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
• 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
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

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Auto GCAS Flight Test Development & Evaluation
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**
Avoid Impeding Operations
An Aggressive Recovery

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Avoid Impeding Operations

A Timely Recovery

The Recovery Initiation Must be Timely

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

- Measure of Performance
  - Time Available

Diagram:
- Delayed Recovery Profile
- Too Late
- Time Available
- Recovery Initiation
The Recovery Initiation Must be Timely

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

**Nuisance Criteria**

\[ T_0 = \frac{h_{\text{min}}}{(V_{\text{init}} + T_0 + \alpha_{\text{init}}) + V_{\text{init}} \cdot \sin(\gamma_{\text{final}})} \]  

Where:
- \( T_0 \) : Time Available
- \( h_{\text{min}} \) : Minimum Height
- \( V_{\text{init}} \) : Initial Velocity
- \( \alpha_{\text{init}} \) : Initial Angle
- \( \gamma_{\text{final}} \) : Final Angle

Too Soon

Recovery Initiation

Too Late

Time Available
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)

Dive Angle (degrees)

<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 (knots)</th>
<th>Load Factor (g)</th>
<th>Average Altitude Pad (ft)</th>
<th>Minimum Altitude Pad (ft)</th>
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<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>
<td>238</td>
<td>57</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>
<td>1.0-1.1</td>
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<td>48</td>
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<td>20-32</td>
<td>6-0</td>
<td>443-675</td>
<td>0.7-1.1</td>
<td>190</td>
<td>104</td>
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<td>Pressed Strafing Attack</td>
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<td>0-8</td>
<td>0-7</td>
<td>363-483</td>
<td>0.7-3.7</td>
<td>27</td>
<td>-2</td>
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<td>g-Induced Loss of Consciousness</td>
<td>7</td>
<td>54-86</td>
<td>1-102</td>
<td>455-583</td>
<td>0.0-1.2</td>
<td>559</td>
<td>139</td>
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<td>g-Induced Loss of Consciousness</td>
<td>2</td>
<td>60 and 77</td>
<td>1 and 4</td>
<td>1.0 and 1.1 Mach</td>
<td>-0.6 and 0.6</td>
<td>98</td>
<td>-3</td>
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<td>Subsonic</td>
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<td>Low Altitude Split</td>
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<td>266 KCAS</td>
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<td>Level Flight Into Mountain</td>
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<td>0-4</td>
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<td>0.2-1.2</td>
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<td>55</td>
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<td>Spatial Disorientation Into Mountain</td>
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<td>30</td>
<td>1-9</td>
<td>475-701</td>
<td>1.0-1.3</td>
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<td>Gear-Up Landing</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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- 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