UAS Integration into the NAS: HSI Full Mission Simulation
Preliminary Results

Presented To: RTCA SC-228

Jay Shively
NASA Ames Research Center
Lisa Fern
The Ohio State University
Conrad Rorie
San Jose State University
Overview

• Experimental Objectives:
  – To examine the effects of different command and control interfaces on UAS pilots’ ability to respond to ATC commands and traffic advisories/warnings
    • What happens when a pilot who is operating “on-the-loop” (i.e., waypoint to waypoint/flight plan mode) needs to quickly get “in-the-loop” to respond to ATC clearance or traffic advisories?

• Experimental Design:
  – 3 (Control Mode) X 3 (Event Type) Within-Subjects Factorial
  – Control Mode:
    1) Waypoint only
    2) Autopilot
    3) Manual
  – Event Type:
    1) ATC Clearance
    2) Well Clear Violation
    3) Resolution Advisory
Overview

• Data Collection:
  – Dates: 8 JUL – 2 AUG 2013
  – Location: Flight Deck Display Research Lab (FDDRL) at NASA ARC

• Simulation Environment
  – Vigilant Spirit Control Station (VSCS; AFRL/RH)
  – Cockpit Situation Display (CSD)
  – SAA Processor
  – Multi Aircraft Control Station (MACS)
    • Airspace and air traffic environment
    • Pseudo pilot stations
    • Air Traffic Control (ATC) Stations
GCS Configuration

UAS Ground Control Station Configuration

Vigilant Spirit Control Station (AFRL/RH). Distribution A: Approved for public release; distribution unlimited. 88ABW Cleared 3/18/2013; 88ABW-2013-1303


**Scenarios**

- Derived from FAA CONOPS scenarios (combination of “Loiter for Surveillance” and “Grid Pattern”)
- Class A & E Oakland Center Airspace (ZOA 40/41) with IFR and VFR traffic
- UAS started at FL190, descended to 6000 ft to conduct a stepped grid pattern search, climbed back to FL190
- Events were generated to force pilots to make quick control inputs:
  - ATC Clearances
  - Self-Separation Violations
  - Resolution (Collision) Advisories
Participants

- 15 RQ-4 pilots Average age = 34 years old
  - 6/15 qualified through RQ-4 Basic Training (AF Specialty Code 18X)
    - Not required to have been previously qualified in a manned AC
  - 9/15 qualified through Undergraduate Pilot Training
    - Previously qualified in a manned AC
  - 9/15 had previous experience flying UAS in civil airspace
    - Average = 98 hours
  - All had Military Combat and/or Non-Combat experience
    - Average = 323 combined hours
- 1 retired Air Traffic Controller with experience in Oakland Center airspace (confederate)
Pilot Tasks

◆ Pilot Task:

- Operate a simulated MQ-1 (HAWK21) along a pre-filed flight path within Oakland Center airspace under Instrument Flight Rules
- Responsible only for air vehicle navigation (no sensor operation)
- Comply with ATC clearances for traffic and/or weather as necessary
- Respond to collision avoidance Resolution Advisories
• Primary Independent Variable: VSCS Control Mode

1) Waypoint-to-Waypoint Mode (Waypoint; WP) (Baseline)
   • Functionality: can only change heading by modifying existing waypoints, can use override to change altitude

2) Autopilot Mode (Autopilot; AP)
   • Retains WP functionality
   • Additional functionality: can change heading and altitude using new graphical interface

3) Manual Mode (Manual; M)
   • Retains WP functionality
   • Additional functionality: can change heading and altitude using stick and throttle inputs

Pilots were able to use any method available to them to implement an edit
   – E.g., in Autopilot mode, the pilot could perform a vertical maneuver via waypoint edits or edits to the auto-pilot interface
Waypoint Mode

- Click and drag interface on TSD to move or add waypoints
- Altitude and airspeed inputs in editing window
- Override capability for altitude and/or airspeed
- Right click or double click waypoint to open editing window

➤ Edits made via Waypoint Window
Autopilot Mode

Right click or double click ownship to open steering window and change mode to AP

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 via keyboard or spinners

Edits made via Steering Window or Compass Rose
Manual Mode

Switch to manual mode via steering window or on HOTAS button

Edits made via Stick and Throttle
Event Type

• Secondary Independent Variable: Event Type

1) ATC Clearances (ATC only):
   • Traffic Alert during level flight
   • Traffic Alert during climb/descent
   • ATC vector for severe weather

2) Self-Separation Violation (ATC & Display):
   • Traffic Advisory (ATC)
   • Alert to future Well Clear Violation (Display)

3) Resolution Advisory (Display only)

_Type and size of events were not experimentally controlled or counterbalanced across participants or scenarios_

• Clearances were up to discretion of controller, as permitted by the scenario
Initial Research Question

• What was the effect of the three different VSCS control modes on pilots’ ability to comply with ATC clearances?
  – Pilot performance can best be understood by assessing their ‘Measured Response’ (MR)
    • MR has been analyzed before by breaking down ATC-Pilot interactions into discrete stages (Shively, Vu & Baker, 2013)
  – Measured response data were analyzed utilizing a 2-Way Analysis of Variance (ANOVA)

• Also measured (but not reported here):
  – Number of Uploads
  – Correctness
  – Size of Maneuver
  – Post Trial & Post Sim Questionnaires
## Stages of ATC-Pilot Interaction

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Example (Left Turn in WP Mode)</th>
<th>Source of Time Stamp</th>
</tr>
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<tbody>
<tr>
<td>$T_0$</td>
<td>Initial ATC Transmission</td>
<td>“HAWK21, turn left heading 1-2-0, vectors for your descent.”</td>
<td>Voice Log – End of Relevant Controller Transmission</td>
</tr>
<tr>
<td>$T_1$</td>
<td>Pilot Reply</td>
<td>“Turn left heading 1-2-0, HAWK21.”</td>
<td>Voice Log – Start of Relevant Pilot Transmission</td>
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<tr>
<td>$T_2$</td>
<td>Pilot Initiates Edit</td>
<td>Pilot opens Waypoint Window</td>
<td>VSCS Camtasia – Moment Relevant Waypoint or Steering Window appears on display</td>
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<tr>
<td>$T_{3a}$</td>
<td>Pilot Uploads 1st Edit</td>
<td>Pilot incorrectly uploads $110^\circ$ Hdg to the aircraft</td>
<td>VSCS Camtasia &amp; VSCS Output – Upload of First Relevant Edit</td>
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<tr>
<td>$T_{3b}$</td>
<td>Pilot Uploads Final Edit</td>
<td>Pilot correctly uploads $120^\circ$ Hdg to the aircraft</td>
<td>VSCS Camtasia &amp; VSCS Output – Upload of Final and Correct Edit</td>
</tr>
<tr>
<td>$T_4$</td>
<td>UAS Completes Maneuver</td>
<td>HAWK21 reaches an acceptable range for the given clearance ($120^\circ$ Hdg, +/- 5°)</td>
<td>VSCS Camtasia – UA Reaches Acceptable Range</td>
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Stages of ATC-Pilot Interaction

$T_0$
ATC: “Turn Left 1-2-0”

$T_1$
Pilot: “Roger. Left 1-2-0”

$T_2$
Pilot: *Opens Edit Window*

$T_{3a}$
Pilot: *Uploads 1st Edit*

$T_{3b}$
Pilot: *Uploads Final Edit*

$T_4$
UAS: *Completes Maneuver*
General Stats

• Pilots were issued a total of:
  – 273 Traffic Advisories
    • Average of 6 advisories per trial
    • No action required; verbal response only
  – 767 Traffic Clearances
    • Average of 17 clearances per trial
    • By type:
      – Altitude Clearances: 229
      – Lateral Clearances: 300
      – ‘Direct To’ & ‘Resume Own Nav’ Clearances: 463
    • Immediate compliance expected

➢ **Clearance Type was not experimentally controlled**
General Stats

- Mode x Method Breakdown

  1) Waypoint = 270 total edits
     - All edits made via waypoint or steering window

  2) Autopilot = 253 total edits
     - 109 edits (43%) made via waypoint or steering window
     - 144 edits (57%) made via autopilot interface (Compass Rose)

  3) Manual = 244 total edits
     - 98 edits (40%) made via waypoint or steering window
     - 146 edits (60%) made via stick and throttle

- Preliminary results include all edits made within a control mode, regardless of input method
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### Timeline

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Verbal Response Time ($T_1 - T_0$)

- Autopilot resulted in significantly shorter response times than Waypoint ($p<.05$)
  - No other differences were significant

- Pilots replied to a total of 1,009 advisories & clearances
  - Waypoint = 1.47 sec
  - Autopilot = 1.18 sec
  - Manual = 1.40 sec
  - Grand Mean = 1.35 sec
• Distribution:
  – 50% of participants replied 2 seconds or sooner following the controller’s clearance
  – 90% of participants replied 3 seconds or sooner following the controller’s clearance
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- $T_4$: UAS Completes Maneuver
Initial Response Time ($T_2 - T_0$)

- Autopilot resulted in significantly shorter Initial Response Times than Waypoint and Manual ($p < .05$)
- Pilots initiated a total of 549 edits in response to ATC clearances
  - Waypoint = 5.82 sec
  - Autopilot = 3.00 sec
  - Manual = 5.66 sec
  - Grand Mean = 4.83 sec
Initial Response Time ($T_2 - T_0$)

• Distribution:
  – 50% of participants started their edit 5 seconds or sooner following the controller’s clearance
  – 90% of participants started their edit at 11 seconds or sooner following the controller’s clearance
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• Manual and autopilot resulted in significantly shorter times than Waypoint (p<.01)
• Pilots successfully uploaded a total of 545 edits
  – Waypoint = 11.81 sec
  – Autopilot = 8.77 sec
  – Manual = 6.90 sec
  ➢ Grand Mean = 9.16 sec
Initial Edit Time ($T_{3a} - T_2$)

- Distribution:
  - 50% of participants uploaded their *initial* edit 8 seconds or sooner following the start of their edit
  - 90% of participants uploaded their *initial* edit 18 seconds or sooner following the start of their edit
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**Timeline Diagram**

- $T_0$: ATC Clearance Ends
- $T_1$: Pilot Responds
- $T_2$: Pilot Initiates Edit
- $T_{3a}$: Pilot Makes 1st Upload
- $T_{3b}$: Pilot Makes Final Upload
- $T_4$: UAS Completes Maneuver
Total Edit Time ($T_{3b} - T_{2}$)

- Manual and Autopilot resulted in significantly short times than Waypoint ($p<.05$)
- Pilots successfully completed a total of 545 edits
  - Waypoint = 19.27 sec
  - Autopilot = 9.15 sec
  - Manual = 7.28 sec
  - Grand Mean = 11.90 sec
• **Distribution:**
  – 50% of participants uploaded their *final* edit 8 seconds or sooner following the start of their edit
  – 90% of participants uploaded their *final* edit 23 seconds or sooner following the start of their edit
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Aircraft Response Time ($T_{3a} - T_0$)

- Manual and Autopilot resulted in significantly shorter times than Waypoint ($p<.01$)
- Pilots successfully completed a total of 602 clearances
  - Waypoint = 17.82 sec
  - Autopilot = 11.77 sec
  - Manual = 10.05 sec
  - Grand Mean = 13.17 sec
Aircraft Response Time ($T_{3a} - T_0$)

- Distribution:
  - 50% of participants started the AC maneuver within 12 seconds of the controller’s clearance
  - 90% of participants started the AC maneuver within 25 seconds of the controller’s clearance upload
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- $T_2$: Pilot Initiates Edit
- $T_{3a}$: Pilot Makes 1st Upload
- $T_{3b}$: Pilot Makes Final Upload
- $T_4$: UAS Completes Maneuver
Aircraft Maneuver Time ($T_4 - T_{3a}$)

- No differences were found to be significant
- Pilots successfully completed a total of 583 clearances
  - Waypoint = 56.14 sec
  - Autopilot = 59.48 sec
  - Manual = 49.94 sec
- Grand Mean = 55.18 sec
Aircraft Maneuver Time ($T_4 - T_{3a}$)

- Distribution:
  - 50% of participants completed their maneuver 26 seconds or sooner following their initial upload
  - 90% of participants completed their maneuver 98 seconds or sooner following their initial upload
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ATC Clearance Ends

- \( T_0 \)  
- Pilot Responds
- Pilot Initiates Edit
- Pilot Makes 1st Upload
- Pilot Makes Final Upload
- UAS Completes Maneuver
- \( T_4 \)
Compliance Time \((T_4 - T_0)\)

• Manual resulted in significantly shorter compliance times than Waypoint \((p<.05)\)
  – No other differences were significant
  ❖ Expect significant results between WP + AP and WP when magnitude, method and dimension of maneuver are accounted for, based on time to initiate and final upload results

• Pilots successfully completed a total of 571 clearances
  – Waypoint = 73.99 sec
  – Auto Pilot = 71.58 sec
  – Manual = 56.95 sec
  ➢ Grand Mean = 67.51 sec
Compliance Time ($T_4 - T_0$)

- Distribution:
  - 50% of participants completed their maneuver 40 seconds or sooner following the controller’s clearance
  - 90% of participants completed their maneuver 120 seconds or sooner following the controller’s clearance
Results Summary

• First phase of analysis examined the effect of three control modes on pilots’ ability to comply with ATC clearances
• The baseline condition (waypoint) showed significantly poorer performance in all but one of the metrics analyzed
• Autopilot had significantly shorter Verbal Response and Initial Response times
  – Initial response times were almost twice as long for Waypoint and Manual
• Both Manual and Autopilot had significantly shorter Edit and Aircraft Response Times
  – Total edit times were up to 12 seconds shorter than Waypoint
  – Aircraft response times were up to 8 seconds shorter than Waypoint
• Manual had significantly shorter Compliance Times
Results Summary

• Takeaway:
  – The earliest stages of interaction, i.e. getting “in-the-loop,” saw an advantage for the Autopilot mode
  – Both Autopilot and Manual saw substantial advantages in editing times
    • Manual mode was on average a few seconds faster the Autopilot because no edits were required (nav mode change only)
  – The limitations of the Waypoint mode is most apparent in its edit time (up to 12 sec slower); could have significant operational impact
  – Need to support pilots’ ability to easily get in the loop to respond to ATC Clearances and SAA System alerts
  – Provide easy method for inputting holds – either through a manual or electronic interface – that are consistent with ATC and SAA system expectations/requirements
  – Waypoint to waypoint only interface may not be sufficient
Results Summary

• Caveats:
  – Preliminary data only
    • Lateral vs horizontal vs “direct to waypoint” inputs should be analyzed by control mode (some modes support different dimensions better)
    • Magnitude of maneuver needs to be accounted for
  – Tradeoff between experimental control and realistic, dynamic environment:
    1. Pilots had the freedom to use whichever method available (within a control mode) for a given clearance
    2. Type and number of clearances were not controlled or counterbalanced across participants or scenarios
  – Not every stage of interaction (T0 – T4) was completed for each event
    • Ex: if a pilot was already in Manual mode and given a heading change, the only stages captured were T3b and T4 (start and end of maneuver)
  – Availability of override functionality in waypoint only mode closely resembles an AP or “quick input” functionality

❖ Data are a result of one instantiation of a single prototype GCS
Questions?

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