Traffic Alert and Collision Avoidance System (TCAS) Program Office

Airborne Collision Avoidance System X (ACAS X) Overview

By: Mike Castle
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Mission Need (TCAS II Performance Review)

**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

- Airport Traffic Pattern 15%
- Approaches to Parallel Runways 12%
- Visual 500’ Vertical Separation 51%
- Controlled 1,000’ Vertical Separation 6%
- Other 16%

Performance monitoring assessment shows that TCAS works as intended but alerts during many normal, safe operations.
Challenges for TCAS II in the Future

<table>
<thead>
<tr>
<th>Future Airspace</th>
<th>TCAS Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional surveillance information</td>
<td>Tightly tuned to transponder-based surveillance, difficult to incorporate ADS-B</td>
</tr>
<tr>
<td>available</td>
<td></td>
</tr>
<tr>
<td>Reduced procedural separation</td>
<td>Alerting thresholds difficult to adjust without compromising safety</td>
</tr>
<tr>
<td>CAS for other user classes</td>
<td>Alerting logic not easily adaptable beyond current TCAS users</td>
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</tbody>
</table>

- TCAS will not easily support new demands for flexibility and efficiency
- Difficult to accommodate new user classes such as general aviation and unmanned systems
TCAS Upgrade Challenges

- Pseudocode is compilation of deterministic rules and heuristics
- Alerting criteria is tightly coupled to transponder surveillance performance
- Modifying alerting criteria or rules to address specific performance issues is difficult due to interdependencies
ACAS X Introduction

Airborne Collision Avoidance System

• ACAS X – An interoperable expansion of a family of aircraft collision avoidance systems developed for use in NextGen airspace

• Provides the same general role as TCAS II:
  – Surveillance of nearby aircraft
  – TA/RA Generation
  – Coordination with other aircraft collision avoidance systems

• Supports New Capabilities:
  – Leverages Additional Surveillance Sources
  – Intended for multiple types of host aircraft
  – Tunable for Reduced Separation Operations
ACAS X Program
Airborne Collision Avoidance System (ACAS X)

• FAA initiated formal research in 2009
  – Decision theoretic safety logic
  – Flexible surveillance tracker

• Benefits
  – Enables reduced separation
  – Fewer unnecessary alerts
  – Extends to new user classes
  – Easier to adapt to changing airspace

ACAS X supports NextGen airborne collision avoidance requirements
ACAS X Threat Logic

State Uncertainty
- Imperfect sensor information leads to uncertainty in position and velocity of aircraft
  - Probabilistic sensor model

Dynamic Uncertainty
- Variability in pilot behavior makes it difficult to predict future trajectories of aircraft
  - Probabilistic dynamic model

Multiple Objectives
- System must carefully balance both safety and operational considerations
  - Multi-objective utility model

Optimal logic produced from probability and utility models
ACAS X Alerting is Different Than TCAS

**Step 1: Is there a hazard?**
Alert if time to closest approach and projected miss distance are below thresholds

**Step 2: Climb or descend?**
Choose sense that maximizes miss distance

**Step 3: What altitude rate?**
Choose the lowest vertical rate predicted to achieve required separation

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**Legacy TCAS**

- **Step 1: State Distribution**
  Estimate ~10M states based on beliefs about own and intruder dynamics

- **Step 2: Look-Up Table**
  For each state estimation, look up expected cost related to available actions

- **Step 3: Choose action**
  Choose the action resulting in the lowest cost

**ACAS X**

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<tr>
<th>Action</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Alert</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Level-off</strong></td>
<td><strong>0.1</strong></td>
</tr>
<tr>
<td>Descend</td>
<td>0.9</td>
</tr>
<tr>
<td>Climb</td>
<td>0.2</td>
</tr>
</tbody>
</table>
How ACAS X and TCAS Alerts are Modified

**Legacy TCAS**
- Change assumptions of own and intruder aircraft behavior

**Assumed behavior**
- Thresholds
  - \( \text{Tau} = 40 \text{ sec} \quad 35 \text{ sec} \)
  - \( \text{Zthr} = 600 \text{ ft} \quad 400 \text{ ft} \)
  - \( \text{ALIM} = 300 \text{ ft} \quad 250 \text{ ft} \)
- Establish new alert criteria
- Change existing pseudo code

**ACAS X**
- Modify weights of belief states and state transitions

**Dynamics**
- \( A \) to \( B \):
  - \( 0.6 \)
  - \( 0.9 \)
- \( B \) to \( A \):
  - \( 0.3 \)
  - \( 0.7 \)
- \( 1 \)
- \( 0.1 \)

**Offline costs**
- NMAC (-1)
- Alert (-0.01)
- Reversal (-0.01)
- Strengthen (-0.009)
- Clear of conflict (0.0001)
- Change the reward values for alerting parameters

**Online costs**
- Alert inhibit altitude
- Used actual parameters live on aircraft

Federal Aviation Administration
TCAS Logic Development

Legacy TCAS Development Cycle

- Logic (pseudo code)
  - Simulation
  - Evaluation
  - Encounters Model
  - Performance Metrics
  - "manual pseudocode revision"

- Human effort focused on pseudocode
- Time-consuming process
- Many parameters require tuning
- Unlikely to be optimal

```plaintext
PROCESS Reversal_modeling:
  NOMINAL_SEP = 0;
  Z = G.ZDWN;
  ZD = G.ZDWN;
  DELAY = 0;
  IF (G.OWN.FOLLOW EQ FALSE)
  THEN CALL MODEL_SEP
  IN (DELAY, Z, ZD, P.VACCCL, OWNTENT(7), ITF.ZINT, ITF.ZDINT, ITF CALL)
  IF (OWNENT(7) EQ TRUE)
  THEN NEW.SENSE = FALSE;
  ELSE NEW.SENSE = TRUE;
  IF (NOMINAL_SEP GT 1.2 * P.CROSSTHR)
  THEN CLEAR ITF.REVERSE;
  ELSE
  "Some error is assumed to follow in RA"
  IF (OWNENT(7) EQ 0)
  THEN DELAY = MAXP(T V1 - G.TCUR - G.TPOSRA), 0;
  IF (OWNENT(7) EQ MALAR)
  THEN ZDGOAL = MAXMIN(ZD, PMAX, P.MINDRAT, P.DESRT);
  CALL PROJECT.VERTICAL.GONE.ZDGOAL
  IN (G.TCUR, - G.TPOSRA), G.ZTV, G.ZDZTN, G.ZDGOAL, P.TV1, P.VACCCL)
  OUT (ZPFO), ZDFO;
  IF (LOWENT(7) EQ SFAIL AND ZPFO GT G.ZOWN AND
  (G.ZOWN GE G.ZDZTN - P.MODEL.ZD) OR
  (LOWENT(7) EQ STRUE AND ZPFO LT G.ZOWN AND
  (G.ZOWN LE G.ZDZTN + P.MODEL.ZD)) AND
  G.TCUR - G.TPOSRA LT P.MODEL.T)
  THEN Z = ZPFO;
  IF (LOWENT(7) EQ SFAIL)
  THEN NEW.SENSE = FALSE;
  ELSE NEW.SENSE = TRUE;
  DELAY = MAXP(T V1 - G.TCUR - G.TLASTNEWRA), P.QUICKRED;
  IF (NEW.SENSE EQ SFAIL)
  THEN ZDGOAL = MAX(P.CLRT, MIN(G.ZDWN, P.MANDRAT));
  ELSE ZDGOAL = MINMAX(ZD, P.MINDRAT, P.DESRT, MAX(G.ZDWN, P.MANDRAT));
  IF (G.REV.ASERT EQ FALSE)
  THEN IF (ITF.INT.CROSS.EQ 0) OR (ITF.ZINT EQ 0 AND
  ITF.RZ.G EQ 0) OR (ITF.ZDINT + G.ZDGOAL GT 0)
  THEN MZDNT = ITF.ZDOUT;
  ELSE MZDNT = ITF.ZDINT;
  CALL MODEL_SEP
  IN (DELAY, ZDGOAL, Z, ZD, P.VACCCL, NEW.SENSE, ITF.ZINT, MZDNT, ITF CALL)
  OUT (ZMP);
  IF (ZMP LE 0 OR NOMINAL.SEP LE 0)
  THEN CLEAR ITF.REVERSE;
END Reversal_modeling;
```
ACAS X Logic Development

Model-Based Optimization Approach

- Human effort focuses on defining performance metrics
- Computers generate lookup table
- Optimal, robust logic

revision of performance metrics and models
ACAS X Architecture

Potential Surveillance Source Combination

- Interrogation/Reply
- 1090ES ADS-B
- UAT ADS-B
- Electro-Optical
- Primary Radar

Surveillance and Tracking Module (STM)
Surveils nearby aircraft and provides TRM with tracked target data

Threat Resolution Module (TRM)
Processes target information from STM to provide evasive maneuver command to pilot if necessary

Standard interface agnostic of input surveillance sources and TRM logic

TAs & RAs
Program Segments and Work Packages

Operational TCAS/ACAS

ACAS Xα/X₀

Not part of this investment
ACAS-X Tuning Process

- ACAS-X tuning accomplished via supervised optimization
  - Analysts specify initial objective function and automated tuning performs search producing candidate logics
  - Automated search is periodically interrupted and analyst preferences incorporated via an updated objective function

Inner Loop Cycle Time: ~20 Minutes

Analyst Feedback
- Aggregate Results
- Flight Testing Results
- Operational Suitability Results

Surrogate Modeling
- Design Parameters
- Surrogate Multi-Optimization
- Tables
- Performance Results

Dynamic Programming

Preference Elicitation

Identify Top Policies

Results

Analyst Loop Cycle: Weekly
Safety Results

EE: Run 12 performance improves upon Run 11, exceeds TCAS
EU: Run 12 performance exceeds TCAS
Overall Alert Rate

Includes CSPO, all military, formation

- Run 9: 98546 (70% TCAS)
- Run 11: 118576 (85% TCAS)
- Run 12 (ADS-B): 86115 (61% TCAS)
- Run 12 (Active): 94035 (67% TCAS)
- TCAS v7.1: 140265

2013 Flight Test
1st Tuned for Altimetry Bias
1st Tuned for ADS-B
### ACAS X Variants

<table>
<thead>
<tr>
<th>User Group</th>
<th>Surveillance Technology</th>
<th>Advisories</th>
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<tbody>
<tr>
<td><strong>ACAS Xₐ</strong>&lt;br&gt;Current TCAS II users (large aircraft)&lt;br&gt;Active radar supplemented with passive</td>
<td>Same as current TCAS II</td>
<td></td>
</tr>
<tr>
<td><strong>ACAS Xₒ</strong>&lt;br&gt;Users of specific operations (e.g., CSPO, Formation Flights, ASAS Operations)&lt;br&gt;Active radar supplemented with passive</td>
<td>Procedure-specific alerts for selected aircraft, global alerting against all others</td>
<td></td>
</tr>
<tr>
<td><strong>ACAS Xᵤ</strong>&lt;br&gt;Unmanned aircraft (controlled airspace)&lt;br&gt;Potentially radar, EO/IR, etc.</td>
<td>“Coordinated” vertical advisories</td>
<td></td>
</tr>
<tr>
<td>*<strong>ACAS Xₚ +</strong>&lt;br&gt;General aviation, etc.&lt;br&gt;Passive only</td>
<td>Reduced advisory set</td>
<td></td>
</tr>
</tbody>
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*ACAS Xₚ – Passive Surveillance

**Useful Segment 1**

**NextGen Concept Maturation**

**Xₐ** – Active Surveillance

**Xₒ** – Operation Specific

**Xᵤ** – Unmanned Aircraft System

**Xₚ** – Passive Surveillance