Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Advanced Collision Avoidance System for UAS (ACAS Xu) Interoperability White Paper Presentation
SC-228 WG-1
• Phase 1 DAA MOPS specified two classes of DAA equipage:
  – Class 1: Remain well clear (RWC) function only
  – Class 2: RWC + Collision Avoidance (CA; TCAS II)
    • Two separate systems

• Phase 2 DAA MOPS will support the development of a third class of DAA equipage:
  – Class 3: ACAS Xu providing RWC + CA
    • Single integrated system
Phase 2 ACAS Xu Scope

- ACAS Xu will specify an integrated DAA system, it will need to show compliance with the RWC alerting thresholds and alerting requirements defined in the DAA MOPS.
- However, integration of RWC and CA functions within ACAS Xu allows for more seamless integration of alerting and guidance than the Class 2 system.
- Phase 2 MOPS should address the following issues/areas to support the integration of RWC and CA functionality for DAA systems:
  - DAA alert levels for both RWC and CA
  - RWC alert processing and performance requirements
  - Visual and aural display of DAA (RWC & CA) alerts
  - RWC guidance processing and performance requirements
  - Visual display of DAA (RWC & CA) guidance
DAA alert levels RWC and CA

• DAA Phase 1 Alerting structure based on DAA timeline and desired pilot actions
• *Preventive Alert:* awareness of intruders within original SARP well clear definition vertical miss distance of 700ft
• *Corrective Alert:* loss of well clear is predicted, coordinate with ATC prior to maneuvering
• *Warning Alert:* loss of well clear imminent, maneuver first, then contact ATC
  – Originally intended to be for Class 1 system only (no CA), but was maintained for Class 2 system based on performance benefits observed in HITLs
  – For ACAS Xu, should the DAA warning alert be maintained separately from ACAS Xu CA “RA”, removed, or combined?
• Any changes to the Phase 1 alert structure will require updates to the alert processing/performance requirements
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="symbol" alt="TCAS RA*" /></td>
<td>TCAS RA*</td>
<td>• Immediate action required&lt;br&gt;• Comply with RA sense and vertical rate&lt;br&gt;• Notify ATC as soon as practicable after taking action</td>
<td>“Climb/Descend”</td>
</tr>
<tr>
<td><img src="symbol" alt="Warning Alert" /></td>
<td>Warning Alert</td>
<td>• Immediate action required&lt;br&gt;• Notify ATC as soon as practicable after taking action</td>
<td>“Traffic, Maneuver Now” X2</td>
</tr>
<tr>
<td><img src="symbol" alt="Corrective Alert" /></td>
<td>Corrective Alert</td>
<td>• On current course, corrective action required&lt;br&gt;• Coordinate with ATC to determine an appropriate maneuver</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td><img src="symbol" alt="Preventive Alert" /></td>
<td>Preventive Alert</td>
<td>• On current course, corrective action should not be required&lt;br&gt;• Monitor for intruder course changes&lt;br&gt;• Talk with ATC if desired</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td><img src="symbol" alt="Guidance Traffic" /></td>
<td>Guidance Traffic</td>
<td>• No action required&lt;br&gt;• Traffic generating guidance bands outside of current course</td>
<td>N/A</td>
</tr>
<tr>
<td><img src="symbol" alt="Remaining Traffic" /></td>
<td>Remaining Traffic</td>
<td>• No action required&lt;br&gt;• No coordination required</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Applies to Class 2 DAA equipment only.
Visual and aural display of DAA (RWC & CA) alerts

- Prescriptive requirements for aural and visual, RWC caution- and warning-level alerts already exist
- Prescriptive requirements for aural and visual vertical CA alerts already exist from TCAS (i.e., RAs)
- If CA and RWC warning alerts are combined, need to determine appropriate symbol
- New aural alerts needed for horizontal CA alerts
  - Tone versus verbal
DAA Phase 1 MOPS provided two types of RWC guidance:
- Guidance to maintain DWC
- Guidance to regain DWC

Maintain DWC guidance provides information about corrective and warning alerts
- Changes to DAA alert structure will affect guidance processing and performance requirements

Guidance to regain DWC requirements driven largely by:
- Need to provide continuous guidance even when a loss of well clear can no longer be avoided
  - Especially when no CA exists, i.e. Class 1
- Need to ensure that pilot will make dual maneuver for the “hard case” with Class 2 system
- Should not be necessary with ACAS Xu, but tuning/analysis required to ensure that there is no gap in positive guidance between suggestive and directive guidance transition
Visual display of DAA (RWC & CA) guidance

- New requirements to display horizontal directive guidance
- Modification of TCAS II requirements to display vertical directive guidance
  - Vertical speed (legacy) versus altitude guidance
- Compliance with blended maneuvers
Operational Environment

- Phase 1 MOPS will be fully supported by the initial ACAS Xu MOPS
- Initial ACAS Xu MOPS is also expected to support much of the Phase 2 DAA MOPS Operational Environments, including sustained operations in Classes B through E airspace and terminal operations for properly equipped UAS
- Coordination between SC-228 and SC-147 will be important to ensure these environments are defined compatibly and with the same operational assumptions.
Assumptions

- SC-228 will address MOPS for RWC and CA alerting and guidance high-level requirements (e.g. timing performance, definitions, and thresholds), as well as the human machine interface requirements for the integrated RWC-CA ACAS Xu equipage.

- SC-147 will address MOPS for RWC and CA alerting and guidance low-level requirements (e.g. textual requirements, proscriptive algorithm implementation), and ACAS Xu will comply with the DAA MOPS developed within SC-228.
Approach

- Safety/risk analysis of integrated Warning Alert/RA threshold
  - Need decision about whether we will combine the two warning alert levels ASAP
- Human factors analysis to determine potential visual and aural alerting and guidance displays for horizontal RAs
- Human factors analysis of how to display vertical RA guidance
- Human-in-the-loop (HITL) evaluation of potential visual and aural alerting and guidance displays for horizontal RAs
- Human factors analysis of how to display/prioritize simultaneous horizontal and vertical RWC and CA guidance
- Validate pilot performance with ACAS Xu through HITL simulation
NASA’s Planned ACAS Xu Support

- Two HITL simulations planned
  - Summer 2017 (Run 3)
  - Summer 2018 (Run 4)
- HITL 1 Schedule
  - Experimental Design: 1 FEB – 1 APR 2018
  - Programming: 1 APR – 15 JULY
  - Shake-down: 1 JULY – 1 AUG
  - Data Collection: 1 AUG – 1 SEPT
  - Analysis: 1 SEPT – 30 SEPT
  - Results Dissemination: 30 SEPT
Proposed Experimental Design

- Primary IV
  - Horizontal RA Guidance (aiming for 2 levels; within-subjects)
    - Directive: explicit, single heading (arrow pointing to precise recommended heading)
      - 2 options to choose between
    - Range: narrow banding region (similar to vertical rate guidance with TCAS)
      - 3 options to choose between

- Secondary IV
  - Text Accompaniment (aiming for 2 levels; within-subjects)
    - No text
    - General text: ‘turn left/right, climb/descend’
    - Directive text: ‘turn left/right heading 310, climb/descend altitude 10 thousand’

- Backup IV
  - Vertical Guidance (2 levels; could be between-subjects)
    - Vertical rate guidance (as done with TCAS)
    - Altitude guidance (as done with JADEM)
Proposed Experimental Design

• Additional considerations:
  – Aural Alerts
  – Blended maneuvers
  – Altitude guidance versus vertical speed:
    • Very difficult to show a single altitude option via bands (issue of granularity and salience)
    • This forces us to either:
      – Use something other than bands to show single recommended heading/altitude
      – Show range instead of single option
    • Important to keep display of vertical guidance in mind for all horizontal options
      – i.e., if range is used for horizontal, should also be used for vertical
**Horizontal RA Guidance – Directive (Option 1)**

Arrow with embedded text shows exact heading to achieve

*Target heading 312°*

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**Vertical RA Guidance – Directive (Option 1)**

Arrow with embedded text shows exact altitude to achieve

*Target altitude 10,000ft*

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**Notes:**

- Embedded text allows exact heading/altitude to be achieved without separate text box or directive aural alert
**Horizontal RA Guidance – Directive (Option 2)**

Arrow (no embedded text) shows exact heading to achieve

*Target heading 312°*

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**Vertical RA Guidance – Directive (Option 2)**

Arrow (no embedded text) shows exact altitude to achieve

*Target altitude 10,000ft*

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**Notes:**

- Absence of embedded text makes determining exact heading very difficult if there is no supplemental text box or directive aural
**Horizontal RA Guidance – Range (Option 1)**

Banding shows a 10° range for horizontal maneuver

*Target heading 312°*

**Vertical RA Guidance – Range (Option 1)**

Banding shows a 500’ range for vertical maneuver

*Target altitude 10,000ft*

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**Notes:**

- Assumes a target heading of 312° with +/-5° of buffer & target altitude of 10000’ with +/-250’ of buffer
  - Provided range should be no smaller than the smallest hash marks (e.g., 10° range markers and 500ft altitude markers)
- Target bands could also be shown as separate bands
Horizontal RA Guidance – Range (Option 2)

Banding (separate from primary bands) shows a 10° range for horizontal maneuver

*Target heading 312°*

Vertical RA Guidance – Range (Option 2)

Banding (separate from primary bands) shows a 500’ range for vertical maneuver

*Target altitude 10,000ft*

**Notes:**

- Assumes a target heading of 312° with +/-5° of buffer & target altitude of 10000’ with +/-250’ of buffer
  - Provided range should be no smaller than the smallest hash marks (e.g., 10° range markers and 500ft altitude markers)
- Target bands could also be shown as separate bands
**Horizontal RA Guidance – Range (Option 3)**
Wedge shows a 10° range for horizontal maneuver

“Turn Left Heading 312°”

**Vertical RA Guidance – Range (Option 3)**
Wedge shows a 500’ range for vertical maneuver

“Climb Altitude 10 thousand”

**Notes:**
- Assumes a target heading of 312° with +/-5° of buffer & target altitude of 10000’ with +/-250’ of buffer
  - Provided range should be no smaller than the smallest hash marks (e.g., 10° range markers and 500ft altitude markers)
Proposed Experimental Design

• Exp set up identical to PT6
  – 2 parallel UAS systems
  – ATC in the loop
  – VSCS generated & MACS generated intruders
  – JADEM will fill gaps to make run 3 closer to Phase 1 DAA MOPS
    • Provide vertical DAA guidance & preventive DAA alerts (and possibly DAA warning alerts)
    • Need to see how well clear recovery behaves with current placement of run 3 RA