AFRL SAA Research

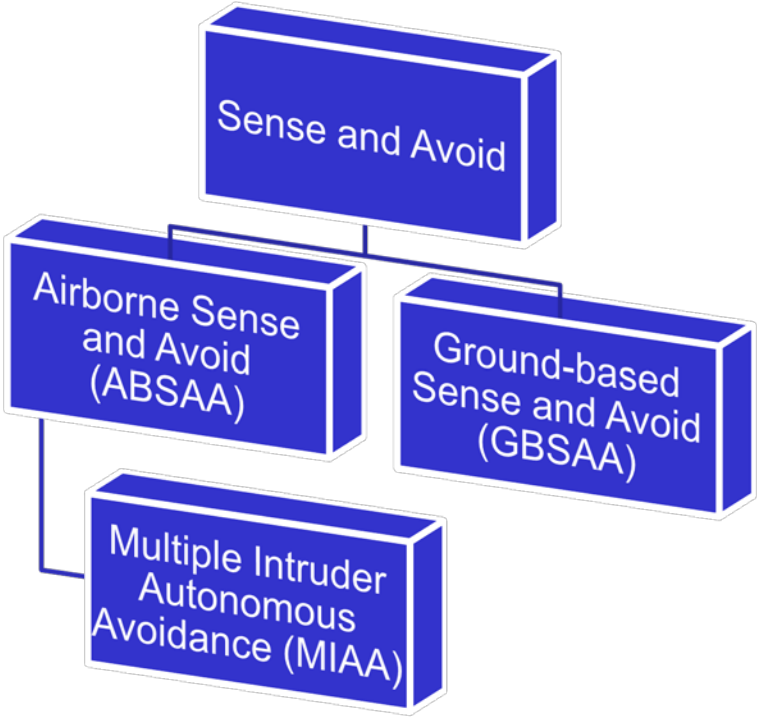
Ohio UAS Conference
18 April 2012

Robert Smith
Air Force Research Laboratory

Federal Aviation Administration

Outline

- **Background**
- **Current Research**
  - Sensors
  - Architecture
  - Algorithms
  - Flight tests
- **Other Activities**
- **Future Directions**



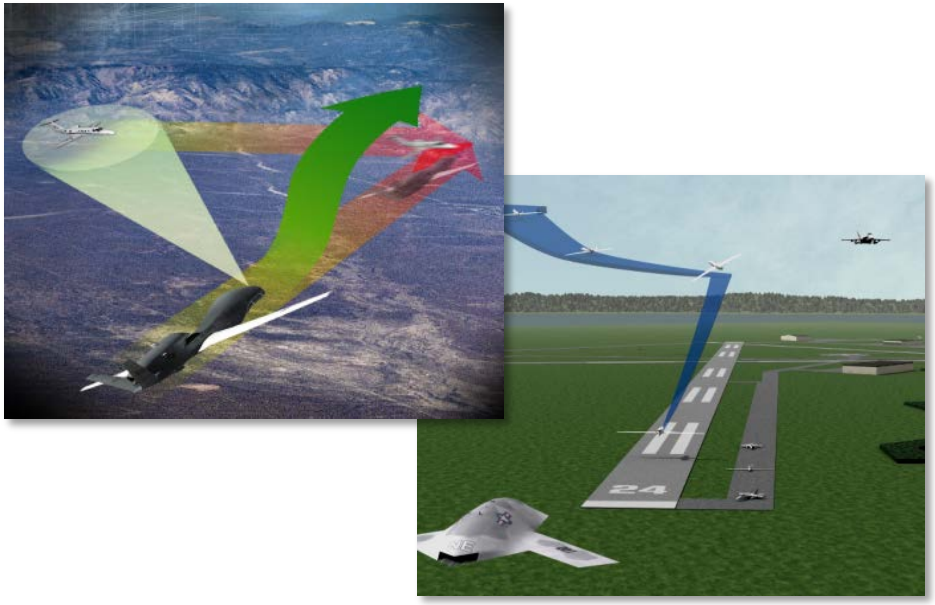
UAS Airspace Integration

Motivation

- DoD UAS require routine access to airspace for training and operations
  - Current Certificate of Auth. (CoA) process is time consuming and highly disruptive to operations

Technical Approach

- Sense and Avoid
  - Algorithms to replicate human pilot "see and avoid" capability for autonomous conflict and collision avoidance
  - Sensor development and integration
  - Automated maneuver
- All classes of airspace – including terminal area and ground operations
- All classes of UAS
- Formations/multiple intruders



Safe operations of unmanned aircraft in the airspace and at airbases

- **As per 14 CFR 91.111 and 91.113**

Enhanced operational availability of airspace for UAS ("Same Base, Same Time, Same Tempo")

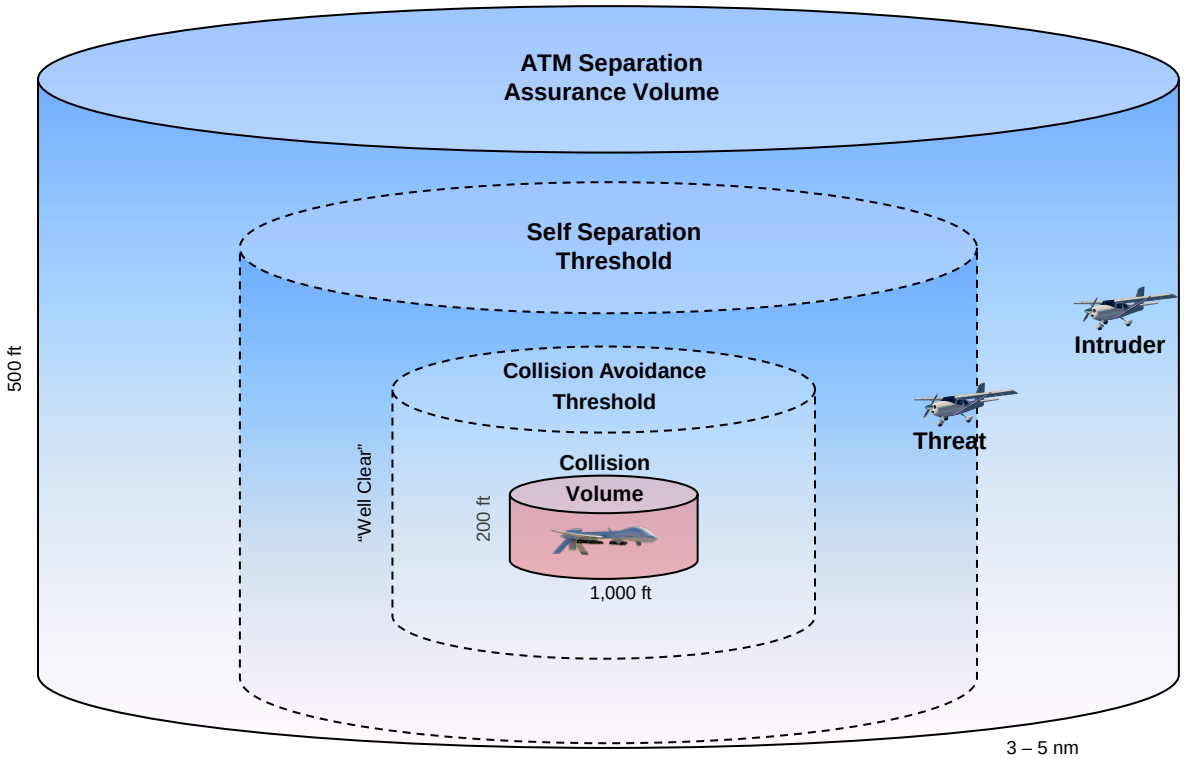
SAA Intended Functions

Self Separation

- Within Minutes
- Benign
- Multiple Objectives
  - Right of Way Rules
  - Well Clear
  - Etc.

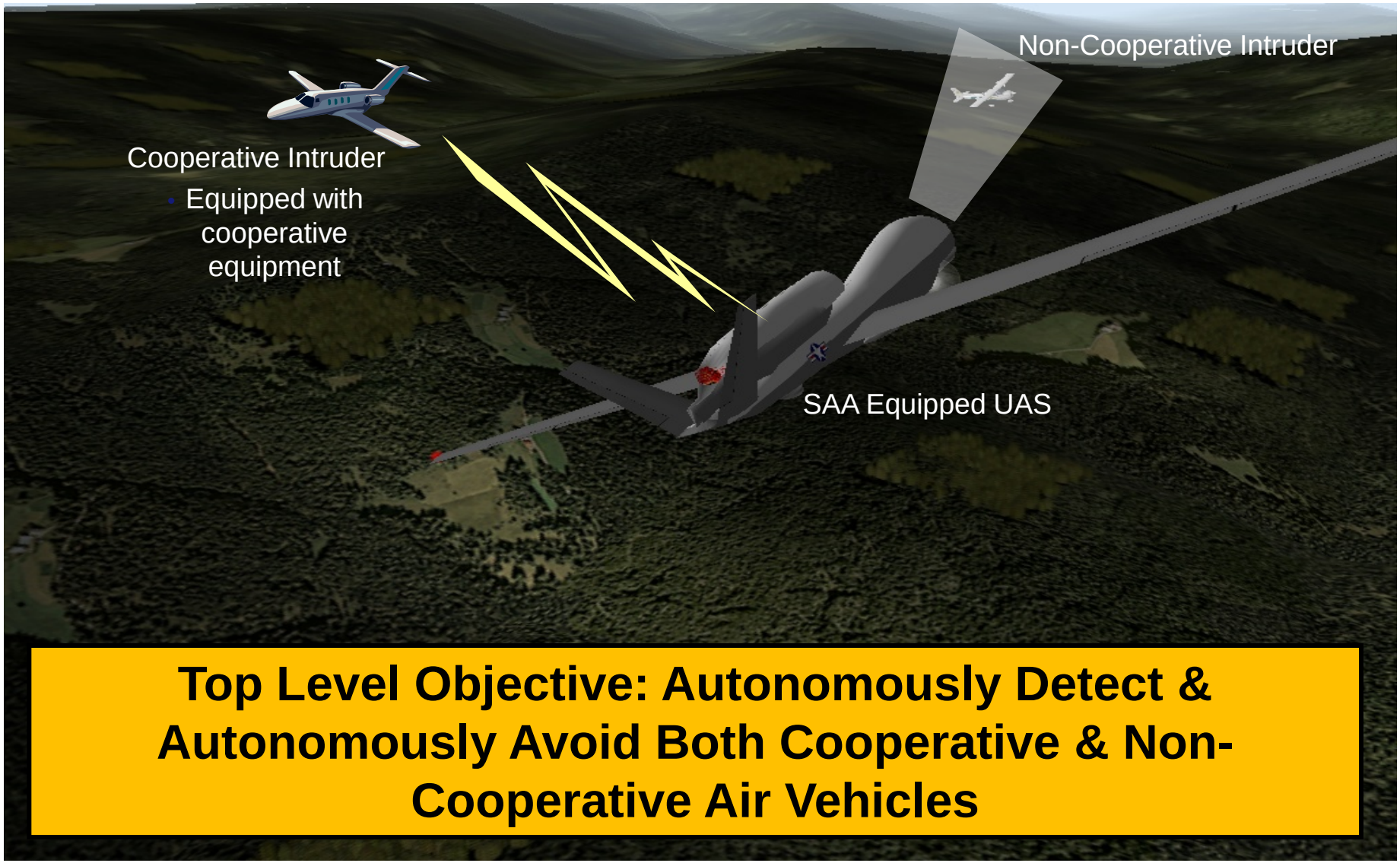
Collision Avoidance

- Within Seconds
- Aggressive
- Single Objective
  - Don't hit!



From FAA sponsored SAA Workshops

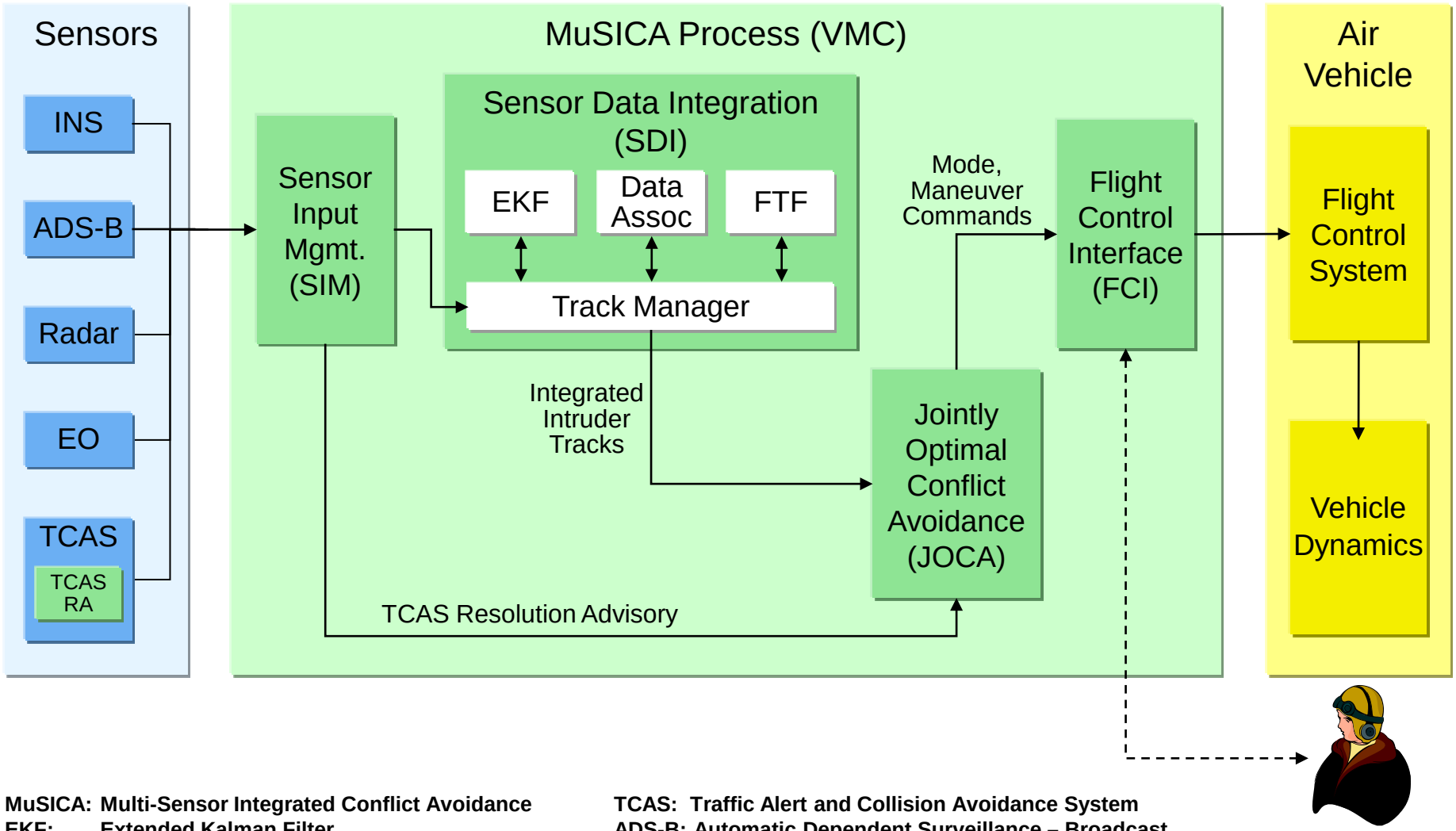
SAA Development



Top Level Objective: Autonomously Detect & Autonomously Avoid Both Cooperative & Non-Cooperative Air Vehicles

5

SAA System Architecture



MuSICA: Multi-Sensor Integrated Conflict Avoidance
EKF: Extended Kalman Filter
FTF: False Track Filtering
VMC: Vehicle Management Computer
TCAS: Traffic Alert and Collision Avoidance System
ADS-B: Automatic Dependent Surveillance – Broadcast
EO: Electro-Optical
INS: Inertial Navigation System

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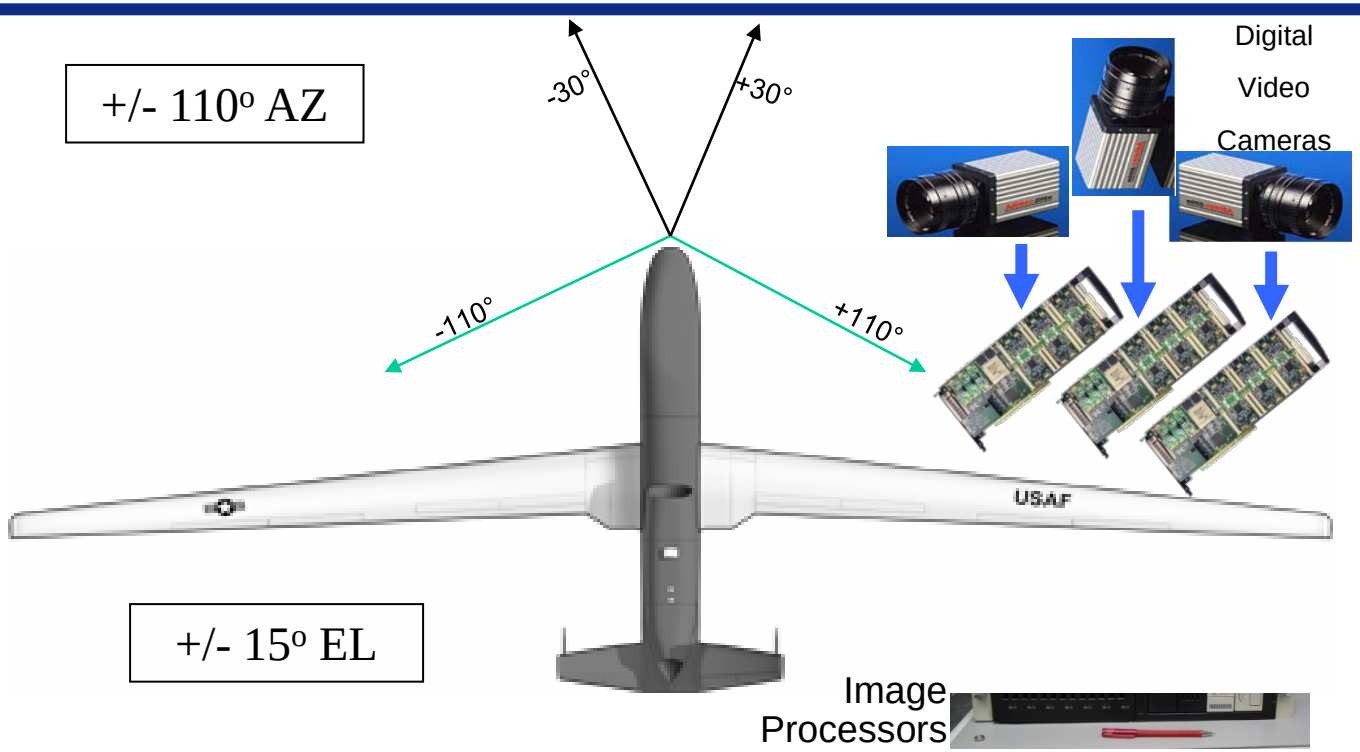
SAA Sensor Development



AI-130 Surrogate

SAA radar in development (FY08 – 10)

EO Sensor Miniaturization

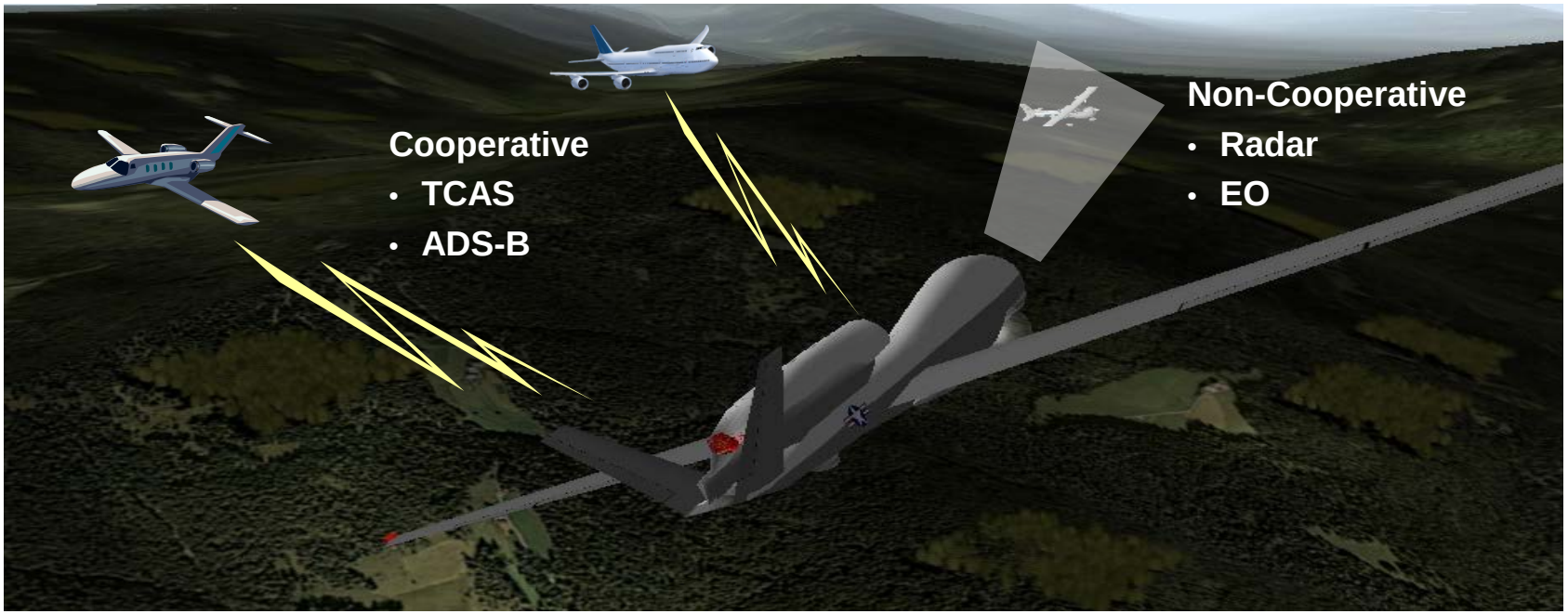
- Reduce sensor SWAP suitable for Tactical 2 (Shadow) class UAS

Approx.	Full	Mini
– Weight (lbs):	75	7.5
– Power (W):	550	76
– Volume (cu.in.):	3000	106

Multi-sensor system

- Dissimilar redundancy
- Complimentary sensors
- Range information
- All-weather
- EMCON operation
- False alarm reduction

SAA Sensors



	TCAS	ADS-B	Radar	EO
Accuracy	Range: 175 – 300 ft Bearing: 9 – 15 deg Altitude: 50 – 100 ft	Horizontal Position: 25 – 250 ft Vertical Position: 50 – 100 ft	Azimuth: 0.5 – 2 deg Elevation: 0.5 – 2 deg Range: 10 – 200 ft Range Rate: 1 – 10 ft/s	Azimuth: 0.1 – 0.5 deg Elevation: 0.1 – 0.5 deg
Update Rate	1 Hz	1 Hz	0.2 to 5 Hz	20 Hz
Declaration Range	≥ 14 nm	≥ 20 nm	5 – 10 nm	2 – 5 nm

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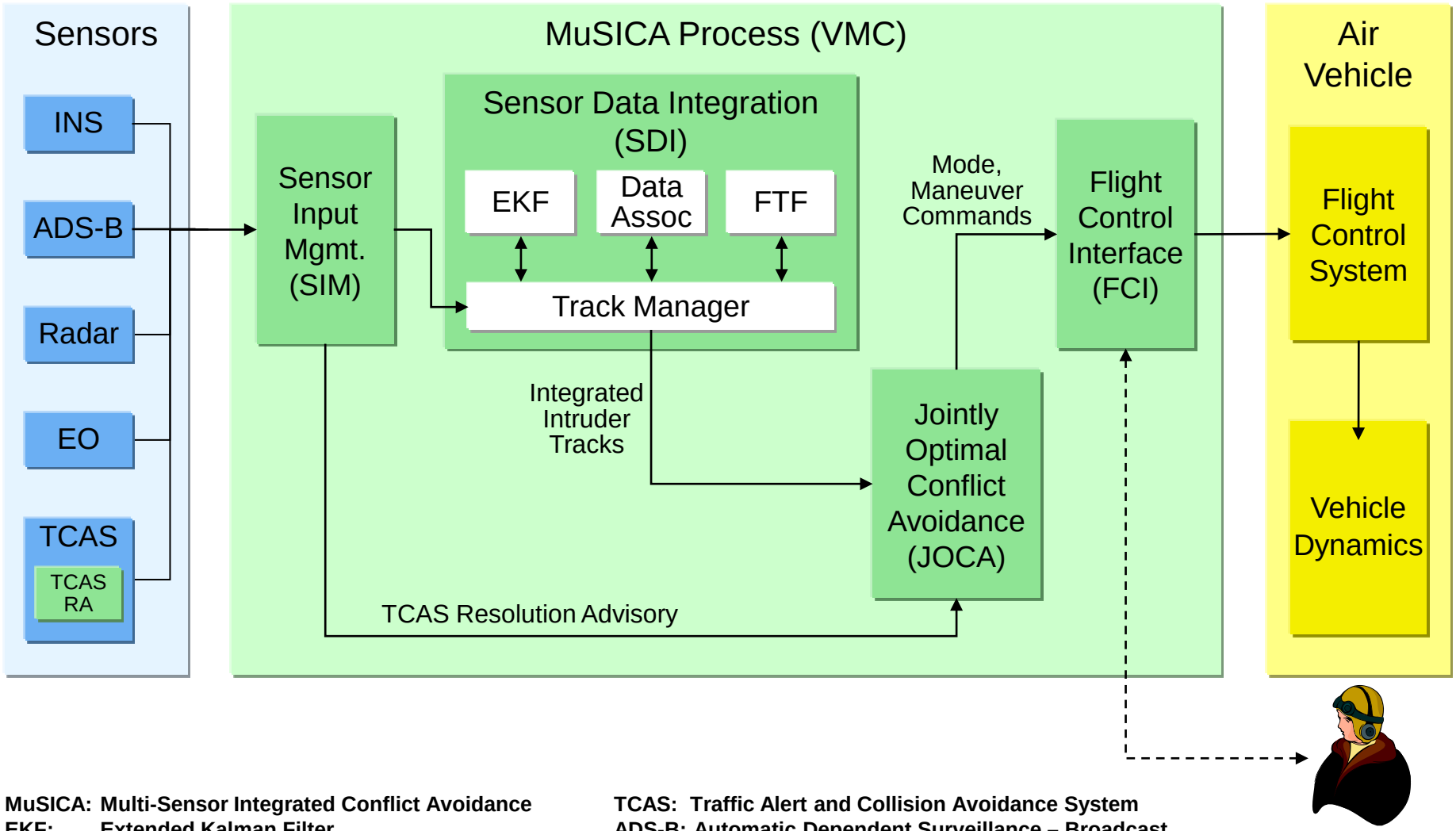
SAA System Architecture



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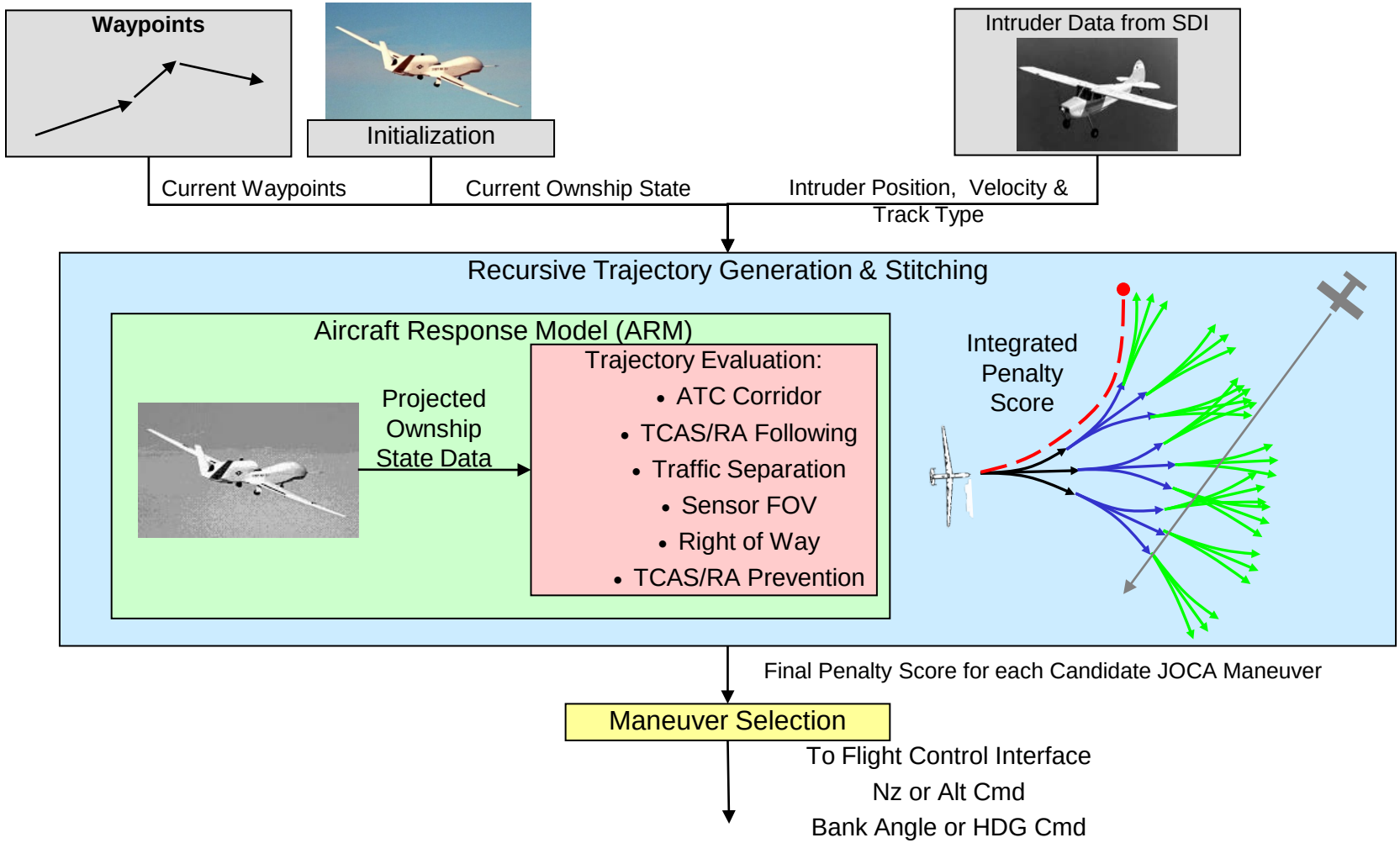
JOCA Design Approach



- Updated at 1Hz to account for uncertainties including intruder maneuvering
  - ARM tailored to ownship performance characteristics & limitations

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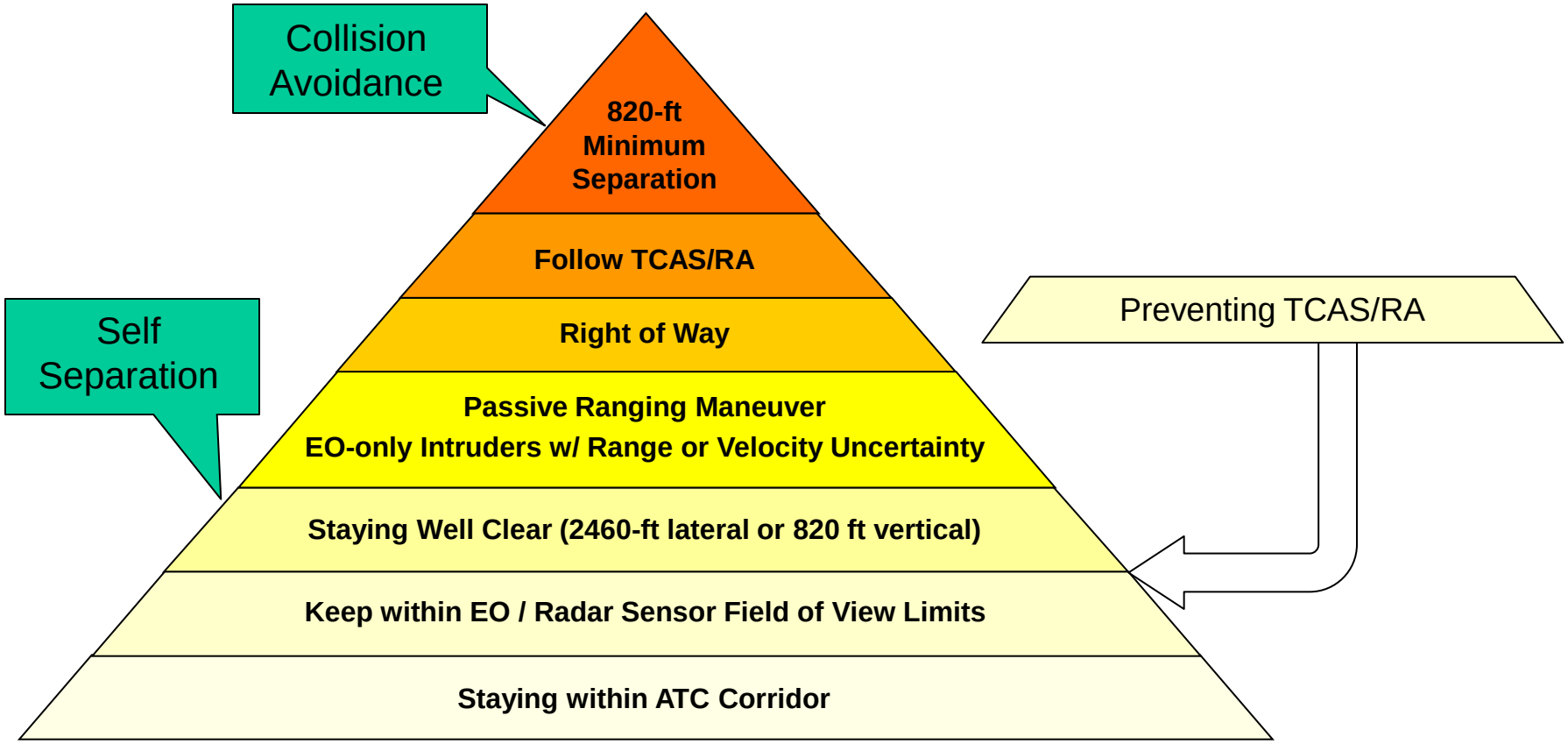
JOCA Constraint Hierarchy



- **Prioritized objectives (top being most important) that mimics human-like behaviors**
- **Specific well clear and ATC corridor parameters expected to be variables and provided externally**
- **Potential additional requirements (e.g., no-flight zone, weather avoidance, etc.)**

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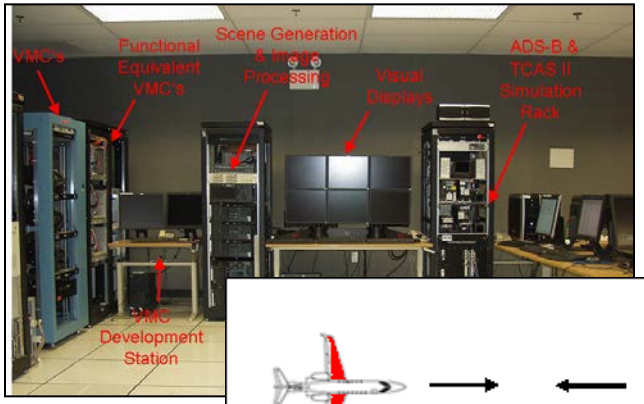
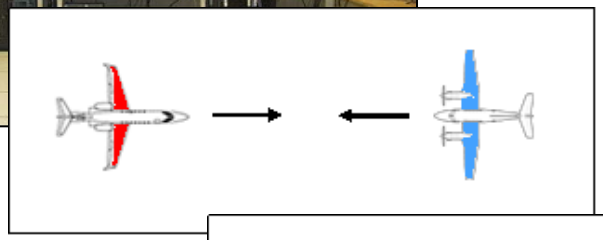
Maturing SAA in Steps



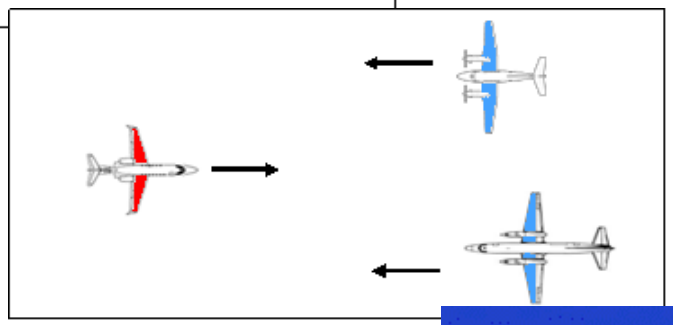
HWIL Integration Lab

- **TCAS + ADS-B + EO + Radar Simulators**
- **Real-time Closed-loop Simulation with up to 10 Intruder Aircraft**



SAA Flight Test (SAAFT)

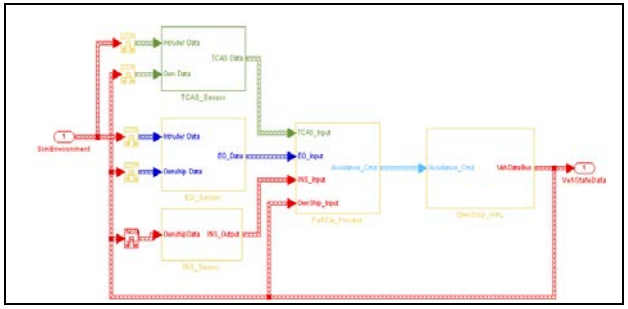
- **Surrogate Programmed to Fly Like Global Hawk**
- **Autonomous Avoidance with TCAS + EO**
- **3 Rounds of Flight Test from Oct 2006 to Jan 2007**



Multiple Intruder Autonomous Avoidance (MIAA)

- **Autonomous Avoidance with EO + Radar + TCAS + ADS-B**
- **2008 - 2012**

Computer M&S



Production Transition

- **GH**
- **BAMS**
- **Reaper**
- **Etc.**

SAA Demonstration Flights

Objective: Autonomous Detect/Mnvr with Radar, EO, TCAS, ADS-B

Oct 06, Dec 06, Niagara Falls IAP, NY (KIAG)
- Open- and closed-loop, coop and non-coop
- Cooperative: TCAS
- Non-cooperative: EO

Jan 07, KIAG
- Non/cooperative encounter: ADS-B
- Collect IR data
- Multiple intruders, open loop

Apr 08, KIAG
- Radar, EO sensor characterization flights

Nov 08, KIAG
- Open loop w/ Radar/EO/TCAS/ADS-B

Aug/Sep 09, KIAG
- Closed loop w/ Radar/EO/TCAS/ADS-B

Jan 11
- Miniaturized EO system on Army RQ-7

Aug/Sep 11, KIAG
- Closed loop w/ EO/TCAS/ADS-B
- Sensor cueing

Aug/Sep 12, KIAG
- Closed loop w/ Radar/EO/TCAS/ADS-B

TCAS II

ICX AI-130 Radar (surrogate)

Surrogate GH-Like UAV

Learjet

General Aviation

Beech King Air

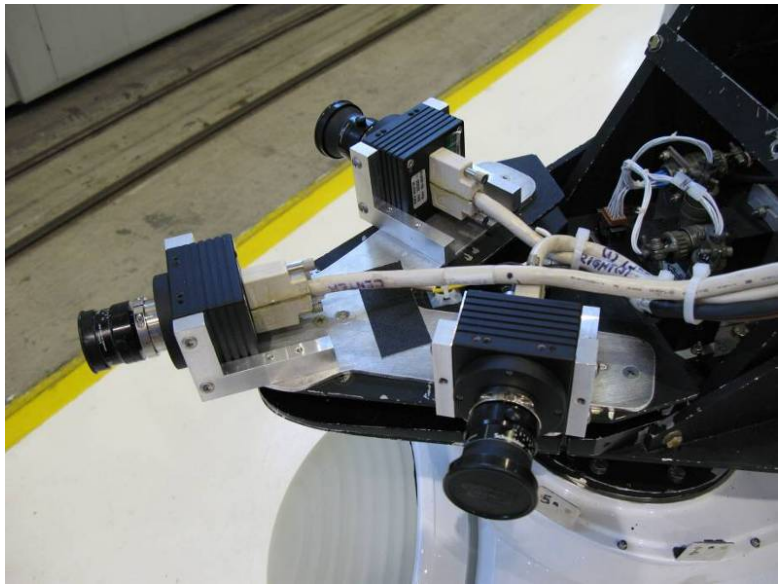
Transport Class

Convair 580

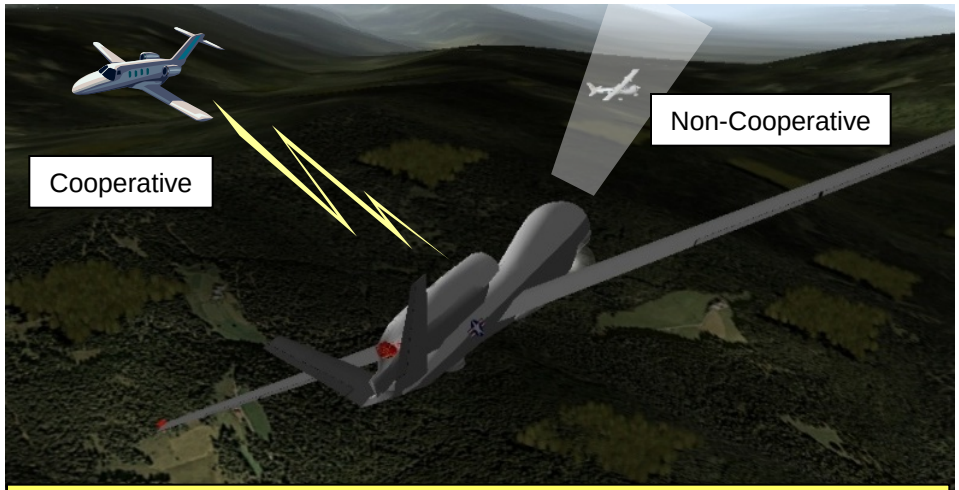
Biz Jet, fast/slow

Learjet

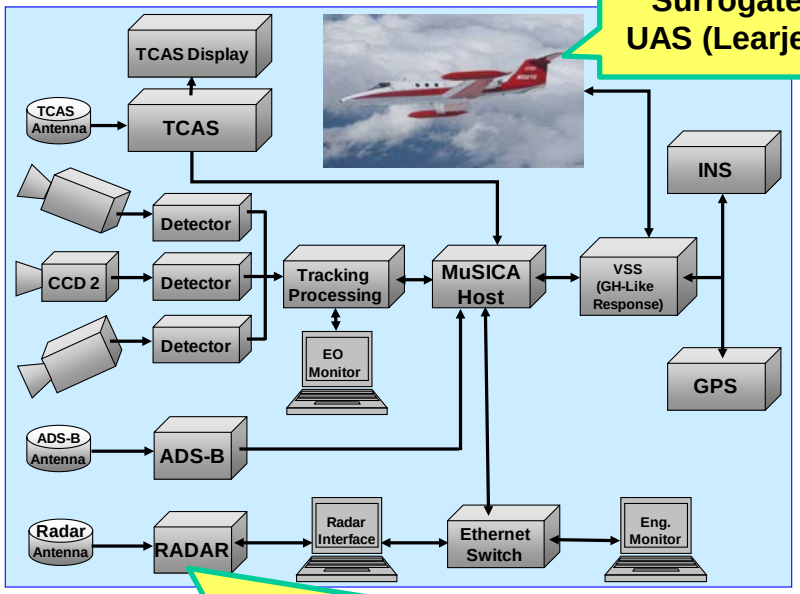
EO and Radar Installation



Round 4A Flight Test



Autonomous Detection and Avoidance of Cooperative and Non-cooperative intruder Aircraft



Surrogate UAS (Learjet)

SAA-specific radar will be included in next round of flight test 2012

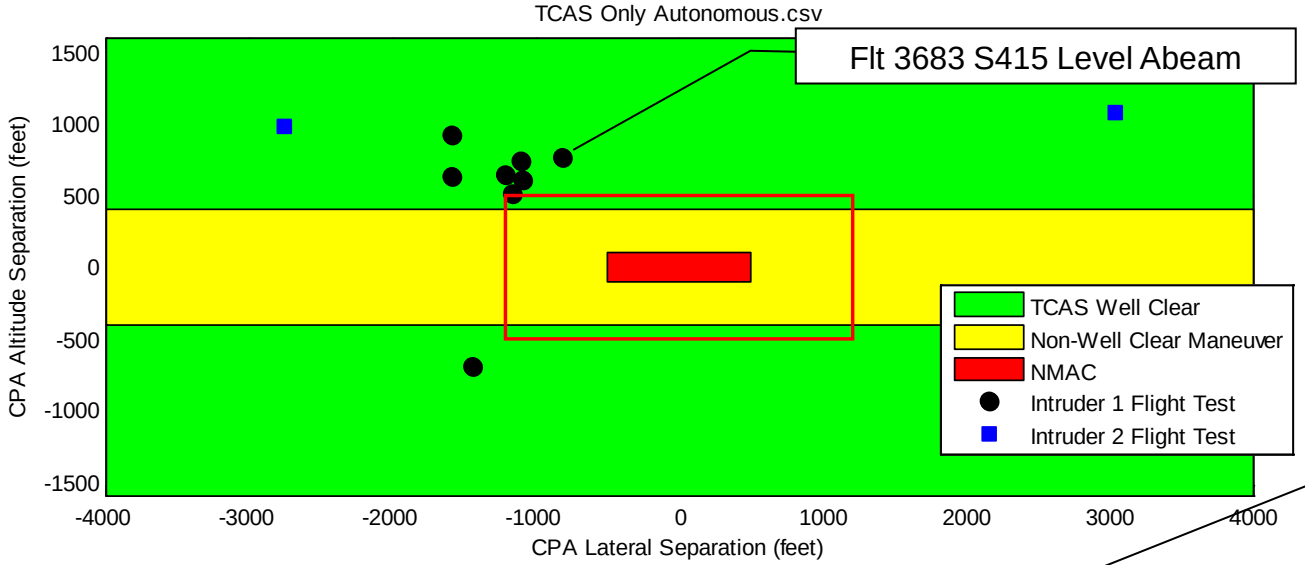
R4A conducted 8/29/11 – 9/2/11:

- 7 test flights
  - 5 single intruder flights
  - 2 multiple intruder flights (2 intruders)
- *4 types of intruder aircraft*
- 55 test scenarios executed
- **All autonomous tests (29 runs) achieved Well Clear!**

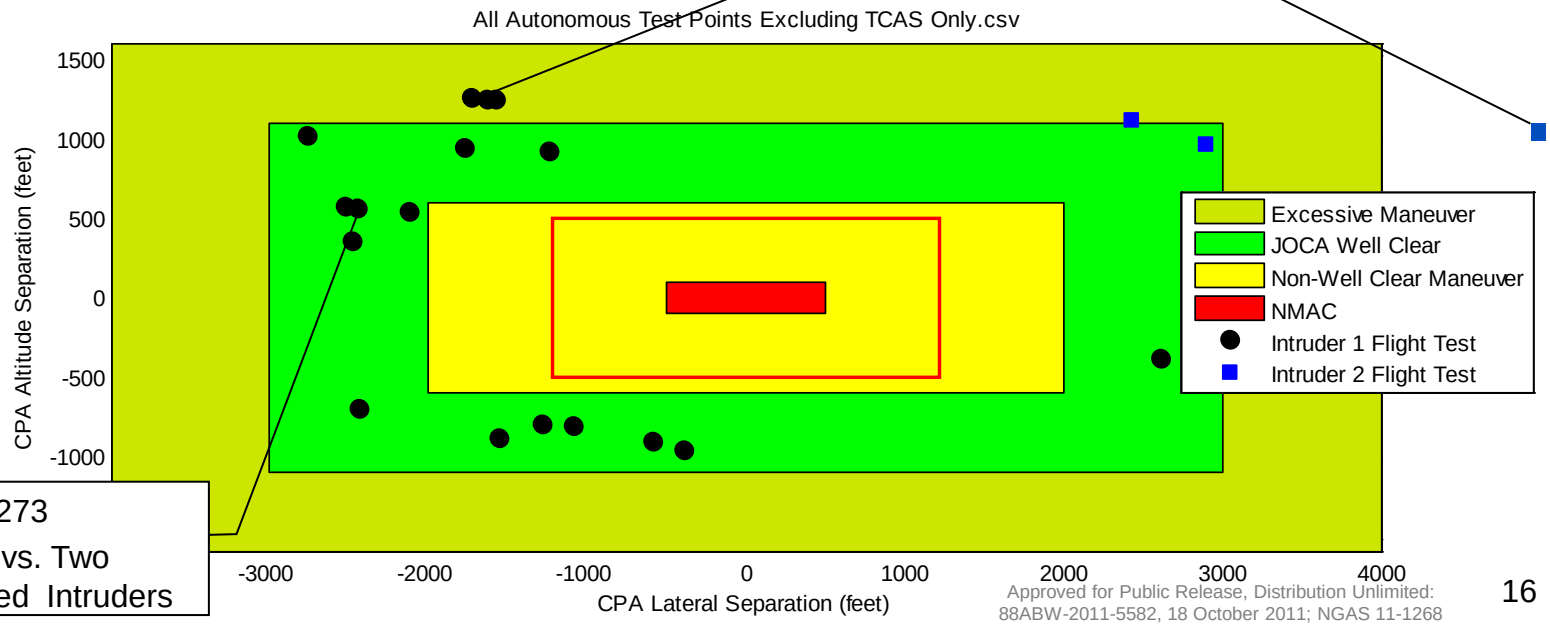
MuSICA Has Achieved TRL 6…

JOCA Performance Summary

MIAA R4A Flight Test Results



Flt 3684 S873
Level Head-On vs. Two
Horizontally Separated Intruders



Flt 3684 S1273
Level Head-On vs. Two
Horizontally Separated Intruders

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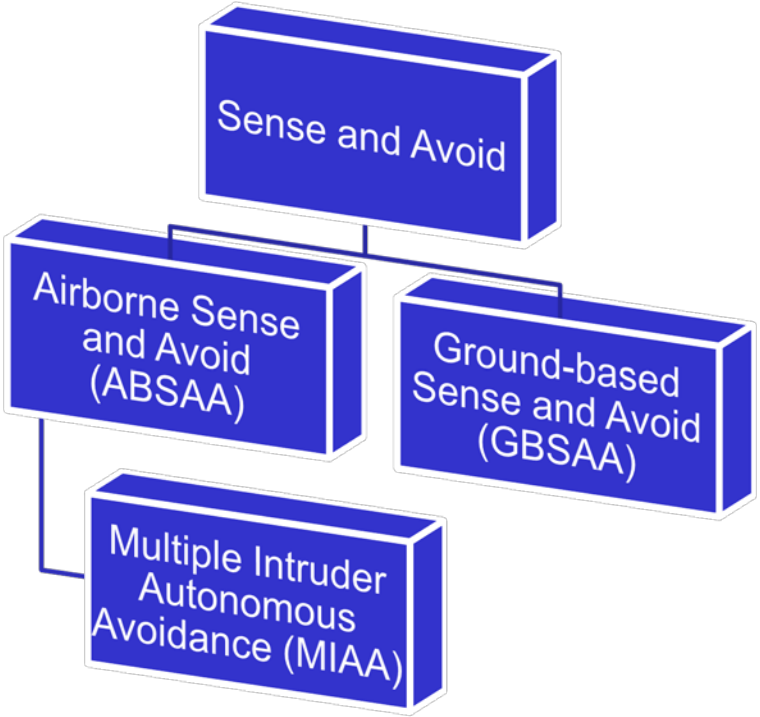
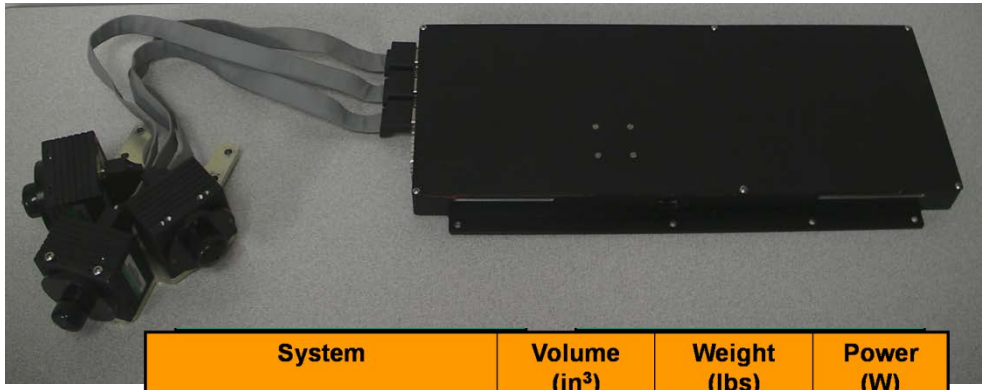
- Future Directions



Small Sense and Avoid System (SSAASy)



System	Volume (in^3)	Weight (lbs)	Power (W)
ATD System	3000	75	550
ATDSS III (Aerostar UAS)	800	24	286
SSAASy	106	7.5	76

RY POC: Dr John F. McCalmont, (937) 528-8805, John.McCalmont@wpafb.af.mil

Description

OSD Technology Transition Initiative to miniaturize Electro-Optical SAA hardware developed under SAA Phase I ATD and demonstrate capability on Group 3 RPA

Technology

- Global Hawk EO sensor system
- Auto-ACAS collision avoidance algorithms

Benefits to the User

- Global Hawk EO SAA hardware miniaturized for SWaP
- Provides EO “See and Avoid” capability for Group 3/4/5 RPAs
- Substantially Expanded Training in U.S. NAS
- Disaster Relief, Homeland Security

SSAASy flown on Army RQ-7B Shadow 21 Jan 2011

Human-Automation Interaction

Autonomous Sense and Avoid for UAVs

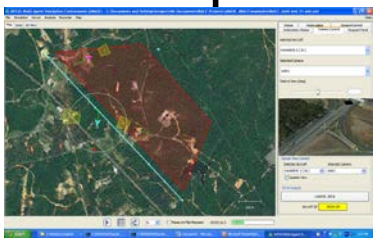
Hypothesis: Effective implementation of key "support functions" (observability, directability, shifting perspective directing attention) can improve human-automation interaction

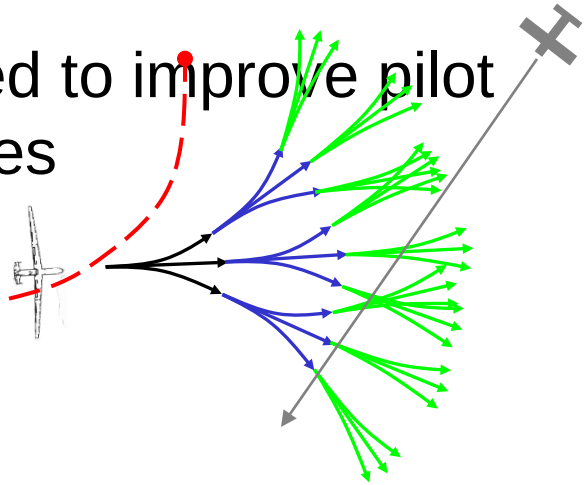
Test Case: Jointly Optimal Conflict Avoidance (JOCA)

- Developed under Sense and Avoid programs since late 2005
- Designed to provide conflict avoidance steering
- Extensively tested in simulation and flight test

Approach: Design / test concepts intended to improve pilot understanding & control of JOCA processes

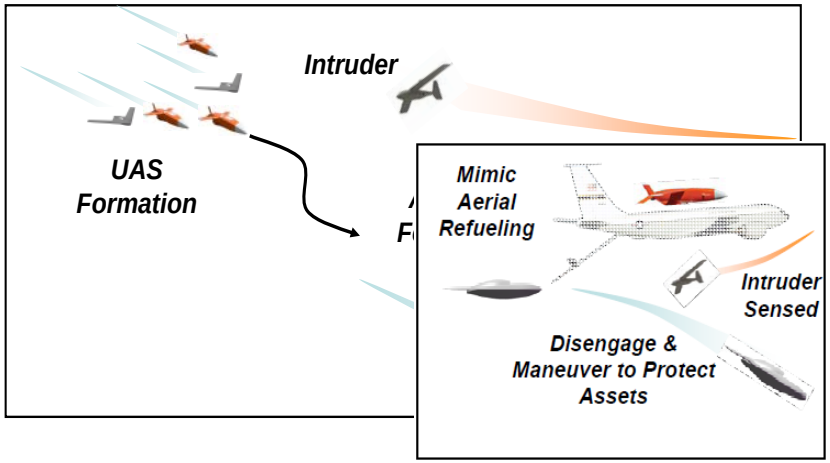
- Quick-look assessment
- Usability assessment
- Controlled experimentation



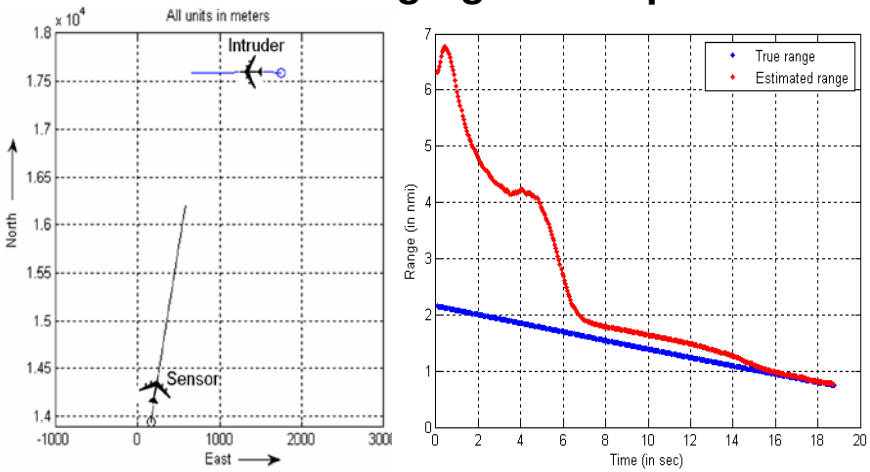


Other Research

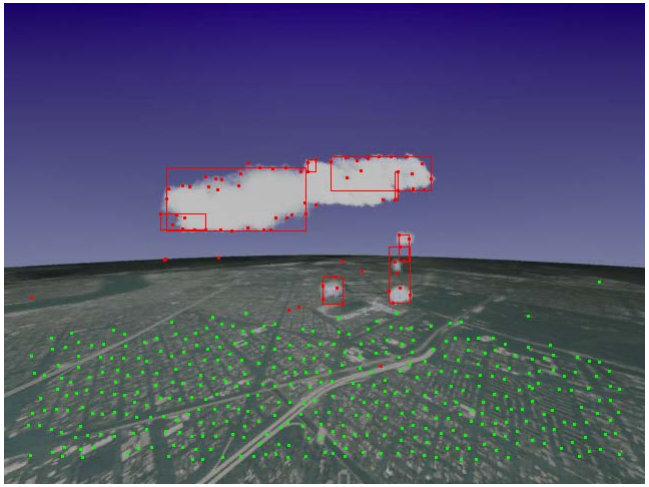
Multi-UAS Sense and Avoid



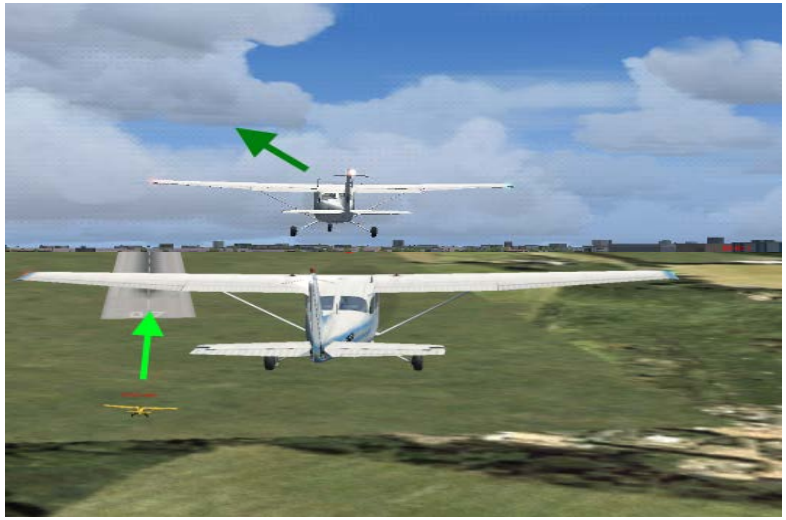
Passive Ranging Techniques



Cloud Detection and Avoidance



Postern Sense and Avoid

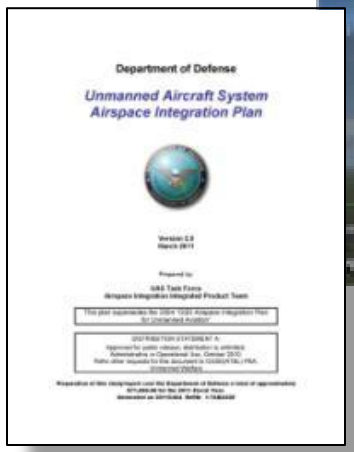


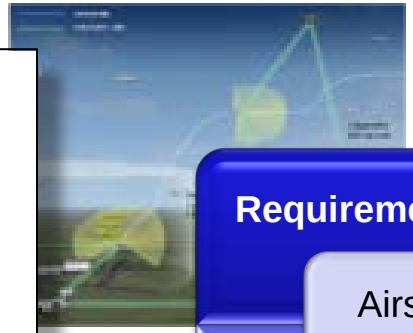
More Than Just The Technology Leaders

RTCA Special Committee 203

- Civil requirements for UAS airspace integration
- International interactions

OSD Airspace Integration Plan





OSD Research & Engineering IPT

- R&E support to UAS Task Force

ASD(R&E) Air Platforms Community

- National Aeronautics R&D Plan

Joint Product Development Office (JPDO)

- R&D plan for UAS in NextGen

FAA-led Sense and Avoid Workshops

- Established foundational definitions and functions of a Sense and Avoid System
- Currently defining safety & certification requirements

OSD Airspace Integration IPT

- Airborne Sense and Avoid (USAF/Navy)

Army UAS Program Office

- Transition to RQ-7 Shadow

Aeronautical System Center

- Transition to RQ-4, MQ-9

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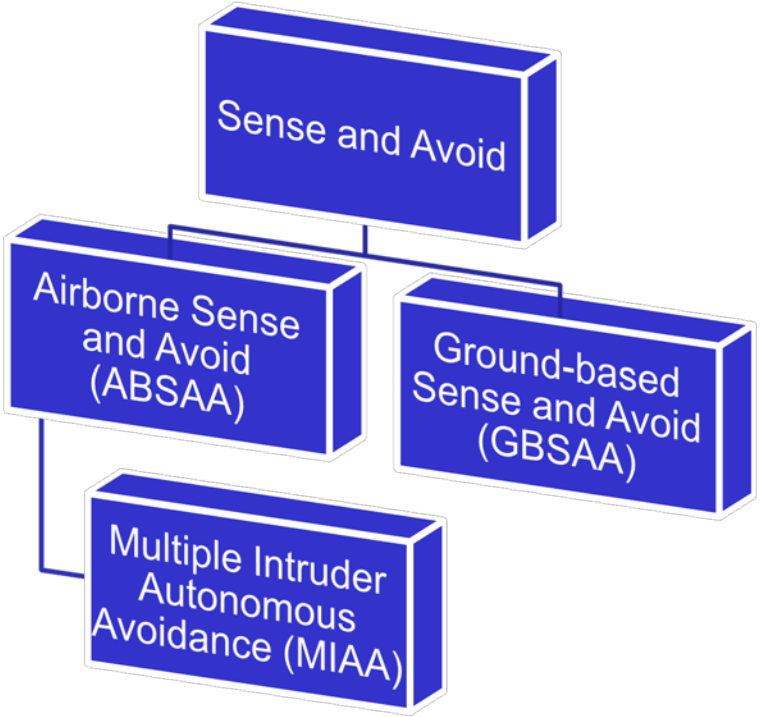
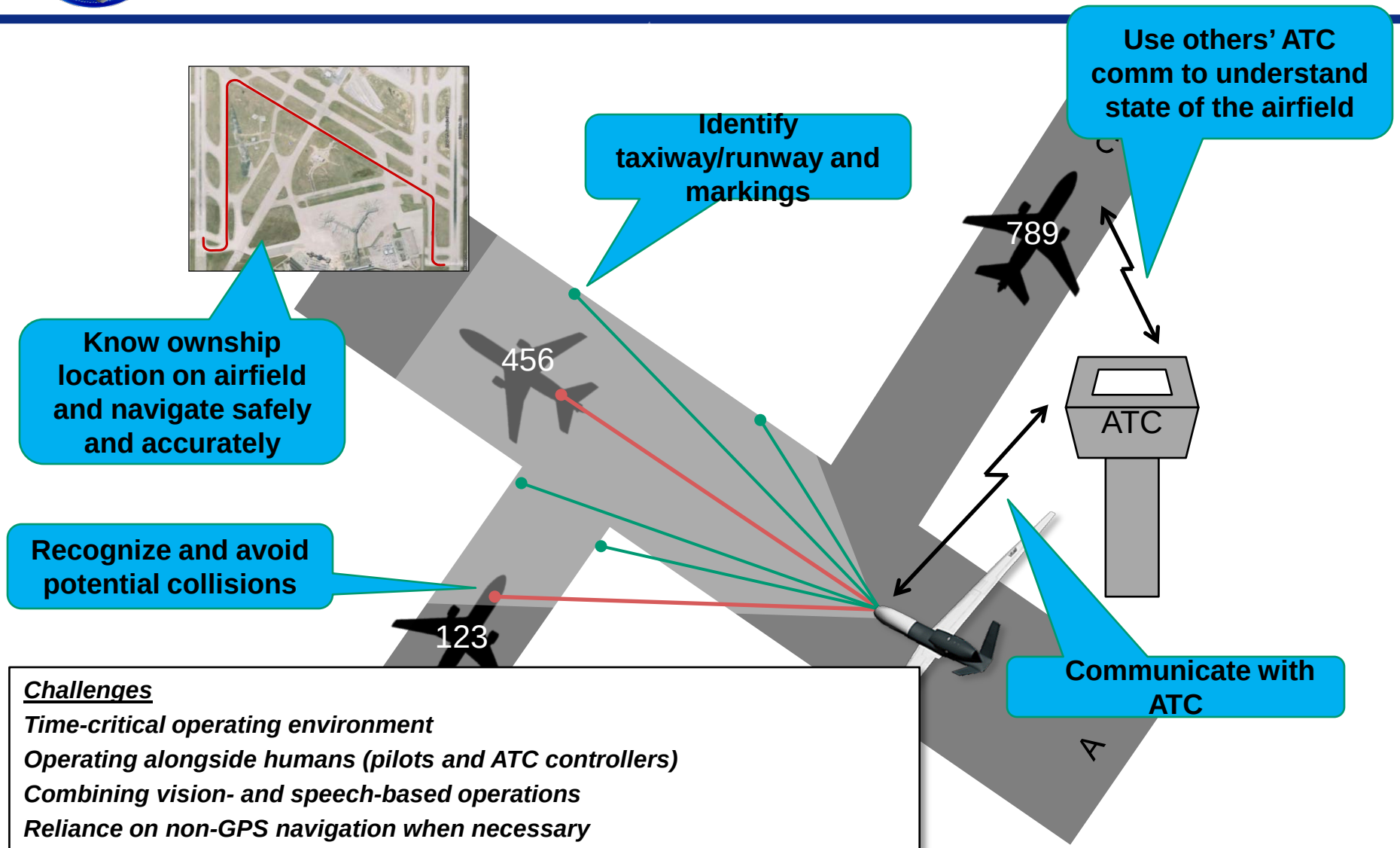


Terminal Area Operations (TAO)



Challenges

Time-critical operating environment

Operating alongside humans (pilots and ATC controllers)

Combining vision- and speech-based operations

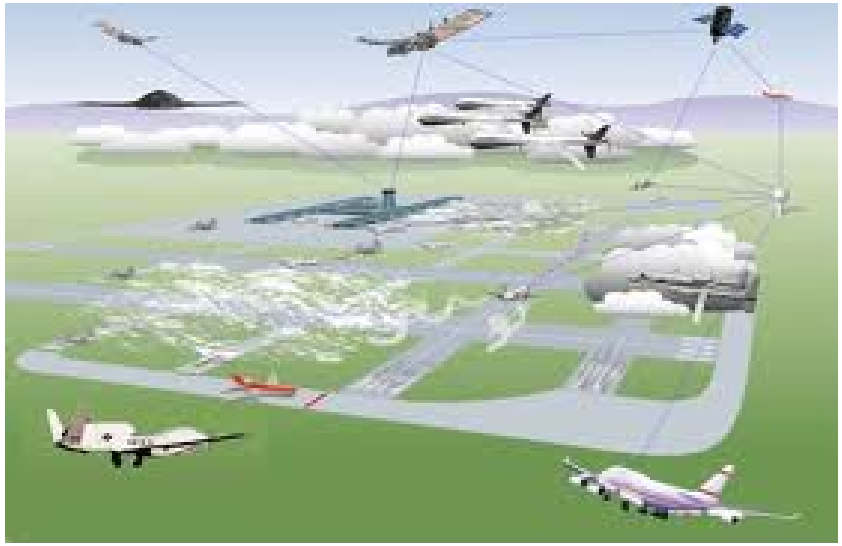
Reliance on non-GPS navigation when necessary

Trust in autonomy

Terminal Area Operations Demo

- **Progression of tests/demos**
  - Simulation
  - Hardware-in-the-Loop
  - Vehicle-based
- **Addressing Tech Challenges**
  - Interactions between UAS and ATC
  - Airfield navigation and conflict avoidance
  - Optimum combination of sensors/algorithms
  - Situational awareness/ intent analysis
  - Integrity management
- **6.2 to 6.3 Decision Point in late FY13/early FY14**

SAA Research Summary

Key element for routine access to airspace

- **Developing and testing key technologies**
  - Architecture
  - Sensors
  - Algorithms
- **Extensive Collaboration**
  - Technology
  - Requirements
  - Acquisition
  - Policy
- **Creating the Future**
  - Terminal Area Operations
  - NextGen