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Evaluation of Fixed-Wing Pilot Strategies in Startle and Surprise Events: A Survey Study

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Abstract. Pilots frequently encounter startle and/or surprise (S&S), which can negatively affect their performance. To investigate the types of non-nominal events that prompt S&S, 92 pilots from different fixed-wing operating backgrounds - commercial, military and general aviation - completed a survey. In addition to exploring the relative prevalence of different S&S events, the survey required participants to reflect on the level of stress and mental workload experienced during these events. They also rated the perceived effectiveness of any S&S management methods or techniques they may have implemented. Overall, 95% of the participants reported that they had experienced S&S events. Spatial disorientation and bird strikes caused the highest levels of stress. Aircraft system malfunctions, severe turbulence and automation surprises induced the highest workload. The respondents indicated that applying S&S management techniques helped relieve stress and mental workload. The perceived effectiveness of applying breathing-based techniques was significantly greater than other methods. However, despite regulatory recommendations, only 23% of participants were trained in breathing-based methods. The survey also asked participants to remark on their openness to adopt methods that are specifically tailored to expedite emotional and cognitive recovery from S&S. In this study, the Aviate-Breathe-Communicate (ABC) method was evaluated. Across a range of hypothetical S&S events, participants rated the ABC method as most useful in disorientation scenarios. The lack of time was perceived as the most significant barrier to applying this method in critical events. Additionally, participants rated the variability and unpredictability of their training; however, no significant relationship was found between these ratings and perceived stress levels during S&S events. These findings highlighted the need for improvement in S&S training programs and emphasised the recommendation of breathing-based techniques for managing acute stress in high-stakes situations.

Keywords: Pilot Startle and/or Surprise · Pilot decision-making · Stress · Crew Resource Management · Pilot/Flight Crew Behaviour · Pilot/Flight Crew Performance · Pilot/Flight Crew Training · Aviation · Pilot/Flight Crew Stress Handling

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1 Introduction

Aviation is one of the safest transport modes in the modern world. The 5-year average all-accident rate per million flights dropped from 1.19 to 0.8 between 2019 and 2023, with 2023 considered the safest year for flying [1]. Due to advancements in technology related to cockpit automation and system reliability, the likelihood of off-nominal situations has decreased. This has translated to an increased focus on pilots' monitoring and managing the aircraft flying, compared to manually flying the aircraft [2, 3]. Occasionally, however, automation does not perform as anticipated, leading to automation surprises [4]. An emergency such as a bird strike or a loss of engine power can cause acute, severe deterioration and can also cause startle and/or surprise (S&S). US Airways Flight 1549 is a typical example [5]; Both pilots experienced startle and surprise caused by a bird strike and a double engine failure. The plane ditching on the Hudson River showed the importance of crew resource management, which helped the crew respond to the unfavorable situation.

Stress is a product of S&S which impairs the flight crew's capability to perceive, comprehend, conduct sensemaking and decision-making, and execute procedural responses [6, 7]. "Startle" is a brief, quick, highly physiological stress response to a sudden, intense, or threatening event such as a loud crash of thunder [8, 9]. The involuntary startle reflex can be characterised by the contraction of muscles on the face, neck, and shoulders and an increase in heart rate, priming the pilot for the adverse situation as a 'fight or flight' response [9]. The startle reflex can influence cognitive and motor skills, leading to approximately 1 ms to 3 s of disruption on simple tasks and probably lasting 10 s for complex tasks [9]. The crew might suffer from tonic immobility in some severe cases [10]. The consequence could be a loss of situational awareness and distraction from tasks [5]. The startle reflex symptoms will disappear quickly when the startle is single and short [8].

"Surprise" refers to the psychological response to unexpected events [11] that arises from a discrepancy between an individual's expectations and what they perceive [5]. Being surprised is followed by a period of "sensemaking" whereby a solution is sought to account for the perceived mismatch [12]. The disparity might be rectified by reframing the event using an alternative explanation for the unexpected event (based on the pilot's past experience). "Explaining away" the unexpected event (perhaps classifying it as an anomaly) can also occur in a way to preserve the pilots' currently held understanding of the situation. Where no path to resolve this mismatch can be found, frustration and anxiety will escalate to the point where stimulus-driven attentional mechanisms supersede goal-directed attentional mechanisms [13]. As a result, unresolved surprise situations will undermine flight crew coordination effectiveness and worsen flight outcomes [5].

The effectiveness of reducing the likelihood and improving recovery from S&S will be influenced by pilots' initial type training or recurrent training in the simulator, which often includes standardised, predictable scenarios [14, 15]. In terms of training adaptability, this kind of training could be considered insufficiently robust and can leave pilots ill-prepared for unexpected emergency situations, as it is difficult to transfer the skills gained in predictable conditions to unpredictable scenarios [7, 15]. Furthermore, type and recurrent training do not include the training of techniques that are specifically intended to reduce stress and counteract its debilitating effects, should S&S be

experienced. Consequently, several dedicated training techniques and methods that are dedicated to facilitating S&S management and recovery have been incorporated into pilot training [16, 17]. Of these methods, Landman et al. [18] conducted a study to evaluate the potential sensemaking benefits of the Calm Down, Observe, Outline, and Lead (COOL) procedure following unexpected events. The study found that pilots who adopted this method experienced improved decision-making when encountering S&S situations. However, the procedure increased distraction and mental workload, and a simpler method would be preferred. Nonetheless, the method proved beneficial for managing stress and observing the entire situation before analysing and acting on the problem. Further research that explored the benefits of a briefer procedure was conducted by Piras et al. (2023) [19], who examined the effectiveness of the Aviate-Breathe-Check (ABC) method (Refer to Fig. 1).

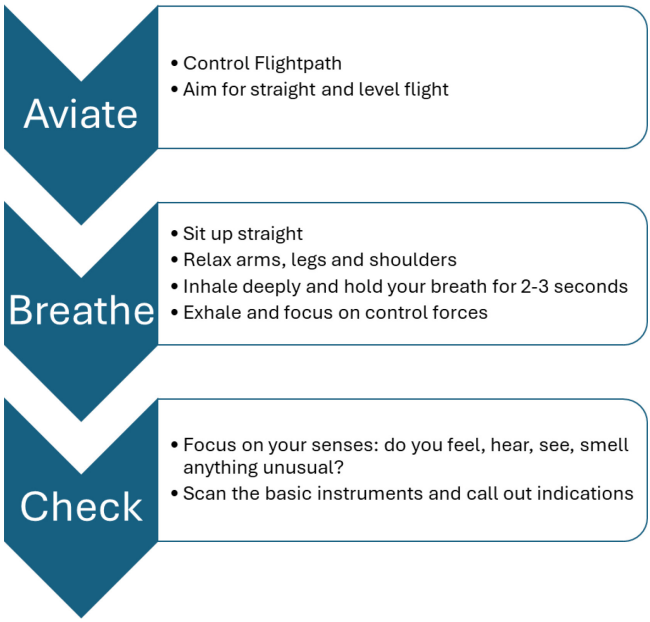

Fig. 1. The ABC method. (Adapted from Piras et al., 2023 [19]).

These studies demonstrated that managing stress-induced S&S can possibly be facilitated by the training of dedicated techniques and methods. The above research, however, was simulator-based and potentially lacked the operational complexity of the civil commercial environment in which pilots encounter S&S situations. Correspondingly, Vlaskamp et al. [20, 21] conducted a qualitative study by interviewing airline pilots about their 5 years of operational experience using an S&S management method. Pilots agreed that the method provided effective stress mitigation and situation awareness benefits. However, some pilots preferred to address problems immediately, particularly in more stressful situations, which was dubbed the "startle paradox": the effect that the more stressful a situation is, the stronger the urge to take action becomes, at the expense

of trying to mitigate the rapidly accumulating stress [22]. Apart from startle management methods, the effect of variable and unpredictable training was investigated as a mitigator of startle and surprise. A simulator study showed that unpredictable and variable training improves the transfer of training to unexpected events in operational practice [23].

The previous studies by Vlaskamp et al. [20, 21] were only focussed on a single airline company. Also, they did not address the nature of the events that elicited startle and surprise, nor differentiate between different S&S management methods. Other studies, such as research on variable and unpredictable training, were only carried out in simulators. This study aims to fill these gaps. The research objectives for this study were:

1. Evaluate which events cause startle and surprise among pilots
2. Evaluate the perceived stress and mental workload caused by these events
3. Evaluate the perceived effect of different S&S management methods
4. Evaluate the perceived usability of and openness to using the ABC method
5. Determine the perceived effect of unpredictable and variable training

2 Method

2.1 Survey Development

A survey was created by the authors and published on the Qualtrics website to explore the research objectives. The survey is structured as follows:

1. **Demographics, Startle, and Surprise Experiences:** Participants were asked to describe all events they had encountered during operations in which they experienced S&S. A range of preselected options were available, and a free text field was used to describe those events that were not prelisted. Perceived stress and mental effort were rated on a scale from 0 to 100, where 0 was no stress or mental workload experienced and 100 was the maximum level (extremely stressed or extremely high workload). Participants also indicated if they used any startle management methods (open question) and then rated their stress and mental effort after using these methods.
2. **Feasibility of the ABC Method:** The third section assesses the feasibility of the ABC method [19]. Participants were asked if, assuming the method can be performed in 10 s, it could have been used in their experienced S&S event and to rate its usefulness. An open question investigated potential barriers to using the method.
3. **Suitability in Different Scenarios:** Participants rated the perceived suitability of the method across various scenarios (based on Vlaskamp et al. [22]): lightning strikes, bird strikes, engine fires, automation surprises, failures with no clear cause, inadvertent flight into IMC, and severe inflight vertigo/disorientation. A five-point Likert scale was used, with the following descriptions: ‘Negative Effects’, ‘Not Useful’, ‘A Little Useful’, ‘Moderately Useful’, and Very Useful.
4. Participants rated the perceived **variability and unpredictability** of training scenarios on a scale from 0 to 10, where 0 meant no variability or unpredictability and 10 is maximal variability or unpredictability.
5. Finally, respondents were asked if they had ever been taught an S&S management method and were invited to share any comments or suggestions.

2.2 Sample

The authors distributed the survey via LinkedIn. 92 Pilots from different operators/backgrounds (46 captains, 29 first officers, 5 second officers, and 12 from other operations, such as search and rescue, weather survey, aerial surveillance for law enforcement agencies, test pilots, trainers, etc) completed the survey. The characteristics of the sample are displayed in Table 1.

Table 1. Characteristics of the respondents.

Item		Number of People (Percentage)
Age range	20–29	7 (8%)
	30–39	19 (21%)
	40–49	26 (28%)
	50–59	26 (29%)
	60+	14 (15%)
Flight hours	0–999	9 (10%)
	1000–1999	9 (10%)
	2000–4999	10 (11%)
	5000–9999	22 (24%)
	10,000+	42 (45%)
Active pilots	Yes	83 (90%)
	No	9 (10%)
Current rank	Captain	46 (50%)
	First Officer	29 (32%)
	Second Officer	5 (5%)
	Others	12 (13%)
Training background	Civil	77 (84%)
	Military	15 (16%)
Instructor / examiner	Yes	52 (57%)
	No	40 (43%)
Most experience operation	Commercial airlines	64 (70%)
	Business jet	11 (12%)
	Military	3 (3%)
	Others	14 (15%)

2.3 Data Analysis

Mean ratings of stress and workload were compared between before and after applying an S&S management method with a two-tailed paired-samples *t*-test. As the relevant data was not normally distributed, a Mann-Whtiney U test was used to compare stress levels before and after using an S&S method to compare breathing-based methods against non-breathing-based methods.

3 Results

3.1 Startle and Surprise Experience

95% of pilots reported having experienced startle and/or surprise. Only four participants reported having no experience with either startle or surprise events. The largest percentage (73%) reported experiencing an event that constituted both startle and surprise combined.

Figure 2 describes the frequency of events as experienced by the respondents. The pre-suggested options were insufficient to cover all events. The 25 free-text answers for "other events" were reviewed and categorised independently by two of the authors. Ten event types were added to existing categories. A new category, "aircraft system malfunctions," contained a variety of technical problems. 15 Responses were left in the "other" category, containing events such as wind shear, a go-around, a rejected take-off, and a low fuel situation. As these were all events that were mentioned only once, they were clustered together for clarity of the chart. The highest frequency of occurrence was found for automation surprise, followed by engine failure and lightning strikes.

3.2 Perceived Stress and Mental Workload

The ratings of perceived stress and mental workload for the events (n = 69) are depicted in Fig. 3. As most of the events with a frequency of 1 were clustered together, the scores for "other" do not have much statistical value. The highest stress score was for vertigo/disorientation (based on 4 events), followed by bird strike (3 events) and aircraft system malfunctions (6 events). For mental workload, the highest scores were given for aircraft system malfunction (6 events), severe turbulence (5 events), and automation surprise (10 events).

3.3 Pilots' Stress Level Before and After Applying the S&S Management Method/Technique

Of the 92 respondents, 36 reported applying an S&S management method/technique. Their stress score before ($M = 54.8$, $SD = 21.6$) was significantly higher than after applying the S&S managing method ($M = 37.0$, $SD = 23.4$), resulting in a mean difference ($M = 17.8$, $SD = 1.8$), $t(35) = 6.13$, $p < .001$, two-tailed 95% CI: 11.89 to 23.66, Cohen's $d = 1.02$, see Fig. 4. Similarly, for the perceived level of mental workload, the results revealed a significant decrease after applying the technique, $t(35) = 5.83$, $p < .001$. Before applying the method, participants' mean rated mental workload was

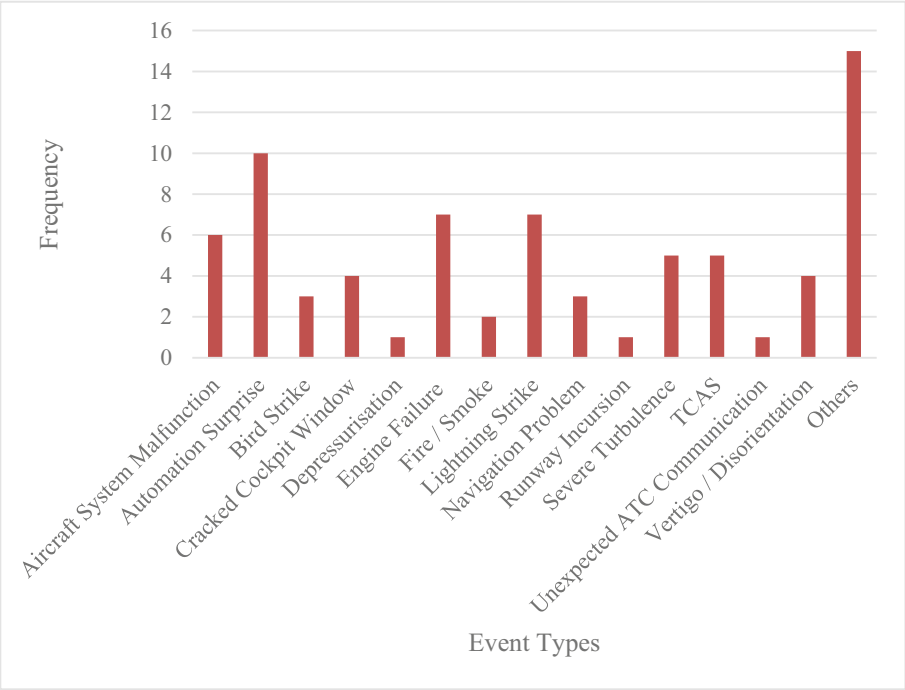

Fig. 2. Frequencies of reported categories of S&S events.

65.0 ($SD = 23.6$), whereas after applying the method, it was 44.2 ($SD = 27.7$), resulting in a mean difference ($M = 20.8$, $SD = 4.1$), $t(35) = 5.83$, $p < .001$, two-tailed 95% CI = 13.53–27.98, Cohen's $d = 0.97$, see Fig. 5.

The most used methods were breathing-based (12 responses). Other responses given were "focus on flying the aircraft" (6 responses), reverting to training or procedures (4 responses) or using a decision-making tool such as FORDEC, CLEAR or DODAR (4 participants). A statistically significant difference was found between immediate stress level scores before and after using the indicated startle management method for individuals who did not use a breathing-based method versus those who did. The analysis revealed a statistically significant difference between the groups, U = 47.00, Z = −3.165, $p = .002$. The mean rank for those who did not use the breathing-based method (n = 23) was 21.96, compared to a mean rank of 10.42 for those who did use the method (n = 12). These results suggest that participants who used the breathing-based method experienced a significantly larger stress reduction compared to those who did not use the method.

To the question: "Have you ever been taught any kind of startle management method (the ABC method or similar) during flying or CRM training?", 29 pilots responded "no" and 36 answered "yes". Additional information was given in the free text. 17 (23%) of the mentioned methods were described as breathing-based methods.

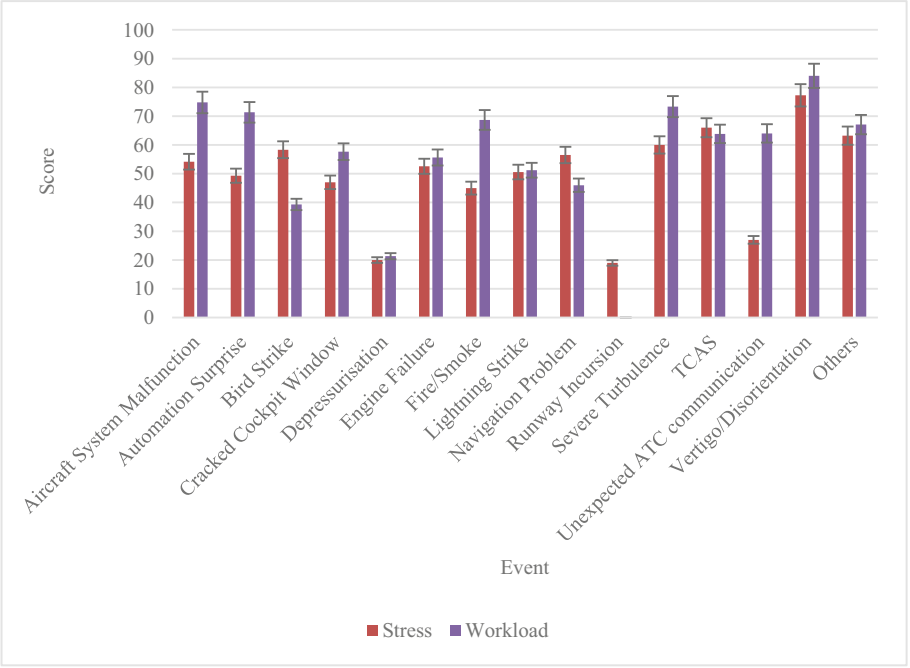

Fig. 3. Ratings of perceived stress and mental workload for different categories of events. Error bars indicate the standard deviations.

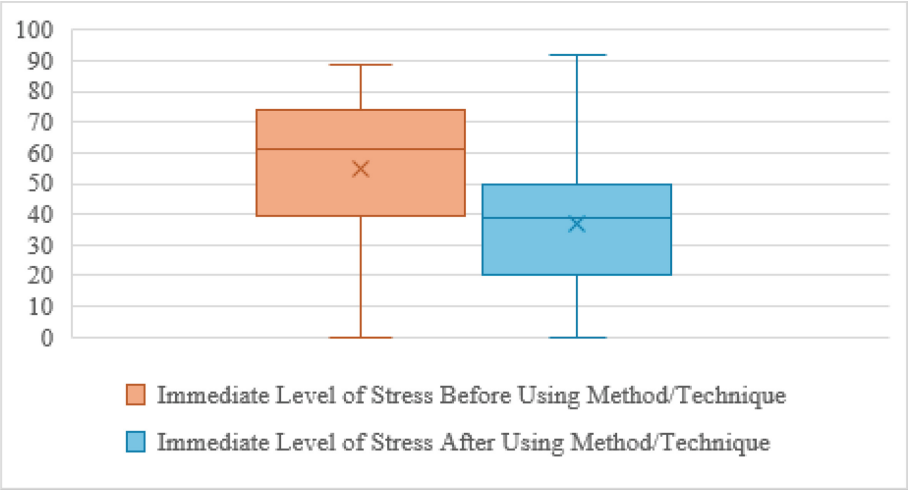

Fig. 4. Perceived stress of the pilots (n = 36) before and after applying an S&S management method. X indicates the mean.

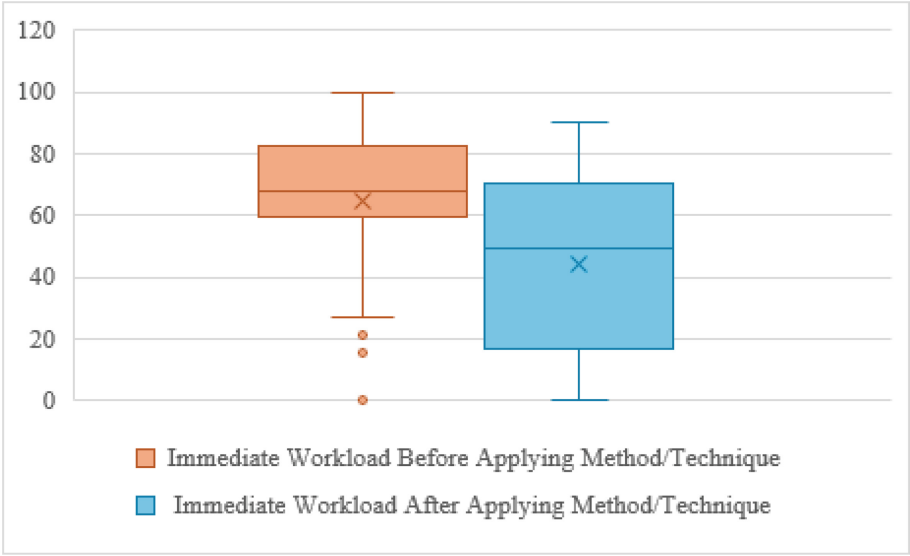

Fig. 5. Perceived Workload of the Pilots (n = 36) Before and After Applying the S&S Management Method/Technique, with X indicating the mean stress scores.

3.4 Openness and Applicability of the ABC Method

Participants were asked if, assuming that performing the ABC method would take about 10 s, there would have been time to perform it in their experienced startle/surprise event. Of the participants who answered the question, 33 (55%) answered "yes," 12 (20%) answered "maybe," and 15 (25%) answered "no."

When asked whether participants would use a startle management method (if trained) in a startle/surprise situation, of the 64 pilots that answered 35 (54.7%) answered "yes", 26 (40.6%) answered "maybe," and only 3 (4.7%) answered: "no".

3.5 Perceived Barriers to the Use of the ABC Method

Participants were asked in a free text question to list any barriers they saw for using the ABC method. 52 Pilots answered the question. These were thematically analysed by two of the authors. The most mentioned barrier was time (23 pilots): "10 seconds is too long", "Holding your breath 2–3 seconds is not realistic", "we need to act immediately", and "No time" were typical answers. Cognitive limitations ("difficult to memorise" and "difficult to fight natural responses to do something", for example) were mentioned by 9 pilots, and 9 mentioned training concerns ("long time for training and implementation"). 3 Pilots voiced concern about the method ("breathe doesn't mean anything to me") and 2 about recognition of S&S. Finally, 3 pilots answered they could see no perceived barriers, 2 voiced CRM concerns, and 1 gave an incomprehensible answer.

3.6 Perceived Usefulness of the ABC Method in Various Hypothetical Scenarios

Participants were asked how useful they expected the "ABC method" to be in several hypothetical scenarios. 66 Participants rated the scenarios. The results are presented in Fig. 6. The highest "very useful" scores were given for severe inflight disorientation/vertigo (47.7%), navigation problems (47.7%), and lightning strikes (37.9%). The highest "negative effects" scores were for TCAS resolution advisory (12.3%), TCAS traffic alert (9.4%), and depressurisation (9.4%).

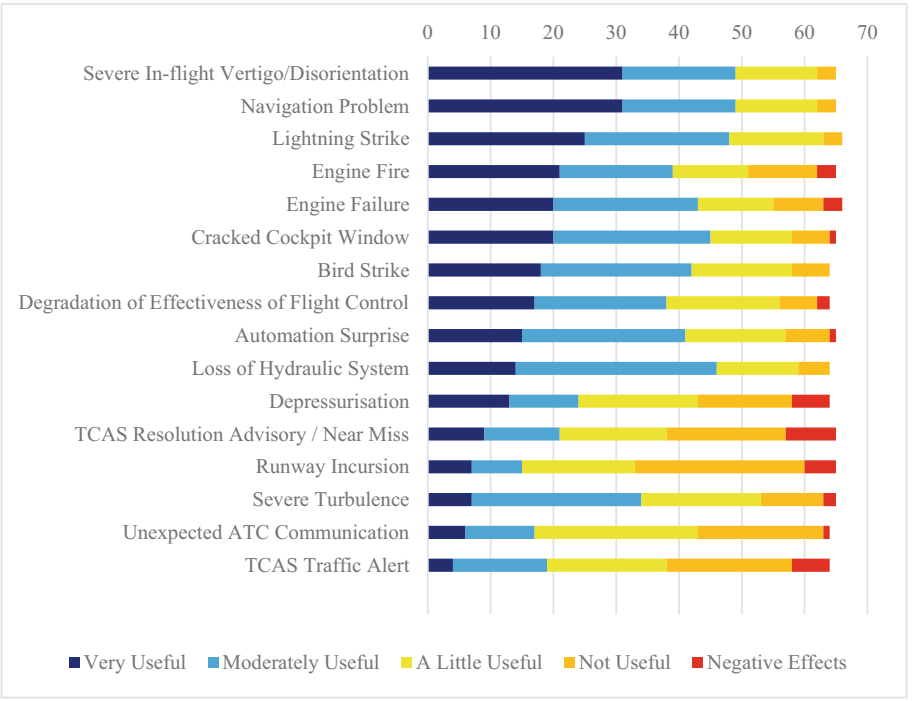

Fig. 6. The participants' opinions of the ABC method in different hypothetical scenarios.

3.7 Variable and Unpredictable Training

Respondents rated the perceived variability and unpredictability of the training they received. The mean score for variability was 5.83 (out of 10), and for unpredictability, 4.83 (out of 10). To evaluate if stress levels immediately after the event were influenced by unpredictable and variable training, Spearman's rank-order correlation was conducted to explore the relationships between stress scores immediately following the event, variability in training, and unpredictability in training. The results indicated no significant correlation between stress scores before the event and either variability, $\rho = -0.076$, $p = 0.56$ or unpredictability, $\rho = -0.089$, $p = 0.50$. As expected, a significant positive correlation was found between variability in training and unpredictability in training,

$\rho = 0.619$, $p < 0.001$, indicating that higher variability in training is associated with higher unpredictability, which aligns with expectations.

4 Discussion

This study evaluated the causes of startle and surprise among pilots, their impact on stress and mental workload, the effectiveness of different S&S management methods, the usability and acceptance of a proposed ABC method, and the influence of unpredictable and variable training. The results confirm earlier observations by Vlaskamp et al. [21] that startle and surprise are common occurrences in aviation: 95% of respondents reported having experienced startle and/or surprise. The most prevalent reported S&S events were automation surprise, engine failure, and lightning strikes. The highest perceived stress scores were reported for vertigo/disorientation, followed by bird strikes and aircraft system malfunctions. For mental workload, the highest scores were given for aircraft system malfunction, severe turbulence, and automation surprise. Contrary to expectations, no significant effect of experience could be found in the degree of stress caused by a startling and/or surprising event. This finding corroborates research from a larger study of helicopter pilots [22] and research by Chen et al. [24]. One explanation could be that more experienced pilots had more exposure to S&S, increasing the chance of encountering a more impactful event.

Pilots experienced benefits (reduced stress level and perceived mental workload) from using S&S management techniques. Strategies varied, from focusing on flying the aircraft and using decision-making tools to breathing-based methods. Stress reduction through using breathing-based methods was compared to non-breathing-based methods. Breathing-based methods are a common tool used to reduce stress [25, 26]. Both breathing-based methods and non-breathing-based methods showed a stress level reduction, but breathing-based methods showed a significantly greater reduction in stress levels. This is the first research comparing startle management methods in actual flight operations, providing the first evidence for the greater effectiveness of a breathing-based startle management method.

Only 36 respondents indicated they had been formally trained in an S&S management method, and only 17 were taught a breathing-based method. This shows that, despite EASA and FAA training recommendations, there is still room for improvement in S&S training. Despite this, most pilots indicated openness to using a method such as the presented ABC method [19]. Less than 5% of pilots were outright negative from the start. Perceived barriers had to do mainly with perceived time available, echoing earlier research [21]. While the urge to act in some cases can be justified, the "startle paradox" likely influences these results: the higher the stress level, the higher the urge to act, at the expense of performing a startle management method. The ABC method was considered most useful in inflight disorientation/vertigo, navigation problems, and lightning strikes. Disorientation also scored the highest for stress level. However, contrary to lightning strikes and navigation problems, this requires quick action, which the researchers expected to lead to a lower score. The result for vertigo/disorientation also conflicts with the low scores for "upset" in research by Vlaskamp et al. [21]. The high score is possibly caused by the high amount of stress the event causes: vertigo/disorientation gave the

highest stress scores among the actual events. As disorientation is a substantial contributor to military and civil aviation accidents [27] the high score is a useful observation and an interesting avenue for further research. The method was considered least useful (possibly having negative effects) in TCAS TA and RA events and depressurisation events. These events require immediate action, so these scores can be explained more readily.

Training variables and unpredictable scenarios have been mentioned by Landman et al. [23] as an effective training intervention for startle and surprise. It should improve the transfer of training to unexpected situations in flight, thus likely reducing the effects of startle and surprise. In contrast to our hypothesis, no significant relationships between rated unexpectedness or variability of training and levels of stress following surprise events could be found. Although the scores are subjective, the sample is limited, and other confounding factors may play a role, these results raise the question of how well variable and unpredictable training prepares pilots for real-life startle and surprise.

5 Limitations and Further Research

The sample size was limited, with 92 valid responses, which may limit the generalisability of some of the findings. Not all of the participants experienced S&S, and not all filled in all questions. Also, the aviation background of the participants was highly varied: some were airline pilots, some were military, and some were instructors on smaller planes. With a larger sample, the power to detect significant relationships and the stability of statistical estimates would improve and would allow for exploring differences between pilot groups. Stress and mental workload scores and the variability and unpredictability of training were subjectively rated instead of measured. Also, considerable time could have passed between experienced startle and surprise events and the survey, influencing recollection of the event. This influences results. Still, we believe the study adds valuable insights and provides interesting avenues for further research. Larger studies could investigate the effect of experience on startle and surprise and investigate the transferability of variable and unpredictable training to real-life situations. Also, the usability of a startle management method for disorientation scenarios, which carried the largest perceived stress scores and high positive scores for the usefulness of the ABC method, should be further investigated.

6 Conclusion

The study confirms startle and surprise are common in aviation and cause varying degrees of stress. It is the first research that provides evidence for the higher effectiveness of a breathing-based startle management method. Although pilots expressed openness to using a breathing-based startle management method, this was very rarely trained. For pilots, the most significant concern around startle management is the lack of time to perform a startle management method, possibly influenced by the startle paradox. Interestingly, this study found no effect of experience, variability, and unpredictability of training on the perceived stress scores of startle and surprise events. Due to the small sample size, a larger study is needed to confirm these results.

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