Developing Sense & Avoid Requirements for Meeting an Equivalent Level of Safety

UVS Tech 2006
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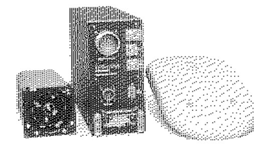
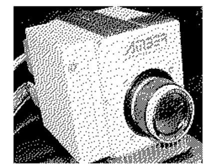
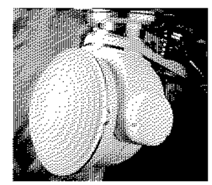
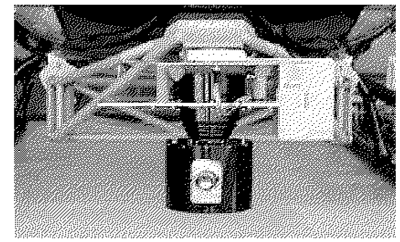
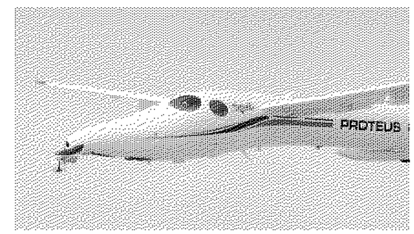
Modern Technology Solutions, Inc

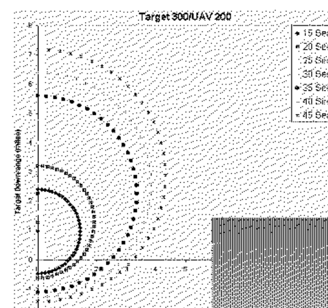
UAS Collision Avoidance Initiatives

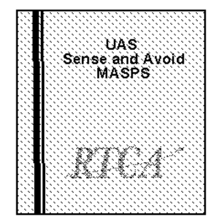
NASA Dryden Flight Research Center

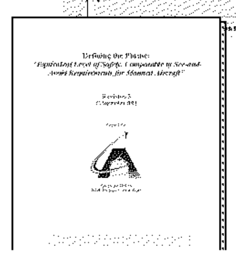
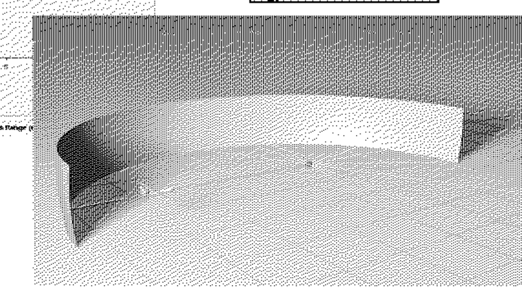
- ERAST: 1993 - 2003
  - Sensor Requirements
  - Sensor Concept Development
  - Flight Test Demonstrations
    - Cooperative
    - EO / IR
    - Radar

- ACCESS 5: 2004 - present
  - Requirements Development
  - Safety Analysis
  - Simulation Tools
  - Flight Test Demonstrations
  - Standards Development

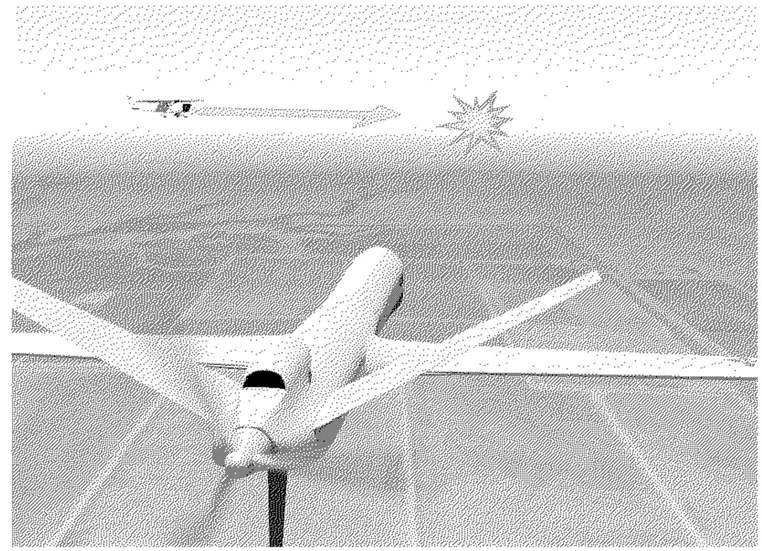




ACCESS 5
Collision Avoidance Work Package

- Work Package Objectives:
  - Define Equivalent Level of Safety (ELOS) for Sense and Avoid.
  - Develop collision avoidance (CA) requirements for Unmanned Aircraft Systems (UAS); validated through analysis, simulation, and flight demonstration.
  - Provide inputs to the FAA and RTCA Special Committee 203 "Unmanned Aircraft Systems"

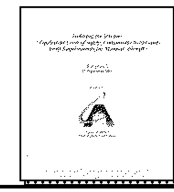


- Team Members:
  - NASA Dryden & Langley
  - Northrop Grumman
  - Lockheed Martin (Ft. Worth)
  - MITRE
  - Modern Technology Solutions
  - Aurora Flight Sciences
  - Federal Aviation Administration

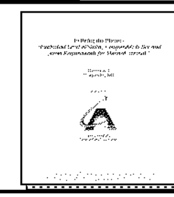
ACCESS 5 Collision Avoidance Work Package

5 Major Task Areas

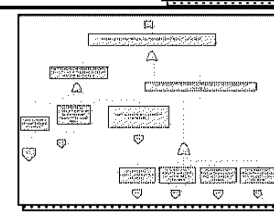
– CA Task 1:
Define ELOS for See & Avoid



– CA Task 2:
Develop CA Requirements

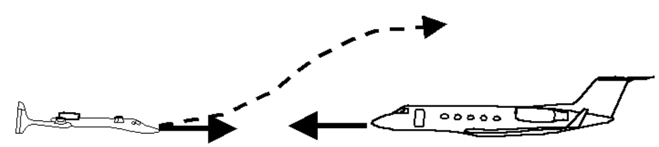


– CA Task 3:
Perform CA Safety Analysis



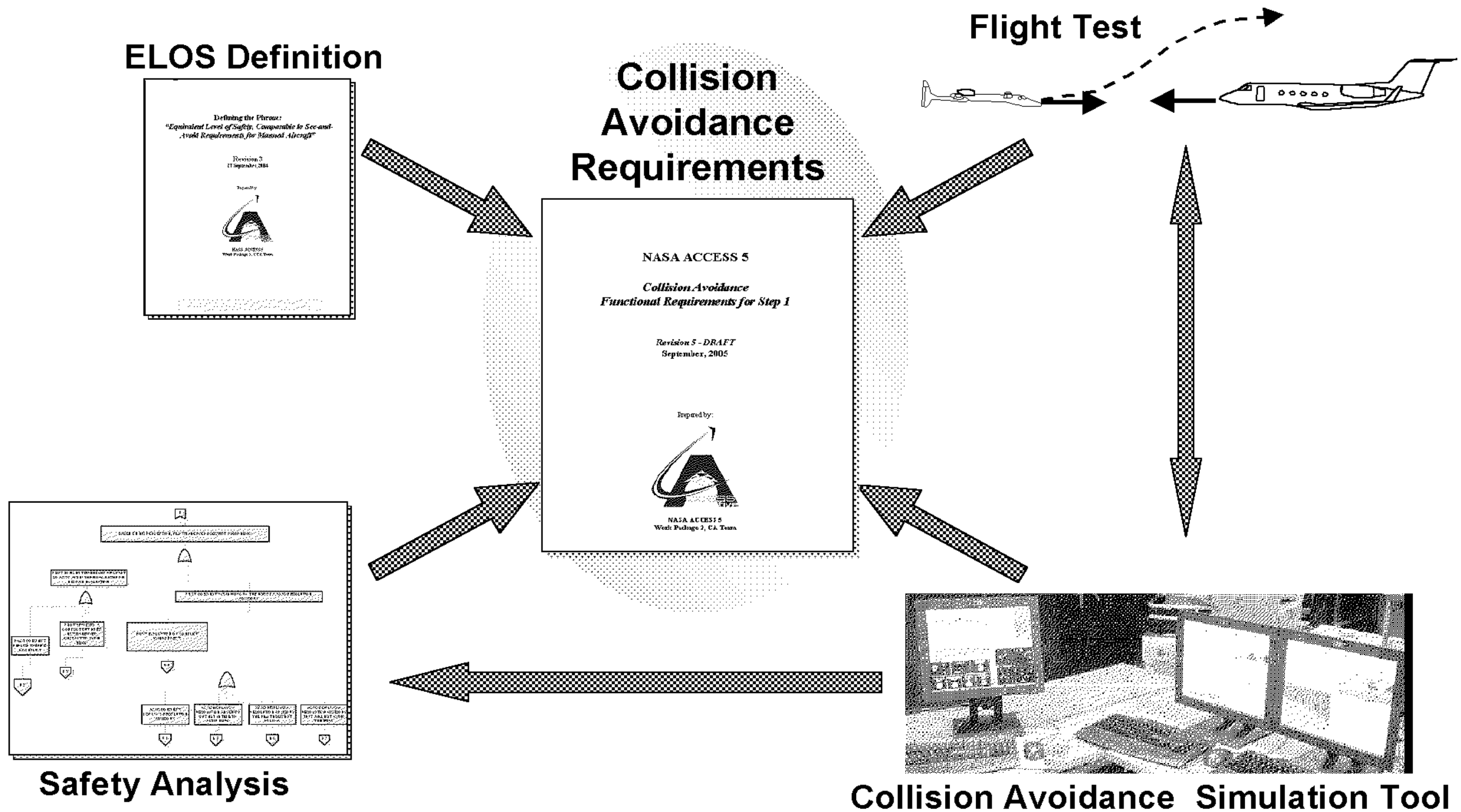
– CA Task 4:
Develop CA Simulation Tool

– CA Task 5:
Perform CA Flight Test



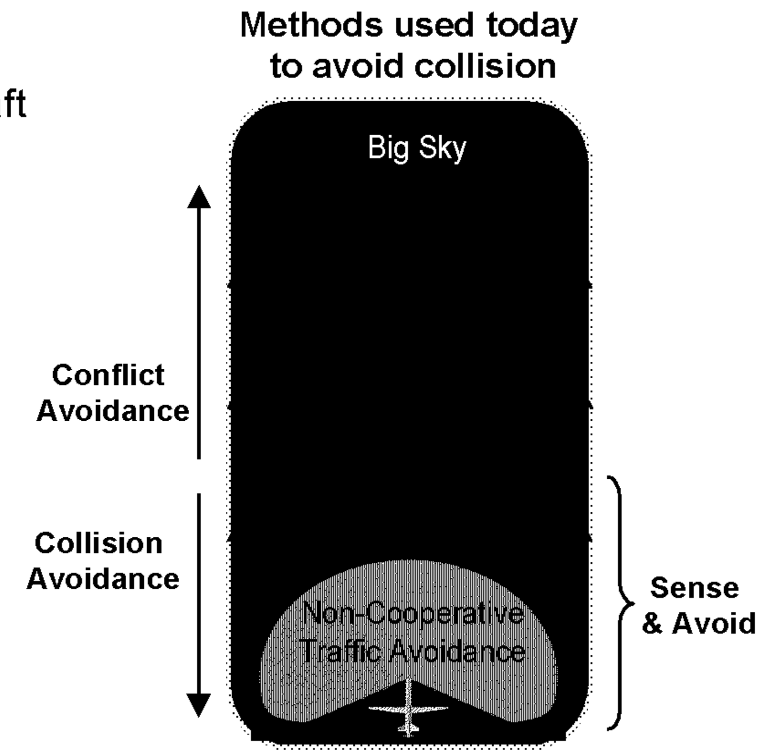
Collision Avoidance Work Package

Task Relationships



Task 1: ELOS Definition Document

- Objective: To present a recommended approach for defining an equivalent level of safety, as it pertains to see and avoid.
- Deliverable Content:
  - Current regulatory / operational environment
    - 14 CFR 91.113(b), Right of Way Rules
    - 14 CFR 91.111, Operating near other aircraft
  - Basis for having to meet an Equivalent Level of Safety
    - 14 CFR 21.21(b), Certification Procedures
    - FAA Order 8110.4C, Equivalent Level of Safety Findings
  - Potential Approaches & Methodologies for defining ELOS
    - 1) Statistical Approach
    - 2) Performance / Rule Based Approach
  - Recommended Definition and Measures of Performance for Sense and Avoid ELOS



- Status: Delivered to FAA on 23 Nov 2004

Task 1: ELOS Definition Document

Definition and Measures of Performance

- Definition: *"Equivalent level of safety to manned aircraft see-and-avoid" is the capability to provide situational awareness with adequate time to detect conflicting traffic and the ability to take the appropriate action necessary to avoid collisions."*

- Measures of Performance:

ELOS for See & Avoid

Surveillance

- Minimum Detect Time
- Field of Regard
- Track Capability
- . . .

Avoidance

- Minimum Miss Distance
- Miss Distance Probability
- System Reaction Time
- . . .

System Quality

- System Integrity
- System Continuity
- System Interoperability
- . . .

Task 2: Develop Collision Avoidance Reqmts

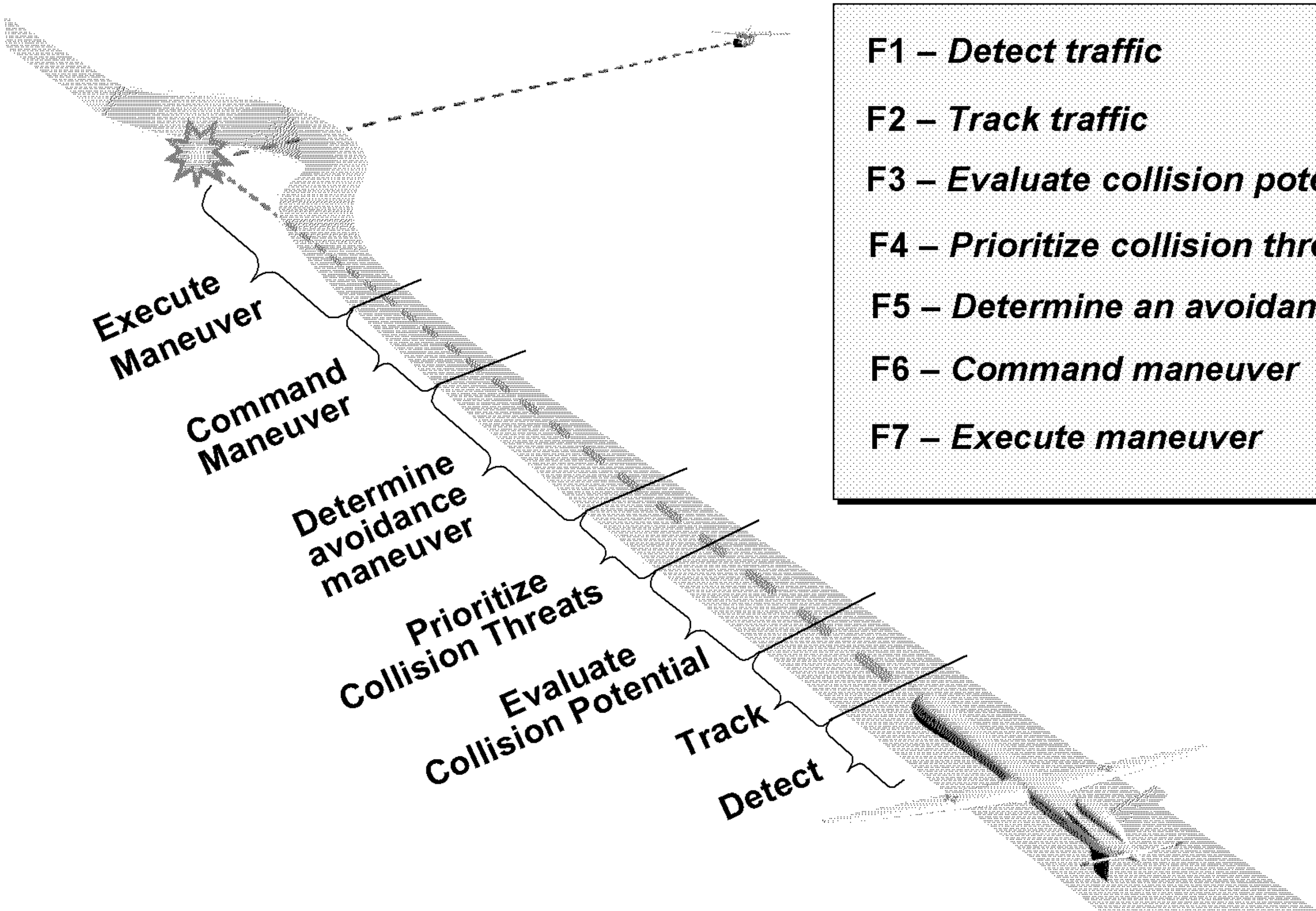
- Objective: To develop the collision avoidance operational, functional, and performance requirements for HALE UAS.

- Deliverable Content:
  - Notional CA Subsystem Description
    - Subsystem Architecture
    - Interfaces
  - Operational Requirements
  - Functional Analysis
    - List of Collision Avoidance Functions
    - Functional Flow Block Diagram
    - Functional Requirements
  - Performance Requirements
    - Design Guidelines
    - Performance Trade-offs
  - Verification Method (Analysis, Inspection, Simulation/Modeling, Demo, Test)

- Status: Intend to release Revision 6.0 in February 2006
  (All previous revisions have included FAA input and review)

Task 2: Develop Collision Avoidance Reqmts

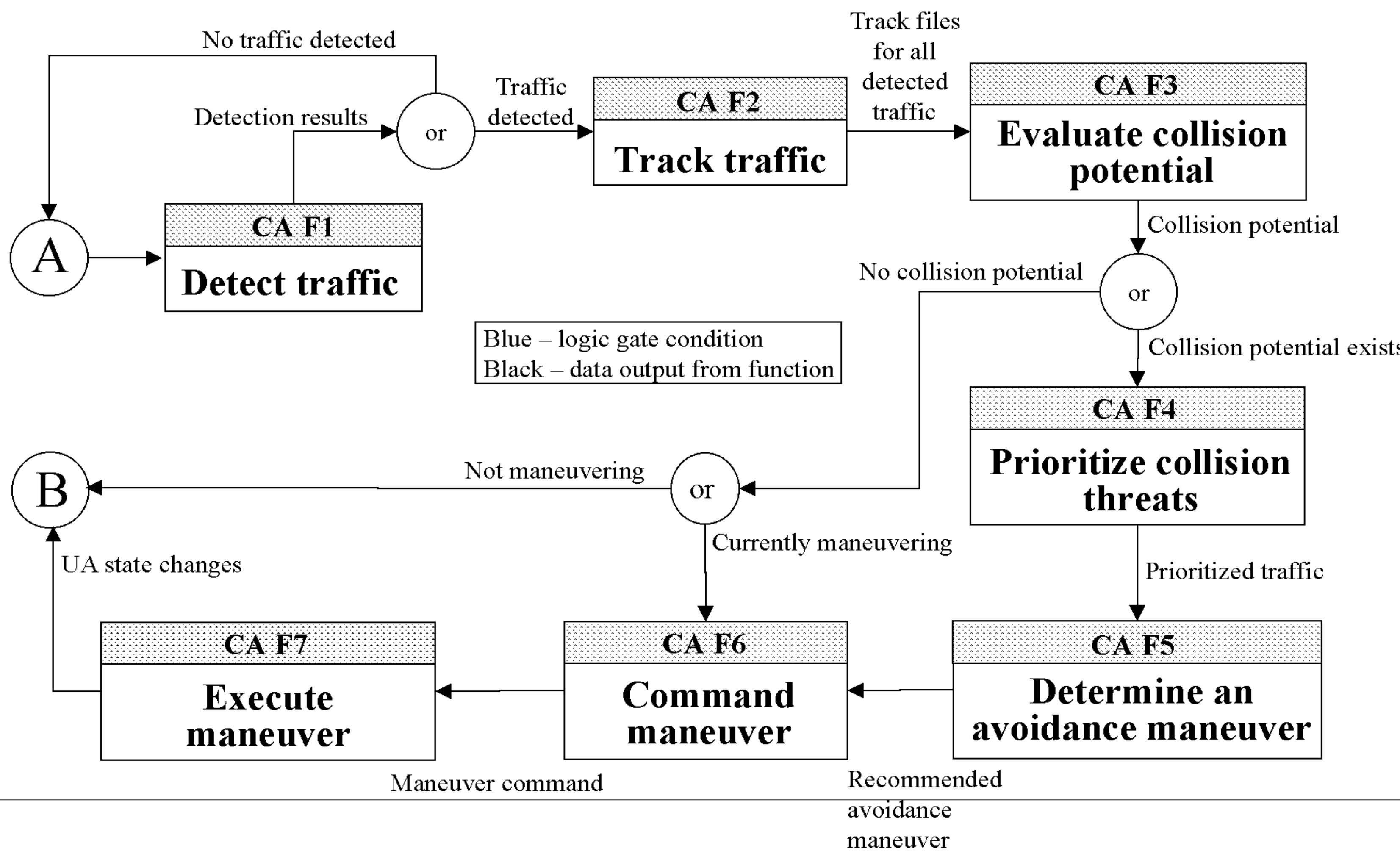
Collision Avoidance Functions



- F1 – *Detect traffic*
- F2 – *Track traffic*
- F3 – *Evaluate collision potential*
- F4 – *Prioritize collision threats*
- F5 – *Determine an avoidance maneuver*
- F6 – *Command maneuver*
- F7 – *Execute maneuver*

Task 2: Develop Collision Avoidance Reqmts

Functional Flow Block Diagram



Task 2: Develop Collision Avoidance Reqmts

Function 1: Detect Traffic Requirements (Example)

- **F1: Detect Traffic - The UAS shall detect traffic within its surveillance volume.**
  - **F1.1: Minimum Detect Time** - The CAS shall detect traffic with sufficient time remaining for successful performance of all required collision avoidance functions.
  - **F1.2: Detection Range** - The CAS shall detect cooperative traffic at a range of at least xx nautical miles. (*see Table F1.2*)
  - **F1.3: Azimuth Field of Regard** - The CAS shall detect cooperative traffic within an azimuth FOR of at least +/-110° referenced from the flight path of the UA.
  - **F1.4: Elevation Field of Regard** - The CAS shall detect cooperative traffic within an elevation FOR of at least +/-15° referenced from the flight path of the UA.
  - **F1.5: Detection Probability** - The CAS shall detect cooperative traffic in the surveillance volume at a rate that supports the track probability guideline (*see F2.3*).
  - **F1.6: Detection Rate** - The average CAS detection rate shall be equal to or greater than xx hertz. (*see Table F1.6*)
  - **F1.7: Detection Accuracy** - The CAS shall detect cooperative traffic with an accuracy of TBD ft for range determinations, and TBD ft for altitude determinations
  - **F1.8: False Detection/Nuisance** - False detections shall account for less than TBD% of all detected traffic.

Task 3: Perform Safety Analysis

- Objective: To develop a method for evaluating the safety of collision avoidance for UAS.
  - Establish equivalent level of safety to manned aircraft using event/fault trees and logic risk ratios

$$\text{Risk Ratio} = \frac{\text{P(collision UAS)}}{\text{P(collision manned AC)}} \leq 1$$

- Accomplishments:
  - Developed visual acquisition model based on Lincoln Lab's SEE1 model
  - Developed surveillance error models for GPS/ADS-B
  - Performed multiple assessments using results from the CA simulation tool for the primary event tree probabilities.
  - Supported requirements development in the areas of Surveillance, Effectiveness, Detection Accuracies, Detection times, Reaction times, Maneuver times, etc.

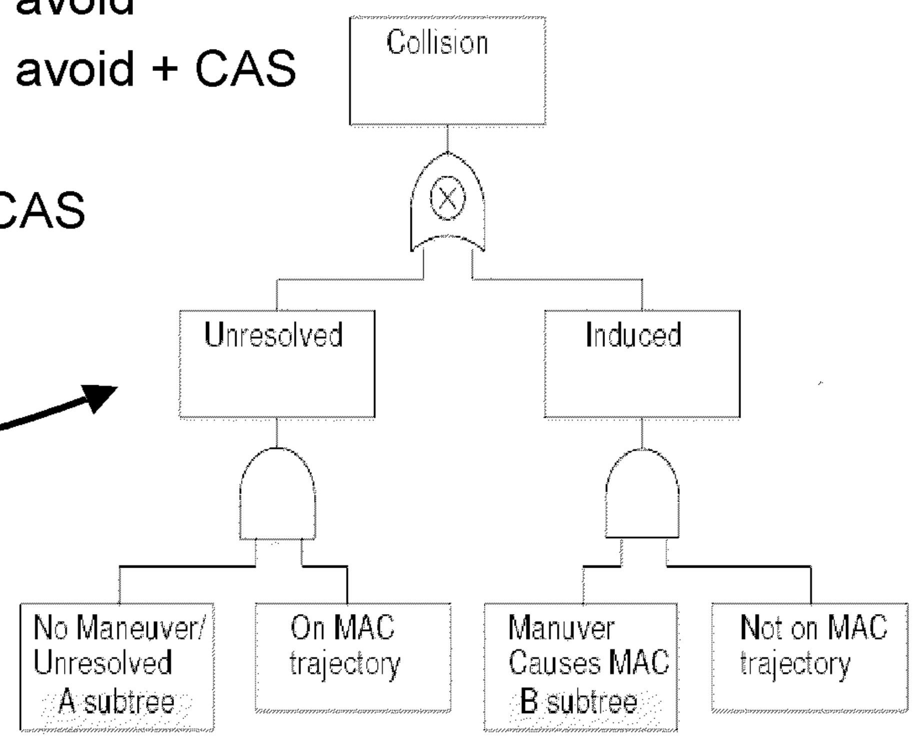
- Status: Currently finalizing final report and lessons learned

Task 3: Perform Safety Analysis

Generic Event/Fault Tree for Collision Probability Estimation

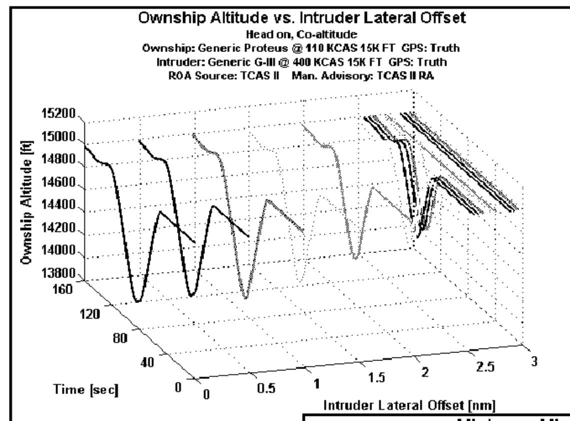
- Generic Event/Fault Tree established to provide a consistent basis for comparison:
  - 1. Manned aircraft using see & avoid
  - 2. Manned aircraft using see & avoid + CAS
  - 3. UAS with Sense & Avoid
  - 4. UAS with Sense & Avoid + CAS

Simplified Fault Tree
(actual tree is several pages long)

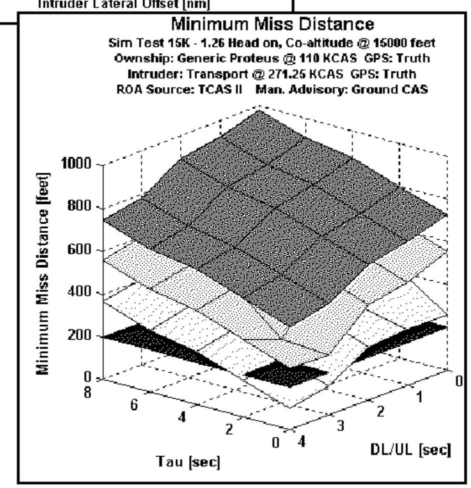


Task 4: Develop CA Simulation Tool

- Objective: To assess the validity of the proposed CA Functional Requirements via Simulation as well as support the CA Flight Test activities.
  - Allows characterization of:
    - Ownship Vehicle Dynamics
    - CA Equipment and Software
    - Encounter Scenarios



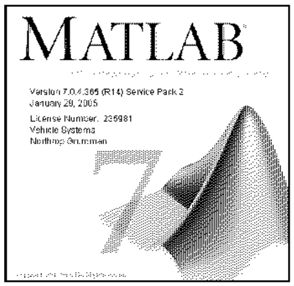
- Accomplishments:
  - Duplicated Tech Demo Scenarios
    - Flight Test Risk Reduction
    - Improve Probability of Obtaining Useful Data
  - Validated Against the System Integration Lab (SIL)
    - Flight Test Risk Reduction
    - CCA Component Models
  - Sensitivity Analyses performed

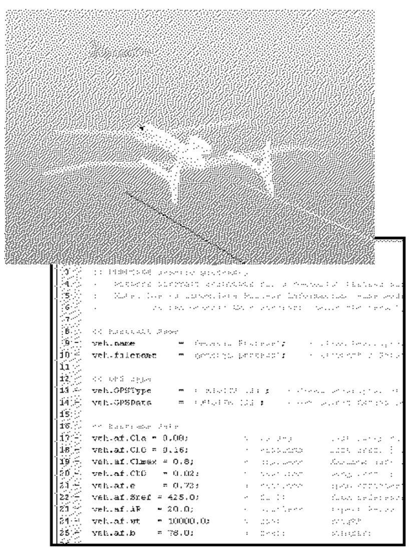


- Status: Currently analyzing flight test data and validating the CA simulation tool.

Task 4: Develop CA Simulation Tool

Simulation Features



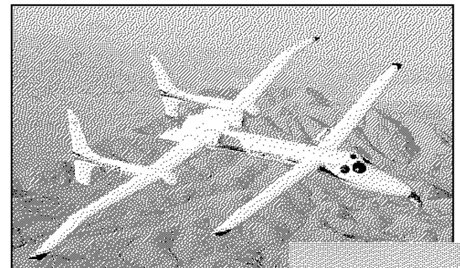


- MATLAB™/Simulink® Simulation Environment
- Multi-Vehicle Simulation (4 Aircraft Max)
- Generic Aircraft Models Represent Any Fixed Wing Aircraft
  - Each Aircraft = 1 Parameter File
  - Scripts Trim & Initialize Aircraft to Any Encounter Geometry
- Modular Components
  - Blocks Can be Copied and/or Swapped Out for Software Upgrades (e.g. CA Sensors, Maneuver Advisory)
- Capable of Batch Runs for Parametric Variation Studies
  - Uses Microsoft Excel Input Dataset
  - Multiple Plot Outputs Available
- PC Portable (< 37 MB)
- Can Run in Both Fast Sim-Time & Soft Real-Time

Task 5: Perform CA Flight Test

- Objective: To collect cooperative collision avoidance data to validate the CA simulation tool

OPV - Proteus



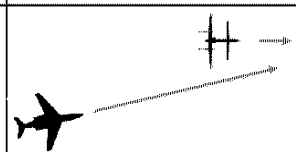
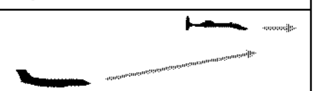
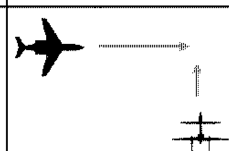
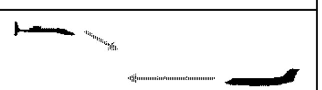
Intruder – Gulfstream III

- Accomplishments:
  - Developed Interface Control Document
  - Developed System Integration Lab (SIL)
  - Developed CA algorithms
  - Developed CA software and human interface tool
  - Procured CA sensors and integrated them onto Proteus platform
  - Developed CA scenarios and test cards
  - Post-processed flight data and prepared for data analysis effort

- Status: Successfully completed over 50 collision scenarios during the last two weeks of September 2005.

Task 5: Perform CA Flight Test

Test Scenarios

	HOST	INTRUDER		PICTORIAL
Scenario #	Climb Rate (fpm)	$\Delta\psi$ (degrees)	Climb Rate (fpm)	
1	0	0	0	
2	0	10	0	
3	0	0	500	
4	0	-90	0	
5	0	180	0	
6	-500	180	0	

- Test scenarios included multiple collision geometries:
  - Co heading, Intruder overtaking
  - Low aspect, co-altitude
  - Co heading, Intruder climbing
  - Abeam, co-altitude
  - Head-on, co-altitude
  - Head-on, descending

	Configuration						
	TGC & AGA					TRT	
Buffer	6	4	2	0	4	0	0
Link Delay	0	0	0	0	2	0	2
Scenario							
1. Co-Heading, Co-Alt, Intruder Overtaking				1		2	
2. Low Aspect, Co-Alt				1		2	
3. Co-Heading, Intruder Climbing				1		2	
4. Abeam, Co-Alt	1	1	1	2	1	1	1
5. Head-On, Co-Alt	1	1	1	2	1	1	1
6. Head-On, Descending	1	1	1	2	1	1	1

Next Steps

- Document the results and lessons learned from the Safety Analysis and Flight Test Activities
- Complete validating the CA Simulation tool
- Derive practical values/ranges for the TBDs in the performance requirements
  - Utilize the validated CA Simulation tool
  - Utilize the safety analysis results
- Begin Non-cooperative Collision Avoidance Activities
  - Derive unique Non-cooperative performance requirements
  - Perform Trade Studies and Concept Assessments
  - Conduct Non-cooperative Simulation Runs and Flight Demos
- Support RTCA SC-203 on developing the Sense & Avoid Minimum Aviation System Performance Standards (MASPS)


QUESTIONS ?
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