AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

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Automatic Collision Avoidance

- **Automatic Ground Collision Avoidance (AGCAS)**
  - Uses Digital Terrain Elevation Data (DTED) for mapping functions
  - Uses Navigation data to place aircraft on map
  - Scans DTED in front of and around aircraft
  - Uses future aircraft trajectory (5g) to provide automatic flyup maneuver when required

- **Automatic Air Collision Avoidance (AACAS)**
  - Uses data link to determine position and closing rate
  - Contains several canned maneuvers to avoid collision
  - Automatic maneuvers occur at last instant and both aircraft maneuver when using data link
  - System can use sensor in place of data link
Auto-GCAS recovers an aircraft before it penetrates a minimum clearance distance from the terrain

- Projects predicted trajectory over a digital terrain map
- Warns pilot of impending collision
- Automatically performs recovery at the last instant if the pilot takes no action

Features
- Recovery model easily tailored to different aircraft
- Embedded integrity monitoring prevents erroneous activation
Development History

• Auto GCAS Development
  – Initial Research & Development – 1984
    • Limited Envelope
    • Flat Earth
  – Follow-on Research & Development – 1990
    • Expanded Envelope
    • Digital Terrain Database
    • Full Envelope
  – LFT&E GLOC Demonstration – 1999
  – ACC Evaluation – 2000

  – Over 2200 Auto-Recoveries in Flight
    • Pilot Activated, SWIM. GLOC, DTS, Flat Earth
  – Over 700 DTS Based Auto-Recoveries
  – Thousands of Simulation Runs
  – Over 30 Evaluation Pilots
  – Prevented the Loss of the AFTI/F-16 in 1995
Auto ACAS prevents penetration of a clearance distance from other aircraft

- Evaluates escape trajectories against other aircraft
  - Does not impede tight formation
  - Uses flight rules such as “UAVs always evade first”
- Initiates the escape maneuver at last instant
- Features
  - Can utilize many sensors depending on requirements
  - Embedded integrity monitoring prevents erroneous activation
Development History

- **Auto ACAS Development**
  - Auto GCAS Follow-On – 1999
  - Concept Study – 2000
    - Concept Study
  - Algorithm Development – 2001
    - Focus on Vehicle Control not Sensors
      - Data Link as Primary Sensor
  - Research Flight Evaluation – 2003
    - Develop & Flight Demonstrate Technology
      - 3 Piloted Fighter Aircraft
      - Surrogate UAV
      - Cooperative & Non-Co-operative Sensors (UAV applications.)
      - Demonstration of Automatic Collision Avoidance
    - Buildup for Unmanned Testing
      - Identify Sensor & System Requirements
  - Nuisance Criteria Testing – TBD
  - Final Development Testing – TBD
- Hosted in 2 Different Architectures
- 416 Evasions Initiated in Flight
- Thousands of Simulation Runs
- 8 Evaluation Pilots
Analytical Findings

- Substantial reductions in F/A CFIT and MIDAIR mishap rates require automatic intervention
- ACAT are feasible & have been proven effective
- If implemented on F-16, F/A-18, F-22, and F-35, ACAT could save over the estimated service lives
  - LIVES 78 pilots
  - ASSETS $6.7B
  - CAPABILITY 136 aircraft

136 aircraft ~ 8 squadrons
SUMMARY

• Auto GCAS
  – Robust & Ready for Production Integration
  – Would Prevent Most CFIT Mishaps in the Fighter Community
    • Inclusion of GPS Navigation Technologies
    • Inclusion of Latest Digital Terrain Data
  – Should be Converted to a More Modular Architecture

• Auto ACAS
  – Promising Technology
    • Platform Specific Requirements & Development Needed
  – Could Prevent Many MAC Mishaps in the Fighter Community
    • Affordable Sensors Appear to be the Primary Limit to Performance
    • Most mishaps occur during training and data link operation can be provided
  – Should be Integrated with Auto GCAS

• Automatic Collision Avoidance Requirements
  – Provide means to ease transition to other air vehicles including UAVs
Automatic Collision Avoidance Technology

Flight Test Development & Evaluation

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Avoid Impeding Operations

Concept

- Nuisance Activations
  - Definition
    - An Unwarranted Recovery as Judged by a situationally aware pilot in command
  - Nuisance Factors
    - A Recovery Must be Both Aggressive and Timely
Nuisance Activations

- Definition
  - An Unwarranted Recovery as Judged by a situationally aware pilot
- Nuisance Factors
  - A Recovery Must be Both **Aggressive** and **Timely**
The Recovery Initiation Must be Timely

- Measure of Performance
  - Time Available
Avoid Impeding Operations
A Timely Recovery

The Recovery Initiation Must be Timely

- Measure of Performance
  - Time Available
The Recovery Initiation Must be Timely

- **Performance**
  - **Objective** \( \leq 1.0 \text{ sec. Time Available} \)
  - **Threshold** \( \leq 1.5 \text{ sec. Time Available} \)

\[
T_o = \frac{h_{\text{min}}}{(V_{2\text{init}} + T_o + \alpha_{2\text{init}}) + V_{\text{init}} \sin(\gamma_{\text{init}})} \quad \text{where:}
\]

- **Too Soon**
- **Too Late**

**Nuisance Criteria**
Auto GCAS Results

30 Missions  38.3 Flight Hours

- Excellent Ground Collision Prevention
  - Successful in all 316 Cases Tested
  - 81 Successful Cases Run from Crash Data Recorder

Pressed Bomb Attack  GLOC Supersonic
Pressed Strafing Run  NVG Disorientation
SDO into Mountain    Gear Up Landing

Calibrated Airspeed (knots)

-30 0 10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700

Dive Angle (degrees)

Mountainous Terrain Testing
Smooth Terrain Testing

<table>
<thead>
<tr>
<th>Mishap Type</th>
<th>Number of Times Flown</th>
<th>Dive Angle (deg)</th>
<th>Bank Angle (deg)</th>
<th>True Airspeed (kts)</th>
<th>Load Factor (g)</th>
<th>Average Altitude Pad (ft)</th>
<th>Minimum Altitude Pad (ft)</th>
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<tr>
<td>Air Score</td>
<td>8</td>
<td>20-32</td>
<td>100-132</td>
<td>303-467</td>
<td>0.9-1.4</td>
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<td>Night Vision Goggle Disorientation</td>
<td>5</td>
<td>13-18</td>
<td>74-93</td>
<td>419-327</td>
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<td>48</td>
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<td>443-675</td>
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<td>Low Altitude Split -S</td>
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<td>55</td>
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<td>0-5</td>
<td>188-211 KCAS</td>
<td>1.1-1.5</td>
<td>13</td>
<td>-6</td>
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</table>
**Auto GCAS Results**

- **Nuisance Free**
  - Initiates Recovery After Pilot Would
  - Nominally 0.25 Seconds Prior to Required Time
    - Pilot Nuisance Threshold is 1.2 Seconds
  - Nuisance Free Flight at 30 Feet Possible

- **SRTM Shuttle Digital Terrain Data**

![Map with data points and labels](image)
Auto ACAS Results

- **Successful Proof of Concept**
- **Collision Avoidance**
  - Head-On
  - Maneuvering Flight
  - Multi-Ship
  - Non-Cooperative (viewed from intruder)
  - Overtaking
- **Nuisance Evaluation Incomplete**
  - Initiates Recovery After Pilot Would
    - Wingman Work Not Completed
- **Follow-On Work Needed**
  - Apply Vehicle Specific Requirements
  - Integrate with Vehicle Specific Sensors
  - Complete Nuisance Evaluation
  - Integrate with Auto GCAS
Automatic Collision Avoidance Technology

Flight Test

Conclusions

ACAT
Top-Level Requirements for Ground Collision Avoidance

Prioritized

1. Do not Cause a Mishap
   - System Wide Integrity Management
     • Do not fly lead into wingman
     • Do not exceed operating limits

2. Avoid Impeding Operations
   - Avoid Unwarranted (nuisance) Activations

3. Avoid Collisions
   - CFIT

4. Minimize Integration Effort  (FRRP Requirement)
   - For F-16, F-35 & others
   - Interface definitions
Minimize Integration Effort

• Concept
  – Create a plug & play software capability
  – Ensure interoperability between all platforms

• Requirements
  – Create a modular functionally partitioned software architecture with clear interface requirements
  – Performance: Leave behind a regression level capability for future platform integration
  – Mid-Level Requirement Examples
    a) Establish a common core modular software architecture
    b) Establish the interfaces between the modules
    c) Document the process for tailoring the modules to specific platform requirements