Contributing Factors:

- Poor visibility due to darkness – inability to see water surface/assess damage
- Loud vibration – impeded situational awareness, crew communications, etc.
- Aircraft crew's attention too channelized on maintaining the aircraft versus analyzing the situation and taking appropriate action.
- Cultural instinct – Cultural imperative to "bring the crew and aircraft home."
- Crew Team Leadership – Poor Crew Resource Management post hoist cable parting. Poor communications, lack of assertiveness, and failure to follow procedures.
- Organizational Training Issues – Lack of emphasis on ditching in pilot/crew development.

Mishap Board Recommendations:

- Installation and evaluation of "dynamic overload (slipping clutch) hoist system" on the H-65 (similar to other CG aircraft).
  - Conduct system safety analysis of all CG hoist systems and replace hoists as necessary.
- Create and mandate use of a protective shroud to cover the aft buoyancy chamber de-watering standpipe during hoisting operations.
- Evaluate requirements of system safety integration into CG asset/acquisition design procedures.
- Increase emphasis and realism of aircraft ditching procedures in pilot/crew training and qualification
- Conduct formal Operational Hazard Assessment of helicopter hoisting operations with small boats.
- Update operating and training manuals.

STAMP – System Theoretic Accident Model Process

1. Identify System, Hazards and System-Level Safety Constraints

2. Define Safety Control Structure

3. Identify Potentially Inadequate Control Actions and Feedback

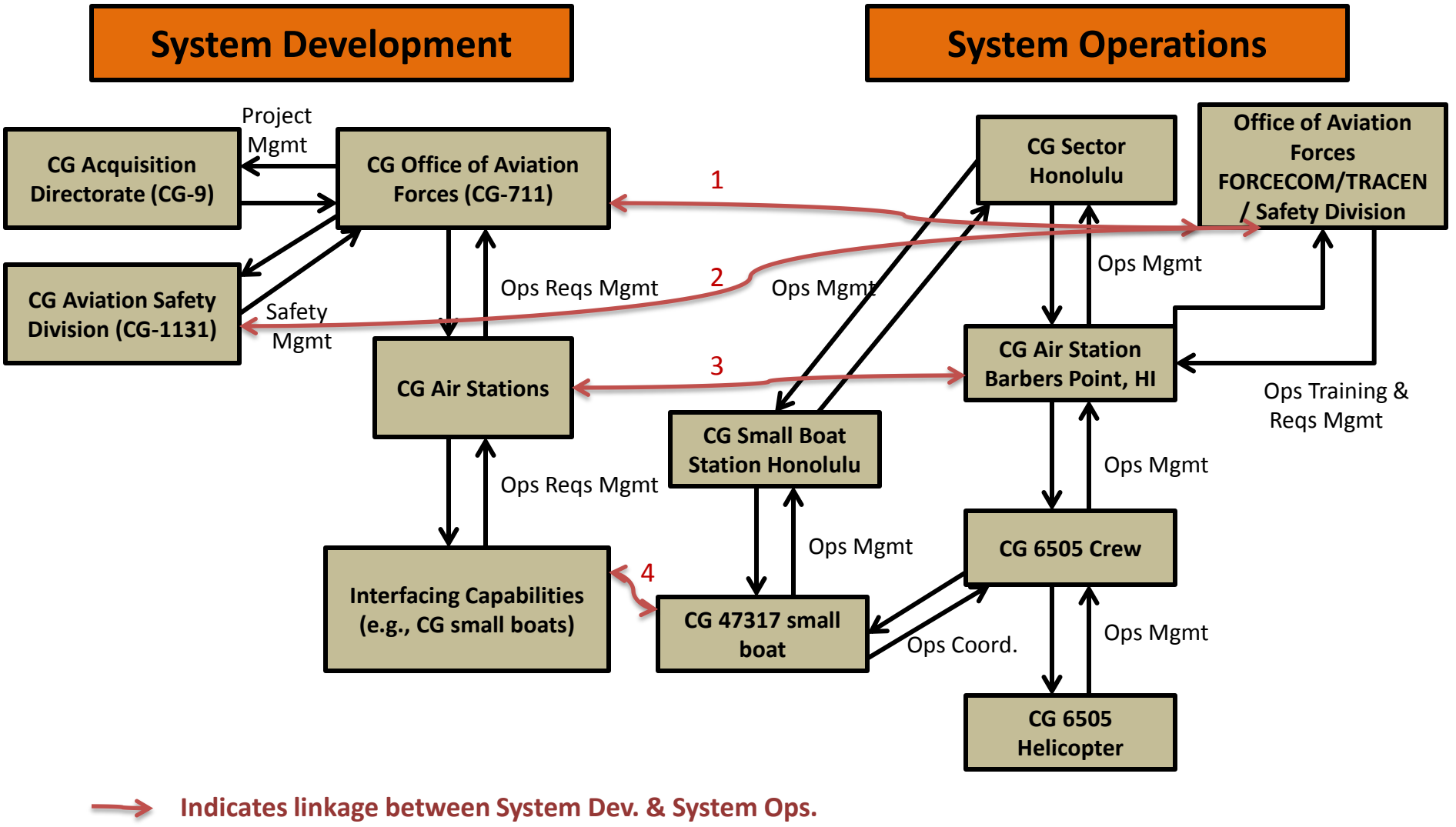
   - *Identify physical control inadequacies*
   - *Analyze saftety-related responsibilities, context, unsafe decisions & control actions, and process model flaws*

4. Identify Mitigating Control Actions/Feedback

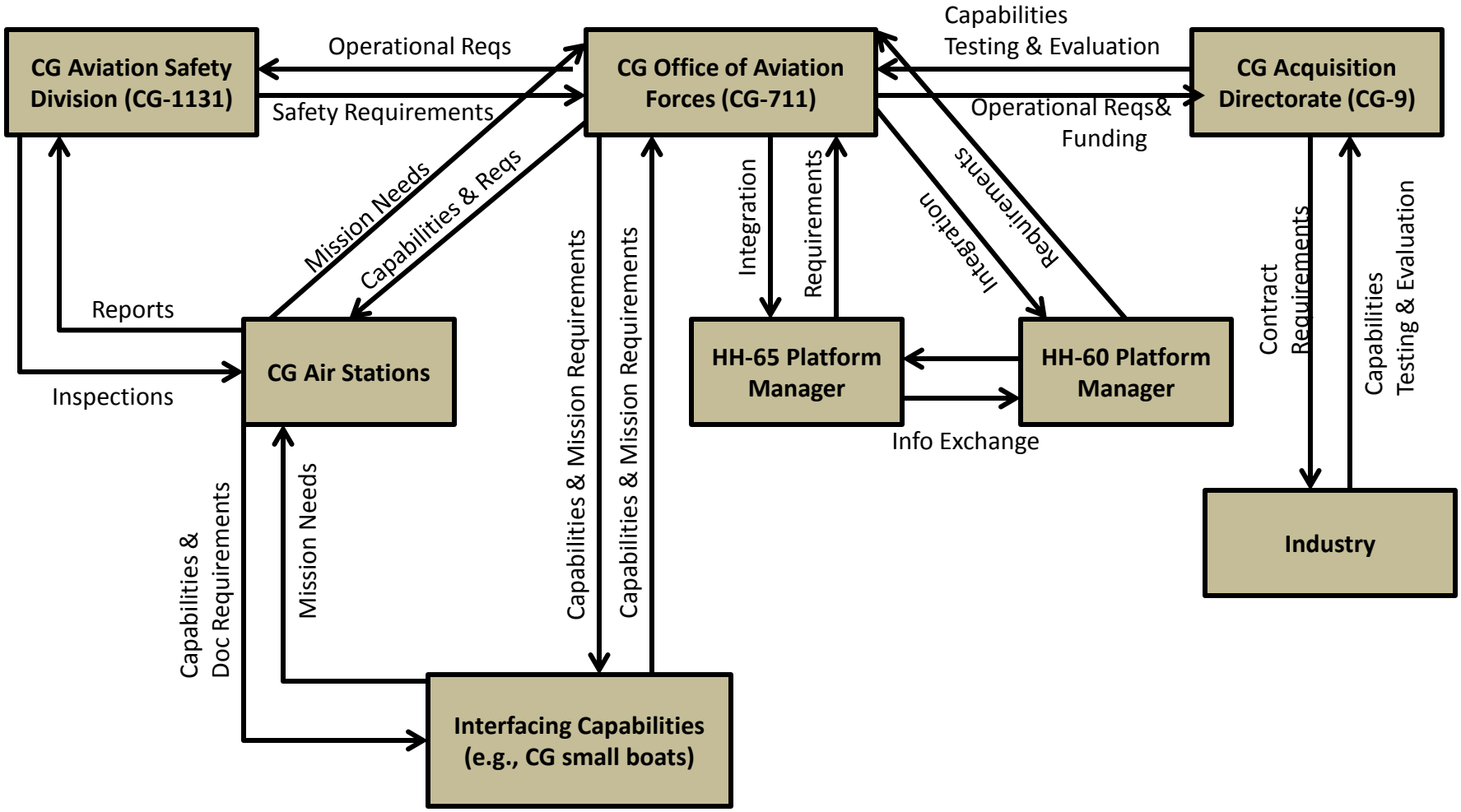
System: *Coast Guard Aviation System*

	Hazards	System Safety Constraints
1	Pilot positions aircraft too close to small boat.	The pilot must not position aircraft too close to small boat.
2	Helicopter hoist gets entangled on small boat.	The hoist must not become entangled 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.
4	Pilot/aircrew continues to fly aircraft after damage.	The pilot/aircrew must abandon aircraft after severe damage to the aircraft.

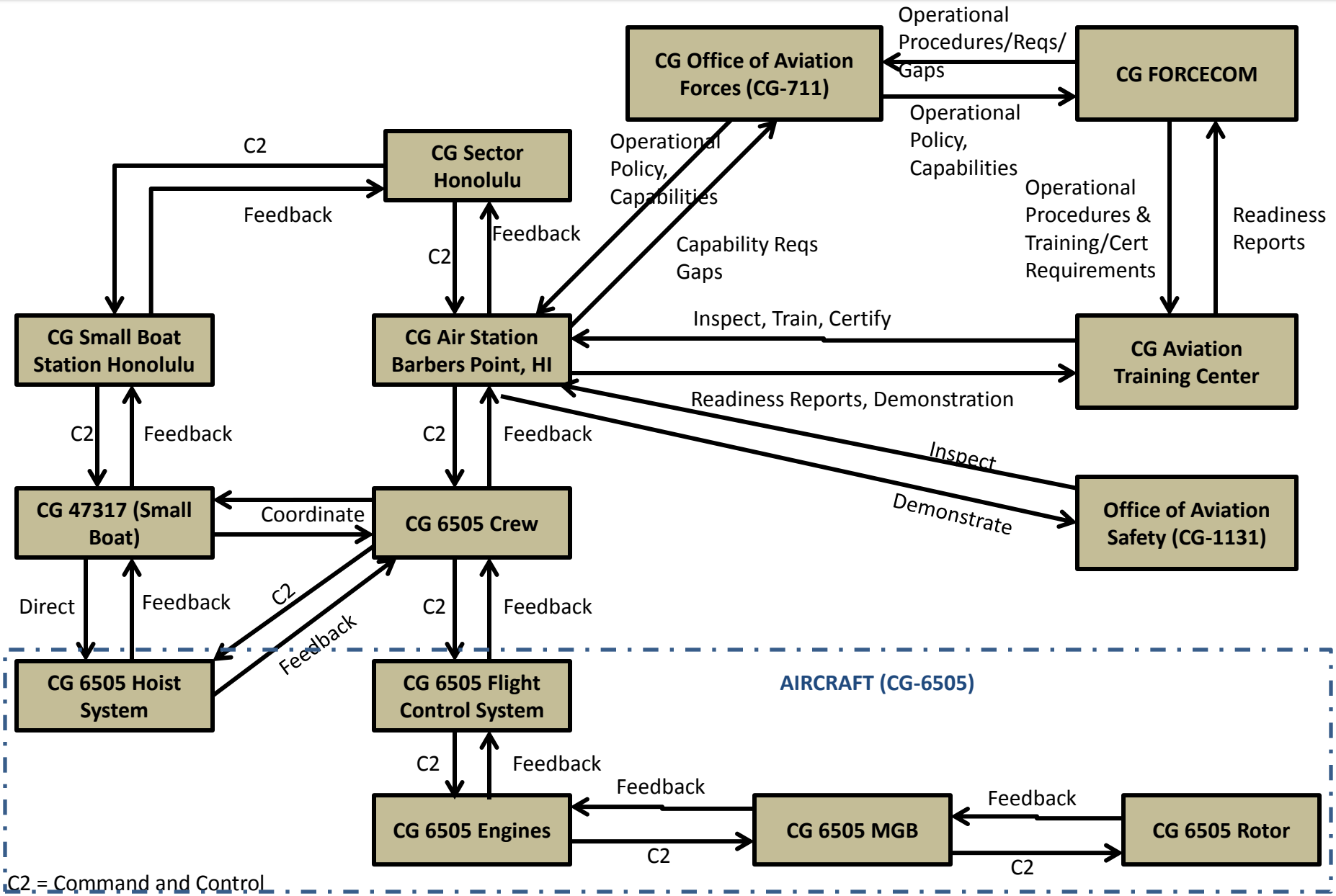
CONTROL STRUCTURE – System Development & Ops (Overview)



CONTROL STRUCTURE – System Development (Detailed View)



CONTROL STRUCTURE – System Operations (Detailed View)



CAST - Analyzing the Physical System

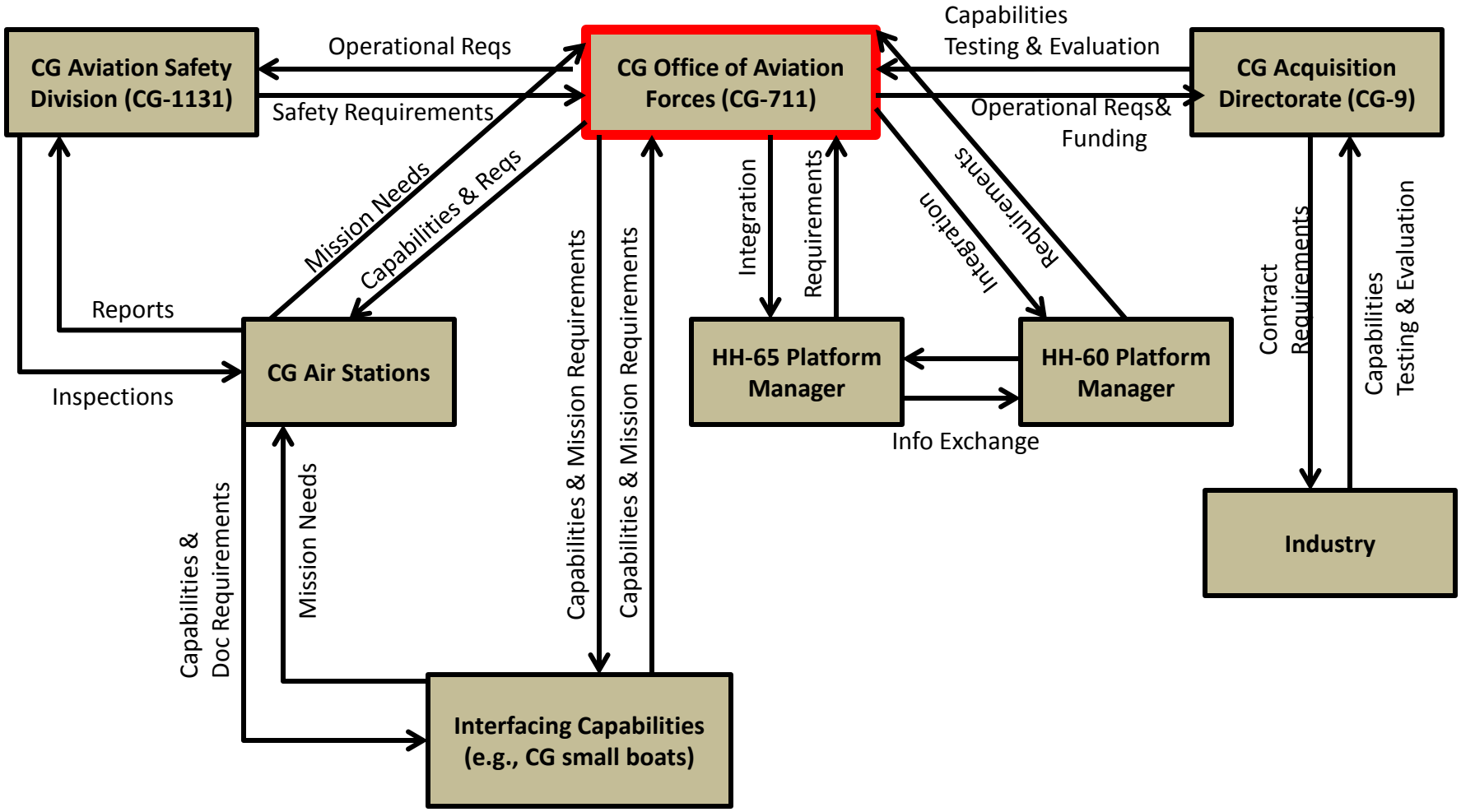
Physical Inadequacy	STAMP-CAST	MAB
1. Insufficient capabilities to prevent pilot from getting too close to small boat	Yes	No
2. Inadequate hoist capabilities (dynamic slip, shear, sensor)	Yes	Yes
3. Inadequate lighting/ditching capabilities.	Yes	No
4. Inadequate feedback to pilot/crew regarding damage 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

Analyzing the Physical System…Capabilities Management???

STAMP analysis, highlights the need to more closely examine the Coast Guard's capabilities management system, raising 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?

CONTROL STRUCTURE – System Development (Detailed View)



Safety-Related Responsibilities

• Provide capabilities to the Coast Guard aviation community (e.g., Coast Guard Sectors and Air Stations) 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).

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.
- Over-emphasis on importance of protecting aircraft (on par with safety of crew).

A Story about Capabilities Mgmt…Migration to an Unsafe State

1985
HH-65
Static Hoist

A Story about Capabilities Mgmt…Migration to an Unsafe State

1985
HH-65
Static Hoist

1990
HH-60
Dynamic Hoist

A Story about Capabilities Mgmt…Migration to an Unsafe State

1985
HH-65
Static Hoist

1990
HH-60
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1990-2007
19 Hoist Snags

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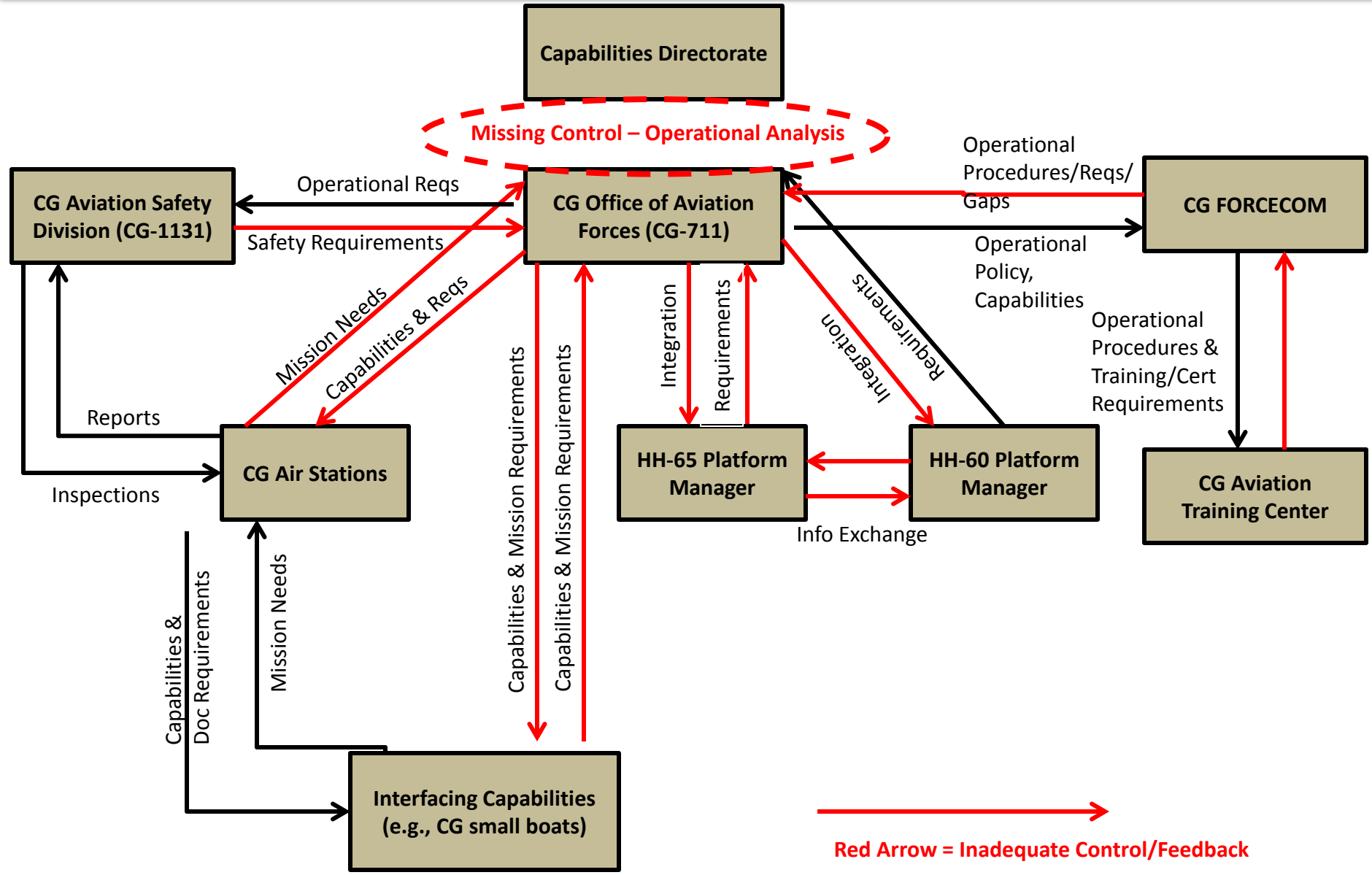
2008
CG-6505 Crash

Capabilities Management – Control/Feedback Inadequacies



A Story about Capabilities Mgmt – SPECIFIC SHORTCOMINGS

Answers…

- **Inadequate communication/documentation of requirements & associated gaps up and down the aviation capabilities chain**
- **Inadequate sharing of information across platform managers**
- Inadequate sharing of information across industry
- **Inadequate review of existing capabilities (failure to follow policy)**
- Inadequate understanding/documentation of system interfaces
- **Inadequate leveraging of user info/lessons learned**

CG MAB PROCESS - GENERAL SHORTCOMINGS

Too focused on human factors.

Active Failures: Completely focused on human factors

Latent Failures: Only Organizational Influences reaches beyond human focus and systemic issues

Not structured into control/feedback loops structured specific to the system at play.

Lacks complete traceability throughout system, therefore there are gaps in the analysis. Analysis is incomplete.

For example, findings such as those listed below stop short at the symptom vice the cause! What is the systemic issue causing these symptoms???

Cultural instinct – Cultural imperative to “bring the crew and aircraft home.”

Lack of dynamic hoist capability

STAMP – The key is the Hierarchical Safety Structure – It forces complete traceability throughout the specific system to ID the system cause in terms of controls and feedback.

Recommendations (1 of 3)

- Capabilities Management System
  - Capabilities Catalogue – include interfaces
  - Interactive Capabilities Community
  - Operational Analysis

- Capabilities improvements:
  - Hovering/Hoisting - sensors
  - Ditching – lighting
  - Communications – crew to crew

- Policy improvements:
  - Safety of aircrew over safety of aircraft
  - Crash spare inventory

Recommendations (2 o 3)

- Training improvements:
  - Increased accountability - Standardization & SAR Check reporting
  - Ditching training – Add to Standardization visits
  - Night time hoisting training – add to simulator
  - CRM/ORM:
    - FORCECOM standardize across CG where possible
    - Add to ATC & CG-1131 Stan Visits
    - CG-1131 catalogue *specific* risks & mitigating TTP

- Design & Sustainment Collaboration:
  - User involvement (interfacing) in design
  - Industry involvement in design and OA

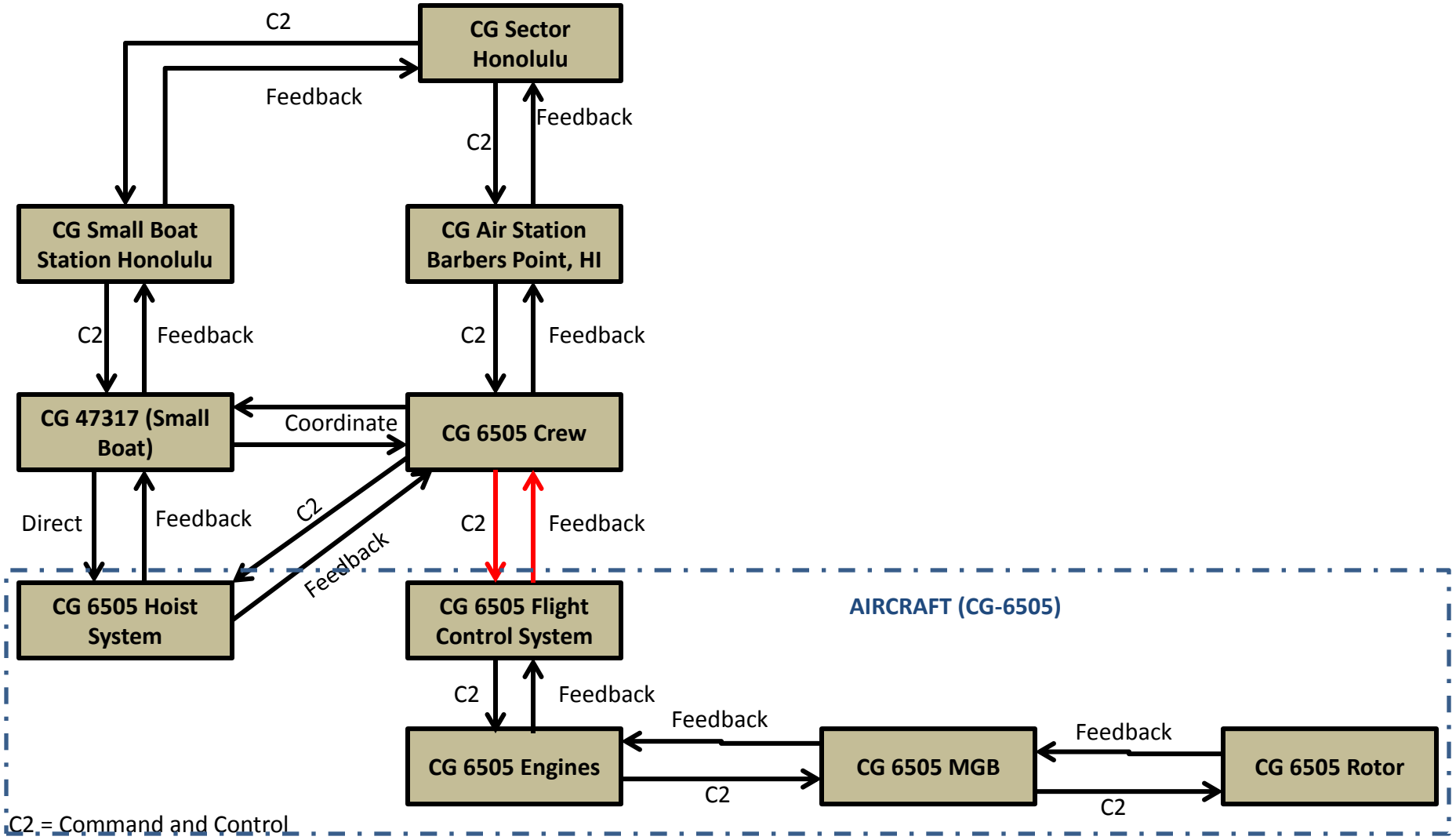
Recommendations (3 of 3)

- Coast Guard should consider:
  - Implementing CAST recommendations to address systemic issues contributing to CG-6505
  - Adopting STAMP as part of mishap investigation process

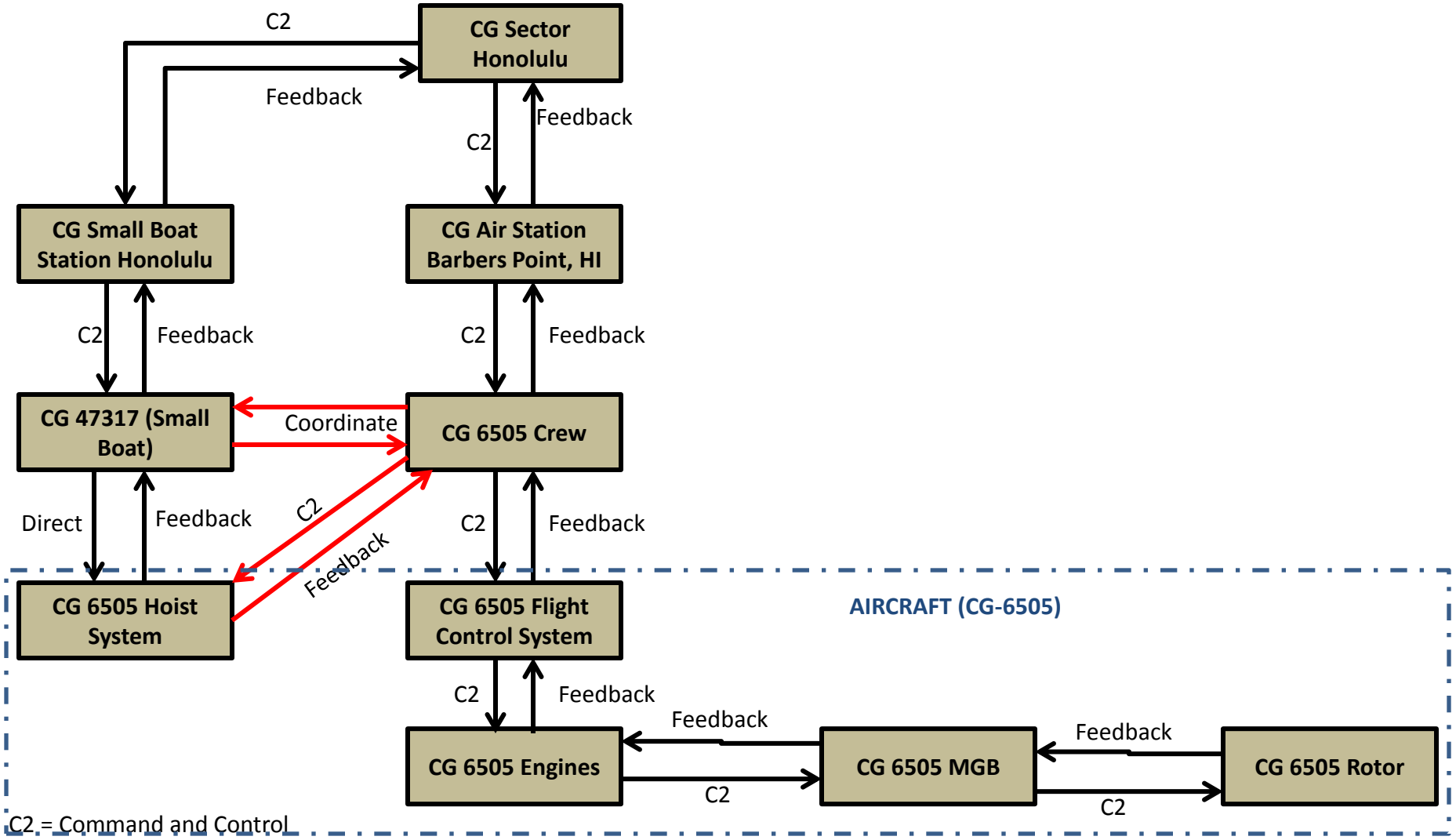
• The good news…CG is considering recommendations including adopting STAMP techniques to augment DOD HFACS mishap analysis approach.

BACK UP SLIDES

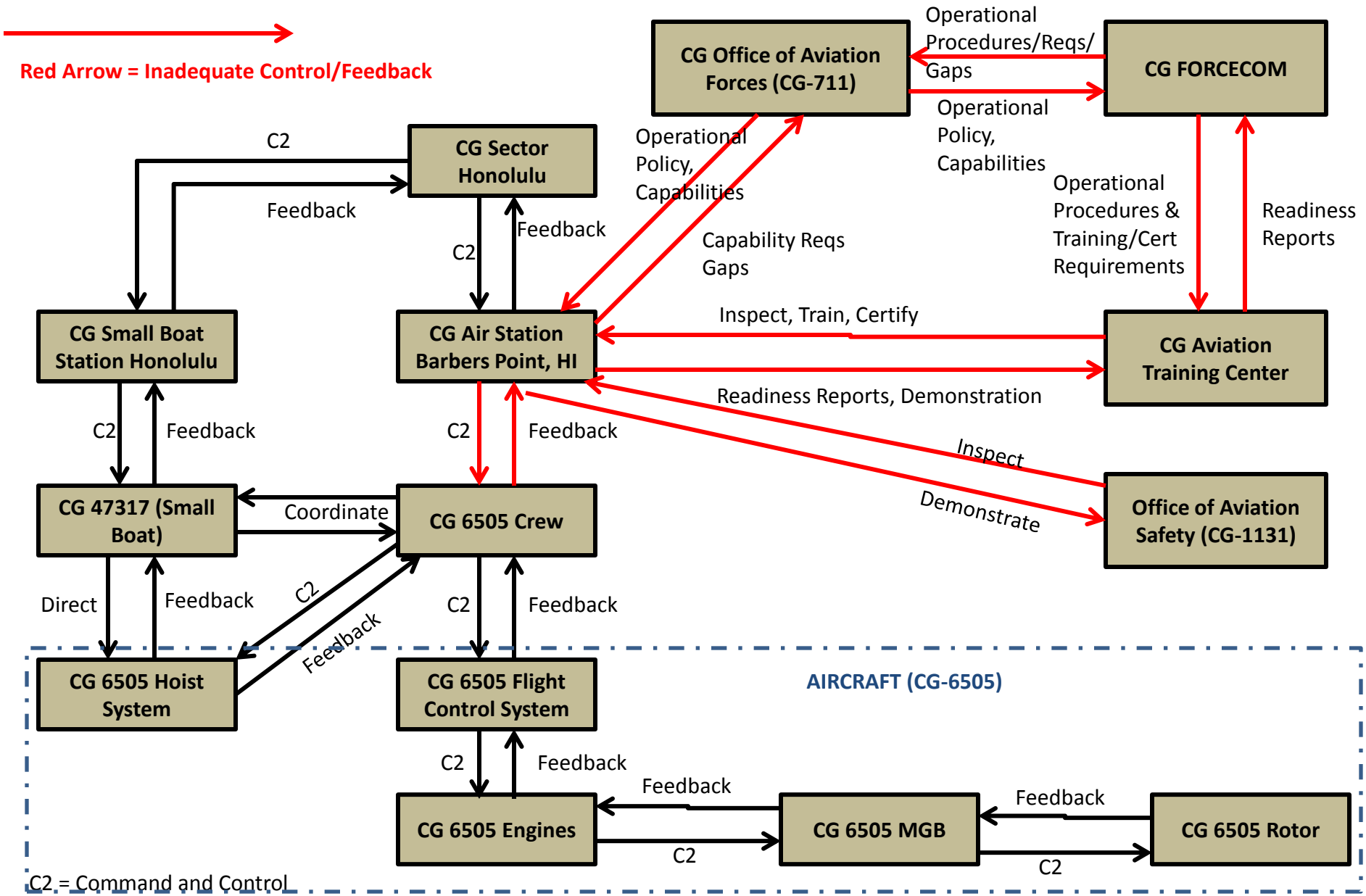
Pilot & Flight Control System in Hover – Control/Feedback Inadequacies



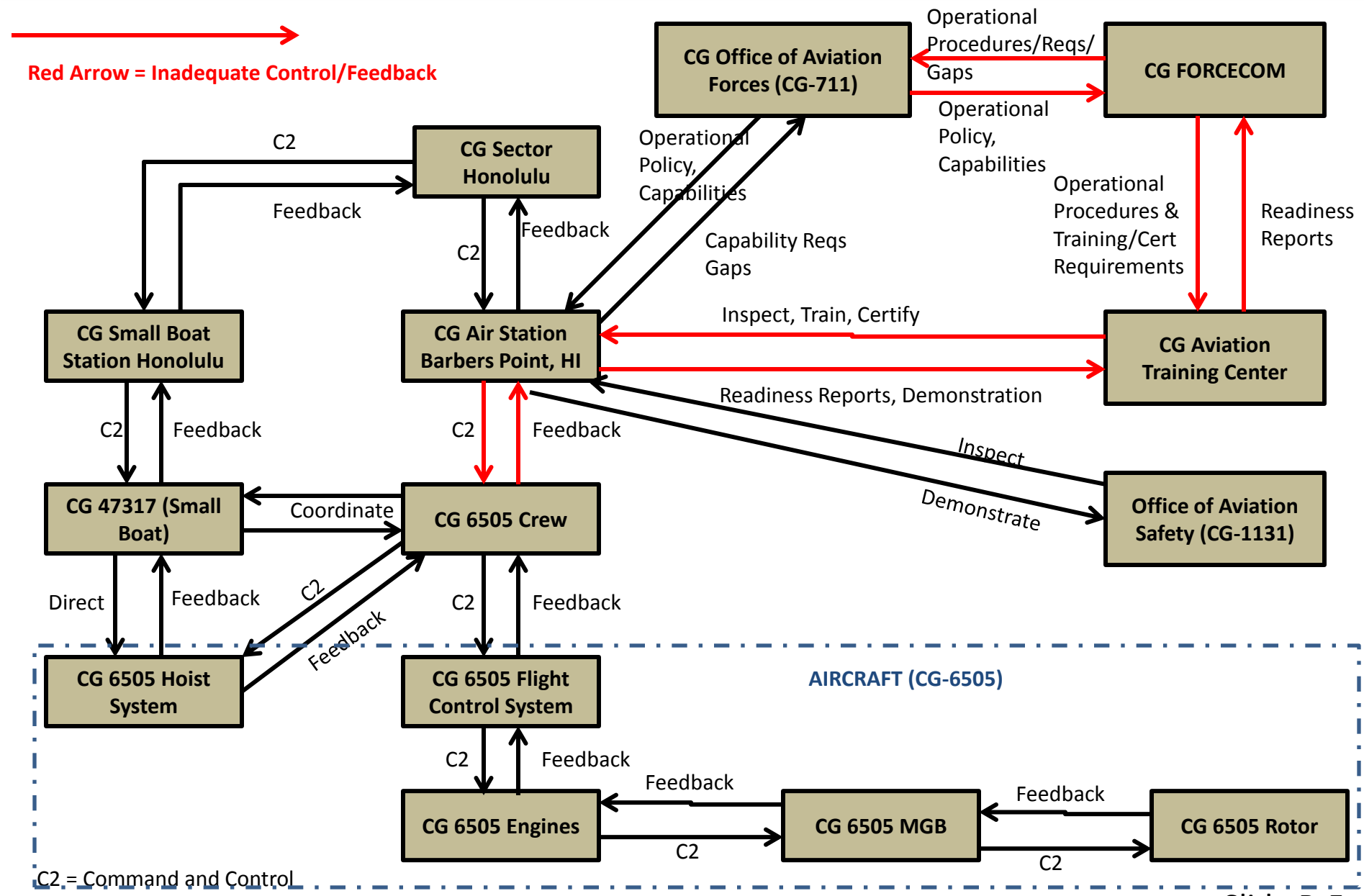
Hoisting Operations – Control/Feedback Inadequacies



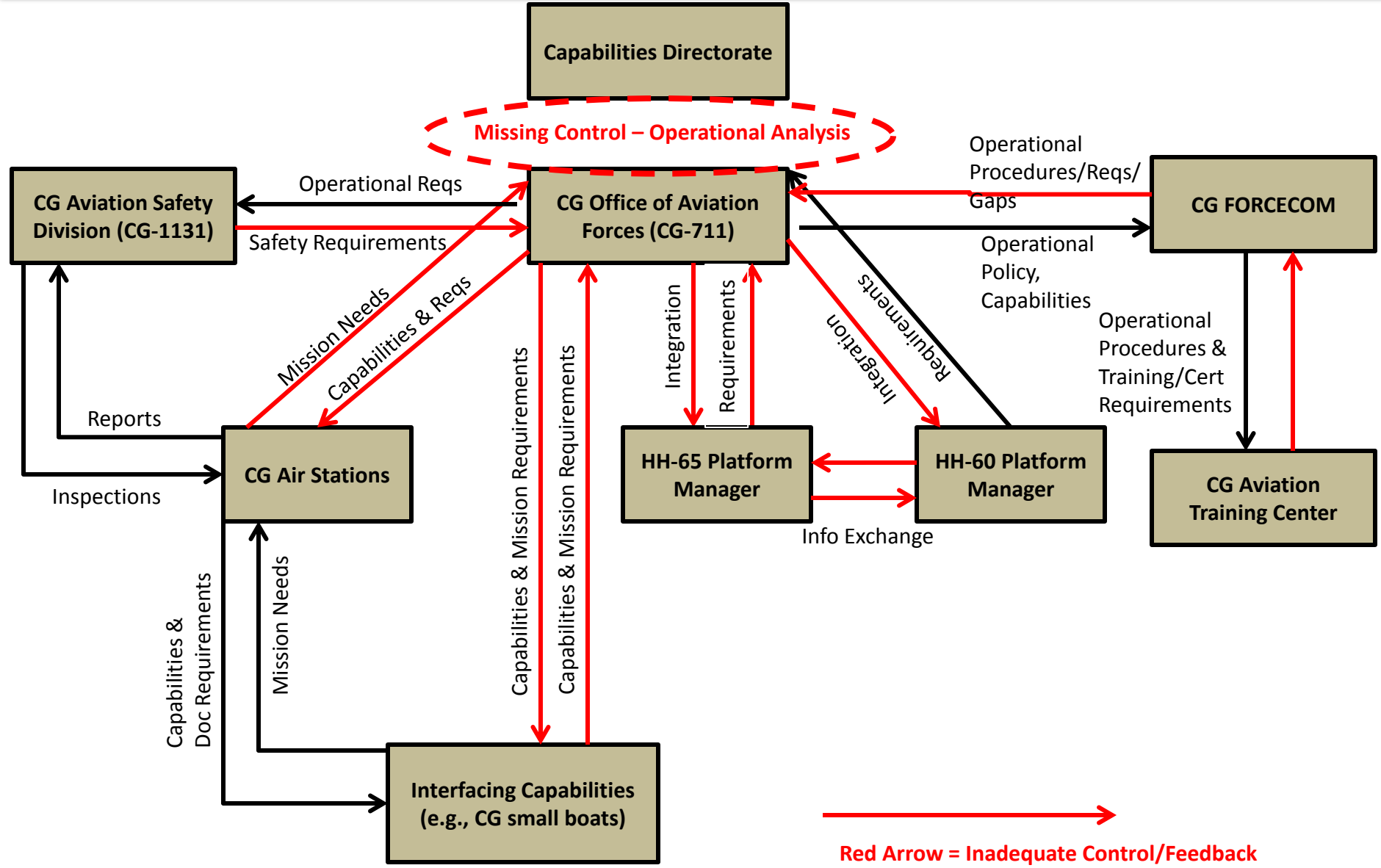
Ditching Procedures & Life Safety Emphasis – Control/Feedback Inadequacies



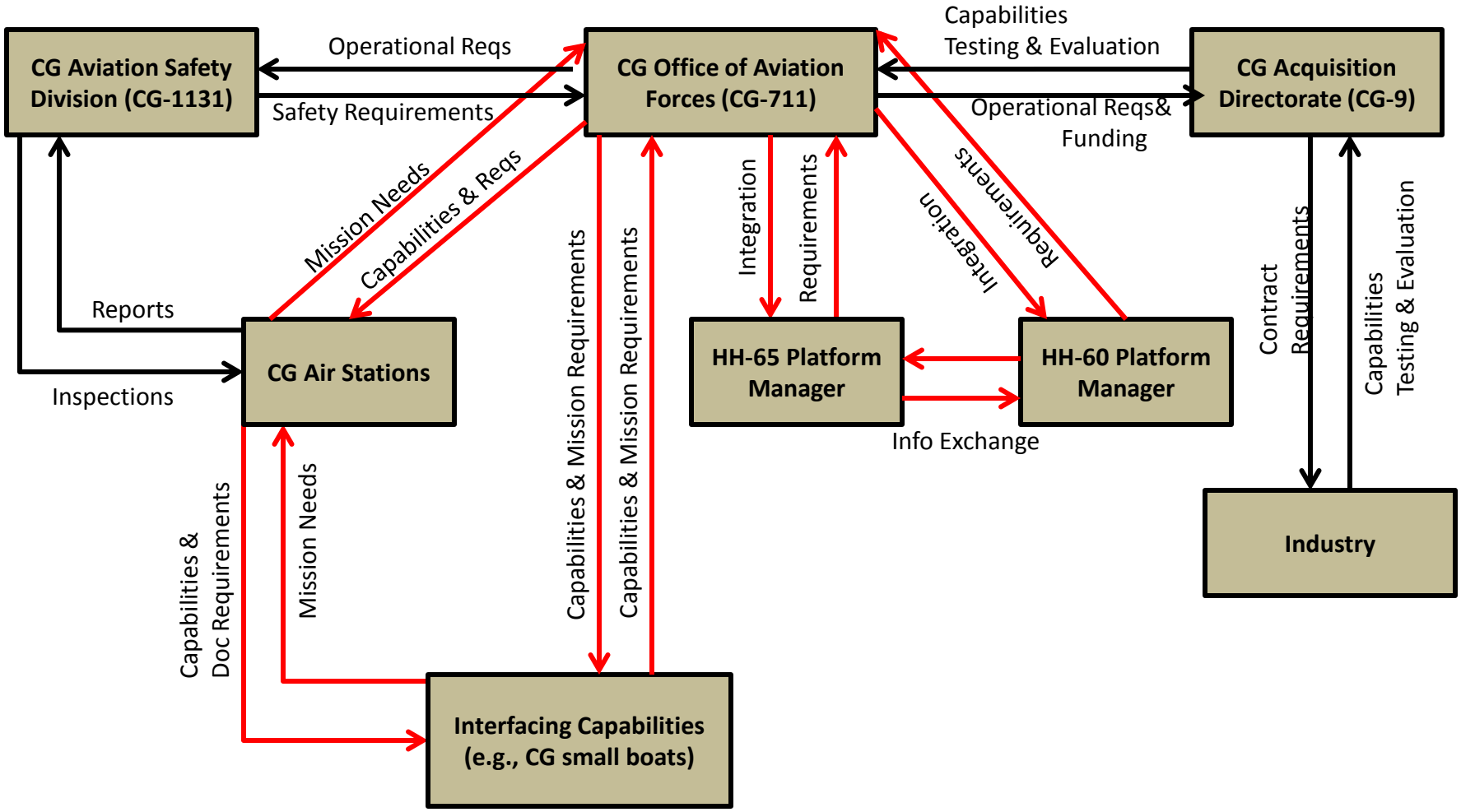
Standardization Visit & SAR Checks – Control/Feedback Inadequacies



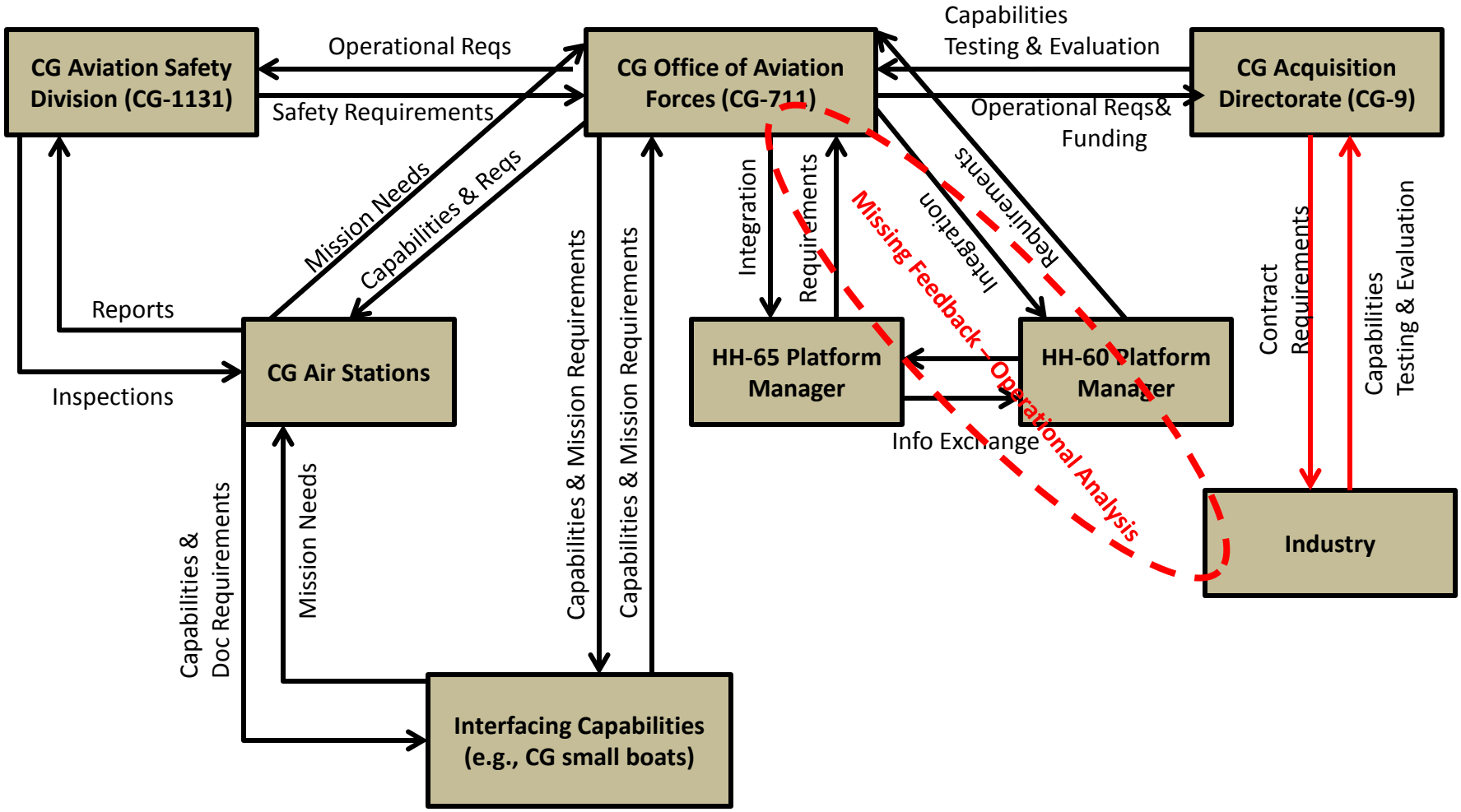
Capabilities Management – Control/Feedback Inadequacies



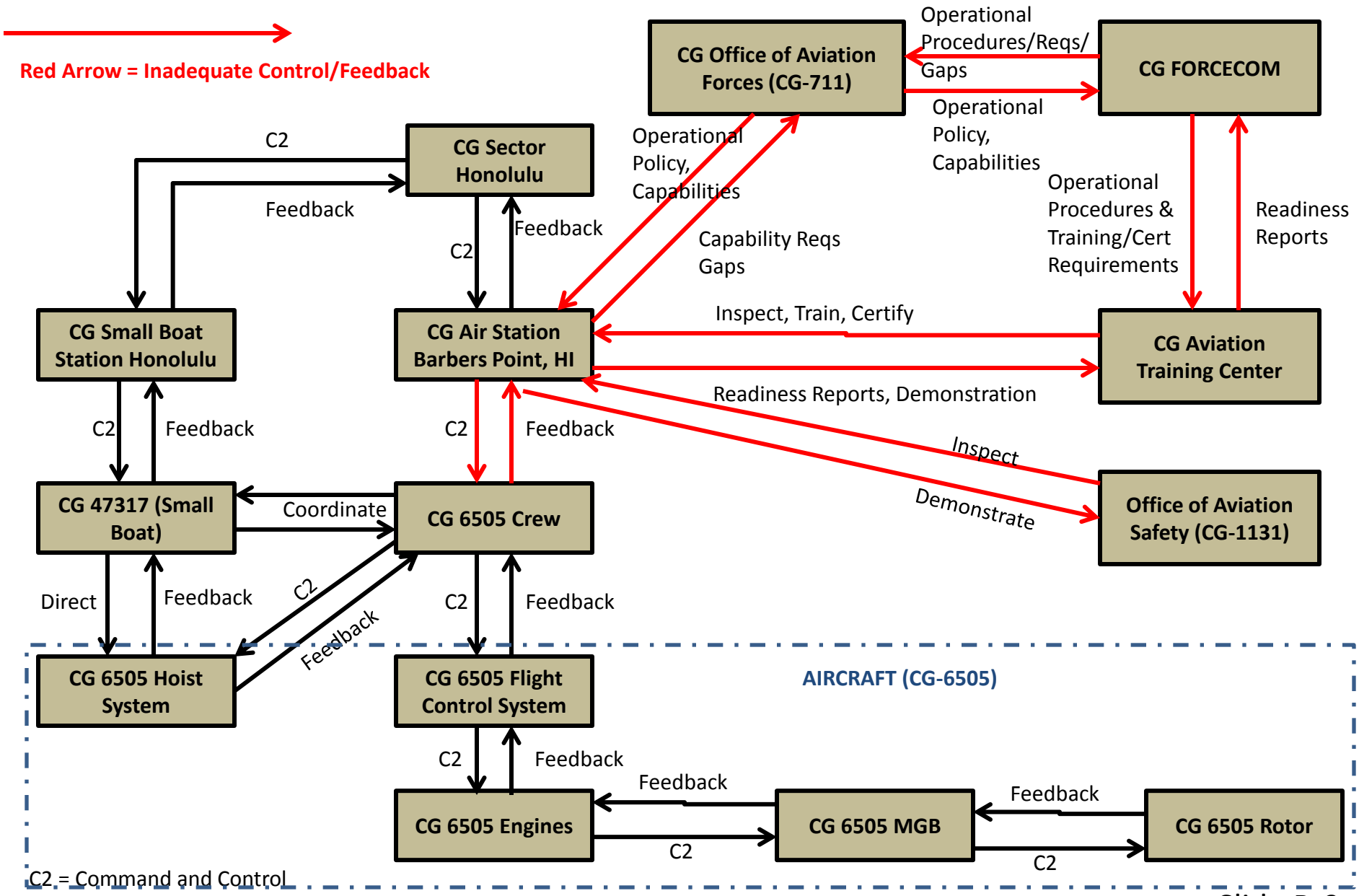
Sponsor/User Involvement in Design & Development – Control/Feedback Inadequacies



Industry Involvement – Control/Feedback Inadequacies



CRM / ORM Training – Control/Feedback Inadequacies



Comparative Analysis of Findings (1 of 4)

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.

Comparative Analysis of Findings (2 of 4)

Issue	CAST Findings	MAB Findings	Comments
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., operations officer, commanding officer) sign the inspection sheet.	No discussion on Standardization or SAR Check procedures.	Development of the Hierarchical Safety Control Structure and analysis of the control and feedback loops highlighted the inadequacies.
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. Policy and resource based changes recommended.	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.

Comparative Analysis of Findings (3 of 4)

Issue	CAST Findings	MAB Findings	Comments
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.	Issues with HH-65 hoist system in place at the time of mishap - recommended fleet-wide replacement. Creation and use of protective shroud over dewatering stand pipe. Also recommended Operational Hazards Assessment of hoisting operations. Did not examine systemic issues resulting in failure to identify capability gap.	CAST systems-based approach enabled broader examination of systemic factors. 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 capabilities.	CAST recommends including sponsor/user representatives from interfacing capabilities in addition to capability of interest in the design & development of new capabilities and evaluation of existing capabilities.	Recommends standing up a team to evaluate requirements of system safety integration into Coast Guard asset/acquisition design procedures.	The CAST hierarchical safety control structure highlights the interfacing capabilities and organizational elements enabling a specific recommendation to address the system safety issues identified in both the MAB and CAST analyses.

Comparative Analysis of Findings (4 of 4)

Issue	CAST Findings	MAB Findings	Comments
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.

Accident Report Identified Causes (4 of 4) – CG-6505

Other Contributing Factors:

- Hoist Cable Shear Control: Initial review found that the hoist cable shear control may not be optimally located.
- Platform to Platform Communication: Inability of boat crew to communicate effectively with aircrew
- Inadequate Maintenance Procedures of Main Gear Box Elastomeric Stops: Dampening elements between the airframe and the main gear box are not monitored/tracked.

Deeper Understanding of Capabilities Management Issues

- No central repository of CG capabilities and sub-system/system interfaces

- Lack of a systematic/inclusive process to identify and document CG capability needs/requirements.

- CG not conducting mandated annual Operational Analyses on existing capabilities