AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

Donald E. Swihart
Air Force Research Laboratory
WPAFB OH 45433

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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
  - 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
  - Affordable Sensors Appear to be the Primary Limit to Performance
  - Most mishaps occur during training and data link operation can be provided

- **Automatic Collision Avoidance Requirements**
  - Should be Integrated with Auto GCAS
  - Provide means to ease transition to other air vehicles including UAV's

**SUMMARY**

ACAT
Automatic Collision Avoidance Technology

Flight Test Development & Evaluation

Mark A. Skoog
NASA Dryden Flight Research Center
UVS 2007
Paris, France
June 12th, 2007
• 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**
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

[Diagram showing the time available and delayed recovery profile]
Nuisance Criteria

The Recovery Initiation Must be Timely

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

\[ T_o = \frac{h_{min}}{(V_{init} + T_a + q_{init}) + V_{init} \cdot \sin(y_{target})} \]

Where:

- $T_o$: Time Available
- $h_{min}$: Minimum Height
- $V_{init}$: Initial Velocity
- $T_a$: Time Available
- $q_{init}$: Initial Angle

- Too Soon
- Too Late

Recovery Initiation

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
- Pressed Strafing Run
- SDO into Mountain
- Gear Up Landing

**Calibrated Airspeed (knots)**

**Dive Angle (degrees)**

**Mountainous Terrain Testing**

**Smooth Terrain Testing**

**Table:**

<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>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>
<td>69</td>
<td>48</td>
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<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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<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>Subsonic</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>Supersonic</td>
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<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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<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>
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<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>
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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

ACAT

Flight Test
Conclusions
## Top-Level Requirements for Ground Collision Avoidance

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Priority</th>
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<tbody>
<tr>
<td>1. Do not Cause a Mishap</td>
<td>System Wide Integrity Management</td>
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<td>- Do not fly lead into wingman</td>
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<tr>
<td>2. Avoid Impeding Operations</td>
<td>Avoid Unwarranted (nuisance) Activations</td>
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<tr>
<td>3. Avoid Collisions</td>
<td>CFIT</td>
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<td>4. Minimize Integration Effort (FRRP Requirement)</td>
<td>For F-16, F-35 &amp; others</td>
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<tr>
<td>- Interface definitions</td>
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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