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
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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Auto GCAS
Flight Test
Development & Evaluation
• 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
The Recovery Initiation Must be Timely

- Measure of Performance
  - Time Available

Avoid Impeding Operations
A Timely Recovery
The Recovery Initiation Must be Timely

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

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

- \( V_{\text{init}} \): Initial Velocity
- \( h_{\text{min}} \): Minimum Height
- \( a_{\text{init}} \): Initial Acceleration
- \( y_{\text{turn}} \): Turn Angle

- **Nuisance Criteria**

- **Too Soon**
  - Recovery Initiation
  - Time Available

- **Too Late**

**Diagram:**
- Recovery Profile
- Minimum Approach To Ground Vector
- Vertical Acceleration
- Flight Path Angle at \( h_{\text{min}} \)
**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

<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>-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

Flight Test

Conclusions

LOCKHEED MARTIN

ACAT
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
Questions