DECODING AN IN-FLIGHT REFUELING INCIDENT: AVIATION COMPLEXITY THROUGH STAMP/CAST AND ACCIMAP METHODS

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Abstract

This study addressed the complexity of sociotechnical systems through an investigative analysis of the accident involving a Boeing F/A-18F Super Hornet and KC-130J during an in-flight refueling procedure conducted by the US Marine Corps in 2018. The event was investigated using Rasmussen's Accimap and Leveson's STAMP/CAST methodologies, identifying the main contributing factors, their correlations, and control failures that led to the critical event. The study emphasizes the demanding nature of in-flight refueling, highlighting the dependence on pilot expertise and the absence of safety systems during critical phases. Conclusions underscore the significance of human factors, such as fatigue and stress, in accidents of this nature, advocating for ongoing research in ergonomics. The limitations and strengths of the methodologies are discussed, with a suggestion for future studies to incorporate Neisser's Perceptual Cycle Model to better understand human factors influencing decision-making in such events.

Keywords: Complex sociotechnical systems, In-Flight Refueling, Accimap, STAMP/CAST, Accident Investigation

1. General Introduction

The interest in the knowledge and understanding of the reasons behind accidents and critical events is of great value for any complex sociotechnical system. According to Hollnagel [1], a sociotechnical system is a composition of numerous subsystems with multiple functions. Despite the expectation that their operations are standardized and predictable, the infinite interactions among the components of this system yield variable outcomes and consequences, both positively and negatively.

In the context of the possibilities of interactions leading to negative and catastrophic events, investigative analysis is of paramount importance in the aviation industry, especially when the goal is to comprehend the sequence of events and the influence of each contributing factor to prevent new occurrences and promote improvements in the process as a whole.

In the aviation context, various players can influence the complexity of the environment, such as each pilot (at the operational level), mechanic (at the maintenance level), engineer (at the design level), to name a few. When considering the airspace composed of civil, public, and military aviation, the complexity becomes even clearer, posing a challenge in managing all assets involved in air operations at the regional level and ultimately at the national or even global level.

Transitioning to the realm of military operations, this complexity is further amplified. Military operations demand precise coordination and synchronization among multiple elements. These include not only aircraft (or aerospace systems) but also communication, intelligence, and logistics systems. Within the military spectrum, every aspect, from combat strategy to logistical support, assumes critical importance [2].

1.1 Air force operation characteristics

Military operations are characterized by the need for a quick and effective response in often hostile and entirely unpredictable environments. This requires advanced training and rigorous preparation of pilots, as well as robust maintenance and engineering support. Additionally, military operations often involve the integration of Air Forces with other branches of the armed forces, such as the Army and Navy, increasing the complexity of planning and executing combined missions.
Effective management of these operations is crucial to ensure national security and the success of assigned missions for any countries considered in the analysis. This implies a delicate balance between available resources, operational tactics, and the constant need to adapt to new technologies and threat scenarios.
It is unanimously acknowledged that the factor of time is crucial in determining the success or failure of a Search and Rescue, Air Defense, or any other mission safeguarding National Objectives.
In Brazil, this significance is even greater, as, according to Air Traffic Control Department (DECEA) [3], the airspace under the jurisdiction of the State consists of an area of 22 million km², which undoubtedly poses a challenge for the success of missions of the Brazilian Air Force (FAB), especially concerning the need to cover long distances in reduced time.
Several characteristics of Aerospace Power are closely linked to these concepts, such as Range, Mobility, Penetration, Perspective, Rapid Response, Technology, Infrastructure Dependency, Persistence, and Payload Restriction.
These characteristics are, in turn, linked to the Air Force Tasks of Combat Support, Force Protection, and Support to State Actions, which are subsidiary to various Air Force Actions, with a highlight on In-Flight Refueling (IFR). Through IFR, the capabilities of the H-36 Caracal aircraft could be amplified in the event of the aforementioned AF447 accident, enabling more effective searches in the peculiar distance at which the incident occurred.

1.2 In-flight refueling as an Air Force Action

In-Flight Refueling (IFR) is an Air Force Action that involves employing Aerospace Means to extend the autonomy and range of friendly aircraft through the transfer of fuel between aircraft in flight [2].
Da Silva [4] considers IFR as a force multiplier, as it eliminates the need for landings/takeoffs from friendly bases for refueling. This perspective is supported by Santos [5], who deems IFR one of the prime factors for maximizing Brazil's Aerospace Power, and also, Pleffken et al. [6] reinforce the importance of IFR for greater autonomy in search and rescue operations.
However, although fundamental for the speed and efficiency of military missions, the in-flight refueling system notably demands high cognitive, physical, emotional, and technical demands, inevitably resulting in uncertainties and variables that require continuous management to maximize operational safety. These infinite interactions and the unpredictability of consequences are part of the social and technical dissimilarity characterizing complex sociotechnical systems and can lead to accidents or incidents of significant impact [7], to which the IFR operation is not immune.
In the occurrence of such events, it is of utmost importance to proceed with relevant investigations to coherently explain the main contributing factors and, above all, to proceed with recommendations that promote improvements in the process.
Considering the complexity of the in-flight refueling system, the analysis methodology should facilitate the mapping of the actors involved in the cause and, above all, highlight their interactions, without restricting itself to simplistic searches [8].
Based on the established concepts related to Aerospace Power discussed earlier, considering also the methodologies of Accimap proposed by Rasmussen [9], and STAMP/CAST proposed by Leveson [10], this work aims to reinterpret the accident involving the Boeing F/A 18F Super Hornet and KC-130J aircraft of the US Air Force during an in-flight refueling procedure in 2018. The objective is to identify the main actors within the complex sociotechnical system, understand the actions and control procedures that failed and were crucial for the occurrence of such an event, and which can be replicated in operations of the Brazilian Air Force. The Brazilian Air Force has been expanding its expertise in this type of operation, extending the practice to other aircraft such as KC-130H Hercules/SC-105 Amazonas SAR and studying the feasibility of the KC-390 Millennium in IFR with

aircraft such as the SC-105 Amazonas SAR and the H-36 Caracal.

1.3 Accimap and STAMP/CAST Model

Investigating accidents in complex sociotechnical systems is a challenge, not only due to the multitude of interactions between technological and human factors that must be collectively assessed but also because of the inherent objective of the investigative process, which is to portray occurrences reliably and faithfully, reducing biases and neutralizing discrepancies between assessments made by experts and novices. In other words, a good method should be capable of illustrating the occurrence and identifying failures and possibilities for improvement on its own [11].
Tied to the reliability of methods and evaluators are the possibilities of recommendations and outputs from the processes. In this case, although it may seem counterintuitive to what was argued earlier, namely the intrinsic possibility of a method portraying the event and allowing for improvements regardless of the expertise of the professional evaluating it, in the face of the primary characteristic of conferring safety and process improvements, inappropriate analyses and methods can result in inaccurate and flawed recommendations [12]. This fact underscores the need for evaluations and studies on the applicability of investigation methodologies [13].
Two well-evaluated and widely used methodologies in the analysis of events that occur in complex sociotechnical systems are Accimap and STAMP/CAST.
The Accimap investigation methodology proposed by Rasmussen [9] involves mapping the key actors related to a critical event, framing their hierarchical levels within the system, and establishing relationships and interactions that occurred within this system.
Technically, the structuring of the event considers a vertical and hierarchical arrangement of actors, where there is direct interference in the behavior and actions of the protagonists located at lower levels. This interference typically results in constraints and limitations, which, in turn, promote disturbances in the system, leading to feedback and feedback loops to restore its stability [14].
One positive aspect of this methodology is the possibility of a holistic understanding of an event, highlighting the influence of public policies, government directives, and legislative determinations at the location of the event, as well as organizational and behavioral aspects that contribute concomitantly to other preceding factors in the occurrence of highly relevant critical events.
The work of Rose, Mugi, and Saleh [15], using Accimap to assess dam disasters in Mariana-MG (Brazil) and Brumadinho-MG (Brazil), allowed for various technical safety recommendations and, especially, identified possibilities for improvements and adjustments in regulatory processes for licensing and policing dam operations. De Oleo et al. [16], evaluating incidents of food contamination in the hospital setting, support the applicability of the Accimap methodology and its ability to integrate internal and external organizational factors, and particularly associate socio-cultural aspects with other contributing factors existing at all hierarchical levels.
Published research reinforces the range of applications of this methodology in various sectors and economic activities. The variability in the magnitude of events does not limit its adoption [17], and there are no identified restrictions for defining the scope of investigation. It is effective for understanding events resulting in fatalities and also for comprehending significant incidents without resulting in material and human losses [18].
In turn, STAMP (Systems-Theoretic Accident Model and Processes) and CAST (Causal Analysis based on Systems Theory) are both concepts developed in the field of system safety, but they have slightly different focuses. STAMP is a model for accident analysis based on systems theory. It views accidents as a result of failures across the entire control structure or in the interactions within a complex system, rather than seeing them merely as a chain of events or failures of isolated components [10]. This model is more comprehensive than traditional approaches based on linear causes and seeks to understand the relationships and contexts in which accidents occur. In summary, STAMP focuses on analyzing how system components interact and how the management and control of the system can fail, leading to accidents.
CAST, in turn, is a specific methodology for conducting accident cause analysis, based on the principles of STAMP.
While STAMP provides a theoretical model for understanding accidents in complex systems, CAST offers a step-by-step method for analyzing the causes of a specific accident, focusing on identifying

failures in the control system and the interactions between system components that contributed to the accident, as well as making recommendations to prevent future accidents.

In summary, STAMP provides the theory and conceptual model for understanding accidents in complex systems, while CAST is a practical application of this theory to analyze specific accidents and identify their causes. The STAMP methodology, when combined with CAST, offers an inclusive model of accident causality.

STAMP/CAST begins with the definition of system hazards, safety constraints, hierarchical control structure, and structural dynamics. This approach not only identifies hazards resulting from individual component failures but also considers the interactions between system components and external factors that disturb the system.

STAMP is known for considering the context of decision-making and failures in mental models as distinctive features, which is useful for understanding complex scenarios, as demonstrated by Salmon et al. [19]. However, implementing STAMP/CAST can be challenging, especially when taking into account human and organizational failures, as well as in relation to defining the timeline of events in the control structure.

One of the main advantages of STAMP is that it applies to very complex systems, working from the top down from a high level of abstraction. It includes software, human factors, the organization as a whole, safety culture, and other factors as causes of accidents, without needing to treat them separately. CAST, operating under STAMP's causality model, allows investigating the design characteristics and operational characteristics of sociotechnical systems, identifying problems in the safety control structure, and the needs for modification to promote safety.

The STAMP/CAST perspective allows for a holistic analysis, considering all the physical, organizational, and social components of the system. Even in scenarios with insufficient data and high uncertainty, it is still possible to identify effective preventive measures by investigating the interactions between the system components. This method has been successfully used in various accident analyses, such as the China-Jiaoli railway accident [20] and the Deepwater Horizon oil platform disaster [21].

The combination of STAMP and CAST represents an advanced methodology for accident analysis, offering a comprehensive and detailed view of modern sociotechnical systems. Despite being challenging in its implementation, it is effective in identifying not only the causes of accidents but also in proposing preventive measures, considering the complexity and interaction of system components at different levels. This approach is particularly valuable in complex systems where interactions and dynamics can be subtle and intricate. Bar-Or and Hartmann [22] corroborate with the idea of concatenate different methods, reinforcing that STAMP/CAST is usefull to enhance process, operation and safety design in nuclear industries, for example.

Among the limitations of both methods, it is pertinent for the analyst to establish a wide range of information sources to accurately contextualize the event and properly determine the roles of the actors, as well as their influences and impacts in establishing controls and restrictions [23].

1.4 The history of the accident

On December 6th, 2018, a tragic aviation accident took place near the coast of Japan, in the southern region of Cape Muroto.

The event involved an F/A-18D Hornet fighter jet and a KC-130J in-flight refueling aircraft from the United States Navy. This mid-air collision during a night training mission (utilizing Night Vision Googles - NVG) resulted in the deaths of six Marines, marking one of the most serious incidents in recent military aviation.

The initial investigation into the accident pointed to the inexperience of the F/A-18 pilot, Captain Jahmar F. Resilard, and identified traces of the medication Ambien in the body of the weapons systems officer, who occupied the rear seat of the fighter jet. Additionally, a culture of complacency in command was highlighted as a contributing factor. However, this investigation was later criticized for its partial approach and lack of depth, raising questions about the accuracy and integrity of its conclusions.

In response to these concerns, a review board was formed, consisting of experts in aviation, medicine, and law, aiming to reexamine the accident. This review revealed several flaws in the

original investigation and helped clarify the events, rectifying Captain Resilard's conduct, emphasizing his experience, and acknowledging the challenges he faced during the flight.
One of the critical factors identified by the review was the unusual maneuver of the F/A-18, attempting to fly to the left of the KC-130J after refueling. Problems in command culture, inadequate training, and suboptimal flight procedures were also identified as contributing factors to the accident, along with delays in the emergency response services.
Based on these findings, the review board proposed various improvements, including enhancements in pilot training, changes to air refueling protocols, and increased attention to the mental health and operational readiness of pilots. These recommendations aimed not only to address identified deficiencies but also to improve flight safety more broadly.
The accident and subsequent investigations had a significant impact on the operations and safety of the United States Navy's Air Operations. Institutional changes implemented after the accident demonstrate a commitment to continuous improvement in safety practices and air operations.
The legacy of this incident underscores the importance of impartial and evidence-based investigations. The lessons learned are crucial for ensuring safety in military aviation and preventing future accidents. The case of the 2018 accident between the F/A-18 and the KC-130J serves as a vital reminder of the inherent risks in military aviation and the need for ongoing assessment and improvement in air safety practices.
Sources include official reports from the U.S. Marine Corps, news articles, and information from flight safety databases such as ASN. These sources provide details about the accident, the investigations conducted, and the conclusions drawn, all considered reliable as they include official reports and detailed journalistic coverage. They offer fundamental information about the accident, its causes, investigations, and impact.
Central themes include:

- Circumstances of the accident: details of the event and contributing factors;
- Investigations and findings: analyses of the causes of the accident and shortcomings in the initial investigation;
- Consequences: impact of the accident on the victims' families, military aviation, and safety practices.

The review is structured around the central themes, with each section addressing different aspects of the accident, from the event to the investigations and long-term implications.
In summary, the accident highlighted significant challenges in military aviation, including the complexity of night air refueling and systemic failures in safety protocols. The review of the initial investigations revealed issues such as bias and data collection flaws. The consequences of the accident were profound, leading to changes in safety procedures and training, as well as emotional impact on the families of the victims.
The F/A-18 Hornet and KC-130J accident was a tragic event that prompted a critical reassessment of safety practices in military aviation. Investigations revealed significant flaws and drove necessary changes to prevent future incidents.

2. Accident Method's: Accimap and CAST

Traditional methods of accident investigation and analysis often fail to account for the complexity associated with modern sociotechnical systems. These methods typically focus only on the components involved at the 'sharp end' of the system, incorrectly attributing blame for the accident in many cases [24].
However, more modern and comprehensive methods have been developed over the years to provide a better understanding of the causes of accidents and offer means of prevention. Among these methods, systemic approaches consider the various layers of the hierarchical structure of a complex sociotechnical system. Notable methods include Accimap [9][25], CAST [26], FRAM [1], and others. Each method has important characteristics and brings benefits in different aspects. For instance, Accimap is based on systems theory and maps contributing factors in a hierarchical diagram, while STAMP/CAST, although also considering the hierarchical structure, relies on the analysis of control failures and feedback, mapping contributing factors in a control model [27].

The combination of these methods has been studied by various authors, offering a more comprehensive view of accidents and providing a broader range of recommendations to prevent future incidents [27]. Additionally, in an accident investigation conducted by a multidisciplinary team, each specialist can use a different method based on their expertise, tailoring the approach to the specific problem under analysis [28]. The results are then combined to achieve a more complete conclusion. Integrating diverse methodologies enhances understanding of aviation incidents for comprehensive conclusions and improved safety strategies [29][30].

In this study, the combination of Accimap and STAMP/CAST methods was applied to the 2018 accident involving US Air Force aircraft during the REVO procedure. The accident information is based on the Final Report [31] and any additional relevant sources.

Initially, Accimap and STAMP/CAST methods were independently applied by different analysts. The analysis through each method produced lists of contributing factors to the accident. The lists were compared, discrepancies were discussed, and the lists were condensed into an overall list of contributing factors to the accident, and then, a list of recommendations was created to prevent future accidents like it.

The process was executed in 5 steps.

- Step 1: Through secondary data related to the official investigation, using the Accimap method, the main actors were listed, and their hierarchical levels were defined;
- Step 2: Evaluation of possible interactions between the actors, establishing levels of control and subordination among them;
- Step 3: Identification of possible control failures, contributing factors and recommendations through both methods, Accimap and STAMP/CAST;
- Step 4: Limitations of the methodologies and comparisons with other investigations conducted using the proposed methodologies, based on data in the literature;
- Step 5: Conclusion on the investigation processes.

The methodologies for applying each method are described in the following sections.

2.1 Accimap

Initially, the main actors within the sociotechnical system associated with the accident were identified and mapped according to the 6-level framework proposed by Rasmussen [9] This framework considers: government and legislation, regulatory bodies and associations, company, technical and operational management, staff/directly involved personnel, and equipment/means.

Using the online diagramming tool MIRO, a framework for the Accimap analysis was created based on the generic framework. The actors were then distributed across the 6 levels of this framework, and the analysis started with the accident event (outcome). At each level, for each related actor, incorrect actions and procedures, failures, and omissions contributing to the accident were identified. Subsequently, the interrelationships between these factors were mapped from cause to effect, creating a network of interaction between the layers of the framework and then, from this interaction network, the main contributing factors to the accident were identified at each level of the framework, and a list was generated.

2.2 STAMP/CAST

The first step in initiating the CAST analysis is the identification of key actors involved in the accident. For proper standardization in the combination of methods, the same actor mapping identified by the Accimap method was utilized through Rasmussen's framework [9]. The CAST analysis began with the identification of risk actions (hazards), representing a state or conditions of the system that, when combined with adverse conditions, can lead to an accident [26].

Based on the mapped risk actions (hazards), restrictions and requirements associated with the sociotechnical system related to the accident were identified, ensuring the safe operation of the system.

From the mapping of the actors involved in the accident, the hierarchical control structure associated with the system was created, representing the interaction among the system's control elements and how they should operate to ensure system safety and control the mapped risk actions. In this

structure, the roles and responsibilities of each actor, the necessary controls for task execution, and the required feedback were included.
In each control and feedback interaction, incorrect actions or procedures, flaws, omissions, dysfunctional interactions, etc., were identified and classified according to the taxonomy of control flaws defined by Leveson [26]. Based on this classification, the contributions of each control and feedback loop to the occurrence of the accident were identified.
In a bottom-up analysis, for each level of the control structure, it was identified how the higher level contributed to inadequate control at the current level, which requirements and restrictions were violated, and possible failures in decision-making processes.
Finally, a list of contributing factors to the accident was generated.

3. Results and Discussion

The objective of this study extended beyond the application of two established investigative methodologies to assess a critical and highly significant event in military aviation. Given the complexity of interactions inherent in sociotechnical systems, it is highly valuable to draw comparisons between different investigative methodologies, establish correlations among contributing factors identified in each method, and provide a clear and objective description of the event.
Additionally, the validation of applying the models to events of varying magnitudes and originating from different segments of the economy becomes crucial. Understanding whether the methodologies' focus allows for the identification of new facts and recommendations for future studies is essential.

3.1 Accimap

It was considered to this investigation that contributing factors are elements such as actions, omissions, events, or conditions—or their combinations—that if removed, circumvented, or absent, would have likely decreased the chance of the accident or incident taking place or would have lessened the impact of its outcomes.
It's important to note that these factors don't quantify the extent of their contribution. It's entirely plausible that some types of contributing factors were not present, and yet an incident could still transpire. Nevertheless, pinpointing these factors enables the institution to concentrate on understanding the ineffectiveness of existing controls in the specific instance and to enhance them for future prevention.
This investigation focused in seven niches, being four of them focused in 4 institutional contributing factors, ejection and Search and Rescue (SAR), organizational Cultural Factors and Causal Factors.
The institutional contributing factors are categorized into four distinct domains: staffing, training and operations, medical response, and safety protocols. Identifying and categorizing these factors not only aids in pinpointing where lapses occurred but also guides the institution in reinforcing these areas to prevent future occurrences.
In the ACCIMAP constructed, it is possible to observe that all levels of decision making took part, in a certain way, of the accident, acting in a chained manner, through successive failures until the point of irreversibility, which occurs when the A/F-18 aircraft collides with the C-130.
For this ACCIMAP, every contributing factor was analyzed as the SAR services, organizational cultural factors and causal factors, as depicted below.

3.1.1 Institutional Manning Contributing Factors Overview

This overview discusses contributing factors to institutional manning, particularly in the context of personnel assignments in the niche of military aviation focused. The most important parts from this part of the report are related to:
Categorization of Contributing Factors: The document categorizes institutional manning contributing factors into two main bins:
First-Tour Assignment Practices for AV-88 Pilots: This refers to the process of selecting and assigning novice pilots to specific aircraft types (F/A-18, AV-8B, or F-35B/C).

Second/Third-Tour Assignment Practices: Related to the assignment of pilots in more advanced stages of their careers.
Flight School Selection Process: The document highlights the importance of the flight school selection process, which determines the platform on which student pilots will be trained. This process is crucial for the development of pilot careers and operational effectiveness.
Control Measure Introduced in 1992: A control measure was implemented in 1992 that established a minimum Naval Standardized Score (NSS) for pilots selected to fly the AV-8B. The document suggests that this AV-8B pipeline assignment process is outdated and might be transferring unidentified and unmitigated risks across the entire tactical aircraft (TACAIR) community.
Assignment of a Pilot's First Duty Station: This is identified as the second institutional manning contributing factor, highlighting the importance of a pilot's initial assignment for their future career and operational efficacy.
These points underscore the complexity and importance of the pilot assignment and training process, as well as the potential impacts of outdated or ineffective practices on institutional manning and operational safety.

3.1.2 Institutional Training and Operations Contributing Factors

This part of the report discusses various aspects of training and operational procedures in a military aviation context. The most important parts from are reproduce below:
Overview of Recommendations and Contributing Factors: The document proposes 19 recommendations from within the Training and Operations section. These are categorized into four sections:
F/A-18 Training and Readiness Manuals, Air-to-Air Refueling (AAR) Operations, Ejection and Search and Rescue (SAR), AN/AVS-11 (night vision googles)
Training and Readiness (T&R) Manuals: The document emphasizes the importance of governing documents for readiness generation and flight progression, including the Navy Marine Corps Publication (NAVMC) 3500.S0C (F/A-18 T&R Manual), NATO STANDARD ATP-3.3.4.2 (ATP-56), and the UNITED STATES ATP 3.3.4.2 Standards Related Document (US SRO). It notes the complexity and time-consuming nature of determining qualifications and proficiency for specific operations, exemplified by a case study of a night aerial refueling sortie on December 6, 2018.
Issues with USMC Aviation Governing Documents: There's an indication of the complexity and perhaps inadequacy of USMC Aviation governing documents, implying that these documents may be overly complicated or not sufficiently clear.
The document appears to conduct a detailed analysis of training and operational procedures, focusing on specific areas that are crucial for the effectiveness and safety of military aviation operations. The emphasis on the complexity and clarity of training manuals suggests a concern with how well these documents facilitate decision-making and operational readiness.

3.1.3 Ejection and Search and Rescue (SAR)

This part of the report, elucidate the aviation mishaps involving 1st MAW (Marine Aircraft Wing) on April 28, 2016, and December 6, 2018.
Ejection Incident Involving Profane 12: The document details the ejection incident involving the F/A-18, callsign Profane 12, which occurred after a collision with C-130 aircraft, callsign Sumo 41. The ejection was immediate and unannounced.
Environmental Conditions and Equipment: It notes that the water temperature in the ITRA-South (the location of the mishap) on December 6, 2018, was between 65 and 72 degrees Fahrenheit (18 a 22 degrees Celsius). The aircrew involved in the mishap were not required to wear anti-exposure suits according to OPNAV 3710.7, and none of them were wearing such suits at the time.
Injuries and Medical Concerns: The document discusses the injuries sustained by the pilot from the F/A-18 during the collision and ejection. The autopsy report noted severe injuries, including bilateral subarachnoid hemorrhages and laxity of the atlantooccipital joint. The document mentions the high fatality rate of subarachnoid hemorrhage and the critical importance of prompt and aggressive medical intervention.

The document provides an in-depth analysis of a specific ejection and SAR incident, focusing on the details of the event, environmental conditions, and the medical implications of the injuries sustained. This analysis likely contributes to understanding the risks and necessary safety measures in military aviation operations.

3.1.4 Institutional Medical Contributing Factors

This part discusses the medical aspects related to the aviation mishap, focusing on the VMFA(AW)-242 unit:

Efforts to Authorize Performance Maintenance Program (PMP) Medications: The aircrew in VMFA(AW)-242 attempted to get authorization for PMP medications, specifically Ambien for sleep regulation, during the lead-up to a 24/7 Unit Level Training Exercise (ULT). However, the use of these medications was not authorized by the 1ST MAW CG (Commanding General).

Presence of PMP Medications in Mishap Aviators: Two aviators involved in the mishap were found to have Ambien and other sedating substances in their urine/blood. The document highlights that the 2018 Mishap Critical Incident (CI) investigation did not adequately explain the potential effects of this illegal use on the mishap.

Objectives of this Section of the report: The section aims to address confusion around the interpretation of medical governing directives. It asserts that while the illegal use of PMP medications by the mishap aircrew was not the direct cause, it may have contributed to the incident.

Recommendations and Future Directions: The document provide recommendations to eliminate confusion and loopholes, aiming for a safer implementation of the PMP in the future. It also indicates that the CDA-RB (presumably a review board or committee) will further examine factors that might have contributed to the incident.

The document delves into the complex relationship between medical policies, particularly regarding the use of specific medications, and their impact on aviation safety and the mishap in focus. The main purpose is on understanding the contributory role of these factors and proposing improvements to enhance safety protocols.

3.1.5 Institutional Safety Contributing Factors

This part of report discusses various aspects of safety within the context, including 5 key Issues in Safety: The document, prepared by the CDA-RB (an investigating or reviewing board), identifies three major issues related to safety: two Institutional Contributing Factors (Mishap Reporting and Mishap Recommendation Completion and Tracking) and the Post Mishap Issue.

Mishap Reporting: The processes and effectiveness of reporting aviation mishaps.

Mishap Recommendation Completion and Tracking: How recommendations following mishaps are implemented and monitored.

Post-Mishap Issue: Relates to the assignment of Investigating Officers, which became apparent following a mishap.

This part of the investigation proceeds with some Investigations Overviews. This document describes the concurrent investigation methodology used by the Navy and Marine Corps for significant mishaps, particularly those crossing a defined cost threshold. For Class A mishaps (that’s the case considered), three separate but independent lines of inquiry must be conducted: Aircraft Mishap Board (AMB), JAGMAN Command Investigation, Field Flight Performance Board (FFPB).

Finally, the Aviation Mishap Board Safety Investigation Report focus on the safety investigation conducted by the AMB, detailing its processes and outputs.

This part of the report provides a thorough analysis of safety-related issues linked to the mishap analyzed, focusing on how mishaps are reported, investigated, and followed up with recommendations. The emphasis on the assignment of Investigating Officers and the process of conducting concurrent investigations highlights the complexity and importance of safety protocols in aviation.

3.1.6 Organizational Cultural Factors

This part of the report delves into the analysis of organizational contributing factors in a military context, focusing on 1ST MAW, MAG-12, VMFA(AW)-242, and VMGR-152. The main parts are underpinned below.

Shift from Institutional to Organizational Factors: After identifying the Institutional Contributing Factors, the document shifts focus to Organizational Contributing Factors, examining specific military units.

Importance of Understanding Organizational Culture: The document stresses the need to understand the organizational culture to grasp these contributing factors. Organizational culture is defined as a pattern of shared basic assumptions learned by an organization as it solves problems of external adaptation and internal integration. These assumptions, considered valid, are taught to new members as the correct way to perceive, think, and feel in relation to those problems.

Dual Nature of Organizational Culture: It highlights that organizational culture can produce both positive and negative results. The negative aspects can lead to blind zones and normalized deviancy among commanders and staff.

Change and Recognition: The document points out that recognizing issues is only one aspect of driving change. The other crucial aspect is the willingness to change.

This part of the report offers an in-depth analysis of the cultural aspects within the main organizational units that have participated from the mishap, emphasizing how ingrained cultural practices and assumptions can impact both positively and negatively. It underlines the importance of awareness and adaptability in organizational culture, especially in the context of military operations and safety.

3.1.7 2018 Mishap Causal Factors

This part of report presents an analysis of the mishap, as it were conducted by the CDA-RB:

Unique Investigative Approach: The CDA-RB, equipped with unique capabilities and experiences, adopted a novel approach in their investigation of the 2018 mishap.

Narrative and Storyboard Analysis: There is a narrative of the mishap, providing the chronological sequence of events. It advises readers not to infer causal factors from the narrative alone, as these factors are explained in the Storyboard Analysis scenes that follow the narrative. The storyboard was an important tool used to aid the design of the Accimap below.

Analysis of the Mishap: For the review of the 2018 mishap, the CDA-RB required detailed diagrams to analyze the final moments. However, they faced limitations in recreating a high-fidelity positional scenario due to the data quality recovered from the aircraft's telemetries.

Purpose of the Document: The document was structured to offer a comprehensive understanding of the mishap, combining a narrative overview with detailed storyboard analysis to elucidate the causal factors behind the event, and was from very high value to construct Accimap.

This document provided an in-depth examination of the mishap, focusing on piecing together a coherent narrative from available data and highlighting the complexities involved in such analyses. The emphasis on a narrative combined with storyboard scenes suggests a thorough and detailed approach to understanding the sequence of events and their underlying causes, essential for constructing Accimap.

The result of Accimap investigation method is presented at figure 1.

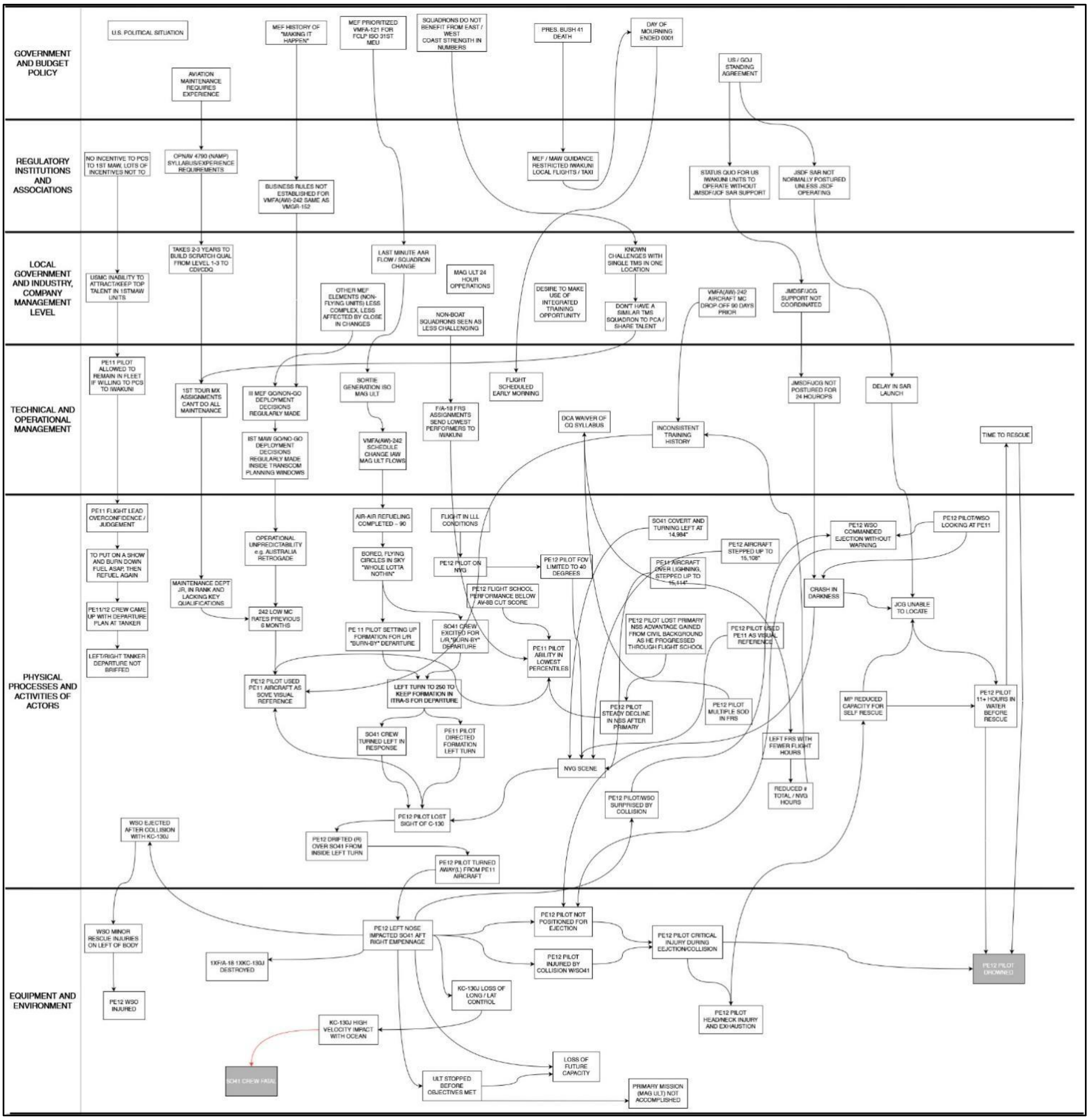

Figure 1 – Accimap structure from accident analysis

Based on Rasmussen's model, Accimap has various applications related to incident assessment in the healthcare sector [32][33], railway transportation [27], mining [15], or even random accidents not specific to a particular industry [19], highlighting its broad applicability for understanding any event. Due to the absence of taxonomy, Accimap allows for the identification of actors and contributing factors with greater flexibility, facilitating the progression of event analysis. It emphasizes that organizational factors and the historical context in which actors are situated are significantly relevant to the occurrence of events, a point supported by Salmon et al. [19].

On the other hand, when making connections between actors of different hierarchies under distant contexts, there is a difficulty in the detailed assessment of facts, leading to inaccuracies and variations related to the analyst's ability to retroact and gather information. Consequently, the reliability of the analysis by this method may be considered low [34], and there are limitations in identifying actors, especially if the analyst lacks the ability to integrate political and normative decisions with technical and ergonomic factors.

3.2 STAMP/CAST

The results of applying the main steps of STAMP/CAST for the investigation of the F/A-18F Super Hornet and KC-130J accident are described in 5 sections: basic information, control structure, identify control structure flaws and, finally, recommendations.
The basic informations are presented at table 1.

Table 1 – General information, scope, description and questions related to event.

Scope of the Assessed System		
The analyzed system is composed of all the agents involved in the air-to-air refueling operation: pilots, aircraft, commanders, search and rescue team, as well as the 'Marine Corps' organization.		
Losses	**Hazard States**	**Constraints**
Aerial collision during aerial refueling operation	Minimum separation between aircraft violated	Aircraft positions must be continuously monitored, and minimum separation must be maintained throughout the entire in-flight refueling process.
		Pilot actions need to be evident and predictable to all agents involved in the operation.
Survivors of the accident do not receive medical assistance in a timely manner	Inability of the search and rescue team to locate survivors in a satisfactory timeframe.	Rescue equipment needs to perform its functions after the accident.
		Search and rescue teams need to be prepared to conduct searches in the event of an accident.

Events leading to the Aerial Collision during aerial refueling operation	
Events	**Questions raised**
Two fighters F/A18F (Profane 11 and Profane 12) required aerial refueling for a KC-130J.	Standard Procedure. No question raised.
Requisition was approved and both F/A18F (Profane 11 and Profane 12) performed the aerial refueling.	Standard Procedure. No question raised.
After the aerial refueling, Profane 11 disconnected first and moved to the right side of KC130J.	Standard Procedure. No question raised.
Profane 11 set the lights configuration from “covert” to “overt”. “Tanker” was set to “covert” and “Profane 12” was set to “Midnight”.	Why did Profane 11 change the light configuration? Why did the other aircrafts remain with different light configurations? Why didn´t Profane 11 warn the other aircrafts about the light configuration modification? Did Profane 12 and “Tanker” notice the light alteration?
Profane 12 drifts back from the “Tanker” and disconnects inadvertently from the Tanker’s hose. Profane 12 required and received approval to remain in the left side of the Tanker. A non-standard maneuver according to the Air-to-air refueling procedure.	Why did Profane 12 require remaining in the left side? Why was it approved? Did anyone notice nothing wrong about Profane 12 Pilot behavior? Why did anyone express any concern or questioning about his decisions?
Profane 11 required a left turn to the Tanker.	Did Profane 12 notice this requisition?
Later, Profane 12 performed an unexpected maneuver crossing over the “Tanker” from left side to the right side.	Whal led the Profane 12 Pilot crossed over to the left side? Why did he cross above the Tanker not below as the standard procedure?
During the maneuver Profane 12 gets too close from Profane 11 and over-corrects, diving down and left, colliding with the tanker	Are there any external factors that impaired the maneuver? Was Profane 12 Pilot trained for this kind of maneuver? Were Profane 11 and the Tanker visible and in the

tail.	right positions?
Events leading to the survivor not receiving medical attention in a timely manner.	
Event	Questions Raised
Profane 12 weapons officer ejected after the collision without informing the pilot.	What is the ejection procedure? What training is associated with it? Did the Profane 12 weapons officer undergo and stay current with the required training?
Profane 12 pilot not positioned for ejection.	Why wasn't the Profane 12 in the correct position during ejection? Was there any indication that could have alerted the pilot to incorrect positioning?
Profane 12 pilot sustained serious injuries during the collision and ejection.	What were the causes of the injuries to the Profane 12 pilot?
Profane 12 pilot contacted Japanese air traffic control for help.	Were Japanese authorities alerted to perform the rescue operation in case of an accident? Was there coordination between the U.S. Air Force and the Japanese authorities?
Profane 12 crew landed in the ocean miles apart and turned on their locator lights.	Were the rescue equipments functioning properly? Was there any adverse weather that could hinder locating the survivors?
A Japanese helicopter took off and found the Profane 12 weapons officer less than an hour after the accident.	Is this a satisfactory rescue time considering the regulations on the matter? Did any factors hinder the rescue time?
An American helicopter took off more than two hours after the accident to find the survivors.	Is this a satisfactory rescue time considering the regulations on the matter? Did any factors hinder the rescue time?
More than ten hours after the accident, the body of the Profane 12 pilot was found floating in the ocean by a Japanese merchant ship.	Why was the Profane 12 pilot not found by the search and rescue teams?

The first analysis shows that there were no system failures that resulted in the collision. Nevertheless, there were four unsafe interactions that contributed to the event.

- Visualization for monitoring the distances between aircraft was carried out with lights configured improperly and adverse environmental conditions.
- Communication between agents did not clarify the difficulties encountered by Profane 12 in keeping up with the maneuvers performed by the other aircraft.
- The tanker was unable to monitor and reveal the differences in lighting configurations between Profane 11 and Profane 12.
- Interaction between Squadron Command and Search and Rescue Team was inadequate or nonexistent for mission planning.

Regarding missing or inadequate controls that could have prevented the accident, it was possible to infer that strict adherence to air refueling procedures and communication protocols would have been valuable in preventing the occurrence of a collision. Additionally, adverse weather conditions and certain unprofessional attitudes from the pilots may have had a significant impact on the event. Building upon the previous assessment, it was possible to establish a structured control framework, as shown in the figure below.

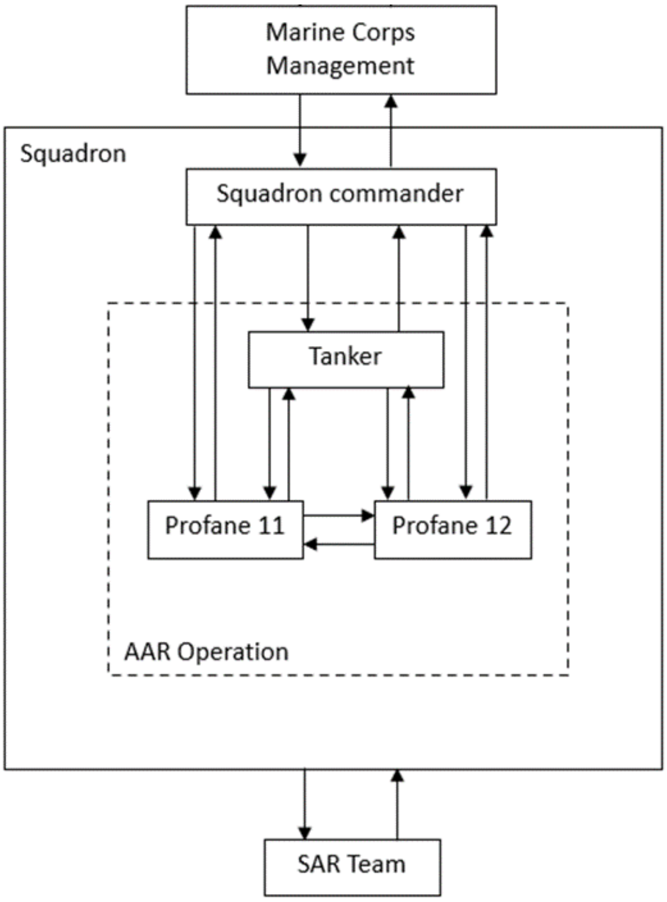

Figure 2 – STAMP/CAST Control structure

The table 2 shows the analysis of each component to the losses.

Table 2 – Agents involved in the accident and their respective responsibilities, contributions, explanations, and recommendations for improvements.

Agent	Relevant Responsibilities for the Accident	Contributions to Losses	Possible Explanation for Behavior	Recommendations
SAR Team	Be prepared, alert, and perform search and rescue in case of accidents.	Unable to find Pilot of Profane 12 in a timely manner.	Lack of planning by Marine Corps command.	Improve planning and coordination between SAR teams and Marine Corps command.
Profane 11	Control maneuvers during the operation. Maintain distance from other aircraft. Be visible. Communicate aircraft status and maneuvers during the operation.	Decision to change light configuration from "covert" to "overt". Decision to make a left turn after aerial refueling. Unprofessional climate in the squadron.	Mental model that the appropriate light configuration for aerial refueling was "overt". Lack of standardized procedures for light configuration.	Standardize procedures for light configuration during aerial refueling. Implement standardized procedures for light configuration during aerial refueling. Foster a more professional climate in the squadron.

Agent	Relevant Responsibilities for the Accident	Contributions to Losses	Possible Explanation for Behavior	Recommendations
Profane 12	Control maneuvers during the operation. Maintain distance from other aircraft. Be visible. Communicate aircraft status and maneuvers during the operation.	Inadvertent disconnection from the tanker. Decision to remain on the left side of the tanker. Did not inform others about visibility difficulties. Executed a maneuver to stay close to the tanker (possibly) and ended up getting too close to Profane 11, resulting in a collision with the tanker's tail.	Confusion between the lights of Profane 11 and the tanker. Did not think it was necessary to report visibility difficulties. Lights of Profane 11 obscured the tanker. Unprofessional climate in the squadron.	Implement standardized procedures for light configuration during aerial refueling. Improve communication about visibility issues during the operation. Enhance communication about visibility conditions during the operation. Foster a more professional climate in the squadron.
Tanker	Coordinate aerial refueling operation. Provide fuel to the fighter jets. Control maneuvers during the operation. Maintain distance from other aircraft. Be visible. Communicate aircraft status and maneuvers during the operation.	Approved Profane 12 to stay on the left side. Did not warn about the lighting difference between Profane 11 and Profane 12. Did not alert Profane 12 when observed crossing over.	Did not think it was necessary to report the lighting difference between Profane 11 and Profane 12. Did not place sufficient value on standardized procedures. Unprofessional climate in the squadron.	Emphasize the importance of adhering to standardized procedures. Improve adherence to standardized procedures. Foster a more professional climate in the squadron.
Squadron Commander	Plan the operation.	Approved the operation without adequate planning.	Did not place sufficient value on strict standardized processes and procedures.	Emphasize the importance of thorough planning and adherence to procedures.

Agent	Relevant Responsibilities for the Accident	Contributions to Losses	Possible Explanation for Behavior	Recommendations
	Ensure readiness and training of the crew involved in the aerial refueling operation. Ensure airworthiness of the aircraft.	Passively overlooked the unprofessional climate in the squadron. Did not ensure pilots were ready for the operation (lack of sleep, preparation, etc.). Did not guarantee that pilots were ready for the operation (lack of sleep, preparation, etc.). Did not address the low morale in the squadron.	Low attention given to this squadron by the Marine Corps organization. Low availability of aircraft for the squadron. Low squadron capability to complete 7 out of 10 essential tasks.	Enhance attention and support for the squadron's readiness and morale. Improve aircraft availability for the squadron. Address factors contributing to low squadron capability.
Marine Corps Management	Provide funding for hiring qualified personnel. Ensure allocation of squadron members with adequate readiness levels. Provide proper direction for complaints presented by the squadrons.	Directed a series of training sessions in a short time without considering the reality of each squadron.	Assumed that accelerated training sessions could be completed in a short time. Increased tension with North Korea.	Evaluate and adapt training programs to squadron-specific needs. Monitor and address external factors affecting squadron readiness. Improve communication and responsiveness to squadron concerns.

And, moving forward with the STAMP/CAST analysis, the table 3 shows the identification of control structure flaws and some recommendations to each systemic factor.

Table 3 – Systemic factors, correlated losses and recommendations

Systemic Factors	**Losses**		**Recommendations**
	Aerial collision during aerial refueling operation	**Survivors of the accident do not receive medical assistance in a timely manner**	
Communication and coordination	The main causes of this accident are related to lack of communication and coordination: Squadron Personnel: • No communication between the pilots about the light configuration.	Between Profane 12 Crew: • Profane 12 Weapons officer did not communicate his ejection. Between Squadron	• Improve the importance of communication between all agents in the AAR Operations training. • Continuous training to enhance the adherence with standard procedures.

<table>
<tr><th rowspan="2">Systemic Factors</th><th colspan="2">Losses</th><th rowspan="2">Recommendations</th></tr>
<tr><th>Aerial collision during aerial refueling operation</th><th>Survivors of the accident do not receive medical assistance in a timely manner</th></tr>
<tr><td></td><td>Lack of coordination of the squadron leader approving the Fighters to stay in a non-standard position.
No coordination of the left turn maneuver between the three aircrafts.
Lack of communication of Profane 12 to report its visual difficulties during the operation.
No coordination of the Profane 12 maneuver crossing over the tanker which finally led to the collision.
<u>Between Squadron personnel and Squadron Commander:</u>
Details of the operation were not briefed to the crew with the proper antecedence.
No time for mission planning was given to the Squadron Personnel.
<u>Between Squadron Commander and Marine Corps Management</u>
Mission request did not consider the readiness of the squadron.</td><td><u>Commander and SAR Team:</u>
Squadron Commander did not coordinate properly the provisions for SAR.</td><td>Additional barriers in the approval process of accelerated missions.
Continuous Monitoring of the squadron readiness by the commanders.
Reinforce the instructions of the ejection procedures.
Standard procedures for SAR coordination before training operations.</td></tr>
<tr><td>Safety information system / Safety Culture</td><td>The unprofessional climate and deviations of the procedures reveal that the safety culture was not promoted within the squadron.</td><td>The “Make it happen” climate overcome the possibility of further planning and improvement of the safety controls, such as SAR operation planning.</td><td>Foster a safety culture within the squadron to place for safety a high value during decision making.</td></tr>
<tr><td>Changes and dynamics over time: in the system and in</td><td colspan="2">The readiness of the squadron, morale and unprofessional climate were worsening over time without any monitoring / control from commanders.</td><td>Create and monitor leading indicators to identify when the squadron is migrating toward a state of high risk.</td></tr>
</table>

Systemic Factors	Losses		Recommendations
	Aerial collision during aerial refueling operation	Survivors of the accident do not receive medical assistance in a timely manner	
the environment			

The recommendations were organized in the same tables of analysis of the STEPs 3 and 4. The recommendations provided in the STEP 3 was focused on the contributions of the individual agents, otherwise, the recommendations related to the systemic contributions to the accident were provided in the Step 4.

4. Conclusions

In-flight-refueling operation is a very complex and risky operation, with low margin for errors. This operation demands a lot of the pilots which must perform with perfection their duties. A simple mistake may lead to catastrophic outcomes.

During the most critical phases of in-flight refueling, there are no interlocks, safety systems, backups etc. to assure the safety of the operation. Safety assurance is most based on the ability of the pilots and their preparation to perform the mission (exhaustive training, adherence to standard procedures etc.).

The benefits of this work for the Brazilian Air Force and the aggregated knowledge related to in-flight refueling missions are extremely broad, encompassing various aspects from improving operational safety, enhancing training, and aligning procedures with reality, to analyzing human factors involved in the entire operation. The improvement in operational safety stems from the application of ACCIMAP and STAMP/CAST accident analysis methodologies, which, through comparison, result in a comprehensive identification of contributing factors to occurrences and allow for the development of specific preventive strategies for risk mitigation, as well as practical recommendations such as standardizing procedures and improving communication between crew and teams involved in the mission. In terms of procedure enhancement, the analyses enable the identification of evidence of failures, which can support training, making it more aligned with reality, as well as identifying procedural failures, allowing for continuous updates, standardization, and clarification as needed. Two important points to mention about human factors are ergonomics (especially those inducing increased stress and fatigue) and organizational culture, with the former being crucial for analysis due to its potential to enhance crew operational efficiency, and the latter through the analysis of organizational culture, which can identify where culture conflicts with operational safety.

STAMP/CAST is focused on finding problems in the system's controls. From this study, it was observed that the application of the STAMP/CAST methodology with all the scrutiny of the control structure brings limited gains for the accident investigation of this kind of operation which human factors are the most important part to be analyzed. Most of the recommendations were identified through the investigation of the behaviors of the agents and interactions between them.

Accimap is a methodology that requires a high level of contextual knowledge, and the inferences made might lead to errors and imprecise assessments, although its lack of taxonomy allows for correlating contributing factors that may not be evident in other methods.

According to evaluation of both methods, incidence of ergonomics related aspects as fatigue, stress, behavioral issues, etc., were relevant to the occurrence of the accident, endorsing the need for continuous research on human factors contributions. In assessing decision-making, it's important to understand which reasons or situational factors contributed to the occurrence of the specific event. Methodologies for evaluating naturalistic decision-making are crucial for this understanding and can be further studied through the application of the Neisser's Perceptual Cycle Model [35], Klein's Recognition Primed Decision [36], Rasmussen's Decision Ladder [37] or any other form of assessment.

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6. Copyright Statement

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