Influence of Cultural, Organizational, and Automation Capability on Human Automation Trust: A Case Study of Auto-GCAS Experimental Test Pilots

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ABSTRACT
This paper discusses a case study that examined the influence of cultural, organizational and automation capability upon human trust in, and reliance on, automation. In particular, this paper focuses on the design and application of an extended case study methodology, and on the foundational lessons revealed by it. Experimental test pilots involved in the research and development of the US Air Force's Automatic Ground Collision Avoidance System served as the context for this examination. An eclectic, multi-pronged approach was designed to conduct this case study, and proved effective in addressing the challenges associated with the case's politically sensitive and military environment. Key findings indicate that the system design aligns with both pilot culture and the organizational mission, indicating the potential for appropriate trust development in operational pilots. These results point to the importance of the low-vulnerability/high risk nature of the pilot profession, automation transparency and suspicion, system reputation, and the setup of and communications among organizations involved in the system development.

Keywords
Trust, automation suspicion, reliance, F-16, military organizational, pilot culture, extended case study methodology, automatic ground collision avoidance

INTRODUCTION

With the increased use of automation in aviation, inappropriate reliance on automation becomes an increasingly relevant issue [11]. Misuse and disuse of automation characterize inappropriate reliance [6]. Misuse is described as the reliance on an automated system for something other than its intended purpose and disuse is when an operator does not use the automation [6, 11]. Research has shown that reliance on automation depends on many things, including the trust that the operator places in the automation and factors related to the capability and complexity of the automation [9]. Trust, in particular, has been shown to be a meaningful concept guiding human-automation reliance similar to the way trust mediates relationships between individuals, between organizations, and between individuals and organizations [3, 5, 9, 12]. The fundamental premise of trust is the willingness of an individual to be vulnerable to the actions of another entity [9], may be it a person or a machine (i.e., automation). In a comprehensive review of trust in technology that sought to link organizational, sociological, interpersonal, psychological, and neurological perspectives on inter-personal trust to the issue of human-automation trust, Lee and See [6] found a general lack of data and research addressing, how cultural and organizational factors influence human-automation trust and reliance. The studies that have addressed this, have shown that these factors can influence human-automation interaction in unexpected ways, but these studies have been mostly confined to experiments that examine the effects of a limited set of independent variables in a well-controlled environment. In actual operations, interactions between humans and automation usually take place in settings where there are many more variables of interest than data points available, and where the investigators do not have control over the events. Thus, to more firmly tie existing experimental findings to the real world, and to lay the foundation for future research, it is essential to capture the richness of the phenomenon and the extensiveness of the real-life context in which human interacts with automation. The work presented in this paper sought to address this in the context of a case study of an actual military automated system. Practical lessons learned and real-world perspectives of the appropriateness of reliance (i.e., where trust and use of automation matches system capabilities) are identified. Moreover, in addition to a standard approach examining how intrinsic properties of automation influence reliance, our emphasis on cultural and organizational factors allowed us to examine how human-automation reliance can be influenced in ways that are less directly related to the characteristics of the automation. Finally, the case study method presented here facilitates the collection of evidence from multiple sources, thus utilizing converging operations to identify the presence of latent variables or constructs (e.g., trust, distrust) in a triangulating fashion.

To identify fundamental lessons and best practices about appropriate reliance on automation, our research approach was to conduct a case study. This study examined the experience of key Department of Defense (DOD) personnel who were involved in developing and operating a specific military automated system, the Automatic Ground Collision Avoidance System (Auto-GCAS). Specifically, using a multi-case design, cultural, organizational, and automation capability factors were studied using three interrelated groups of participants: 1) experimental test pilots; 2) engineers; and 3) management. All participants were at some point involved with the development and testing of the Auto-GCAS program. This paper reports findings from the experimental test pilot (ETP) case, while future papers will address findings from the examinations of engineers and managers.

In the remainder of this paper we will first describe the methodology/methods we utilized, along with the lessons we learned about the use of a contemporary methodological research design and implementation processes. Following this, we will discuss the key findings about the influence of automation capability, cultural, and organizational factors on trust development. In the last section, we will present conclusions and implications for using the results of this research to add to the body of knowledge on human automation trust.

METHODOLOGY AND METHODS

Extended Case Study Methodology

Our methodology was inspired by Michael Burawoy, who proposed in his 1991 book, Ethnography Unbound [2], to combine the advantages of two traditions, qualitative and quantitative approaches, of empirical evidence and theories. Burawoy emphasized the contribution of qualitative research in understanding the values of a group of people by understanding their views. Following this guide, we immersed the research team into the culture and world of our subjects so we could gain a deeper understanding of the norms and values of that group, and insight into the views of the group that could not be gained from detached surveys or interviews. Qualitative methodology methods like ethnographic field notes, participant observation, and open-ended questions provide a rich set of data, and make it possible to introduce a subject's interpretation into conclusions. This subjective, complex, and in-depth process provides context and completeness to information gathered from the population. On the other hand, by using quantitative methodologies, that included using surveys and closed question interviews, we could gather data from a larger <u>N</u>, and a basis for comparison between different populations or individuals. Studies utilizing only using quantitative methodologies are often quick to complete, and very effective in gathering data for answering proposed questions, but they often create many more unanswered questions at the end. Using both methodologies (qualitative and quantitative), a fuller set of data is collected. Theories were then generated from this collected data that can be further tested in experimental studies.

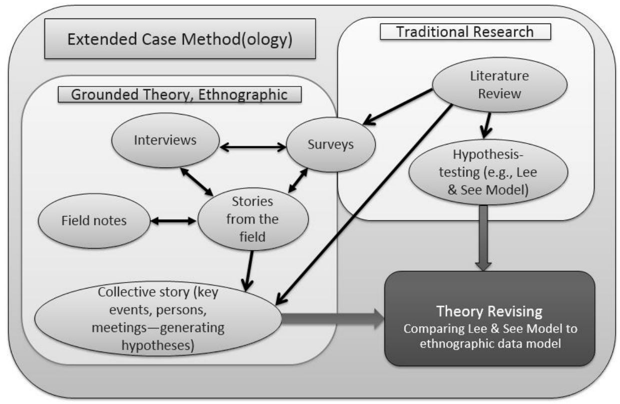

Figure 1: Research Design Process and Strategy

Methods

Figure 1 depicts the project's methodology which combines literature reviews, participant-observation data and interview and survey data, in the analysis and discussion/revision of existing theories on human automation trust. The methodology combines grounded theory (described below) and traditional research approaches. The grounded theory approach sets the framework for the project's primary sources, while the traditional research methodology provides the project's secondary sources.

- Grounded theory is a qualitative methodological approach that is an inductive hypothesis generating process, as opposed to a deductive quantitative hypothesis-testing approach. Hypotheses are generated from observing patterns that emerge out of ethnographic data, rather than extracting hypotheses from existing theories and then collecting data to test these hypotheses. Using grounded theory, the project aimed to answer research questions by using questionnaires, surveys, field notes, and observations. These qualitative methods provide the ethnographic approach dimension to the study.
- In contrast to grounded theory, traditional research tests theories in a deductive manner. In this project, the research team immersed itself in the current literature on human automation trust development, with an emphasis on automation capability, cultural, and organizational factors. This included doing extensive literature review on the cultures and organizations involved with the development and testing of Auto-GCAS. After the synthesis of the literature review was completed, the results of this review were used to generate hypotheses to be tested.

Using data from both processes, comparisons with existing theories about trust in automation can then be made. That is, once theories were generated from both the traditional literature review, and from the grounded theory methods, these theories and hypothesis were compared to see if they converged or diverged from each other.

Unique Challenges and Solutions

To capture the influence of cultural and organizational factors, the research design process had to address a number of unique challenges.

- The first was the research team's lack of familiarity with experimental test pilot (ETP) culture. ETPs reside within a small, tight-knit community in which cultural studies are not often conducted. Since the literature on ETPs is limited, to effectively study how ETP culture influences trust development in automation, we had to first study and define ETP culture.
- However, this then led to another challenge, which was gaining access to selective personnel and recruiting ETPs to participate in the research. This required coordination with government contacts at the Air Force Flight Test Center (AFFTC) and the National Aeronautics and Space Administration (NASA). Since this study was done within the context of the ETPs' Air Force duties, traditional incentives (e.g., monetary) for participation could not be offered. In addition, by the nature of their profession, ETPs are small in number and have incredibly busy work schedules.
- The military and government environment of Auto-GCAS required the research team to have an understanding of the extensive developmental history of Auto-GCAS, and to understand and be respectful of the political and sensitive nature of studying a developing military technology. This understanding and respect facilitates creating a smooth and unobtrusive process in collecting data with the participants.
- The research team also needed to quickly gain an adequate understanding of a highly technical topic (Auto-GCAS), and of a complex organizational structure (with respect to US Air Force and NASA technology development processes) in order to effectively process literature and findings, and to converse with personnel and participants.
- Geography also was a challenge because the research team was based in Los Angeles, California, while ETP locations ranged from Edwards, California to Arlington, Virginia. Part of the methods used in the study, as explained in the next section, involved interviews, which were ideally conducted face-to-face and required traveling to several air force bases (AFBs).
- As stated by Lee & See [6], there is a lack of extensive literature regarding cultural and organizational factors in human-automation trust development. This provided less of an immediate literature foundation for the research team.
- In addition to these issues, the project also attempted to capture a large quantity of information within the relatively short time frame of 18 months.

To address these challenges, three main solutions were developed and implemented: 1) an agile implementation of methods, which allowed the research team to adapt to the opportunities that emerged during our investigation, and to the uniqueness of the population groups; 2) utilization of key people who could assist in gaining entrée to participants and research sites, as well as providing information and insights; and 3) development, by the research team, of cultural and technical competency in order to effectively interact with the ETP population and work within the constraints of the complex organizational structures.

RESULTS

Methodological Lessons Learned

The extended case study research design, and its implementation, proved effective for obtaining the necessary data from which foundational lessons about ETP trust development in Auto-GCAS could be extracted. These were based upon the three main techniques implemented in this study. Specifically,

- An agile implementation of the methods proved to be critical. Initially, we planned for a 2-hour interview with the participants; however, after discovering the time constraints of participants, the method was quickly restructured to include an online questionnaire that could be completed at each participant's convenience, with a follow-up 1-hour interview. Interviews were restructured to include open-ended questions and follow-up questions based upon how a respondent completed the questionnaire. Field observations, which were initially intended to just include observing mission testing, were extended as permitted by circumstances and access granted to the research team. As a result, the research team was able to immerse itself deeper into ETP culture by conducting numerous observations not only at the work place (i.e., during mission testing and at AFBs), but at formal congregations (e.g., ETP conferences), and informal gatherings (e.g., meals and post-work bonding social events).
- The project also owes a large part of its success to the assistance from key personnel with entrée into the ETP community and other organizations. These key personnel were able to provide valuable insights and feedback during the research process. They facilitated in obtaining access to several AFBs, including Edwards, Nellis, Shaw, and Hill, as well as in organizing visitation rights to observe mission tests (from pre-mission briefing to post-mission de-briefing). They also assisted in recruiting 14 male and 1 female Caucasian, US born, ETP participants, with ages ranging from 28 to 65 years old. All participants had flown Auto-GCAS at least once during its 30 year development and had a median of 2.5 years of

experience working with Auto-GCAS. Our association with these participants also helped the research team establish credibility and trustworthiness in the communities of the participants.

- Building a deep understanding and cultural competency with respect to the ETPs and their community also proved to be highly critical for, and beneficial to, the conduct of the study. The substantial efforts made by the research team to learn ETP culture not only helped the team understand the values and norms of the culture, but also helped them converse and interact with ETPs using their technical language and vernaculars. This, in turn, helped the team to gain respect, build rapport, and gain the trust of the ETPs. By strengthening that connection between the research team and the ETPs, the research team was able to gather necessary data.

Influence of Automation Capability, Cultural, and Organizational Factors on Trust Development

A number of key lessons and best practices regarding how automation capability, as well as cultural and organizational factors, influence ETPs' trust in Auto-GCAS were identified and are summarized in this section. These findings are pulled from the analysis of interviews, field notes, participant observations, surveys and literature review.

- For safety systems such as Auto-GCAS, determining the right threshold at which to take control away from the operator is critical for developing a system that does not impede or interfere with the operator. Auto-GCAS was designed to automatically execute a roll to wings-level, 5-G recovery maneuver when the time available to avoid ground impact (TAAGI) is 1.5 seconds. This 1.5-second "budget" was established through flight tests in which ETPs flew towards terrain and rated the TAAGI in relation to their anxiety. The TAAGI was a design requirement that helped eliminate nuisance activations. A nuisance activation of Auto-GCAS would be an activation of the recovery maneuver before a pilot deemed it to be necessary. Nuisance activations that take away the control of the aircraft is aversive to both ETPs and operational F-16 fighter pilots, and the elimination of these false alarms is highly valued. Having a nuisance free system builds appropriate trust in the system. The 1.5 second budget is specifically designed to address the needs of the operators: F-16 pilots. Pilots stated in interviews that Auto-GCAS does not activate sooner than they would execute an evasive maneuver themselves. This increases their trust that Auto-GCAS will not interfere with their flight mission. This identified lesson is extremely valuable for developers of future safety systems with similar characteristics to Auto-GCAS.
- It was found that national differences may have an influence on Auto-GCAS reliance/compliance. Ideally, participants were to include international pilots with Auto-GCAS experience, but those pilots were not able to be recruited for this study. Based on the responses of the US born pilots, there was evidence indicating that national differences can influence air force pilots' reliance on automated technologies. A few pilots with great exposure to international cultures said that pilots from non-Western or Soviet nations, who fly according to commands from centralized ground control stations, may be more likely to comply with Auto-GCAS due to their being from cultures that prefer conformity. It was also stated that Eastern Asian cultures with heavy conformity and adherence to hierarchy may also heavily rely on such autonomous technologies. This hypothesis is interesting and warrants further exploration.
- In a survey rating their opinions of the Auto-GCAS engineers and managers/leaders, the majority of the ETPs rated "strongly agreed" to questions regarding positive working relationships with them. ETPs confirmed such statements (e.g. trusting the engineering and management teams, that they were competent, and that they could have honest conversations with them) in both their interviews and during field observations. Pilots stated they had an increased trust in Auto-GCAS before flying just by the positive opinions of the competency of the teams that worked on developing it. This opinion is consistent with the mutual respect that the research team observed among the ETPs, engineers, and managers in their interviews and personal relationships. Thus, the nature of relationships among members of different occupations/organizations can have positive or negative influence on trust development. In the Auto-GCAS case, participants stated that having respect and a positive opinion of other people's work, profession, and organization, facilitated a positive trust in the automation they produce, before even gaining experience with that automation.
- Generational differences can affect the acceptance/use of automation. Participants often stated in their interviews that there were differences in terms of acceptance of automation between the older "fly-by-the-seat-of-your-pants" generation and the young "Nintendo" generation. Pilots stated that the younger generation of pilots grew up with more exposure and familiarity with automation which, in turn, makes them more likely to accept new automated technologies. It was also observed during observations at the Society of Experimental Test Pilot (SETP) symposia that older pilots emphasized that automation cannot replace the pilot. Thus, pilots tended to suggest that younger pilots then are more likely to accept new automated technologies, like Auto-GCAS. This generational shift was also mentioned when discussing the acceptance of Auto-GCAS by older pilots who are now in position of decision making authority. Pilots stated in interviews that some older pilots (both currently flying and in administrative roles) may be the slowest group to develop trust in Auto-GCAS. Given that the current composition of F-16 pilots is made up of mostly younger pilots, and the composition of personnel in decision making occupations is made up of mostly older pilots, it would be interesting to gain a deeper

understanding of how generational issues affect the development and use of automated technologies.

- The approval of Auto-GCAS's funding was influenced by how its business case was developed and marketed to users and decision makers [15]. Auto-GCAS is ultimately a system designed to prevent controlled flight into terrain (CFIT), one of the main types of aviation accidents in the USAF [8]. CFIT occurs when a nominally functioning aircraft, for some reason, is flown into terrain (i.e. mountains, ground). . In the interviews, it was revealed that combat systems often have a higher funding priority than safety systems, and auto-GCAS was often thought of as just a safety system. Furthermore, we learned that some individuals with the Air Force have believed, and some still believe, that "CFIT weeds out the weak. This ideology means that some individuals believe that good pilots don't crash and therefore would not need a technology like Auto-GCAS. To address this, Auto-GCAS was marketed as both a combat and safety improvement to both decision makers and end users. The background and credentials of the individual(s) who made and presented this business case were also important [15]. We also noted that the importance of the perceived credibility of those making the recommendations was not only important in marketing Auto-GCAS to decision makers, but in the marketing to the pilots will use the system. For example, ETPs stated in the interviews that they are more likely to trust a new technology when it is presented by a peer pilot (instead of a manager or an engineer). This ideological can even begin to affect working relationships between different groups if intentions/agendas are not analogous. Conflicting agendas can foster mistrust between groups. Thus, it can be seen that inherent organizational ideological differences may create a tier system of importance for different types of automated technologies (e.g., preference for combat capability improvements over safety capability improvements). This tier system can foster distrust in systems lower on the totem pole.

- ETPs reported in the survey and interviews that healthy skepticism (also known as automation suspicion) is an integral part of their training, and is essential for developing and calibrating their trust as they gain more exposure to, and knowledge of, how the system works. Trust calibration, which is the process of developing an appropriate level of trust, occurs over repeated positive/negative exposures and experiences with the system [6]. This notion of trust calibration is consistent with, and substantiated by, data collected on the ETPs' trust evolution. Specifically, we asked ETP participants to mark their initial and final trust of Auto-GCAS as a function of its perceived capability on a graph where a 45-degree line represents ideal trust calibration, i.e. a 1:1 relationship between trust and capability. As such, this line separates the over-trust region (above the line) and the under-trust region (below the line). The results are shown in Figure 2 for 11 ETPs who completed the graph. The trend shows that pilots tend to begin at under-trust points but as they gain experience and exposure to Auto-GCAS, they began to calibrate their trust close to the ideal trust line. However, their final trust is still slightly under the ideal line, indicating that ETPs maintain some healthy skepticism in their trust calibration. This tendency of skepticism can be attributed to a number of factors, such as avoiding strong negative consequences of over-trusting, not having enough experience with the system, or the training philosophy inculcated in them during test pilot school. It would be important in future field studies to determine which factors are the most dominant and at what point they are most relevant during the trust calibration process.

- A design intention of Auto-GCAS was not to change the way pilots fly. While Auto-GCAS was designed to prevent up to 98% of historical incidents and to work only for situations when the pilot is saturated with tasks, disoriented, or unconscious (due to high acceleration), pilots can misuse the system if they over-trust it and believe that "Auto-GCAS will always save them." This misbelief can cause the pilot to fly more aggressively or brazenly, and misuse Auto-GCAS as a combat tool. Of the 15 participants, three commented (either in an interview or questionnaire) that having Auto-GCAS would change the way pilots fly. Two of those respondents also had a long history of exposure to Auto-GCAS and had opportunities to observe changes in flying of other pilots. One pilot stated that he "actually few lower more comfortably" as a result of flying with Auto-GCAS. This misuse can stem from gaining too much confidence in the system's capabilities. Another plausible explanation for this is that the pilot occupational culture pushes pilots to strive to become better fighters and to use every tool that they have to their advantage, even if it is an unintended use/misuse of the system. Thus, Auto-GCAS then can be misused by future operational pilots despite a designer's intentions to prevent it. It would be beneficial to follow Auto-GCAS during actual operation to learn whether misuse would occur and the circumstances and reasons when this happens.

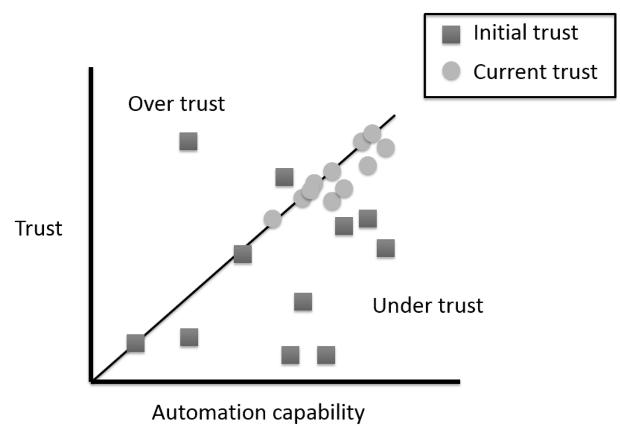

Figure 2: Self report of trust evolution of ETPs with Auto-GCAS

- Pilots are trained to be independent, self-reliant, and make life-or-death decisions using real-time data, thus it would be reasonable to hypothesize that they would dislike an automated system that took control of the aircraft away from them. To gain a better understanding of this attitude, and its implications for automatic systems such as Auto-GCAS, participants were asked to use the Sheridan and Verplank [13, 14] taxonomy to rate the highest level of Auto-GCAS automation that they would be comfortable with. The taxonomy uses 10 automation levels where level 1 is lowest level (Human does the whole job up to the point of turning it over to the computer to implement) and level 10 is the highest level (Computer does the whole job if it decides it should be done, and if so, tells human, if it decides that the human should be told). The majority of pilots (64%) indicated that they would be comfortable with level 7 (Computer does whole job and necessarily tells human what it did). The rest of the responses trended towards this ranking as well. This result at first seems surprising, but from a perspective of trust calibration and evolution, it reinforces the notion that having an extensive and positive experience with a technology facilitates acceptance of that technology's high automation levels. It is worth noting that the participants with the least amount of exposure to Auto-GCAS provided the lowest rankings. This gives evidence that pilots can be accepting of a highly autonomous system that takes control away from them. Again, this result needs further validation with data from actual operation.
- Automation transparency was an important topic that emerged in this study as it affected how pilots develop and calibrate their trust. Auto-GCAS has several different display features that contribute to its transparency to a pilot, one of which is the use of chevrons on the heads up display (HUD) as shown in Figure 3 (the chevrons are two carets pointing at each other). The chevrons will appear from the left and right sides of the HUD when the Auto GCAS system detects a potential collision. These chevrons move toward the middle of the HUD and intersect at a TAAGI of 1.5 seconds, when a pull up maneuver occurs. The interviews revealed a debate over whether the chevrons should be included. Pilots provided two opposing arguments on whether chevrons should be included in the fielded version of Auto-GCAS and whether they should default to "on." The chevrons provide feedback and help increase pilot awareness of an impending pull-up maneuver. However, there is a concern that the presence of the chevrons can alter the way in which pilots fly. For example, it could encourage them to become more brazen and aggressive. Pilots may also attempt to fly closer to terrain and use the chevron symbology as an indicator of how close they are to collision. However, some pilots argue that the chevrons are beneficial, as they give feedback to the pilot and allow the pilot to execute his/her own maneuver before the automation. The decision to have the chevrons be on or off by default during actual operation is a hotly debated topic. Typically, Developmental Test (DT) pilots believe that chevrons should default off while Operational Test (OT) pilots believe they should default on. These debates suggest that the design for automation transparency needs to take into account and balance the potential benefits of having information and the potential for misuse of the information. It also seems reasonable to hypothesize that if ETPs have already calibrated trust during the developmental stages with transparency-driven features such as the chevrons, then operational pilots may not need to have the chevrons. This also suggests that differing groups of pilots may need differing types of transparency to facilitate appropriate trust. These are questions that deserve further examination.
- By the high standards of their profession, only the best of the best pilots are selected to fly fighter aircraft. As such, these pilots possess a mindset of supreme confidence and low vulnerability, which they need in order to be effective in high-risk combat environments. This was supported by participant observations and responses in the surveys and interviews. In an extension of this mindset, a number of pilots commented in their interviews that Auto-GCAS will be beneficial for their colleagues but failed to mentioned how it will improve their own safety (because they are competent/good). It has been stated in interviews that "a pilot does not go out thinking he is going to crash into the ground." Pilots are very aware of the mortality of their profession, as nearly every pilot mentioned a colleague who has passed away due to CFIT. Pilots had a tendency to emphasis the need for Auto-GCAS as a benefit to the fighter pilot community, but not as a need for themselves. This attitude can lead to potential disuse of the system, and also needs further investigation.

Figure 3: HUD image with chevrons

- Misinformation, which can be defined as the operator either misinterpreting information or having inaccurate information, can have detrimental effects on the opinion and trust of a system because it affects the user's initial perception of the system [5]. Misinformation can exist in terms of the system providing incorrect information, but it can originate by misleading information from other people. During the course of the project, a number of instances of misinformation about Auto-GCAS appeared during interviews and participant/field observations. This included gossip that the system doesn't work (when in fact Auto-GCAS was not installed on any crashed aircraft), and pilots believing that they have flown Auto-GCAS (when in fact they have flown other systems, never Auto-GCAS). The misinformation can be attributed to the confusion from the heavy use of acronyms within government groups, the fielding of different systems with the same or similar names, the long developmental history of Auto-GCAS, and potential rumors spread by Auto-GCAS opponents. Consequently, distrust can be formed due to misinformation, creating a hurdle in fostering appropriate trust development.

DISCUSSION & FUTURE RESEARCH

Discussion

The research design of the extended case study and the implementation strategies were effective for conducting the study in a military environment that possessed numerous challenges. The methodological approach developed here can be used to study the cultural/organizational dimensions of human-automation trust in other technological systems.

The lessons learned, best practices, and research issues emerging from this study add to the body knowledge in trust research in a number of ways. First, the present results speak to the importance of transparency [7] as an influence on trust of automated systems. Specifically, the current results show that avoiding false alarms by the system was beneficial to the trust development of the ETPs. The system was designed and tested to approximate the appropriate time to impact threshold (i.e., time available to avoid ground impact) before initiating an action. This relates to the social intent facet of transparency described by Lyons [7], and demonstrates the importance of system design having a focus on the needs/wants of the user. That is, not only does this suggest that systems should evidence "benevolent intentions" but it also shows the costs of false alarms within automated systems, particularly for safety systems that assume control of one's aircraft. Second, the study shows that trust in automated systems can be calibrated through exposure and experience in real-world scenarios. In this instance, after pilots had experienced the successful initiation of the Auto-GCAS system, they were more likely to have positive trust perceptions associated with it. This is consistent with prior research by Hancock and colleagues [4] who found that system performance was the strongest predictor of human trust of robotic systems. Finally, the present study confirms the potential for anomalous unintended consequences associated with automated systems [11]. Safety systems, like Auto-GCAS, are designed to promote safe flight operations, and are effective at doing just that. Yet, the current study suggests that there may be times where a pilot engages in more risky flight patterns due to the understanding that the Auto-GCAS will protect them from a crash. This finding is an exemplar for Parasuraman and Riley's concept of "misuse" [11], caused by an over trust of a system. The use of a transparent HUD display (i.e., the chevrons) was implicated as a potential root cause driving the future possible overreliance (misuse) on Auto-GCAS in operational F-16 pilots. This raises important research issues concerning what the appropriate mechanisms are to foster appropriate transparency for safety systems that are used in high-risk operations, such as combat. Warfighters naturally seek to attain the highest level of performance possible, and as such, real-time transparency inputs may be used to calibrate one's sense of boundary conditions afforded by one's aircraft. There are a number of ways to instantiate transparency into human-machine contexts [7], and future research is certainly warranted to help engineers anticipate how humans will respond to novel designs. This study's findings can be used as the basis to explore how transparency mediates trust development. This can be accomplished with empirical studies in the context of the chevrons in Auto-GCAS and its sister Air Force Auto-Air Collision Avoidance (Auto-ACAS) system, which is currently under development and testing. These empirical results could then be used to spearhead applied research in creating transparency-oriented design principles and for infusing them into various phases of system development cycle.

Limitations

While the current study provided rich data from which to evaluate the utility and constraints associated with a complex form of automation, there were several limitations resulting from the methods employed. First, the target sample for the initial work involved test pilots and engineers associated with the Auto GCAS development and testing. The involvement of these individuals, while necessary, may have introduced a positivity bias into our results. Further, pilots without the extensive background/history with Auto GCAS may react differently to the technology than the ETPs who were very experienced in the technology. Future research is needed to examine reactions to Auto GCAS from pilots who were not involved in the development and testing of the system. A second limitation involves the lack of controlled experimental methods used in the study. Given that the data were qualitative, one cannot derive causal inference from the data. Controlled experimental studies are needed in order to identify causality within this domain, and one such experiment is briefly described below.

Conclusions & Future Research Avenues

The findings in this study suggest that Auto-GCAS design was in alignment with pilot culture and organizational mission, indicating a strong potential for appropriate trust development in operational pilots. However, these findings are based on pre-deployment data. Because trust calibration is a dynamic process, spanning the time from when the system is first conceived until it goes into operation and then retirement, it would be beneficial to conduct a field study of the deployment of Auto-GCAS with operational pilots. This is needed in order to collect data to validate the hypotheses and to examine the various research issues raised (e.g., potential Auto-GCAS misuse/disuse due to pilot occupational culture and/or operational circumstances, trust evolution from beginning of deployment to stages when opinions are stabilized). Such a field study would generate data and results that could influence and improve the design of the class of systems that take away control from the operator (like Auto-GCAS) while eliminating nuisance activations and preventing interference with the mission.

Future research may also focus on better understanding trust in automation disparities originating from cross-cultural differences, generational differences, and individual differences. Cultures align to various forms of social norms, expectations, and value sets. Prior research suggests that there are cultural differences in the domain of interpersonal trust [15], therefore differences in trust of automated systems in different cultural groups warrant future research consideration. Similar to individuals of a different cultural background, individuals of different age groups may also have differing expectations and comfort levels associated with novel technology. Research has shown that younger and older samples report different trust levels for novel automated tools involving anthropomorphic features, with younger individuals reporting higher trust relative to older individuals [10]. Thus, the speculation of younger pilots being more "comfortable" or "accepting" of the Auto-GCAS should be taken seriously and these effects should be given more systematic analysis. Lastly, future research should examine how individual differences influence reliance on automated tools. One promising domain that links to the current study is the construct of suspicion [1]. ETPs reported an inherent suspicion of new tools, which may be indicative of their career field or training. Given recent advances in the domain of automation suspicion in IT contexts [1] further research should examine what features of the technology, training, culture, or organizational doctrine are related to suspicion.

Potential Experimental Design

The qualitative data suggested that the use of chevrons as a form of transparency be examined further to determine if this manipulation has a positive or negative impact on how pilots use the system. An experiment could be developed to explore how the presence of the chevrons changes pilot behavior. For instance, researchers could provide some pilots with the chevrons, while not providing these to other pilots, during a simulation of the Auto GCAS system, and explore whether one group evidences significant changes in altitude flown. Other key metrics that could be included in this study are: trust in automation, efficacy in piloting at low altitudes, perceived risk, and attitudes toward safety.

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