

Haptic Shared Control during Automated Take-off: Effects on Trust and Workload

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Abstract—Automation reduces pilot workload but introduces risks such as mode confusion and automation surprise, which can impair situation awareness and delay responses. Haptic shared control, delivered via active sidesticks, may mitigate these risks by providing continuous force feedback to convey automation intent and warnings. This study examined how the haptic information in shared control systems affects trust, workload, and awareness during automated take-off scenarios involving normal and abnormal autopilot behaviors. Twenty participants monitored automation performance while completing a secondary 2-back task under two shared control conditions: haptic shared versus input-mixing shared control. Results show that abnormal autopilot behaviors significantly increased workload and reduced trust, with haptic shared control having context-dependent effects - supporting trust and reducing workload during over-rotation but lowering trust in normal conditions. Haptic shared control had no significant effect upon participant situation awareness or secondary task performance. These findings suggest that the provision of haptic information within shared control can support pilots during automation anomalies but require human-centered implementation and training to avoid unintended effects under normal conditions.

I. INTRODUCTION

In the past decades cockpit automation has reduced pilot workload and errors but also introduced new risks, such as mode confusion and automation surprise [1]. These events increase cognitive workload and can delay responses. Future systems must balance complexity with transparency to maintain trust and prevent pilots from becoming “out-of-the-loop.” Designing information that complements human processing in an intuitive fashion is critical.

On the visually saturated flight deck, the haptic channel offers a way to improve transparency and trust. Haptic shared control (HSC), via an active sidestick, can provide continuous force feedback to convey automation inputs and warnings [2], like the stall stick shaker. In addition, the provision of supplementary haptic information, in general, has proven to reduce workload, enhance situational awareness (SA), and improve task performance [3].

This study evaluates HSC’s effects on trust, workload, and SA during automated take-off, aiming to inform design of human-machine interfaces (HMI) that enhance safety and efficiency in highly automated systems.

A. Trust in Automation

Automation involves the transfer of functions or tasks previously performed by humans to machines [1], in which the level of automation in a system is determined by the extent to which the function is delegated to the machine [4]. Higher levels of automation increase pilots’ monitoring role, highlighting the criticality of appropriate trust in automation, as over-reliance and under-reliance can compromise performance and safety. Trust is one factor which determines the degree to which a pilot will rely on automation. In cockpits, trust can be defined as the attitude that the automation will help achieve tasks characterized by uncertainty and that expose the pilot to vulnerability [5]. Consequently, trust is influenced by automation reliability and understandability, with lower trust associated with automation that is unreliable or that exhibits unpredictable failures [1], [5], [6].

According to Chiou & Lee [7], trust is also closely associated with system transparency and alignment with the operator’s intent. When automation is transparent, its current state and intended actions are clearly communicated to the operator, enabling them to form an accurate mental model, leading to higher trust [8]. Trust levels tend to elevate when the automation behavior aligns with the operator’s mental model and expectations. In contrast, unpredictable automation can lower trust and create a mismatch between the pilot’s mental model, leading to significantly delayed reframing [9] and impaired SA.

B. Human Information Processing Limitations

One of the most influential frameworks to understand how humans process and allocate resources in complex environments is the Multiple Resource Theory (MRT) [10]. MRT proposes that humans possess multiple pools of attentional resources that can be allocated across concurrent tasks. When two or more tasks compete for the same resource (e.g., visual information), task interference occurs, while the use of varying resource pools maintains performance.

The MRT framework has been widely applied in aviation research to explain task modality effects on workload and SA during high-demand phases [10]. Pilots are required to multitask communication, navigation, instrument monitoring and decision-making tasks [11]. MRT explains why such multitasking is more challenging when tasks compete for the same sensory modality (e.g., concurrently scanning multiple visual displays), especially during expected system failures. As a result, displays are attended to according to their

Research supported by the EPSRC New Investigator grant (EP/Y00194X/1)

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importance. For instance, speed indicators are usually monitored more regularly than the fuel indicator [6]. Research shows that distributing information across sensory modalities can reduce workload and improve performance [10].

With modern aircraft cockpits being heavily dependent on visual and auditory cues, the communication of information via haptic feedback has the potential to reduce the dependence on the already saturated visual and auditory channels [12], [13], [14]. This supports a more balanced distribution of resource allocation and may help pilots maintain SA, workload during automation failures.

C. Haptic Shared Control in Aviation

Haptic feedback is a modality that conveys information through touch. It includes several types with distinct mechanisms and applications. Vibrotactile feedback uses vibrations to transmit information and is common in handheld devices. Surface haptics simulate textures on smooth surfaces using electrostatic or ultrasonic technology, often in touchscreens. Force feedback applies physical resistance to simulate touch, widely used in gaming and aviation for flight envelope protection. Proprioceptive feedback relates to the perception of body movement and position.

In aviation, multiple studies [15], [16] have explored the influence of haptics (e.g., alerting vibration cues and dynamic control stiffness) to signal pilots of an approaching maximum load factor. Both Schuet et al. [15] and Van Baelen et al. [16] found haptic related pilot efficiency improvements during high workload phases of flight. However, initial evaluations by Van Baelen et al. [2] on performance, safety, or workload were found to be inconclusive, despite clear preference by pilots. Haptic feedback has also significantly promoted compliance with defined flight envelope limits, increasing SA and performance [17]. In contrast, findings from the limited studies on haptics during aircraft taxiing have been consistently positive. Galea et al. [18] found haptic feedback to reduce pilot cross-track error compared with conventional taxiing mechanisms, whilst Blundell et al. [12] demonstrated that multimodal displays, combining visual and haptic cues, enhanced safety and efficiency in low-visibility operations.

In terms of automation transparency, HSC is beneficial as an HMI paradigm due to both human operator and automation simultaneously exerting control through a shared physical interface—such as a motorized sidestick or joystick—with continuous force feedback reflecting the automation’s actions [19], [20].

D. Research Gaps and Aim

Several critical gaps remain in understanding how pilots can be better supported during unexpected automation behaviors. While HSC shows potential to enhance the SA of pilots and facilitate quicker responses to automation anomalies, empirical evidence on its effectiveness remains limited. Thus, the current study examines the haptic component of HSC upon pilot automation trust. This is achieved through an empirical comparison of two shared control systems - HSC and input mixing - during simulated interaction with aircraft autopilot failures during take-off. The input-mixing system implements shared control by blending pilot and automation inputs internally, without explicitly signalling the automation’s activity through the control

interface. The HSC system, by contrast, also conveys automation intent via haptic forces applied to the side stick, thereby making the shared authority perceptible and supporting continuous pilot–automation interaction [21].

II. METHODOLOGY

A. Participants

Twenty non-pilot participants (15 males, 5 females) aged between 22 and 52 ($M = 28.60$, $SD = 7.03$) took part in the study. The research was approved by the Cranfield University Research Ethics System (CURES), Approval Number: 29285.

B. Flight Simulator Setup

A desktop-based simulator running an X-Plane 11 Cirrus Vision SF50 aircraft model was used (Fig. 1). The aircraft cockpit was displayed on a 24-inch display monitor and a Brunner CLS-E MKII active stick was used as a control interface (peak force 6.8 Nm for 35 s., nominal force 4 Nm, travel pitch/roll 20.5°). The manufacturer-recommended default values were used for autopilot force and speed. A secondary 2-back task, rendered in PsyToolkit software and presented on a 13-inch display, was used to simulate the additional working memory load of real-world multitasking (e.g., running checklists and ATC communication) while monitoring the autopilot.

C. Automated Take-Off Scenarios

In the current study, automation behaviors were ‘mimicked’ by executing pre-recorded control inputs. Three automation take-off scenarios were created in this way: 1) a standard aircraft rotation (V1 at 90 kts) and climb without any errors; 2) an early rotation scenario (V1 minus 20 kts), and 3) an over-rotation scenario. Table 1 summarizes the take-off speeds and pitch attitudes of these 3 scenarios. In all scenarios, the thrust setting was set to 75% N1 prior to take-off roll-out. Participants were expected to detect and correct any unexpected automation control behaviors using the sidestick.

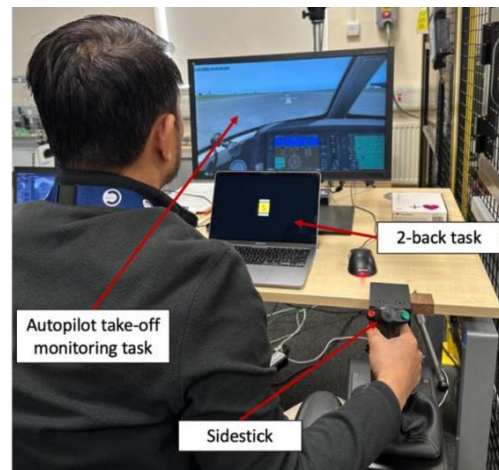


Figure 1: Flight simulator setup

D. Procedure

Participants completed 12 trials where they monitored the automation’s take-off performance while performing the secondary visual 2-back task – for which they were required to respond on the keyboard if the presented letter matched the

letter presented two letters earlier. The trials were presented in two counter-balanced blocks of 6 trials each – a block where automation inputs were haptically communicated via the active stick (HSC - *Haptics ON*), and a block of trials where the automation inputs were not haptically communicated (input mixing - *Haptics OFF*). Within block (scenario type) randomization was performed. After each trial, participants completed the subjective scales for workload (NASA-TLX [22]), SA (SART [23]) and automation trust (TAS [24]). Fig 2. provides a schematic of the procedure.

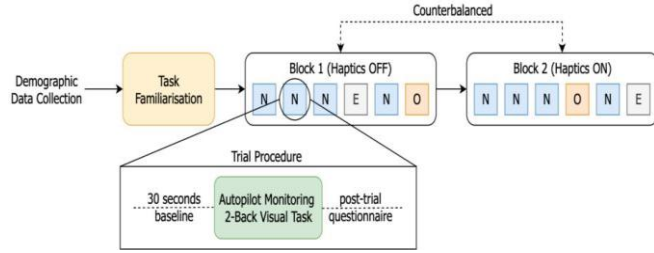


Figure 2: Experimental procedure (N = Normal take-off; E = Early rotation; O = Over-rotation.)

TABLE I. AUTOMATION TAKE-OFF SCENARIOS

Scenario	Rotation Speed (kts)	Pitch Attitude (degrees)
Normal Take-off	90	10
Early Rotation	70	10
Over-rotation	90	20

E. Data Analysis

Data was analyzed using IBM SPSS 29. Dependent measures included post-trial subjective report for workload, SA and automation trust, as well as the percentage of correct secondary task responses. All dependent measures were analyzed using a two-way repeated measures ANOVA to investigate the main effect, and interactions between, two independent measures – *Haptics* (2-levels: ON / OFF) and *Scenario* (3-levels: Normal / Early / Over-Rotate). Significant main effects and interactions were investigated using an alpha level of 0.05. Where appropriate, post-hoc pairwise comparisons were performed with Bonferroni correction. Effect sizes were reported to support the interpretation of results.

III. RESULTS

Participant workload, SA, automation trust ratings and secondary task performance are shown in Fig 3. These results are presented in turn.

A. Workload

NASA-TLX workload scores exist on a 100-point scale, with higher ratings reflecting higher self-perceived workload. As expected, across scenarios, workload ratings were lower during take-offs where the automation functioned normally compared to the non-normal take-off conditions – confirmed by a main effect of *Scenario* ($F(2, 38) = 4.03, p = .026, \eta^2 =$

0.18). There was no main effect for *Haptics* ($p = .973$), however an interaction between *Scenario* and *Haptics* did exist ($F(2, 38) = 3.56, p = .038, \eta^2 = 0.16$). Pairwise comparisons showed that workload was higher during early-rotation scenarios with haptics compared to without (mean difference = 1.64, SE = 2.22), with workload being higher without the haptics for over-rotations (mean difference = 3.41, SE = 2.40). However, neither comparison was significant ($p > .171$).

B. Situation Awareness

Participant composite SART scores were calculated whereby higher scores represented greater self-perceived SA (range 0–28). Across the take-off scenarios, SART scores were highest for normal take-offs and were lower for each non-normal take-off. In addition, average SART scores were higher during non-normal take-off trials with the haptics. ANOVA results for SART score revealed no significant main effects or interactions ($p > 0.05$), however.

C. Trust in Automation

Automation Trust ratings were made on a 7-point scale, with higher ratings indicating greater trust in automation. The pattern of automation trust results in Fig 3 shows trust to be impacted by the presence of automation failure during early- and over-rotation scenarios ($F(2, 38) = 11.20, p < .001, \eta^2 = 0.37$). No main effect of *Haptics* was found ($p = .844$), however, the interaction between *Haptic* by *Scenario* was marginally significant, $F(2, 38) = 2.68, p = .082, \eta^2 = 0.12$. Bonferroni-corrected pairwise comparisons showed that during normal autopilot behavior, trust was significantly higher for Haptic OFF compared to Haptic ON conditions (mean difference = 0.30, SE = 0.12, $p = .024$). In contrast, during over-rotation, trust tended to be higher for the Haptic ON condition, nearly significant (mean difference = 0.37, SE = 0.20, $p = .086$).

D. Secondary Task Performance

Participants' accuracy to the secondary task, as a percentage of correct responses to experienced 2-back trials, was the highest during scenarios where the automation functioned normally - $F(2, 38) = 5.51, p = .008, \eta^2 = 0.23$. In addition, in all automation scenarios participants' secondary task performance was worse with Haptics ON. However, neither a main effect of *Haptics* nor an interaction was found.

IV. DISCUSSION

In this study, the effects of the haptic information within shared control systems on pilot workload, automation trust, and SA whilst monitoring normal and non-normal autopilot take-off behavior were examined. It was hypothesized that haptics would have a significant impact on these subjective measures compared to shared control without haptics (i.e., input mixing), particularly in non-normal autopilot conditions. The primary findings revealed that non-normal autopilot behaviors considerably increased perceived workload and reduced trust. Haptics had a subtle context-dependent effect on this influence, reducing workload and improving trust in some conditions whilst having the opposite effect in other conditions.

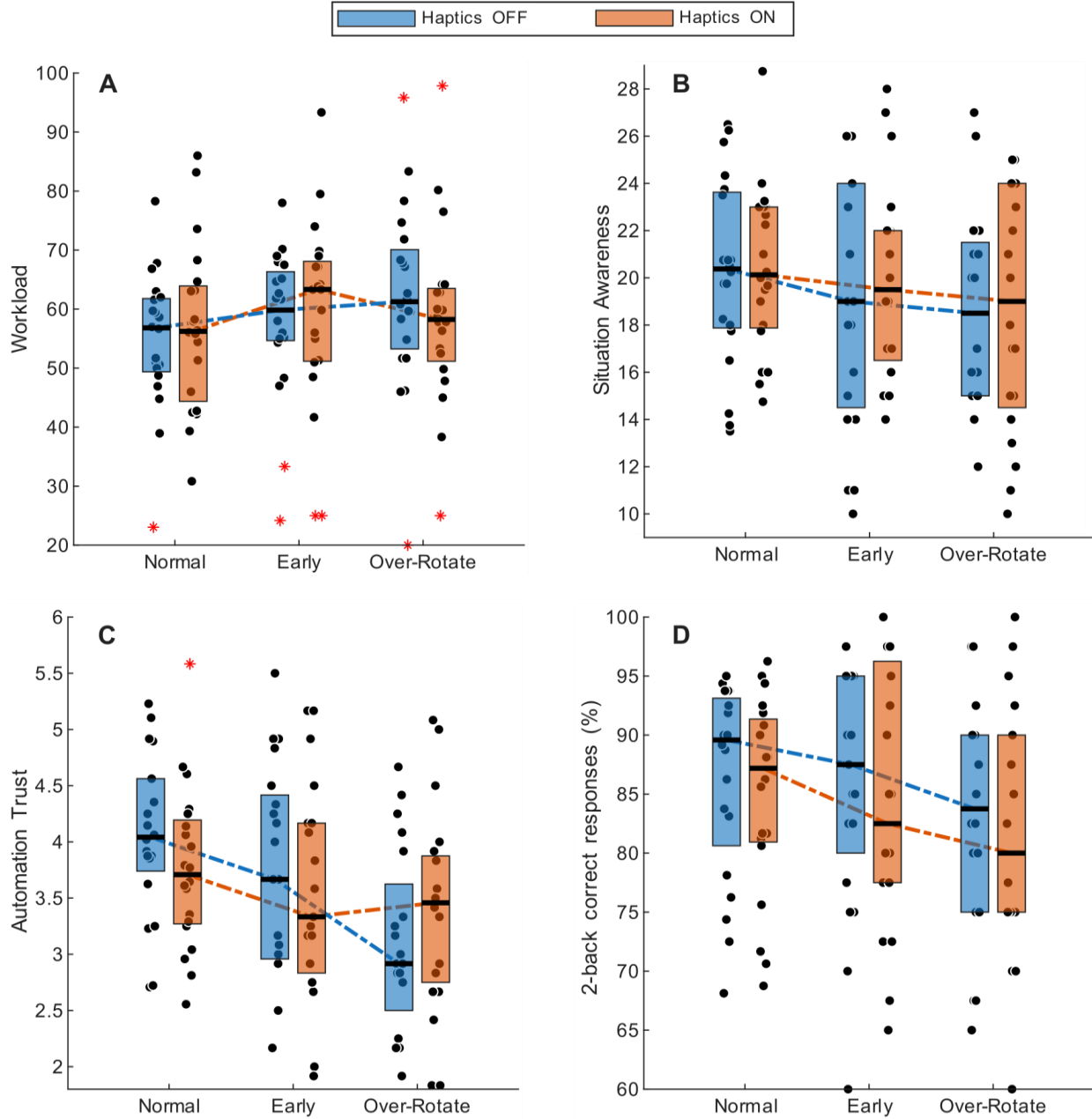


Figure 3: Boxplots showing participant workload (A), situation awareness (B), automation trust (C) and secondary task performance on the 2-back task (D). The data are grouped by haptic condition (OFF = blue boxes / ON = red boxes). Take-off scenario is organized on the x-axis.

Trust in automation emerged as one of the most notable outcomes in this study. Consistent with prior research on automation reliance [5], [25], trust was notably higher during normal autopilot than non-normal conditions (e.g., over-rotation). In addition, the presence of haptics highlighted a more complex pattern of results. The marginally significant interaction ($p = 0.086$) suggested that haptics influenced how the participants assessed shared control information under different conditions. Pairwise comparisons revealed that in normal automation conditions, trust was significantly higher without haptics than when it was present. In contrast, during

haptics was observed. This pattern indicates that the impact of haptics on trust is highly context-dependent in shared control interactions. However, these marginally significant results should be treated as exploratory that warrant future investigation with a larger sample.

These mixed HSC findings resonate with broader theoretical models of trusting automation by [7]. Trust in automation relies on functional reliability as well as its interpretation and understanding. Firstly, previous studies have shown that haptic cues can lower confidence when they are perceived as

intrusive or misaligned with the operator's expectations [19], [26]. In this study, when haptic feedback was introduced in normal conditions, participants may have felt the feedback to be unnecessary or overly authoritative, reducing their sense of control and confidence in the autopilot. This is supported by some participants who queried during normal trials whether the presence of haptics required them to intervene manually, suggesting they misinterpreted the force feedback as a signal of automation deviation. Similarly, in Collins et al. [14] some participants initially found the nudge forces distracting and highlighted the need for learning and training to be used effectively.

Secondly, the lack of non-haptic communication cues may have exacerbated this effect. For instance, in multi-crew environments with active sidesticks or yoke, movement of the controls is often supplemented by verbal communication between pilots, reducing uncertainty of the co-pilot's intention. However, in this experiment, pilots were only provided haptic cues to build their mental model of autopilot. This aligns with previous work by Verberne et al. [8] that showed lower trust ratings when automation provides cues without transparency about purpose and misalignment of shared goals. These findings highlight the importance of automation transparency and legibility [5].

In contrast, the higher trust during abnormal autopilot behavior (i.e., over-rotation) indicates that the participants interpreted haptics as supportive guidance in reinforcing trust and correction. This is because haptics in HSC offer continuous, salient, feedback of the autopilot behavior allowing participants to intervene appropriately. Thus, allowing pilots to collaborate with the autopilot in a shared task goal through aligned intention and supporting higher trust [26].

Furthermore, the trust results could have been influenced by novelty and unfamiliarity. Most participants did not have prior experience with HSC. This may have led them to be suspicious, particularly in normal conditions where the purpose of feedback was not obvious. The novelty could also explain the similarity in trust ratings in early-rotation conditions with and without haptics. However, the marginal trust benefits observed in over-rotation scenarios suggest that when the haptic cues clearly supported their task goals, they viewed the system more positively. This is consistent with the notion that exposure and training are crucial to building trust in novel automation aids [25].

B. Impact of Workload and Situation Awareness

NASA-TLX ratings showed a significant main effect of autopilot behavior: workload was higher during abnormal automation (early rotation, over-rotation) than normal take-offs, consistent with findings that reliable automation reduces workload [27]. An interaction between sidestick type and autopilot behavior was observed but was not significant; descriptively, haptics slightly increased workload in normal scenarios but reduced it during over-rotation, supporting

MRT principles [10]. Prior studies report mixed effects of haptics on workload [11], [12], [13], [16].

The SART-10D results showed no significant SA differences between haptic and non-haptic conditions, though a slight, non-significant increase in understanding occurred with haptics. This contrasts with trust improvements under abnormal autopilot, suggesting trust and SA respond differently. Previous research found haptic cues can improve SA [11], [17], [28], but limitations of SART and unfamiliarity with haptics may explain null effects [6].

C. 2-Back Task Performance

Accuracy on the secondary 2-back task showed no significant main effect of haptics or interaction with autopilot behavior. High performance across conditions suggests participants managed cognitive demands effectively, supporting the idea that haptic sense operates as an independent channel processed in parallel with visual/auditory inputs [29], [30]. This aligns with Van Baelen et al. [31], who found haptic feedback had no significant impact on workload or task performance.

However, this contrasts with Collins et al. [14] who reported improved N-back performance when using directional haptic cues during tracking tasks. In the current study, non-directional cues were used, which may explain the absence of performance benefits. Directional cues provide spatially meaningful information that can directly support visuospatial memory, whereas non-directional force feedback primarily aids in monitoring and control rather than enhancing memory processes. This difference in cue type likely accounts for the discrepancy in findings, highlighting the importance of cue design in multimodal interaction research.

D. Limitations

A key limitation of this study is the use of non-pilot participants, which limits the generalization of the current findings to the targeted population - pilots. While this approach is common in early-stage human-automation research, participants responses to autopilot behavior will not fully represent the responses of licensed pilots. These pilots possess robust domain-specific mental models for conducting safety critical take-off procedures through the long-term procedural training that they receive. Future work should replicate these findings with licensed pilots to assess operational validity.

V. CONCLUSION

This study evaluated the role of haptics within HSC in reducing workload and enhancing trust during monitoring of a take-off autopilot. The findings suggest the cognitive effects of haptic feedback are context-dependent in shared control systems. HSC supported the pilot under abnormal conditions, whilst reducing trust and elevated workload under reliable automation. This mixed effect indicates that haptic cues may not provide uniform benefits, and their effectiveness depends on the pilot's mental model and the reliability of automation. While no substantial effects were observed on SA, secondary task performance remained high, suggesting that

supplementary haptic information did not create excessive cognitive strain. Overall, these findings highlight the importance of multi-modal cues and adaptive feedback systems to enhance pilot trust and support effective human-automation teaming in aviation.

ACKNOWLEDGMENT

For this research Dr James Blundell and Dr Wojciech Korek were recipients of an EPSRC New Investigator grant (EP/Y00194X/1), used to support their time on this research.

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2026-07-01

Institute of Electrical and Electronics Engineers (IEEE)

<https://doi.org/10.1109/ichms69701.2026.11602165>

Jilaau A, Blundell J, Korek W, et al., (2026) Haptic shared control during automated take-off: effects on trust and workload. In: Proceedings of the 2026 IEEE International Conference on Human-Machine Systems (ICHMS), 1-3 Jul 2026, Singapore, Singapore, pp. 14-19