Conceptual Models of Startle, Surprise and Automation Bias Analyzed Through Recent Aviation Accident Reports

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ABSTRACT

This work aims to analyze three conceptual models of startle, surprise and automation bias found in the literature: Conceptual Model of Startle and Surprise, Integrated Model of Complacency, and Automation Bias and Conceptual Model of Threat, Appraisal and Information Processing. Afterwards, an analysis of accidents reports of Lion Air 43, Lion Air 610 (737-MAX), Emirates 407 and TAM 3054 is carried out using the selected conceptual models. The aim is to deepen the knowledge about startle, surprise and automation bias by means of an analysis of how they are found in recent accidents, disseminate the subject to the aeronautical community and reinforce their importance for aviation safety.

Keywords: Human factors; Pilots; Performance; Air transportation.

INTRODUCTION

Contextualization

Advances of technology in modern aircraft have offered several benefits and increased safety (Rankin *et al.* 2016). There are many advantages in using modern technologies in aviation, such as aircraft automation, which contributes to decreasing the manual workload of pilots and increasing their focus on other tasks.

However, these new technologies impacted the variations and disturbances to which pilots are exposed to during abnormal operations (Rankin *et al.* 2016). Unexpected situations that arise after extended periods of automated flight and that cannot be handled by automation systems are complex and require human intervention and the use of quick judgment and decision-making (Landman *et al.* 2017a).

Addressing pilot training and abnormal situations, Casner *et al.* (2013) claim that emergency training became predictable and repetitive for pilots and when facing real abnormal events, they are taken by surprise and fail to respond quickly. Although training

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may improve pilots' abilities to respond to unexpected events, they may fail to recognize and react when influenced by surprise (Casner *et al.* 2013).

In response to these events, new regulations started including recommendations to incorporate startle and surprise in training programs to prepare pilots for unexpected events (Landman *et al.* 2017a).

Based on the conceptual models of startle, surprise and automation bias found in the literature, an analysis of accident reports of Lion Air 43, Lion Air 610, Emirates 407 and TAM 3054 is carried using the selected conceptual models.

The aim is to deepen the knowledge about startle, surprise and automation bias by means of an analysis of how they are found in recent accidents, disseminate the subject to the aeronautical community and reinforce their importance for aviation safety.

Differences between startle and surprise

The U.S. Federal Aviation Administration (FAA 2017) defines startle as an automatic muscle reflex that increases heart rate and blood pressure and can be elicited by exposure to a sudden, intense event that violates the pilots' expectations.

The physical startle response is a simple reflex that is common to all humans and its severity depends on individual factors, such as emotional state, stress levels and attentional process (Martin *et al.* 2012). It can generate an involuntary physiological reflex and an emotional response component (Rivera *et al.* 2014).

The reflex can inhibit the muscle activity and a startled person can involuntarily contract the muscles and prepare the body for protection against adverse situations (Rivera *et al.* 2014).

The startle or surprise reaction activates an area of the brain that involves the nervous system and the amygdala, with sensory signals being projected through various regions of the amygdala complex for rudimentary interpretation of emotional response to a threat (Martin *et al.* 2012).

The nervous system is composed of sympathetic and parasympathetic systems. The sympathetic system involves the fight or flight reaction and the parasympathetic system involves anxiety and stress controls, respiration, and conscience regarding a situation (Stephen David Entertainment 2021).

In terms of physical response, the startle reflex produces an increase in blood pressure and heart rate following a high intensity stimulus. Rivera *et al.* (2014) analyzed studies that have determined that the motor response performance following a startling stimulus, in terms of duration, is disrupted for approximately 0.3 s to less than 1 s for a mild response and a high-intensity response can last from 1 to 1.5 s.

During laboratory research, Thackray and Touchstone (1983) evaluated time monitoring and information processing tasks to examine recovery time after unexpected events. This research and the analysis of other studies results showed that some tasks, such as information processing abilities, could be impaired from 17 to 60 s after a startle event (Thackray 1988).

Since startle and surprise have often been used interchangeably in the literature, Landman *et al.* 2017a and Rivera *et al.* 2014 have pointed out that startle and surprise have different responses with different causes and effects. Startle and surprise stimuli may occur simultaneously, but a surprise stimulus may occur in the absence of startle (Landman *et al.* 2017a).

FAA (2017) defines surprise as an unexpected event that violates pilot's expectations and can affect the mental processes used to respond to the event. Surprise can also be described as a combination of physiological, cognitive and behavioral responses, including increased heart rate, increased blood pressure, an inability to comprehend/analyze, not remembering appropriate operating standards, *freezing* and loss of situational awareness (Rivera *et al.* 2014).

Very few experimental studies focusing specifically on surprise and startle in the cockpit have been published and some of results will be presented to show that pilot performance may decrease significantly when pilots are surprised, startled, or both, during unanticipated events.

Previous studies on startle and surprise

Casner *et al.* (2013) investigated the efficiency of airline pilots training and performed a simulation evaluation in a Boeing 747-400 simulator device involving 18 pilots. Pilots were presented with three abnormal events: aerodynamic stall, windshear, and engine failure on takeoff. Each event was presented under familiar circumstances and under less predictable circumstances.

During expected abnormal events, pilots gave appropriate responses and showed little variability. However, when abnormal events were presented unexpectedly, pilots' responses were less appropriate and showed great variability. In instances, some pilots did not even recognize that an abnormal event was occurring. For the low-altitude aerodynamic stall, for example, response times ranged between 1.9 and 18.2 s and pilots exhibited much greater variability, with two pilots never even applying maximum power.

Martin *et al.* (2016) performed a flight simulator study to investigate the effects of startle on pilots during unexpected events; it was conducted in a Boeing 737 flight simulator device with 18 pilots. The objective was to create startle reactions and to quantify the effects of startle on pilots' performance during a go-around. The experiment involved hand-flown instrument landing systems approaches, in which the bad weather was such that a missed approach would be required. On the first approach a startling stimulus—a cargo fire warning bell and coincident loud bang—were administered. There was no stimulus on the second approach; however, pilots were required to commence standard missed approach due to the meteorological conditions. Results showed that, when a stimulus preceded a decision-making task, one third of the pilots' performance was affected. During the events where a loud bang was administered, there was an average delay of approximately 5 s in commencing the missed approach following startle compared with that without startle. Results have suggested that startle may indeed affect pilots' performance during unexpected events. This experiment also showed that startle recovery responses presented individual variations: some pilots were less affected and recovered quickly, but one third of them were so badly affected that their performances following startle resulted in considerable delay to the point where flight safety was impacted.

Landman *et al.* (2017b) conducted research that took place in a Boeing 737 simulator with 20 pilots. They tested if airline pilots abilities to perform recovery procedures, after an aerodynamic stall, would decrease when they were surprised, compared to when they anticipated a stall event. First, a briefing on aerodynamics and recovery techniques was given, then subjective and psychological measurements were performed to check data relating to surprise and startle. The aerodynamic stall scenarios were tested in anticipated and surprise conditions. During the surprise condition pilots were distracted by the instructor with spatial disorientation scenarios to divert their focus from the aerodynamic stall. Subjective evaluations were measured using electrocardiography with five electrodes to determine heartbeat interval durations and two electrodes to measure the galvanic skin response—an equipment that was used to measure the peak skin conductance—10 s before and 10 s after the stall. Results showed that pilots had significantly more difficulty with adhering to the recovery procedures in the surprise condition compared to the anticipation condition. The proportion of pilots meeting each single recovery criterion decreased from 75% in the anticipation trials to 25% in the surprise trials. The galvanic skin response results were significantly higher in the surprise condition and the medium heart rate measures were similar in both scenarios.

Scarpari *et al.* (2021) conducted an extensive flight test campaign to verify the feasibility of establishing quantitative physiological parameters to better assess the workload endured by pilots undergoing emergency situations. Eleven experienced helicopter pilots were submitted to simulated emergency situations in order to understand if the physiological responses of the pilots could be associated with the workload. Although the research was conducted in helicopters, "results revealed that cognitive workload was associated with flight profile and that the strain intensity showed a correlation with measurable physiological responses" (Scarpari *et al.* 2021, p. 1). The measured subjective workload assessment used involved success rate, reaction time, electrodermal activity, heartrate and respiration frequency. Both electrodermal activity and heartrate showed abrupt increases after the engine failure, respiration frequency presented instantaneous reduction. Reaction time results showed that only two pilots had the average reaction time required by the helicopter certification standards, suggesting that current certification processes may need an upgrade.

Research in the area is essential so, as proposed in this work, the selected conceptual models found in the literature will be analyzed and applied to case studies of recent accidents and incidents in commercial aviation.

METHODOLOGY

This research has a bibliographic, qualitative and exploratory character. The research is carried out using the keywords presented in the abstract of this article on the Capes Portal in addition to some references pointed out by the authors of the selected articles.

The aim is to analyze the three conceptual models found on the subject, and specifically understand how the influence on the performance of pilots occurs through case studies of four relevant accidents and incidents.

RESULTS AND DISCUSSION

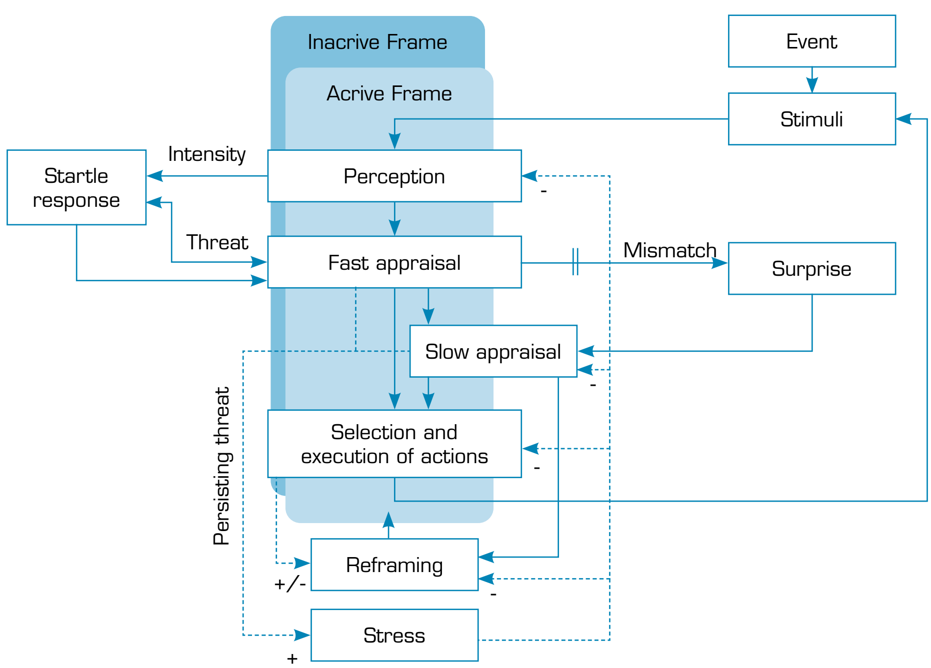
Conceptual Models of Startle, Surprise, and Automation Bias

The selected conceptual models found in the literature regarding startle, surprise, and automation to be analyzed herein are Conceptual Model of Startle and Surprise by Landman *et al.* (2017a); Integrated Model of Complacency and Automation Bias by Parasuraman and Manzey (2010), and Conceptual Model of Threat, Appraisal and Information Processing by Martin *et al.* (2010).

Conceptual Model of Startle and Surprise

Landman *et al.* (2017a) proposed the Conceptual Model of Startle and Surprise, aiming to explain sensemaking and decision-making during unexpected events.

In Fig. 1, the bold lines are the perceptual cycles and represent the individuals' perception and interpretation to the stimuli, assessment of the situation (appraisal), and selection and execution of actions (Landman *et al.* 2017a).



Source: Retrieved from Landman *et al.* (2017a).

Figure 1. Conceptual Model of Startle and Surprise.

There are two appraisal cycles in the model that presented as fast appraisal and/or slow appraisal, where the individuals will analyze and execute actions based on the available data and their perception of effectiveness. When new information arises, the cycle may restart with a frame switch, presented as reframing on the model. On the left side of the framework, startle responses are the possible reactions due to intense stimuli that may startle pilots and influence performance. In cases when startle occurs in the absence of surprise, only the left cycle may be activated. On the right side of the framework, if the event causes surprise, with unexpected information, the surprise cycle will be activated. The perceptual cycle will remain active with actions being taken in response to threats or until the event is resolved, for example, in a false alarm situation (Landman *et al.* 2017a).

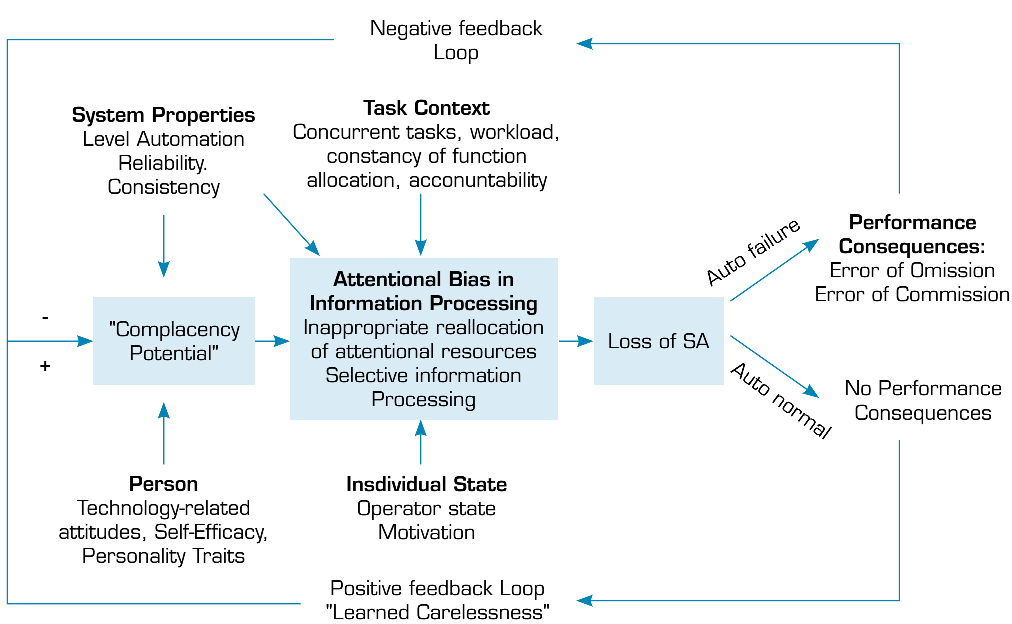
In order to explain the causes and effects of surprise, the concept of frames is used. As per Landman et al. (2017a), frames can be explained as mental models, explanatory structures, scripts, and other types of knowledge structures in long-term memory, that describe generic or specific situations, which links perceived individual data, gives them meaning and points out which actions are appropriate.

In the model (Fig. 1), frames are divided into two cycles of sensemaking: active and inactive frames. When a mismatch happens between mental mode and expectations, and there are previous experiences and repertory available, slow and fast appraisals cycles may be used to better understand the variables and different actions will be taken, called the reframing cycle for a decision-making based on the new data. Active and inactive frames depend on knowledge, previous experiences and personal skills and it can help the decision-making process during abnormal events. Lack of inactive frames, stress and individual experiences can influence decisions that may be vulnerable due to startle and surprise. The double lines on the model, located before surprise and reframing, indicate confirmation bias found in the perception of some individuals that can lead to judgment errors, even when incompatible information arises (Landman *et al.* 2017a).

Landman *et al.* (2017a) suggested prevention methods to mitigate the effects of startle and surprise, such as practical and variable training, judgment skills and domain expertise to increase experience and it also suggested a more transparent automated system with the design of technologies to aid the sensemaking process and supply of available frames.

Integrated Model of Complacency and Automation Bias

Parasuraman and Manzey (2010) developed the Integrated Model of Complacency and Automation Bias (Fig. 2). In this theoretical model, automation is analyzed from a perspective of unintended misuse and disuse of automation systems that could be associated with maladaptive use of poorly designed or inadequately trained-for automation.



Source: Retrieved from Parasuraman and Manzey (2010).

Figure 2. Integrated Model of Complacency and Automation Bias.

It is suggested that there are paradigms between human-automation interaction, supervisory control and decision-making support. The research points out that these paradigms occur due to two human performance concepts that have often been considered separately and should be integrated: complacency and automation bias. Complacency and automation bias may occur under conditions of multiple-task load and it also depends on attentional processes where the pilot's focus is divided between manual and automated tasks (Parasuraman and Manzey 2010).

In Fig. 1 complacency potential relates to the individual's complacency potential. This potential is subject to the human beings' abilities, automation levels, trust levels and systems consistency. The attentional bias in information processing relates to the variables that may influence complacency potential and that could lead to a clear attentional bias in interaction with automation. In this case, the attentional allocation process may depend on variables such as information available, workload, allocation of resources and task prioritization. If there are issues related with these processes, it could develop a complacency potential and attentional bias in information processing on the individual, that could lead to a loss of situational awareness (Parasuraman and Manzey 2010).

Figure 1 shows two possible framework loops can be activated, once there is loss of situational awareness: the positive or the negative feedback loop. The positive feedback loop is related to the over reliance on automated systems that rarely fails on an individual, which increases the complacency potential and attentional bias. Over time, the lack of performance consequences due to the high reliability of automated systems, might increase the positive feedback loop and complacency potential and induce a cognitive process that has been referred to as *learned carelessness* (Parasuraman and Manzey 2010).

In this scenario, when an unexpected automation failure occurs, two possible performance consequences may happen: error of omission and error of commission. Error of omission is related to situations, for example, when an alerting system is activated and the individual fails to observe and use this information in the decision-making process. Error of commission occurs when the individual observes the system alert information and makes a wrong decision (Parasuraman and Manzey 2010).

In the opposite loop direction, when the negative feedback loop is activated, the individuals have experienced automated systems failures and therefore decreased their trust in these systems (Parasuraman and Manzey 2010).

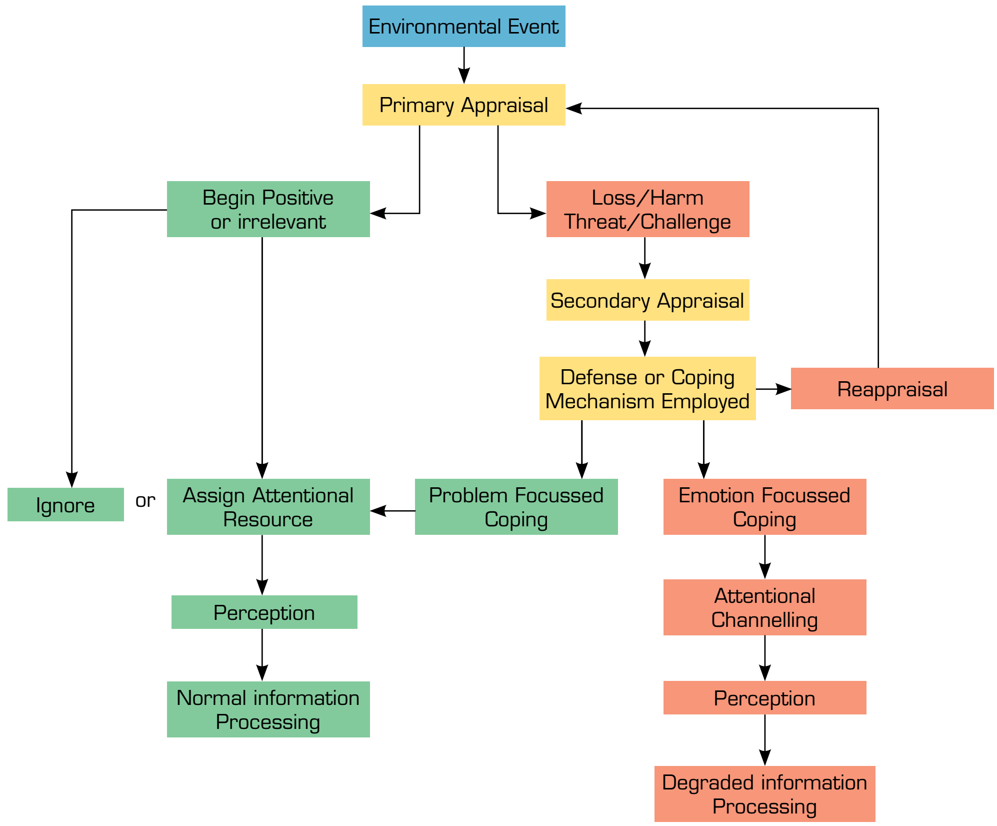
This is a normative model and suggests that attentional allocation can be measured by equipment, such as eye tracking, so that complacency potential, attentional bias in information processing, learned carelessness and loss of situational awareness can be identified. The study points out that negative performance consequences, due to automation system failure, always decrease the individual's trust, may it be a conscious or an unconscious response (Parasuraman and Manzey 2010).

The integrated model provides a framework within which practical applications, particularly those aimed at mitigating complacency and bias in automated systems, can be used. It is suggested that better use of automation can be provided by systems that display information about systems errors instead of automatic system alerts; other than that, also by giving more experience with the automated systems and individuals responsibility allocation, and finally by providing negative feedback loop experiences through training, for example, that could help individuals be less affected by the effects of complacency and automation bias (Parasuraman and Manzey 2010).

Conceptual Model of Threat, Appraisal and Information Processing

The Conceptual Model of Threat, Appraisal and Information Processing was developed by Martin *et al.* (2010) during research that investigated the effects of acute stress, startle reactions and how these reactions are perceived by pilots working in highly reliable environments and with insufficient training to deal with unexpected events. Some cases in which effects of acute stress, such as startle, freezing, dissociation and denial, observed in several aircraft accidents and incidents, potentially generated negative consequences during emergency situations. There were cases in which the startle reactions were exacerbated by a *nothing wrong will happen* expectation, a non-intentional sense of complacency usual to the reliability of airline operations.

Figure 3 depicts the conceptual model splits an environmental event appraisal in two interdependent processes: primary and secondary appraisal. Primary appraisal is the process in which after an abnormal event, pilots will evaluate if the data about the stimuli is considered benign/positive or irrelevant, and can be resolved by ignoring or allocating attention to the data, with expected responses and normal information processing (Martin *et al*. 2010).



Source: Retrieved from Martin *et al.* (2010).

Figure 3. Conceptual model of threat, appraisal and information processing.

During the primary appraisal, data can also involve loss/harm/threat/challenge and, in this case, the secondary appraisal cycle is activated with two defense/coping mechanisms employed: problem focused coping or emotion focused coping. Problem focused coping is the ideal coping mechanism, since in this situation, pilots focus their attention in solving the problem and the stimuli response would occur with normal information processing. On the other hand, if the emotion focused coping is activated, the individual might only focus on his/her emotions and could be influenced by tunnel vision, freezing, denial, refusal to believe in the worst, reality distortion, which could decrease the individual's performance and situational awareness. The reappraisal cycle is the assessment of available defense options and if the chosen defense mechanism was effective. In case of negative evaluation, a reappraisal is activated to seek suitable coping mechanisms (Martin *et al.* 2010).

Martin *et al.* (2010) suggests that unexpected emergencies can cause negative startle reactions and that including competences to provide experience with unexpected events is essential and could help reduce stress levels and improve information processing. The study also recommends non-punitive training and competence by repetition, so pilots can activate secondary appraisals with problem focused coping mechanisms. Offering these skills to pilots can improve decision making, situational awareness and increase chances of better outcomes during abnormal events.

Accidents and Incidents in Commercial Aviation and the Conceptual Models

The four accident and incidents reports are evaluated in this section in the context of the selected conceptual models. These four cases were selected because they seem to demonstrate several different aspects of automation, startle, and surprise effects on the individual's perception, actions and decision-making.

Case 1

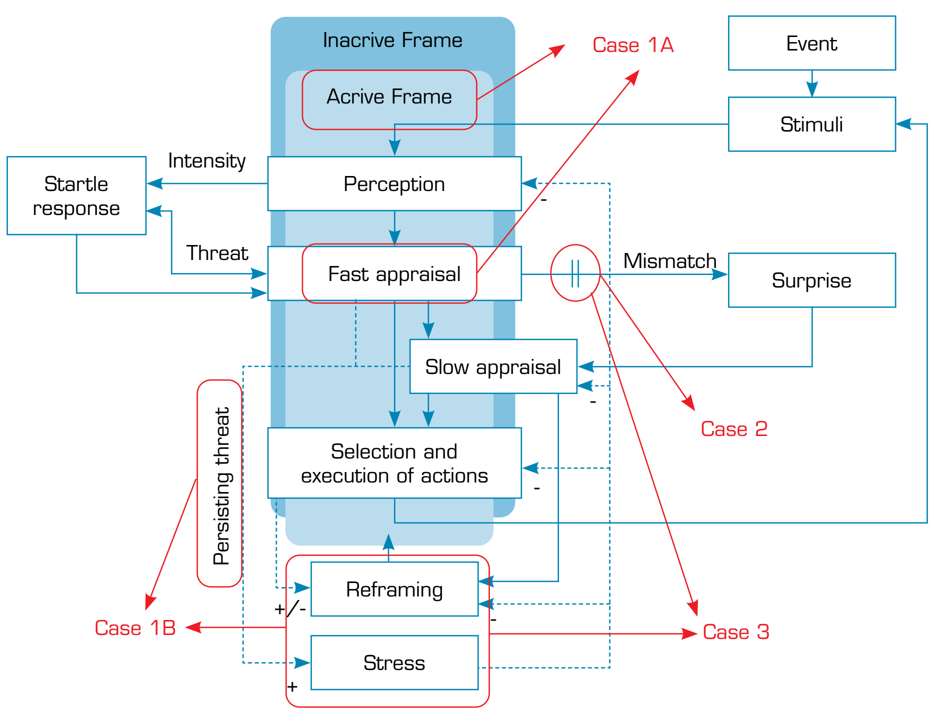
An analysis of the accident of Lion Air Flight 610 in 2018 (KNKT 2019) suggests that the pilots were affected by startle and that slow decision-making played a significant role, after they reported problems maintaining aircraft altitude and airspeed, and subsequently impacted the West Java Ocean, completely destroying the aircraft. The accident report shows that days before, there were failures in the airspeed and altitude displays on the captain's side and there was a replacement of the left angle of attack (AOA) sensor. The installed sensor had a 21° bias which was undetected during the installation test.

The flight prior to the accident, Lion Air Flight 43, departed Denpasar with the erroneous AOA indication, which resulted in an incident that will be analyzed. In this flight, there were airspeed and altitude disagreement indications between the captain and first officer's displays, shortly after takeoff (KNKT 2019).

There was also the activation of the Maneuvering Characteristics Augmentation System (MCAS), which commanded the aircraft to lower the nose and the activation of the stick shaker. MCAS is a new technology introduced in the 737-800 (MAX) to improve attitude characteristics with flaps retracted during manual flights with high angles of attack (KNKT 2019).

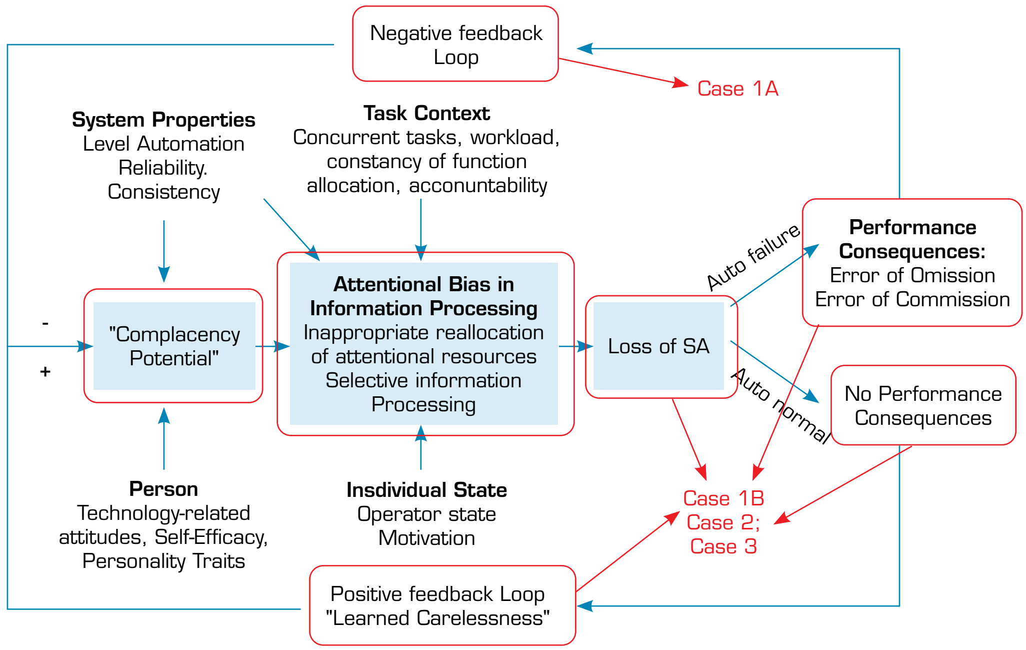
In this occasion, the crew showed high levels of situational awareness, with precise transfer of commands between pilot flying and pilot monitoring, correct observance of recurrent problems in the aircraft (AOA replacement) and the decision to deactivate the stabilizer compensator which prevented the activation of the MCAS and allowed the flight to safely reach its destination (KNKT 2019).

In the analysis using the methodology presented in Fig. 4 (Case 1A), there is a perception that factors, such as the captain's situational awareness (previously aware of the aircraft's maintenance) and even under the effects of startle and surprise, may have contributed to the use of effective active and inactive frames, with quick decision-making (fast appraisal) and correct execution of actions. The analogy with Fig. 5 (Case 1A), shows that factors, such as previous experiences and individual skills of the pilots, may have contributed to this incident. The under reliance on automation (negative feedback loop) may have increased situational awareness and decision-making that reversed the unexpected situation. In the analogy with Fig. 6 (Case 1A), the pilots' secondary appraisal of threat contributed to a fast decision-making and correct coping method.



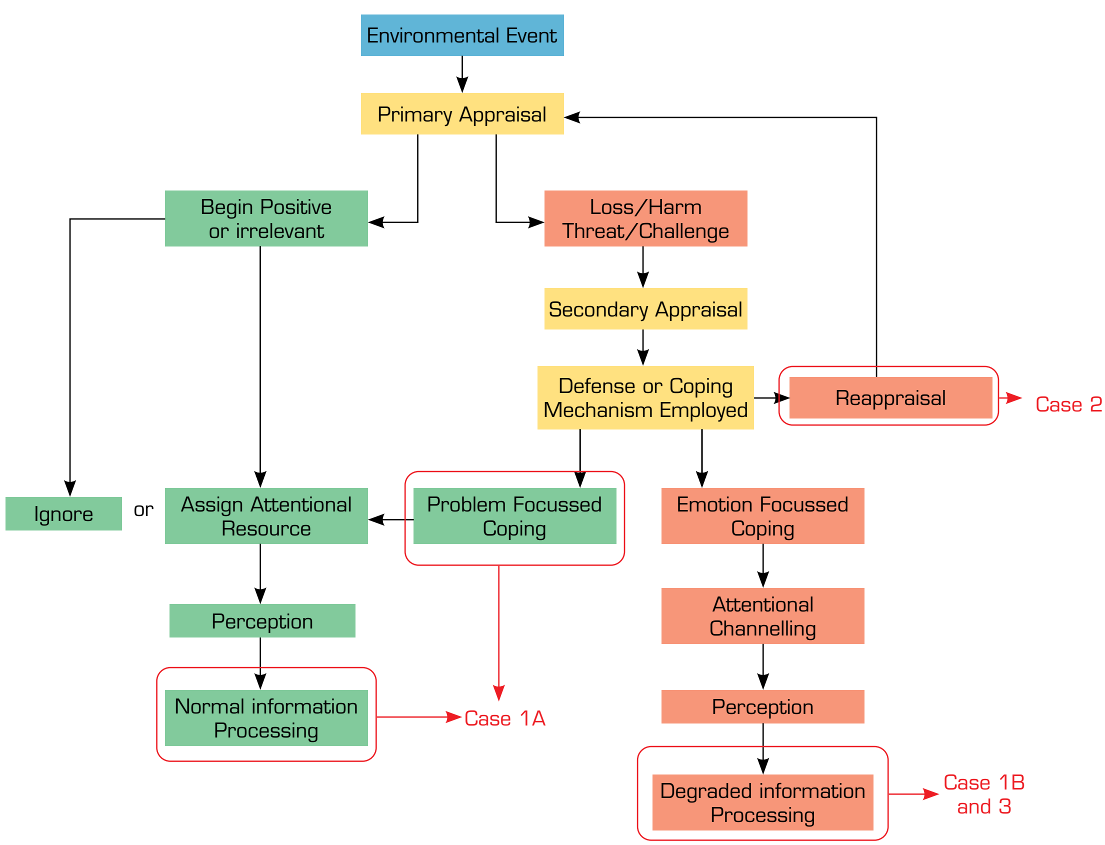
Source: Adapted from Landman *et al.* (2017a).

Figure 4. Estimated causal factors in four cases as mapped onto the conceptual model of Landman *et al.* (2017a).



Source: Adapted from Parasuraman and Manzey (2010).

Figure 5. Estimated causal factors in four cases as mapped onto the conceptual model of Parasuraman and Manzey (2010).



Source: Adapted from Martin *et al.* (2010).

Figure 6. Estimated causal factors in four cases as mapped onto the conceptual model of Martin *et al.* (2010).

The deactivation of the stabilizer compensator and the activation of the stick shaker during flight were not reported by the crew in the maintenance logbook, so the necessary tests to verify these problems were not performed (KNKT 2019).

On the fateful day of the accident, Lion Air Flight 610 faced similar problems to the previous flight, with multiple alerts, MCAS activations and communication distractions, that contributed to the difficulty in controlling the aircraft. Perhaps, the crew's actions were greatly influenced by startle and surprise, due to conflicting automation commands. In the transcription of the moments before the accident, factors such as confusion, stress, communication failure, inobservance of procedures, and memory items were present (KNKT 2019).

Using the methodology in Fig. 4 (Case 1B), it is observed that the reframing process may have been influenced by stress, which led to a slow decision-making process to understand the situation. There were excessive flap retractions and extensions, failure to manually compensate controls and disable the stabilizer compensator. These pilots probably lacked active and inactive frames, essential for situational awareness and quick decision-making, probably being affected by startle and surprise. The analogy with Fig. 5 (Case 1B), comes from the perception that over-reliance on the aircraft's autonomous systems (positive feedback loop), may have contributed for attentional and automation bias, in a routine where the systems usually does not fail.

There may have been an error of commission, as the pilots failed to perform essential manual corrections. In addition, the failure to observe the recent replacement of the aircraft's left AOA, could have alerted to the possibility of disabling the stabilizer compensator (KNKT 2019). These actions could have contributed for faster and more effective decision-making.

Analyzing with the methodology in Fig. 6 (Case 1B), it can be mentioned that the secondary appraisal was possibly with emotion focused coping, which degraded the information processing and understanding about the event.

The aircraft flight and crew training manuals did not include information about MCAS. The investigation found that the design and certification of the new technology were inadequate. A similar accident occurred in 2019, involving another 737-800 (MAX), related to AOA sensor errors (KNKT 2019).

Case 2

The Emirates Flight 407 accident in 2009 seems to involve a combination of automation complacency bias that caused surprise, with ability of problem focused coping to deal with the abnormal event. During flight preparation, the first officer, while entering the takeoff weight of 362.9tons, inadvertently entered 262.9tons. As a consequence, the electronic flight bag calculated that the aircraft would be lighter, requiring less speed and runway distance for takeoff (ATSB 2011).

While performing takeoff run, the captain (pilot monitoring) informed the first officer (pilot flying) that the rotational speed for takeoff had been reached. The first officer pulled the side stick but the aircraft did not lift off. At that point the captain applied extra engine power. The aircraft took off but suffered a tail strike on the runway (ATSB 2011).

The accident report showed that during the aircraft preparation, the captain was distracted and did not perform Standard Operating Procedures checks to ensure that no data had been erroneously entered. The report showed no software issues in the electronic flight bag as a contributing factor. There were many distractions during cockpit workload. The checklists and Standard Operating Procedures that were not followed would have been barriers to prevent these mistakes (ATSB 2011).

Analyzing this accident with the methodology in Fig. 4 (Case 2), it shows that during cabin preparation the captain did not check the weight in the flight computers, and was surprised only during takeoff. The surprise cycle may have been activated when the aircraft did not respond as expected during takeoff and, at this moment, the captain performed the correct fast appraisal and applied engine power, realizing that *something was not right*.

By means of an analogy with Fig. 5 (Case 2), possibly the positive feedback loop occurred, due to the overconfidence in the aircraft automation, with the eventual learned carelessness. There was loss of situational awareness, as the parameters entered were not checked and the crew, perhaps, committed an error of omission. The methodology presented in Fig. 6 (Case 2), comes from the perception that during the takeoff roll, secondary appraisal with a focus on problem-solving occurred. The pilots, during the abnormal takeoff and the subsequent detection of the error, made effective decisions to address the abnormal event. There was a mismatch between what was expected (aircraft rotation) and what happened (aircraft did not respond to the command), and the captain performed a reappraisal to execute the necessary actions. The reappraisal process occurred with the normal processing of information and after one-hour flight the aircraft safely returned to the departure airport.

Case 3

TAM Airlines Flight 3054 accident in 2007, may be an example in which lack of inactive frames, positive feedback loop and emotion focused coping had negative consequences. The aircraft took off from Porto Alegre with its number 2 engine reverser deactivated, which would have no impact on that operation. The flight was uneventful until the final approach to the destination. The crew, who had shown in the Cockpit Voice Recorder concerns due to the weather conditions, received a warning from the control tower about the airport runway being wet and slippery. After landing, the aircraft did not decelerate as planned and veered off to the left. Then, the aircraft overran the left edge of the runway and crossed over an avenue and hit a fuel service station and air cargo service building, being completely destroyed (CENIPA 2009).

In the accident report, two hypotheses were considered for this accident: one was a possible failure of the engines' power control system, which would have provided engine number 2 the information that the power lever was in the climb position, regardless of the actual position determined by the pilot. The other hypothesis, which will be the focus of this analysis, was that the pilots performed an erroneous engine's reverse deactivation procedure. The correct procedure would have been to reduce the power lever to idle, apply reverse only on engine number 1, take into account the addition of 55 m in the expected landing distance. It is important to highlight that this crew had already landed in Porto Alegre, following the procedures foreseen for the engine's reverse deactivation (CENIPA 2009).

It was found during the investigation that the operation in the destination airport was a source of concern for pilots. Other relevant factors are the occurrences recorded in previous days: the maximum capacity and weight of the aircraft, the pressure to proceed to the destination, the captain's physiological condition (headache), and the first officer lack of experience in the position and the aircraft, thus, little experience with the auto-thrust system (CENIPA 2009).

Several factors could have contributed to the startle effect and the pilots' surprise. Without the correct understanding of what was happening, the pilots may have been led to believe that the aircraft was hydroplaning, a possibility discarded after the Flight Data Recorder (FDR) data and the aircraft tires analysis (CENIPA 2009).

Analyzing this accident with the methodology of Fig. 4 (Case 3), the wrong frame and reframing may have contributed to the mental confusion and stress, which would explain the captain's delayed action in the application of brakes and the deviation in the execution of expected procedures, besides the failure in monitoring and callouts by the copilot. Another aggravating factor would be that the landing occurred at night, contributing to the difficult visualization of the controls position (CENIPA 2009).

The analogy with Fig. 5 (Case 3) comes from the perception that the crew experienced the positive feedback loop and, supposedly, because there were no previous experiences with automation failures, they presented an attentional bias and loss of situational awareness, when committing the error of omission. In this situation, the pilots could, for example, when facing the aircraft's weak deceleration, check the engine pressure ratio values, which, perhaps, would lead them to observe the engine parameters. If the handle of engine 2 was out of the IDLE position, consequently, the crew would correct it to the ideal position (CENIPA 2009).

Analyzing the accident through the methodology presented in Fig. 6 (Case 3), it seems to indicate that the pilots, during secondary appraisal, may have been influenced by emotion focused coping, cognitive tunneling, and information processing degradation. In the final moments of the accident, it was observed confusion, focus on applying of brakes and freezing, which may have contributed to this fatal accident.

CONCLUSION

This work aims to analyze conceptual models of startle, surprise and automation bias through case studies of accidents reports of Lion Air 610, Emirates 407, TAM 3054 and the Lion Air 43 incident. It was possible to understand that pilots may be affected in variable and sometimes incapacitating ways by startle and surprise, becoming crucial to mitigate these effects for aviation safety.

The Conceptual Model of Startle and Surprise, by Landman *et al.* (2017a) pointed out some inappropriate pilot responses that may result from a mismatch between perception and active frame. Inappropriate responses may occur due to factors such as startle and/or surprise impairment, lack of repertoire of active and inactive frames, reframing problems, stress and issues using complex systems.

In the Integrated Model of Complacency and Automation Bias, Parasuraman and Manzey (2010) created a framework that pointed out the connection between complacency and automation bias. It was evidenced that there are challenges in individuals' attentional allocation between manual and automated tasks. The research highlighted the possibility of designing training and simulations that provide experiences with systems failures (negative feedback loop), so that the effects of complacency and automation bias, such as errors and loss of situational awareness, might be mitigated.

The Conceptual Model of Threat, Appraisal and Information Processing, developed by Martin *et al.* (2010), showed the importance for pilots, when dealing with unexpected events, to carry out secondary appraisals focusing on the problem (problem-focused coping).

Highlighting the unexpected events that occurred on Lion Air 43 and Lion Air 610 flights, the pilots, who ideally received the same training, dealt in different ways in dealing with startle, surprise and conflicting information of automation.

As an example, the crew of Lion Air 610 perhaps did not have enough mental models (active and inactive frames), so probably there were reframing problems, due to little experience in performing fast appraisals or slow appraisals, in addition to low situational awareness and inefficient decision-making.

In the Emirates 407 accident, it was observed that factors such as complacency, automation bias and error of omission, may have contributed to the deterioration of pilots' performance. Due to the normal operating environment and highly reliable systems, they deviated from operational standards, and the error remained undetected.

In the TAM 3054 accident, it is observed that during the unexpected event, the crew's focus may have been emotional. Possibly, factors such as lack of experience with surprising situations occurred during secondary appraisal. In this sense, training including startle and surprise, could have contributed to this crew in focusing attention on problem-focused coping and taking the necessary corrective actions.

The incident of Lion Air Flight 43 and Emirates 407 are examples in which the actions of the pilots might have been less affected by the surprising event. Despite these events, which had the potential to cause serious accidents, possibly the correct mental model of the pilots, assertive decision-making, the focus on solving the problem and factors such as training and experiences with failures, may have been decisive in the outcome of these specific cases.

It is important to point out that the analysis of the accidents and incidents in this work was not intended to produce conclusions, accusations, or point out errors, but only to highlight the importance of automation, startle effect, and surprise in its chain of events.

Some individuals may be less affected due to their personal skills, experiences, and the specific event itself. However, other individuals may be strongly affected or may have impaired abilities to understand the unexpected event and make effective decisions.

The development of pilot training, including competencies related to providing better experience with surprising events, may contribute to the improvement of decision-making, offering pilots tools for greater focus on problem-solving, increasing situational awareness, and, consequently, increasing chances of better outcomes during abnormal situations.

For further studies, it is suggested the analysis of more accidents and incidents using conceptual models, and possibly practical research with pilots' exposure to startle and surprise in simulators and actual flights, to expand the comprehension of the startle and surprise effects in highly automated environments.

AUTHORS' CONTRIBUTION

Conceptualization: Gardini KC; **Methodology:** Gardini KC; **Writing – Original Draft:** Gardini KC; **Writing – Review & Editing:** Chiavelli FH; Scarpari RSS and de Andrade D; **Visualization:** Gardini KC; **Supervision:** Scarpari RSS and de Andrade D.

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