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

- 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
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
• 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**
• **Nuisance Activations**
  - Definition
    • An Unwarranted Recovery as Judged by a situationally aware pilot
  - Nuisance Factors
    • A Recovery Must be Both **Aggressive** and **Timely**
The Recovery Initiation Must be Timely

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

- Measure of Performance
  - Time Available

Avoid Impeding Operations
A Timely Recovery

Too Late

Recovery Initiation

Time Available

Delayed Recovery Profile

Too Late
The Recovery Initiation Must be Timely

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

$T_o = \frac{h_{\text{min}}}{(V_{\text{init}} + T_o \cdot a_{\text{init}} + V_{\text{init}} \cdot \sin(y_{\text{turn}}))}$

Where:

- $V_{\text{init}}$: Initial Velocity
- $a_{\text{init}}$: Initial Acceleration
- $h_{\text{min}}$: Minimum Height
- $y_{\text{turn}}$: Flight Path Angle at $h_{\text{min}}$
- $T_o$: Time to Initiate Recovery

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**Nuisance Criteria**

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

<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>20-32</td>
<td>100-132</td>
<td>303-467</td>
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<td>13-18</td>
<td>74-93</td>
<td>419-327</td>
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<td>54-86</td>
<td>1-102</td>
<td>455-583</td>
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<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>
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<td>Gear-Up Landing</td>
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<td>0-5</td>
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<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

[Graph showing scatter plot with labels: Utility, Clean, Heavy]
Auto ACAS
Flight Test Development & Evaluation
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