Trust-Based Analysis of an Air Force Collision Avoidance System

Engaging test pilots in the analysis reveals the qualities of the system that can lead to increased trust and, as a result, fewer crashes into the terrain.

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FEATURE AT A GLANCE:
This case study analyzes the factors that influence trust and acceptance among users (in this case, test pilots) of the Air Force's Automatic Ground Collision Avoidance System. Our analyses revealed that test pilots' trust depended on a number of factors, including the development of a nuisance-free algorithm, designing fly-up evasive maneuvers consistent with a pilot's preferred behavior, and using training to assess, demonstrate, and verify the system's reliability. These factors are consistent with the literature on trust in automation and could lead to best practices for automation design, testing, and acceptance.

KEYWORDS:
trust in automation, automation reliance, CFIT, nuisance budget, test pilot, Auto-GCAS technology, design, automation design, human–machine interaction, automated system

In military aviation, controlled flight into terrain (CFIT) is a significant cause of the loss of life for pilots (Richardson, Eger, & Hamilton, 2015). CFIT occurs when a properly functioning aircraft collides with terrain because the pilot is unaware of or unable to avoid the danger before it is too late. These collisions may occur because of the pilot's spatial disorientation (which is a cognitive precursor to CFIT) or from G-force-induced loss of consciousness.

To mitigate the precursors of CFIT, the Air Force and its collaborators in the past three decades have developed the Automatic Ground Collision Avoidance System (Auto-GCAS), which has been successfully flight-tested and is being integrated into and used in operational F-16 aircraft. Auto-GCAS is a technology that assumes control of an aircraft when an imminent collision with the ground is detected and returns control back to the pilot when the collision is averted.

We describe a case study that analyzed Auto-GCAS from a human–machine trust perspective. In particular, we explain the role of trust as related to the development and acceptance of this technology by discussing the critical drivers of trust from the perspective of test pilots who have extensive experience with Auto-GCAS. We conclude with recommendations for automated system design to foster trust of future automated systems.

WHY TRUST MATTERS

Trust, one's willingness to accept vulnerabilities in relation to another entity (i.e., technology), is a critical driver of human–machine interactions (Chen & Barnes, 2014; Lee & See, 2004; Lyons & Stokes, 2012). An individual's trust of technology will influence how much he or she will accept that technology and rely on it (Lee & See, 2004).

Pilots' acceptance of Auto-GCAS has been an ongoing concern (Richardson et al., 2015) because it is a system that takes control away from the pilot, albeit briefly. Understanding pilot trust of Auto-GCAS is critical to its operational performance because pilots have the option to turn the system on or off during operations.

Although Auto-GCAS was designed to prevent up to 98% of historical incidents, and to work only in situations when the pilot is experiencing spatial disorientation or G-force-induced loss of consciousness, pilots can misuse the system if they overtrust it and believe that Auto-GCAS will always save them. This misbelief can motivate the pilot to fly more aggressively or brazenly and to misuse Auto-GCAS as a combat tool. Thus understanding pilot trust is a crucial step in preventing pilot complacency (i.e., misuse).

The vast majority of studies focusing on human–machine trust have been conducted in laboratory settings. These studies, along with limited field studies, have identified a number of consistent predictors of trust in automation (for reviews on the topic, see Hoff & Bashir, 2015; Lee & See, 2004; Onnasch, Wickens, Li, & Manzey, 2014; Rice, 2009). Key findings from this literature show that factors such as high reliability, low error rates (particularly low false-alarm rates), transparency, familiarity, and anthropomorphic features increase trust (Hoff & Bashir, 2015).

Similarly, Lee and See (2004) suggested that to increase trust, designers should show the system's past performance and how it works, simplify algorithms to make them understandable, highlight the system's intent, and conduct training to demonstrate the system's reliability. Research also shows that in addition to performance-based beliefs, social beliefs and institutional norms are predictive of early trust of new technologies (Li, Hess, & Valacich, 2008); thus it is important to capture the full spectrum of trust antecedents during technology evaluations with users. Yet, it is unknown how well these factors will map onto trust of test pilots using an actual automated system that employs a high level of automation during high-risk operations.

DESIGN MOTIVATIONS FOR AUTO-GCAS THAT IMPACT PILOT TRUST

Auto-GCAS was designed with three ranked design principles meant to guide the development and acceptance of the system: (1) do no harm, which requires that Auto-GCAS not cause any harm to the pilot or the aircraft; (2) do not impede, which requires the system to be nuisance free and thus not interfere with the mission; and (3) avoid collision, which requires the system to avoid collision with terrain (Richardson et al., 2015). The principal goal of Auto-GCAS is to mitigate the problem of CFIT. It is designed to do so by taking over control of the aircraft, maneuvering it away from danger, and returning control back to the pilot. This functionality can be contrasted with previous collision avoidance technologies, which primarily used warning systems and proved insufficient for mitigating CFIT (Richardson et al., 2015).

Warning-based systems were not an ideal solution to the CFIT problem because (a) they are prone to false alarms, which can degrade trust (Geels-Blair, Rice, & Schwark, 2013); (b) they require the user to manually respond and thus are not effective when the pilot is incapacitated or spatially disoriented; and (c) the pilot may not always correctly recognize a warning or correctly make the terrain collision evasion maneuver.

To overcome these limitations, Auto-GCAS was developed with a number of innovative approaches and solutions. To address the nuisance problem, a nuisance threshold was determined that ensured that in the pilot's view, Auto-GCAS would not trigger too early. This solution was accomplished by conducting a flight-test program to define what would be the maximum acceptable time before CFIT to initiate a recovery maneuver that the pilot would not consider to be a nuisance. Considering only this problem from a temporal perspective was unique, as previous efforts had used distance above the ground as a metric for nuisance.

To determine the time to CFIT at which a fly-up maneuver would not be a nuisance, pilots flew aircraft toward terrain in different conditions and manually initiated a recover as they reached their own comfort threshold. They then rated their anxiety level at recovery initiation to capture whether they had accidentally initiated the recovery sooner or later than they had intended. The duration between the point at which a recovery initiation would no longer be considered a nuisance and the point at which the aircraft's maximum performance recovery would just clear the ground is called a *nuisance budget*.

Figure 1. Head-up display image with chevrons.

Auto-GCAS was also designed with a head-up display (HUD) anticipation cue for potential activation. Providing human operators with transparency into the system's capabilities, purpose, intent, and analytical underpinnings is another way to foster trust (Lyons, 2013). In the Auto-GCAS system, operators are able to see two chevrons (i.e., the two arrows shown in Figure 1) on the HUD that dynamically intersect as the aircraft approaches a possible CFIT situation. These chevrons allow the pilot to anticipate when the system is about to engage.

TEST PILOT EVALUATION

Our research occurred in the context of a larger case study of the Auto-GCAS technology involving engineers, test pilots, and managers engaged in the Auto-GCAS program. This article focuses solely on the test-pilot portion of that case study, and specifically the factors that influenced test-pilot trust. Our general strategy for assessing test-pilot trust of Auto-GCAS involved a qualitative review of the factors that influenced their trust development of the system. This assessment was accomplished through survey and interview techniques.

First, test pilots responded to an online survey that assessed their general attitudes toward Auto-GCAS, initial perceptions of the system, experiences with the system, and open-ended questions about the factors that influenced their trust or distrust with the system. (The majority of questions in the online survey involved perceptions of engineers and managers associated with the Auto-GCAS program and are out of the scope of this article.) The survey data formed the basis for follow-up interview questions relating to what factors influenced the pilots' trust over time.

Experimental test pilots ($N = 15$) from Edwards Air Force Base participated in a serious of interviews. Two to four interviewers were present, and the interviews lasted approximately 20 to 60 min, depending on the availability of the pilots. The interview focused on revealing pilot attitudes toward Auto-GCAS, identifying the trust levels among test pilots of Auto-GCAS, and discussing reasons for trust or distrust of Auto-GCAS. The interviews were recorded and transcribed using NVivo software. The interview team then reviewed the files and looked for common themes and trends using a grounded-theory approach.

SUBSET OF FACTORS SHAPING TEST PILOT TRUST OF AUTO-GCAS

The following sections represent the factors that influenced trust of Auto-GCAS among the test pilot community.

Avoiding false alarms. The primary driver of trust among test pilots was the demonstrated ability of Auto-GCAS to avoid false alarms (i.e., the creation of the nuisance budget). The nuisance criteria were found to be governed by two principles for an avoidance maneuver to be acceptable to a pilot: It must be both aggressive and timely – aggressive in the sense that the avoidance is using a significant amount of the aircraft's available maneuvering capability, and timely in the sense that it does not begin the maneuver so early that it is deemed a nuisance or so late that the aircraft does not have sufficient maneuverability to avoid hitting the surrounding terrain.

The pilots apply a safety buffer based on their uncertainty of the situation (rapidly changing aircraft attitude or conditions, high turbulence, poor visibility, etc.) to determine when the aggressive avoidance maneuver should be initiated. Because the aggressive portion of the criteria embeds within it the aerodynamics unique to a vehicle, the timely portion of the criteria remains the same for all aircraft. We also found that the timely criterion could be approximated by a single equation, with the maximum acceptable time being the point at which the aggressive recovery will just miss the ground. This finding is consistent with research on trust in automation showing how false alarms can degrade trust (Geels-Blair et al., 2013; Hoff & Bashir, 2015; Rice, 2009).

Performance of the system. A second factor driving test-pilot trust was the knowledge of the system's reliability. Auto-GCAS was designed to approach 98% reliability in preventing CFIT. The test pilots experienced this high reliability in operational testing, which was clearly to the benefit of their trust in Auto-GCAS. This finding is consistent with prior research showing that performance is a significant predictor of human–machine trust (Hancock et al., 2011; Hoff & Bashir, 2015; Lee & See, 2004).

Transparency. Automation transparency, in the form of chevrons, was an important topic that emerged in this study because it affects how pilots develop and calibrate their trust of Auto-GCAS. The test pilots reported that the chevrons enabled them to better anticipate the behavior of Auto-GCAS, consistent with prior views of transparency (Lyons, 2013).

However, we must approach this issue with some degree of caution given the context of Auto-GCAS. It is possible, for instance, given that Auto-GCAS is a safety system, that pilots (who are faced with situations that require intense aerial maneuvers) could use the chevrons to operate their aircraft with greater risk, as the chevrons provide enhanced awareness of one's relative proximity to the ground. Such behaviors would conflict with the overall intent and design of Auto-GCAS, both of which assume that pilots will fly their aircraft in the same manner that they had prior to the availability of Auto-GCAS. Authors of future research should explore the role of transparency within safety systems, specifically within the context of Auto-GCAS.

Familiarity of the maneuver. Test pilots reported strong positive perceptions of the Auto-GCAS maneuvering capabilities. Auto-GCAS was designed to engage a wings-level, 5-G pull-up, which is consistent with pilot training and behavior. This familiarity supported stronger trust perceptions among the test pilots.

CONCLUSION AND LESSONS LEARNED

In this article, we discussed the Air Force's Auto-GCAS system and highlighted several of the drivers of trust of this system from the perspective of test pilots. All these factors correspond to variables noted in the trust literature; from a real-life context in which humans interact with automation, they lend applied support to the literature. Additionally, we described a few design features used by the Auto-GCAS program that resulted in higher trust perceptions among test pilots. Although the current results are qualitative in nature, they provide a rich set of inputs from an operational community regarding the factors that shape trust in automation.

The lessons learned in conducting this research are both methodological and design based in nature. The study reinforced the notion that flexibility and access to applied participants are keys to success in researching applied systems. The test pilots had rigorous schedules, and the research team had to adapt to the pilots' constraints. Second, none of this research is possible without the support of key stakeholders to foster access to the applied participants.

From a design standpoint, it is clear that the issue of false alarms was paramount to the pilots. These individuals are at the "tip of the spear" of military operations, and the last thing they wanted was interference from an automated system. Once these concerns were subdued, the test pilots became much more accepting of the technology. This finding reinforces the importance of user-centered design, as the guiding principle for the collision avoidance algorithm was based on the pilot's nuisance budget.

A second lesson learned involves giving users an opportunity to experience the system in action, as this appeared to be a key driver of test-pilot trust of the system. Third, designing the system to provide cues related to activations was useful. This form of real-time transparency was an important driver of trust in our study. Finally, the maneuver designed into the system was one familiar to pilots, which also contributed to their trust of the system. Designers of future automated systems might consider incorporating these elements into their design process, lest they be faced with a distrustful user base.

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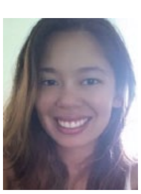

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