UAS Integration in the NAS: Airspace Concept Evaluation System (ACES) Simulation Studies

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Outline

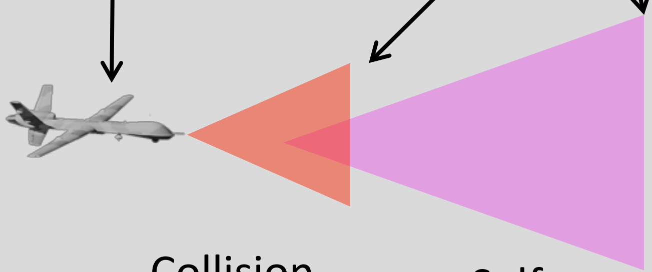
- Introduction
- Research Capabilities
- Research Overview
- Fast-Time Simulation Studies
  - Unmitigated Encounter Rate Evaluation
  - Mitigated Encounter Rate Evaluation
  - Surveillance Evaluation
- Expected Reporting and Timeline

DAA Sense and Avoid Requirements

How do the surveillance limits depend on UAS performance?

What are the surveillance requirements for these functions?

How do the surveillance limits depend on (expected) intruder performance?



Collision Avoidance

Self Separation

What is the appropriate interaction between CA and SS

Sense and Avoid

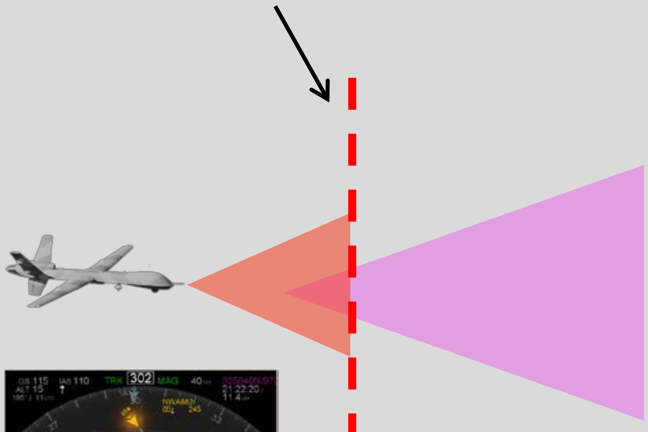
DAA Performance Requirements

- Research questions addressed
  - Airborne surveillance system requirements (range, field of regard, accuracy)
  - Evaluations of specific self-separation (SS) and collision avoidance (CA) algorithms and tradeoffs with UAS performance
  - Interoperability of SS and CA functions, including human role

- Expected outcomes
  - Contributions to development of DAA Minimum Operational Performance Standards (MOPS) (FY15)
    - Required UAS performance to equip with DAA systems
    - Required DAA performance as a function of UAS characteristics and expected intruder performance
  - Recommendations for improvements to specific algorithms (FY14 – 16)
  - BADA UAS performance models (FY13)

Interoperability of DAA Systems

What is the appropriate definition of well clear, what does it depend on?

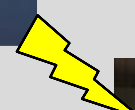


Integration of DAA concepts with traffic displays

Maintenance of an overall level of safety in the airspace

Avoidance of TCAS RAs and TAs, or the DAA equivalent

Avoidance of undue concern by pilots of proximate aircraft



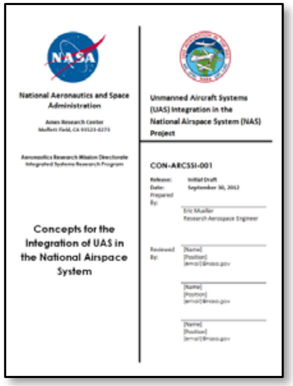
Avoidance of traffic alerts by ATC

DAA Interoperability Requirements

- Research questions addressed
  - What is "well clear" and how should pilots and controllers interact to stay well clear?
  - How can DAA algorithms be made compatible with TCAS?
  - How can DAA algorithms be made compatible with pilot and controller expectations?
  - What are the interoperability requirements between different DAA algorithms?
  - What is the effect on the NAS of a UAS equipped with an DAA system meeting the above requirements?

- Expected outcomes
  - Principles for integration of DAA concepts and traffic displays (FY14)
  - Recommendations for establishing a "well clear" definition (FY14)
  - Algorithm requirements that improve TCAS, pilot, controller interoperability (FY16)
  - UAS-NAS integration concepts informed by analysis and simulation (FY16)
  - Quantified impacts of UAS operations on the NAS for a range of integration concepts (FY16)

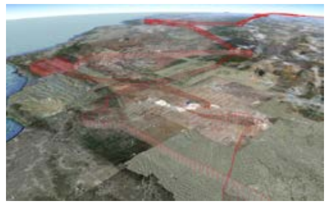
Research Capabilities



UAS-NAS integration concepts

New UAS-related modeling and simulation capabilities

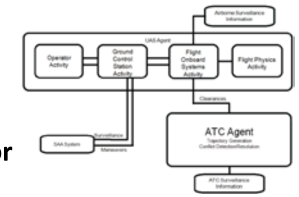
19 UAS mission profiles



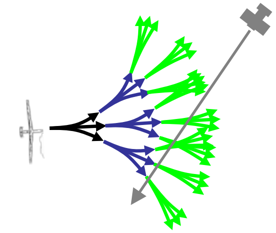
17 UAS types

DAA sensor models

UAS models, comm. link models

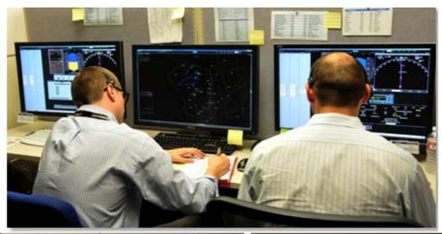


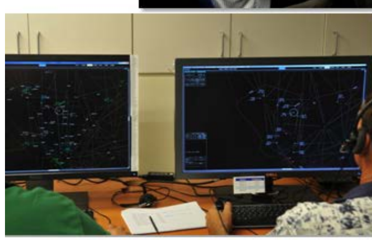
DAA algorithms



Human-in-the-Loop and Flight Test Evaluation

Pseudo-pilot stations





Air Traffic Control Stations

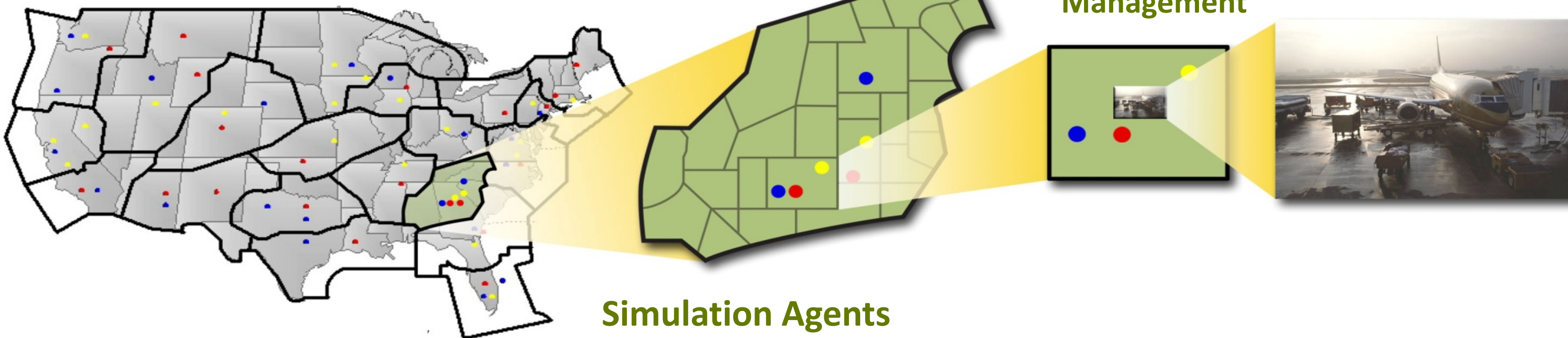
Vigilant Spirit Control Station

Traffic displays, DAA algorithms, ATC, Ground Control Station

NAS-wide Simulation

ACES: Flight plan and NAS-agent modeling system

Modeling and Simulation: ACES



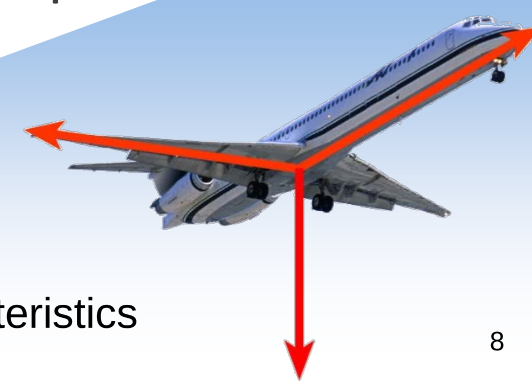
NAS-wide Simulation

- Gate-to-gate simulation of ATM operations
- Full flight schedule with flight plans
- Sector and center models with some airspace procedures

Simulation Agents

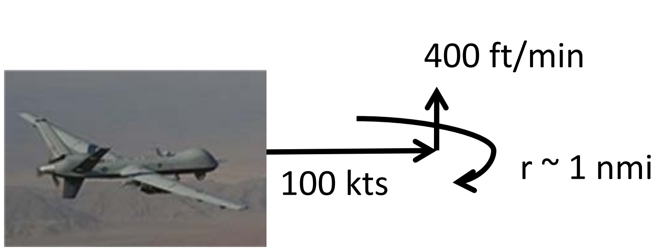
- Air traffic controller decision making
- Traffic flow management models
- Individual aircraft characteristics
- IFR Flight Tracks from ASDI data
- VFR Flight Tracks from 84th Squadron RADES data

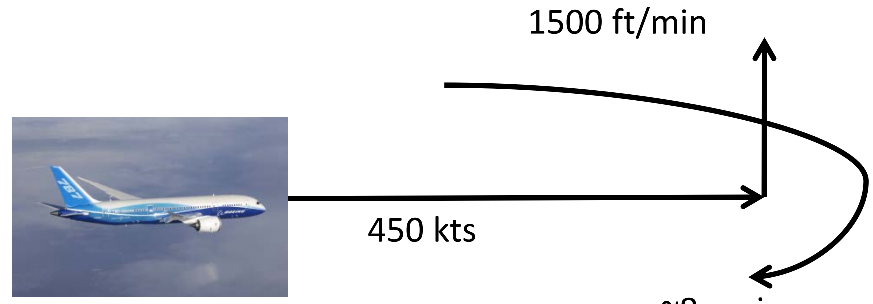
4-DOF Trajectory Model
  Aerodynamic models of aircraft
  Models replicate pilot behavior
  User-definable uncertainty characteristics



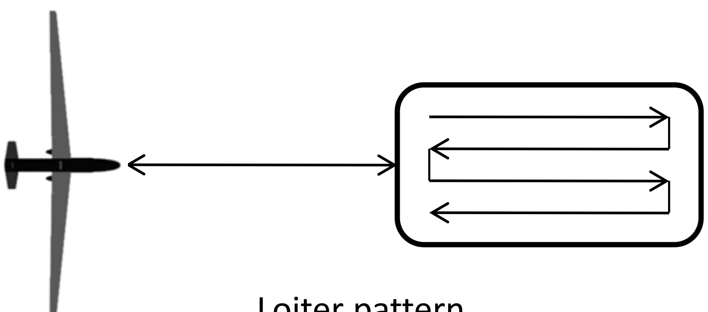
UAS Mission and Performance

- Aircraft performance
  - Climb and descent rates, cruise speeds, turn rates atypical





- Missions
  - Loitering creates different per-aircraft impact on airspace
  - Different mission objectives than "getting to point B"

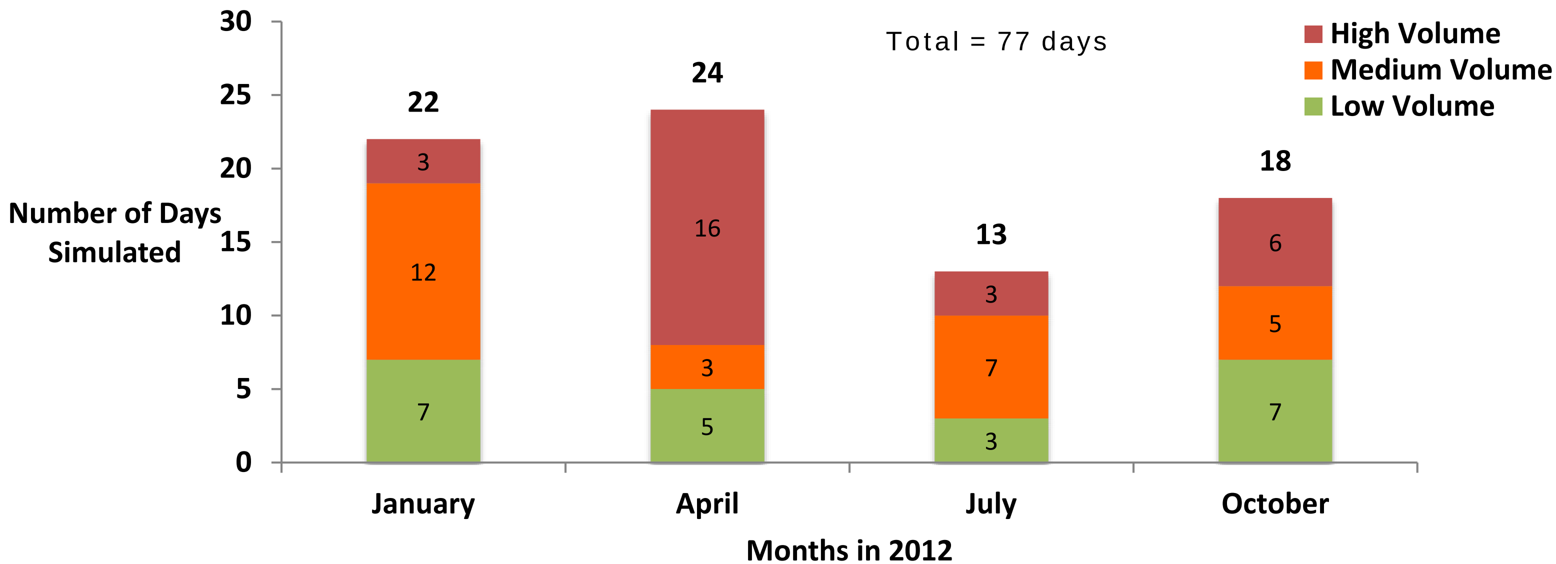


Loiter pattern

Point-to-point

Background Manned Traffic

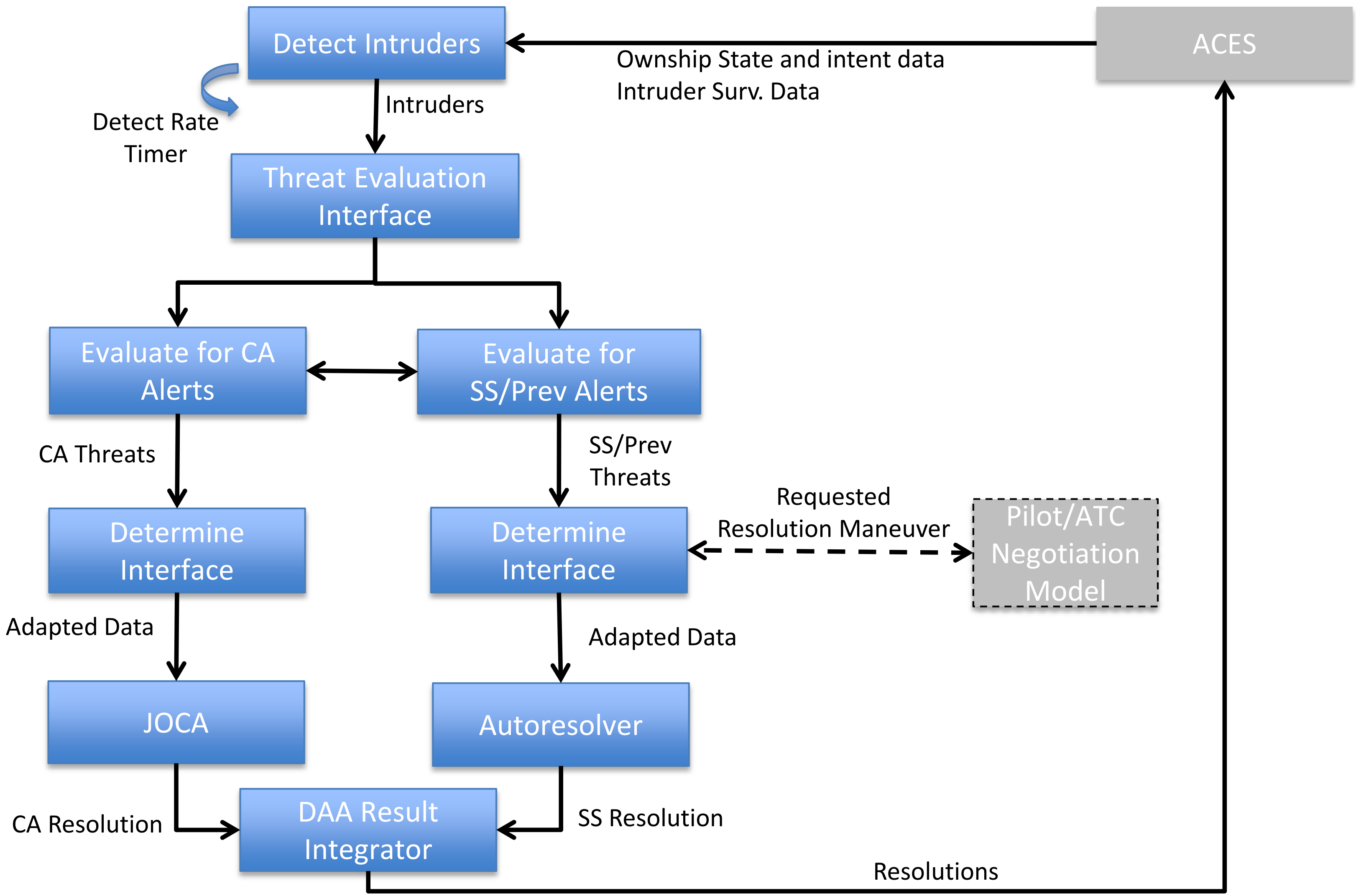
- All manned traffic fly under instrument flight rules (IFR) or visual flight rules (VFR)
- IFR Flight plans generated from Aircraft Situation Display to Industry (ASDI) data
- VFR Flight trajectories generated from 84th Squadron RADES data
  - Cooperative Traffic (FY14) & Non-cooperative Traffic (FY14-Honeywell)
- Each simulation run is a single day in the NAS (24 hours starting at 0 UTC)
- The simulation runs were chosen across 4 seasons in 2012 on days with minimal weather impacts and low/medium/high traffic volumes



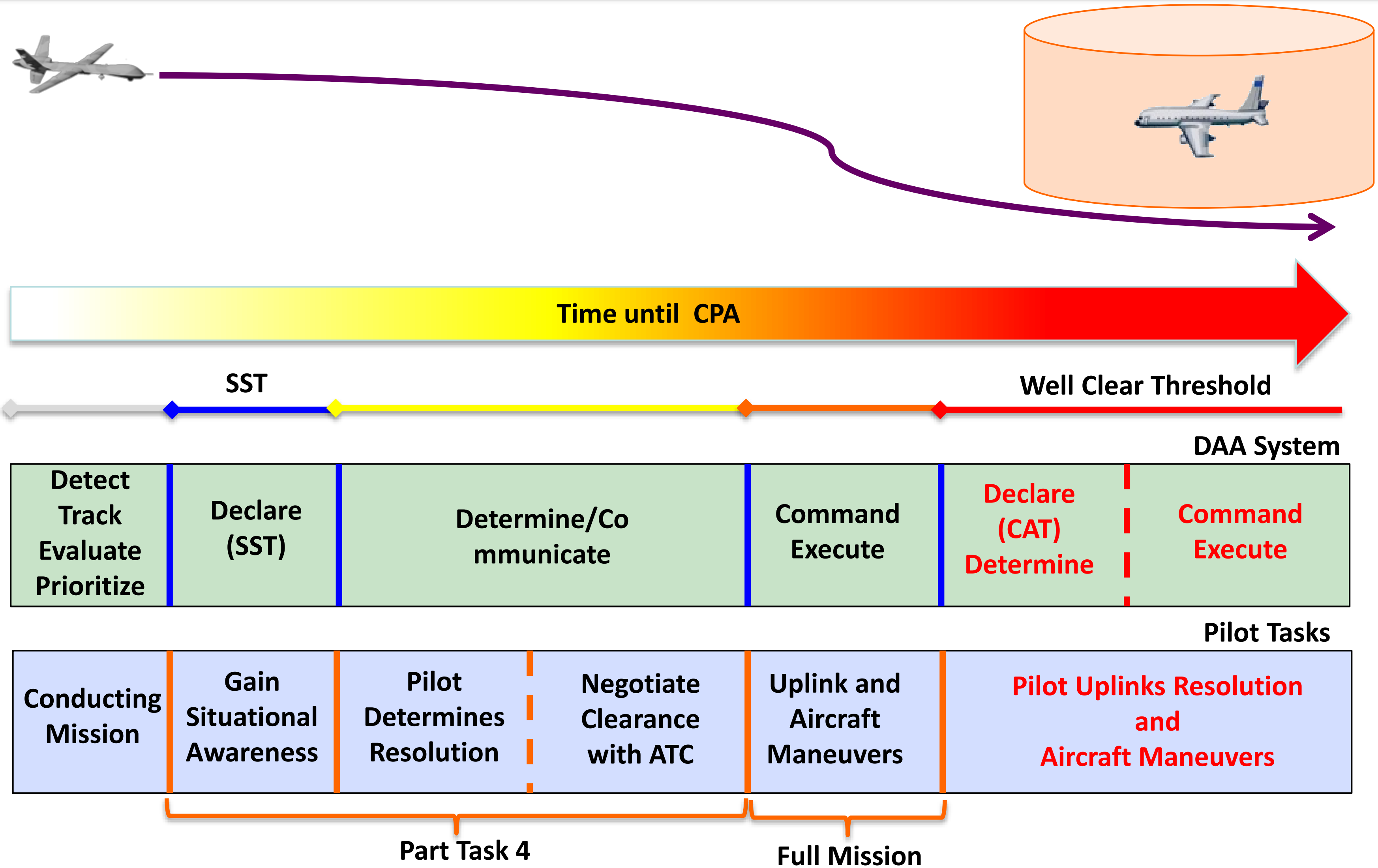
UAS Missions

- Atmospheric Sampling
  - Global Hawk (RQ4-A) [2350 flights]
- Border Patrol
  - Global Hawk (RQ4-A) [665 flights]
- Cargo Transport
  - UAS Cessna 208 [1320 flights]
- Strategic Wildfire Monitoring
  - Predator B (MQ-9) [325 flights]
- Air Quality Monitoring
  - Shadow-B (RQ7B) [1050 flights]
- On-Demand Air Taxi
  - Cessna Mustang (C510) [2560 flights]
  - Cirrus (SR22T) [10500 flights]
- Flood Mapping
- Traffic Monitoring (Metro Areas)
- Current-Day Missions

DAA Architecture



DAA Timeline Integration



SS Algorithm (AutoResolver)

- Autoresolver was designed as a strategic separation assurance algorithm that addresses four air traffic control problems in an integrated fashion:
  - Separation conflicts (typically 5 nmi and 1,000 feet)
  - Convective weather avoidance
  - Arrival sequencing
  - Altitude and route out-of-conformance

- Autoresolver has been tested in NAS-wide fast-time simulations using the Airspace Concept Evaluation System (ACES) and in human-in-the-loop simulation's using Multiple Aircraft Control System (MACS) and Center-TRACON Automation System (CTAS).

- HITLs involved Autoresolver as a Decision Support Tool for radar-side air traffic controller

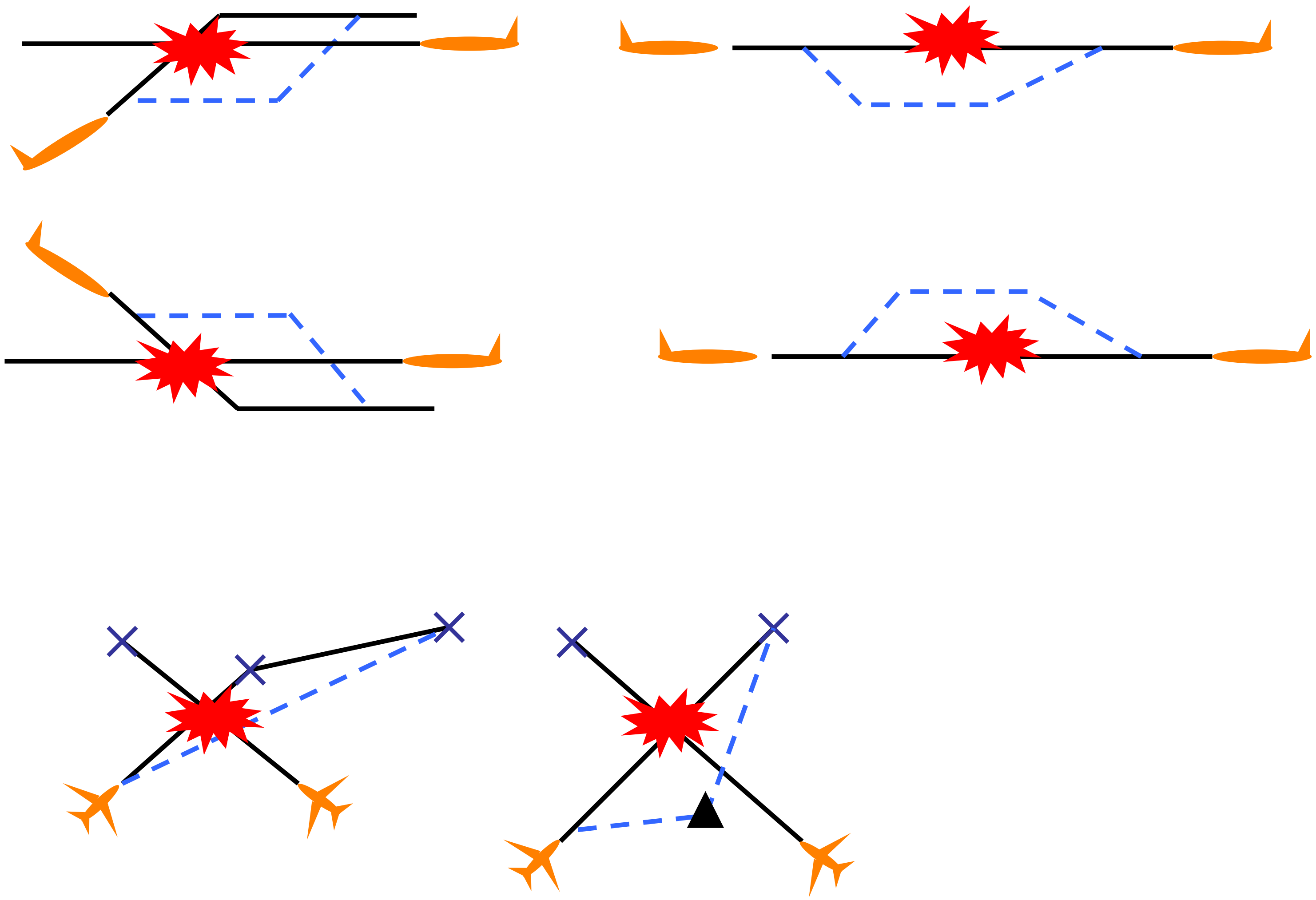
SS Algorithm (AutoResolver)

- Autoresolver has been integrated to use trajectory prediction and threat evaluation logic that meet the requirements for DAA; which are much different when compared to Autoresolver's history in the ATC realm, e.g.:
  - Smaller look-ahead-times
  - Lack of intent from intruder aircraft
  - Smaller spatial separation standards
  - Closest point of approach centric
  - Faster update rates
  - Pilot in the loop

SS Algorithm (AutoResolver)

Altitude

Horizontal

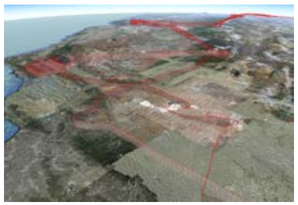


* Autoresolver supports other maneuvers such as speed and combinations, but these are disabled for DAA.

Research Overview

New UAS-related modeling and simulation capabilities

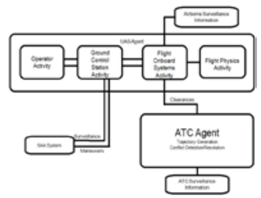
UAS mission profiles



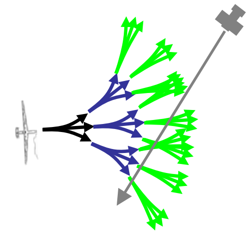
UAS types

DAA sensor models

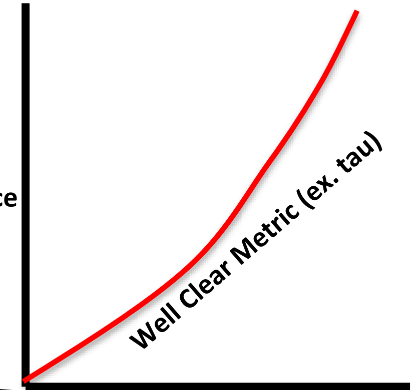
UAS models, comm. link models



DAA algorithms



Rate of Occurrence

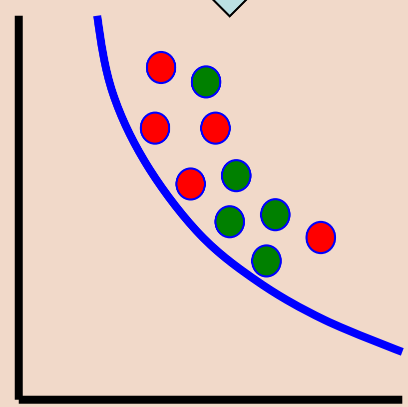


Dependent Variable (ex. FOR, Well Clear Threshold)

Pilot/ATC Procedures
Latencies
Environmental Uncertainties

NAS-wide Simulation

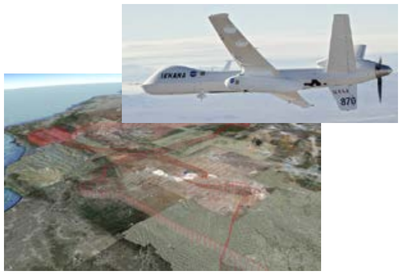
ACES: Flight plan and NAS-agent modeling system



Risk Ratio

Unmitigated Encounter Rate Evaluation

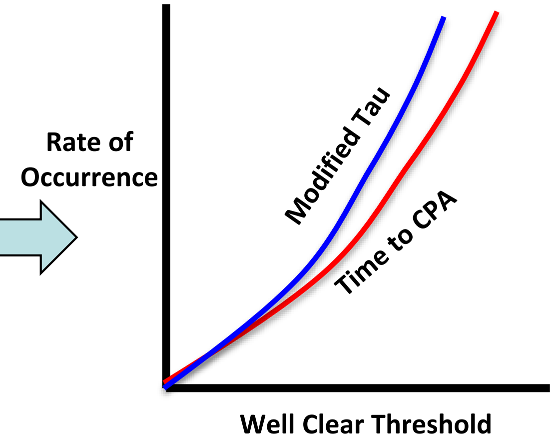
UAS Models



UAS Mission Profiles

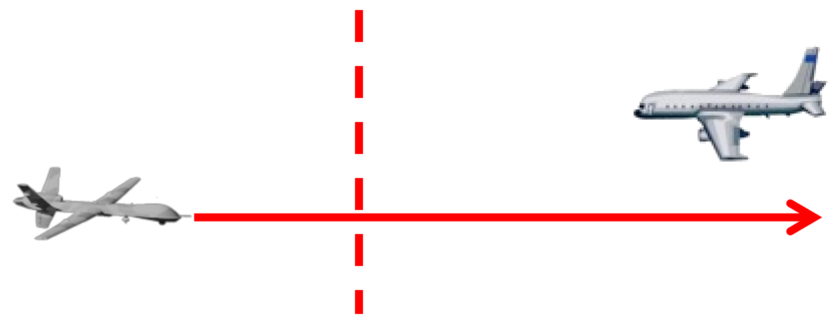
NAS-wide Simulation

ACES: Flight plan and NAS-agent modeling system



Study 1: (FY14)
- UAS Missions & Models
- Cooperative VFR Traffic

Study 2: ((FY14)
- UAS Missions & Models
- Cooperative and Non-cooperative VFR Traffic



Well Clear Threshold

Unmitigated Encounter Rate Evaluation

- Evaluating the effect of well-clear metric definitions on the rate of well-clear violations (WCV)
  - Modified Tau with Horizontal Miss Distance Filter
  - Time to CPA
  - Distance-based criteria
- Evaluating rate well clear violations with respect to different types of UAS missions
- Characterize encounters from mission-based profiles
  - Conflict Distributions by:
    - Altitude
    - Encounter Geometry
    - Closure Rates
    - CPA
    - Geographic Location
    - Etc.

Experiment Matrix

- Simulation Configurations:
  - 9 Different Missions:
    - Different UAS performance
    - Different flight profiles
    - Different cruise altitudes
  - Total of 77 possible days to simulate manned (IFR and VFR) with UAS
    - Days with minimal delay
    - Varying volume of traffic (high,medium,low)
    - Days are spread over 4 seasons in 2012
  - Total number of simulated days depends on run-time
    - Min. Goal: 1 day for high/low traffic volumes from 1 seasons per mission
    - Min. Goal: Total would be 18 ACES runs
- Outputs (for each configuration):
  - Encounter characteristic statistics
  - Unmitigated encounter rates for each of the "well clear" metrics

Unmitigated Encounter Rate Evaluation

Study 1: (FY14)

- UAS Missions & Models
- Cooperative VFR Traffic

Study 2: (FY14)

- UAS Missions & Models
- Cooperative and Non-cooperative VFR Traffic

RTCA SC-228 DAA: Safety Subgroup

- Encounter Rates and Distributions based on UAS Mission and VFR Traffic

RTCA SC-228 DAA: Requirements

- Use cases based on encounters with high frequency

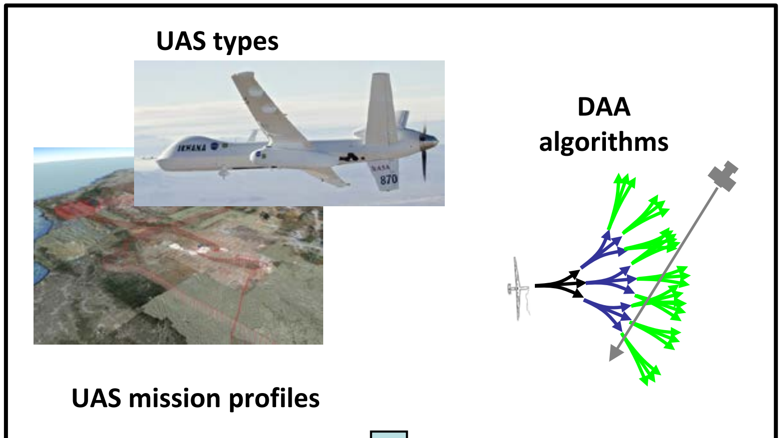
SARP Well Clear Studies

- Comparison of Well Clear Definitions with different mission profiles

NASA Fast-time Studies:

- Supports Target Level of Safety study to calculate risk ratios

Mitigated Encounter Rate Evaluation



Study 1: (FY14)
- UAS Missions
- Cooperative VFR Traffic

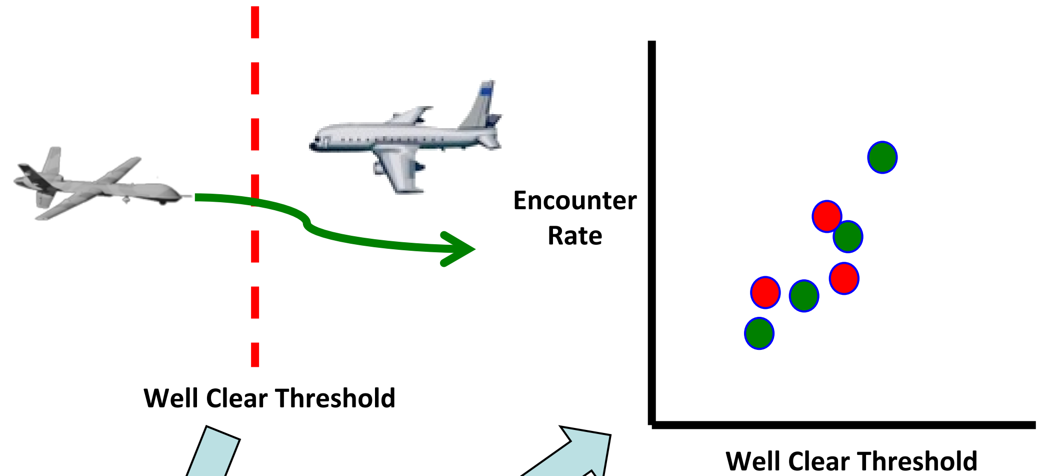
Study 2: (FY14)
- UAS Missions & Models
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models

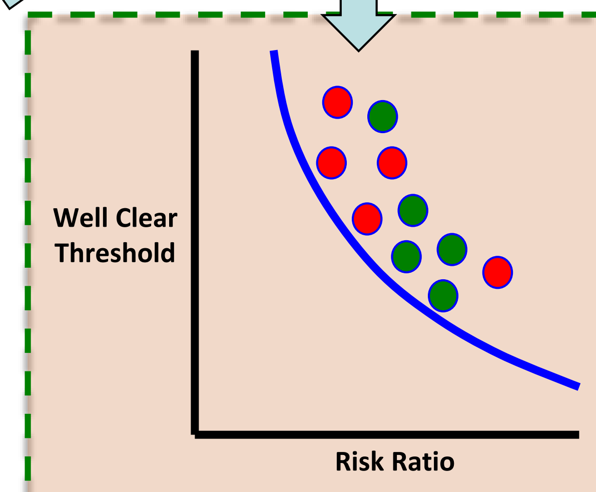
Study 3: (FY15)
- UAS Missions & Models
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models
- Environmental Uncertainties
- Latencies
- ATC/Pilot Procedures

Study 4: (FY16)
- Comprehensive Safety sim. For final MOPS

NAS-wide Simulation

ACES: Flight plan and NAS-agent modeling system





Mitigated Encounter Rate Evaluation

- Objectives:
  - Demonstrate the ability to evaluate a proposed Self Separation algorithm (AutoResolver) in a NAS-wide (ACES) simulation.
  - Demonstrate that one or more Well Clear Definitions is able to achieve sufficient TLS with an example Self Separation system with reasonable vehicle performance and sensor requirements (e.g. does not require excessive surveillance range).
  - According to same factors as Well Clear Definition studies, identify and characterize encounters of greatest TLS/RR impact: compare those to the 'stress cases' used by the SARP and SC228.

Experiment Matrix

- Simulation Configurations:
  - Self-Separation Algorithm
    - Configured algorithm parameters: Look ahead time, well clear definition, etc.
    - UAS DAA maneuvering against VFR traffic
  - 9 Different Missions:
    - Different UAS performance
    - Different flight profiles
    - Different cruise altitudes
  - Same simulated days as the unmitigated
    - Days with minimal delay
    - Varying volume of traffic (high,medium,low)
    - Days are spread over 4 seasons in 2012
- Outputs (for each configuration):
  - Encounter characteristic statistics
  - Mitigated encounter rates based on a definition of "well clear"

Mitigated Encounter Rate Evaluation

Study 1: (FY14)
- UAS Missions
- Cooperative VFR Traffic

Study 2: (FY14)
- UAS Missions & Models
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models

Study 3: (FY15)
- UAS Missions & Models
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models
- Environmental Uncertainties
- Latencies
- ATC/Pilot Procedures

Study 4: (FY16)
- Comprehensive Safety sim. For final MOPS

NASA HILT Studies
- Studies will support Pilot Alerting times and DAA display work

SARP Well Clear Studies
- Calculation of Risk Ratios based on a given well clear definition
- Well Clear Violation encounter rates given a SS mitigation

RTCA SC-228 DAA: Safety
- Encounter Rates and Risk Ratios based on UAS Mission and VFR Traffic

RTCA SC-228 DAA: Requirements
- Inform DAA functional requirements (Evaluate, Declare, Determine, Etc.)

RTCA SC-228 DAA: Timeline
- Evaluate the impact of DAA timeline on well clear violations
- Evaluate the DAA timeline impact on algorithm measures of performance

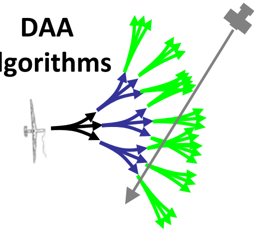
RTCA SC-228 DAA: V&V
- Simulated Operational Environmental Testing

Surveillance Evaluation

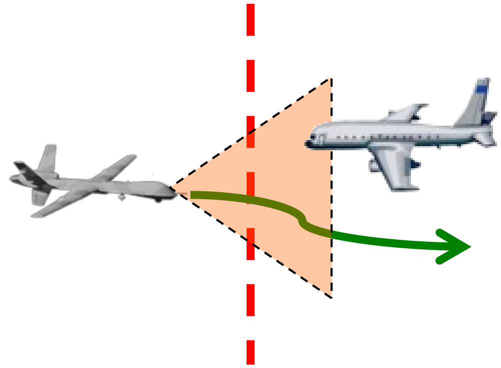
UAS types

UAS mission profiles

DAA algorithms

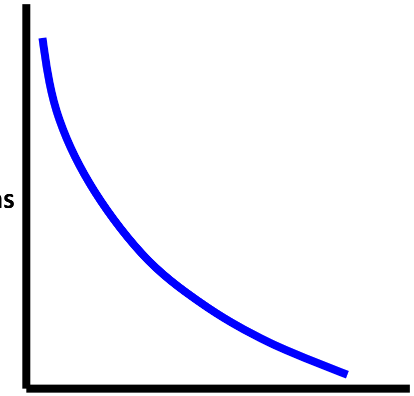


DAA sensor models



Well Clear Threshold

Missed Detections



Field of Regard

Study 1: (FY14)
- Range/FOR Effects on SS Alerting Metrics (Unmitigated)
- Cooperative VFR Traffic

Study 2: (FY14)
- Range/FOR Effects on SS Algorithm Metrics (Mitigated)
- Cooperative/Non-cooperative VFR Traffic

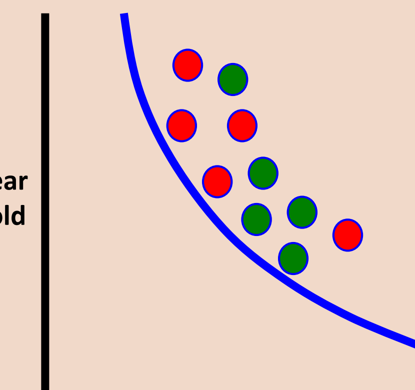
Study 3: (FY15)
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models
- ATC/Pilot Procedures

Study 4: (FY16)
- UAS Performance trade-offs with DAA sub-functions

NAS-wide Simulation

ACES: Flight plan and NAS-agent modeling system

Well Clear Threshold



Risk Ratio

Surveillance Evaluation

- Experiment Objective:
  - Investigation on the performance of intruder detection using algorithm measures of effectiveness
  - Investigate the effect of range and field of regard (FOR) on the well-clear violation rate

- Measures of Effectiveness
  - Well Clear Violation Encounter Rate
  - Risk Ratio
  - Missed Detection Rate
  - Late Alert Rate
  - False Alert Rate

Surveillance Evaluation

- Simulation Configurations:
  - 9 Different Missions:
    - Different UAS performance
    - Different flight profiles
    - Different cruise altitudes
  - Same simulated days as the unmitigated
    - Days with minimal delay
    - Varying volume of traffic (high,medium,low)
    - Days are spread over 4 seasons in 2012
- Independent Variables:
  - Spherical pyramid
    - Range and Field of regard
- Outputs:
  - Encounter characteristic statistics
  - Unmitigated encounter rates for each of the "well clear" metrics
  - Rate of missed and late detections and false alerts

Surveillance Requirements Evaluation

Study 1: (FY14)
- Range/FOR Effects on SS Algorithm Metrics (Unmitigated)
- Cooperative VFR Traffic

Study 2: (FY14)
- Range/FOR Effects on SS Algorithm Metrics (Mitigated)
- Cooperative/Non-cooperative VFR Traffic

Study 3: (FY15)
- Cooperative/Non-cooperative VFR Traffic
- Surveillance & Tracking Sensor Models
- ATC/Pilot Procedures

Study 4: (FY16)
- UAS Performance trade-offs with DAA sub-functions

NASA HILT Studies
- Studies will support Pilot Alerting times and DAA display work

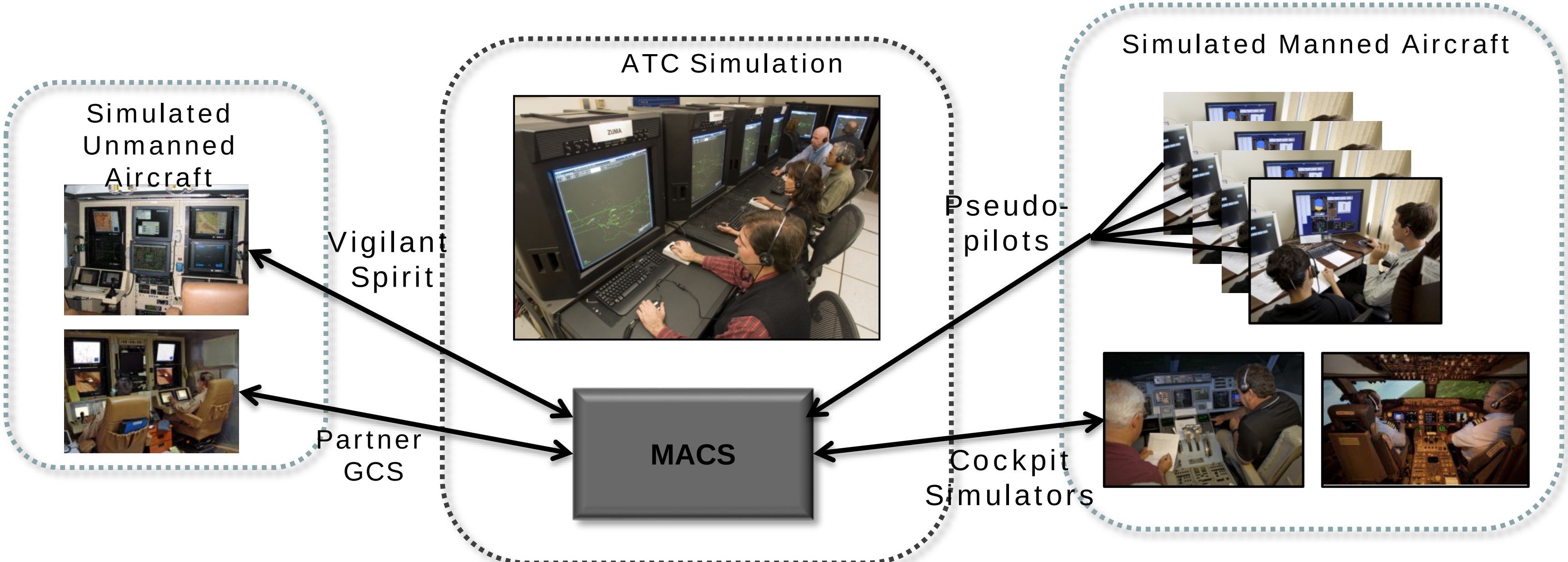
RTCA SC-228 DAA: Safety
- Encounter Rates and Risk Ratios based on sensor performance against VFR Traffic

RTCA SC-228 DAA: Requirements
- Informs DAA functional requirements (Detect and Track)

RTCA SC-228 DAA: Timeline
- Informs the impact of sensor limitations

RTCA SC-228 DAA: V&V
- Simulated Operational Environmental Testing

Human-in-the-Loop Simulations (FY14)



- Objectives
  - Integrate and evaluate the state of UAS concepts and supporting technologies
  - Evaluate and measure the effectiveness and acceptability of the DAA algorithms and displays
  - Verify and validate results of lower-fidelity simulations and analyses
  - Identify areas of future research and development emphasis
  - Reduce risk for the flight tests

Research Questions Addressed in HitL

- DAA performance requirements
  - Interoperability of SS and CA functions, including human role
  - Surveillance requirements impact on effectiveness of pilot-in-the-loop self-separation function
- DAA interoperability requirements
  - “Well clear” definition and procedures for the interaction between pilots and controllers to remain well clear
  - DAA algorithm compatibility with TCAS
  - Compatibility of DAA algorithms with pilot and controller expectations
- Airspace integration considerations
  - NAS impacts due to atypical performance and mission-oriented operations
  - Allowable communication latencies

Tentative Schedule

Unmitigated Encounter Rate Evaluation

Study 1: (FY14)
- **UAS Missions & Models**
- **Cooperative VFR Traffic**

July 2014

Study 2: (FY14)
- **UAS Missions & Models**
- **Cooperative and Non-cooperative VFR Traffic**

Jan. 2015

Mitigated Encounter Rate Evaluation

Study 1: (FY14)
- **UAS Missions**
- **Cooperative VFR Traffic**

July 2014

Study 2: (FY14)
- **UAS Missions & Models**
- **Cooperative/Non-cooperative VFR Traffic**
- **Surveillance & Tracking Sensor Models**

Jan. 2015

Study 3: (FY15)
- **UAS Missions & Models**
- **Cooperative/Non-cooperative VFR Traffic**
- **Surveillance & Tracking Sensor Models**
- **Environmental Uncertainties**

Sept. 2015

- **Latencies**
- **ATC/Pilot Procedures**

Study 4: (FY16)
- **Comprehensive TLoS sim. For final MOPS**

July 2016

RTCA SC-228 Schedule

Aug. 2014	July. 2015	July. 2016
Well ClearDef.	**Draft MOPS**	**Final MOPS**

Tentative Schedule

Surveillance Evaluation

Study 1: (FY14)
- **Range/FOR Effects on SS Algorithm Metrics (Unmitigated)**
- **Cooperative VFR Traffic**

May 2014

Study 2: (FY14)
- **Range/FOR Effects on SS Algorithm Metrics (Mitigated)**
- **Cooperative/Non-cooperative VFR Traffic**

Jan. 2015

Study 3: (FY15)
- **Cooperative/Non-cooperative VFR Traffic**

Sept. 2015

- **Surveillance & Tracking Sensor Models**
- **ATC/Pilot Procedures**

Study 4: (FY16)
- **UAS Performance trade-offs with DAA sub-functions**

July 2016

Human-in-the-Loop and Flight Test

March 2014 — **PT4.**

Aug. 2014 — **IHitL.**

Sept. 2015 — **FT3**

RTCA SC-228 Schedule

Aug. 2014 — **Well Clear Def.**

July. 2015 — **Draft MOPS**

July. 2016 — **Final MOPS**

Questions

Backup Slides

Honeywell Sensor Models

- Surveillance Models
  - Ideal Sensor (truth pass-through)
  - Generalized Sensor
  - Airborne Radar (ABR) Model
  - Ground-Based Radar (GBR) Model
  - EO/IR Model
  - Generalized ADS-B Model
  - TCAS – Mode C Model
  - TCAS – Mode S Model (Constant Update Rate)
  - TCAS – Mode S Model (Dynamic Update Rate)
  - ADS-B
- Sensor Fusion Algorithm
  - Joint Probabilistic Data Association (Data Association)
  - Sequential Probability Ratio Test (Track Manager)

Generalized Parameters:

- SensorID
- Range Noise Mean/ Std
- Range Noise Std
- Bearing Noise Mean/Std
- Elevation Noise Mean/Std
- Range Max/Min
- Azimuth Max/Min
- Elevation Max/Min
- Range Quantization
- Bearing Quantization
- Elevation Quantization
- Probability of detection
- Poison parameter
- Time To Track
- Relative Altitude Max/Min
- Ownship Altitude Quantization
- Intruder Altitude Quantization

UAS BADA-based Aircraft Models

- Aerosonde
- Cargo UAS
- Fire Scout
- Global Hawk
- Gray Eagle
- Hunter UAS
- Neo II VTOL
- Orbiter
- Predator A
- Predator B
- Predator C
- Shadow B
- Bat 3 (Group 1)
- Silvertone Flamingo (Group 2, from Queensland University of Technology Airborne Systems Lab)
- Raven (Group 3, ITAR version, no distribution outside NASA)
- Optionally piloted Cessna 172 (Group 4, Queensland University of Technology Airborne Systems Lab)
- QF-4 (Group 5, drone version of the F-4 Phantom)

UAS Missions

UAS Mission Profiles (Delivered)

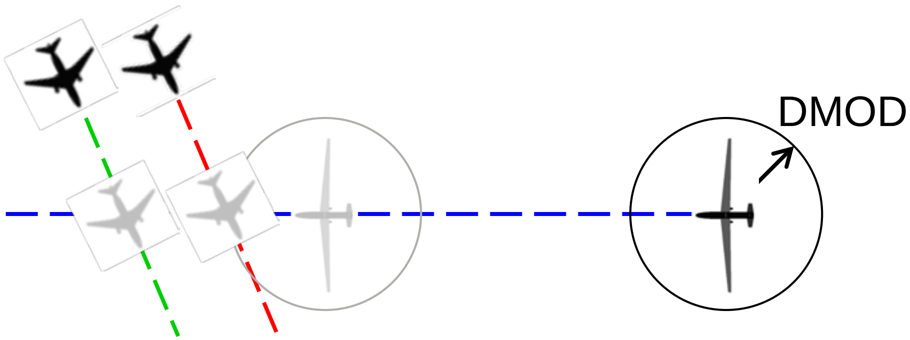
- Air Quality Monitoring Mission
- Border Patrol
- Cargo Transport
- Weather Data Collection (Atmospheric Sampling)
- On-demand air taxi
- Wildfire detection and reconnaissance

UAS Mission Profiles (In Development, to be completed by Sept. 2014)

- Flood Mapping
- Law Enforcement/Suspect Tracking
- Search and Rescue
- Pollution Monitoring
- Wildlife Monitoring
- Spill Monitoring
- Maritime Patrol
- Imaging and Mapping
- Traffic Monitoring around Metro Areas
- FAA Waypoint Inspection
- Communication and Broadcast Relay
- Damage/Survey Assessment
- Extensions to Mail/Freight Demand

Modified Tau with Miss-Distance Filter

- Modified tau with Bramson's criteria and horizontal/vertical miss-distance filtering



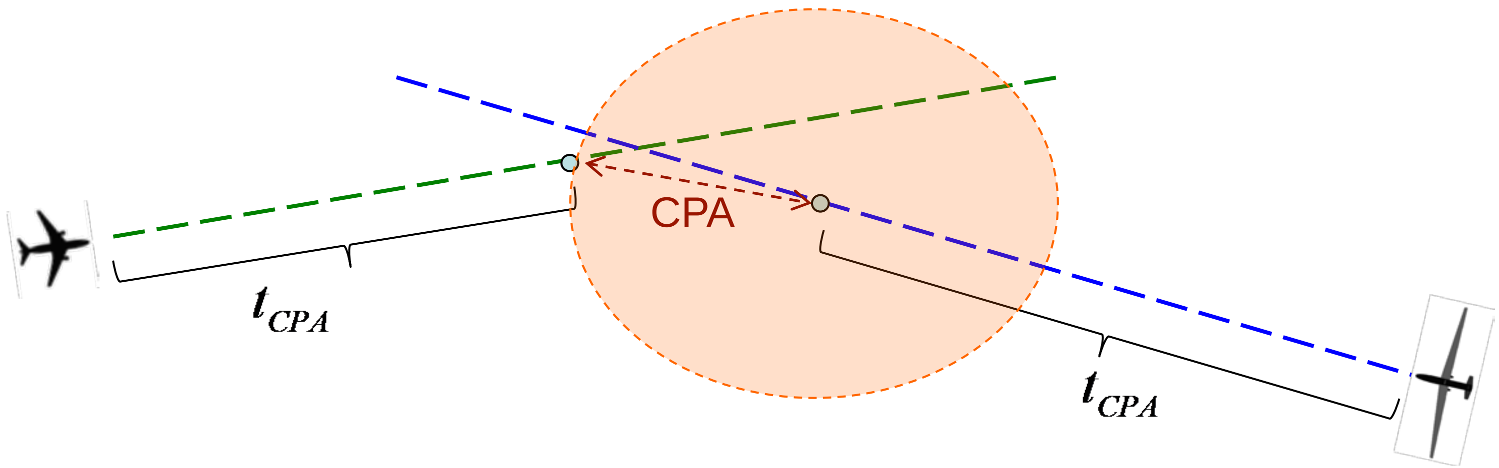
DMOD:
Horizontal Filter = 1.1 nmi
Vertical Filter = 700 ft

Buffer Volume (VOL):
Horizontal Filter = 3.5 nmi
Vertical Filter = 1000 ft

- An improvement in TCAS II is the addition of miss-distance filtering at CPA
- Reduces nuisance alerts experienced from the Modified Tau
- Requires additional information to predict relative states at CPA

Time to CPA

- Predicted Time to CPA:



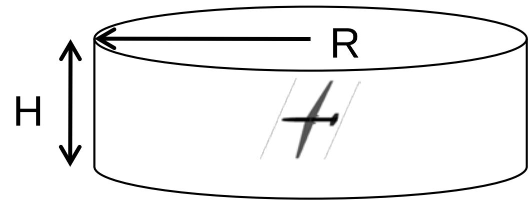
- Time to CPA is a more accurate measure than tau
- Intuitive to pilots as to when action needs to be taken
- Requires additional information to predict CPA and could be a noisy prediction

Distance-based Volume

- Horizontal radius and vertical separation minima (“hockey puck”)

ATC Legal Standard

R = 5 nmi
H = 1000 ft



Operator Well Clear

R = 3 nmi
H = 700 ft

ATC Well Clear (from TASATS)

R = 4 nmi
H = 900 ft

TCAS Threat Boundary

R = 1.1 nmi
H = 700 ft

- Simple separation concept that is used by Air Traffic Controllers
- Very intuitive to understand and interpret for operator situational awareness
- Susceptible to high closure rate encounters if volume is too small and nuisance alerts if volume is too large