Public Trust and Acceptance for Concepts of Remotely Operated Urban Air Mobility Transportation

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There is building interest within industry and government to enable Urban Air Mobility (i.e., air-taxies). One concept envisions remotely piloted aircraft, yet it is unclear how this will impact public trust and acceptance. **Method**: Two hundred participants read vignettes describing remotely-piloted UAM operations and then responded to a series of questionnaires. The study employed a one-way between-subjects design manipulating five levels of Pilot-in-Command Distance: Onboard Pilot; Remote Control Pilot; Dedicated Remote Operator; Remote Operator; System Manager. **Results**: The Remote Control Pilot group indicated they would be less likely than the Onboard Pilot group to use UAM, based on the mediating effect of trust in the automation. The Remote Control Pilot and Remote Operator groups indicated they would be less likely to use UAM than the Onboard Pilot group, based on the mediating effect of trust in the remote pilot/operator. **Conclusion**: Trust in UAM automation and remote pilots/operators will likely affect public acceptance of UAM.

Along with the expansion of traditional aviation operations, emerging entrants are offering a diverse set of aircraft to carry out new missions. The concept of Urban Air Mobility (UAM) represents an ambitious subset of these new entrants, and envisions a significant change to current transportation and package delivery paradigms. Enabling this change, however, requires technological leaps, reexamination of the role of the human pilot, and insight into how these changes will impact the general public's acceptance of this paradigm shift.

Urban Air Mobility

NASA defines Urban Air Mobility (UAM) as "a safe and efficient system for air passenger and cargo transportation within an urban area" (Chan et al., 2018, p. 4). The passenger transport element is a high frequency, high density extension of current passenger-carrying helicopter operations enabled by the newly emerging electric Vertical Takeoff and Landing (eVTOL) aircraft industry. In the United States, there are currently no certified passenger carrying eVTOL aircraft, but according to the Federal Aviation Administration (FAA), at least six aircraft intended for UAM operations are well along in the certification process (Garrett-Glaser, 2020). Initial passenger-carrying UAM operations are expected to begin by 2022, with hundreds of simultaneous operations within a city projected by 2028 (Hackenberg, 2019). Although FAA regulations are expected to require a pilot onboard the aircraft in the near-term, vehicle configurations and pilot/operator roles are expected to evolve as technology and regulations permit.

Remote Vehicle Operations (RVO). One concept of operations (ConOps) for UAM takes an RVO approach, in which aircraft are remotely controlled by some combination of one or more humans piloting a single aircraft or operating/managing many aircraft, with varying degrees of automation support. Beyond freeing a seat for a paying customer, lower human-to-aircraft ratios allow fewer humans to operate more aircraft. Indeed, the operational pace required to attain affordability may not be achievable with a limited number of available qualified pilots, as the training process of a commercial pilot is time and resource intensive (Holden & Goel, 2016). To achieve lower human-to-aircraft ratios, however, requires transitioning to higher levels of automation (LOA) across a broader range of functions than current operations support (see Parasuraman, Sheridan, & Wickens, 2000, for LOA discussion).

Pilot-in-Command (PIC) Distance. To discuss this transition, we introduce the concept of *Level of Pilot-in-Command (PIC) Distance*. This framework, although not adequately granular in description for all applications, provides an accessible method to label the roles of a human within RVO-based systems comprising a diverse set of technical capabilities and leveraging different function allocation strategies. Increasing Level of PIC Distance entails geographically removing the pilot from the aircraft, decreasing the human-to-aircraft ratio, and increasing the LOA for a greater number of functions previously carried out by the human (i.e., pilots transition to operators and then to system managers):

- **Level 1 - Onboard Pilot**: A single onboard pilot will be entirely responsible for the operation of the aircraft.
- **Level 2 - Remote Control Pilot**: There will not be a human pilot onboard the aircraft. Instead, a single ground-based, remotely located pilot will be entirely responsible for the operation of the aircraft.
- **Level 3 - Dedicated Remote Operator**: There will not be a human pilot onboard the aircraft. Instead, a single ground-based, remotely located pilot will be mostly responsible for the operation of the aircraft, with support from onboard automation.
- **Level 4 - Remote Operator**: There will not be a human pilot onboard the aircraft. Instead, a single ground-based, remotely located operator will be responsible for monitoring many automated aircraft. During emergency or challenging situations, however, that operator will have the ability to take control of that aircraft.
- **Level 5 - System Manager**: There will not be a human pilot onboard the aircraft. Instead, automation will be entirely responsible for the operation of the aircraft. However, a ground-based, remotely located operator will monitor many automated aircraft and provide situation updates (e.g., weather, traffic, winds) to the automation as needed.

Although economically attractive to UAM providers, a key assumption for pursuing RVO and increased Levels of PIC Distance, is that neither will also degrade safety nor the number of passengers that are willing to use UAM transportation; in other words *public acceptance*.

Public Acceptance of UAM via Trust

Acceptance is "the degree to which an individual incorporates a system in his/her goal-directed tasks, or, *if a system is not available, intends to use it*" (Adell, Varhelyi, & Nilson, 2014,p. 18; italics added). Public acceptance of UAM will be based on achieving and maintaining the perception that it is a safe and effective alternative to current transportation options. One aspect that will drive public acceptance is trust (cf. Booz Allen Hamilton's, 2018, UAM Market study). Trust is "an attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p. 51), where the perceived risk of being vulnerable to that agent (e.g., automation, human) is critical in translating trust into behaviors (Chancey, Bliss, Yamani, & Handley, 2017; Mayer, Davis, & Schoorman, 1995).

Lee and See (2004) proposed informational bases for human-automation trust: *Performance* describes the behaviors of the automation; *Process* describes how the automation is performing a task; *Purpose* describes why the automation was developed. Similar to interpersonal trust, a trustee's affective evaluation of their beliefs about the automation (i.e., Performance, Process, Purpose) form the basis to then adopt a particular level of trust. This level of trust determines the intention to then perform an action (e.g., public acceptance/intention to use UAM). Intentions capture the motivational factors that influence how much effort an individual is willing to exert to execute a behavior (Ajzen, 1991). Studies have shown that intentions to use technology are predictive of actual technology use (e.g., Davis, Bagozzi, & Warshaw, 1989; Venkatesh, Morris, Davis, & Davis, 2003).

Thus, the belief structure formed by information the public has about UAM transportation should generate a level of trust that subsequently affects public acceptance/intention to use UAM. Ghazizadeh, Lee, and Boyle (2012) proposed an indirect link between LOA and acceptance of technology through trust, where trust is reduced when the selected LOA is incompatible with achieving the goals of the human. Because Level of PIC Distance inherently incorporates LOA, trust should be predictive of intention to use UAM (i.e., trust should mediate the relationship). Researchers have begun to evaluate the role of trust in determining public acceptance for highly automated vehicles (e.g., Nees, 2016; Nordhoff, de Winter, Kyriakidis, van Arem, & Happee, 2018) and passengers' willingness to fly in pilotless fully automated commercial aircraft (Rice, Winter, Mehta, & Ragbir, 2019). Yet there is a relative dearth of research investigating the mediating role of trust in determining the effects of UAM ConOps on public acceptance; the purpose of this study was to fill this gap.

Hypotheses (H) and Research Questions (RQ)

- <u>H1:</u> Human-automation trust mediates the relationship between Level of PIC Distance and Intention to Use UAM transportation (Ghazizadeh et al., 2011).
- <u>H2:</u> The mediating effect of human-automation trust on intention to use UAM will be moderated by the perceived risk of UAM (Chancey et al., 2017; Mayer et al., 1995).
- <u>RQ1:</u> Does trust in the pilot mediate the relationship between Level of PIC Distance and intention to use UAM?
- <u>RQ2:</u> Does perceived risk moderate the mediating effect of trust in the pilot between Level of PIC Distance and intention to use UAM?

METHOD

Participants

The experiment included n = 200 (98 females) participants, with a mean self-reported age of 40.26 (SD = 10.76). Eligible participants were 18 years or older, had a "Master Qualification" status in Amazon's Mechanical Turk (MTurk), and currently resided in the United States (US). Participants received $1.81, which was based on the US federally-set minimum wage ($7.25) and an estimated 15 minutes to complete the study (completion time: M=14 m, 28 s, SD = 7 m, 44 s). Participants completed the study only once.

MTurk

The experiment was hosted on MTurk, an online crowdsourcing labor market created and managed by Amazon (Seattle, WA). Research indicates MTurk data show similarly adequate psychometric qualities as traditional lab-based studies, such as acceptable reliability levels (Buhrmester, Kwang, & Gosling, 2011) and external and internal validity (Berinsky, Huber, & Lenz, 2012). See Cheung, Burns, Sinclair, and Sliter (2017) for an overview, and Rice, Winter, Doherty, and Milner (2017) for an overview in aviation-related research.

Design

The experiment employed a one-way five level between-subjects design for Level of PIC Distance: Onboard Pilot (L1); Remote Control Pilot (L2); Dedicated Remote Operator (L3); Remote Operator (L4); System Manager (L5).

Dependent Measures. *UAM Automation* and *Pilot Trust* were measured with two modified versions of Madsen and Gregor's (2000) questionnaire used in Chancey et al. (2017). A modified version of Simon, Houghton, and Aquino's (1999) questionnaire was used to measure *Perceived Risk*. A modified version of Rahman, Lesch, Horrey, and Strawderman's (2017) questionnaire was used to measure *Intention to Use UAM*. Dependent measures showed adequate internal consistency with $\alpha_{Cronbach's} > .70$. For all measures, a statement was presented and participants indicated their agreement from Strongly Disagree (1) to Strongly Agree (100) on a slider.

Procedure

Participants were recruited via the MTurk website and directed to the experiment website, hosted on Survey-Monkey.com. Participants first received a participation agreement form, which required completion/agreement to continue. Participants then proceeded through an experimentally manipulated vignette describing UAM (see Appendix). Participants were randomly assigned to one of the five groups of PIC Distance. Following the vignette, participants were asked to indicate their trust in UAM automation, trust in UAM pilots, perceived risk of UAM, and intention to use UAM transportation (randomized item and questionnaire presentation order). Participants then completed a background questionnaire. Five additional questionnaires were also presented, the results of which are not presented in the current work: perceived ease of UAM use, attitude toward UAM, perceived usefulness of UAM, automation complacency-potential scale, and willingness to fly scale. Finally, participants were navigated to a debrief page, which described the experiment, links to information on NASA's UAM work, and an optional open-ended comment section.

Data Quality. Several approaches were taken to promote data quality (see Cheung et al., 2017):

Attention check items. Five inattentiveness items were randomly placed throughout the questionnaires. Participants were asked to make a specific response (e.g., "To check if you are reading carefully, please select any number in the forties"). Participants that did not correctly answer all five items were excluded from data analysis.

Completion times. Participants were given a maximum of one hour to complete the study. An outlier-labeling rule with a multiplier of 2.2 was consulted to identify lower-limit completion times (Hoaglin & Iglewicz, 1987). Participants that completed the entire experimental session quicker than 6 m, 50 s were excluded from the analyses.

Initial warning. A benign warning was included on the participation agreement screen:

> "I understand that my Human Intelligence Task (HIT) may also be rejected and payment forfeit if I fail to follow instructions or provide adequate responses according to the directions. Specifically, response patterns will be monitored and any indications of random responding will result in no compensation."

Limited questionnaire length. Rice et al. (2017) suggested limiting the study length to no more than 30 minutes, as participants tend to abruptly quit or begin responding randomly. The experiment was purposefully limited in both the length of the vignette and questionnaire items.

Questionnaire progression indicator. Rice et al. (2017) suggested providing a progress bar at the bottom of the screen to reduce the rate of participants that abruptly quit due to a lack of awareness for progression and remaining screens to complete. Therefore, each screen was accompanied by a visual cue and fraction of screens remaining to be completed.

RESULTS

Descriptive Statistics are presented in Table 1. Data were inspected for outliers and equal numbers among groups. To test the proposed mediation and moderated mediation hypotheses and research questions, multiple process models were constructed, which were based on a non-parametric bootstrapping method where the assumption of normality is not required (see Hayes, 2018, for complete description of this method). Process analyses employed standard errors based on the HC3 estimator, to address the assumption of homoscedasticity. The process analyses were based on indicator coding, where ratings for the Remote Control Pilot, Dedicated Remote Operator, Remote Operator, and System Manager groups were all compared to the Onboard Pilot Group. The mediating effects are referred to as relative indirect effects. To minimize the chances of making a Type I error, $p < .05$ was established to indicate statistical significance.

Table 1. *Means for Dependent Measures*

	Level of PIC Distance				
Source	***Onboard Pilot (L1)***	***Remote Control Pilot (L2)***	***Ded. Remote Op. (L3)***	***Remote Op. (L4)***	***System Man. (L5)***
Aut. Trust	66.62 (3.40)	58.28 (3.40)	61.88 (3.40)	63.00 (3.40)	60.77 (3.40)
• **Per.**	70.50 (3.58)	62.00 (3.58)	64.89 (3.58)	65.32 (3.58)	62.23 (3.58)
• **Pro.**	61.16 (3.65)	54.26 (3.65)	57.34 (3.65)	59.17 (3.65)	60.27 (3.65)
• **Pur.**	68.89 (3.55)	59.03 (3.55)	63.38 (3.55)	65.81 (3.55)	62.46 (3.55)
Pil. Trust	67.72 (3.34)	57.44 (3.34)	61.51 (3.34)	60.60 (3.34)	62.13 (3.34)
• **Per.**	69.80 (3.49)	61.87 (3.49)	63.28 (3.49)	66.03 (3.49)	65.93 (3.49)
• **Pro.**	63.98 (3.46)	52.00 (3.46)	55.72 (3.46)	52.88 (3.46)	56.53 (3.46)
• **Pur.**	68.89 (3.28)	59.40 (3.28)	65.28 (3.28)	62.81 (3.28)	64.99 (3.28)
Intention to Use	55.56 (5.36)	46.68 (5.36)	56.64 (5.36)	52.96 (5.36)	48.71 (5.36)
Perceived Risk	44.60 (4.26)	53.27 (4.26)	43.15 (4.26)	51.06 (4.26)	53.79 (4.26)

Note. Standard Errors in parentheses. Ded. Remote Op. = Dedicated Remote Operator, Remote Op. = Remote Operator, Aut. Trust = Automation Trust, Pil. Trust = Pilot Trust, Per. = Performance, Pro. = Process, Pur. = Purpose.

Trust in UAM Automation

A simple mediation analysis using the aggregate score of Trust in UAM automation did not reveal a significant relevant indirect effect between Level of PIC Distance and Intention to Use UAM. A follow-up parallel multiple mediation analysis in which the trust scores were analyzed as separate factors of Performance, Process, and Purpose, showed a significant relevant indirect effect for the Purpose factor. Participants in the Remote Control Pilot Group (L2) rated their Intention to Use UAM 5.43 points lower (*95% CI*[-11.88,-.17]) than the Onboard Pilot Group (L1) as a result of the Purpose-based Trust in UAM Automation. Neither the Performance nor Process bases of trust mediated the relationship between PIC Distance and Intention to Use UAM (Figure 1 and Table 2). The mediating effect of Trust in UAM automation on Intention to Use UAM was not moderated by the Perceived Risk of UAM.

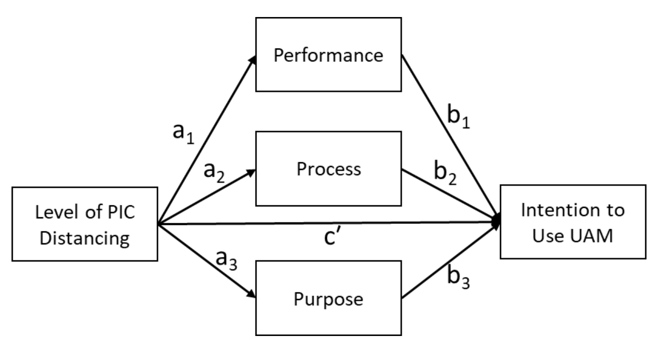

Figure 1. Parallel Multiple Mediation Model.

Table 2. *Path coefficients for the trust in UAM automation analyses for the parallel multiple mediation model in Figure 1.*

	Level of PIC Distance (Referencing the Onboard Pilot Group)				
Source	***Remote Control Pilot***	***Dedicated Remote Operator***	***Remote Operator***	***System Manager***	
a_1 (Perf.)	-8.50 (5.12)	-5.61 (4.99)	-5.18 (4.64)	-8.27 (5.54)	
a_2 (Pro.)	-6.90 (5.28)	-3.82 (5.72)	-1.99 (5.44)	-.89 (5.62)	
a_3 (Pur.)	-9.87^{a} (4.80)	-5.51 (5.09)	-3.08 (4.38)	-6.43 (5.44)	
b_1 (Per.)					.43^{b} (.17)
b_2 (Pro.)					.22 (.13)
b_3 (Pur.)					.55^{c} (.16)
c′	1.73 (5.64)	7.36 (4.94)	1.76 (5.59)	.44 (4.75)	

Note. Standard Errors (HC3) in parentheses. Perf. = Performance, Proc. = Process, Pur. = Purpose. $p = .041^{a}$, $p=.013^{b}$, $p<.001^{c}$.

Trust in the UAM Pilot/Operator/Manager

A simple mediation analysis using the aggregate score of Trust in the UAM pilot revealed a significant relevant indirect effect between Level of PIC Distance and Intention to use UAM. Participants in the Remote Control Pilot Group (L2) rated their intention to use UAM 13.15 points lower (*95% CI*[-23.95,-2.19]) than the Onboard Pilot Group (L1) as a result of their Trust in the UAM pilot. A follow-up parallel multiple mediation analysis in which the trust scores were analyzed as separate factors of Performance, Process, and Purpose, also revealed three significant indirect effects. Participants in the Remote Control Pilot Group (L2) rated their Intention to Use UAM 4.03 points lower (95% CI[-8.65, -.62]) than the Onboard Pilot Group (L1) as a result of Process-based trust in the UAM pilot. Participants in the Remote Operator Group (L4) rated their Intention to Use UAM 3.73 points lower (95% CI[-8.16, -.39]) than the Onboard Pilot Group (L1) as a result of Process-based trust in the UAM pilot. Finally, Participants in the Remote Control Pilot Group (L2) rated their Intention to Use UAM 6.91 points lower (95% CI[-13.89, -.49]) than the Onboard Pilot Group (L1) as a result of Purpose-based Trust in the UAM pilot (Table 3). The mediating effect of Trust in the UAM Pilot/Operator on Intention to Use UAM was not moderated by Perceived Risk of UAM.

Table 3. *Path coefficients for the trust in the UAM pilot/operator analyses for the parallel multiple mediation model in Figure 1.*

	Level of PIC Distance (Referencing the Onboard Pilot Group)				
Source	***Remote Control Pilot***	***Dedicated Remote Operator***	***Remote Operator***	***System Manager***	
a_1 (Perf.)	-7.93 (4.79)	-6.52 (5.22)	-3.77 (4.79)	-3.88 (5.36)	
a_2 (Pro.)	-11.95^{a} (4.65)	-8.23 (5.28)	-11.08^{b} (4.75)	-7.42 (5.02)	
a_3 (Pur.)	-9.49^{c} (4.47)	-3.62 (4.37)	-6.08 (4.56)	-3.90 (5.09)	
b_1 (Per.)					.26 (.15)
b_2 (Pro.)					.34^{d} (.12)
b_3 (Pur.)					.73^{e} (.13)
c′	4.10 (5.12)	8.16 (4.96)	6.53 (5.42)	-.51 (5.16)	

Note. Standard Errors (HC3) in parentheses. Perf. = Performance, Proc. = Process, Pur. = Purpose. $p=.011^{a}$, $p=.021^{b}$, $p=.035^{c}$, $p=.004^{d}$, $p<.001^{e}$

DISCUSSION

Supporting H1, participants who were told that the UAM pilot (i.e., 1:1 human-to-aircraft ratio) would remotely control the aircraft indicated they would be less likely to use UAM transportation as a result of their lack of trust in UAM automation (compared to the Onboard Pilot group). This mediating relationship was only present for Purpose-based trust in the automation, or trust based in why the automation was developed. Similarly, participants who were told that the UAM pilot would remotely control the aircraft also indicated that they would be less likely to use UAM transportation as a result of their lack of trust in the UAM pilot (compared to the Onboard Pilot group). This relationship was generally based on both Process-based trust (i.e., how the pilot is completing the task) and Purpose-based trust in the pilot (i.e., why the pilot is completing the task). Moreover, the results showed that participants were less likely to use UAM transportation when told that the aircraft would have a remote operator (i.e., 1:n human-to-aircraft ratio) as a result of their lack of trust in that operator (compared to the Onboard Pilot group). This relationship was observed for only Purpose-based trust in the pilot. None of the mediating relationships were moderated by perceived risk of UAM, failing to support H2.

Application. Aircraft manufacturers must consider numerous design constraints as they work toward developing safe and efficient UAM Transportation. This study suggests that passenger perception of the PIC should be included in these design constraints. Although regulations are expected to require onboard pilots as air-taxi services are initially introduced, a transition to remotely controlled operations appears inevitable (cf. Thipphavong et al., 2018). This study implies that this transition may require careful understanding and calibration of passenger trust to maintain adequate levels of passenger acceptance. Additional research will be required to determine the most effective methods, but approaches should consider the level of automation transparency available to the passenger if the pilot is not onboard the vehicle.

Limitations and future research. This study provides preliminary evidence to suggest trust affects public acceptance of UAM, given a Level of PIC Distance. Yet these results should not be over interpreted. Although participants were likely able to make some judgement for likely use, UAM is novel and may be difficult to imagine (based on a vignette description) for a majority of the general public. Future studies should use immersive testing environments and provide participants with a more complete mental model of UAM operations. Additionally, because of the lack of similar UAM-specific studies, it is difficult to place the magnitude of statistically significant results in context (i.e., replication is required). Finally, research should compare UAM to established forms of transportation (e.g., commercial airlines, public and private ground-based transportation), to further contextualize results.

Conclusion

Proposed RVO-based concepts of UAM operation may be used by/acceptable to the general public if human-automation trust is properly addressed, given the current results. Additionally, trust in UAM automation and pilots will likely affect public acceptance. Yet, this study represents only an initial evaluation of public acceptance, and further research and replication is required.

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APPENDIX

This study is investigating whether people will use a new form of airborne public transportation. This "air-taxi" service will be affordable, occur frequently, and include many airborne aircraft operating in close proximity. This service will use a new type of Vertical Takeoff and Landing aircraft, or VTOL (pronounced vee-tol), which will enable frequent, short-distance flights between fixed locations, through dense urban centers and into surrounding suburbs. Each VTOL will carry two to six passengers and travel 10 to 70 miles between destination points. The goal of VTOL transportation is to provide the public with an affordable alternative method of traveling with benefits such as alleviating traffic congestion on busy streets, reducing the travel time commuters experience each day, and minimizing noise and pollution through use of electric power. The figure below shows a visual concept of what VTOL transportation might look like over a city. (See image at: https://www.nasa.gov/sites/default/files/thumbnails/image/uam-3-4x3-v2-sm.jpg) To make VTOL transportation affordable to the general public, many aircraft (100s) will need to be operating continuously over a single city or area. Moreover, [PIC Distance Here].