Current and future operations of airborne collision avoidance systems

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Bangkok, 5-6 November 2018
• Why change TCAS II 7.1?
• ACAS X Suite of Products
• Interoperability between current and future ACAS
• ACAS X and ADS-B
• Towards ACAS X deployment
Contents

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How well does TCAS perform?

- Performance monitoring assessment shows that TCAS works as intended but alerts during many normal, safe operations.

**Safety**
- No U.S. commercial air carrier collisions since mandate
- Numerous TCAS saves
  - “…TCAS saved our lives.” - Pilots
- Mid-air collision risk reduced by 90%

**Operational Suitability**
- > 80% of alerts occur during intentional, safe operations
  - Most cause minimal disturbance to pilots

![Risk Ratio](image)

![Operational Suitability](image)
Current TCAS for the Future

- **TCAS limitations for Future Airspace Growth**
  - ADS-B is not fully leveraged
  - Nuisance alerts occur during normal ATC operations
  - No capability to allow more complex operations in traffic rich environments. Increased nuisance alerts for closely spaced or converging traffic.
  - Code is complex and interdependent causing long update cycles
  - Limited application to larger and higher performing aircraft classes (2000’/min).
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The ACAS X Family
The ACAS X Family

ACAS X₀

ADS-B In Avionics used to designate traffic for ACAS X₀ Alerting

Global ACAS X₀ Protection

1. CSPO – 3000: ACAS X₀ Modified RA Protection Criteria – Designated Intruder

2. DNA – No RA, No TA - Designated Intruder

Procedure-Specific Alerting
1. DNA (Do Not Alert) – Visual Separation Procedures
2. CSPO 3000 – IMC Parallel Approach Operations

Global ACAS X₀ protection against all other traffic
The ACAS X Family

ACAS $X_u$ for Larger UAS

Alerting with Horizontal and Vertical Guidance
Caution Alerts – Remain Well Clear
Warning Alerts – Collision Avoidance

Turn Left, heading 340
ACAS X Solution

- ACAS X is a family of collision avoidance capabilities being developed to support future airspace requirements & address TCAS II Shortfalls (RTCA DO-337)
  - Transitions from Explicit Programming (TCAS) to Decision Theoretic Planning (ACAS X)
    - Optimal Threat Resolution Logic produced from Probability Models (Logic Tables) vs Deterministic Models (Heuristic Logic)
  - Decoupled Surveillance and Threat Resolution Modules

<table>
<thead>
<tr>
<th>User Group</th>
<th>Surveillance Technology</th>
<th>Advisories</th>
<th>MOPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACAS X_a</strong> (Active Surveillance)</td>
<td>Current ACAS II users (large aircraft)</td>
<td>Active surveillance supplemented with ADS-B</td>
<td>2018</td>
</tr>
<tr>
<td><strong>ACAS X_o</strong> (Operation Specific)</td>
<td>Users of specific operations (e.g., closely-spaced parallel operations)</td>
<td>Active surveillance supplemented with ADS-B</td>
<td></td>
</tr>
<tr>
<td><strong>ACAS X_u</strong> (Unmanned Aircraft System)</td>
<td>Phase II / Class 3 DAA Equipped UAS</td>
<td>Procedure-specific alerts for selected aircraft, global alerting against all others</td>
<td></td>
</tr>
<tr>
<td><strong>ACAS X_p</strong> (Passive Surveillance)</td>
<td>General Aviation / Rotorcraft</td>
<td>Vertical and horizontal advisories (DAA-RWC &amp; CA)</td>
<td>2020</td>
</tr>
</tbody>
</table>
Variants share an underlying design but are tailored (optimized logic tables) for different user groups.
ACAS X Development Timeline

Xa, Xo Flt Tests: 2013, 2015
- Suitability of ACAS X RAs
- Interoperability with TCAS
- Legacy TCAS surveillance for alerting and to validate ADS-B

- Vertical and horizontal maneuvers
- ADS-B, radar surveillance
- Interoperability with TCAS
- Autonomous maneuvers

Xa Op Eval: 2017
- 10 aircraft flying in US NAS over 10 months
- Validated performance in airspace
- Final step prior to MOPS publication

R & D Standards development Op Eval FAA Guidance Operational Use

ACAS Xa
- 2013 Proof of Concept Flight Test
- 2015 Full System Flight Test
- Initial MOPS complete
- FAA TSO & AC Complete

ACAS Xo
- 2014 Proof of Concept Flight Test
- Flight Test 2
- Initial MOPS complete
- LIP

FAA Guidance
TCAS and ACAS X comparison

TCAS II
- Beacon-only Surveillance
- Rule-based Pseudocode

ACAS X
- Plug-and-Play Surveillance
- Optimized Logic Table

Surveillance Enhancements
Advisory Logic Enhancements
Contents

• Why change TCAS II 7.1?
• ACAS X Suite of Products
• Interoperability between current and future ACAS
  – Current ICAO interoperability requirements
  – Experience with ACAS Xa and TCAS v7.1
  – Development of new interoperability requirements
• ACAS X and ADS-B
• Towards ACAS X deployment
To avoid aircraft independently choosing manoeuvres towards each other
Coordination requirements (2)

- Coordination message contains sense to select
  - First aircraft choice prevails
    - Ties are resolved through Mode S address comparison
Annex 10 Volume IV:

4.4.2.8

COMPATIBILITY BETWEEN DIFFERENT COLLISION AVOIDANCE LOGIC DESIGNS

**Recommendation.** — When considering alternative collision avoidance logic designs, certification authorities should verify that:

a) the performances of the alternative design are acceptable in encounters involving ACAS units that use existing designs; and

b) the performances of the existing designs are not degraded by the use of the alternative design.

Note. — To address the compatibility between different collision avoidance logic designs, the conditions described in 4.4.2.7 b) are the most severe that can be anticipated in this respect.
Experience with TCAS and ACAS Xa

• Performance degradation was observed in mixed encounters
  – Same coordination process

• Explanatory factors
  – Difference in surveillance
  – Difference in RA triggering logic
    • Constraints
    • Handling of specific geometries
    • Alert timing
Example from ACAS Xa Run 11 (1)

- Operational suitability issue:
Example from ACAS Xa Run 11 (2)

- The burden was put on the TCAS equipped aircraft
• All logic interoperability issues corrected with Run 15.2
• Resulting safety performance:

Safety of equipped-equipped encounters (pNMAC)
• Resulting operational suitability:

![Graph showing reduction in overall reversals](chart)

- Reduction in overall reversals (both single and double) in mixed equipage encounters

-63% reduction in encounters in which only one aircraft triggers a Reverse RA

-30% reduction in encounters in which both aircraft trigger Reverse RAs
• Effect on TCAS:

![Graph showing the effect on TCAS](image-url)
Development of new requirements

• Recent joint RTCA / EUROCAE effort

• Objectives for future CAS:
  – No degradation of existing CAS performance
  – No change required from existing CAS
  – Minimize restrictions on later CAS systems from taking advantage of technological advances and innovative designs.

• MASPS Formal Review period starts in December
  – Basis for possible Annex 10 update
• High-level requirements
  – On coordination
    • Ex: Any two systems that generate RAs or directive guidance during a CA horizon shall ensure compatible RAs or guidance using a standardized coordination protocol
    • Ex: All systems shall have the capability to select the coordination protocol that is appropriate for use with each potential intruder from among the coordination protocols defined in this MASPS
  – On performance
    • Ex: The combined efficacy of two coordinated CA systems shall (R.2.8) exceed the efficacy of each individual system with an unequipped intruder in otherwise identical encounters
Future MASPS overview (2)

- Methods to achieve these requirements
  - Based on current experience
  - Imagined for new systems / new users
    - Protocols for passive & responsive coordination

- Horizontal RAs and speed RAs
- Interoperability with DAA RWC
Conclusions

• Interoperability is not only technical but also operational

• Good interoperability of ACAS Xa/Xo with TCAS will allow safe and smooth transition

• Lessons learned led to define a framework for interoperability between CA systems
Contents

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• ACAS X Suite of Products
• Interoperability between current and future ACAS
• ACAS X and ADS-B
  – Use of ADS-B for surveillance
  – Use of ADS-B for threat resolution
  – Use of ADS-B for coordination
  – Use of ADS-B for reporting RAs
• Towards ACAS X deployment
Use of ADS-B for surveillance

• ACAS Xa implements hybrid and extended hybrid surveillance

• Reduction of:
  - 1030 MHz interrogations by ~ -70%
  - 1090 MHz replies by ~ -85%
Use of ADS-B for surveillance

• Use of ADS-B for surveillance when on-the-ground
  – No 1030 MHz interrogations

• Detection of Mode S equipped aircraft by listening to ADS-B squitters
  – in addition of Mode S short squitters
  – possibility to switch to a full ADS-B detection in the future
Use of ADS-B for surveillance

- **ACAS must know number of other interrogating ACAS around**
  - for Interference Limiting purposes
  - listens to 1030 MHz ad-hoc messages (BIM)

- **Operational Status Message will indicate active interrogation**

- **Opportunity to use only ADS-B OSM**
  - Reduction of 1030 MHz load
Use of ADS-B for threat resolution

- TCAS only used the active tracks
- STM chooses the best track to send to TRM
  - ADS-B position validated by active position

<table>
<thead>
<tr>
<th>ID</th>
<th>Active Surveillance</th>
<th>Passive Surveillance</th>
<th>Active Validation State</th>
<th>TRM Protection</th>
<th>Track Passed to TRM &amp; Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Mode S NORMAL</td>
<td>High Quality ADS-B</td>
<td>Passes</td>
<td>TA/RA</td>
<td>Passive</td>
</tr>
<tr>
<td>6</td>
<td>Mode S REDUCED</td>
<td>High Quality ADS-B</td>
<td>Passes</td>
<td>None</td>
<td>Passive</td>
</tr>
<tr>
<td>10</td>
<td>Mode S HS Validation</td>
<td>High or Low Quality ADS-B</td>
<td>N/A</td>
<td>None</td>
<td>Passive</td>
</tr>
<tr>
<td>11</td>
<td>None</td>
<td>High Quality ADS-B or ADS-R</td>
<td>N/A</td>
<td>None (see Note 1)</td>
<td>Passive</td>
</tr>
</tbody>
</table>

- Optionally, TAs can be generated on an ADS-B only track (including when on-the-surface)
Use of ADS-B for coordination

• Currently aircraft equipped with Collision Avoidance:
  – have similar performance
  – use active surveillance
  – can listen to 1030 MHz coordination messages

• It is necessary to ensure coordination between ACAS Xa and:
  – Future CA systems onboard aircraft…
    • …with more limited performance
    • …using only passive surveillance
      – not considered as peers for CA
    • …not equipped with a 1030 MHz receiver
      – can’t coordinate using TCAS scheme
  – Future DAA systems with no active CA
    • not considered as peers for CA
Use of ADS-B for coordination

- ADS-B is used to determine intruder’s coordination capability

<table>
<thead>
<tr>
<th>OSM subfield</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>Tells if there is an operational CA onboard</td>
</tr>
</tbody>
</table>
| CCCB         | Tells if:  
- the intruder is a peer  
- the intruder CA can listen to 1030 MHz |
| DAA          | Tells if:  
- the intruder has a DAA capability  
- the intruder DAA can listen to 1030 MHz |
• If the intruder has CA and is a peer, ADS-B is not used for coordination.

Classical active coordination
Aircraft with higher mode S address is the master aircraft
Use of ADS-B for coordination

- If the intruder:
  - has CA but is not a peer, or has DAA without CA; and
  - can listen to 1030 MHz

ADS-B is not used for coordination

**Modified active coordination**

Aircraft with ACAS Xa is the master aircraft
Use of ADS-B for coordination

• If the intruder:
  – has CA but is not a peer, or has DAA; and
  – can’t listen to 1030 MHz

ADS-B is used for coordination

Operational Coordination Message
(DF=17 or 18)

Modified passive coordination
Aircraft with ACAS Xa is the master aircraft
Use of ADS-B for reporting RAs

- **Current means of RA data collection on the ground**

  - RA Report request (UF=4,5,20,21)
  - RA Report (DF=20,21)
  - RA Broadcast (UF=16)
  - TCAS Resolution (UF=16)
  - Coordination Reply (DF=16)

- **Modes S radar**
- **Omnidirectional antenna**

- **TCAS Resolution (UF=16)**

- **1030 MHz**
- **1090 MHz**

- **Current means of RA data collection on the ground**

  - Use of ADS-B for reporting RAs
Use of ADS-B for reporting RAs

- New 1090ES message
- New information:
  - more data on RAs
  - designated intruder
  - descend inhibits
  - ACAS Xu ready
Towards ACAS X deployment

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Xa Operational Benefit: Reduction in RAs

- Alerting comparison between ACASX V1R0 (RTCA DO-385) and TCAS II v7.1 on TRAMS encounter set (~250,000 Observed Encounters between October 2008 and July 2016)
Xa Safety Benefit: Reduction in Collision Risk

- Risk ratio comparison between ACAS X V1R0 (RTCA DO-385) and TCAS II v7.1 on Lincoln Laboratory Correlated Encounter Model

- Notes:
  - Induced risk difference due to the prevention of crossing RAs
  - Unresolved risk reduction 23%
  - Total risk reduction of 20% across airspace

Risk Ratio = \frac{P(\text{NMAC with CA})}{P(\text{NMAC without CA})}
Xa Benefits: Variability over the Airspace

- Exact benefit depends on the airspace
  - Traffic distribution - terminal and en-route
  - Control methods
  - Various Ops Procedures

- Example of European airspace
ACAS X Operation in European Airspace – approximate timescales (to be confirmed)

Important Milestone/Date

ACAS X MOPS available and statement of acceptability from Eurocae WG 75

1. NPA preparations

→ Triggers release of NPA for ETSO

→ Triggers release of NPA for Rule Change

→ Triggers release of NPA for CS-ACNS

ACAS X operations permitted in EU airspace (ETSO available, Rule published, CS (Certification Specification) available).

→ Committology for Rule Change

Two years - approx

→ One year - approx

→ One year - approx
Regulatory Products & Timeline

- **ACAS Xa – Class 1**
  - Publish New TSO: Nov 2019
  - Publish New AC: Jan 2020
  - Amend Existing Operating Rules: Dec 2020
  - Amendment to ICAO Annex 10, Volume IV and ACAS Manual Doc 9863: Dec 2020

- **ACAS Xu**
  - Publish New TSO: May 2021
  - Revise DAA AC and ACAS X AC: Dec 2021
  - Amend Operating Rules as necessary: July 2022

**Timeline**
- 2018
  - Q1
  - Q2
  - Q3

- 2019
  - Q1
  - Q2
  - Q3

- 2020
  - Q1
  - Q2
  - Q3

- 2021
  - Q1
  - Q2
  - Q3

- 2022
  - Q1
  - Q2
  - Q3
Deployment of ACAS Xa – Class 1

- **Optional replacement to TCAS II v7.1**
  - Full integration by 2046 AD (projected)
- **ICAO/EASA - No retrofit or forward-fit mandate**
  - TCAS II v7.1 currently required for European Airspace and ICAO Annex 10, Vol 4
  - ACAS Xa will be alternate option for TCAS II v7.1 installations
- **FAA - No retro-fit mandate, potential for forward-fit mandate,**
  - ACAS Xa will be alternate option for current TCAS II v7.1 installations
  - TCAS 6.04A and TCAS 7.0 are still allowed configurations for US Airspace
  - Possible mandate to install ACAS Xa for newly manufactured aircraft by a certain date (TBD) to relieve 1030/1090 congestion and upgrade to accommodate NEX GEN operations
• Other States
  • Need to decide retrofit or forward-fit mandates
  • Amend ACAS II and related regulations as necessary

• ACAS monitoring programs
  • Update software to receive and process new ACAS Xa/Xo messages
  • Train personnel (especially incident investigators) on new ACAS Xa/Xo functionality

• Guidance on developing national regulations will be found in the ACAS manual, Doc 9863, due Dec 2020
THANK YOU