AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

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UVS 2007 Paris, France June 12, 2007
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

ACAT
• 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
    - 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
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
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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Paris, France
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

- Nuisance Activations
  - Definition
  - An Unwarranted Recovery as Judged by a situationally aware pilot

- Nuisance Factors
  - A Recovery Must be Both Aggressive and Timely

- Aggressive Recovery
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
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

**Mishap Type**
- Pressed Bomb Attack
- Pressed Strafing Run
- SDO into Mountain
- GLOC Supersonic
- NVG Disorientation
- Gear Up Landing

<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 GLOC</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>13-18</td>
<td>74-93</td>
<td>419-327</td>
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<td>443-675</td>
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<td>11-14</td>
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<td>5-14</td>
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<td>1 and 4</td>
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<td>-0.6 and 0.6</td>
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<td>1.1-1.5</td>
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<td>-6</td>
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Calibrated Airspeed (knots)

-30 -20 -10 0 10 20 30 40 50 60 70

Dive Angle (degrees)

-30 -20 -10 0 10 20 30 40 50 60 70

Mountainous Terrain Testing

Smooth Terrain Testing
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

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
Questions