National Aeronautics and Space Administration

UAS Integration into the NAS:
Phase 1 Human Systems Integration Activities

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Human Systems Integration

- HSI Technical Barriers to UAS integration into the NAS:
  - Lack of Ground Control Station (GCS) Standards
  - Lack of a common definition or understanding of the GCS information needed to operate a UAS in the NAS
- HSI Objectives that address Technical Barriers:
  - I. Develop GCS guidelines to operate in the NAS
  - II. Develop a prototype display suite within an existing GCS to:
    1. Serve as a test bed for UAS pilot procedures and displays
    2. Provide a database to support guidelines development
    3. Provide an instantiated proof of concept for those guidelines
- Technical Approach/Activities:
  - Determine minimum GCS information requirements to operate in the NAS
  - Examine UAS pilot performance under various operating conditions and GCS configurations
  - Understand the impact of nominal and off-nominal UAS operations on Air Traffic Control (ATC) performance and workload
  - Develop a relevant and robust simulation environment

Human Systems Integration

Coordinate with ATC - w/o increase to ATC workload

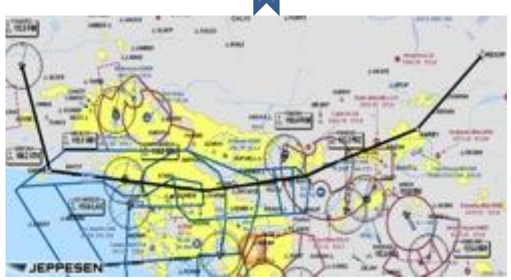
Efficiently manage contingency operations w/o disruption of the NAS

Seamlessly interact with SSI

Research **test-bed and database to provide data and proof of concept for GCS operations in the NAS**

Human factors guidelines for GCS operation in the NAS

Ensure operator knowledge of complex airspace and rules

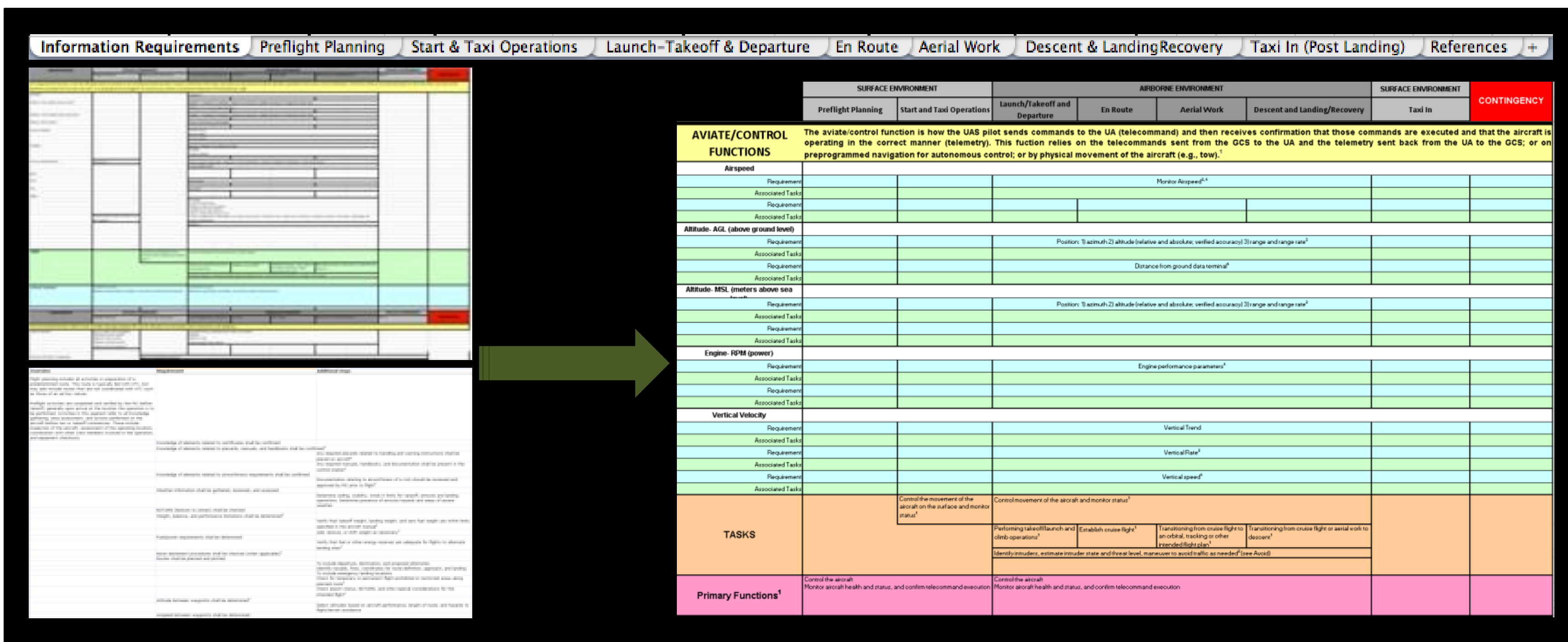


Standard aeronautical database for compatibility

Traffic information for situation awareness and self-separation (well clear)

Information Requirements

- Parallel Information Requirements Analyses:
  - Phase of Flight
  - Functional (e.g., aviate/control, manage, avoid, etc.)
  - Evaluation of existing Federal Air Regulations (FARs)
- Combined into a single, searchable database
  - Primary reference for development of prototype GCS displays and guidelines



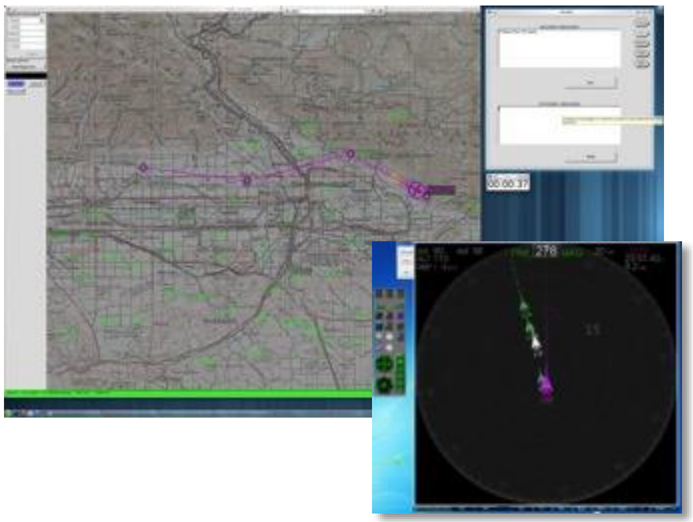
UAS Pilot Performance

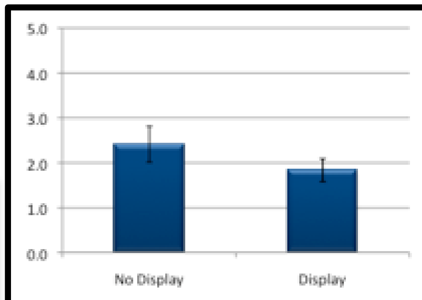
- Key Issues for UAS Pilot Performance:
  - Ability to perform comparably to pilots of manned aircraft (transparent to ATC)
  - Traffic display elements that support ability to maintain self-separation
  - Design of, and levels of automation in, command and control/navigation interfaces
- Simulation Experiments Examining UAS Pilot Performance:
  - Part Task Simulation 1 – Baseline Compliance
    - Fern, L., Kenny, C., Shively, R. J., & Johnson, W. (2012). UAS integration into the NAS: an examination of baseline compliance in the current airspace system. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, Boston, MA, October 22-26.
  - Measured Response A – Response to ATC Clearances
    - Shively, R. J., Vu, K. P. L., & Buker, T. J. (2013). Unmanned aircraft system response to air traffic control clearances: measured response. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting*, San Diego, CA, October 1-3.
  - Full Mission Simulation 1 – GCS Control Mode Interfaces
    - Rorie, R. C., Fern, L., & Shively, R. J. (submitted). UAS measured response: the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting,* Chicago, IL, October 27 -31.

UAS Pilot Performance

Part Task Simulation 1: An Examination of Baseline Compliance

- **Objectives**:
  1. Examine baseline compliance of UAS operations in the current airspace system
  2. Examine the effects of introducing a traffic display into a UAS ground control station on pilot performance, workload and situation awareness





Pilot Workload

Situation Awareness Statement	No Display Mean Rating	Display Mean Rating	p
I was aware of the locations of surrounding traffic	0.9	5.4	<.001
I was confident in my assessment of the traffic situation	1.3	5.9	<.001
I was aware of traffic conflicts developing	0.8	4.3	<.001
My SA was sufficient and effective	3.1	5.0	<.01
I had the airspace information that I needed to complete mission reroutes	2.8	4.5	<.05
I was confident in my responses to mission and ATC requirements	5.3	5.8	>.05

Pilot SA

Main results/conclusions:

- ATC reported appropriate and immediate compliance by UAS pilots, and sufficient knowledge of the airspace and required procedures
- No effect of traffic display on maintenance of separation in Class A airspace
- Potential benefits to both Pilots and Controllers when a traffic display is present in the GCS
  - significantly higher pilot SA on several dimensions
  - significantly lower workload for pilots when communicating with ATC

UAS Pilot Performance

Measured Response A: UAS Response to ATC Clearances

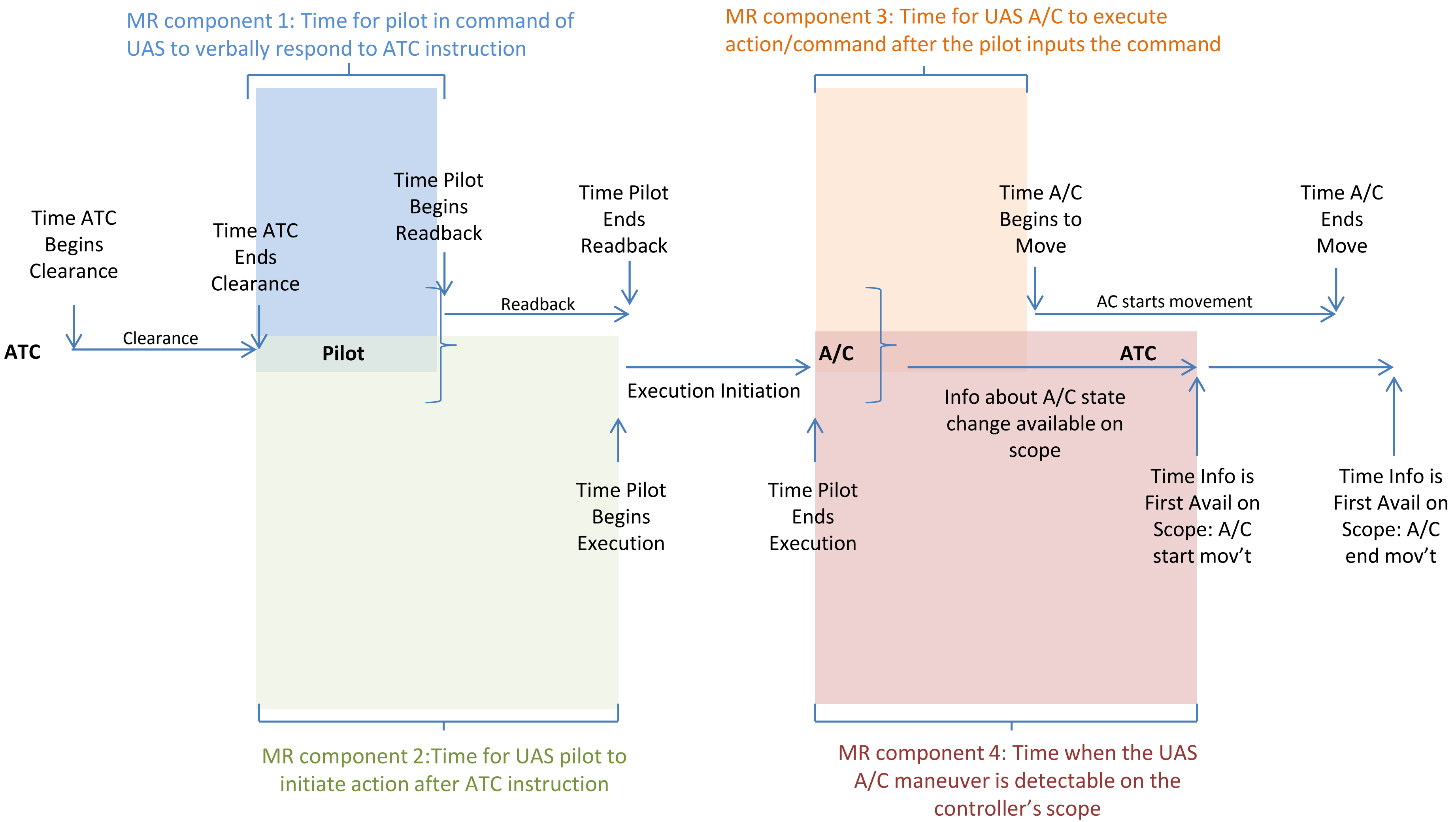
- **Objectives**:
  1. Demonstrate the ability to capture measured response components
  2. Identify UAS pilot verbal latencies and latencies in onset of command execution of standard ATC commands and clearances
  3. Obtain acceptability ratings of these latencies to ATC

	Clearance Type					
Measures	Crossing Restriction	Direct To	Route Amend- Altitude+ Traffic	Route Amend- Heading	Route Amend- Altitude	Traffic Alert + Immediate Turn
MR1 Time (in seconds)	2.64	2.71	2.43	2.71	2.07	2.86
MR2 Time (in seconds)	7.61	7.29	1.18	4.86	2.64	1.54
MR3 Time	Not captured because event occurs instantaneously in MUSIM					
MR4 Time (in seconds)	4.43	1.16	4.00	3.02	4.21	2.48
Pilot Workload Rating (1= Very low; 7 = Very high)	2.25	2.2	1.61	1.63	1.45	1.79
ATC Acceptability Rating (1= Not Acceptable; 7 = Highly Acceptable)	6.10	6.15	6.55	6.39	6.38	6.51

Main results/conclusions:

- MR components can be extracted for many ATC clearances along with their acceptability ratings
- Different MR components can occur in parallel/overlap with other MR components. As a result, the entire MR cannot simply be computed by adding up all the MR components

UAS Pilot Performance



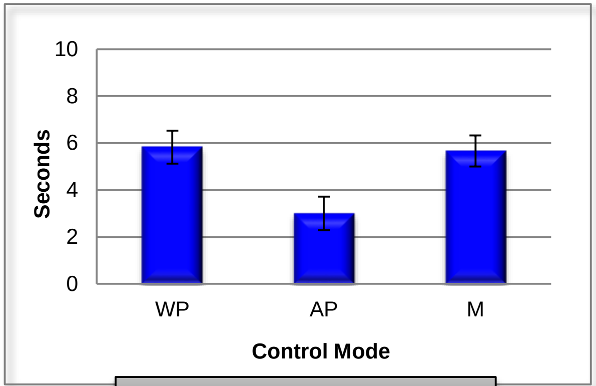
Measured Response A Identified Four Key Measured Response Components

UAS Pilot Performance

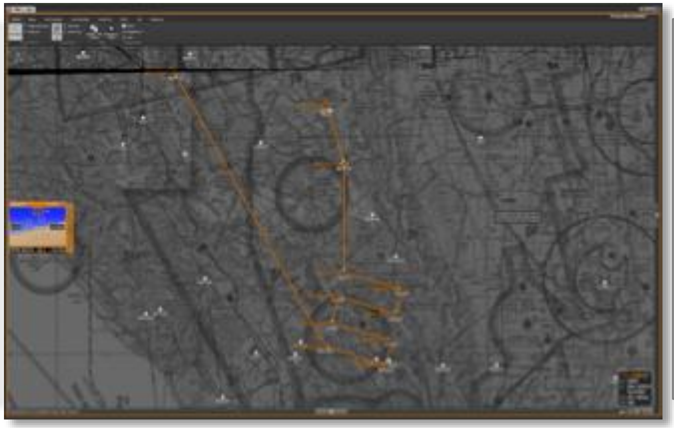
Full Mission 1: The Effect of GCS Control Mode Interfaces

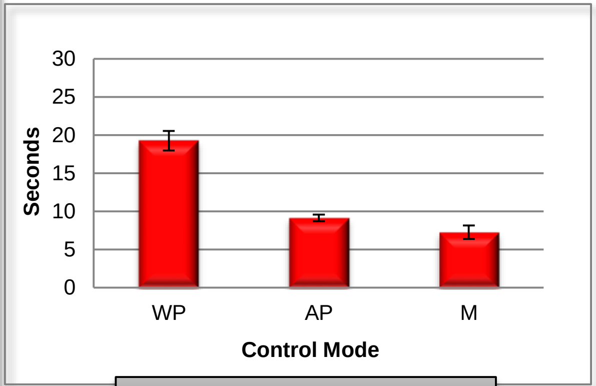
➢ **Objective**: to examine the effects of three different command and control interfaces on UAS pilots' ability to respond to ATC commands:

1. Waypoint-to-Waypoint only (WP; baseline)
2. Autopilot (quick input interface)
3. Manual (stick and throttle)



Pilot Response Time





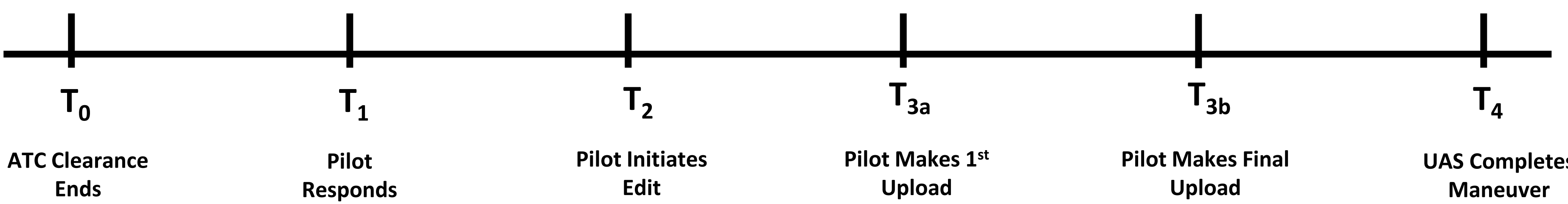
Pilot Edit Time

Main results/conclusions:

- Waypoint-to-waypoint control mode demonstrated significant deficits in all of the pilot measured response components
- AP mode showed significant advantages in the the initial/earliest stages of ATC-Pilot interaction (i.e., verbal response time and initial response time)
- M mode showed significant advantages in the editing stages of ATC-Pilot interaction (i.e., initial and final edit time)
- AP and M had significantly shorter compliance times overall than WP

UAS Pilot Performance

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



ATC Performance

- Key Issues for ATC Performance
  - Lost link and other UAS-specific contingency procedures
  - Communication and control latencies

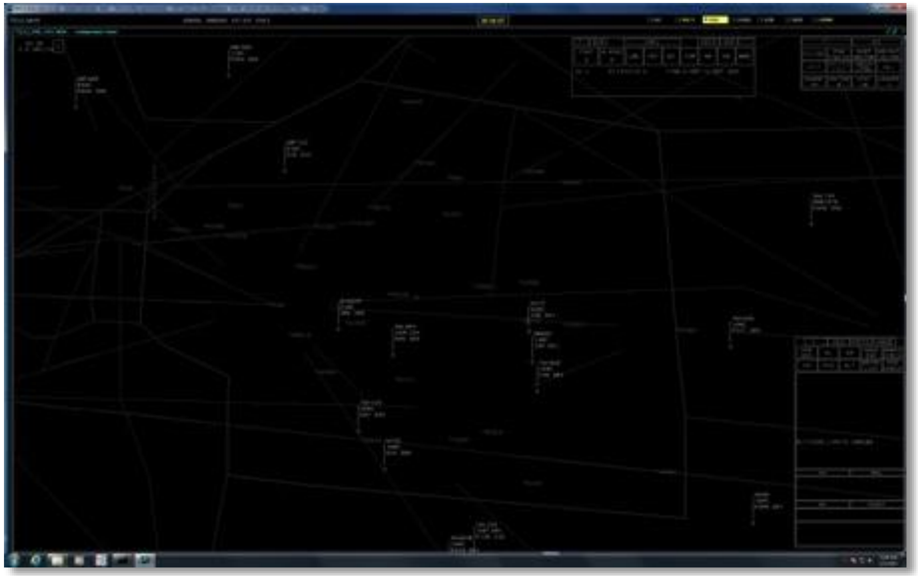
- Simulation Experiments Examining UAS Pilot Performance:
  - Part Task Simulation 3 – Contingency Management
    - Fern, L., Rorie, R. C., & Shively, R. J. (in press). UAS contingency management: the effect of different procedures on ATC in civil airspace operations. *Proceedings of the 14th Annual AIAA Aviation, Technology, Integration and Operations Conference*, Atlanta, GA, June 16-20.
  - Measured Response B – Controller Acceptability
    - Vu, K. 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. *Proceedings of the 32nd Digital Avionics Systems Conference*, Syracuse, NY, October 6-10.

ATC Performance

Part Task 3: Impact of UAS Contingency Operations on ATC

- **Objective**: to examine the effects of various, currently-employed UAS contingency procedures on sector safety and efficiency, and ATC workload.
  - Five levels of contingency procedures
  - Two main categories of contingencies: lost link and critical systems failure

ID	Event	Contingency Behavior	Time to Execute
C1	Baseline	N/A	N/A
C2	Lost Link	Return to base	1 min
C3	Lost Link	Return to base	8 min
C4	Lost Link	Maintain pre-programmed course, return to mission altitude	1 min
C5	Drop in Oil Pressure	Land at emergency site	Immediate



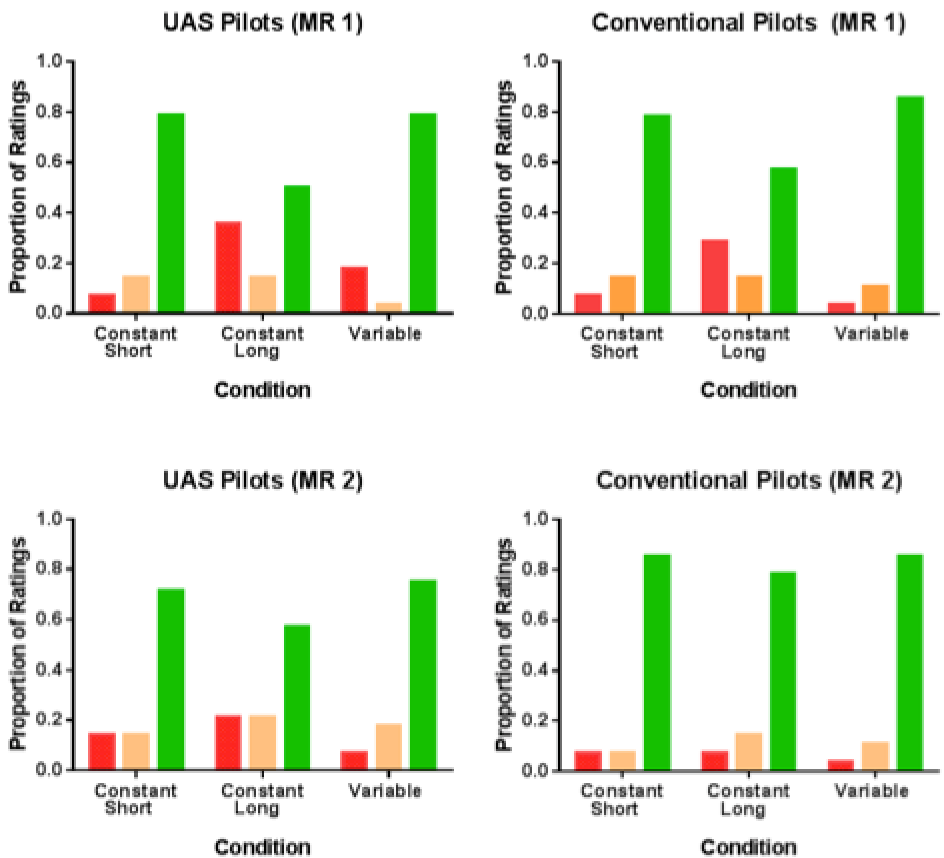
Main results/conclusions:

- Contingency procedures had no significant on objective measures of sector safety or efficiency; none differed significantly from baseline (no contingency)
- No significant differences in self-reported workload or situation awareness of the ATC participants
- Participants preferred procedures that minimized deviations and/or provided them with sufficient time to manage nearby aircraft in preparation for pre-planned deviations

ATC Performance

Measured Response B: Effect of Pilot Communication and Execution Delay

- **Objective**: to determine how delays in UAS pilot verbal communication (MR1) and clearance execution (MR2) impact ATC acceptability ratings of UAS and conventional pilot responses when a single UAS is operating in the NAS environment



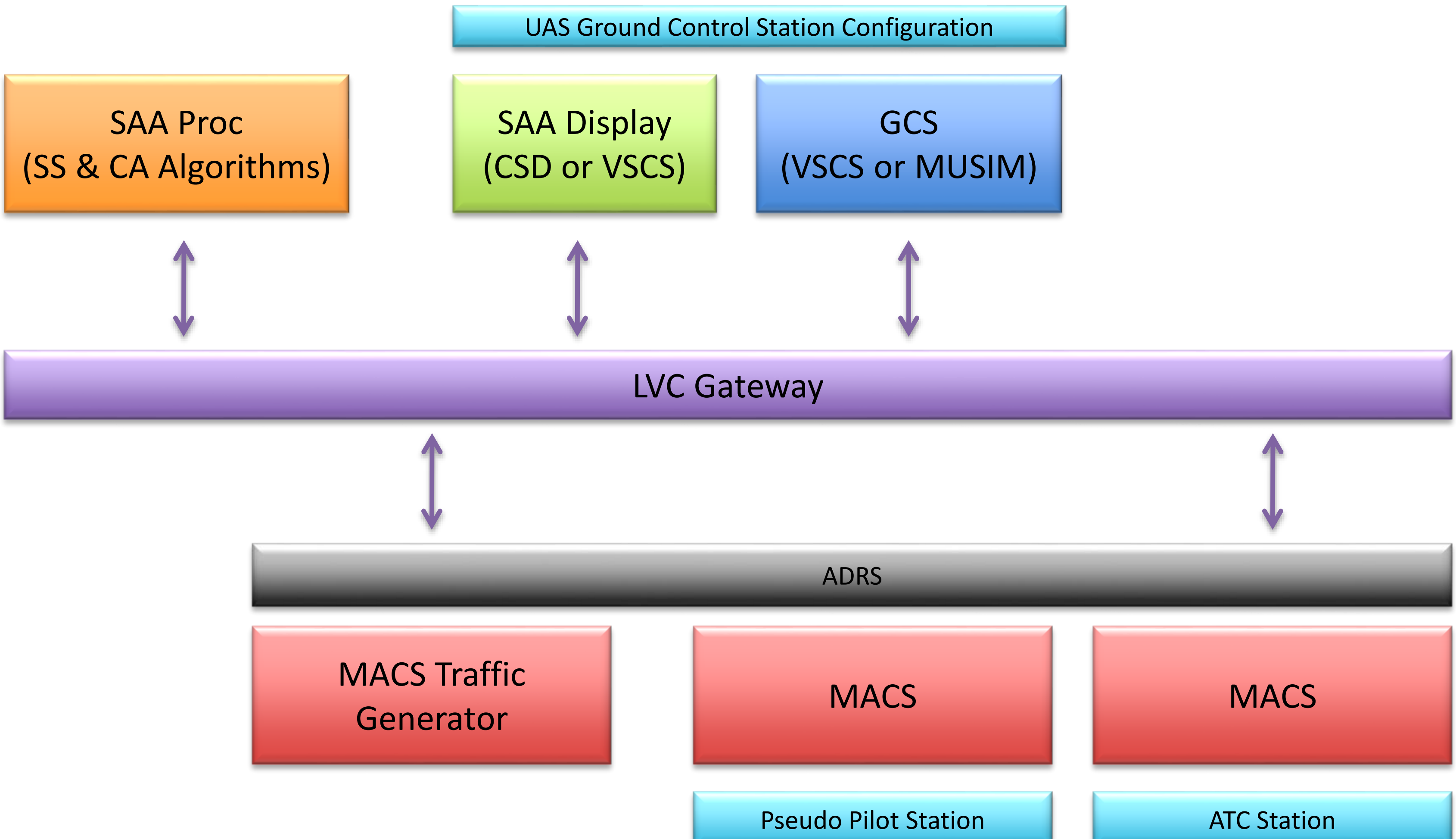
Main results/conclusions:

- ATC acceptability ratings were driven mainly by the verbal latencies (MR1).
    - Short UAS verbal latencies averaging 2.10s were mostly acceptable to ATC
    - Long UAS verbal latencies averaging 5.48s were not as acceptable (rated as acceptable on only about half of the scenarios)
    - UAS communication latencies affected ATC acceptability ratings of conventional pilots, despite the fact that delays were only added to the UAS.
- Execution latencies (MR2) and the predictability of the delays had less of an influence on ATC acceptability ratings.

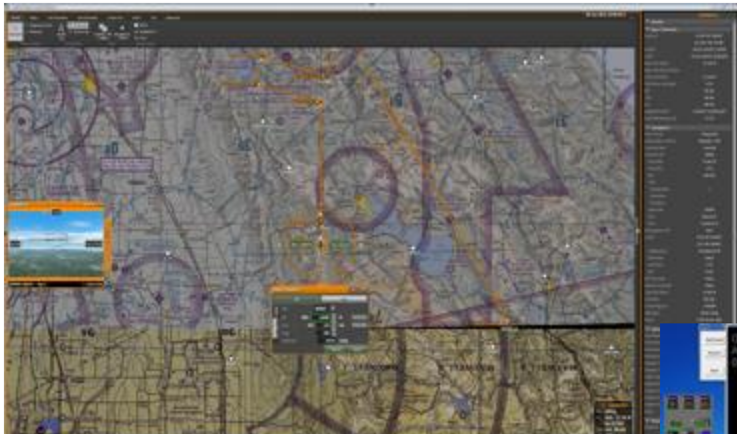
Simulation Environment Development

- HSI's simulation studies utilize the Integrated Test and Evaluation subproject's Live, Virtual, Constructive (LVC) Gateway to integrate key software:
  - Multiple UAS Simulator (MUSIM)
    - Developed by the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC)
  - Vigilant Spirit Control Station (VSCS)
    - Developed by the Air Force Research Laboratory (AFRL/RH)
  - Cockpit Situation Display (CSD)
    - Developed by NASA Ames Research Center, Human Systems Integration Division
  - Multi Aircraft Control Station (MACS)
    - Multiple stations provide:
      - Airspace and air traffic environment
      - Pseudo pilot stations
      - ATC Stations
    - Developed by NASA Ames Research Center, Human Systems Integration Division
  - Sense and Avoid (SAA) Processor
    - Hosts Self-Separation (SS) and Collision Avoidance (CA) algorithms
    - Developed by NASA Ames Research Center, Aviation Systems Division

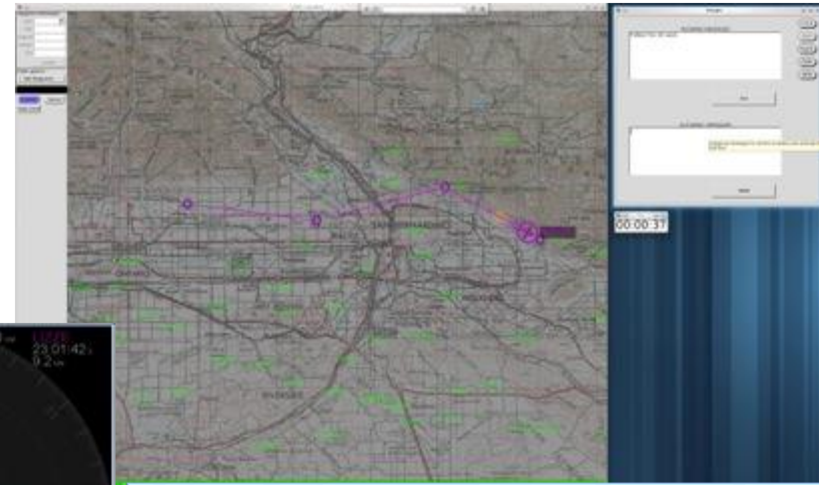
Simulation Environment Development



Simulation Environment Development



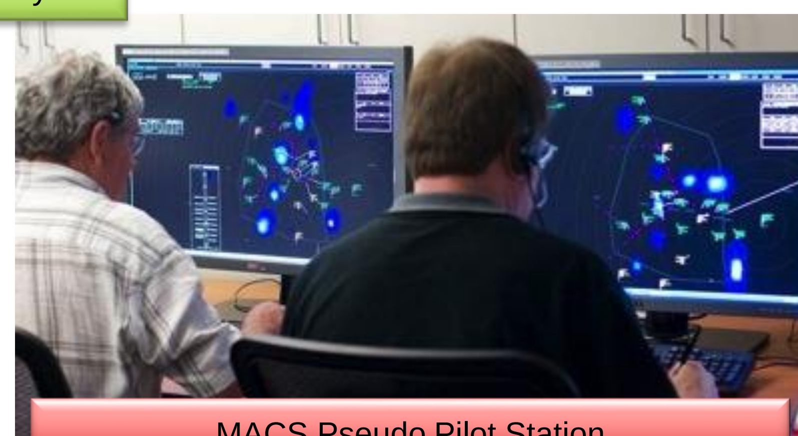
Vigilant Spirit Control Station



Multiple UAS Control Station

Cockpit Situation Display

MACS Air Traffic Control Station



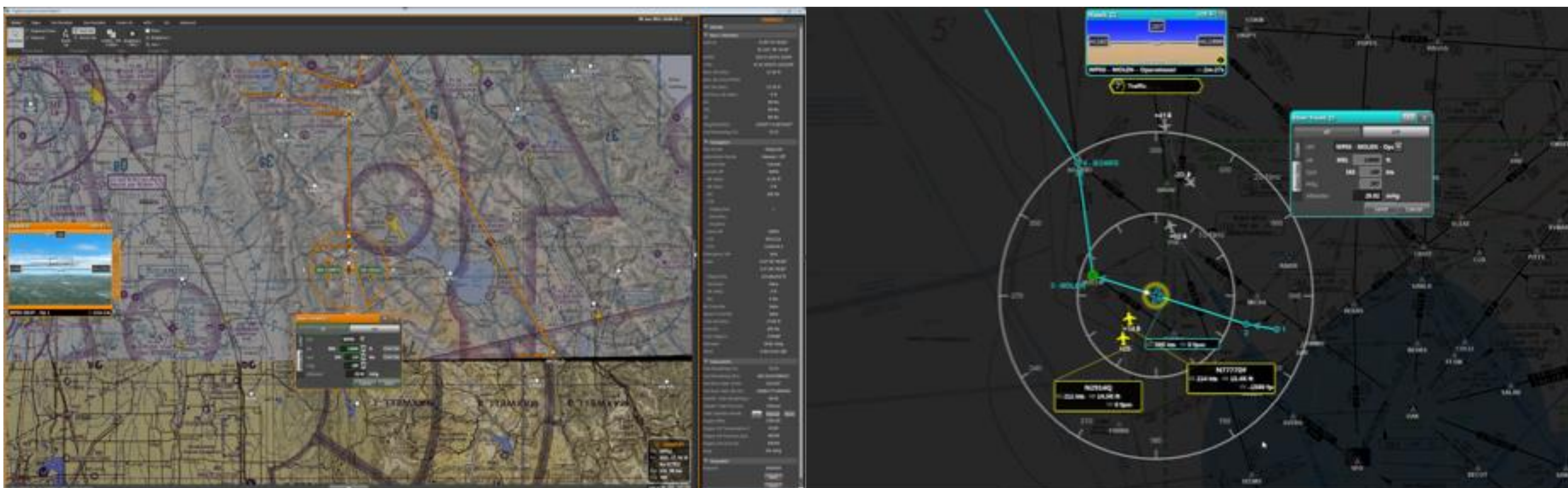
MACS Pseudo Pilot Station

Objective I: GCS Guidelines Development

- Radio Technical Commission for Aeronautics (RTCA)
  - *Utilized as a Federal advisory committee, to be the premier Public-Private Partnership venue for developing consensus among diverse and competing interests and provide advice and recommendations on key issues critical to aviation modernization in an increasingly global enterprise*
  - Special Committee 228: Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft System
  - HSI is currently leading the Human-Machine Interface (HMI) requirements for the DAA and C2 sections of the MOPS. Potential HMI MOPS Requirements, Recommendations or Impacts include:
    - Detect and Avoid (DAA)
      - Displays (minimum information, alerting, advanced decision aiding/pilot guidance)
      - Alerting
      - Control interfaces
      - Behavior
    - Command and Control (C2)
      - Displays (monitoring and control of C2 links)
      - Visual (i.e., camera/out-the-window) information requirements by phase of flight
      - Levels of automation (effect on C2 links)
- General GCS Requirements
  - Will include those requirements not covered within the DAA and C2 sections of the SC-228 MOPS
  - To be published as a NASA report

Objective II: Prototype Development

- The Vigilant Spirit Control Station (VSCS) will serve as the prototype GCS for the UAS Integration into the NAS Project
  - Robust, flexible interface
  - Multi-UAS control with VSCS has been tested in simulation and flight by AFRL
  - STANAG 4586 Compliant
- Current UAS in the NAS version includes:
  - Single UAS control
  - NAS-compatible database (low- and high- altitude charts with navigational aids/”fixes”)
  - Integrated traffic display



Summary of HSI Activities

- Information Requirements:
  - Single searchable database combining three separate analyses:
    - Phase of Flight
    - Functional (e.g., aviate/control, manage, avoid, etc.)
    - Evaluation of existing Federal Air Regulations (FARs)
- Simulation Experiments:
  - Pilot Performance
    - Part Task Simulation 1– Baseline Compliance
    - Measured Response A – Response to ATC Clearances
    - Full Mission Simulation 1 – Command and Control Interfaces
  - ATC Performance
    - Part Task Simulation 3 – Contingency Management
    - Measured Response B – Pilot Communication and Execution Delay
- Simulation Environment Development:
  - LVC Gateway
  - Multiple UAS Simulator (MUSIM)
  - Vigilant Spirit Control Station (VSCS)
  - Cockpit Situation Display (CSD)
  - Multi Aircraft Control Station (MACS)
  - Sense and Avoid (SAA) Processor
- Objective I: GCS Guidelines
- Objective II: Prototype Development

Phase 2 Activities

- Simulation experiments to focus on DAA requirements:
  - Part Task Simulation 4:
    - Minimum display requirements
    - Advanced information and pilot guidance
    - Stand alone versus integrated displays
  - Part Task Simulation 5:
    - Evaluation of additional DAA displays
  - Full Mission Simulation 2:
    - Evaluation of boundary between self-separation, collision avoidance and autonomous collision avoidance
- Flight Tests to validate prototype GCS displays in operationally relevant environment
  - ACAS Xu
  - Flight Test 3
  - Flight Test 4