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
  - 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
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**
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

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

\[
T_0 = \frac{h_{\text{min}}}{(V_{\text{init}} + T_0 + \Delta z_{\text{init}}) + V_{\text{init}} \sin(y_{\text{tan}})}
\]

Where:

- **Too Soon**
- **Too Late**

**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

<table>
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<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>13-18</td>
<td>74-93</td>
<td>419-327</td>
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<td>6-0</td>
<td>443-675</td>
<td>0.7-1.1</td>
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<td>0-7</td>
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<td>54-86</td>
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<td>1.0 and 1.1 Mach</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
First-Level Requirements

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