Multimodal detection of an electric aircraft propulsion system failure

Lamyea Ahmed[1], Michael A. Bromfield[2]

[1]Aerospace Engineering Master's Student, University of Birmingham, [2]Associate Professor in Aerospace, University of Birmingham. CIEHF Member and Corresponding Author.

SUMMARY

The need for sustainable aviation has accelerated the development of electric aircraft and propulsion systems. These systems generate less noise compared to conventional piston engines (Moshov & Toropylina, 2022) and provide limited cues to the pilot in the event of a propulsion system's failure. Not recognising powerplant failure and taking prompt recovery actions in a timely manner may lead to aerodynamic stall and loss of control in flight (Smith & Bromfield, 2022). This research aims to explore how multimodal presentation of electric propulsion system information affects pilot response times during propulsion system failure. A human-centred design approach was employed to develop multimodal presentations of data, incorporating visual, auditory and visual/auditory feedback in combination. Simulated flights were conducted in a fixed-base flight simulator, using control and experimental groups consisting of student pilots (n=eight). Preliminary results indicate that pilot response times are reduced when using a combination of visual/auditory information.

KEYWORDS

Electric Aircraft, Multimodal Presentation, Response Time, Workload, Propulsion System Usability

Introduction

Safety is paramount in aviation, and the presentation of vital, contextual information for electric aircraft propulsion system management is relatively new. This research aims to explore how multimodal presentation of electric propulsion system information affects pilot response times during propulsion system failure. The objectives of this research are to design multimodal presentations of essential propulsion system data, enhance engine failure detection, reduce pilot workload during emergencies, and assess the usability of various information presentations for electric propulsion systems. This will inform future design of propulsion system monitoring and alerting systems for use in electric aircraft.

Methodology

Auditory presentation (A) was developed using a sound effects engine, comprising of a pure tone sinewave used for sonification (Kramer, et al., 1999), where the frequency was proportional to the aircraft propulsion system's revolutions per minute (RPM). A separate sound file, featuring a female voice aural alert annunciating "Engine failure" was created for engine failure events. The visual presentation (V) used a simulated Head Up Display (HUD), created using a game engine, and was positioned to the left of the pilot's forward field-of-view in the cockpit. A red warning cross ("X") with the caption "Engine Failure" was also presented during an engine failure. The multimodal presentation (VA) was the combination of the visual (V) and auditory (A) presentations, in addition to the conventional cockpit instrument displays (N). A fixed-base engineering flight simulator was used to simulate flights and propulsion system failures. Eight student pilots (mean age: 20.6, mean real aircraft flying hours: 11.5) were divided equally into control and experimental groups. A between-groups mixed experimental design was used, with participants performing four simulated flight scenarios (normal take-off, normal landing, take-off with engine failure, landing with engine failure), either with presentation (experimental group) or without presentation (control group). To avoid learning effects, the scenario sequence was pseudo-randomised and balanced for each group. Engine failure was also pseudo-randomised and manually triggered using the Flight Instructor/Operator Station at approximately 400 ft above ground level (AGL) for take-off and 750 ft AGL for the landing. Participants were instructed to press a button on the control yoke in the event of an engine failure, capturing their response time. After the completion of each scenario, system usability was assessed using the System Usability Scale (Brooke, 1996) and workload was evaluated using the NASA-TLX (Hart & Staveland, 1988).

Preliminary Results Analysis and Discussion

Preliminary results comparing Control vs Experimental Groups showed that, during take-off with engine failure, multimodal presentation (VA) response times were 1.27s faster than no presentation (N) response times. For the landing, multimodal presentation (VA) response times were 1.29s faster than no presentation (N) response times. The multimodal (VA) results are consistent with previous research findings of Spence & Santangelo (Spence & Santangelo, 2007), where response times during high perceived load were improved using audio-visual cueing. Some participants commented that they used the RPM sonification and aural alert as their primary source of information on system status. Some participants predominantly used the appearance of the red cross as an indication of propulsion system failure. The visual presentation (V) ranked the highest for usability, however, this may have been influenced by participants' preferred feedback styles (Chui, et al., 2020). During propulsion system failures, some participants prioritised establishing a glide speed and delayed registering their response time. In one case, a participant forgot to press the yoke button entirely.

Conclusions

Preliminary results, with respect to response times for the different forms of information presentations, are encouraging. Further analysis of the simulated flight data (including pilot control inputs) is needed to investigate response times more comprehensively. The experiment will be repeated with more participants to consolidate results and a full statistical analysis will be conducted on all measures. This research will inform future human-centred electric aircraft cockpit and HUD design, potentially preventing the loss of control in flight accidents for electric propulsion system failures.

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