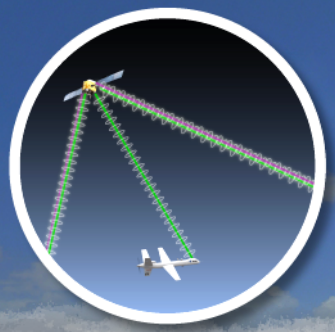

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Advanced Collision Avoidance System for UAS

(ACAS Xu) Interoperability White Paper Presentation

SC-228 WG-1

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Tech Lead, HSI

Background

- 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

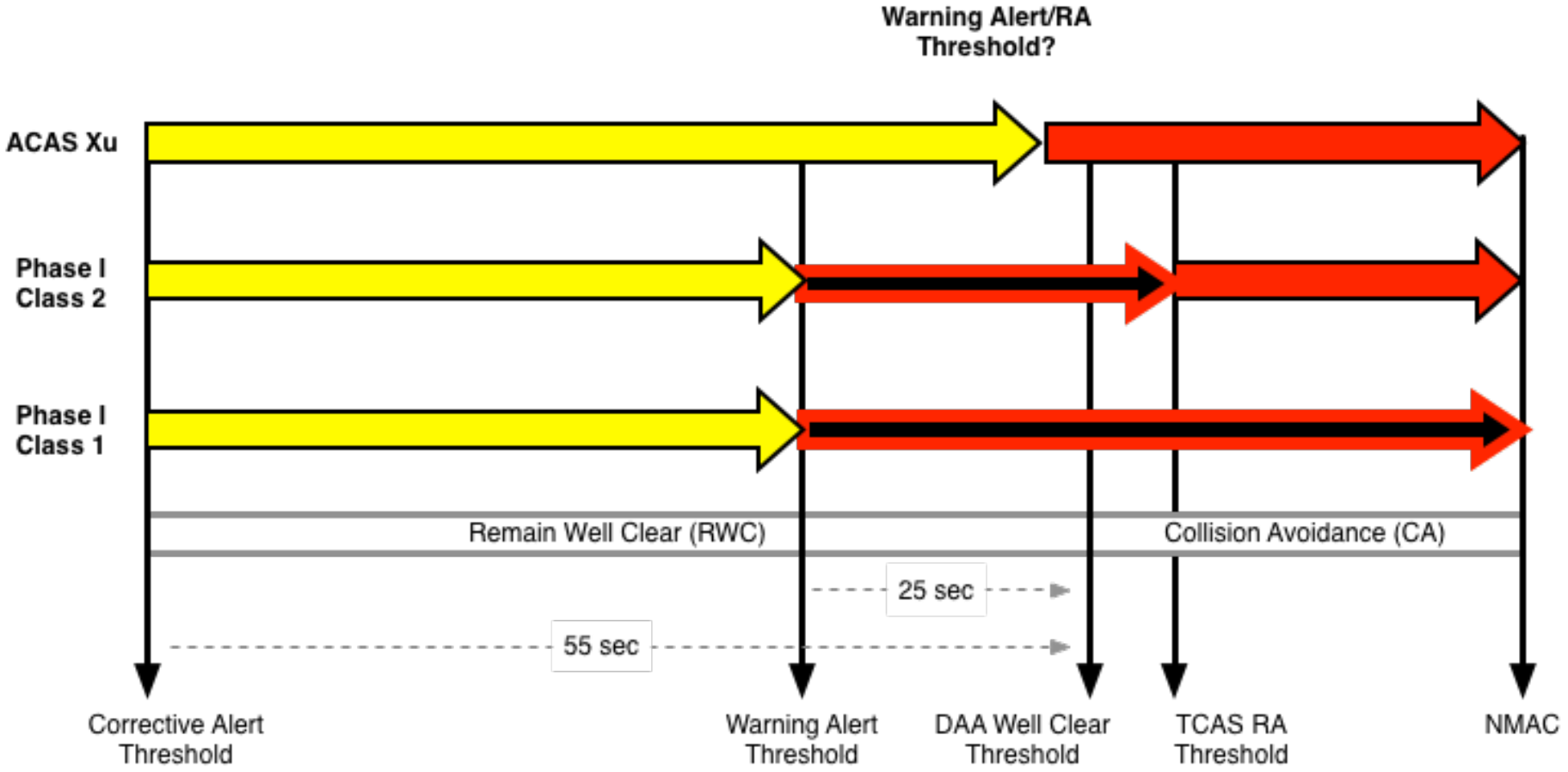
- ACAS Xu will specify an integrated DAA system, it will need to show compliance with the RWC alerting thresholds and alerting requirements defined in the DAA MOPS
- However, integration of RWC and CA functions within ACAS Xu allows for more seamless integration of alerting and guidance than the Class 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

	DAA Alert Structure Phase I MOPS		
Symbol	Name	Pilot Action	Aural Alert Verbiage
	TCAS RA*	• ***Immediate action required*** • Comply with RA sense and vertical rate • Notify ATC as soon as practicable after taking action	"Climb/ Descend"
	Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	"Traffic, Maneuver Now" X2
	Corrective Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	"Traffic, Avoid"
	Preventive Alert	• On current course, corrective action **should not be required** • Monitor for intruder course changes • Talk with ATC if desired	"Traffic, Monitor"
	Guidance Traffic	• **No action required** • Traffic generating guidance bands outside of current course	N/A
	Remaining Traffic	• **No action required** • No coordination required	N/A

* Applies to Class 2 DAA equipment only.


Warning Alert/RA Threshold?
ACAS Xu
Phase I Class 2
Phase I Class 1
Remain Well Clear (RWC)
Collision Avoidance (CA)
25 sec
55 sec
Corrective Alert Threshold
Warning Alert Threshold
DAA Well Clear Threshold
TCAS RA Threshold
NMAC

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

RWC guidance processing and performance requirements

- 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)

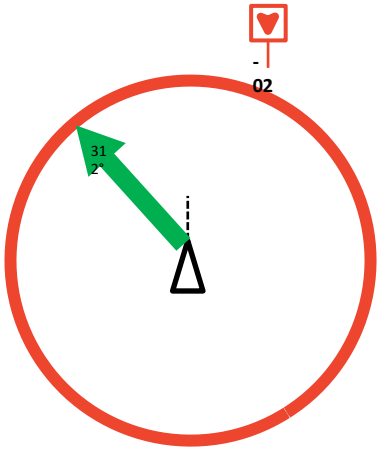
Proposed Experimental Design

- 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°

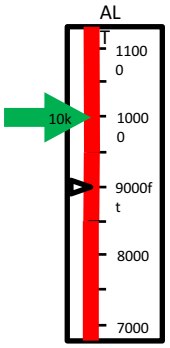


Inner Range Ring

Vertical RA Guidance – Directive (Option 1)

Arrow with embedded text shows exact altitude to achieve

Target altitude 10,000ft



Altitude Tape

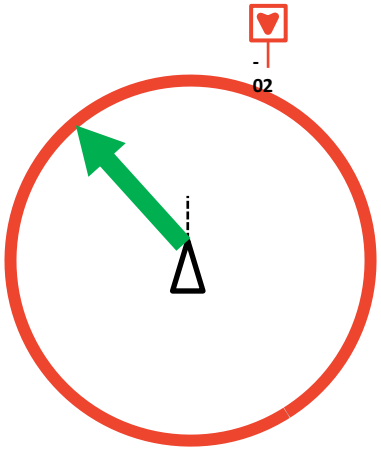
Notes:

- 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°

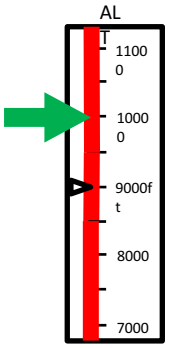


Inner Range Ring

Vertical RA Guidance – Directive (Option 2)

Arrow (no embedded text) shows exact altitude to achieve

Target altitude 10,000ft



Altitude Tape

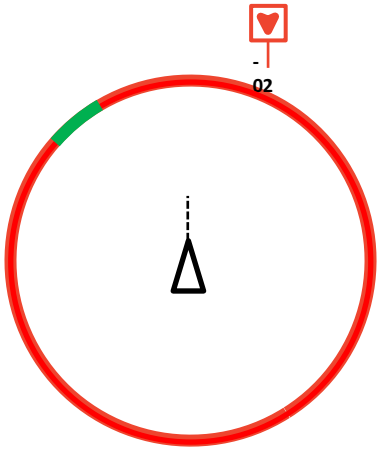
Notes:

- 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°

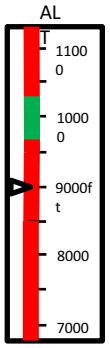


Inner Range Ring

Vertical RA Guidance – Range (Option 1)

Banding shows a 500’ range for vertical maneuver

Target altitude 10,000ft



Altitude Tape

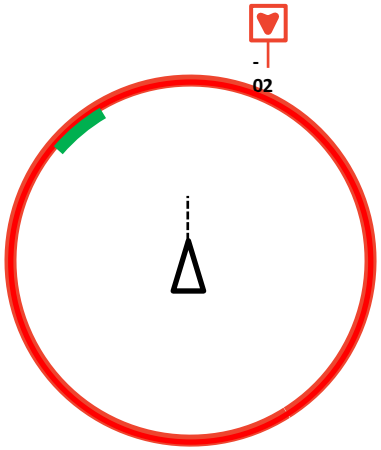
Notes:

- 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°

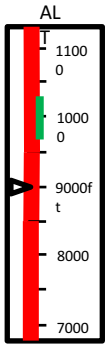


Inner Range Ring

Vertical RA Guidance – Range (Option 2)

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

Target altitude 10,000ft



Altitude Tape

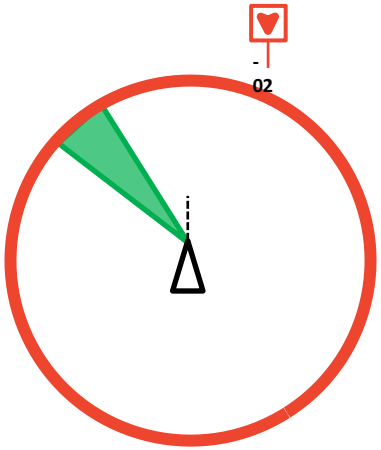
Notes:

- 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°"

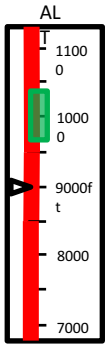


Inner Range Ring

Vertical RA Guidance – Range (Option 3)

Wedge shows a 500' range for vertical maneuver

"Climb Altitude 10 thousand"



Altitude Tape

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