NASA UAS Integration Into the NAS Project
Human Systems Integration

AUVSI
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Summary of Contributions

• Suggestive Displays
  – Guidance Bands
• Integrated or stand alone*
• Alerting Logic
• Minimum Information tags
• TCAS/DAA interop logic
• Well Clear Recovery logic/display
• Pilot response timeline
  – Derived RADAR Requirements
Simulation Environment: 
LVC Architecture

**SaaProc Input:**
- Traffic
- Ownship

**SaaProc Output:**
- Intruders
- Saa Threat Alerts and Resolutions

**VSCS Input:**
- Intruders
- SAA Threat Alerts

**VSCS Output:**
- Ownship

**Stratway Input:**
- Intruders
- Ownship

**Stratway Output:**
- Stratway Bands Msg

**ATC & PPIlots Input:**
- Ownship

**ATC & PPIlots Output:**
- Traffic

**Traffic:**
- Flt State,
- Flt Plan,
- Traj. Intent

**Ownship:**
- Flt State,
- Flt Plan,
- Traj. Intent

**Intruders:** Flt State

**SaaProc/JADEM (sensor model)**

**LVC Gateway**

**ADRS (LaRC)**

**GCS (MACS)**

**ATC & Pseudo Pilot System (MACS)**
Project Background

• Approach: Conduct a series of iterative human in the loop experiments, in a representative simulation environment, with different display configurations to objectively measure pilot performance when maintaining well clear from scripted conflicts
  – Key metrics: pilot response time, losses of well clear, severity of losses of well clear
  – Three simulations have been conducted: PT4, iHITL, PT5
    • Displays are modified/improved/changed based on data/observations
    • Displays are carried through to new HITLs to create anchors or linkages to previous data for comparison
    • New displays are developed for test
    • Test/simulation environment/protocols also updated and improved between HITLs
  – Two “mini-HITLs” (i.e., engineering evaluations)
    • TCAS interoperability
    • Missing Information
Project Background

• Display Types:
  
  – **Informative**: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. *No maneuver guidance or decision aiding is provided to the pilot.*
  
  – **Suggestive**: *Provides a range of potential resolution maneuvers to avoid a hazard with manual execution.* An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers.
  
  – **Directive**: *Provides specific recommended resolution guidance to avoid a hazard with manual or automated execution.* An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver.
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DAA Guidance Display

Green Bands

No Green Bands
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Loss of Well Clear Guidance

Horizontal Guidance

Vertical Guidance

Limited Suggestive
Loss of Well Clear: Directional

Horizontal Guidance

Vertical Guidance

Directional
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Latest Display

• **Auditory Alert**
  - RA sense presented aurally (source: TCAS II v7.1)

• **Text Based**
  - RA sense shown in text box next to Baseball Card

• **Vertical Rate Guidance**
  - Presented within VVI
  - Green = desired vertical speed
  - Red = vertical speed to avoid

“CLIMB, CLIMB”

(source: TCAS II v7.1)
TCAS Interoperability

• A TCAS Interoperability Workshop was held to determine potential display/alerting/guidance issues that could be explored in a NASA “mini” HITL
  – Development of a DAA-TCAS Interoperability concept
  – Prioritized list of independent variables for experimental design
  – Set of use cases to stress TCAS Interoperability

• Main Issues for DAA-TCAS Interoperability
  – TCAS is not aware of all aircraft and so can give guidance that causes conflicts with non-cooperative aircraft
  – DAA system is aware of all aircraft and must conform to TCAS functioning
    • Key interoperability issues with DAA during “well clear recovery”
      – When a loss of well clear can no longer be avoided
    • Urgency of well clear penetration and need to interoperate with TCAS drives a directive or limited suggestive guidance solution
TCAS Interoperability

- DAA-TCAS Interoperability Concept:
  - Any target with an active corrective RA should be removed from all DAA guidance calculations
    - Horizontal DAA guidance will be shown for non-RA aircraft
    - All DAA vertical guidance should be *suppressed* during a corrective RA to prevent showing conflicting guidance to the pilot
  - During a preventive RA, TCAS guidance should be an input to the DAA vertical guidance so that it is consistent
  - Well clear recovery is limited to horizontal only for cooperative intruders
    - Prevents pilots from making maneuvers near the collision avoidance boundary which may degrade TCAS II performance

- Purpose of HITL:
  1. Examine performance difference for different methods of showing well clear recovery and DAA guidance
  2. Test overall suitability of interoperability concept
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## DAA-TCAS Alerting Structure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Buffered Well Clear Criteria</th>
<th>Alerting Time Threshold</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCAS RA</td>
<td>• <strong>Immediate action required</strong>&lt;br&gt;• Comply with RA sense and vertical rate&lt;br&gt;• Notify ATC as soon as practicable after taking action</td>
<td>(Driven by TCAS-II)</td>
<td>x</td>
<td>“Climb/Desc end”</td>
</tr>
<tr>
<td></td>
<td>DAA Warning Alert</td>
<td>• <strong>Immediate action required</strong>&lt;br&gt;• Notify ATC as soon as practicable after taking action</td>
<td>DMOD = 0.75 nmi&lt;br&gt;HMD = 0.75 nmi&lt;br&gt;ZTHR = 450 ft&lt;br&gt;modTau = 35 sec</td>
<td>25 sec (TCPA approximate: 60 sec)</td>
<td>“Traffic, Maneuver Now”</td>
</tr>
<tr>
<td></td>
<td>DAA Corrective Alert</td>
<td>• On current course, <strong>corrective action required</strong>&lt;br&gt;• Coordinate with ATC to determine an appropriate maneuver</td>
<td>DMOD = 0.75 nmi&lt;br&gt;HMD = 0.75 nmi&lt;br&gt;ZTHR = 450 ft&lt;br&gt;modTau = 35 sec</td>
<td>55 sec (TCPA approximate: 90 sec)</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td></td>
<td>DAA Preventive Alert</td>
<td>• On current course, corrective action <strong>should not be required</strong>&lt;br&gt;• Monitor for intruder course changes&lt;br&gt;• Talk with ATC if desired</td>
<td>DMOD = 1.0 nmi&lt;br&gt;HMD = 1.0 nmi&lt;br&gt;ZTHR = 700 ft&lt;br&gt;modTau = 35 sec</td>
<td>55 sec (TCPA approximate: 90 sec)</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td></td>
<td>Remaining Traffic</td>
<td>• No action expected</td>
<td>Within surveillance field of regard</td>
<td>x</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Video Demo
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Self-Separation Timeline

- Time until CPA Well Clear Threshold (~35 sec)
- Aircraft Maneuver Time (~65 sec)
- Pilot Response Time (~30 sec)
- ATC Interaction Time (~10 sec)
- Latency

TOTAL RESPONSE TIME: Detect Intruders, Pilots Determine Resolution, Negotiate Clearance with ATC and uplink maneuver to aircraft

Approximate detection range = 8 nm
Approximate detection range = 6 nm

Approximate detection range = 8 nm
Pilot-DAA Timeline

- **Traffic Display Alert (SS or CA)**
- **Pilot Notifies ATC**
- **ATC Approval**
- **Pilot Initiates Edit**
- **Pilot Uploads First Edit**
- **Pilot Uploads Final Edit**
- **Traffic Alert Removed**
- **UAS Completes Maneuver**

**Time Points**:
- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit
- **T₅**: Traffic Alert Removed
- **T₆**: UAS Completes Maneuver

**Key Timings**:
- **Initial Response Time**
- **Clearance Approval Time**
- **Total Response Time**
- **Total Edit Time (First Upload)**
- **Total Edit Time (Final Upload)**
- **Compliance Time**

**Additional Timings**:
- **Notification Time**
- **Initial Edit Time (First Upload)**
- **Approval vs Upload Time**
- **Notify vs Upload Time**
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RTCA SC 228

• Phase 1 MOPS – Final Aug 2016
  – Alerting
  – Guidance
  – Displays
Next Steps

• Support SC 228 Phase 2 MOPS
  – Terminal Areas
  – ACAS-Xu
  – Alternative Sensors
  – GBSAA
  – Mid-size A/C

• Support ICAO – RPAS - Human In The System (HITS) working group

• “Common” GCS

• GCS Guidelines
Questions?