AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

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UVS 2007 Paris, France June 12, 2007
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

- **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-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
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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June 12th, 2007
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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  - Definition
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  - Nuisance Factors
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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
The Recovery Initiation Must be Timely

- Performance
  - Objective $\leq 1.0$ sec. Time Available
  - Threshold $\leq 1.5$ sec. Time Available

\[
T_o = \frac{h_{\text{min}}}{(V_{\text{init}} + T_o \cdot a_{\text{init}} + V_{\text{init}} \cdot \sin(\gamma_{\text{turn}}))}
\]

Where:

- $h_{\text{min}}$: Minimum Height
- $V_{\text{init}}$: Initial Velocity
- $a_{\text{init}}$: Initial Acceleration
- $\gamma_{\text{turn}}$: Turn Angle

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

### Mishap Type Breakdown

<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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<tbody>
<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>
<td>238</td>
<td>57</td>
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<tr>
<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>
<td>69</td>
<td>48</td>
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<tr>
<td>Pressed Bombing Attack</td>
<td>20</td>
<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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<tr>
<td>Pressed Strafing Attack</td>
<td>19</td>
<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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<tr>
<td>g-Induced Loss of Consciousness Subsonic</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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<tr>
<td>g-Induced Loss of Consciousness Supersonic</td>
<td>-</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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<tr>
<td>Low Altitude Split -S</td>
<td>1</td>
<td>29</td>
<td>178</td>
<td>266 KCAS</td>
<td>21 deg</td>
<td>132</td>
<td>132</td>
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<td>Level Flight Into Mountain</td>
<td>11</td>
<td>0</td>
<td>0-4</td>
<td>461-508</td>
<td>0.2-1.2</td>
<td>200</td>
<td>55</td>
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<tr>
<td>Spatial Disorientation Into Mountain</td>
<td>5</td>
<td>30</td>
<td>1-9</td>
<td>475-701</td>
<td>1.0-1.3</td>
<td>230</td>
<td>181</td>
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<tr>
<td>Gear-Up Landing</td>
<td>3</td>
<td>0-5</td>
<td>0-5</td>
<td>188-211 KCAS</td>
<td>1.1-1.5</td>
<td>13</td>
<td>-6</td>
</tr>
</tbody>
</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
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
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