Airborne Collision Avoidance System X_U

Concept and Flight Test Summary

FAA TCAS Program Office

March 31, 2015
Briefing to Royal Aeronautical Society DAA Workshop
Agenda

- Introduction
- ACAS Xu Concept
- 2014 Flight Test Summary
- Conclusion / Next Steps
Separation is the tactical process of ensuring that the risk of collision between two aircraft is acceptably small.

Two aircraft are not at risk of colliding if they are actively separated under direction of Air Traffic Control (ATC) or well clear of each other using visual means.

**Detect and Avoid: Two Functions**

- **Self-Separation (SS)**
  - The function of a UAS separating from other aircraft to remain well clear

- **Collision Avoidance (CA)**
  - Final layer of safety to prevent midair collisions when all other mitigations have failed
  - Hard maneuvers to prevent an NMAC in case of unanticipated failures of larger Conflict Management System (CMS) to maintain safe separation

**ACAS Xu** performs collision avoidance function
Distinct Yet Complementary Roles

Self-Separation sub-functions timeline

SS

Detect
Track
Evaluate
Prioritize
Declare
Determine
Command
Execute

CA

Detect
Track
Validate
Estimate State
Coordinate
Select Action
Command
Execute

Shared surveillance

Elements of tracking algorithms may be shared but CA and SS performance quality requirements may differ (e.g. validation for CA)

Implicit coordination vs Explicit coordination

Compatible with AT management vs Tuned to aircraft performance

Horizontal Maneuvers vs Vertical Maneuvers

Pilot in-the-loop vs Automatic Response

Collision Avoidance sub-functions timeline

Explicit coordination

• The STM is responsible for performing surveillance of nearby aircraft, tracking the aircraft under surveillance, and providing tracks and other relevant information to the TRM.
• The TRM uses tracks and other state information obtained from the STM to determine whether an intruder aircraft poses a threat and, if so, selects a recommended course of action.
- If equipped with a 1030 MHz transmitter, Xu can use active validation of ADS-B and active coordination for threat resolution (expected baseline).
- Surveillance inputs from cooperative targets expected to be the same as for ACAS Xa (ADS-B, Mode S, Mode C).
- Allows for additional surveillance methods to track non-cooperative traffic.
- Possibility of using reduced surveillance is an open area of research.
Surveillance processing generally includes track association, outlier detection, and tracking.

Cooperative processing includes validation (of ADS-B using active surveillance) and correlation (to determine if different surveillance tracks came from the same target).
Correlation between cooperative and non-cooperative tracks is necessary to determine if the tracks came from the same or different targets.

- If a cooperative and a non-cooperative track come from the same target, correlation will identify that and will make a policy decision to send only the cooperative track to the TRM.
- If a cooperative and a non-cooperative track come from different targets, correlation will identify that and will make a policy decision to send both of the tracks to the TRM.
- Cooperative/non-cooperative correlation algorithms currently under development.
Threat Resolution Module

- Tailored threat logic: flexibility of the ACAS X family allows ACAS Xu logic tables to be tuned for specific UAS capability classes
In general, vertical collision avoidance logic will be used to resolve encounters with cooperative traffic (similar to TCAS II and ACAS Xa).

In general, horizontal collision avoidance logic will be used to resolve encounters with non-cooperative traffic (research has shown that horizontal maneuvers are more effective than vertical maneuvers at resolving encounters with these types of targets).
Coordination

- Allows for global interoperability; maintains explicit coordination with TCAS II and all ACAS X platforms
- Backward compatibility: no changes required to legacy TCAS systems
- Forward compatibility: new passive coordination techniques achieve explicit coordination while minimizing spoofing risk and impact on spectrum utilization
- Horizontal coordination is an open area of research

Horizontal coordination not flight tested in 2014
• Identifies whether ownship is a peer to the intruder in order to select which collision avoidance method (vertical or horizontal) is most appropriate to resolve an encounter
• Nucleus is a wrapper around the TRM and uses various inputs (cooperative/non-cooperative track indication, surveillance quality, maximum climb rate, maximum turn rate, altitude) to make its decision
• Nucleus currently under development

Nucleus not flight tested in 2014
• ACAS Xu expects to be installed on vehicles with automatic response to RA, though this is an integration decision and not an Xu requirement
• Control systems must be integrated to properly provide automated RA response in all situations, as well as orderly return to normal control
• Automated RA response should also include some sort of indication to the flight crew so they know that the UAS is responding to an RA
Two-year collaboration effort between the FAA’s TCAS Program Office, General Atomics (Honeywell & BAE Systems), and NASA Armstrong

- Design, implement, and test an optimized CA functionality for larger/higher performance (i.e., DOD Class 5) UAS.

Test scenarios involving:

- FAA’s Convair (N39) and Armstrong’s Ikhana
- Armstrong’s Ikhana and General Atomics Pred B Capital Asset
Flight Test Concept

- **DAA Processor**
  - Surveillance Tracking Module (STM) with Honeywell Tracker
  - Threat Resolution Module (TRM)
  - Flight Controls
  - Tracks
  - ACAS Xu RA
  - Pilot Input

- **ADS-B 1090ES**
  - Active Coordination Emulation (ACE)
  - ADS-B UAT (Future Req.)
  - Active 1030 MHz Surveillance Responsive Coordination

- **TCAS II / ACAS XA Equipped**
  - Transponder Equipped (No CAS)

- **Air-to-Air Radar**
  - LOS or BLOS Datalink
  - ACAS XU RA Tracks

- **Ground Control Station**
  - Heads Up Display (HUD)
  - Pilot

- **Self Separation Maneuvers with CPDS:**
  - Pilot-in-the-Loop
  - Automatic with Pilot Override

- **ACAS XU Collision Avoidance Maneuvers:**
  - Automatic with Pilot Override
ACAS Xu System Overview

BAE Systems IFF AN/DPX-7
- ADS-B
- Mode S

Honeywell TCAS TPA-100
- Active Surveillance

GA-ASI Prototype Due Regard Radar
- Air-to-air radar

Sense and Avoid Processor
ACAS Xu Configuration Management Wrapper

Surveillance and Tracking Module (STM)
- FAA Coop STM
- FAA Non-Coop STM
- Honeywell Fusion Tracker STM

Threat Resolution Module (TRM)
- FAA Vertical TRM
- FAA Horizontal TRM

ACAS Xu System Components
- Tracks

Digital Flight Control System (DFCS)
- CA Maneuver

Ground Control Station
- Heads Up Display (HUD)
- Pilot

Aircraft
- Pilot Input

Self-Separation Module / Display
- GA CPDS
- NASA Langley Stratway+
- NASA Ames VSTD
- LVC-DE Connection

Federal Aviation Administration

2013-RSG-0089R5
Configuration #1 – Cooperative

Goals – to flight test:
- ACAS X\textsubscript{U} vertical collision avoidance with passive surveillance (ADS-B)
- Interoperability (backward compatibility) with TCAS II via Responsive Coordination
- Interoperability (forward compatibility) with ACAS X\textsubscript{U} via Active Coordination Emulation (ACE)
- Interoperability with non-CAS equipped aircraft
- Predator B automatic response using new vertical autopilot mode
Configuration #2 – Cooperative (HW Tracker)

Goals – to flight test:
- Fusion Tracking with ADS-B, Active, and non-cooperative* surveillance
- ACAS X\textsubscript{U} vertical collision avoidance
- Interoperability (backward compatibility) with TCAS II via Responsive Coordination
- Interoperability with non-CAS equipped aircraft
- Predator B automatic response using new vertical autopilot mode

*DRR will not be able to see intruders in the Configuration #2 scenarios, but fusion will still be turned on
Configuration #3 – Non-cooperative

Goals – to flight test:
- ACAS $X_U$ horizontal collision avoidance with non-cooperative surveillance (Air-to-Air Radar)
- Interoperability with non-cooperative aircraft
- Predator B automatic response using horizontal autopilot mode
Configuration #4 – Non-cooperative (HW Tracker)

Goals – to flight test:
- Fusion Tracking with ADS-B, Active, and non-cooperative* surveillance
- ACAS X\(_U\) horizontal collision avoidance
- Predator B automatic response using horizontal autopilot mode

*DRR will be able to see intruders during the encounters for Configuration #4, so ADS-B and Active surveillance inputs can be turned on as desired to demonstrate fusion tracker.
Self-Separation Configurations

Ground Control Station

<table>
<thead>
<tr>
<th>Self-Separation Module / Display</th>
<th>GA CPDS</th>
<th>NASA Langley Stratway+</th>
<th>NASA Ames VSTD</th>
<th>LVC-DE Connection</th>
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<tr>
<td>Heads Up Display</td>
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<td>Pilot</td>
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General Atomics

Conflict Prediction and Display System (CPDS)

NASA Langley

SSI Stratway Display

NASA Ames

Vigilant Spirit Traffic Display (VSTD)

LVC-DE Connection

Federal Aviation Administration
Flight Test Results / Summary

- Four configurations tested: FAA & Honeywell STM; Vertical and Horizontal TRM
- Both advisory and automatic maneuver modes
- Each encounter designed to elicit a scripted alerting response
- All encounters planned to achieve 3,000’ Horizontal Miss Distance (HMD) and a minimum of 200’ Vertical Miss Distance (VMD)

- Unmanned versus Manned Goal (Nov 17-21): validate the concept of responsive coordination (using passive-only ADS-B surveillance) between two airborne CA systems
  - 4 days of flight testing, 85 encounters, >20 hrs of flight test
  - All required encounters flown: 500’ level, 200’ level, 500’ blunder, 1,000’ blunder, non-cooperative
  - Demonstrated interoperability with both legacy TCAS and future ACAS X systems in support of the ongoing MOPS effort in RTCA SC-228

- Unmanned vs. Unmanned Goal (Dec 9-10): validate the concept of passive coordination of collision avoidance maneuvers (‘Active Coordination Emulation’) between two airborne CA systems
  - 2 days of flight testing, 30 encounters, >9 hrs of flight test
  - Using the new 1090ES Operational Coordination Message implemented by BAE Systems in the DPX-7 IFF Transponder
Conclusion

The first time an optimally tuned collision avoidance system was installed and flight tested on a high performance, automatically-maneuvering UAS vehicle against intruder aircraft with real-world (200 feet) vertical offsets, utilizing ADS-B Only surveillance for cooperative intruders and primary Air-to-Air radar (developed by General Atomics) for non-cooperative intruders.

FAA Goals 2014 / 2016

2014

*Proof-of-Concept of Methods and Components*

- Facilitate the design, development, and demonstration of ACAS $X_U$ through integration and flight test on a UAS
- Flight test Automatic Response to Resolution Advisories
- Demonstrate feasibility of ACAS $X_U$ coordination techniques; Responsive Coordination and Active Coordination Emulation (ACE) as potential future CA requirements

2016

*Interoperability & Integration Operational Capability*

- Fully-integrated Surveillance and Tracking Module (STM) for ADS-B, interrogation/reply, and non-cooperative surveillance
- Intelligent Threat Resolution Module (TRM) switching between vertical and horizontal modes depending on aircraft capability
- Fully-integrated Collision Avoidance (CA) operational capability with Automatic Response on UAS