UAS Measured Response: The Effect of GCS Control Mode Interfaces on Pilot Ability to Comply with ATC Clearances

R. Conrad Rorie & Lisa Fern
San Jose State University

The present study examined the effects of three different control mode interfaces on unmanned aerial system (UAS) pilots' ability to comply with air traffic controller (ATC) traffic clearances. Pilots controlled a simulated UAS with a waypoint-only interface, an auto-pilot interface and a manual, stick and throttle interface. Researchers recorded pilots' 'measured response' at several stages of ATC-pilot interaction, which consisted of verbal response times, initial response times, initial edit times, total edit times, and overall compliance times. Results indicate that pilots are best able to comply with ATC clearances when provided with auto-pilot and manual control inputs. Limitations to the present study and future analyses are discussed.

INTRODUCTION

Integration of Unmanned Aerial Systems (UAS) into the U.S. National Airspace System (NAS) will require that "UAS operators comply with existing, adapted, and/or new operating rules or procedures" (Federal Aviation Administration [FAA], 2012). Among these operating rules and procedures is the ability to comply with Air Traffic Control (ATC) clearances. UAS will be expected to respond to, and complete, these clearances in a timely manner similar to manned aircraft (ICAO, 2011). However, acceptable response times for manned aircraft are based on decades of integrated operation and existing airworthiness standards, both of which are lacking for UAS. Further, though FAA regulations require pilots to respond promptly so as not to compromise the safe operation of aircraft in the airspace, actual, quantitative acceptable response times are not provided.

In an effort to quantify pilot performance, recent research has defined the end-to-end response time for a UAS to complete a clearance as Measured Response (MR) (Shively, Vu & Buker, 2013; Vu, Morales, Chiappe, Strybel, Battiste, Shively & Buker, 2013). Shively, et al. (2013) identify four discrete components of MR: 1) time for the pilot to verbally reply to ATC 2) time for the pilot to initiate an edit following an ATC clearance, 3) time for the pilot to execute the edit following an ATC clearance, and 4) the time to reach a just noticeable difference on the ATC display following the execution of the edit. Shively et al. study found that execution times (MR-3) were negatively correlated with ATC acceptability ratings. A follow-on study by Vu et al. (2013), found that longer verbal communication delays (MR-1) also resulted in lower ATC acceptability ratings and more step-ons (pilot and ATC talking simultaneously). These studies suggest that MR can serve as a useful tool for evaluating UAS response times in order to better understand the performance of UAS interface designs and their potential effects on ATC.

Due to a lack of clear guidelines or standards, current operational UAS vary widely in their command and control (C2) interfaces and automation. Some UAS, like the RQ-4 Global Hawk, rely heavily on a preprogrammed waypoint-to-waypoint navigation mode with pilots typically operating "on-the-loop" as supervisors of the aircraft's autopilot system. Pilots of other UAS, like the MQ-9 Reaper, typically fly "in-the-loop," utilizing Hands on Throttle-And-Stick (HOTAS) to perform tasks that closely resemble those traditionally associated with manual flying. Thus a critical question for UAS operations in the NAS, is: what happens when a pilot operating on-the-loop needs to quickly get in-the-loop to comply with ATC in a timely manner?

A previous study examined the effect of different levels of automation in C2 interfaces on pilots' ability to respond to conflict avoidance resolution advisories (Kenny & Fern, 2012). Response times, defined as the time from the initial resolution advisory until the pilot uploaded a response in the simulated GCS, were found to be significantly slower for lower levels of automation. The highest level of automation had a 3.5 sec average response time while the lower automation levels had average response times of 10.8 and 12.2 sec. The results of the study indicate that the C2 interface and automation level could significantly affect pilot response times to ATC clearances.

The present study examines the effect of different C2 interfaces on UAS pilots' ability to get in-the-loop to respond to ATC clearances. The authors presented UAS pilots with three different control mode interfaces, each requiring different strategies for getting into the loop. Pilots were tasked with flying a simulated UAS through civil airspace, responding to and complying with ATC when necessary. Seven different MR components were recorded and compared across the three control interfaces.

METHOD

Participants

Fifteen active duty RQ-4 pilots (*M* = 34 years of age) with an average of 98 hours of experience flying UAS in civil airspace were recruited to participate in this study. Participants had an average of 323 hours of combined experience in military combat and military non-combat UAS operation. A single retired air traffic controller served as a confederate.

Simulation Environment

Participants interacted with the simulation software using desktop PCs and standard keyboard and mouse inputs. The UAS pilot participants were situated at a UAS Ground Control Station (GCS) provided by the Air Force Research Laboratory's (AFRL) Vigilant Spirit Control Station (VSCS) software (Feitshans, Rowe, Davis, Holland & Berger, 2008).

Participants sat in front of two separate monitors. Their primary monitor contained VSCS's Tactical Situation Display (TSD; shown in Figure 1), which displayed the UAS ownship and mission route over a moving map. All C2 commands performed by the participants were executed using editing and navigation windows within the TSD. A second monitor displayed VSCS's simulated out-the-window nose camera view. This 'soda straw' nose camera view provided pilots with accurate terrain information and an integrated head up display that contained current airspeed, altitude and heading information. No outside traffic was viewable in the out-the-window view.

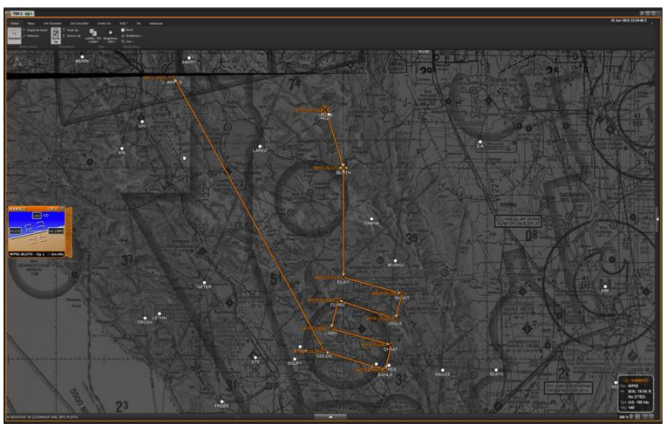

Figure 1. Vigilant Spirit Control Station tactical situation display (AFRL/RH). Distribution A: Approved for public release; distribution unlimited, 3/18/2013; 88ABW-2013-1303

The rest of the simulation environment included ATC and pseudo-pilot stations, and simulated manned aircraft scenarios provided by the Multi-Aircraft Control Station (MACS) software suite (Prevot, 2002). The pseudo-pilots were able to monitor, control and respond as any of the manned aircraft within the controller's sector. The controller, pseudo-pilots and UAS pilot all communicated over a common frequency using push-to-talk headsets.

Experimental Design

This study utilized a within-subjects, repeated measures factorial design to assess the MR of UAS pilots complying with ATC clearances while operating in civil airspace. Three control mode conditions were presented to pilots: Waypoint-to-Waypoint, Auto-Pilot, and Manual. Each control mode provided pilots with a variety of control interfaces for uploading changes to the UAS in compliance with ATC. Pilots were given permission to make edits using any interface they desired within a given control mode condition. The order of presentation of the overall control mode condition was counterbalanced across participants.

Control Modes and Interfaces. The Waypoint-to-Waypoint control mode condition consisted of two default VSCS control interfaces: waypoint editing and altitude override. (As default features, these interfaces were available to pilots in all three of the control mode conditions.) The waypoint editing interface allowed pilots to implement changes to the assigned altitude or location of one or more waypoints on their flight plan at a time. The override interface allowed pilots to take the UAS off the altitude assigned by the waypoints on their route.

Lateral maneuvers in Waypoint-to-Waypoint control mode were only achievable using the waypoint edits. In cases where ATC required the pilot to fly a heading vector, pilots had to edit their flight plan to include a waypoint in the direction of the required heading. Vertical maneuvers in this condition, however, were achievable either through waypoint edits, where pilots could change the assigned altitude for one or more waypoints at a time, or through an altitude override option, which kept the aircraft at the specified altitude until the function was disengaged. In general, edits made using the waypoint interface required pilots to complete four steps: 1) enter 'edit mode', 2) implement the desired location or altitude changes to the waypoint(s), 3) upload the changes to the aircraft, and 4) confirm the changes to the aircraft's flight plan. Altitude modifications made via the override function required pilots to: 1) engage the override via a 'steering window' for the UAS, 2) input the desired altitude, and 3) upload the changes to the aircraft.

The Auto-Pilot control mode condition provided pilots with an additional navigation interface that was capable of altitude, heading, and speed holds. In this condition, lateral maneuvers were achievable either through waypoint edits (a default feature) or through the new Auto-Pilot heading hold function. Vertical maneuvers were still achievable through the default waypoint editing and override interfaces as well as the Auto-Pilot altitude hold function. To execute maneuvers via the Auto-Pilot interface, pilots were required to: 1) enter Auto-Pilot mode, 2) input the desired altitude, heading or speed hold, and 3) upload the changes to the aircraft.

A final control mode condition, Manual, replaced the Auto-Pilot navigation mode with a new interface that supported pilot inputs from a HOTAS. In this control condition, lateral maneuvers were achievable either through waypoint editing or through joystick deflections. Vertical maneuvers were achievable through waypoint edits, the override function, or joystick deflections. The HOTAS model utilized in the study required continuous deflection until the desired heading or altitude was reached. To execute maneuvers using the Manual interface, pilots were required to: 1) enter Manual mode, and 2) deflect the joystick or throttle until the desired state was reached. Unlike the previously mentioned control interfaces, the Manual control interface required only a change in navigation mode in order to start the aircraft's maneuver.

Pilot Task. Pilots were tasked with operating a simulated MQ-1 Predator (HAWK21) along a pre-filed flight path in

Class A and E Oakland Center airspace (ZOA 40/41). Pilots flew under instrument flight rules (IFR). The pilots were required to verbally reply to and immediately comply with any advisories or clearances issued by ATC.

ATC issued four types of clearances in response to traffic and weather concerns: 1) altitude vector, 2) heading vector, 3) direct to (flying to a further waypoint along the pilot's current path), and 4) return to course. The clearances presented to pilots in this study were not experimentally controlled or counterbalanced; rather, the ATC confederate issued them in genuine response to a simulated, dynamic, traffic environment. The number of each type of clearance was approximately the same for each participant.

Scenarios. Pilots flew the same route for all three of the experimental conditions. The scenario launched with the UAS at 19,000 ft and quickly required the pilot to descend to 6,000 ft. Once at 6,000 ft the route simulated a stepped grid pattern, where each leg of the grid required the pilot to climb 1,000 ft. At the end of the grid pattern, the pilot returned the UAS to 19,000 ft. All altitude changes were performed by the pilot and coordinated with ATC. The traffic patterns and density were developed alongside an ATC subject matter expert and designed to represent a busy, current day at Oakland Center.

Procedure

Participants completed an informed consent for minimal risk form and a demographic survey that elicited information about their manned and unmanned flight experience.

Training. Participants began with extensive training on the basic functionality of VSCS. Prior to each experimental trial, participants were briefed on the unique aspects of the relevant control mode interface and then completed a 20 min practice scenario.

Experimental Trials. Participants completed three experimental trials, one in each of the control mode conditions. Experimental trials were 45 min long. After each trial, participants completed the NASA Task Load Index (TLX; Hart & Staveland, 1988) and a post-trial subjective questionnaire. At the end of the experiment, participants completed a post-simulation questionnaire.

MEASURES

Pilots' MR values were extrapolated from time stamps at six different stages of interaction between ATC and the UAS pilot (Table 1). These stages corresponded to the operationally relevant steps required to successfully comply with an ATC clearance. (For the purposes of this study, inputs to the C2 interface in order to comply with a clearance are termed "edits.") The time stamps were collected from a variety of data sources, including raw MACS and VSCS output files, voice logs and recordings, and screen recordings of the pilot display. Screen recordings of the pilot display were also referenced post hoc to provide context of the results.

The following measures were calculated for all ATC-initiated clearances using the time stamps listed in Table 1. All response times (RTs) were calculated in seconds. See Figure 2 for a graph depicting the temporal relationship between all the metrics described below.

Table 1. Stages of ATC-Pilot Interaction

Stage	Description	Example
T_0	Initial ATC Transmission	"HAWK21, turn left heading 1-2-0, vectors for your descent"
T_1	Pilot Reply	"Turn left heading 1-2-0, HAWK21"
T_2	Pilot Initiates Edit	Pilot opens editing window
T_{3a}	Pilot Uploads 1st Edit	Pilot incorrectly uploads *110˚ Hdg* to the aircraft
T_{3b}	Pilot Uploads Final Edit	Pilot correctly uploads *120˚ Hdg* to the aircraft
T_4	UAS Completes Maneuver	HAWK21 reaches 120º Hdg

Verbal RT (T_1-T_0). A measure of the time it takes a pilot to verbally respond to an ATC advisory or clearance. Calculated as the time between the end of the controller's relevant clearance and the beginning of the pilot's response.

Initial RT (T_2-T_0). A measure of the time it takes a pilot to initiate the edit process in response to an ATC clearance (e.g., begin a switch from WP navigation mode into AP or M). Calculated as the difference between the end of a controller's transmission and the start of the relevant edit.

Initial Edit Time (T_{3a}-T_2). A measure of the time it takes a pilot to make their initial edit. Calculated as the time between starting an edit and uploading it to the UAS. (Metric only relevant when pilots made multiple uploads.)

Total Edit Time (T_{3b}-T_2). A measure of the time it takes a pilot to complete an edit. Calculated as the time between the start of an edit and the final, correct upload to the aircraft.

Aircraft RT (T_{3a}-T_0). The time it takes the pilot to start the aircraft maneuver. Calculated as the difference between the end of the relevant ATC clearance and the initial upload to the aircraft.

Compliance Time (T_4-T_0). A measure of the time it takes a pilot to complete all stages of the ATC-Pilot interaction. Calculated as the time between the end of an ATC clearance and the completion of the maneuver by the pilot and aircraft.

RESULTS

Each of the metrics described above were analyzed using a one-way repeated measures ANOVA. An alpha level of .05 was used for all analyses, with Bonferroni corrections made for pairwise comparisons. The results that follow compare pilots' ability to respond to ATC clearances with three of the input methods described previously: the waypoint editing interface (WP), the Auto-Pilot interface (AP), and the Manual interface (M). Edits using the altitude override function were excluded to allow for a more direct comparison of the specific WP, AP and M interfaces.

These analyses also exclude ATC clearances that commanded lateral maneuvers greater than 90 degrees and vertical maneuvers greater than 1000 feet. These events were removed in order to keep the maneuvers sizes within a range consistent with typical ATC clearances around traffic.

Verbal RT

Input method was not found to have a significant impact on pilots' ability to reply to ATC, $F(2,28) = 1.21$, $p > .05$. While not significantly different, pilots replied faster to the controller when they went on to use the WP interface ($M = 1.31$, $SE = 0.07$), followed by the M interface ($M = 1.34$, $SE = 0.12$) and the AP interface ($M = 1.47$, $SE = 0.12$).

Initial RT

Input method was found to have a significant impact on initial RT, $F(2,28) = 10.20$, $p < .01$ (Figure 3). Pilots initiated the edit process following an ATC clearance the quickest using the AP interface ($M = 1.22$, $SE = 0.92$), with initial RTs roughly twice as long when using the M interface ($M = 3.69$, $SE = 0.67$) and five times as long with the WP interface ($M = 6.00$, $SE = 0.93$). The difference between AP and WP was significant ($p < .05$), while the difference between AP and M only approached significance ($p = .07$). The WP and M interfaces did not differ significantly.

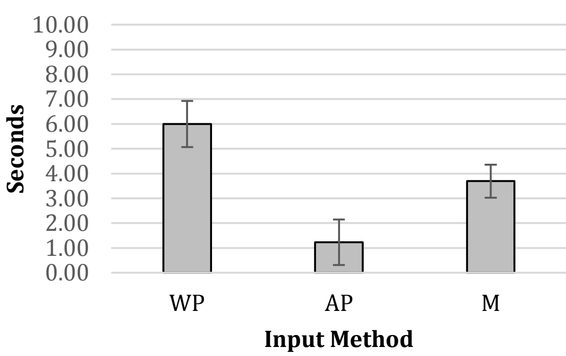

Figure 3. Mean Initial RTs (and standard error) by method.

Initial and Total Edit Time

Initial edit times were found to vary significantly between input methods, $F(2,28) = 103.58$, $p < .001$ (Figure 4). Both the AP interface ($M = 9.11$, $SE = 0.76$) and the M interface ($M = 1.38$, $SE = 0.26$) led to significantly shorter initial edit times than the WP interface ($M = 15.31$, $SE = 0.78$; p's $< .001$). The M interface also led to significantly shorter initial edit times than the AP interface ($p < .001$).

Total edit times followed the same pattern observed for initial edit times, but were more pronounced. Input method again had a significant main effect, $F(2,28) = 68.41$, $p < .001$ (Figure 4). Total edit times were significantly shorter for the AP interface ($M = 9.24$, $SE = 0.75$) and the M interface ($M = 1.38$, $SE = 0.25$) than they were for the WP interface ($M = 32.79$, $SE = 3.19$; p's $< .05$). The M interface also had significantly shorter total edit times than the AP interface ($p < .001$).

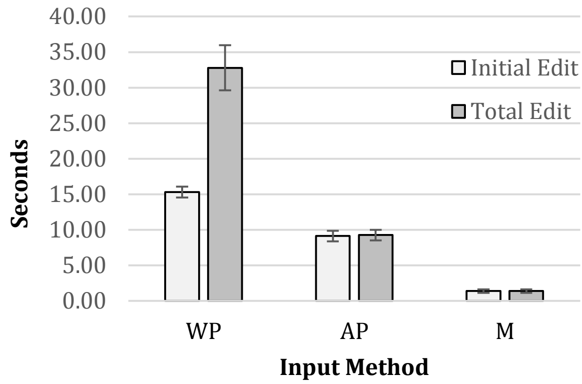

Figure 4. Mean initial and total edit times (and standard error) by input method.

Aircraft RT

Input method had a significant effect on aircraft RTs, $F(2,28) = 113.15$, $p < .001$. As seen with the edit times, pilots were able to start the aircraft's maneuver quickest using the M interface ($M = 4.70$, $SE = 0.43$) and the AP interface ($M = 10.43$, $SE = 1.16$), which were both significantly quicker than the WP interface ($M = 21.66$, $SE = 1.15$; p's $< .001$). The M interface also led to significantly shorter aircraft RTs than the AP interface ($p < .01$).

Compliance Time

Input method also had a significant main effect on overall compliance times, $F(2,28) = 44.73$, $p < .001$. The M interface led to the shortest compliance times ($M = 27.40$, $SE = 1.72$), which were found to be significantly shorter than the WP interface compliance times ($M = 54.05$, $SE = 2.37$), but were not found to be significantly shorter than the AP interface compliance times ($M = 31.33$, $SE = 1.74$).

DISCUSSION AND CONCLUSION

The data presented above demonstrate the various effects that method of input has on UAS pilots' ability to comply with ATC clearances at different stages of the pilot-ATC interaction. In the earliest stage of interaction, verbal response, pilots were consistent across all three input methods, responding, on average, 1.5 seconds after the ATC finished the clearance. This finding is not surprising, since this stage of interaction required no use of the control interfaces. The second stage of interaction, initial RT, however, did see a significant effect of input method. Pilots' initial RTs when using the AP interface were roughly five seconds shorter than initial RTs with the WP interface, and roughly two seconds shorter than those for the M interface. Review of video recordings of participants using the AP interface revealed that pilots often pre-loaded their edits into the interface while the controller was still issuing a clearance. The simplicity of the AP interface, as well as the ability to keep the window open for extended periods of time, likely led to more immediate inputs in this mode than were seen with the WP or M interfaces.

The next three stages of interaction – initial edit time, total edit time, and aircraft RT – saw significant benefits for pilots using the M interface. The relatively small times observed for Manual edits were due to the fact that pilots simply had to enter Manual mode in order to start the aircraft maneuver. Edits to the AP interface required pilots to, in addition to a navigation mode change, enter the desired altitude or heading value into the relevant window, while edits to the WP interface required pilots to either reposition waypoints or edit their flight plan altitude. These additional steps are likely responsible for the longer edit times for those control interfaces.

As highlighted in Figure 4, WP edits also exhibited substantial differences between the initial and total edit times, a finding that was not observed with edits made using the AP or M interfaces. This suggests that pilots made more uploads, on average, when editing waypoints than when using the other two methods. The AP and M methods, with virtually no difference between their initial and total edit times, likely allowed pilots to implement desired changes on the first attempt. A review of video recordings of pilots using the WP editing interface showed participants often making multiple, lengthy edits to their flight plan when trying to fly a heading vector by repositioning waypoints along their path. This imprecise method of reaching a new heading is likely the primary cause for the differences in initial and total edit times for the WP interface.

The last stage of interaction, overall compliance time, also showed a significant effect of input method. With the cumulative effects of the earlier stages of interaction, the AP and M methods led to overall compliance times nearly 50% shorter than those found following WP edits. All together, the findings suggest that the AP interface uniquely benefited pilots getting "in-the-loop," as demonstrated by shorter initial RTs. The M interface, however, supported more immediate maneuvering than the AP or WP interfaces, demonstrated by shorter edit times and aircraft RTs.

Most apparent in this data are the limitations of a system restricted to only waypoint edits. The increased number of steps required to upload waypoint changes to the aircraft, as well as an inability to enter simple heading holds, led to less timely and less accurate performance. These findings argue in favor of UAS ground control station interfaces that support pilots' ability to get into-the-loop and make quick, precise altitude or heading maneuvers. Such interfaces, whether software-based (as with the AP interface) or hardware-based (as with the M interface), may best support pilots' ability to conform to ATC expectations and overall airspace requirements.

Limitations and Future Research

It is worth noting that the data provided in this paper presents only a subset of the data collected in this study. As already mentioned, any edits made using the altitude override function were discarded since the researchers were interested in pilot performance with the specific waypoint, auto-pilot and manual interfaces modeled within VSCS. Also excluded from the paper are lower level analyses, such as those that take into account the type of ATC clearance, and participant responses to the post-trial, post-simulation and workload questionnaires.

Lastly, the data presented above must only be interpreted within the context of one instantiation of a GCS. The results cannot be generalized to the C2 interfaces of any other operational GCSs, due to the fact that the three control modes modeled in this paper were specific to the VSCS operator interface.

Despite these limitations, the authors feel the data demonstrate the ability of various control mode interfaces to have a substantial effect on pilot performance. Future research and analyses should continue to define the interface requirements of UAS pilots operating in civilian airspace.

REFERENCES

Federal Aviation Administration (2012). Integration of unmanned aircraft systems into the national airspace system: Concept of operations.

Feitshans, G. L., Rowe, A. J., Davis, J. E., Holland, M., & Berger, L. (2008). Vigilant spirit control station (VSCS)—'The face of COUNTER'. *In Proceedings of AIAA Guidance, Navigation and Control Conf. Exhibition*, Honolulu, HI. AIAA Paper (No. 2008-6309).

Hart, S., & Staveland, L. (1988). Development of NASA TLX (task load index): Results of empirical and theoretical research, In P. Hancock and N. Meshkati (Eds.), Human Mental Workload (pp. 139-183). Elsevier, Amsterdam, 1988.

ICAO. (2011). Unmanned Aircraft Systems (UAS) (ICAO Cir 328). Montreal, Canada: International Civil Aviation Organization.

Kenny, C. & Fern, L.C. (2012). Varying levels of automation on UAS operator responses to traffic resolution advisories in civil airspace. In Landry, S. J. (Eds.), Advances in human aspects of aviation (pp. 279–288). Boca Raton, FL: CRC Press.

Prevot, T. (2002). Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System MACS. *In Proceedings of the HCI-Aero* (pp. 149-154).

Shively, R. J., Vu, K.-P. L., & Buker, T. J. (2013, October). Unmanned aircraft system response to air traffic control clearances: Measured Response. *In Proceedings of the 57th Annual Human Factors and Ergonomics Society International Annual Meeting*. San Diego, CA.

Vu, K. P. L., Morales, G., Chiappe, D., Strybel, T. Z., Battiste, V., Shively, J., & Buker, T. J. (2013). Influence of UAS pilot communication and execution delay on controller's acceptability ratings of UAS-ATC interactions. *In Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd* (pp. 6D4-1). IEEE.