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:
  o Lack of Ground Control Station (GCS) Standards
  o 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:
  o Determine minimum GCS information requirements to operate in the NAS
  o Examine UAS pilot performance under various operating conditions and GCS
    configurations
  o Understand the impact of nominal and off-nominal UAS operations on Air Traffic Control
    (ATC) performance and workload
  o 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

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

Standard aeronautical database for compatibility
Information Requirements

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

• Key Issues for UAS Pilot Performance:
  o Ability to perform comparably to pilots of manned aircraft (transparent to ATC)
  o Traffic display elements that support ability to maintain self-separation
  o Design of, and levels of automation in, command and control/navigation interfaces

• Simulation Experiments Examining UAS Pilot Performance:
  o Part Task Simulation 1 – Baseline Compliance
  
  o Measured Response A – Response to ATC Clearances
  
  o Full Mission Simulation 1 – GCS Control Mode Interfaces
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
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

**Four Key Measured Response Components**

1. **MR component 1:** Time for pilot in command of UAS to verbally respond to ATC instruction.
2. **MR component 2:** Time for UAS pilot to initiate action after ATC instruction.
3. **MR component 3:** Time for UAS A/C to execute action/command after the pilot inputs the command.
4. **MR component 4:** Time when the UAS A/C maneuver is detectable on the controller’s scope.

### Measured Response A

**ATC**
- Time ATC Begins Clearance
- Time ATC Ends Clearance
- Time ATC Begins to Move
- Time ATC Ends Move
- Time ATC Begins Clearance

**Pilot**
- Time Pilot Begins Clearance
- Time Pilot Ends Readback
- Time Pilot Begins Execution
- Time Pilot Ends Readback

**A/C**
- Time A/C Begins to Move
- Time A/C Ends Move
- Time A/C Begins
- Time A/C Ends

**AC starts movement**

**Info about A/C state change available on scope**

**Execution Initiation**

**Time Info is First Avail on Scope: A/C start mov’t**

**Time Info is First Avail on Scope: A/C end mov’t**
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 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

<table>
<thead>
<tr>
<th>Metric</th>
<th>Calculation</th>
<th>Description</th>
</tr>
</thead>
<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>
</tr>
<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>Aircraft Response Time</td>
<td>$T_{3a} - T_0$</td>
<td>Time it took for the aircraft to begin maneuvering from ATC clearance</td>
</tr>
<tr>
<td>Aircraft Maneuver Time</td>
<td>$T_4 - T_{3a}$</td>
<td>Time it took the UAS to complete its maneuver once the maneuver began</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>
</tr>
</tbody>
</table>

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ATC Clearance Ends | Pilot Responds | Pilot Initiates Edit | Pilot Makes 1st Upload | Pilot Makes Final Upload | UAS Completes Maneuver

$T_0$ | $T_1$ | $T_2$ | $T_{3a}$ | $T_{3b}$ | $T_4$
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
  - Measured Response B – Controller Acceptability
**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

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

**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

- SAA Proc (SS & CA Algorithms)
- SAA Display (CSD or VSCS)
- GCS (VSCS or MUSIM)
- LVC Gateway
- ADRS
- MACS Traffic Generator
- MACS
- MACS
- Pseudo Pilot Station
- ATC Station
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:
  o 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:
  o Pilot Performance
    ▪ Part Task Simulation 1 – Baseline Compliance
    ▪ Measured Response A – Response to ATC Clearances
    ▪ Full Mission Simulation 1 – Command and Control Interfaces
  o ATC Performance
    ▪ Part Task Simulation 3 – Contingency Management
    ▪ Measured Response B – Pilot Communication and Execution Delay

• Simulation Environment Development:
  o LVC Gateway
  o Multiple UAS Simulator (MUSIM)
  o Vigilant Spirit Control Station (VSCS)
  o Cockpit Situation Display (CSD)
  o Multi Aircraft Control Station (MACS)
  o Sense and Avoid (SAA) Processor

• Objective I: GCS Guidelines
• Objective II: Prototype Development
Phase 2 Activities

• Simulation experiments to focus on DAA requirements:
  o Part Task Simulation 4:
    ▪ Minimum display requirements
    ▪ Advanced information and pilot guidance
    ▪ Stand alone versus integrated displays
  o Part Task Simulation 5:
    ▪ Evaluation of additional DAA displays
  o 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
  o ACAS Xu
  o Flight Test 3
  o Flight Test 4