THE ROLE OF COGNITIVE LOAD IN DECISION-MAKING PROCESS FOR PILOTS IN HIGH INTENSITY ENVIRONMENTS

George Adrian AIONESEI, Sorin PARASCHIV

Boboc Air Force Base, Buzău, Romania (aioneseiadrian11@gmail.com, sorinparaschiv_atu@yahoo.com)

DOI: 10.19062/2247-3173.2024.25.1

Abstract: *This paper explores the critical role of cognitive load in the aviation decision-making process, emphasizing its impact on flight safety and pilots' performance. Cognitive load, the amount of working memory resources used to learn a new subject or to solve a problem, is usually understood as the information-gathering part that happens at the beginning of a decision-making process, but in fact, it is present through every step of a decision-making model. This is illustrated through an in-depth analysis of cognitive load theory and three decision-making models, particularly the DECIDE model. The study provides a comprehensive examination of how cognitive load influences pilot actions during high-stakes situations, highlighting two pivotal aviation incidents, the "Miracle on the Hudson" and Air France Flight 447. These case studies serve as empirical evidence to support the assertion that managing cognitive load is essential for effective decision-making in aviation.*

Keywords: cognitive load, decision-making process, aviation, safety.

1. INTRODUCTION

The decision-making process (DMP) in aviation is a critical determinant of flight safety, as pilots are often required to make fast and accurate judgements under different levels of cognitive load. The capacity to make fast, accurate judgements in complex scenarios directly influences mission outcomes and lastly, safety. Central to this process is the concept of cognitive load, the total amount of mental effort to retain information or to solve a problem. Although information gathering, which happens in the first steps of DMPs is frequently highlighted as a phase where cognitive load has the heaviest impact. In fact, it is present through every step of the DMP, from problem identification to the evaluation of action taken. Cognitive load theory provides a great framework for understanding how pilots process information, assess situations and implement decisions under pressure. The objectives of this paper are to explore the extensive impact of cognitive load on the DMPs for pilots during high-intensity scenarios such as emergency procedures, also to show that the cognitive load extends beyond the simple collection of information, playing a critical role through the entirety of the DMP.

The paper will approach a methodology that includes an in-depth analysis of cognitive load theory and decision-making models, enriched by case studies of aviation incidents. The case studies will highlight how cognitive load affects decision-making at different stages, providing empirical evidence to support the assertion that cognitive load influences DMP more than just during information collection. Through this approach, the paper intends to contribute to a deeper understanding of cognitive load management strategies that can improve the efficacy of decision-making and propose directions for future research to enhance pilot performance and safety in demanding operational contexts.

2. AVIATION SAFETY

The aviation domain has been a critical factor in shaping military operations and strategy. From early experiments with balloons in 1783 by the two French brothers Joseph-Michel and Jacques-Etienne Montgolfier, or gliders in 1853 by Sir George Cayley [1], to the breakthroughs by the Wright brothers, aviation has transformed aviation and warfare. The evolution of aviation, from its early stages in the early 20th century to its current state represents a remarkable journey of technological, operational, and psychological improvements.

In order for aviation to move forward and know a great ascension, it was required to create an environment where people and the flying machines coexist in a safe environment. Aviation safety, stated by the International Civil Aviation Organization (ICAO) is “a state in which the possibility of harm to persons or of property damage is reduced to, and maintain at or below, an acceptable level through a continuing process of hazard identification and safety risk management” [2]. It encompasses the strategies, regulations, and measures aimed at minimizing the risks associated with air travel, ensuring the well-being of passengers, crew and cargo, as well as people on the ground.

Initially, the primary focus of this new domain was on crafting aircraft and infrastructures capable of ensuring a safe flight through all its phases, from takeoff to landing. The development efforts involved new prototypes and systems to be more efficiently by continuously analyzing the mechanics and controls, material science, power, landing gear and hydraulics, electrical and avionics, assembly, quality control, integration of systems and the physics of flight. As aviation technology became more and more successful leading to fewer accidents by the end of 1960, there was another crucial factor for safety that needed to be taking into account in order to minimize the failures: the human factor, officially included by the ICAO in 1970. Later, in 1990, the organizational factor was introduced as a notion of aviation safety [2].

Over time, these factors were continuously analyzed and progressively contributed to updating the aviation safety. As a result, the greater number of flights, the fewer cases of non-fatal and fatal. This aspect is presented by an Airbus statistic on aviation accidents in the Fig.1 bellow.

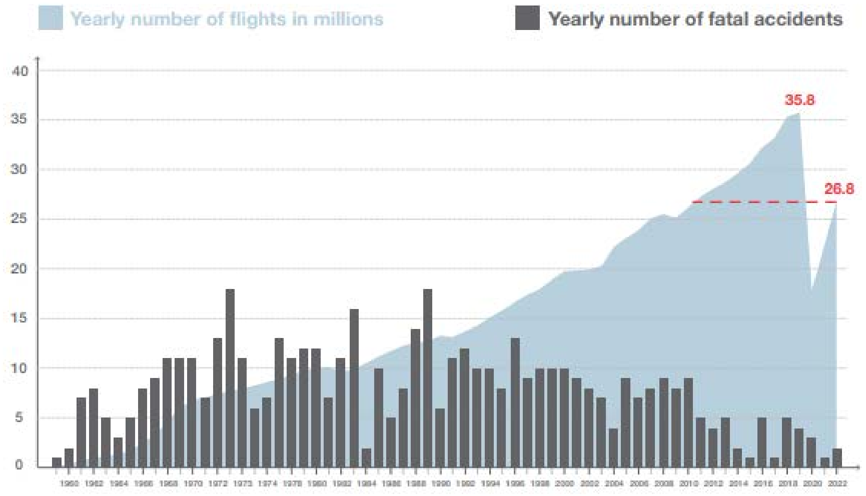


FIG.1 Fatal airline accident compared to the number of flights between 1960-2022 [3]

With aircraft technology and reliability advancing, technical factors contributing to aviation incidents have significantly declined. Conversely, along with the introduction of these concepts by ICAO, human factors have emerged as the primary contributors to accidents, now accounting for approximately 80% of all root causes of aviation mishaps [4], depicted in Fig.2. This high percentage is concerning and need to be approached seriously in order to find what factors and decisions were involved in the past accidents.

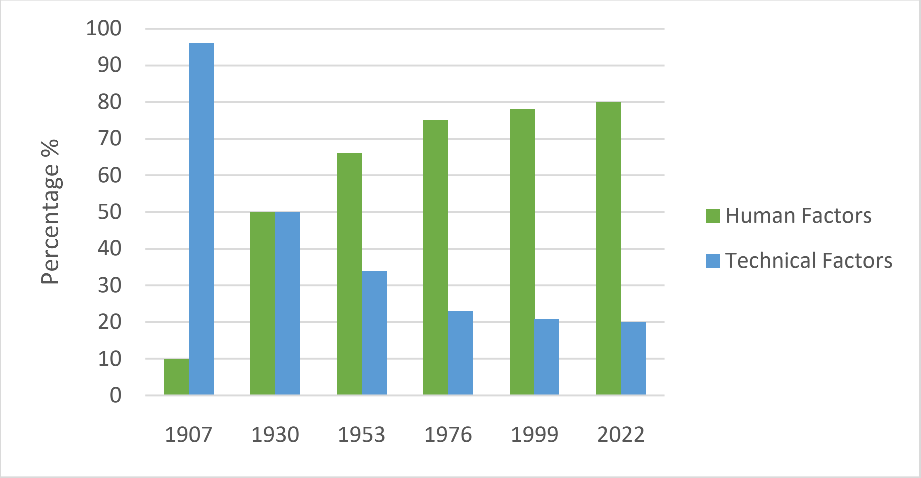


FIG.2 Accident root causes in aviation evolution

The DMP in the aviation context has always been complex, requiring pilots to process vast amounts of information, perform multiple tasks simultaneously, and make quick, accurate decisions under pressure. On the military side, the DMP is even more demanding due to the added layers of tactical considerations, engagement rules, and often hostile environments. There are multiple elements that can influence the DMP. The environmental conditions (weather or terrain), technological aspects of the aircraft or systems, or human factors, including fatigue, stress, communication, situational awareness, emotional state and others are a big part of the decision-making capacity.

Despite this, one area that has received relatively less attention is the effects of cognitive load on pilots' DMP. With the development of systems and technology that became more sophisticated, the need to digest all the associated information has grown too. In high-stakes environments such as emergency procedures, highjacks or in military operations (which necessitates a different approach on each aspect of the most efficient decision), pilots are required to process a multitude of simultaneous inputs and make split-second decisions that could have life-or-death outcomes. The nature of these operations can induce high levels of cognitive load, influencing the ability to process information efficiently, maintain situational awareness, and consider the implications of different courses of action.

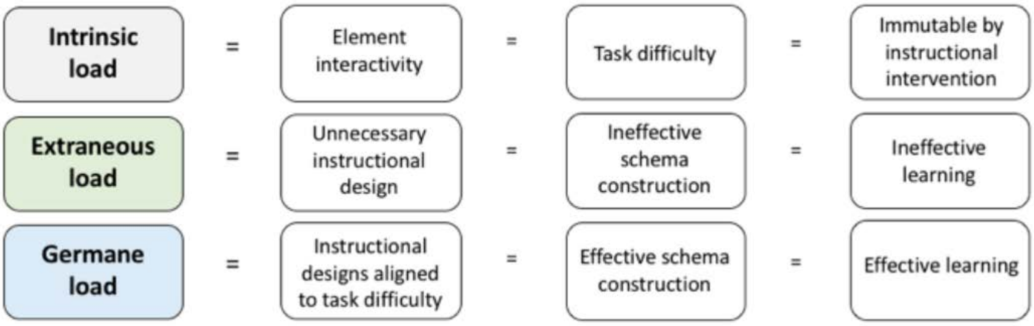
3. COGNITIVE LOAD THEORY

Cognitive load, as a concept, is most of the time associated with the information overload of an individual or a group, that ultimately leads to fatigue or exhaustion, influencing the wellbeing of that person or group. According to cognitive psychology, it represents the amount of working memory resources used to learn a new subject or to solve a problem. In the 1980s, educational psychologist John Sweller took this concept and integrated it in the Cognitive Load Theory (CLT) in order to show the capacity of working memory and its limitations in processing new information. In his study, Sweller illustrated that for an effective learning and task performance, the cognitive load of an individual's working memory must be carefully managed [5]. This theory created a base in understanding how cognitive load affects different fields, from education, financial and organizational sectors to high-demanding environments like aviation, including both civilian and military sides.

In order to understand how the CLT works, we need to refer to the long-term memory, which functions as an extensive repository for data, similar to the unlimited storage capacity of a computer. Conversely, working memory possesses a limited capacity, capable of analyzing and processing only a small percentage of information simultaneously. As information is not revisited or reinforced within working memory, it is at risk of being forgotten. CLT suggests that in order for learning and problem-solving to be efficient, it is necessary to acknowledge this limitation and supply the information in small quantities to the working memory. Otherwise, cognitive overloading increases the likelihood of forgetting or inaccurately integrating the information.

According to Paas, Renk and Sweller [6], cognitive load is categorized into three types as shown in Fig.3:

- **Intrinsic load –** refers to the complexity of the subject matter or task at hand. This form of cognitive load is directly related to the difficulty of the concepts or operations that an individual wants to understand or execute [7]. In aviation, for example, it can vary based on the complexity of flight operations, such as flying through turbulent weather compares to executing routine takeoff procedures;
- **Extraneous load –** is associated with how information or tasks are presented to the individual. Different from the previous one, extraneous load cannot be controlled in the learning or DMPs [8]. Poorly structured educational materials, complex instructions, or irrelevant information add to the cognitive load, creating a difficult environment to work in. Regarding aviation, this could translate into display information in the cockpit or the way flight manuals are written;
- **Germane load –** represents the effort dedicated to processing, creating and automating schemas, in order to organize and interpret information easily [9]. This part of CLT is considered beneficial to learning, by facilitating integration of new information into the long-term memory. It resumes at training and simulation-based activities for pilots.



Intrinsic load = Element interactivity = Task difficulty = Immutable by instructional intervention
Extraneous load = Unnecessary instructional design = Ineffective schema construction = Ineffective learning
Germane load = Instructional designs aligned to task difficulty = Effective schema construction = Effective learning

FIG.3 The three types of cognitive load [10]

Understanding and effectively managing these three types of cognitive loads is critical in aviation, where the margin of error is minimal. CLT represents a great start in understanding how cognitive load is affected by different factors, such as the individual itself or the environment, but most of the studies associate the concept with the fields of education and learning, demonstrating how individuals comprehend, structure and memorize information on particular topics. Ayres [11] for example, investigated how this concept influences the process of acquiring new skills, enhancing the educational effectiveness in various disciplines. On the same idea, De Jong explored the complexities of managing cognitive load within educational context, but did not agree with the division of cognitive load by the three components: intrinsic (neutral), extraneous (harmful), and germane (beneficial). He also mentioned the lack of ways to measure the cognitive load characterizes a barrier in order to understand how cognitive load works [12].

In aviation, especially for pilots, CLT is critical in both the design of cockpit systems and in simulation and training programs. The complexity of flying tasks, especially in bad weather conditions or during emergencies, has a significant impact on the intrinsic cognitive load on pilots. Poorly designed instrument display or complicated procedural instructions can add extraneous load, while effective training methods that enforce the development of schemas for various tasks contribute to the germane load. These put together facilitate learning and expertise on flying activities. The implications of cognitive load are particularly pronounced in military aviation, where pilots often operate in environments of greater complexities and under higher pressure.

When an event occurs, it does not involve just one factor, but a succession of them, like the domino pieces. The cognitive load can also be examined from this perspective, taking into consideration the other human factors, creating an interrelationship between them. Some of them that can affect the cognitive load are:

-Task complexity – different phases of flight, such as takeoff, cruising, maneuvering or landing, necessitate various levels of cognitive demands. Takeoff and landing can be considered the most cognitively demanding phases, through precise protocols, monitoring multiple systems and readiness for rapid decision-making in case of unexpected conditions. On the other hand, cruising or holding maneuvers might offer a period of reduced cognitive involvement;

- Information overload – during a flight, the vast amount of information from aircraft systems, communications with air traffic controllers or navigation aids, require the pilots to find a balance in order to not become overwhelmed;

- Time pressure – the need to make quick decisions, especially during emergencies, adds significant time pressure, increasing the load on extraneous load;

- Fatigue – it significantly affects cognitive load by reducing pilot’s ability to process information, make decisions or react in time. Long flights, irregular schedules or minimal rest periods can be critical for this factor;

- Automation – this factor goes both ways. As the aircraft systems take over routine tasks, allowing pilots to be more of managers of systems, they still have to maintain a deep understanding of these systems in order to intervene whenever they cannot rely on them.

4. UNDERSTANDING THE RELATION BETWEEN COGNITIVE LOAD AND DECISION-MAKING PROCESS

The ability to recognize a problem as it emerges, preferably before it has fully materialized, to choose the optimal solution and then implement it at the right time stands in the hands of a pilot. While the skill and procedural aspects of flying have seen significant automation advancements, from early autopilots to contemporary computerized management systems, the necessity for the pilot to engage in critical thinking, reasoning and evaluation of unforeseen events remains essential for the future [13].

There are multiple models of DMP that were developed through time, and many of them were adapted and improved for different domains, including aviation. The rational model was one of the first models, presented step by step by Bazerman and Moore [14].

The rational model includes six steps:

1. Define the problem;
2. Identify the criteria;
3. Weight the criteria;
4. Generate alternatives;
5. Rate each alternative on each criterion;
6. Compute the optimal decision.

In order to fulfill other needs, this model can be adapted by adding more steps or completely change the framework. Regarding the cognitive load in the DMP, there are a few models that can be analyzed and applied for getting the best outcome.

Dual-Process Model

This model was defined by Daniel Kahneman in his work *Thinking, Fast and Slow* [15], as two distinct systems of thinking that influence human judgement and decision-making: System 1, illustrated as fast, automatic and emotion-driven, and System 2, as slow, deliberate and logical.

System 1 (intuitive thinking) operates automatically and with little-to-no effort. It is responsible for the gut reactions and quick judgements. Under low to moderate cognitive load, System 1 can be efficient, being able to process information from the environment or memory almost instantaneously. It is driven by experience and heuristics, enabling pilots to make fast decisions based on familiar patterns and situations. At the level of each type of cognitive load, due to the automatic nature of System 1, the intrinsic cognitive load is manageable, as this type of thinking is based on well-established schemas, extraneous load is minimal, as decision are intuition based rather than complex processes and the germane load can be optimized as pilots are allowed to allocate mental resources for learning new patterns, even during routine operations.

System 2 (analytical thinking) requires significant mental effort, attention and analyzing. It is engaged in logical reasoning and conscious decision-making, essential for dealing with new situations, complex problem-solving or decision-making in sensitive times. Pilots must balance the intuitive responses of System 1 with the analytical processing of the second one, especially during emergencies. Intrinsic load is high as it requires the processing of complex information (new and existing knowledge), extraneous load might be increased due to poorly design interfaces or ineffective communications, whilst the germane load contributes to the development of expertise.

For example, for a simple routine flight, System 2 is in advantage because everything is working by chart, but for a crisis situation the intensity increases and System 1 will take charge. For this model, the key for an efficient cognitive load stays in finding a balance between intuitive and analytical thinking, not choosing one or the other.

Recognition-Primed Decision (RPD)

Another important model is the RPD, developed by Gary Klein [17]. This model describes how experienced individuals, like first-time responders (firefighters, doctors), make decisions in real life scenarios by recognizing patterns and simulating potential actions without a previous analysis of all available options.

The core steps to understanding the RPD model are:

- Recognition of relevant cues – the observer identifies the signs that make the situation recognizable based on past experiences. Pilots are trained to recognize a wide variety of cues from the environment, instruments and the behavior of the aircraft. This recognition is based on their experience and knowledge, allowing them to quickly identify what is happening. The intrinsic cognitive load is of importance in this situation because the cues identification relies on the pilot's understanding of aviation dynamics.

- Situation judgement – After identifying the cues, pilots assess the situation in order to understand its significance, by comparing it to past experiences. This step allows them to appreciate the severity of the situation, potential outcomes, or any unique characteristic. The germane cognitive load is critical at this stage, as pilots use their cognitive resources to link the circumstances with their stored knowledge, including standard procedures or mnemonics.
- Mental Simulation – Pilots mentally simulate potential actions related to the scenario. This involves projecting steps they might take and anticipating the outcomes. By doing this multiple times, pilots can evaluate whether the proposed action will address efficiently the situation. Herbert Simon refers to this approach, identifying a strategy that he calls "satisficing", where instead of analyzing multiple possible actions until the most optimized is found, just use the first approach that works. In these circumstances, the key to simplifying the DMP is to find a good enough solution that just works and not the best optimized one [18].
- Action Implementation – Based on the mental simulation, pilots implement the action they believe is most likely to succeed. Due to the lack of time in most situations, this decision is made fast, without deliberating alternative options extensively. Besides the time constraint, if the cockpit environment is cluttered or communication poor, the extraneous cognitive load can be significant during the implementation of action.

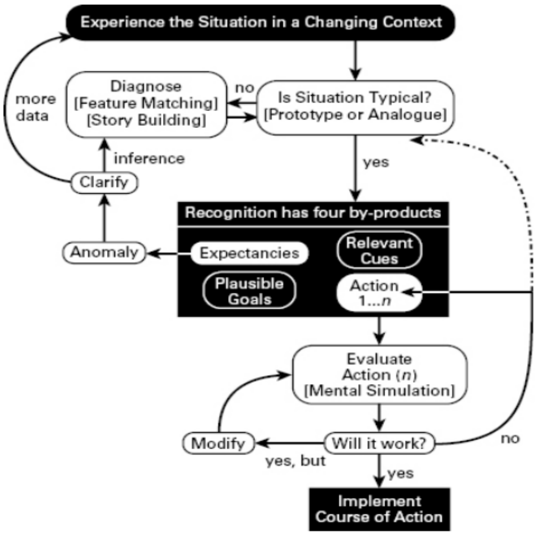


FIG.4 Recognition Primed Decision Model [17]

This model is based on training and past experiences in order for an individual to recognize a pattern or some familiar characteristic that might ease the decision for an optimized outcome. The cognitive load is present in most steps, but especially in cues recognition and situation judgement, where if the principles are applied accordingly, the final decision is easier to make. In order for this to happen, aviation professionals can develop strategies to enhance pilots' decision-making capabilities, by developing schemas and mental models.

On the same idea, the **Naturalistic Decision Making (NDM)** model is also based on intuition and how individuals use their knowledge and expertise to make decisions in complex situations, but is more oriented to the situation's complexity, uncertainty and time pressure. It also takes in consideration team-based and organizational decision-making and instead of a single course of action identified and mentally tested, it involves multiple stakeholders, a series of decisions, and adaptations to plans based on evolving situations [19]. From the team work and adaptability points of view, NDM provides a framework for dealing with uncertainty and scenarios that may not match any previous experience directly. The model's emphasis on situational awareness, team collaboration and adaptive decision-making offers a more flexible approach to managing cognitive load when faced with new or complex problems.

Federal Aviation Administration (FAA) analyzed and adopted three models for problem-solving and decision-making: the **5P**, the **3P** and the **DECIDE** models. The administration sustains that there is no right answer in how to approach decision-making in aviation, rather each pilot should analyze a specific situation based on the experience level, personal minimum standards and current physical and mental readiness level [20].

The **5Ps check** include **the Plan, the Plane, the Pilot, the Passengers and the Programming**. This model is based on the idea that during a flight the pilots have 5 variables that impact their environment and in a critical situation, the attention should be distributed to each individual one. After analyzing all five, the decision specific to each variable need to be added together and create the best outcome possible. In order to arrive at a critical situation, pilots are enforced to apply the 5 Ps in key moments during the flight: before the flight, prior to takeoff, midpoint of the flight, prior to descend or prior to final approach. Therefore, the cognition load is well structured and not chaotic in this case.

The **3P** model include **Perceive, Process, and Perform** variables, being more simplistic than the one before. This model can be used during all phases of flight, where the pilots is needed to:

- Perceive the given set of circumstances of flight;
- Process by evaluating their impact on flight safety;
- Perform by implementing the best course of action.

In order for this model to be more efficient, FAA brought a few tools that help the germane cognitive load in analyzing the situation, such as mnemonics or boldface checklists:

- PAVE – **P**ilot, **A**ircraft, en**V**ironment and **E**xternal pressures; it focuses on identifying (<u>perceive</u>) hazards associated with all aspects of the flight;
- CARE – **C**onsequences, **A**lternatives, **R**eality, **E**xternal factors; it shows whether the hazards that pilots identified represent risks (<u>process</u>);
- TEAM – **T**ransfer, **E**liminate, **A**ccept, **M**itigate; the checklist's goal is for pilots to <u>perform</u> by taking action to eliminate hazards.

Another model that is recognized worldwide is the **DECIDE** model, designed to assist pilots and aviation professionals in making informed and effective decisions, especially in high intensity situations, such as emergencies. This model offers a systematic approach to DMP, with the focus on efficiency. The cognitive load can be well managed using this acronym, as it emphasizes the importance of continuous awareness, information assessment and adaptability, principles that are critical for aviation. The elements of the DECIDE model are:

- **Detect** (the problem): This first step involves detecting the fact that a change has occurred. This step is the most important regarding cognitive load, as pilots must go through a great amount of information in order to identify discrepancies or potential issues. Depending on other human factors too, this process can strain cognitive capacity, particularly when fatigue sets in or when there is an information overload.

The best approach for this step lays in training and leveraging cockpit technologies designed to alert pilots.

- **Estimate** (the nature of the problem): Once a change has occurred, the next phase is to estimate the need to react to it. This involves assessing risk and potential outcomes, which can significantly increase cognitive load. At the pre-existing information, there is the new information (i.e. emergency), which need to be estimated in order to find how much it will affect the wellness of flight. It requires analytical thinking and the ability to project future scenarios based on current data.
- **Choose** (a course of action): Choosing a course of action involves evaluating multiple options and their potential outcomes. Depending on the time pressure or the type of the emergency situations, the intrinsic cognitive load is more needed based on the frameworks and checklists, providing structured pathways for action.
- **Identify** (solutions): After analyzing multiple courses of action, pilots need to implement the most effective one, requiring a detailed understanding of the aircraft's systems and capabilities, phase where germane load is more present.
- **Do** (the necessary actions to solve the problem): In order to execute the chosen solution, pilots must coordinate actions while continuously monitoring the situation to ensure the desired outcome achieved. On top of the pre-existing flying data, the unexpected situation, the cognitive load must be applied efficiently by adding other actions in order to solve the problem. This step shows the cognitive load at its peak.
- **Evaluate** (the effect of the actions): In order to know whether the chosen course of action was the best fit for the situation, pilots need to compare the current state with the desired outcome, involving both observation and analysis. This phase has two possible outcomes: if the situation becomes more manageable or it gets worse, requiring a reassessment and a potential change in strategy.

Each step of this model poses unique cognitive challenges, highlighting the importance of strategies to manage cognitive load effectively.

All the models above are similar in the big picture, but offer different solutions for specific scenarios. The cognitive load is thought to be present more in the beginning of each DMP, but as shown above on these models, the cognitive load, either as a whole, or intrinsic, extraneous and germane, is present in different proportions on each step of the process. Therefore, is necessary to understand the importance of cognitive load and the ways to train it in order to not become an obstacle in any of the steps. Also, the interrelationships with the other human factors need to be taken into account in order to eliminate the possibility of a downhill domino effect.

5. CASE STUDIES

THE MIRACLE ON THE HUDSON

On January 15 2009, US Airways Flight 1549 departed from LaGuardia Airport (New York), for Charlotte (North Carolina). About 2 minutes after takeoff, the Airbus A320 collided with a flock of Canada geese, causing both engines to fail. As the plane started to descend in a glide, the captain of the plane Chesley (Sully) Sullenberger and First Officer Jeffrey Skiles realized, because of the low altitude, that the plane would be unable to reach any close airport. He made the decision to attempt to land in the Hudson River. In three and a half minutes from the collision with the birds, the plane landed onto the river, resulting in all 155 people on bord being rescued without any fatalities. This remarkable water landing, known as the Miracle on the Hudson River remains one of the most successful emergency landings in aviation history [21].

In order to understand how cognitive load was involved in this scenario, the DECIDE model will be used for a step-by-step analyzation:

- Detect – The flock of birds caused the loss of power in both engines. The pilots detected the unprecedented emergency, demonstrating their situational awareness. Despite the sudden urgency and the increased extraneous cognitive load, their training and experience enabled an immediate and clear recognition of the critical situation.
- Estimate the nature of the problem – The severity of the situation was estimated by both pilots, a dual engine failure over a density populated location with no options for a safe landing. The cognitive load was increased in this phase as the pilots had to quickly process the aircraft's altitude, attitude, potential landing sites and the limited glide distance.
- Choose a course of action – Under extreme cognitive load and time pressure, the crew considered returning to LaGuardia or diverting to Teterboro Airport. Relying on his extensive flying experience and situational assessment (intrinsic load), Captain Sullenberger chose to ditch the aircraft in the Hudson River, a decision both novel and fraught with risk, requiring a confidence and a descriptive mental simulation (germane load).
- Identify solutions – This step involved intrinsic and extraneous loads as pilots had to configure the airplane for a water landing and determine the best angle and speed to hit the water in order to maximize the chances of survival for all passengers and crew. There were involved not just the technical knowledge, but also the mental preparation to execute these actions under stress.
- Do the necessary actions – Executing the water landing required precision and calm, characteristics that are not present in other similar situations. Their cognitive load was critically involved in this step, as the pilots' actions were guided by a combination of procedural knowledge, muscle memory from training and a deep understanding of the aircraft's capabilities.
- Evaluate the effect of the actions – Even though they landed successfully, the cognitive load switched scenarios in order to evaluate the situation to proceed for evacuation of the passengers.

The main cognitive load factors involved in this incident enumerate:

- Situational awareness: despite the immediate and unexpected loss of power, the crew understanded their available options;
- Decision-making under stress: Understanding the circumstances, made pilots to make the best decision for safety of the passengers than apply the protocols of turning back to the airport;
- Experience and training: the training represented a crucial role for the crew in their ability to manage a situation;
- Cognitive load management: the most important factor was that the pilots managed to assess and understand all the information through effectively communicating, prioritizing tasks and made decisions that kept the cognitive load at manageable levels.

AIR FRANCE FLIGHT 447

Air France Flight 447 from Rio de Janeiro to Paris crashed into the Atlantic Ocean on June 1st 2009 at 02:14 UTC – Universal Coordinated Time, resulting in the tragic loss of all 216 passengers and 12 crew members on board. There were three pilots, Captain Dubois resting in the crew rest area, First Officer Bonin as pilot flying and First Officer Robert as pilot non flying. The Airbus A330, at Flight level 350 encountered severe weather conditions three hours after the takeoff. The primary issue began when the aircraft's 3 Pitot tubes were clogged with ice crystals, causing inaccurate airspeed readings for the pilots. At that moment, the autopilot disengaged and Bonin took manual control of the aircraft. Instead of maintaining straight and level flight, he pulled back on the side-stick continuously, raising the nose and exceeding the critical angle of attack, triggering the stall warning. Based on the information displayed on Primary Flight Display, instead of pushing the stick to level the aircraft, Bonin did the opposite, deepening the stall. Focusing on multiple warnings none of the two pilots in command did not realize the attitude of the aircraft, or that the stick should not be pulled so long. The crew, including Captain Dubois, did not understand that they were stalling, and consequently, did not apply the recovery maneuvers, maintaining their stall for 3:30 minutes descent until they impacted the ocean.

The final report, released in 2012, pointed out that the environmental stressors faced by the crew, multiple visual prompts, inadequate pilots' response and a lack of training for such high-altitude stalls were key factors in the accident. The results of the investigation concluded in the need for improved pilots training on handling a stall recovery as well as the importance of better understanding the interaction between human factors and aircrafts systems under pressure [22].

The course of this flight will be analyzed as the case before, trough the DECIDE model, emphasizing the phases where the cognitive load is present:

- <u>Detect</u> – The problem began when the autopilot disconnected due to the inconsistency in airspeed readings, caused by the icing of the 3 Pitot tubes. This is the crucial moment where the cognitive load immediately elevated because of the unexpected nature of the problem and the need to understand the malfunction having limited information and sensory feedback;
- <u>Estimate the nature of the problem</u> – The crew had to assess the severity of the situation and the reasons of the faulty airspeed data. The high cognitive load, which in this case translates to information overload, amplified by stress, night conditions and the sudden disengagement of the autopilot control, impaired their ability to estimate the problem's nature clearly. The lack of clear airspeed readings and the stall warnings at high altitude, which they were not familiar with, added to the extraneous cognitive load, increasing the confusion;
- <u>Choose a course of action</u> – The right course of action required the pilots to call their past experience and expertise in order to respond to the stall warnings correctly. However, as the report showed, the pilots' training had not sufficiently prepared them for this type of emergency, especially for recognizing and recovering from a high-altitude stall. Most likely the ambiguity of the situation, the pressure of the moment and the information overload, lead them to decision paralysis or incorrect decisions, such as continuously pulling the stick instead of leveling the plane;
- <u>Identify solutions</u> – The best solution for this scenario was to level up the aircraft. However, the misunderstanding of the aircraft's position and the system warnings indicated that cognitive overload delayed pilots' ability to identify and implement effective maneuvers. For this step is important to have a clear mind, which was not the case for the three pilots on board;
- <u>Do the necessary actions</u> – Executing the maneuvers, such as pushing the lever in order for the aircraft to be leveled and gain speed, were the right things to do. Unfortunately, the chosen actions to pull the stick, keeping the nose up were counterproductive and amplified the stall. This decision-making error shows how excessive cognitive load can affect motor functions and procedural memory in stress situations, leading to actions that are in contrary to the standard operational procedures;
- <u>Evaluate the effect of the actions</u> – Because of the series of events that were negatively amplified from the first cue (autopilot disengagement) to the rapid descent and the eventual crash, combined with the rapidly escalating cognitive load, driven by the

deteriorating situation, there was little to no time for evaluating and follow another course of action. In this case, the last step cannot be taken into account.

For this second case, the main cognitive load factors that can be taken into account are:

- Situational awareness (tunnel vision): the pilots focused on the altitude and electronic alerts, but ignored the clear and repeated stall warnings;
- Reliance on technology: it was assumed that the flight systems would prevent a stall, except this does not work when the autopilot is disengaged. Also, the sudden shift to manual control created confusion for the pilots, applying chaotic maneuvers (pull only instead of level the aircraft);
- Team engagement: instead of communicating the maneuvers and applying the checklist for the standard procedure, pilots could not understand clearly the emergency and could not communicate efficiently;
- Cognitive overload: The multitude of external information present in the situation made pilots unable to reach to a correct decision in time;
- Lack of training: Because of the possibility of such emergency at high altitude was low, the pilots did not posses the right skills and strategies to manage such loads effectively.

The incidents of the “Miracle on the Hudson” and Air France Flight 447 clearly show the crucial role of cognitive load on pilots’ decision-making process. Lessons that can be withdrawn from these events highlight the importance of comprehensive training for unexpected and rare emergency situations, skills that help pilots to manage cognitive load effectively and maintain situational awareness under extreme stress. Also, the necessity of a healthy Crew Resource Management (CRM) is crucial for coordinated team efforts, for the importance of fast and clear decision-making and for a deep understanding of aircraft systems and automation. Lastly these two cases enforce the significance of psychological preparedness and resilience, illustrating that if cognitive load is managed through training, awareness, teamwork and analytical readiness, it can certainly change positively the outcome of any emergency situation. Furthermore, by analyzing the chronological steps of a decision-making model (DECIDE), both cases showed that the cognitive load, no matter its form (as a whole, intrinsic, extraneous or germane) was present on each phase, influencing the following part of the model.

Incorporating more comprehensive simulator training that includes rare scenarios, focusing on recognizing and recovering from different situations, improving CRM training by insisting on effective communication and decision-making under stress, or support pilots on mental health and stress management to increase psychological resilience are key factors for diminishing this kind of scenarios. Through these measures the risk associated with high cognitive load situations can be mitigated significantly.

It is important to understand the implication of cognitive load in the decision-making process in aviation, especially for pilots, as it is an important factor on ensuring the safety of the passengers, the crew and the aircraft, it allows for the design of more effective training programs in order to recognize emergencies and assess every situation, promotes better CRM emphasizing teamwork and communication, can change the design of cockpit interfaces for a better understanding of the aircraft, facilitates error management and help pilots to manage better their mental and physical health. As a general conclusion, cognitive load contributes to a culture of safety, continuous improvement and resilience in aviation.

6. CONCLUSION

Referring to the comprehensive exploration of cognitive load and its impact on pilots' decision-making processes, as highlighted through the two case studies, this paper has underscored the multifaceted nature of aviation safety and decision-making. From the first steps of aviation evolution to the current impressive implementation of flight systems and training, the air safety can be considered a nucleus of aviation structure that is continuously analyzed and developed. This translates into the three main elements of safety: the technical, human and organizational factors. From the multitude of human factors that have been studied over time, such as fatigue, communication, stress, situational awareness or emotional state, the cognitive load is one that has not received as much attention as others.

The cognitive load is most of the time considered as being the beginning part of a decision-making process, where the information gathering takes place. On the contrary, this paper aimed to show that the cognitive load, either intrinsic, extraneous or germane, is present in every step of the decision-making process. By analyzing the dual process model, the RPD or the DECIDE models, it was shown that cognitive load, as a factor, has an important role in how each decision-making phase works. Another important aspect is that it is strongly influenced by other human factors. As fatigue or stress is increased, the clarity on cognitive load diminishes exponentially, or if the situational awareness is low, so the cognitive load would be. Therefore, whenever it is analyzed, it cannot be taken into account by itself, but in correlation with other factors.

The two case studies not only provided empirical evidence of cognitive load's influence on decision-making processes for pilots, but also served as a basis for deriving actionable insights and recommendations aimed at enhancing pilot performance and aviation safety. For a better understanding of the cognitive load in relation to the decision-making process, the paper also emphasized the necessity of advanced training programs that simulate emergency scenarios, developing a strong CRM and a more serious approach to understanding the automation systems on board. By prioritizing the development of strategies to reduce and manage cognitive load, the aviation industry can ensure that pilots are better trained to handle emergencies.

REFERENCES

[1] H.L. Scamehorn, *Balloons to jets: A century of aeronautics in Illinois, 1855-1955*. Carbondale: Southern Illinois University Press, 2000;

[2] ICAO – *Safety Management Manual (SMM), Doc 9859 AN/474*, 3rd Edition, 2012, pp. 12-36;

[3] Airbus, *A Statistical Analysis of Commercial Aviation Accidents 1958-2022*, 2023;

[4] L.F.Santos, R. Melicio, *Stress, pressure and fatigue on aircraft maintenance personal*, International Review of Aerospace Engineering (IREASE), vol. 12, pp. 35-45, 2019;

[5] J. Sweller, *Cognitive load during problem solving: Effects on learning*. Cognitive Science, 12(2), 257-285, 1988;

[6] F. Paas, A.Renkl and J. Sweller, *Cognitive load theory and instructional design: Recent developments*, Educational Psychologist, 38(1), pp.1-4, 2003;

[7] G. Cooper, *Research into Cognitive Load Theory and Instructional Design at UNSW*, University of New South Wales, Australia, 1998;

[8] J. G. J. Van Merrienboer, and J. Sweller, *Cognitive Load Theory and Complex Learning: Recent Developments and Future Directions*, Educational Psychology Review, vol. 17, pp.147-177, 2005, DOI: 10.1007/s10648-005-3951-0;

[9] J. Sweller, J. G. J.Van Merrienboer and F. Paas, *Cognitive Architecture and Instructional Design*, Educational Psychology Review vol.10, pp.251-296, 1998, DOI:10.1023/a:1022193728205;

[10] G. Orru and L. Longo, *The Evolution of Cognitive Load Theory and the Measurement of Its Intrinsic, Extraneous and Germane Loads: A Review*, International Symposium on Human Mental Workload: Models and Applications, 2019, DOI: 10.1007/978-3-030-14273-5_3;

[11 P. Ayres, *Using subjective measures to detect variations of intrinsic cognitive load within problems,* Learning and Instruction, vol. 16(5), pp. 389-400, 2006;

[12] T. De Jong, *Cognitive load theory, educational research, and instructional design: some food for thought*, Instructional Science, vol. 38(2), pp. 105-134, 2010;

[13] R. G. Green, H. Muir et. al, *Human Factors for Pilots*, Brookfield, Vermont: Gower Publishing Company, pp. 58-59, 1991;

[14] M. H. Bazerman and D. A. Moore, *Judgment in Managerial Decision Making*, 8th ed. Wiley, pp.2-5, 2013;

[15] D. Kahneman, *Thinking, Fast and Slow*, New York: Farrar, Straus and Giroux, 2011;

[16] G. Gigerenzer, *Gut feelings: The intelligence of the unconscious*, pp. 16-17, 2007;

[17] G. Klein, *Sources of Power: How People Make Decisions*, London: MIT Press, 1999;

[18] H. Simon, *Models of Man: Social and Rational: Mathematical Essays on Rational Human Behavior in a Social Setting*, New York: John Wiley & Sons, pp. 204-205, 1987;

[19] C. E. Zsambok and G. Klein, *Naturalistic Decision Making*, Lawrence Erlbaum Associate, 1997;

[20] Federal Aviation Administration, *"Chapter 2: Aeronautical Decision-Making". Pilot's Handbook of Aeronautical Knowledge,* 2016;

[21] National Transportation Safety Board, *Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, US Airways Flight 1549, Airbus A320-214, N106US, Weehawken, New Jersey, January 15, 2009*, Aircraft Accident Report NTSB/AAR-10 /03. Washington, DC, 2010;

[22] Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile, *Final Report on the Accident on 1st June 2009 to the Airbus A330-203* (F-GZCP), 2012.