AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

Donald E. Swihart
Air Force Research Laboratory
WPAFB OH 45433

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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
  - *Nuisance Criteria Testing – 1997*
  - *Final Development Testing – 1998*
    - 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
    • Develop & Flight Demonstrate Technology
      – 3 Piloted Fighter Aircraft
      – Surrogate UAV
      – Cooperative & Non-Cooperative 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

– ACAT
Modular Integrated Architecture
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
• 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

Mark A. Skoog
NASA Dryden Flight Research Center
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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**

Recovery Initiation

Aggressive but not timely

Timely but not aggressive
• Nuisance Activations
  – Definition
    • An Unwarranted Recovery as Judged by a situationally aware pilot
  – Nuisance Factors
    • A Recovery Must be Both **Aggressive** and **Timely**
Avoid Impeding Operations
A Timely Recovery

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

Recovery Initiation

Delayed Recovery Profile

Time Available

Too Late
The Recovery Initiation Must be Timely

- **Performance**
  - Objective ≤ 1.0 sec. Time Available
  - Threshold ≤ 1.5 sec. Time Available

\[ T_o = \min \left( \frac{T_{min} + a \cdot T_{init}}{V_{init} + T_o \cdot a \cdot \sin(\gamma_{\text{trim}})} \right) \]

Where:
- \( T_{min} \): Minimum Time
- \( a \): Acceleration
- \( V_{init} \): Initial Velocity
- \( \gamma_{\text{trim}} \): Trim Angle

**Nuisance Criteria**

- **Too Soon**
- **Too Late**
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
- Pressed Strafing Run
- GLOC Supersonic
- NVG Disorientation
- SDO into Mountain
- Gear Up Landing

Calibrated Airspeed (knots)

<table>
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<tr>
<th>Dive Angle (degrees)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
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<tr>
<td>Smooth Terrain Testing</td>
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<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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<td>100-132</td>
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<td>Night Vision Goggle Disorientation</td>
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<td>13-18</td>
<td>74-93</td>
<td>419-327</td>
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<td>20-32</td>
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<td>443-675</td>
<td>0.7-1.1</td>
<td>190</td>
<td>104</td>
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<td>0-8</td>
<td>0-7</td>
<td>363-483</td>
<td>0.7-3.7</td>
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<td>g-Induced Loss of Consciousness Supersonic</td>
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<td>1-102</td>
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<td>g-Induced Loss of Consciousness Subsonic</td>
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<td>1 and 4</td>
<td>1.0 and 1.1 Mach</td>
<td>-0.6 and -0.6</td>
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<td>-6</td>
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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
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
Top-Level Requirements for Ground Collision Avoidance

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
Questions