AUTOMATIC COLLISION AVOIDANCE TECHNOLOGY (ACAT)

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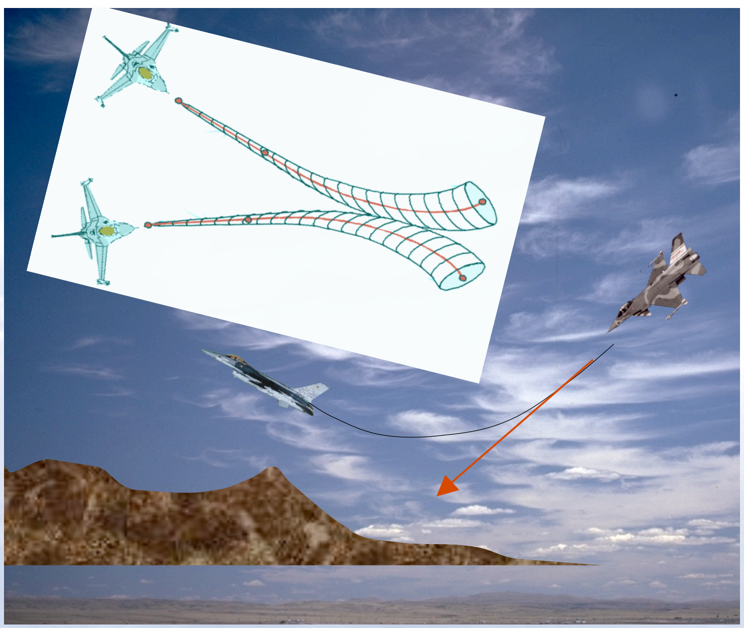

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Automatic Collision Avoidance

- **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

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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
  - ***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

- **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**

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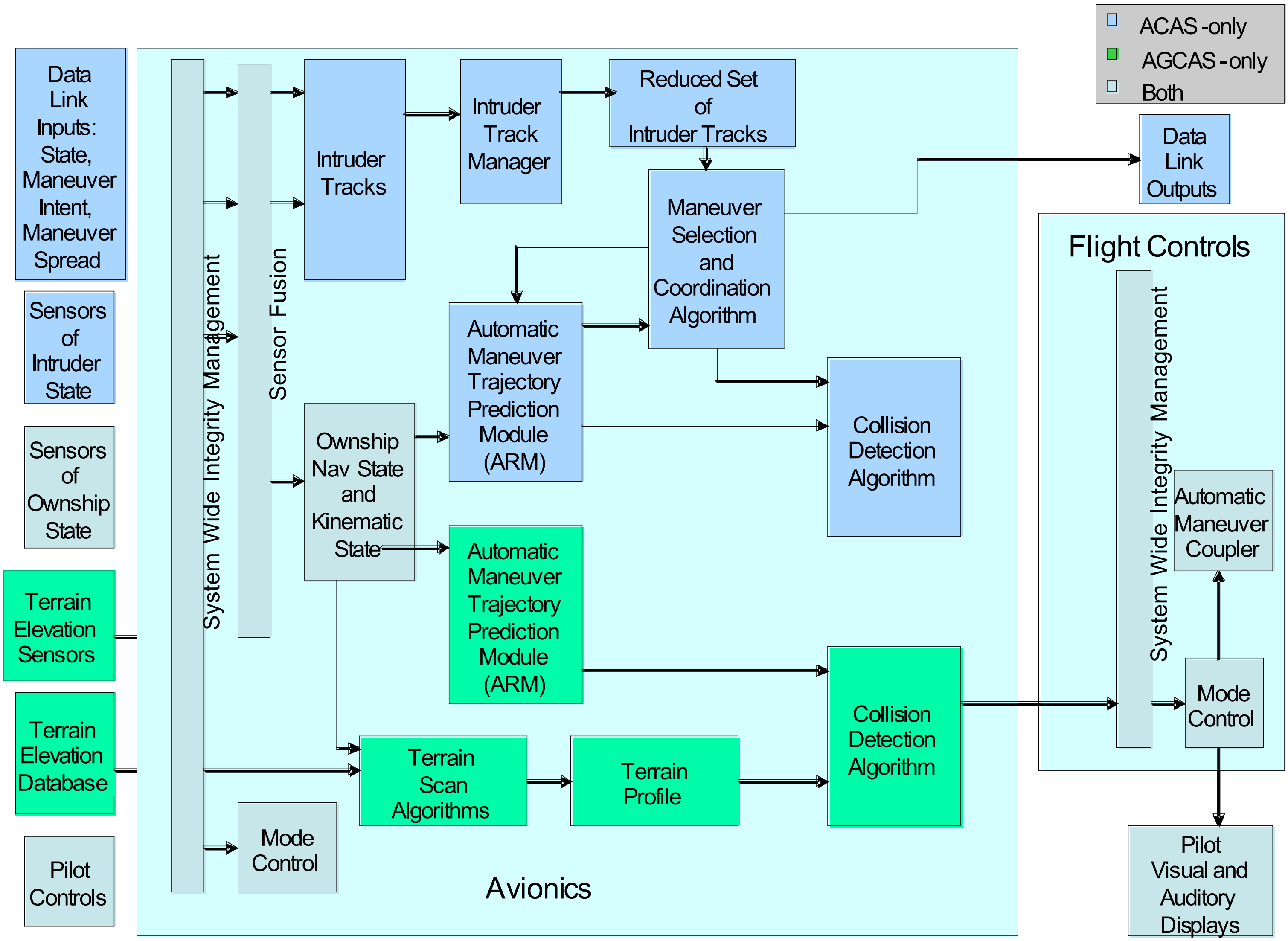
Development History

- 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



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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

ACAT

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

ACAT

Flight Test Development & Evaluation

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NASA Dryden Flight Research Center

UVS 2007

Paris, France

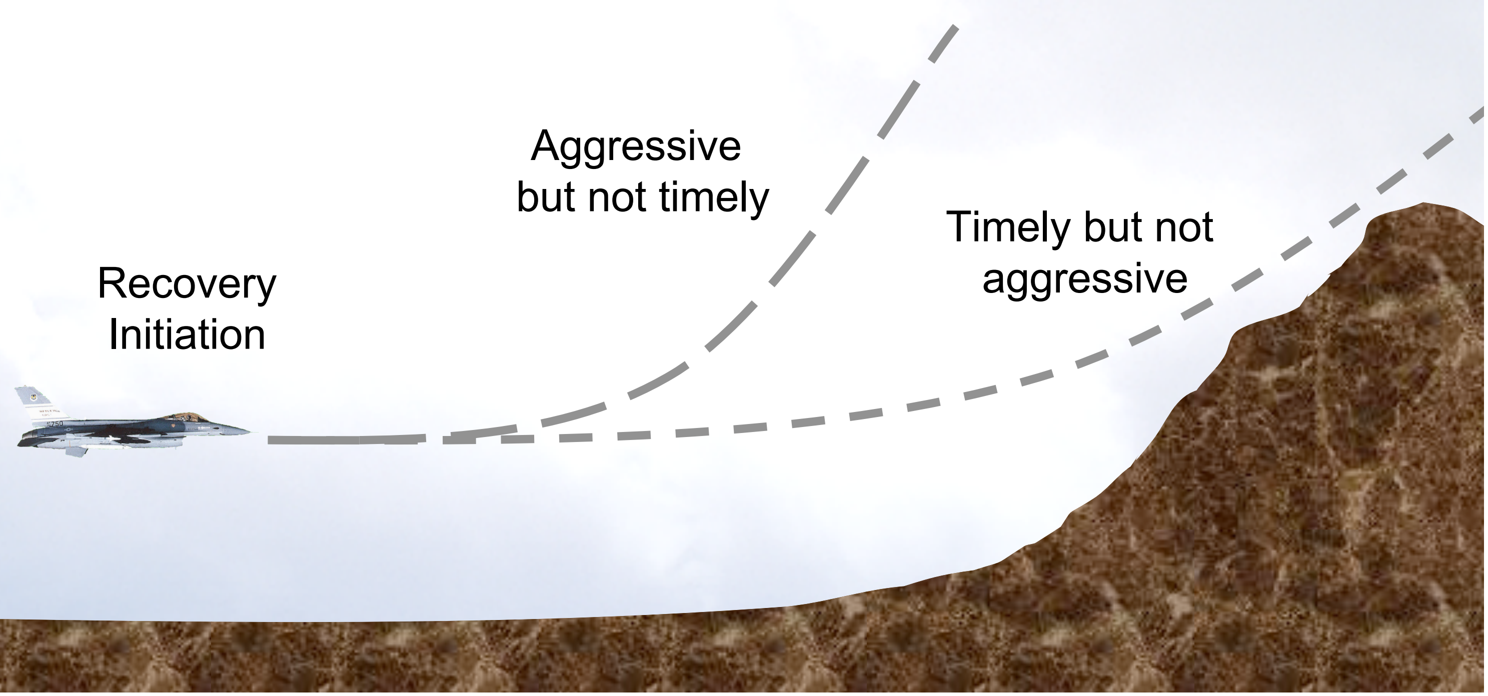
June 12th, 2007

Auto GCAS

Flight Test
Development & Evaluation

Avoid Impeding Operations
Concept

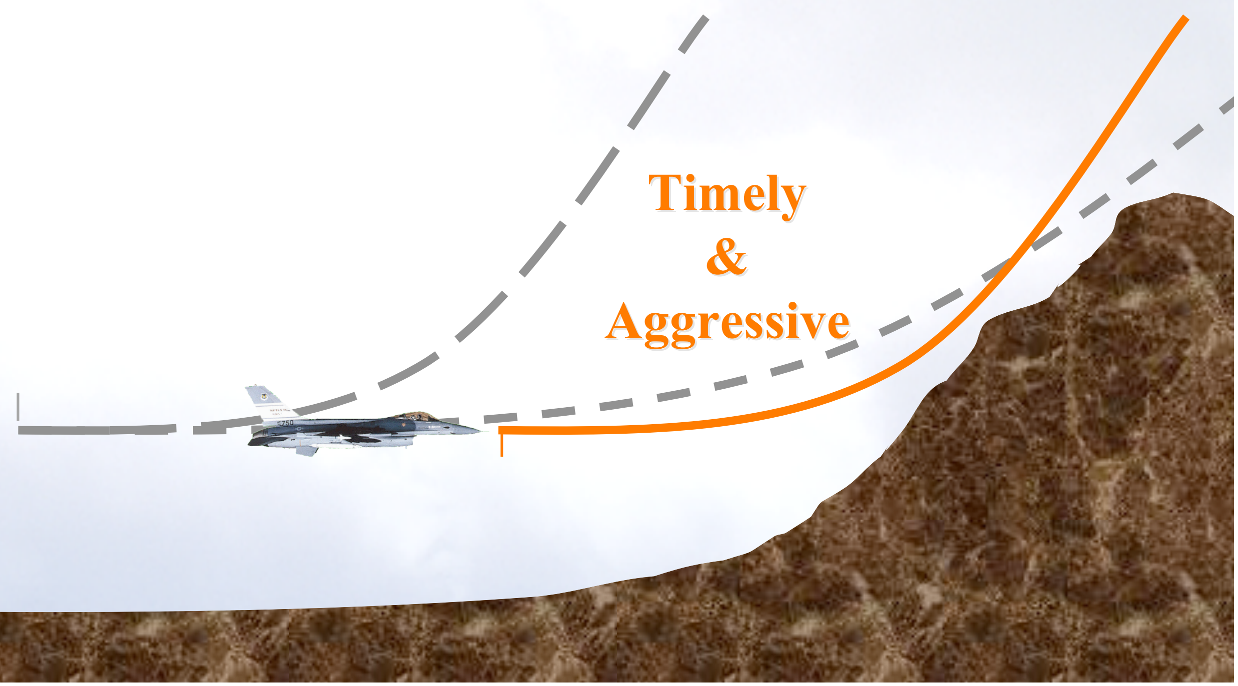
- **Nuisance Activations**
  - Definition
    - **An Unwarranted Recovery as Judged by a situationally aware pilot in command**
  - Nuisance Factors
    - **A Recovery Must be Both Aggressive and Timely**



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 <u>Aggressive</u> and <u>Timely</u>**

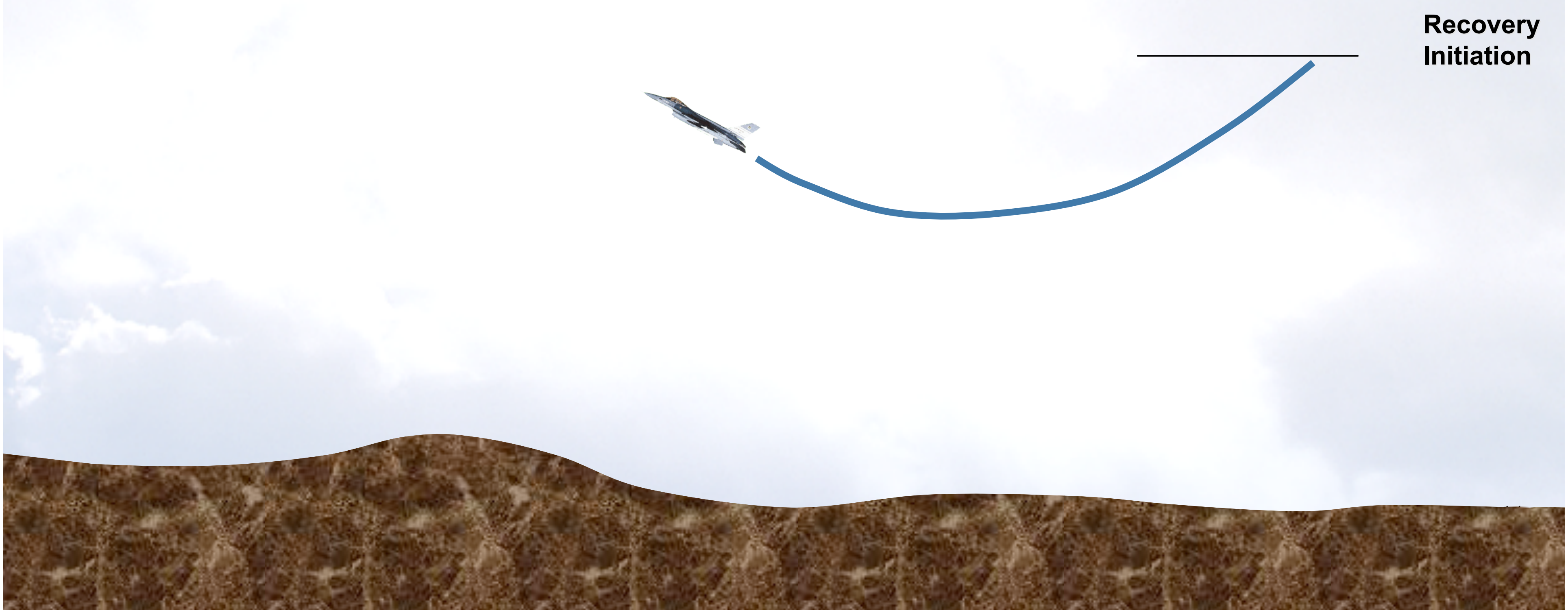


Avoid Impeding Operations

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

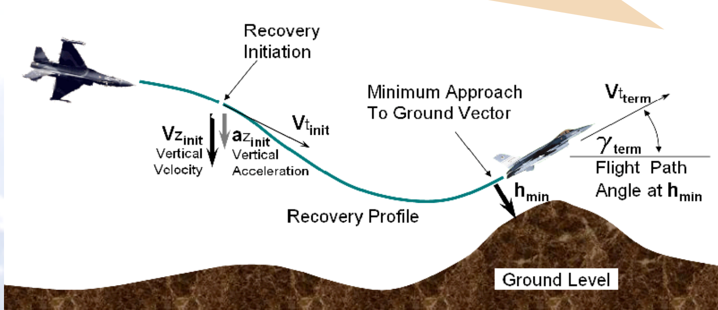
Nuisance Criteria

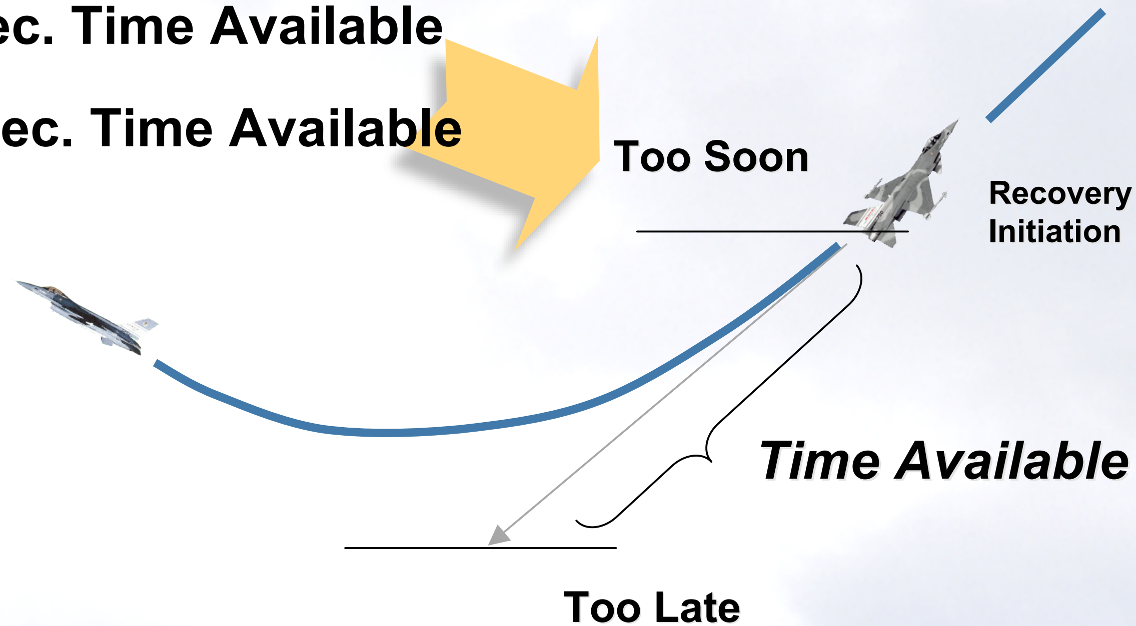
The Recovery Initiation Must be Timely

- Performance
  - Objective ≤ 1.0 sec. Time Available
  - Threshold ≤ 1.5 sec. Time Available

$$T_a = \frac{h_{\min}}{(Vz_{init} + T_a * az_{init}) + Vt_{init} * \sin(\gamma_{term})}$$

Where:





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

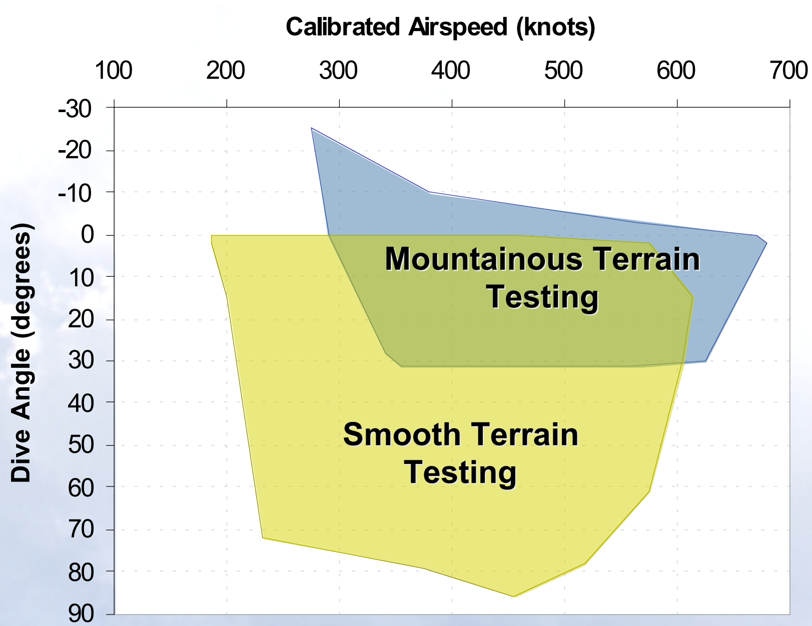
 Pressed Strafing Run

 SDO into Mountain

 GLOC Supersonic

 NVG Disorientation

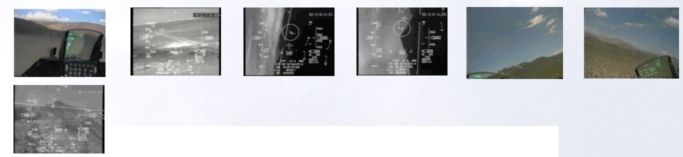
 Gear Up Landing

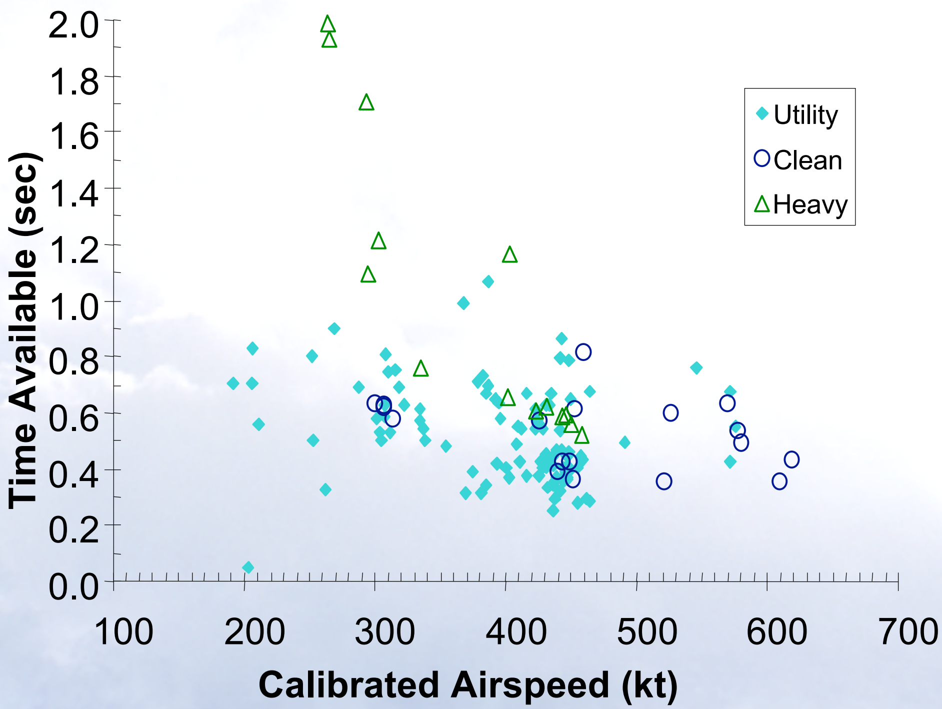


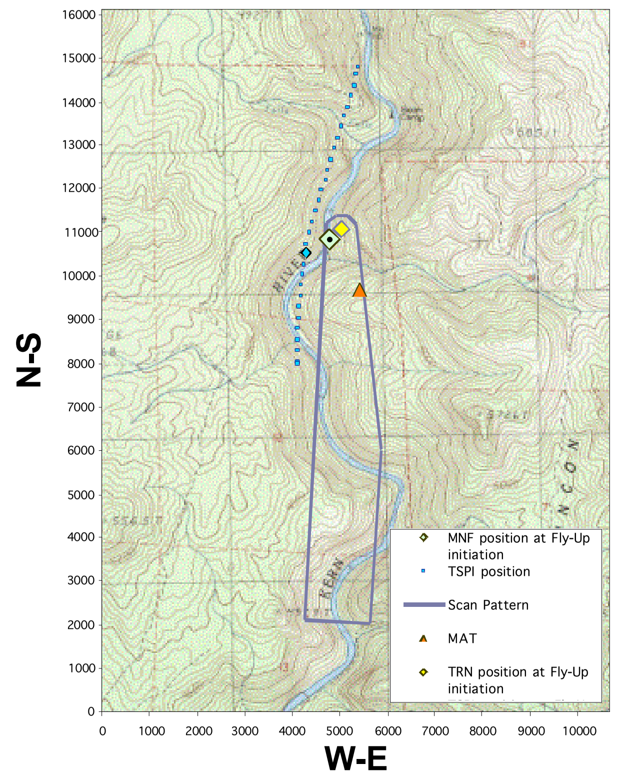
Mi shap Type	Number of Times Flown	Dive Angle (deg)	Bank Angle (deg)	True Airspeed (kts)	Load Factor (g)	Average Altitude Pad (ft)	Minimum Altitude Pad (ft)
Air Score	8	20-32	100-132	303-467	0.9-1.4	238	57
Night Vision Goggle Disorientation	5	13-18	74-93	419-327	1.0-1.1	69	48
Pressed Bombing Attack	20	20-32	6-0	443-675	0.7-1.1	190	104
Pressed Stra fing Attack	19	0-8	0-7	363-483	0.7-3.7	27	-2
g-Induced Loss of Consciousness – Subsonic	7	54-86	1-102	455-583	0.0-1.2	559	139
g-Induced Loss of Consciousness – Supersonic	2	60 and 77	1 and 4	1.0 and 1.1 Mach	-0.6 and 0.6	98	-3
Low Altitude Split -S	1	29	178	266 KCAS	21 deg	132	132
Level Flight Into Mountain	11	0	0-4	461-508	0.2-1.2	200	55
Spatial Disorientation Into Mountain	5	30	1-9	475-701	1.0-1.3	230	181
Gear -Up Landing	3	0-5	0-5	188-211 KCAS	1.1-1.5	13	-6

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**





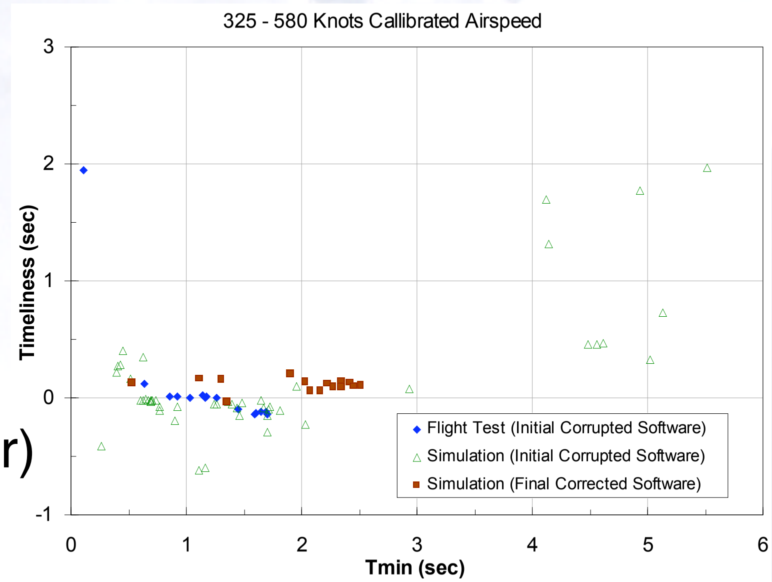


Auto ACAS

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



Automatic Collision Avoidance Technology

ACAT

Flight Test Conclusions

LOCKHEED MARTIN

LOCKHEED MARTIN

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