National Aeronautics and Space Administration

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

Presented To: RTCA SC-228

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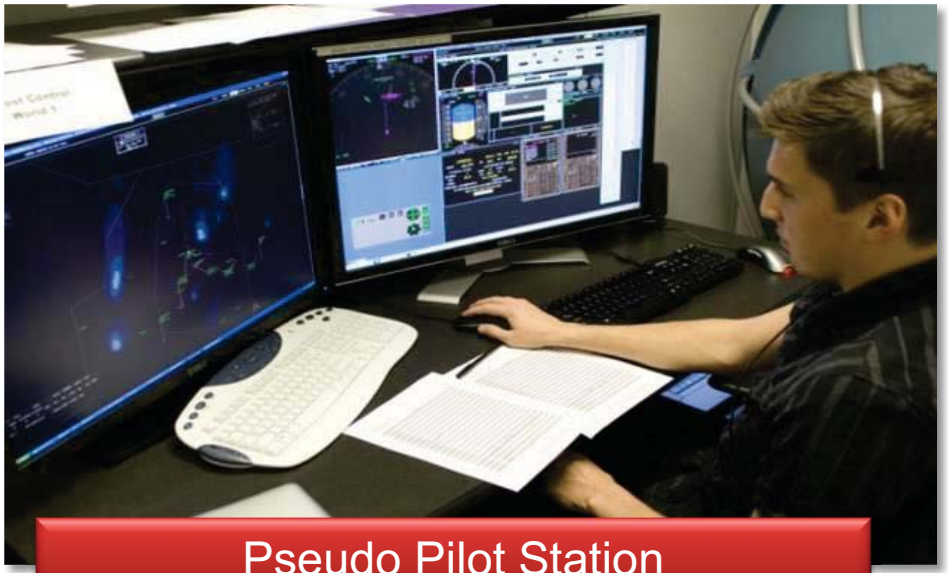
Overview

- 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

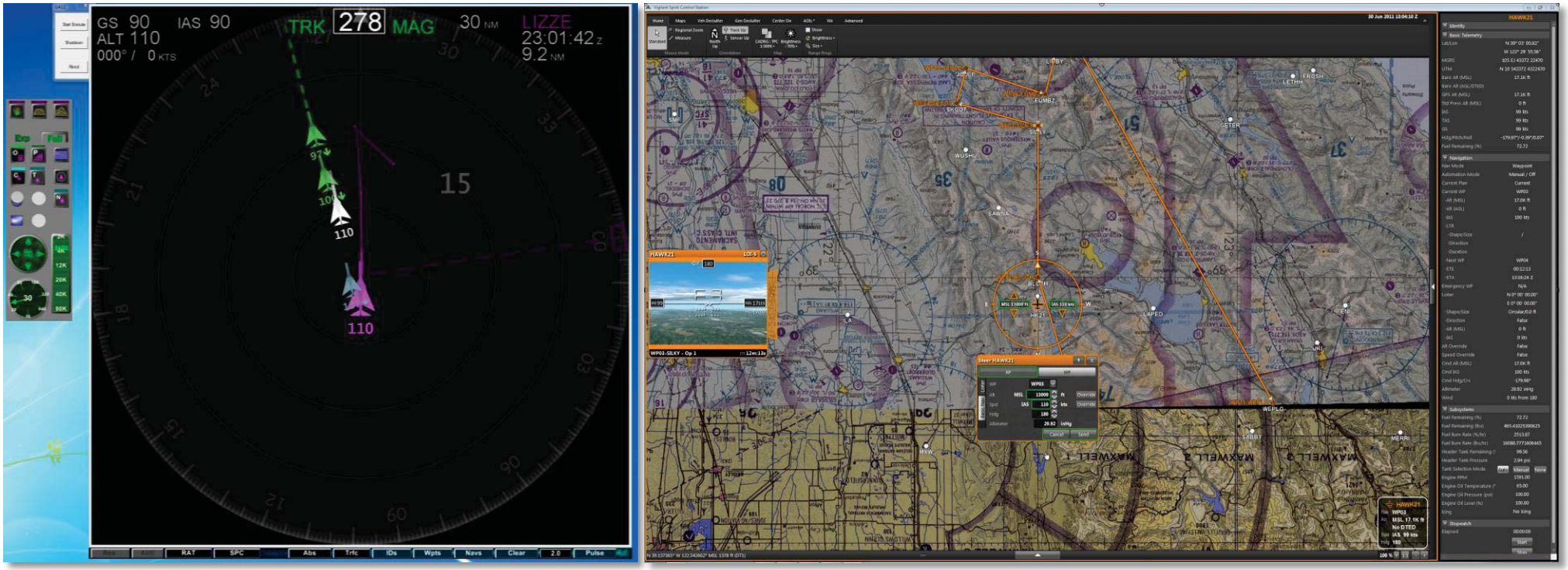
Air Traffic Control Station



Pseudo Pilot Station

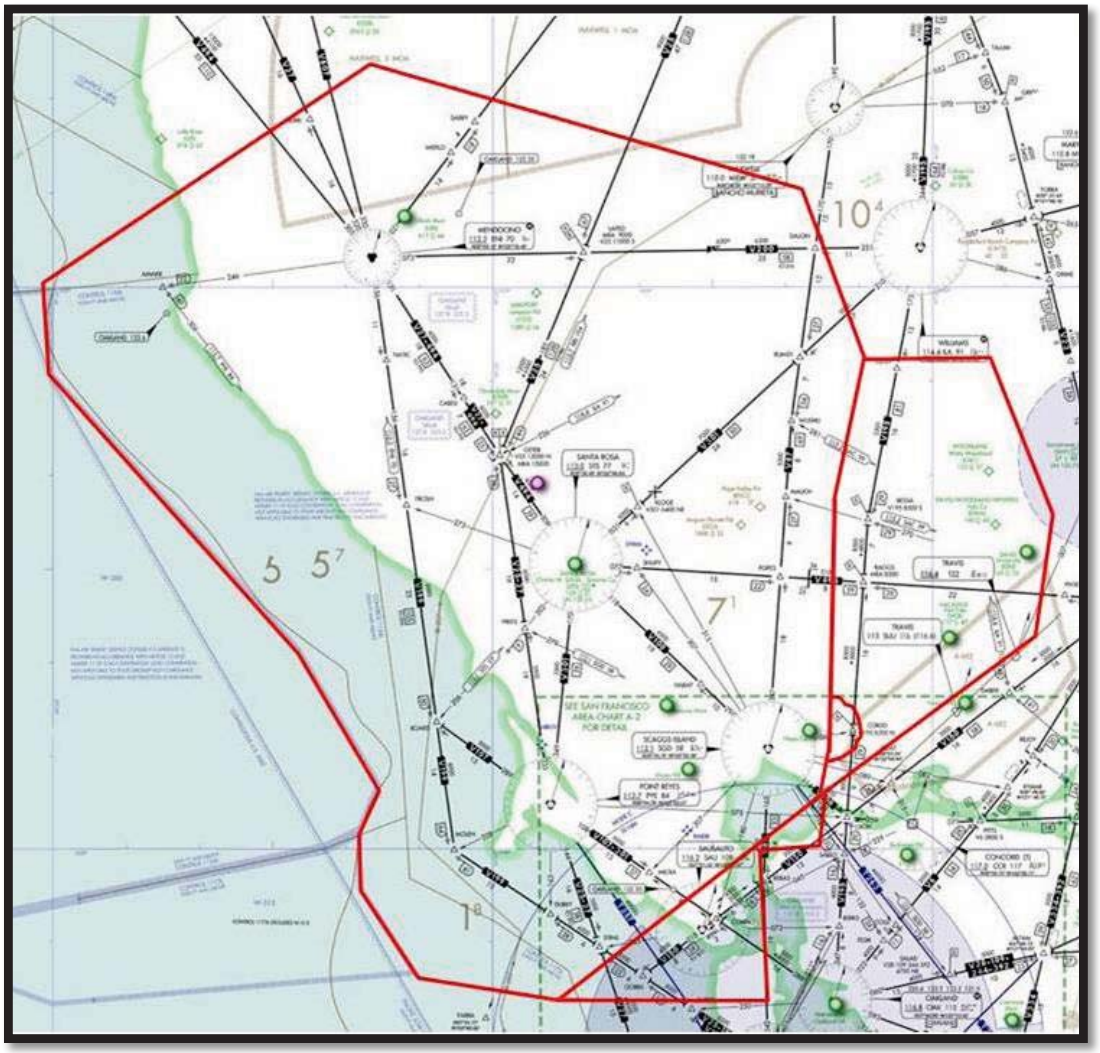
GCS Configuration

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



◆ 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

- 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

VSCS Control Mode

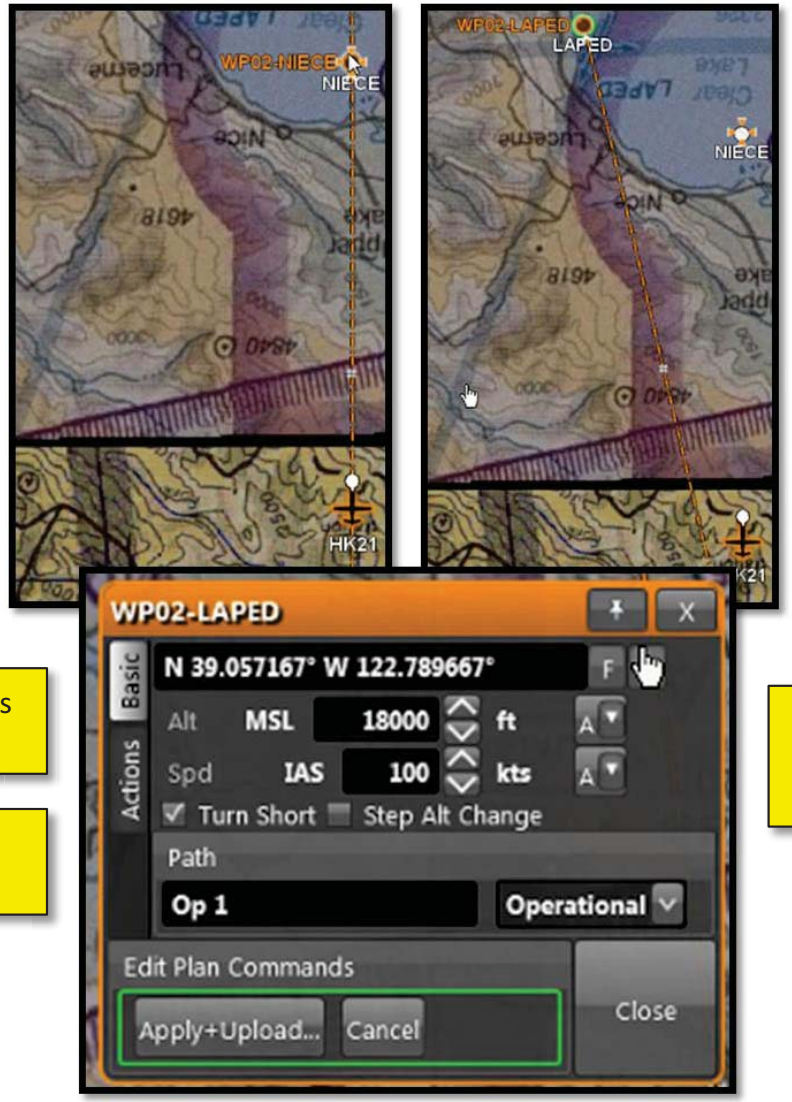
- Primary Independent Variable: VSCS Control Mode
  1) Waypoint-to-Waypoint Mode (Waypoint; WP) (Baseline)
     - Functionality: can only change heading by modifying existing waypoints, can use override to change altitude
  2) Autopilot Mode (Autopilot; AP)
     - Retains WP functionality
     - Additional 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



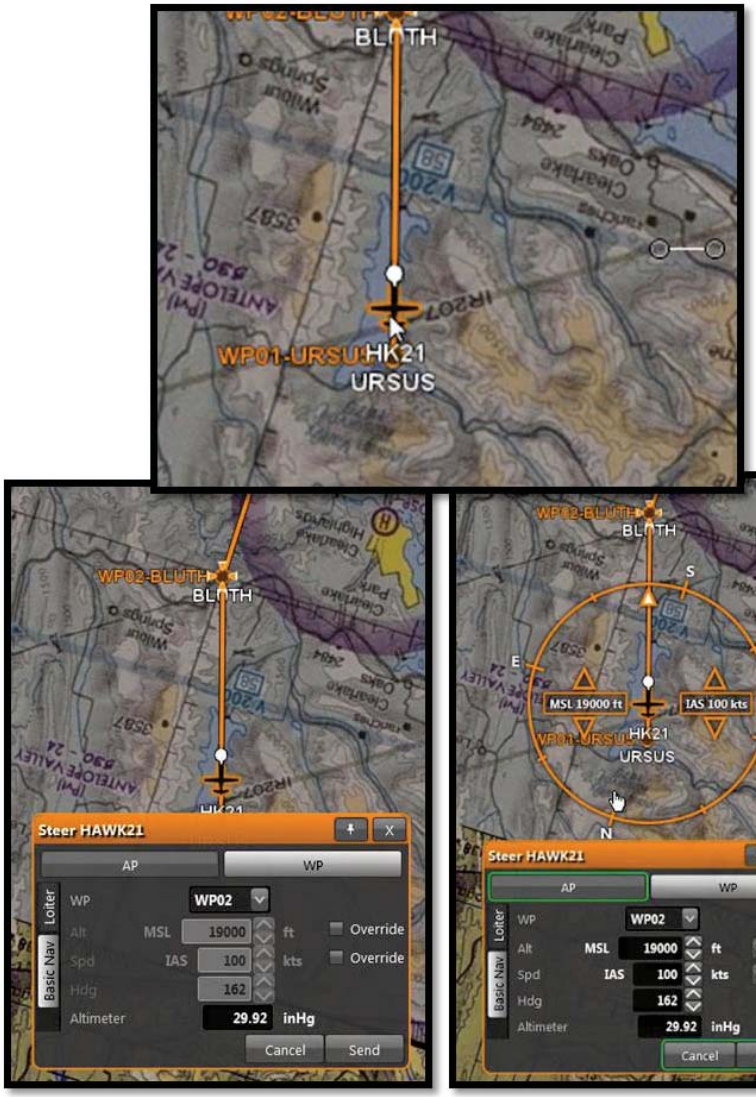
Altitude and airspeed inputs in editing window

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

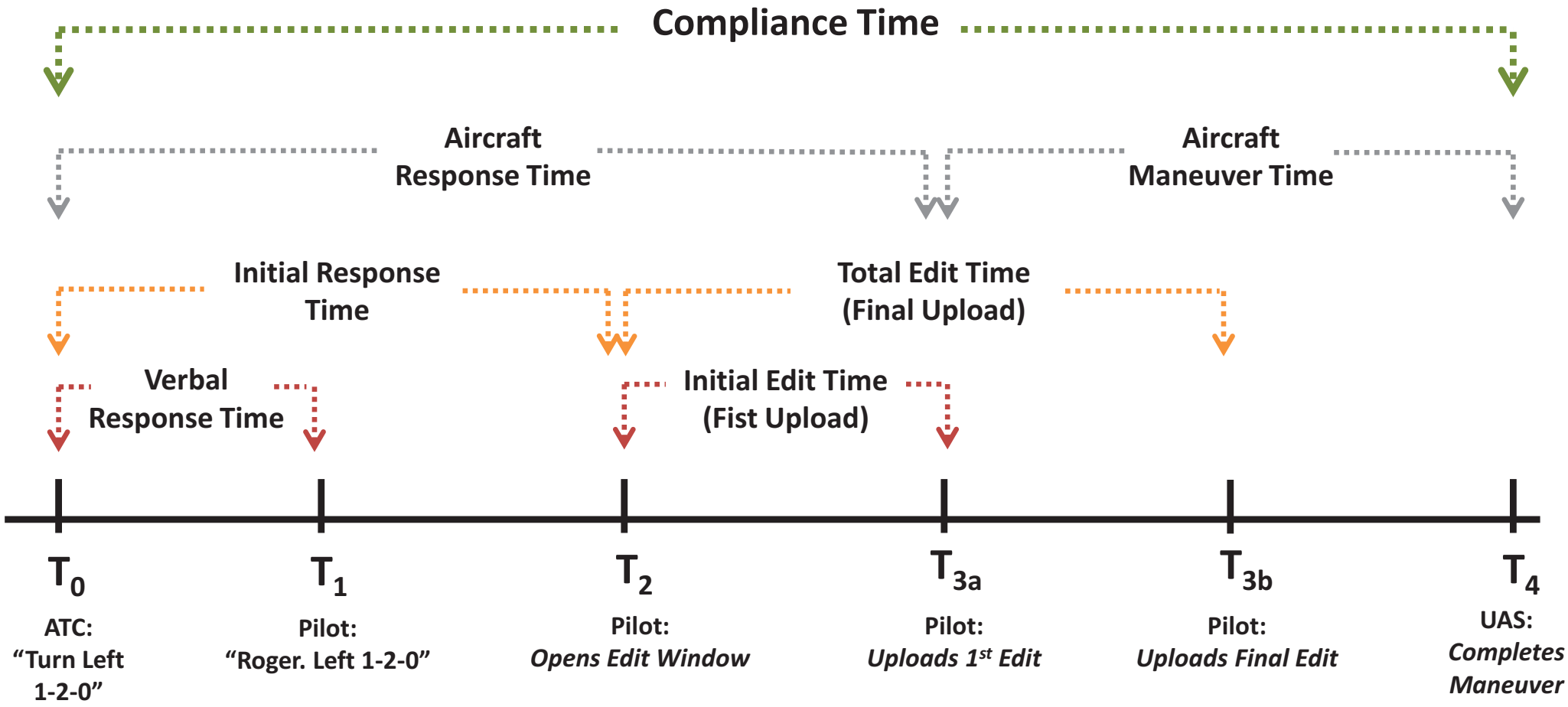
ATC Initiates

TIME

Maneuver Completed

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

Stages of ATC-Pilot Interaction



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

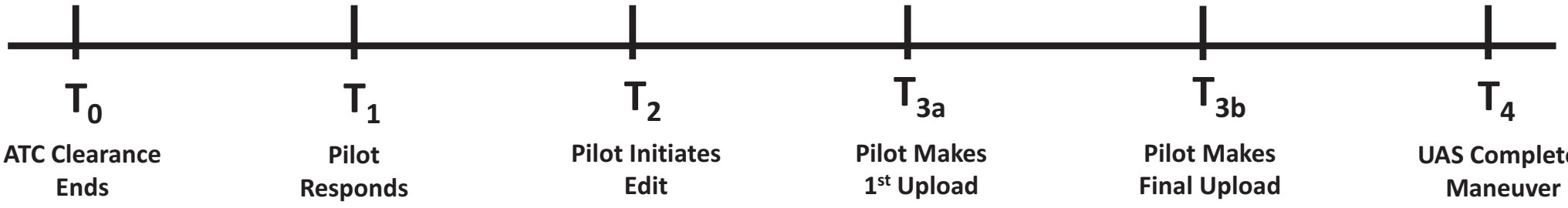
➢ ***Clearance Type was not experimentally controlled***

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

Preliminary Metrics

Metric	Calculation	Description
Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
Initial Response Time	$T_2 - T_0$	Time it took for pilots to initiate edits in response to ATC clearances
Initial Edit Time (1st Upload)	$T_{3a} - T_2$	Time it took pilots to upload their first edit from the moment they began editing
Total Edit Time (Final Upload)	$T_{3b} - T_2$	Time it took pilots to upload their final edit from the moment they began editing
Aircraft Response Time	$T_{3a} - T_0$	Time it took for the aircraft to begin maneuvering from ATC clearance
Aircraft Maneuver Time	$T_4 - T_{3a}$	Time it took the UAS to complete its maneuver once the maneuver began
Compliance Time	$T_4 - T_0$	Time it took the UAS operator to complete *all* stages of ATC-Pilot interaction



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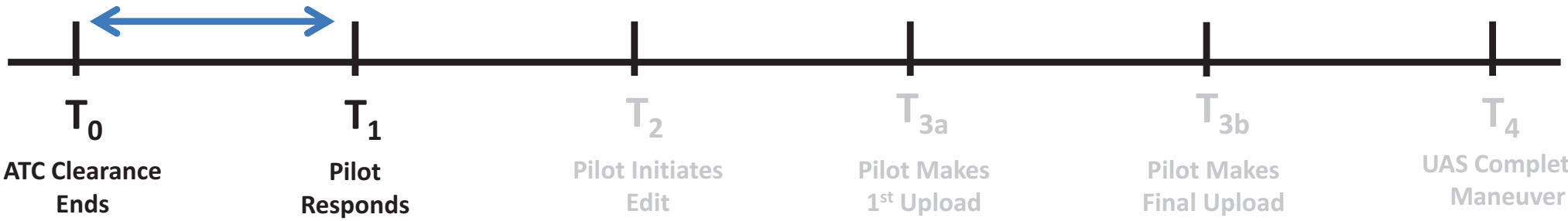
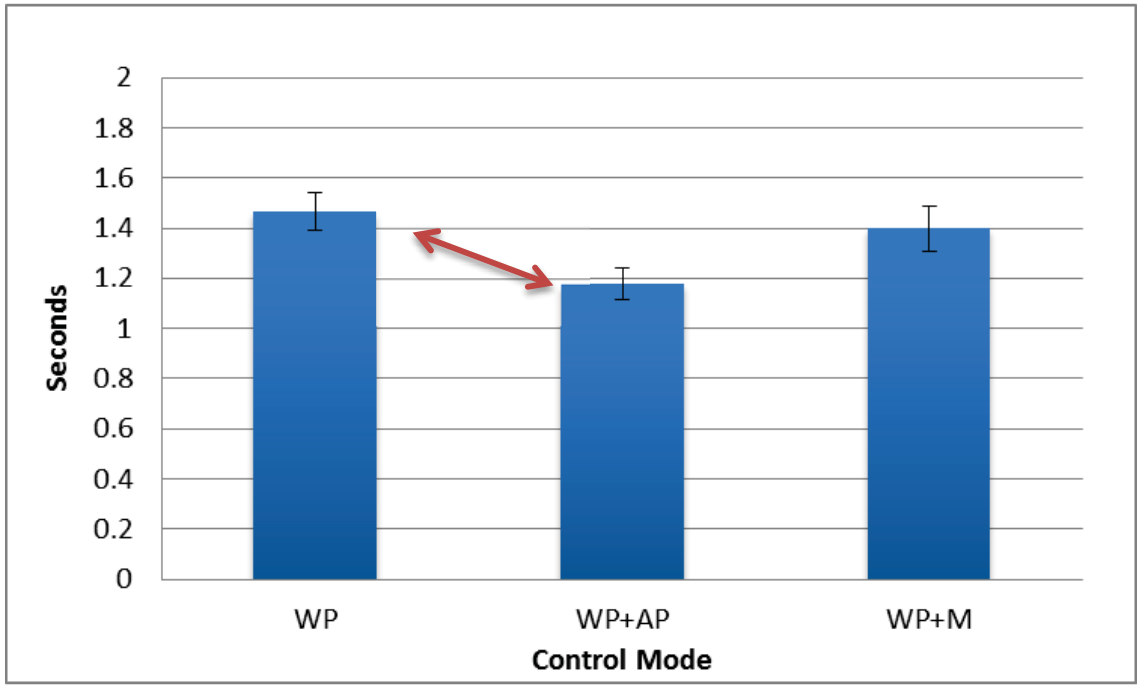


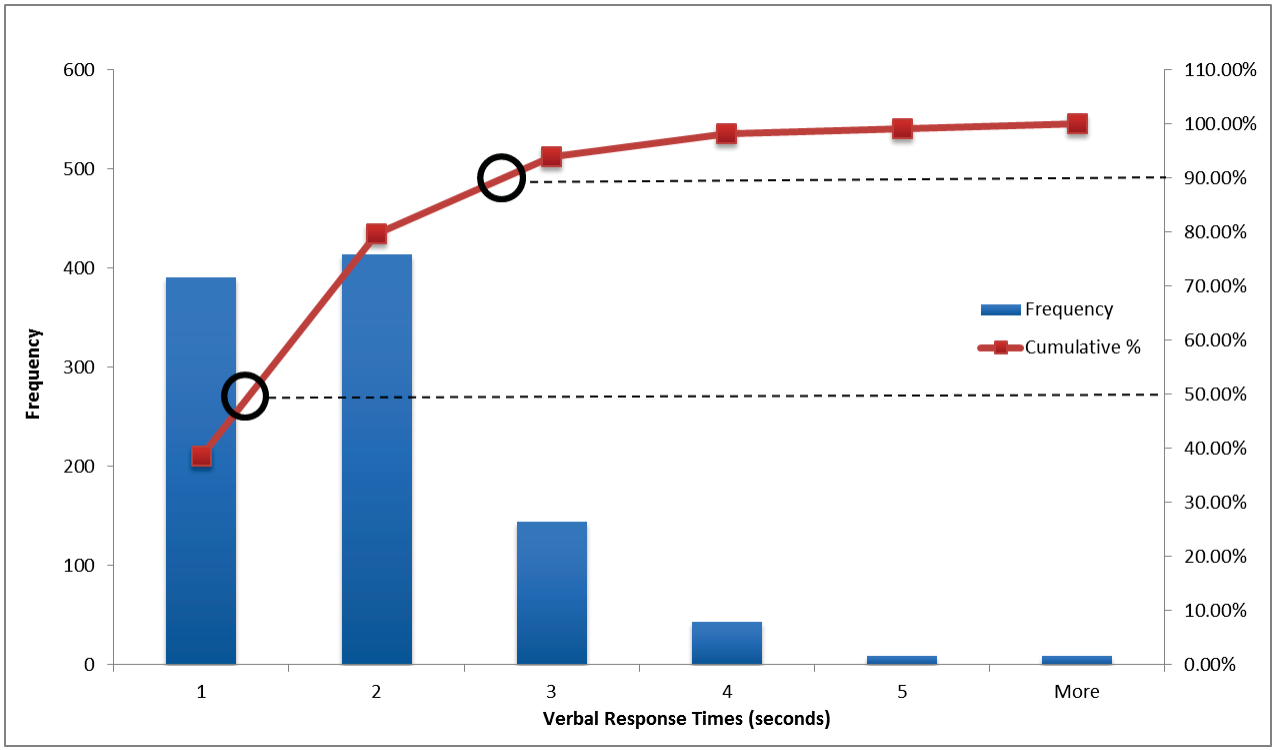
Verbal Response Time ($T_1 - T_0$)

Time from ATC clearance to Pilot verbal response



- 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

Verbal Response Time ($T_1 - T_0$)



- 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

Preliminary Metrics

Metric	Calculation	Description
Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
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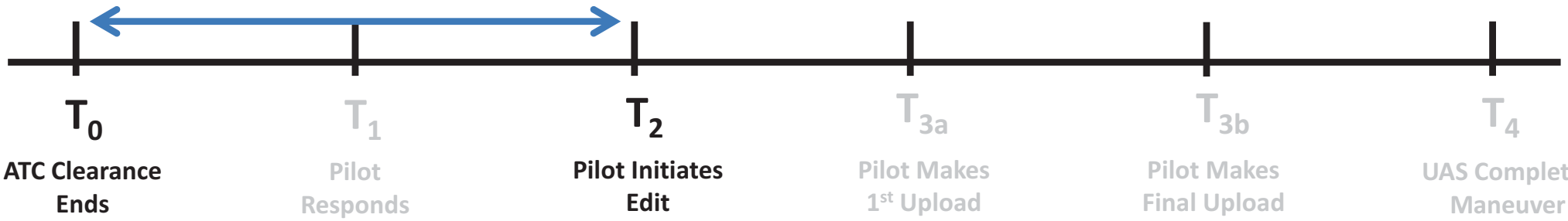
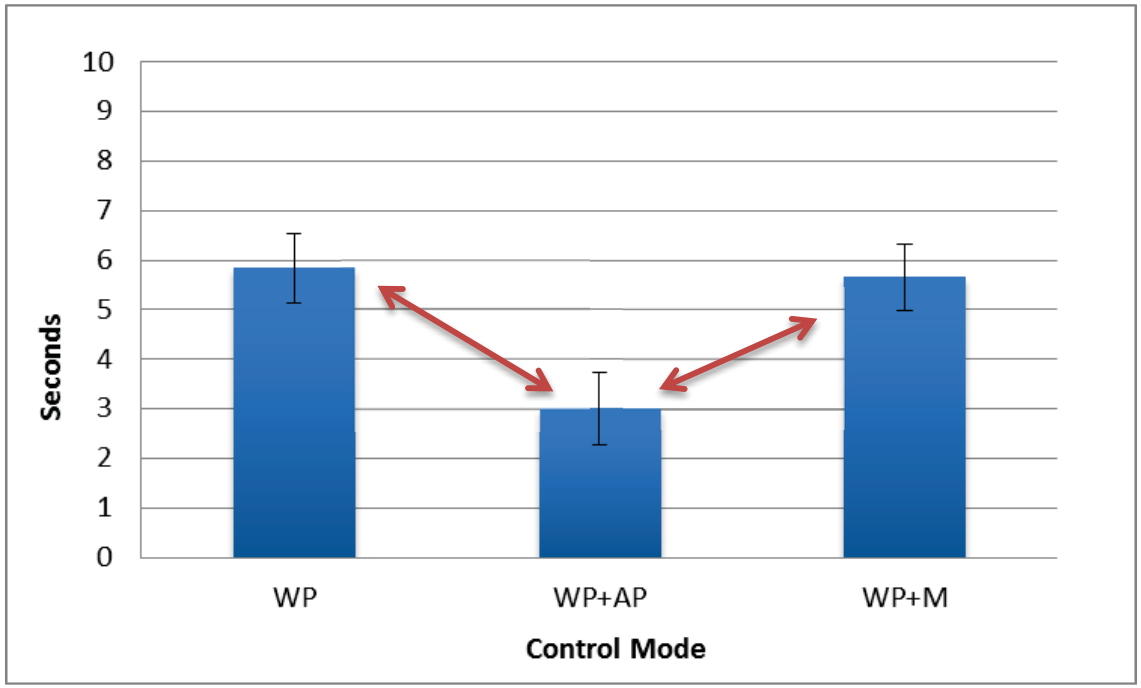
Compliance Time	$T_4 - T_0$	Time it took the UAS operator to complete *all* stages of ATC-Pilot interaction



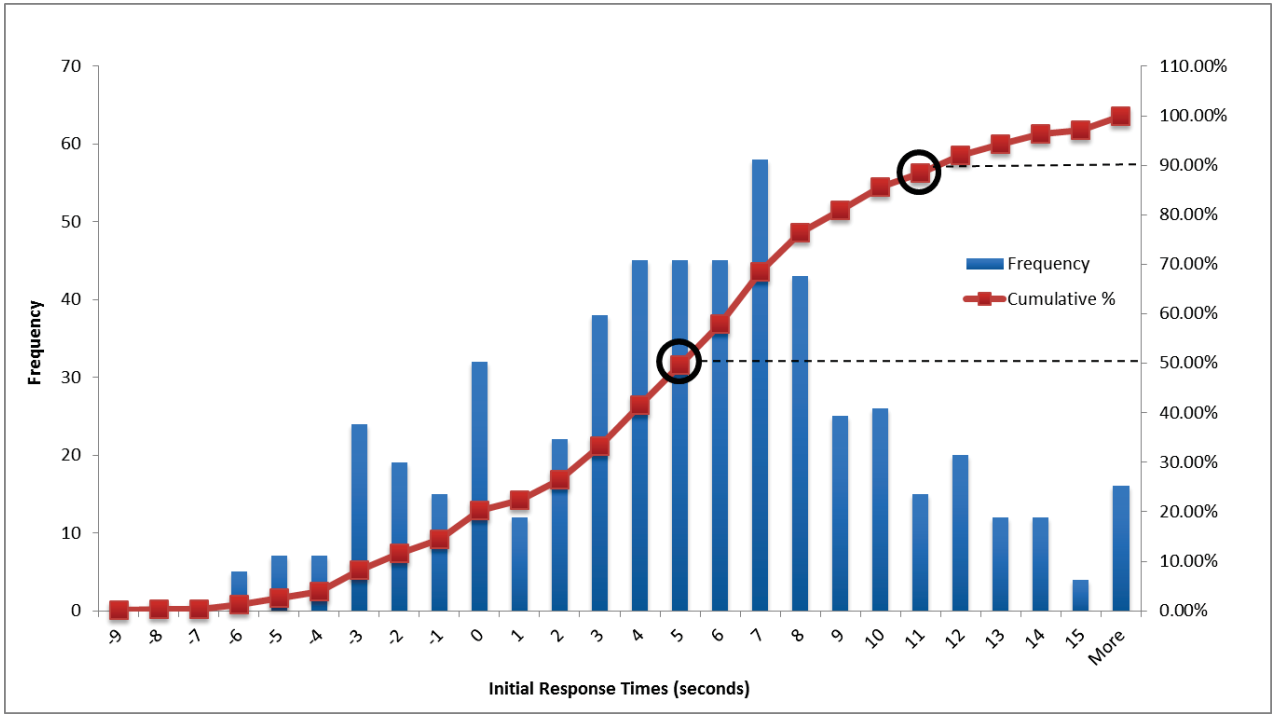
Initial Response Time ($T_2 - T_0$)

Time from ATC clearance to Pilot initial control input



- 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

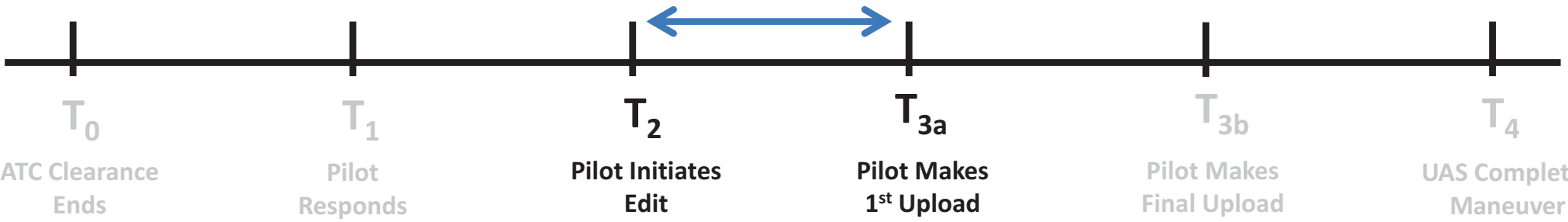
Initial Response Time ($T_2 - T_0$)



- 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

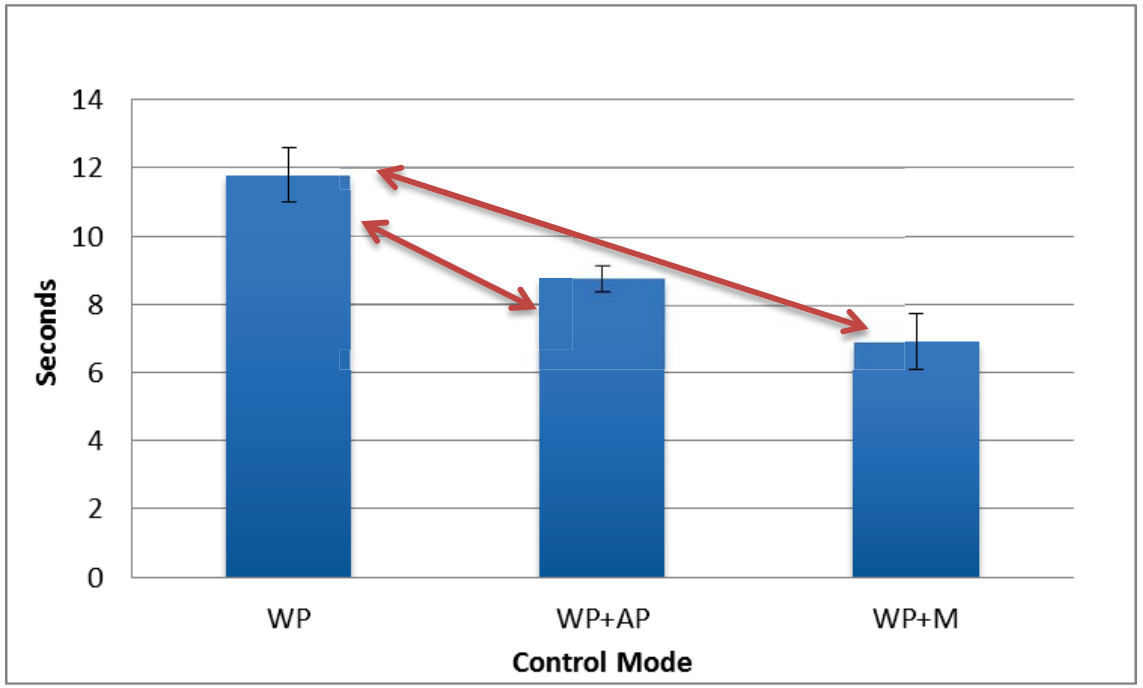
Preliminary Metrics

Metric	Calculation	Description
Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
Initial Response Time	$T_2 - T_0$	Time it took for pilots to initiate edits in response to ATC clearances
Initial Edit Time (1st Upload)	**$T_{3a} - T_2$**	**Time it took pilots to upload their first edit from the moment they began editing**
Total Edit Time (Final Upload)	$T_{3b} - T_2$	Time it took pilots to upload their final edit from the moment they began editing
Aircraft Response Time	$T_{3a} - T_0$	Time it took for the aircraft to begin maneuvering from ATC clearance
Aircraft Maneuver Time	$T_4 - T_{3a}$	Time it took the UAS to complete its maneuver once the maneuver began
Compliance Time	$T_4 - T_0$	Time it took the UAS operator to complete *all* stages of ATC-Pilot interaction



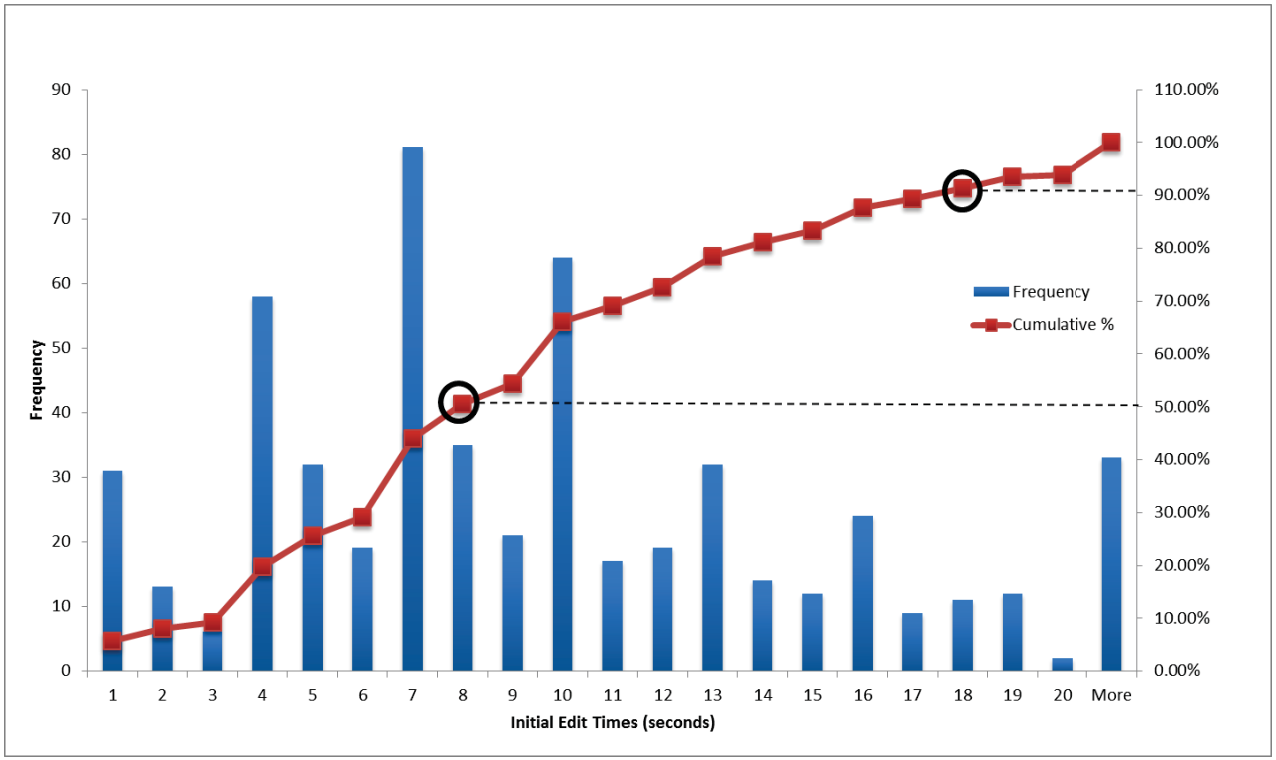
Initial Edit Time ($T_{3a} - T_2$)

Time from Pilot initial control input to first upload



- 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

Preliminary Metrics

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Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
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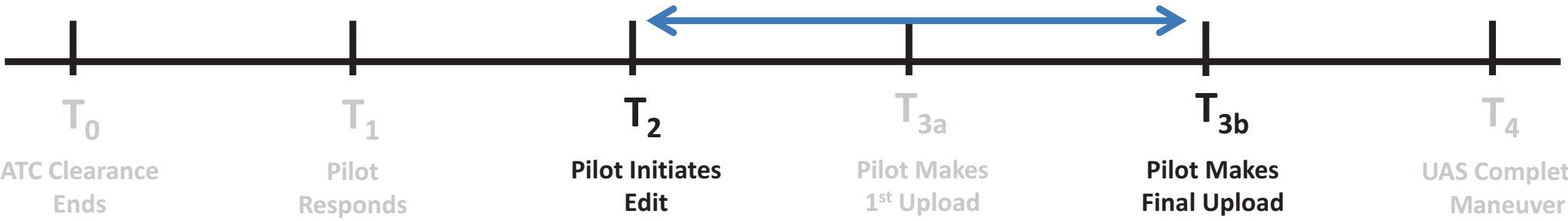
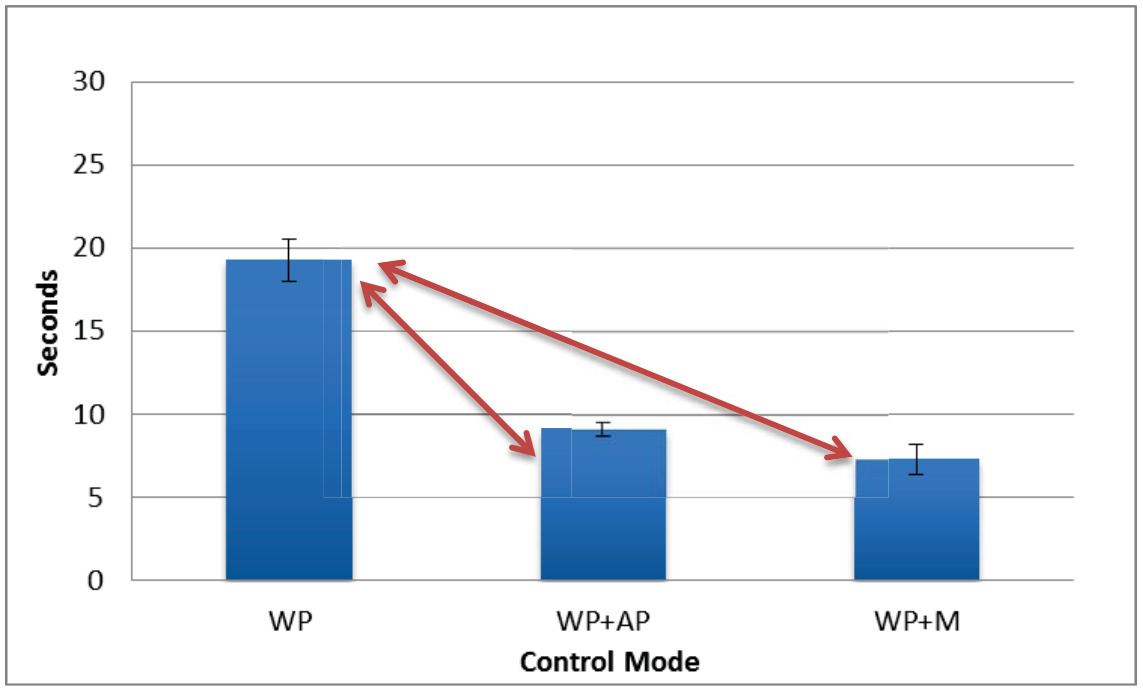


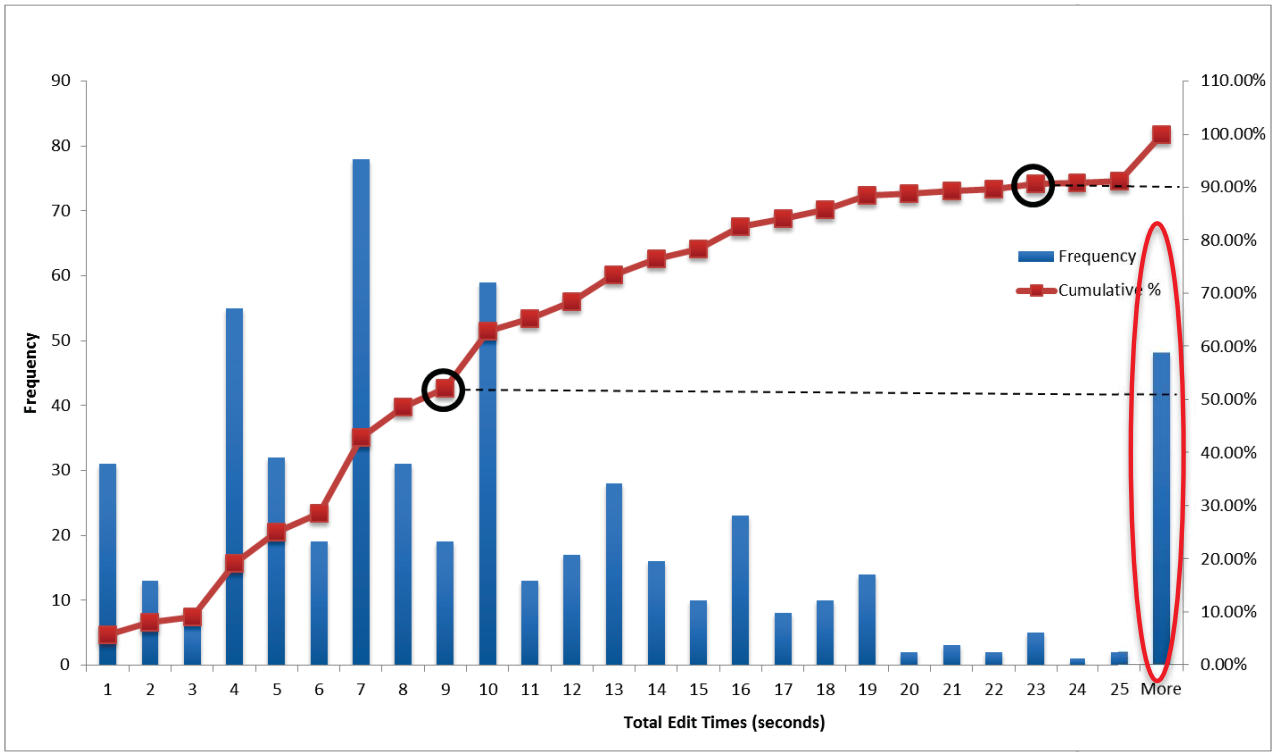
Total Edit Time ($T_{3b} - T_2$)

Time from Pilot initial control input to final upload



- 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

Total Edit Time ($T_{3b} - T_2$)



- 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

Preliminary Metrics

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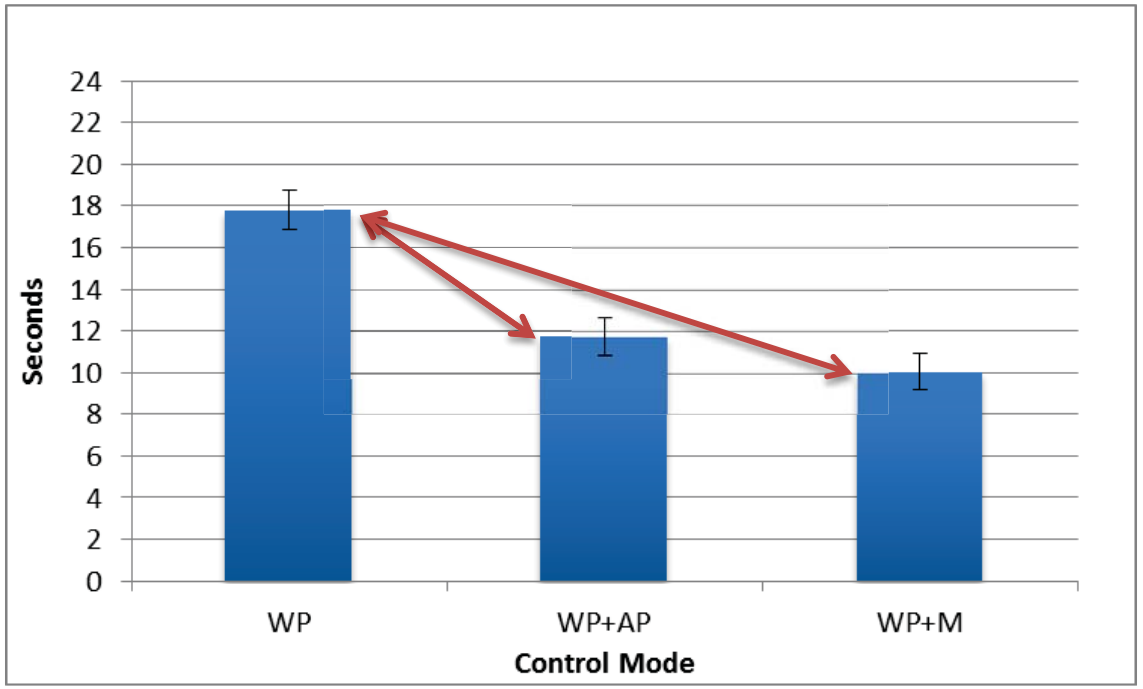
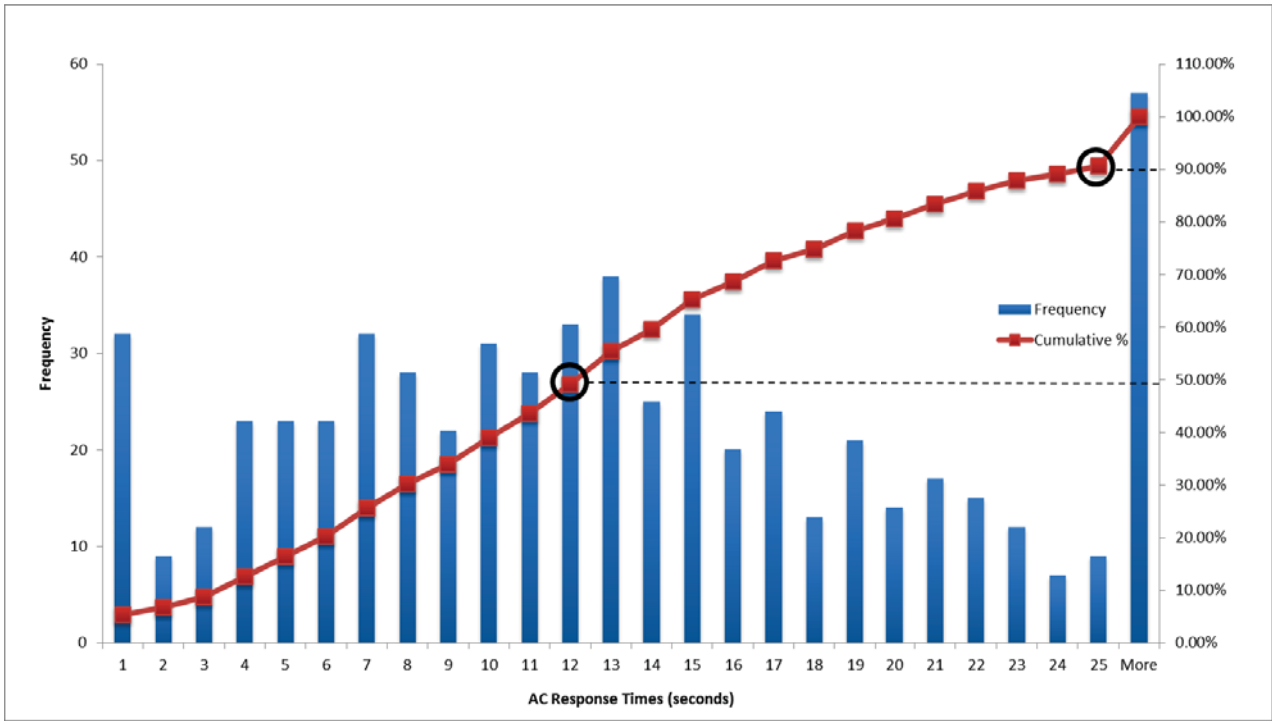
Aircraft Response Time ($T_{3a} - T_0$)

Aircraft Response Time



- 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

Preliminary Metrics

Metric	Calculation	Description
Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
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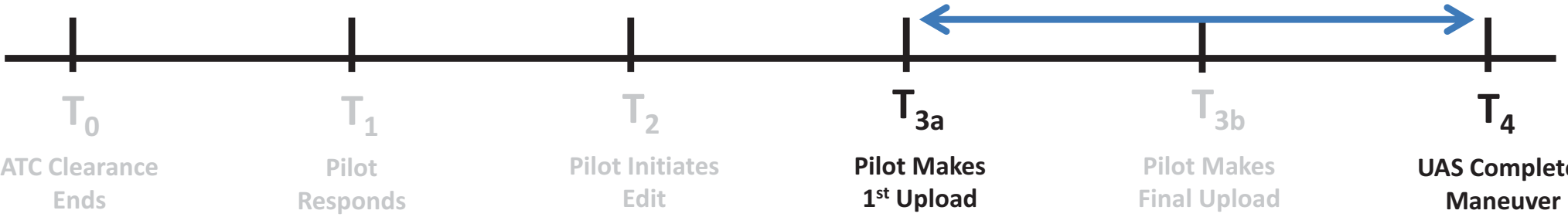
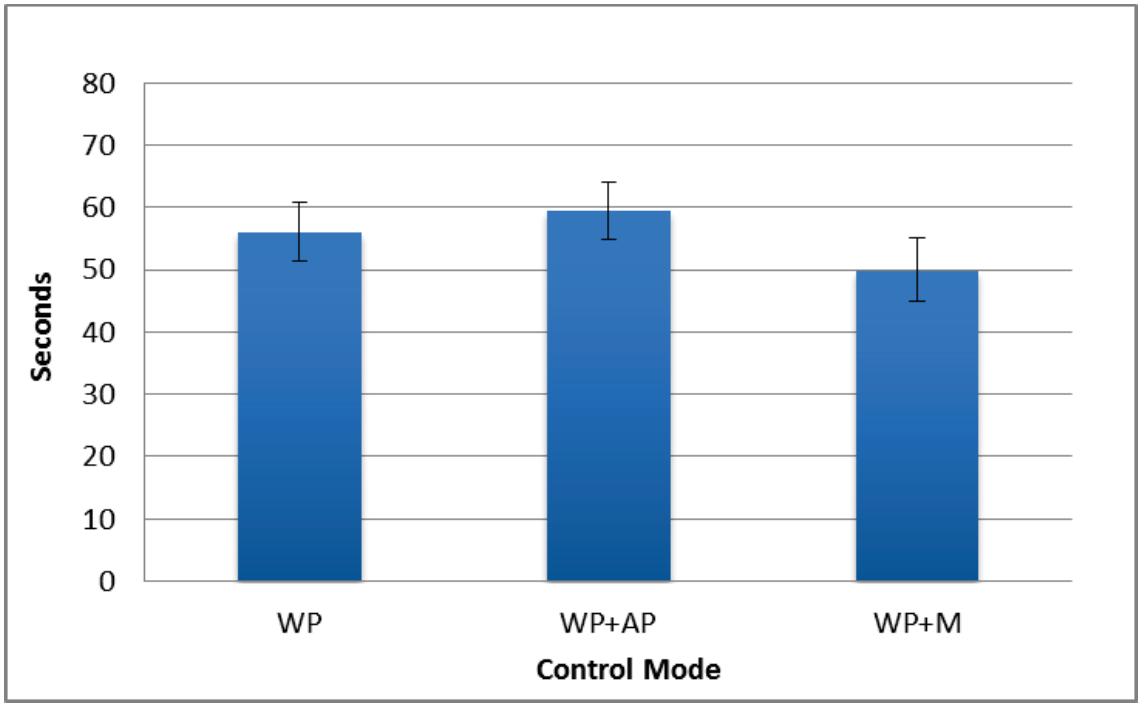
Aircraft Maneuver Time	$\mathbf{T_4 - T_{3a}}$	**Time it took the UAS to complete its maneuver once the maneuver began**
Compliance Time	$T_4 - T_0$	Time it took the UAS operator to complete *all* stages of ATC-Pilot interaction



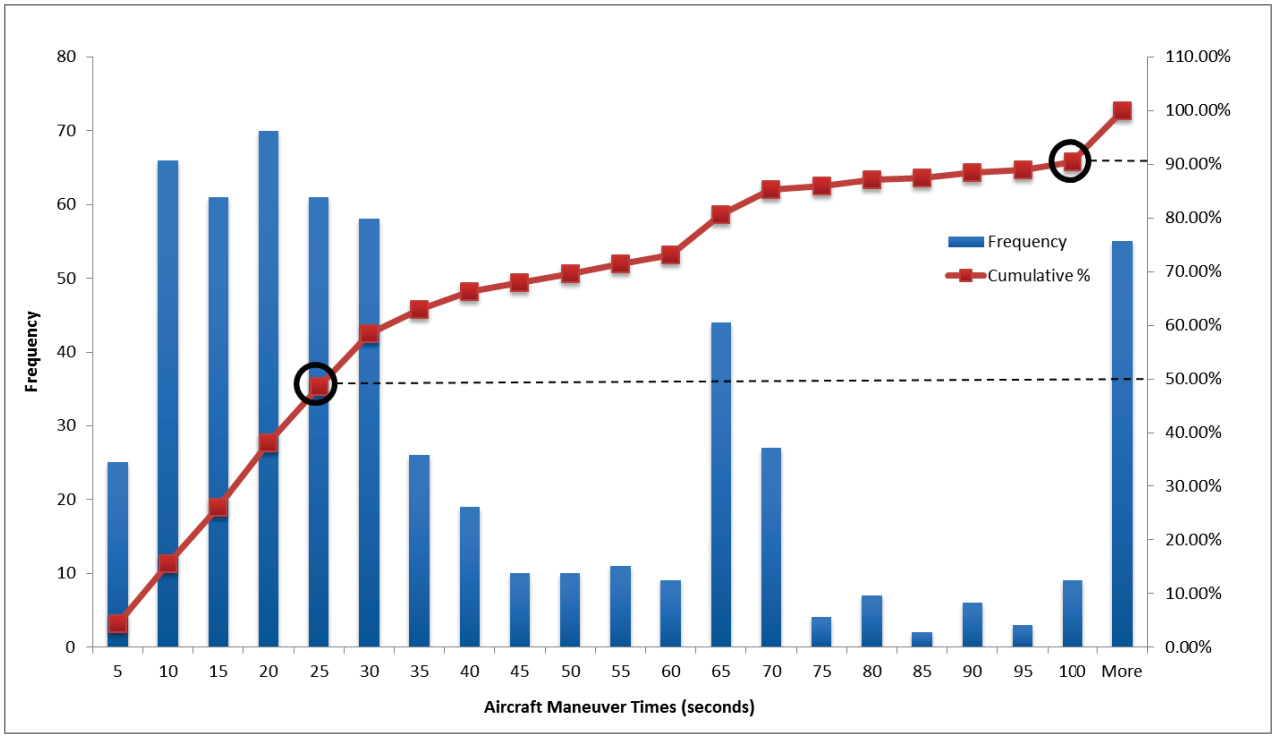
Aircraft Maneuver Time ($T_4 - T_{3a}$)

Time for aircraft to complete maneuver from initial upload



- 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

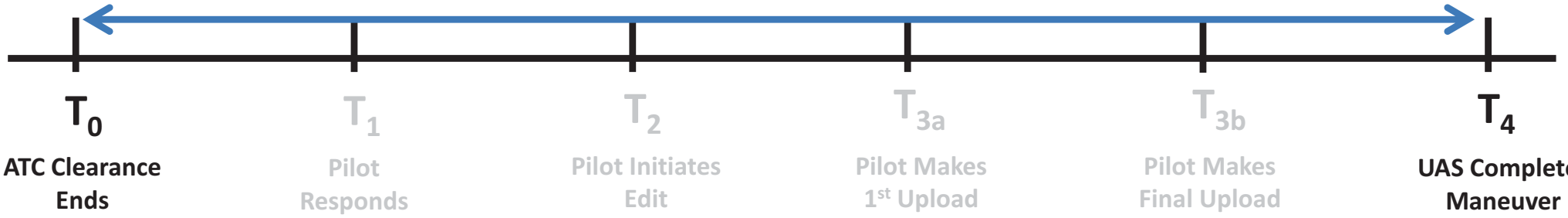
Aircraft Maneuver Time ($T_4 - T_{3a}$)



- 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

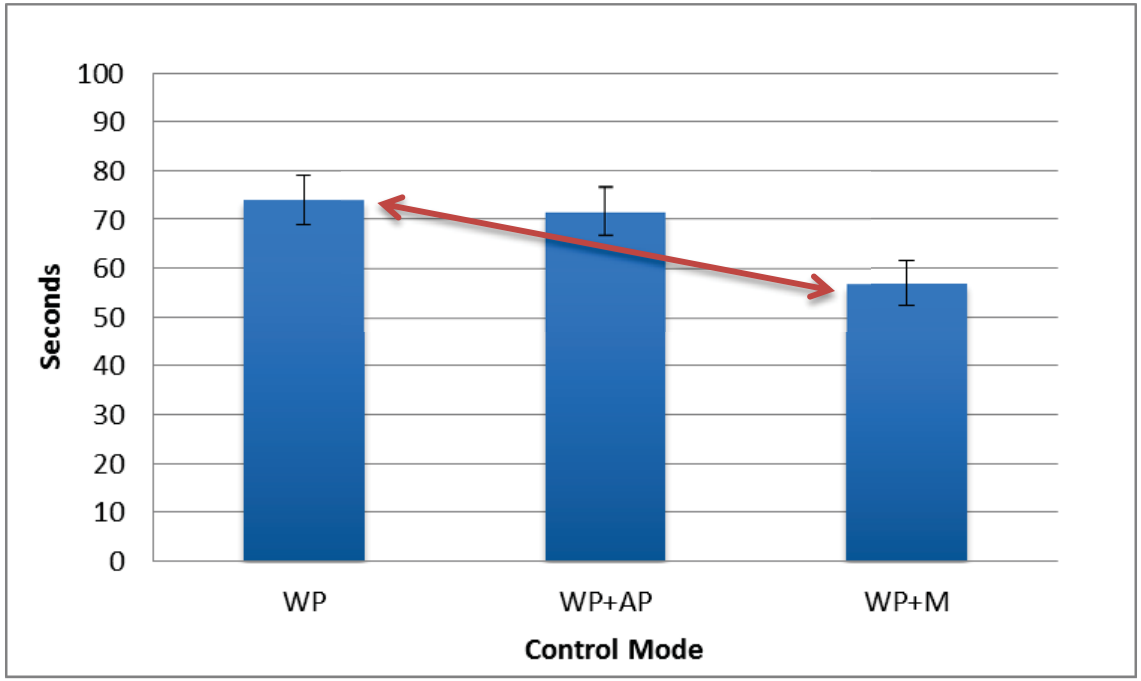
Preliminary Metrics

Metric	Calculation	Description
Verbal Response Time	$T_1 - T_0$	Time it took for pilots to respond verbally to ATC advisories and clearances
Initial Response Time	$T_2 - T_0$	Time it took for pilots to initiate edits in response to ATC clearances
Initial Edit Time (1st Upload)	$T_{3a} - T_2$	Time it took pilots to upload their first edit from the moment they began editing
Total Edit Time (Final Upload)	$T_{3b} - T_2$	Time it took pilots to upload their final edit from the moment they began editing
Aircraft Response Time	$T_{3a} - T_0$	Time it took for the aircraft to begin maneuvering from ATC clearance
Aircraft Maneuver Time	$T_4 - T_{3a}$	Time it took the UAS to complete its maneuver once the maneuver began
Compliance Time	$T_4 - T_0$	Time it took the UAS operator to complete *all* stages of ATC-Pilot interaction



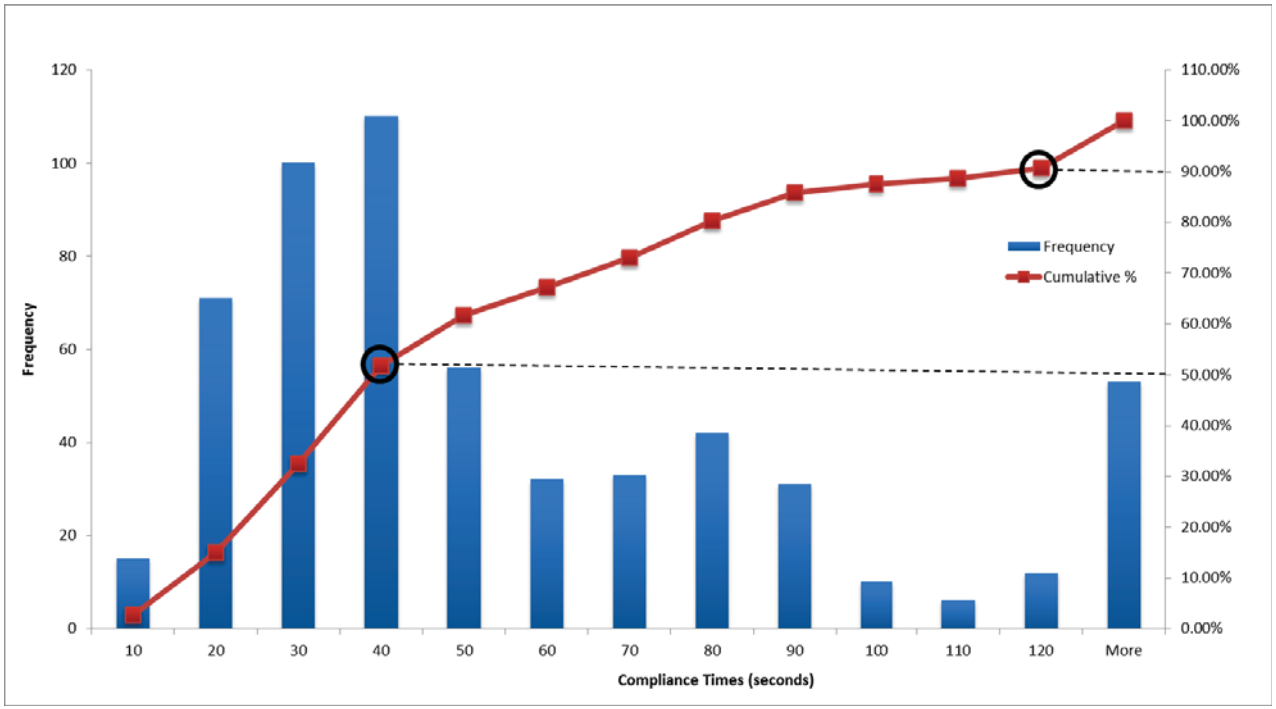
Compliance Time ($T_4 - T_0$)

Time from ATC clearance to complete maneuver



- 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 then 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?

Many thanks to the entire team …

- Human Systems Integration (HSI)
  - Jay Shively
  - Lisa Fern
  - Conrad Rorie
  - Dominic Wong
  - Quang Dao
  - Sabrina Billinghurst
  - Kevin Monk
  - Joseph Ott
- Separation Assurance Sense and Avoid Interoperability (SSI)
  - Eric Mueller
  - Confesor Santiago
  - Michael Abramson
- Integrated Test and Evaluation (IT&E)
  - Srba Jovic
  - Wayne Bridges
  - Jeffery Hernandez
  - Jacob Pfeiffer
  - Riva Canton
  - Dave Brown
  - Charles Walter

Back Up Slides

Sim Architecture