National Aeronautics and Space Administration

Evaluating Performance of UAS Detect-And-Avoid System Using a Fast-Time Simulation Tool

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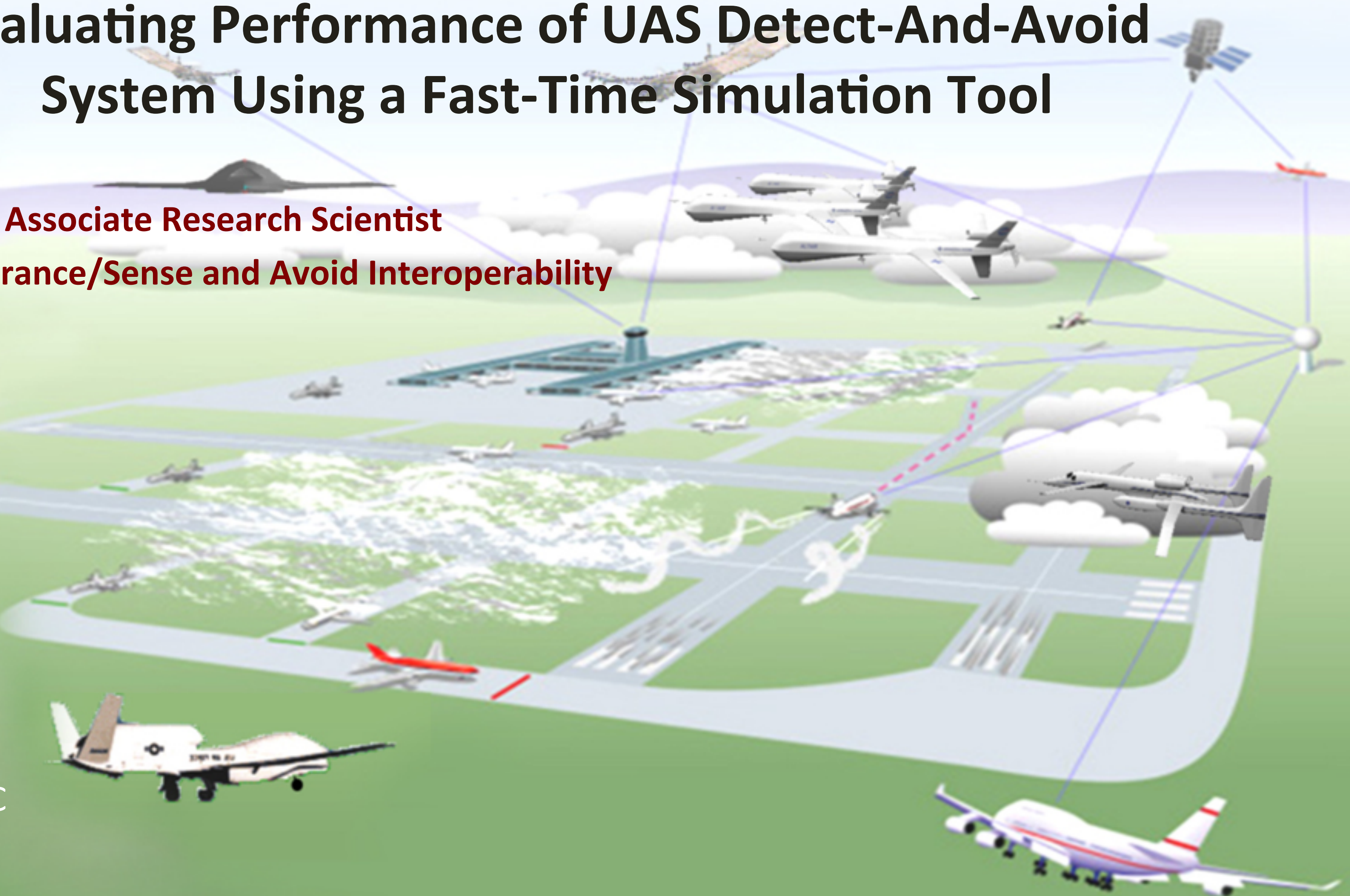
Separation Assurance/Sense and Avoid Interoperability



Seminar at UCSC

06/04/2015

Agenda

- Background and Research Goals
- Airspace Separation Assurance for UAS
- Concept of Well Clear Separation Standard
- Modeling and Simulation Research Capabilities
- UAS Missions and VFR Traffic Scenarios
- Accomplished and On-going UAS Simulation Studies
- Preliminary Simulation Results
- Future Research Areas

Background

- Increasing Demand of UAS operations in Civil Airspace and UAS operations are currently very restrictive to operate in the NAS
  - The FAA believes that there may be as many as 30,000 unmanned aircraft flying in the NAS by as early as 2025.
- Accommodating UAS operations will cause increasing complexity of the NAS and changing the roles and responsibilities of ATC
- One of the most important research efforts is to improve safety and reducing technical barriers and operational challenges associated with flying unmanned aircraft in airspace shared by commercial and civil air traffic.

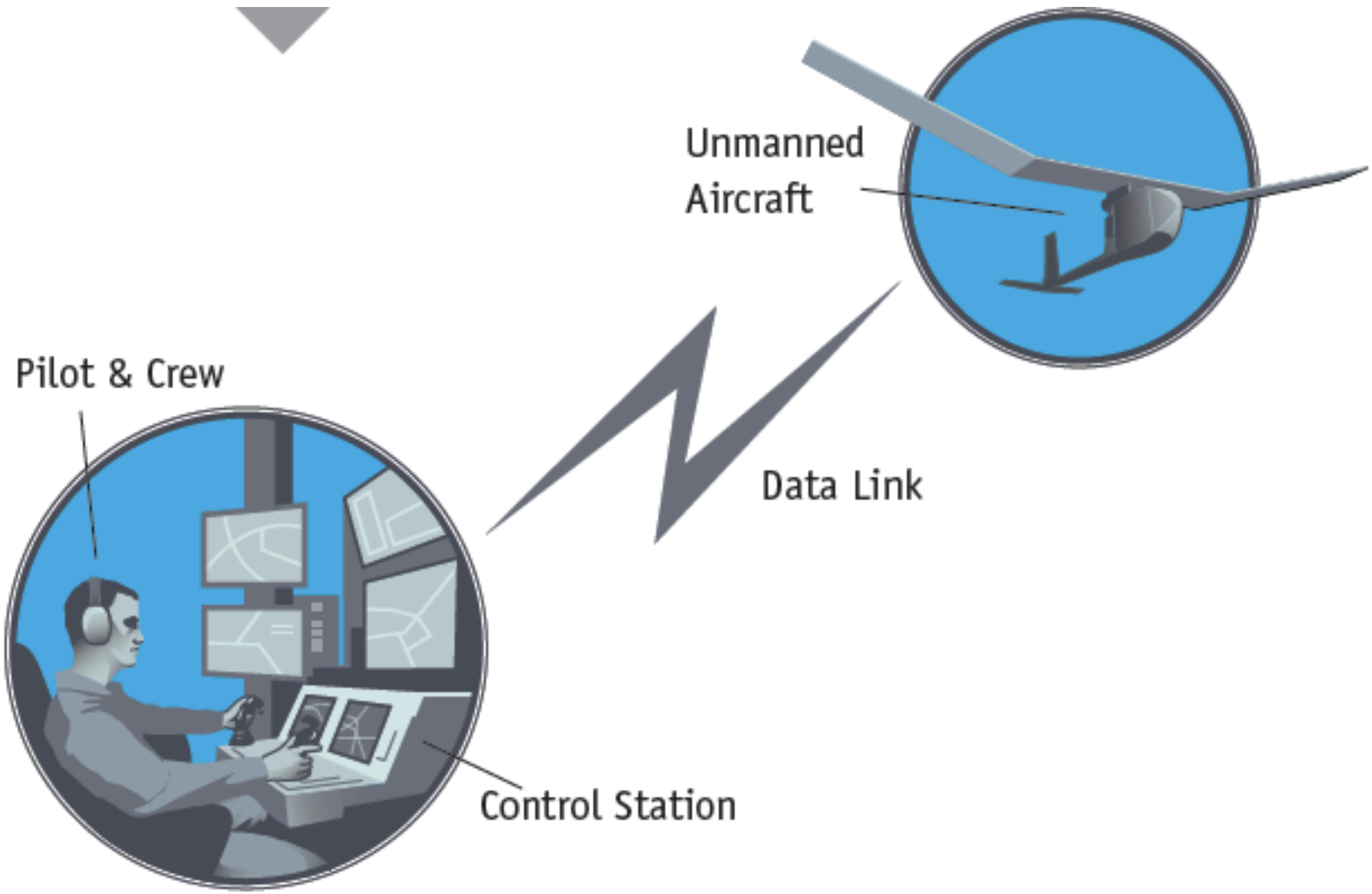
Some of Challenges to Integrate UAS into the NAS

- Ensuring separation assurance
- Ensuring adequate collision avoidance
- Ensuring robust and secure communications technologies
- Solving the constraints of frequency spectrum allocation
- Designing and evaluating ground control station displays
- Defining airworthiness and operational standards
- Defining pilot certifications requirements
- Developing certification standards for automated systems
- Defining appropriate level of safety through systematic safety analysis
- Developing certification standards for a wide range and/or type of UAS
- Developing integrated solutions for off-nominal operations
- Defining operational requirements for current and future missions sets
- Definitions of roles and responsibilities between pilots and controllers

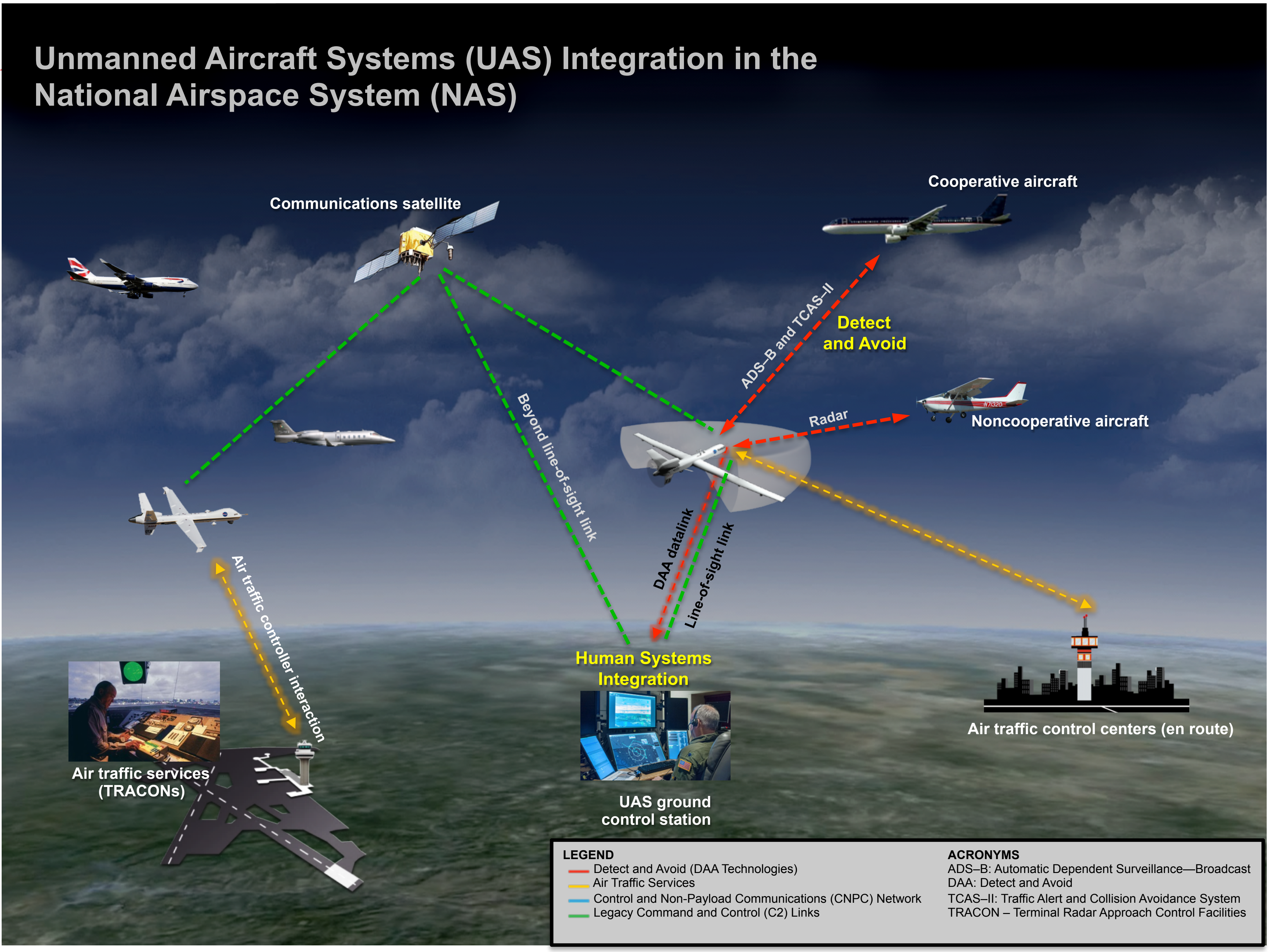
Primary Research Objectives

- Develop and evaluate concepts of operations, procedures, regulations, and advanced technologies to support safe and efficient UAS operations in the NAS
- Investigate how the integration of UAS into the current ground-based ATM system operations affect safety, capacity and efficiency of the NAS
  - Evaluate the impacts of UAS operations (wide range of UAS missions and vehicle performance characteristics) on the NAS
- Assess the acceptability of the concepts and to evaluate the effectiveness of the associated technologies and procedures through fast-time, human-in-the-loop simulations, and field tests
- Support FAA and RTCA SC-228 to develop the minimum operational performance standards (MOPS) for UAS Detect-And-Avoid (DAA) systems and traffic displays

Unmanned Aircraft System (UAS)



Source: FAA Report, Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap, 2013



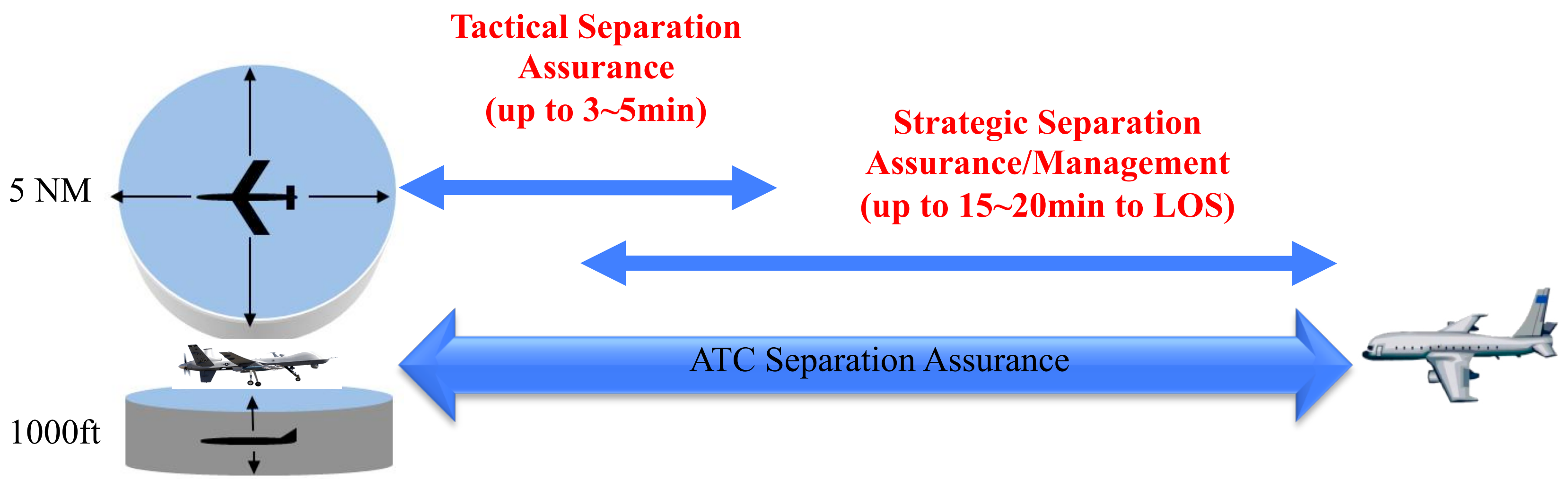
Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS)
Communications satellite
Cooperative aircraft
ADS–B and TCAS–II
Detect and Avoid
Radar
Noncooperative aircraft
Beyond line-of-sight link
DAA datalink
Line-of-sight link
Air traffic controller interaction
Human Systems Integration
Air traffic services (TRACONs)
UAS ground control station
Air traffic control centers (en route)
LEGEND
Detect and Avoid (DAA Technologies)
Air Traffic Services
Control and Non-Payload Communications (CNPC) Network
Legacy Command and Control (C2) Links
ACRONYMS
ADS–B: Automatic Dependent Surveillance—Broadcast
DAA: Detect and Avoid
TCAS–II: Traffic Alert and Collision Avoidance System
TRACON – Terminal Radar Approach Control Facilities

Video Clip for Integrating UAS into the NAS

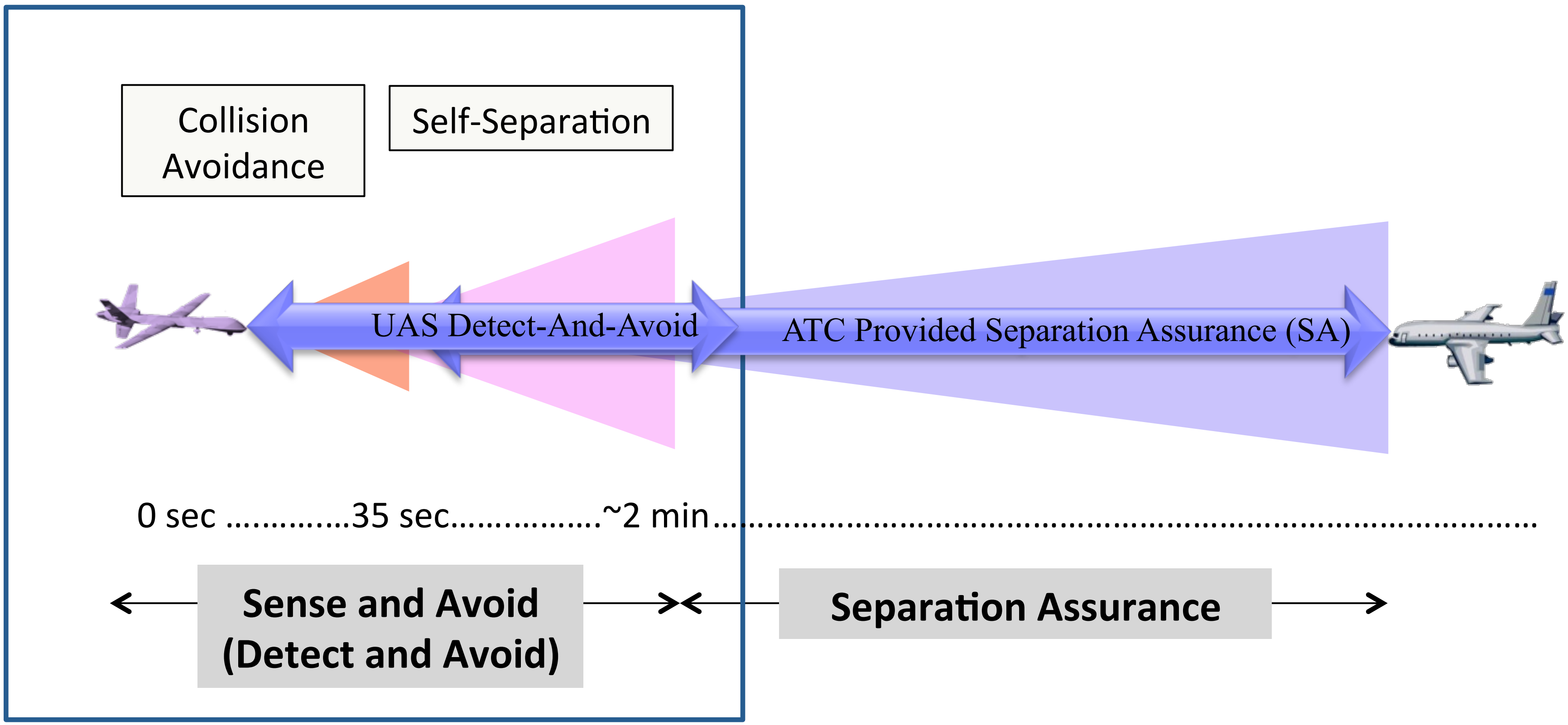
Source: https://www.youtube.com/watch?v=7hBcugTsWRQ

Separation Assurance in the NAS

- To ensure safe separation between two or more aircraft flying under IFR
- To ensure avoidance of bad weather, special use of airspace, terrain, or other hazards
- ATC separation standards (typically in Class A airspace):



Airspace Separation Assurance for UAS



- FAA Regulatory requirements (14CFR Part 91, §91.111 and §91.113) to "see and avoid" and to remain "well clear" of other aircraft.
- UAS will be required to equip with a new system in order to fulfill the regulatory requirement "see and avoid" to maintain a safe separation from other air traffic.

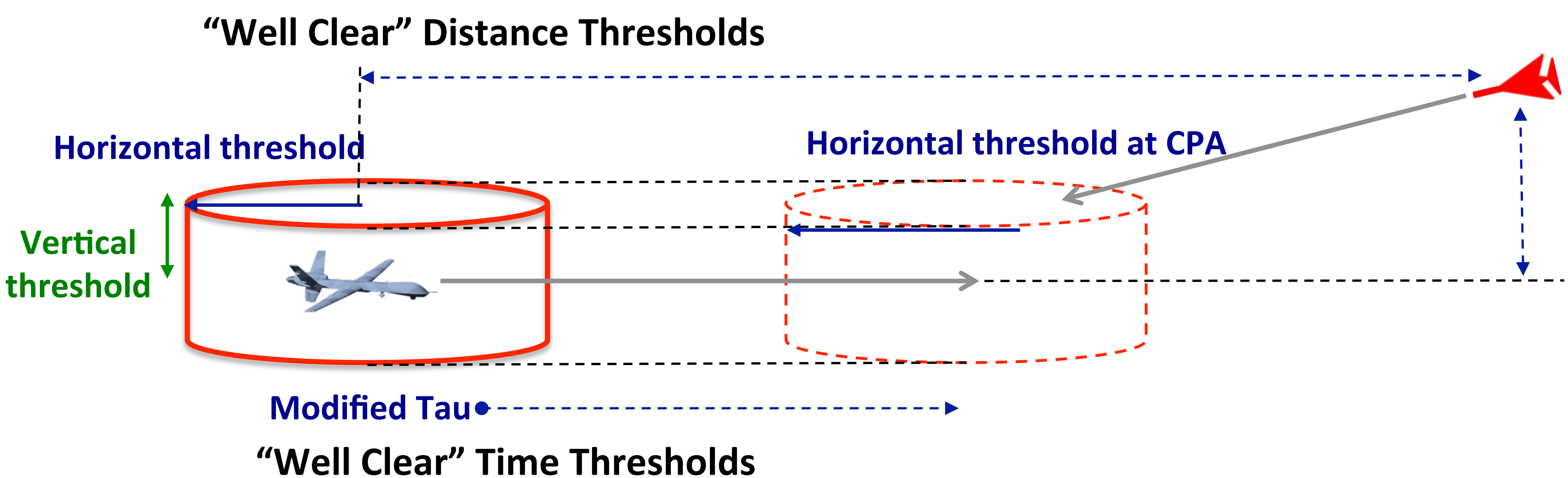
UAS Detect-And-Avoid (DAA) System

- DAA is defined as "the capability of a UAS to remain well clear from, and avoid collisions with, other airborne traffic. DAA provides the intended functions of self separation and collision avoidance compatible with expected behavior of aircraft operating in the NAS."
  - Self-Separation Function, which keeps the aircraft "well clear" of other airborne traffic;
  - Collision Avoidance Function, which avoids near-mid air collisions (NMAC)

- DAA system will replace the "see-and-avoid" function provided by pilots in manned aircraft, which is an important contributor to today's safe air traffic operations.

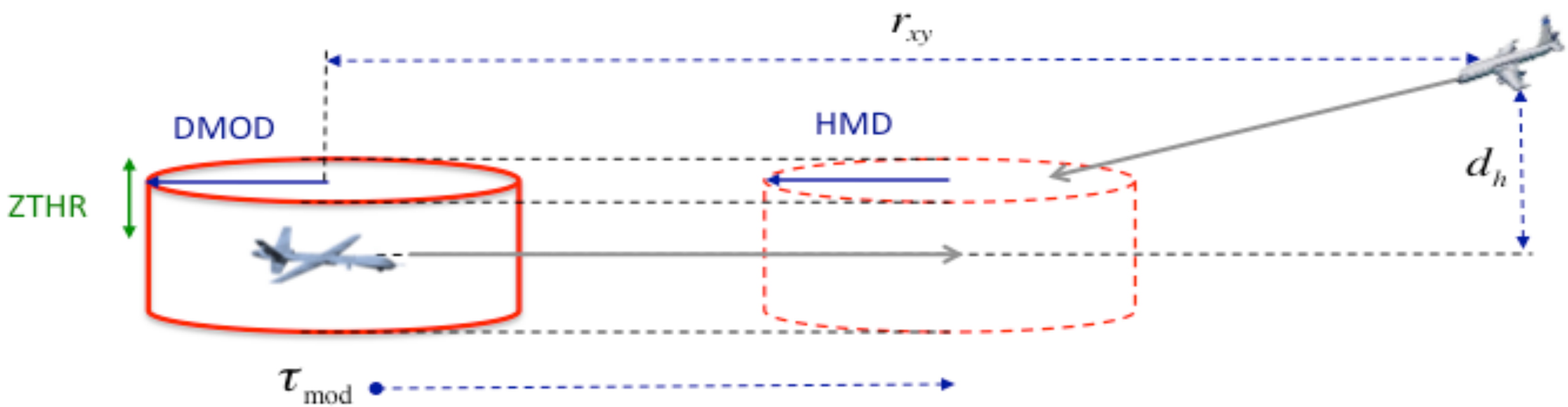
Concept of Well Clear Separation Standard

- Airborne separation standard for DAA Self-Separation system
- A well clear separation standard should be large enough to
  - Avoid collision avoidance maneuvers by intruders,
  - Minimize traffic alert issuances by air traffic control,
- Time and distance-based definition of "Loss of Well Clear (LoWC)"
  - When two aircraft are within distance thresholds
  - When the projected horizontal range at closest point of approach (CPA) of two aircraft is within a distance-based volume in a particular time threshold (Tau)



Definition of Well Clear (RTCA Special Committee)

$$[0 \le \tau_{mod} \le \tau^{*}_{mod} \; and \; HMD \le HMD^{*}] \; and \; [-ZTHR^{*} \le d_z \le ZTHR^{*}]$$



$$\tau_{mod} : \text{Modified Tau} \begin{cases} -\dfrac{R_{xy}^2 - DMOD^2}{R_{xy}\dot{R}_{xy}} & \text{for } R_{xy} > DMOD \\ 0 & \text{for } R_{xy} \le DMOD \end{cases}$$

Parameters	Values	Descriptions
Modified Tau*	35 sec	Ratio of range to range rate with DMOD
DMOD	4,000 ft	Distance modification that represents a minimum desirable range between two aircraft
HMD*	4,000 ft	Horizontal distance at the predicted horizontal CPA
ZTHR	450 ft	Vertical separation threshold

Self-Separation Alerting Threshold

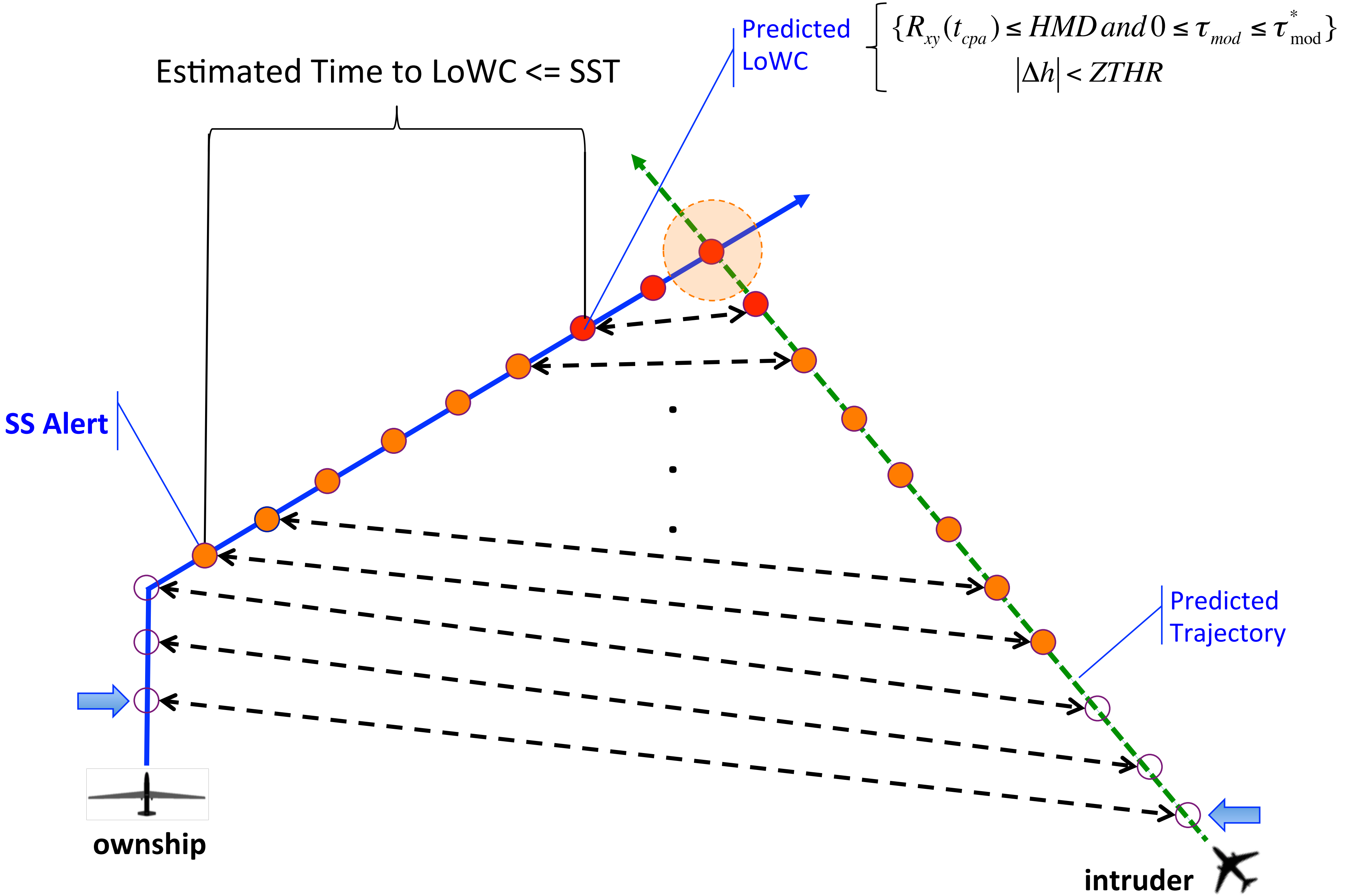
- Self-separation declare threshold (SST), at which the DAA Self-Separation (SS) function declares that an action is needed to preclude a threat aircraft from causing a well clear violation.

- Several ways of defining SST as alerting criteria (zone)
  - Time-based alerting threshold parameters
    - Time to Loss of Well Clear (LoWC)
    - Time to Predicted Closest Point of Approach
  - Distance-based alerting threshold parameters
    - DMOD, HMD*, ZTHR*

- Meaningful DAA performance must alert the UAS pilot to potential threats at ranges sufficient for reaction time and avoidance actions by safe margins

Self-Separation Alerting Threshold

- SST: Time to predicted LoWC



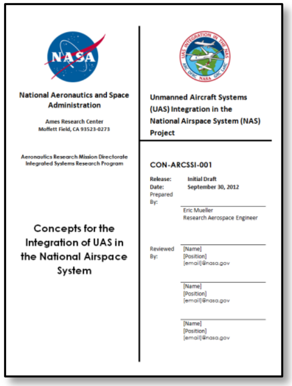
Alerting and Resolution Performance of DAA System

- The performance of DAA system will be dependent upon how SST is defined and how the values of the alerting threshold parameters are set
  - Large alerting zone: excessive number of nuisance alerts
  - Small alerting zone: not be able to avoid LoWC within a short period of time

- Investigation of the effects of different alerting thresholds on the safety and performance of DAA system
  - Number of LoWC (Success Rate)
  - Probability of correct alerts, nuisance alerts, late alerts and missed alerts
  - Actual time to LoWC given correct alerts
  - Etc.

Modeling and Simulation Research Capabilities

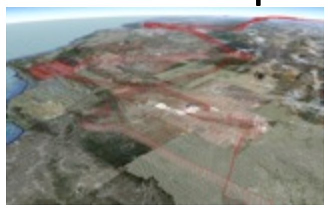
Research Capabilities


National Aeronautics and Space Administration
Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project
CON-ARCSSI-001
Concepts for the Integration of UAS in the National Airspace System

UAS-NAS integration concepts

New UAS-related modeling and simulation capabilities

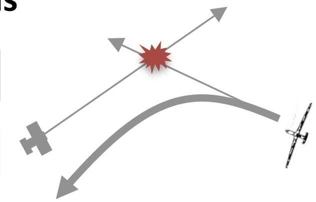
18 UAS mission profiles



17 UAV types

UAS models, comm. link models

DAA algorithms



DAA sensor models

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

Fast-Time Simulation Environment

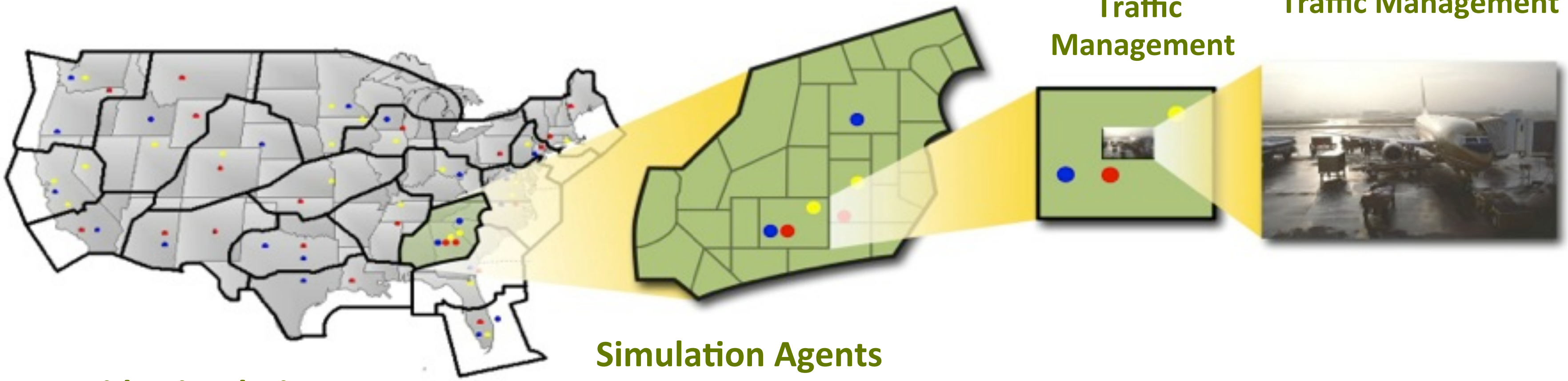
Airspace Concepts Evaluation System (ACES)

National Traffic Management

Regional Traffic Management

Local Approach and Departure Traffic Management

Airport and Surface Traffic Management



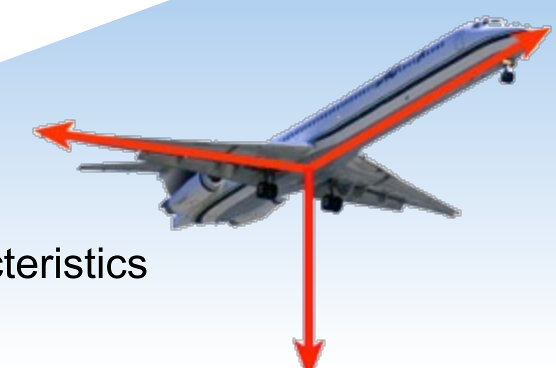
Simulation Agents

- Air traffic controller decision making
- Traffic flow management models
- Individual aircraft characteristics
- UAS Detect and Avoid algorithms
- UAS pilot response model

NAS-wide Simulation

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

4-DOF Trajectory Model
  Aerodynamic models of aircraft
  User-definable uncertainty characteristics



Overview of UAS Missions

- Developed under contract with Intelligent Automation Inc. (IAI)

	UAS Mission	Total Number of Flights	Total Flight Time (hr)
1	Aerial Imaging and Mapping	295	182.60
2	Air Qualtiy Monitoring	1044	2393.49
3	On-Demand Air Taxi Cirrus	8720	6240.12
4	On-Demand Air Taxi Mustang	3180	1107.76
5	Airborne Pathogen Tracking	1308	3002.24
6	Border Patrol	867	3357.90
7	Cargo Delivery	1317	1966.07
8	Flood Inund. Mapping	127	275.02
9	Flood Stream Flow	200	368.51
10	Law Enforcement	300	859.11
11	Maritime Patrol	1512	11267.74
12	Point Source Emission Monitoring	432	648.05
13	Spill Monitoring	836	2078.07
14	Strategic Fire Monitoring	312	4959.85
15	Tactical Fire Monitoring	2496	3373.88
16	Traffic Monitoring	1043	1953.05
17	Weather Data Collection	2401	13324.86
18	Wildlife Monitoring	308	189.34
	Total	26698	57547.66

Mission Characteristics

	UAV group	Duration (per flight)	Flights per day	Cruise Alt.	Flight Pattern
Air Quality Monitoring	Shadow-B	1-4 hrs.	104-1044	4k,5k, and 6k ft AGL	Radiator Grid Pattern
Cargo Transport	Cessna 208	varies	1.4k	2k-16k	Point to Point
Atmospheric Sampling	Global Hawk	1.5-13 hrs.	2352	5k-35k ft AGL	Radiator Grid Pattern
On-demand Remote Air Taxi -Cirrus	Cirrus SR22T	varies	8k	6k-11k	Point to Point
On-demand Remote Air Taxi - Mustang	Cessna Mustang	varies	2k-4k	9k-20k	Point to Point
Strategic Fire Monitoring	Predator-B	20 hrs.	74-324	31k ft MSL	Radiator Grid Pattern
Tactical Fire Monitoring	Shadow-B	1-1.5 hrs.	varies	varies	Circular Loitering Orbit
Flood Inundation Mapping	Aerosonde	1-4 hrs.	varies	4k ft AGL	Radiator Grid Pattern Point to Point
Flow Stream Monitoring	Aerosonde	1-4 hrs.	20-200	4k	Radiator Grid Pattern Point to Point

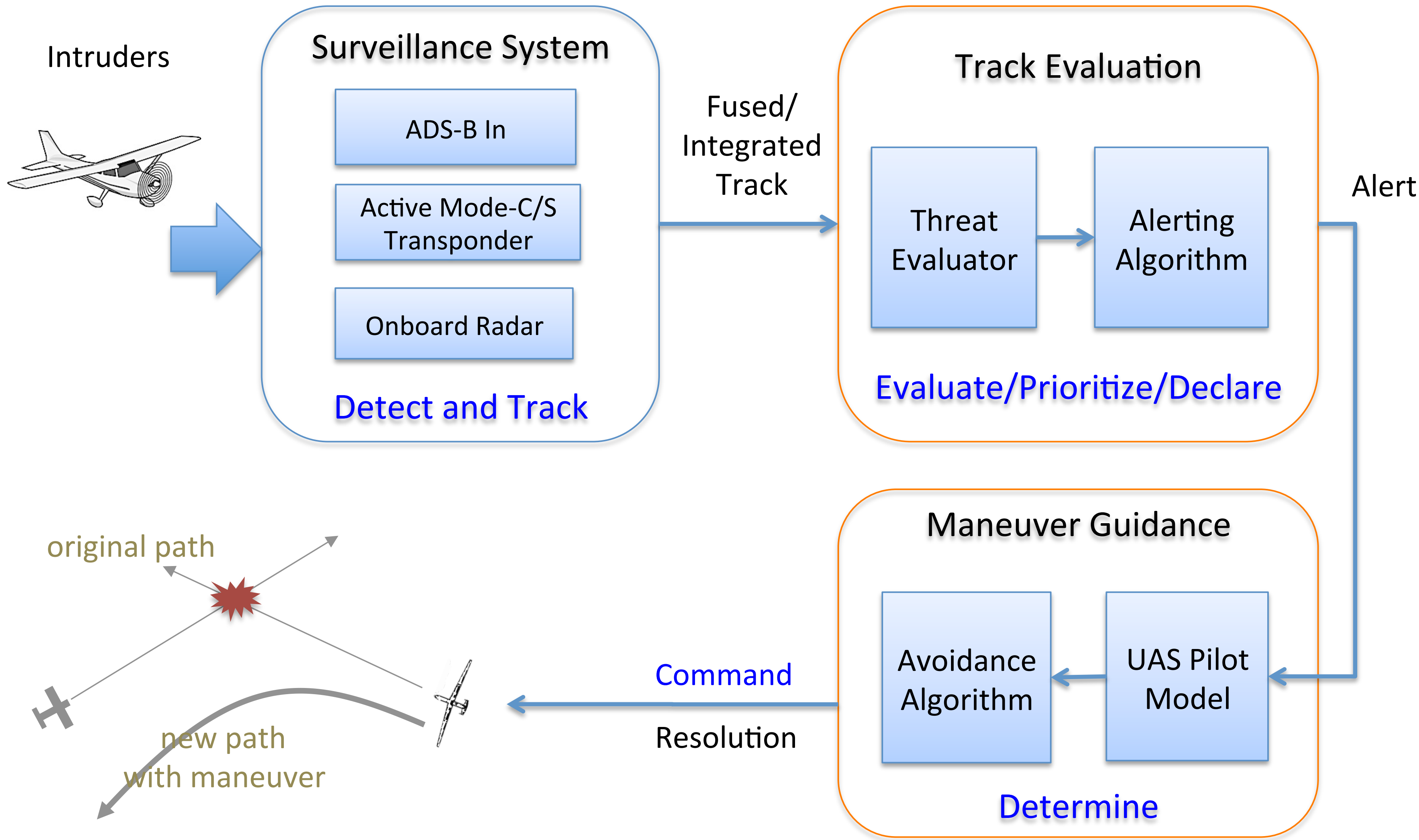
VFR Traffic (courtesy of 84th RADES)

- The 84th Radar Evaluation Squadron (RADES) data were used.
  - The data contain the radar hits collected from hundreds of radar sites in U.S, and each hit provide timestamp, latitude, longitude and others but does not always provide Mode 3 code, Mode C code.
  - All cooperative VFR has the same Mode 3 code, 1200.
  - Extracted and generated nation-wide VFR flight paths that VFR aircraft actually flown from the historical Air Defense 84th Radar Evaluation Squadron (RADES) radar data

- Cooperative VFR tracks were processed using
  - A clustering method based on a modified minimum spanning tree algorithm,
  - The quadratic regression to estimate the aircraft position within a time window,
  - A Kalman filter to generate smooth trajectories,
  - Filters to categorize each track into IFR or VFR: altitude, speed, and Mode 3 code.

- Non-cooperative VFR tracks were processed
  - Using algorithm developed by Honeywell to process non-cooperative VFR tracks and estimates altitude measurements

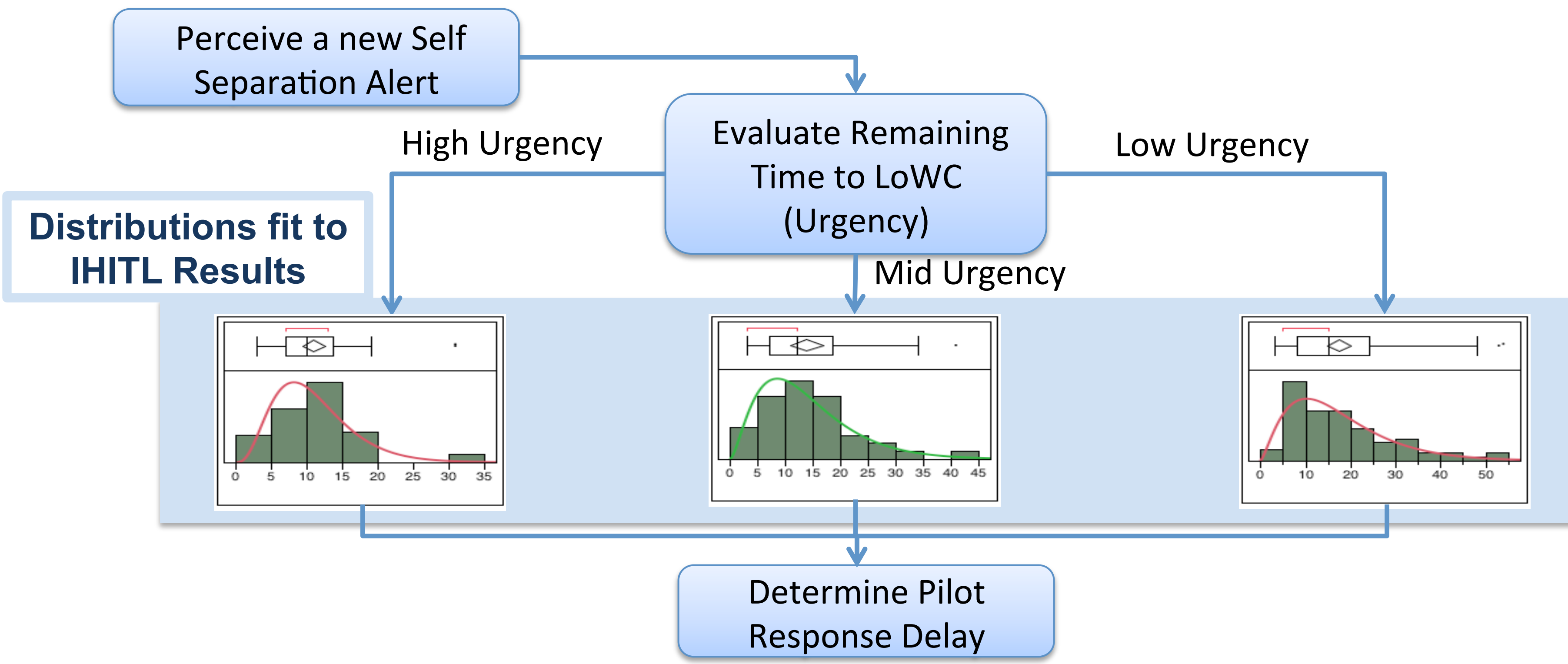
A Schematic of DAA System Model



A Stochastic Pilot Response Model

- Pilot total response time is the time from the first self-separation alert to the time pilot uploads maneuver to prevent loss of well clear.
  - *NASA HSI team breaks this down by different measures*

- Use total pilot response time data from HITL to build a pilot response time model, so there are realistic responses to SS alerts in ACES simulations
  - Sample from a distribution, and "wait" that amount of time before commanding maneuver



Preliminary Simulation Results of On-going UAS DAA Study Using ACES Simulation

Accomplished ACES Fast-Time Simulation Studies

- DAA Surveillance Performance Study
  – To evaluate the performance of a surveillance system with different parameters, such as the ratio of undetected and late-detected LoWC, and the time to LoWC at first detection for given surveillance parameters
- Well Clear Definition Simulation Study
  – To evaluate the effect of different Well Clear definitions on LoWC rates by measuring the LoWC rates per UAS flight hour
- Airspace Safety Threshold Study
  – To evaluate the safety of current airspace based on encounter rates of simulated UAS missions with historical IFR and VFR flight tracks

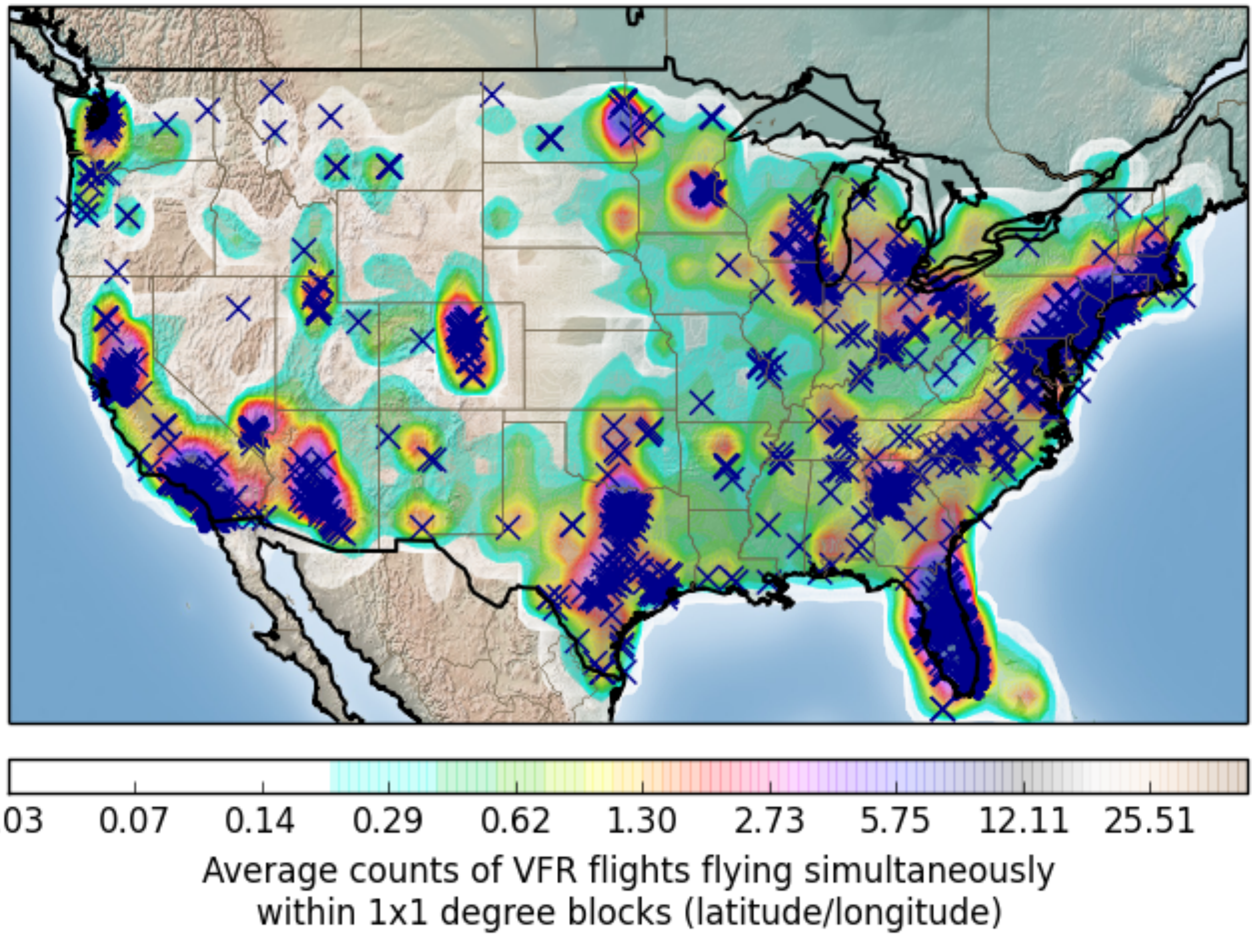
* All accomplished studies were unmitigated studies in which no UAS or VFR flights were maneuvered to avoid potential Loss of Well Clear.

On-going UAS DAA Simulation Study

- DAA Alert and Resolution Performance Study
  - To investigate encounter characteristics at alerts and at LoWC (e.g. range, relative speed, relative heading, and vertical closure rate)
  - To investigate the effects of different SST settings on the performance of DSS SS system by measuring metrics such as correct/nuisance/late/missed alerts, time to LoWC at first alerts, alerting duration, and resolution success rates
  - To derive required surveillance volumes to detect all/some intruders and threats as a function of different SST settings with/without execution delays
    - Surveillance volume in terms of surveillance detection range, horizontal field of regard, and vertical field of regard
  - To investigate the effects of realistic sensor models with uncertainty (Range, Bearing, Elevation Noise) of airborne radar sensor on the safety and on the DAA performance

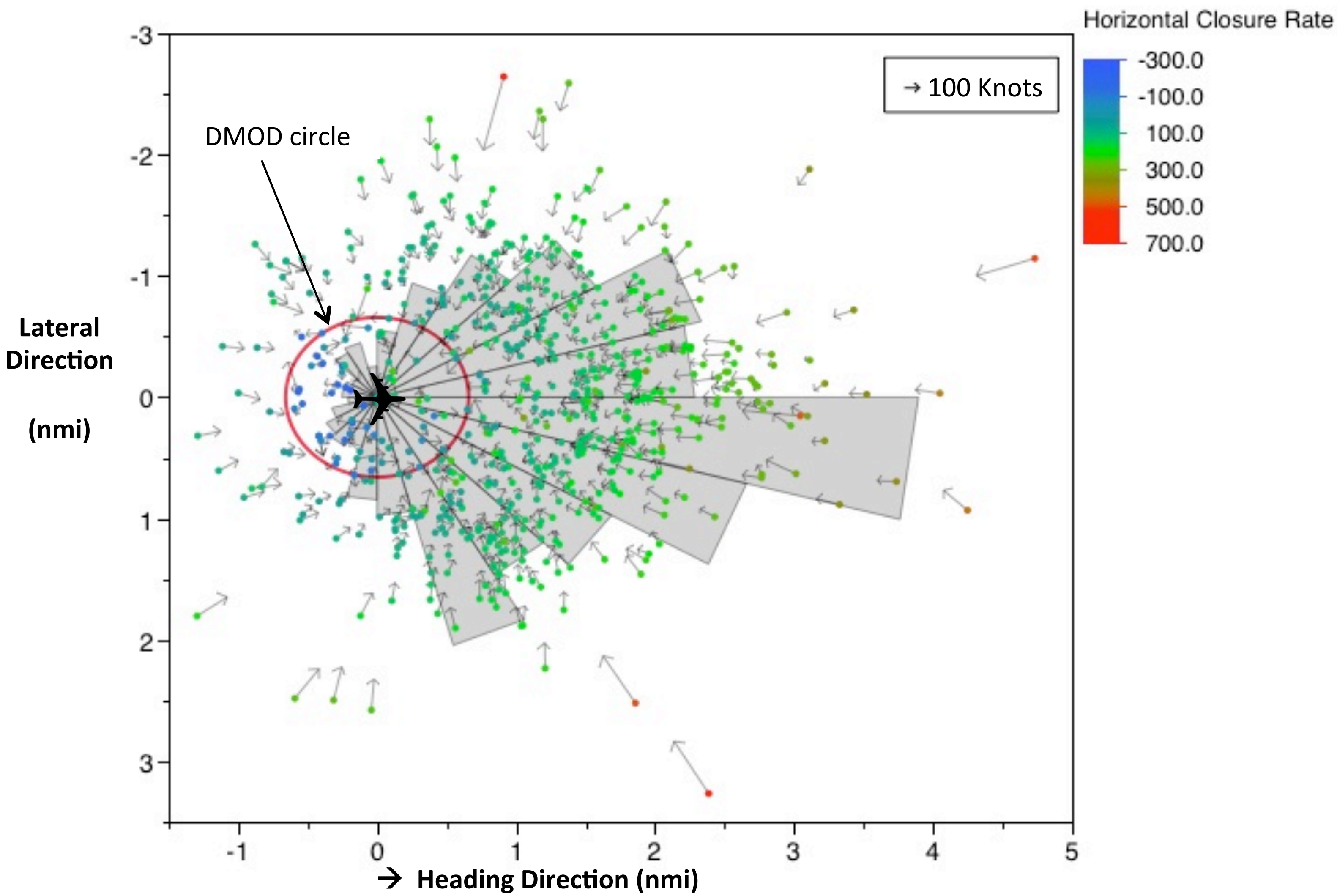
Sample Results: Loss of Well Clear on CONUS

- Simulating UAS missions without DAA system and ATC separation provision services on cooperative VFR traffic on April 4, 2012,
  - 2,664 Loss of Well Clears.
  - LoWCs occurred mostly in the regions that have high VFR density.

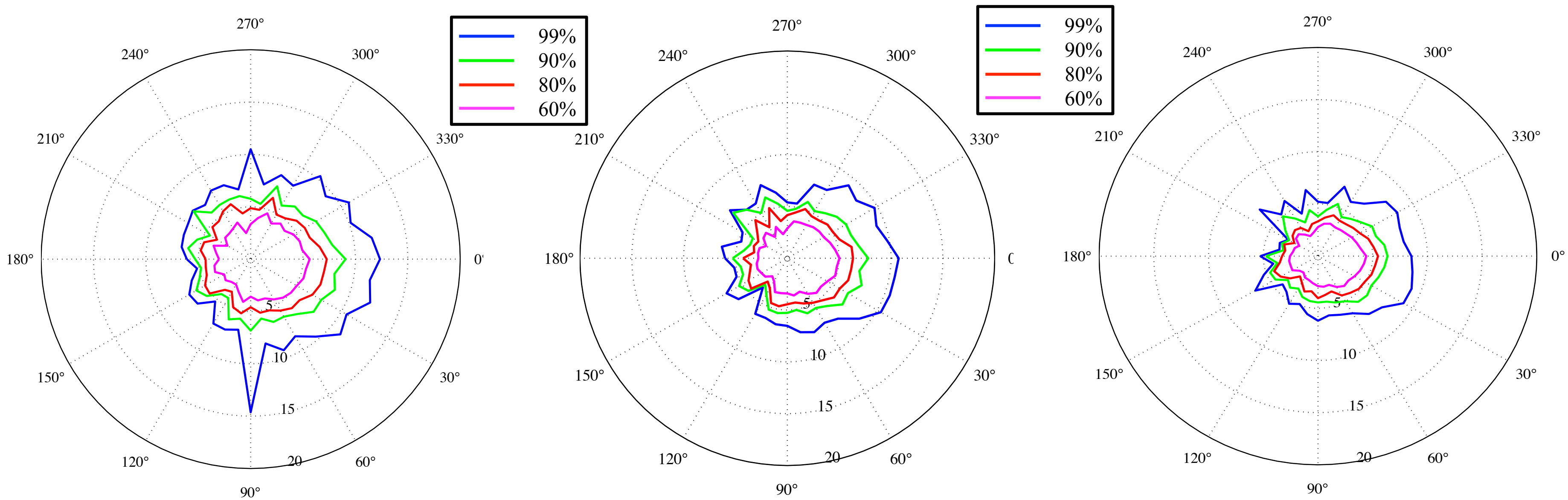


Encounter Characteristics of Intruders at LoWC

- Relative position, Bearing distribution, and Horizontal Closure Rate



Relative Range and Bearing Angle at SS Alerts

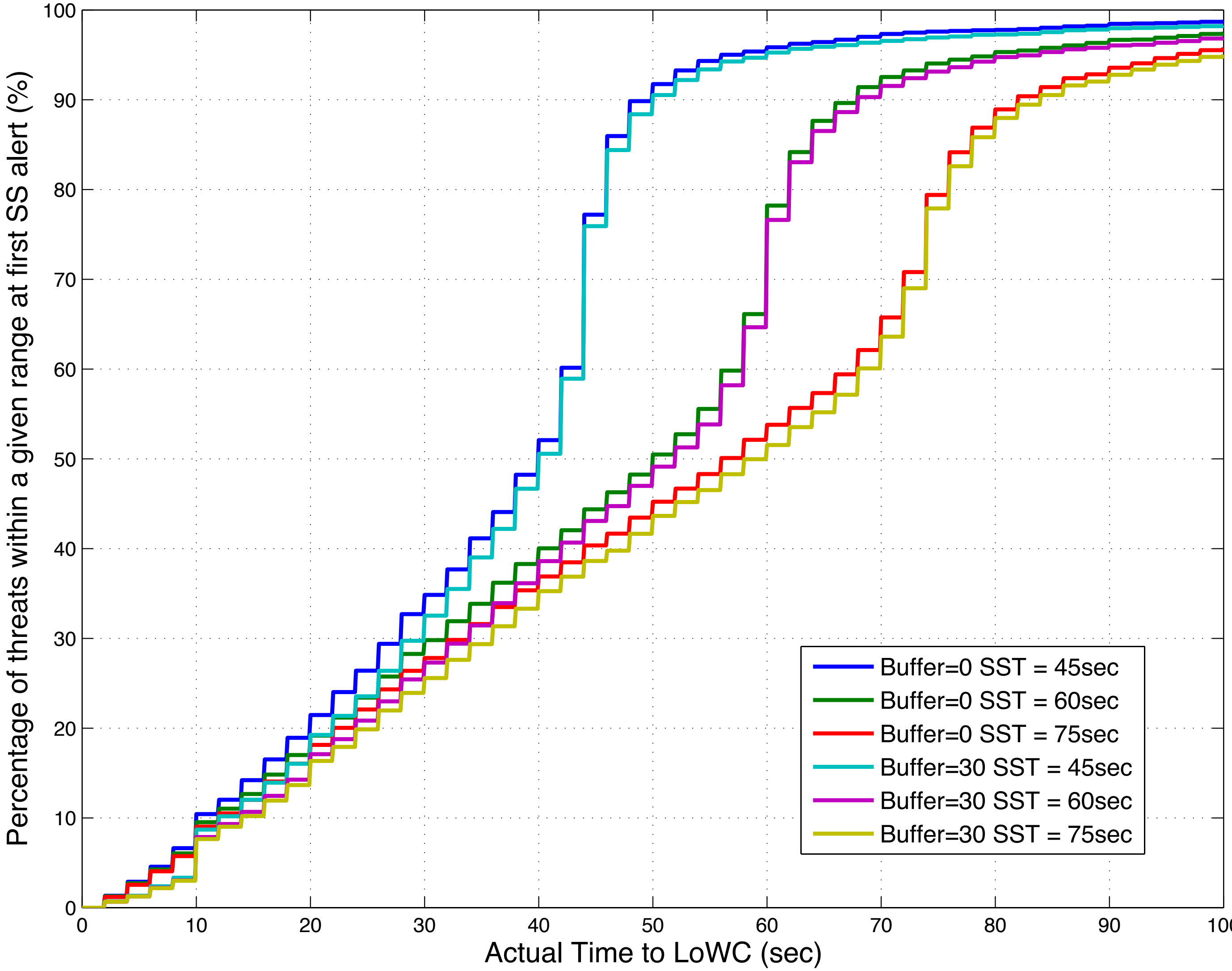


SST* = 75 sec

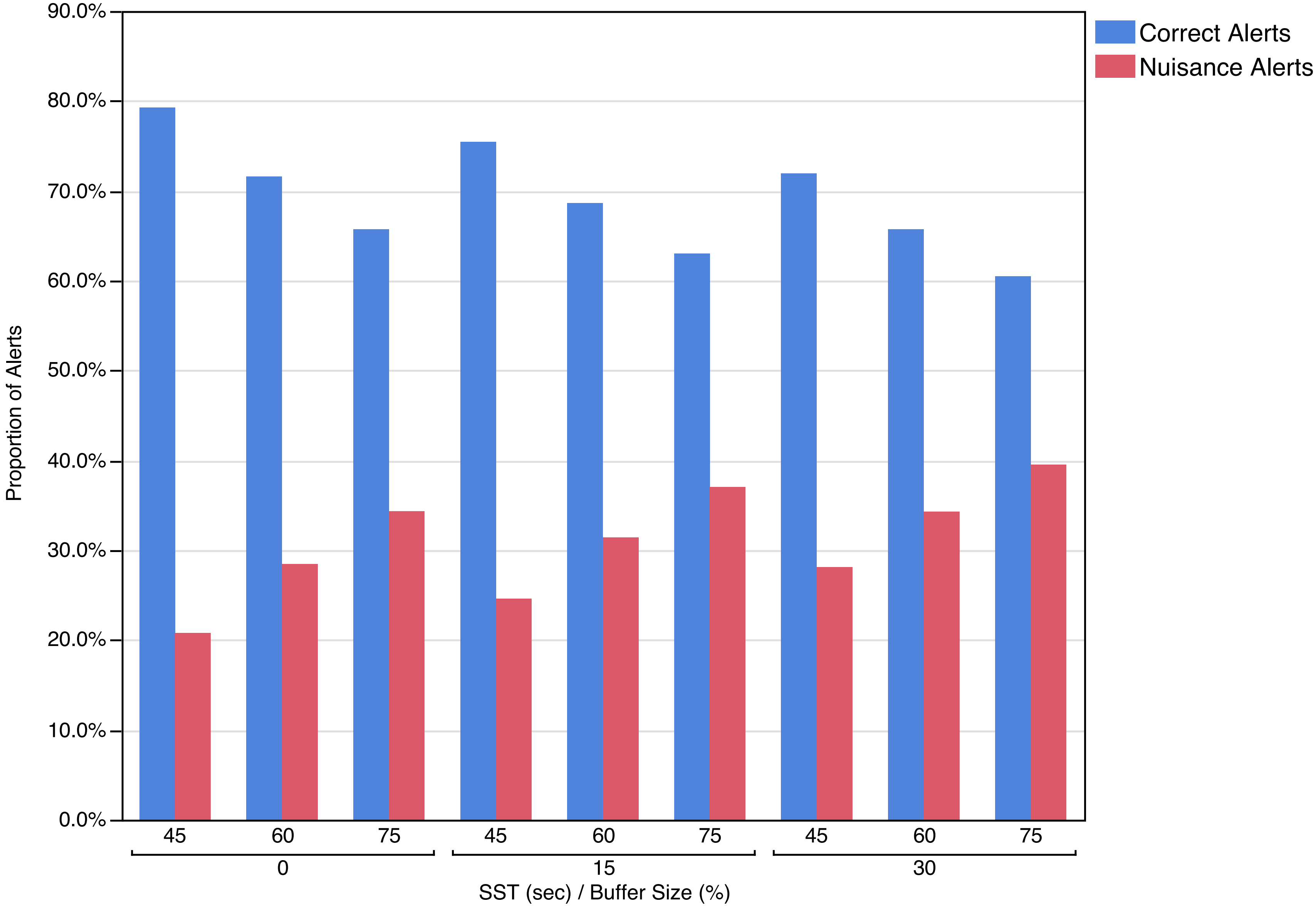
SST* = 60 sec

SST* = 45 sec

CDF for Actual Time to LoWC from Alerts



Probability of Correct and Nuisance Alerts



Summary

- ACES is used to simulate NAS-wide operations of UAS and VFR flights
  - UAS missions and background VFR traffic
  - DAA alerting and resolution algorithms
  - Stochastic pilot response model

- Fast-time simulation studies have been accomplished
  - Airborne encounter characteristics, alerting performance, and airspace safety have been investigated
  - The simulation results were provided to RTCA SC-228 for developing minimum operational performance standard (MOPS) for DAA systems

- Keep working on improving ACES simulation fidelity and capabilities to simulate more realistically and investigate the impact of UAS integration into the NAS on the safety and performance of the NAS.

Potential Research Area

- High-fidelity Surveillance Sensor Models with Uncertainty
  - Tracking Algorithms
- Alerting and Resolution Algorithms
  - Trajectory Prediction Algorithms
  - Alerting Logics and criteria
  - Avoidance algorithms
  - Performance evaluation methodology and metrics
- Interoperability with TCAS II System of Manned Aircraft and with Advanced NextGen Separation Assurance systems
- Decision Support Systems and Displays for UAS Pilot
  - To help UAS pilot to make a better decision on avoidance maneuver
  - Computational agent models for UAS pilot
- Assessment of Different Functional Allocations
  - Controller/Pilot-provided aircraft separation
  - Autonomous airborne self-separation