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

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AS3 - Breaking Down Barriers to UAS Integration

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Background

• Integration of unmanned aerial systems (UAS) into the National Airspace System (NAS):
  – In order to comply with existing operating procedures, UAS will need to comply with ATC clearances within an acceptable amount of time
    • An ‘acceptable’ amount of time has not been quantified or provided by the FAA
  – Several studies have started the task of quantifying UAS pilot ‘measured response’ (i.e., end-to-end response time to complete a clearance)
    • Shively et al. (2013) examined 4 different components of measured response (verbal response time, initiation time, execution time, and maneuver completion time)
      – Found that longer execution times resulted in lower air traffic controller acceptability ratings
    • Vu et al. (2013) found that longer verbal communication delays also resulted in lower controller acceptability ratings, as well as more ‘step-ons’
Background

- Since excessive verbal response and execution times result in lower levels of acceptability from controllers, the question then turns to:
  - How do we design the ground control station to promote efficient and effective pilot responses?
    - Do certain control mode interfaces prove more effective for UAS pilots trying to get “into-the-loop”
  - Different UAS platforms utilize very different control mode interfaces
    - RQ-4 (Global Hawk) pilots fly using mouse and keyboard
    - MQ-9 (Reaper) pilots fly using a stick and throttle
  - Important to understand the differences that arise from these different ground control station input methods
    - Kenny & Fern (2012) found that higher levels of automation lead to faster execution times when pilots were responding to resolution advisories
• Goal of present study:
  – Examine the effects of different command and control interfaces on UAS pilots’ ability to get in-the-loop in response to ATC commands
  • 3 different control mode interfaces:
    – Waypoint-to-Waypoint control mode
    – Auto-pilot control mode
    – Manual control mode
  • Pilots tasked with flying a simulated UAS through civil airspace, responding to and complying with ATC when necessary
  • Seven different components of measured response were recorded and compared across the 3 control interfaces
Method

- **Participants:**
  - 15 RQ-4 Global Hawk pilots ($M = 34$ years of age)
    - Average of 98 hours of experience flying in civil airspace
    - Average of 323 hours of combined military combat and military non-combat UAS operation
  - 1 retired Air Traffic Controller

- **Pilot Task:**
  - Operate a simulated MQ-1 (HAWK21) along a pre-filed flight plan under Instrument Flight Rules
    - Responsible only for air vehicle navigation (no sensor operation)
  - Respond to ATC traffic advisories and clearances
  - Route inside Oakland Center airspace
    - Flew Class A and Class E airspace, encountering IFR and VFR traffic
    - Simulated a busy day
Method

- Ground Control Station
  - Vigilant Spirit Control Station (Air Force Research Laboratory)
    - Tactical Situation Display (TSD; shown below) provided ownship information, moving map, and editing and navigation windows for uploading command and control information
Method

• Control Mode Interfaces
  – Waypoint-to-Waypoint
    • Heading maneuvers
      – Pilots required to edit their flight plan to include a waypoint in the desired direction
    • Altitude maneuvers
      – Pilots had option to change flight plan altitude or use altitude override function
Method

• Control Mode Interfaces
  – Auto-Pilot
    • Heading maneuvers
      – Pilots provided with Compass Rose GUI to fly heading vector
      – Pilots were still able to make edits using waypoint interface
    • Altitude maneuvers
      – Pilots provided with navigation window that altitude holds
      – Pilots still able to make edits using waypoint and override interface

Compass rose has drag-able heading bug and heading and altitude spinners

Heading, altitude and speed holds can be input to the steering window interface
Method

• Control Mode Interfaces
  – Manual
    • Heading maneuvers
      – Pilots able to switch into stick and throttle control
      – Pilots were still able to make edits using waypoint interface
    • Altitude maneuvers
      – Pilots able to switch into stick and throttle control
      – Pilots still able to make edits using waypoint and override interface
# Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Calculation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Verbal Response Time</td>
<td>$T_1 - T_0$</td>
<td>Time it took for pilots to respond verbally to ATC advisories and clearances</td>
</tr>
<tr>
<td>Initial Response Time</td>
<td>$T_2 - T_0$</td>
<td>Time it took for pilots to initiate edits in response to ATC clearances</td>
</tr>
<tr>
<td>Initial Edit Time (1st Upload)</td>
<td>$T_{3a} - T_2$</td>
<td>Time it took pilots to upload their first edit from the moment they began editing</td>
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<tr>
<td>Total Edit Time (Final Upload)</td>
<td>$T_{3b} - T_2$</td>
<td>Time it took pilots to upload their final edit from the moment they began editing</td>
</tr>
<tr>
<td>Compliance Time</td>
<td>$T_4 - T_0$</td>
<td>Time it took the UAS operator to complete all stages of ATC-Pilot interaction</td>
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</table>
Metrics

Total Compliance Time

Initial Response Time

Verbal Response Time

Initial Edit Time (First Upload)

Total Edit Time (Final Upload)

T₀
ATC: “Turn Left 1-2-0”

T₁
Pilot: “Roger. Left 1-2-0”

T₂
Pilot: Opens Edit Window

T₃a
Pilot: Uploads 1st Edit

T₃b
Pilot: Uploads Final Edit

T₄
UAS: Completes Maneuver

Initial Edit Time

Total Edit Time

Initial Response Time

Total Compliance Time
Results

• Each of the 5 measured response metrics were analyzed using one-way repeated measures ANOVA
  – Pilots’ ability to comply with ATC clearances compared across the three different input methods
    • Waypoint editing interface – required all modifications to be made via waypoint edits
    • Auto-pilot interface – provided pilots with ability to enter heading and altitude holds
    • Manual (stick and throttle) interface – provided pilot with ability to switch to a stick and throttle input
• **Verbal Response Time**
  – Input method did not have a significant impact on pilots’ ability to reply to ATC in a timely manner ($p > .05$)

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Results

- **Initial Response Time**
  - Autopilot resulted in significantly shorter Initial Response Times than Waypoint-to-Waypoint ($p < .05$); difference with Manual mode approached significance ($p = .07$)
    - AP resulted in 80% shorter initial response times than WP mode and 65% shorter times than Manual mode

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Results

- **Initial and Total Edit Times**
  - Manual resulted in significantly shorter initial and total edit times than WP or AP ($p<.001$)
    - Initial Edit Times: 90% shorter than WP, 85% shorter than AP
    - Total Edit Times: 95% shorter than WP, 85% shorter than AP
  - Autopilot also resulted in significantly shorter initial and total edit times than WP ($p < .001$)
    - Initial Edit Times: 40% shorter than WP
    - Total Edit Times: 70% shorter than WP

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Results

• Compliance Times
  – Manual and Autopilot both resulted in significantly shorter total compliance times than WP ($p < .001$)
    • Autopilot led to 40% shorter total compliance times than WP
    • Manual led to 50% shorter total compliance times that WP

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<td>Time from the end of the controller’s clearance to completion of the maneuver</td>
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Discussion

• All together, pilots were able to comply with ATC roughly 50% faster when using the Autopilot or Manual control interfaces
  – The difference is largely explained by the difference in initial and total edit times
    • The WP mode led to drastically longer edit times
      – Required more steps to upload edits
      – Forced pilots to approximate their heading using waypoint modifications
        » This resulted in large differences between initial and total edit times
      – Manual control mode had especially small edit times due to the fact that pilots simply had to enter that navigation mode in order to start moving the aircraft
  – There was also a significant benefit in initial reaction times for the Autopilot interface
    • Pilots were far more likely to initiate an edit prior to a controller completing the clearance
      – Likely due to ease of prepping the steering window for an edit
    • Modest impact compared to the differences in edit time
Conclusions/Limitations

• Data underlies the limitations of a system restricted to waypoint edits
  – Led to less timely and less accurate performance

• Supports need for ground control station interfaces that support pilots’ ability to get in-the-loop to make quick and precise altitude and heading maneuvers
  – Whether they are software-based (as with the AP interface) or hardware-based (as with the Manual interface)

• Keeping these considerations in mind should help UAS pilots conform to ATC expectations and overall airspace requirements
Conclusions/Limitations

• Limitations
  – These analyses do not take into account the type of air traffic control clearance issued by the controller (e.g., vertical vs. horizontal maneuver)
  – These results must be interpreted within the context of one instantiation of a ground control station (AFRL’s Vigilant Spirit Control Station)
    • The 3 modes tested in this study were existing functionalities within the Vigilant Spirit framework

• Follow-on research
  – Results allow for a nice baseline of how quickly UAS pilots can get into the loop to immediately comply with an ATC clearance
  – We have started to use these results as a comparison to pilot response times when responding to alerts to potential well clear violations from their traffic display
    • The difference between the times in this study and the times in the follow on studies should largely be the decision making time pilots require to assess and determine a course of action