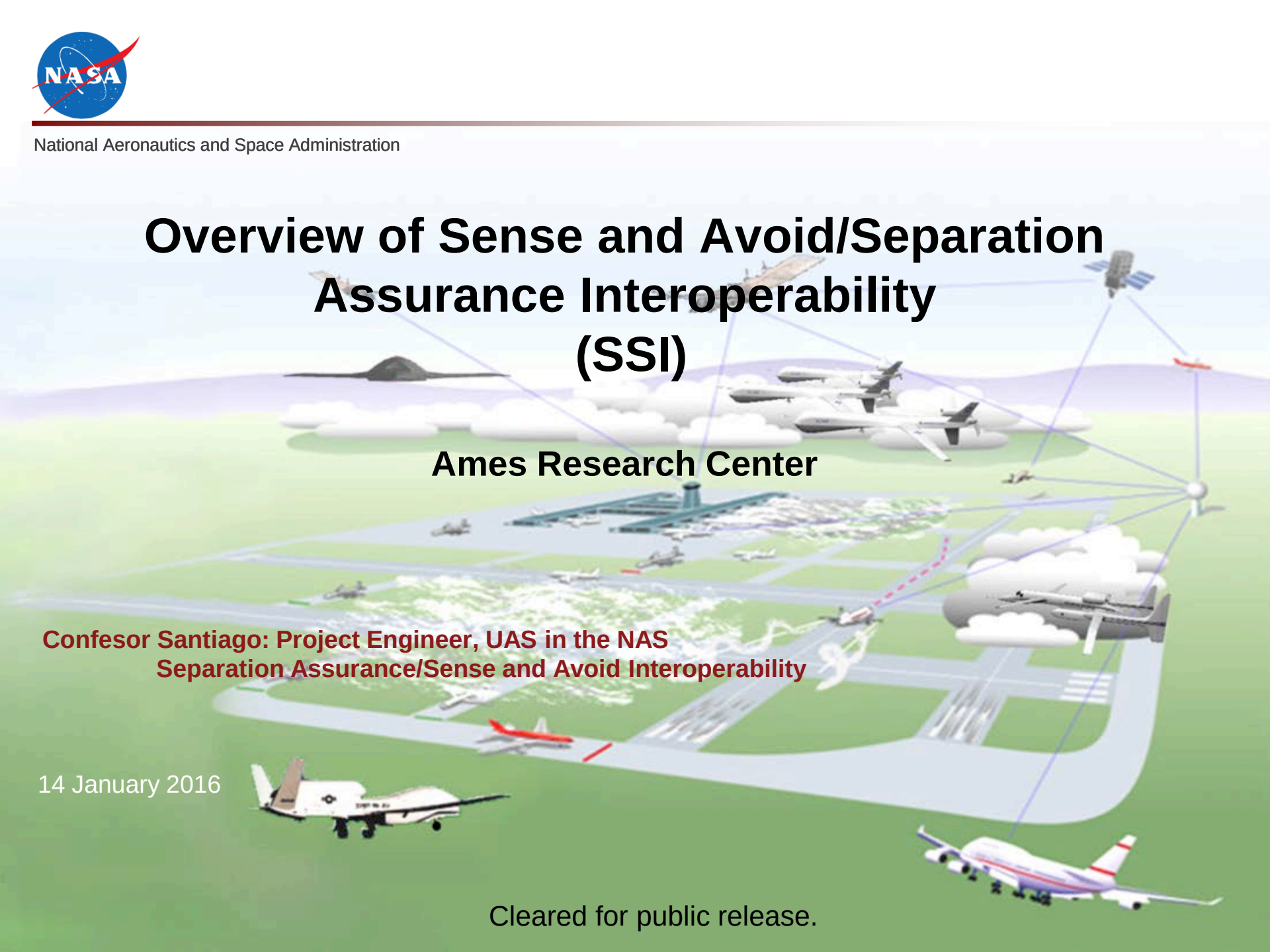
National Aeronautics and Space Administration

# Overview of Sense and Avoid/Separation Assurance Interoperability (SSI)

## Ames Research Center



**Confesor Santiago: Project Engineer, UAS in the NAS**
**Separation Assurance/Sense and Avoid Interoperability**

14 January 2016

# Overview

- Motivation and Scope
- Detect and Avoid - Capabilities and Models
- Example Results

# Motivation

**Interoperability?**

Air Traffic Control

Airspace Procedures

"See and Avoid"

Instrument Flight Rules (IFR)

Visual Flight Rules (VFR)

**Safety**

**Requirements?**

All aircraft are required to ***"see and avoid"*** and ***remain well clear*** of other traffic

**"Detect and Avoid"**

Unmanned Aircraft Systems (UAS)

# Scope

- Stakeholder: RTCA Special Committee (SC) 228
  - RTCA: Public-Private committee for developing consensus on critical aviation modernization issues
  - SC-228: Initial phase is to develop standards for civil UAS equipped to operate under Instrument Flight Rules.
  - Operational Environment: UAS transitioning to and from Class A airspace (18k feet and above) or special use airspace traversing Class D, E, and G airspace in the process.

- Detect and Avoid - Minimum Operational Performance Standards
  - Equipment requirements for UAS's detect and avoid system in order to operate in the National Airspace System safely
  - Surveillance, alerting, guidance, human-machine interface requirements

# Well Clear Background

- Well clear is vague, subjective, but vitally important, because it's the basis of developing a detect and avoid system

- A well clear separation standard is recommended to be,

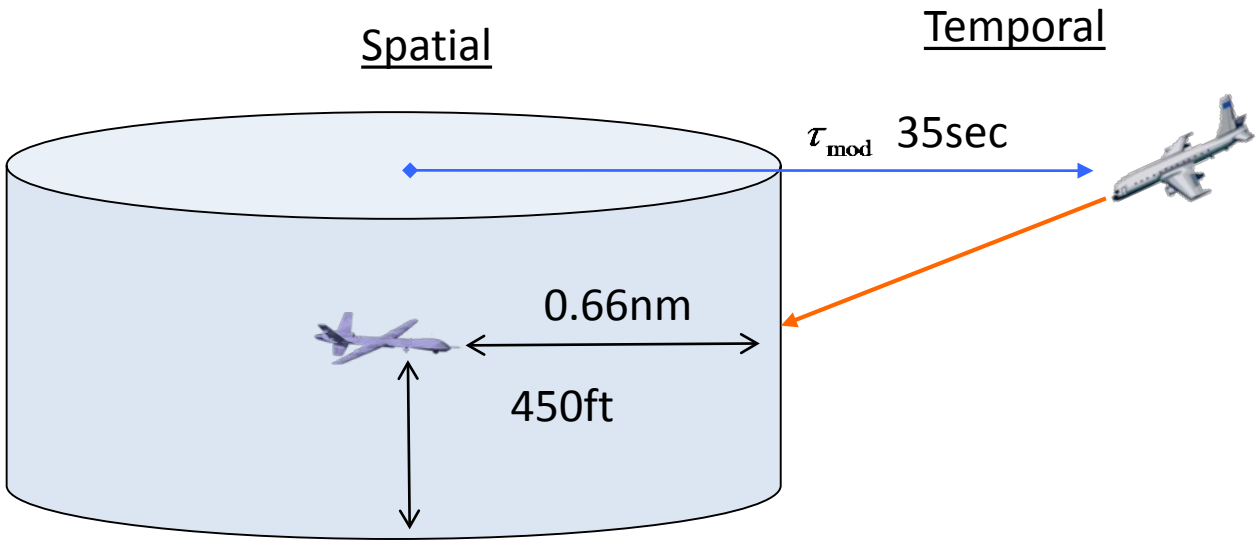
  Large enough to:

  – Avoid inducing collision avoidance maneuvers
  – Avoid excessive concern for pilots of proximate piloted aircraft
  – Minimize traffic alert issuances by air traffic control

  But, small enough to:

  – Prevent the need for large deviations that potentially disrupt traffic flow and ATC separation management plans

# Well Clear Definition




*Cook, S. P., Brooks, D., Cole, R., Hackenburg, D., Raska, V., "Defining well clear for unmanned aircraft systems," In Proceedings of AIAA Infotech @ Aerospace, AIAA 2015-0481, January 2015*

# Capabilities

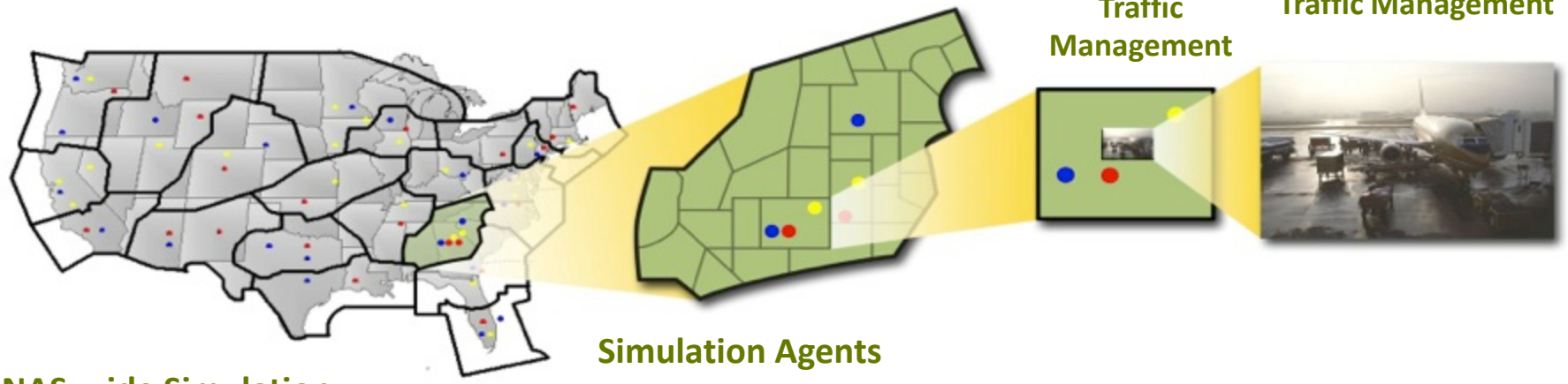
# Airspace Concept Evaluation System (ACES)

National Traffic Management

Regional Traffic Management

Local Approach and Departure Traffic Management

Airport and Surface Traffic Management



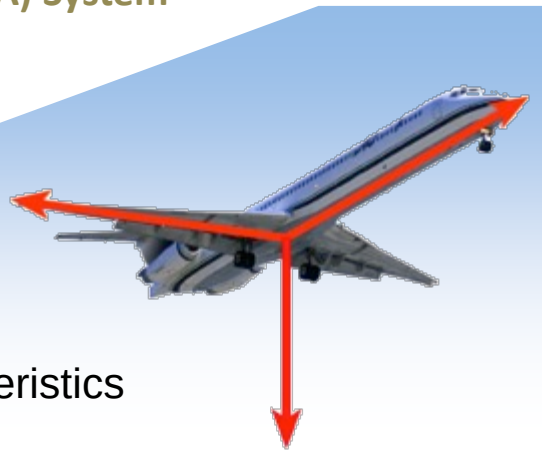
## NAS-wide Simulation

- 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
- UAS Detect-and-Avoid (DAA) System [JADEM]

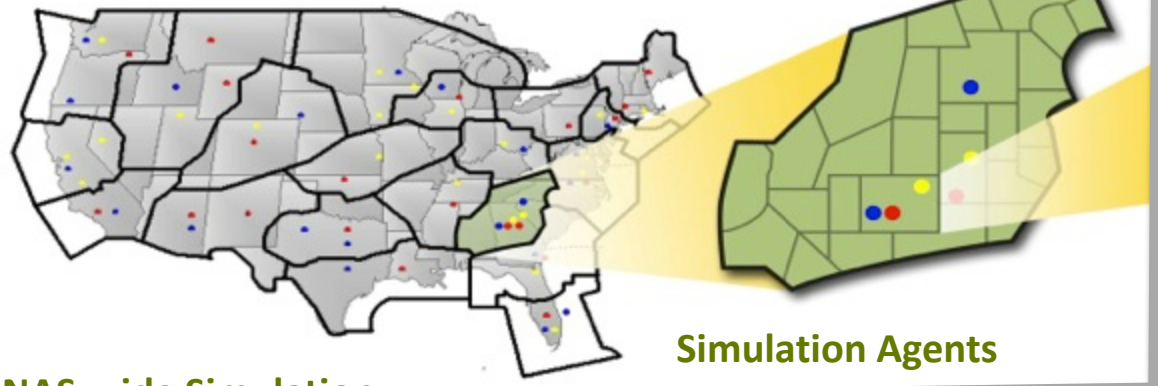
4-DOF Trajectory Model
Aerodynamic models of aircraft
Models replicate pilot behavior
User-definable uncertainty characteristics



# Airspace Concept Evaluation System (ACES)

National Traffic Management

Regional Traffic Management



NAS-wide Simulation

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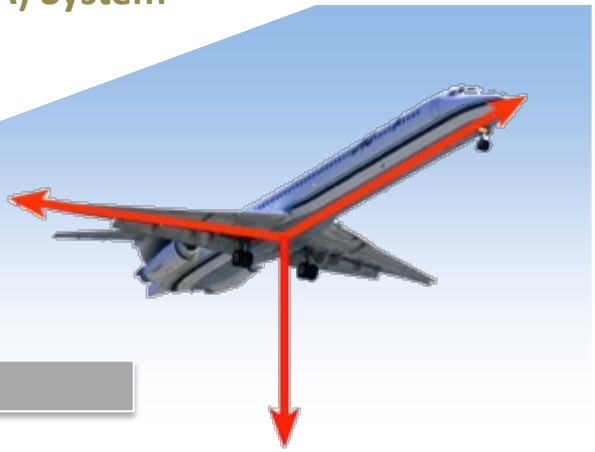
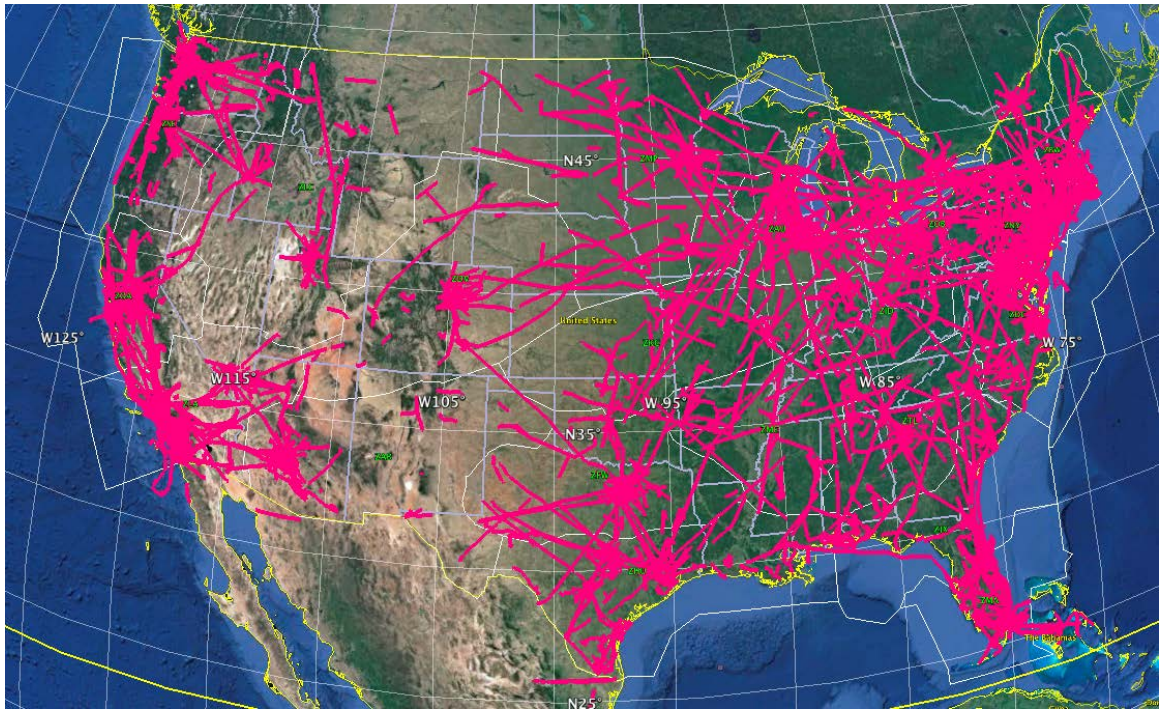


# UAS Mission Characteristics

| | UAS group | Duration (per flight) | Cruise Speed (knots) | Cruise Alt. (ft) | Flight Pattern |
|---|---|---|---|---|---|
| **Air Quality Monitoring** | Shadow-B | 1-4 hrs. | 74-89 | 4k,5k, and 6k ft AGL | Radiator Grid Pattern |
| **Cargo Transport** | Cessna 208 | varies | 137-172 | 2k-16k | Point to Point |
| **Atmospheric Sampling** | Global Hawk | 1.5-13 hrs. | 151-321 | 5k-35k ft AGL | Radiator Grid Pattern |
| **On-demand Remote Air Taxi -Cirrus** | Cirrus SR22T | varies | 153-166 | 6k-11k | Point to Point |
| **On-demand Remote Air Taxi - Mustang** | Cessna Mustang | varies | 156-340 | 9k-20k | Point to Point |
| **Strategic Fire Monitoring** | Predator-B | 20 hrs. | ~209 | 31k ft MSL | Radiator Grid Pattern |
| **Tactical Fire Monitoring** | Shadow-B | 1-1.5 hrs. | 72-75 | 3k-7k AGL | Circular Loitering Orbit |
| **Flood Inundation Mapping** | Aerosonde | 1-4 hrs. | 46-51 | 4k ft AGL | Radiator Grid Pattern<br>Point to Point |
| **Flow Stream Monitoring** | Aerosonde | 1-4 hrs. | 46-51 | 4k AGL | Radiator Grid Pattern<br>Point to Point |
| **Border Patrol** | Predator-B | 2-7 hrs. | 129-173 | 4k – 15k AGL | Radiator Grid Pattern |

# Large Database of Historical Flight Tracks

- 3-months database of historical radar data courtesy of RADES (84th Radar Evaluation Squadron)
  - Data contain the radar hits collected from hundreds of radar sites in U.S
  - Developed methodology for associating distinct tracks and classify tracks as IFR or VFR (cooperative and non-cooperative)

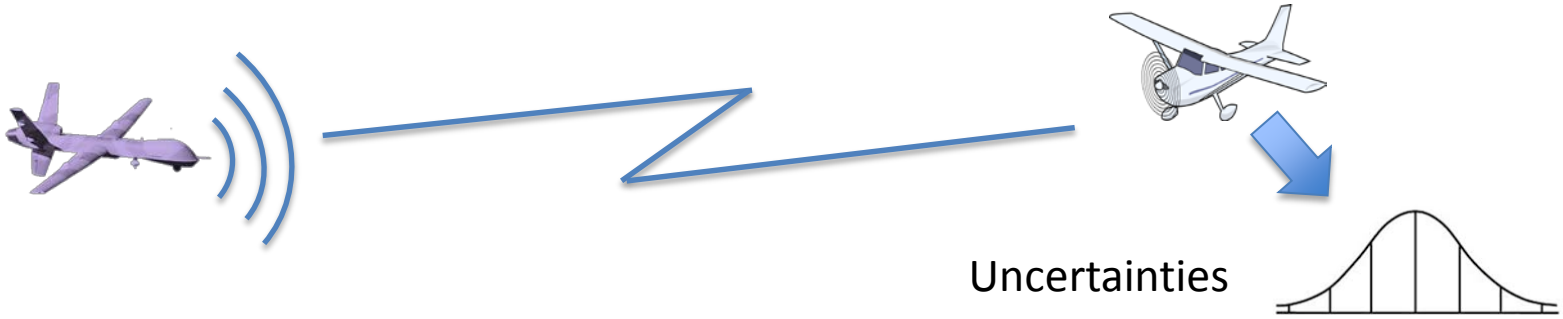



Cooperative VFR Traffic – July 25, 2013

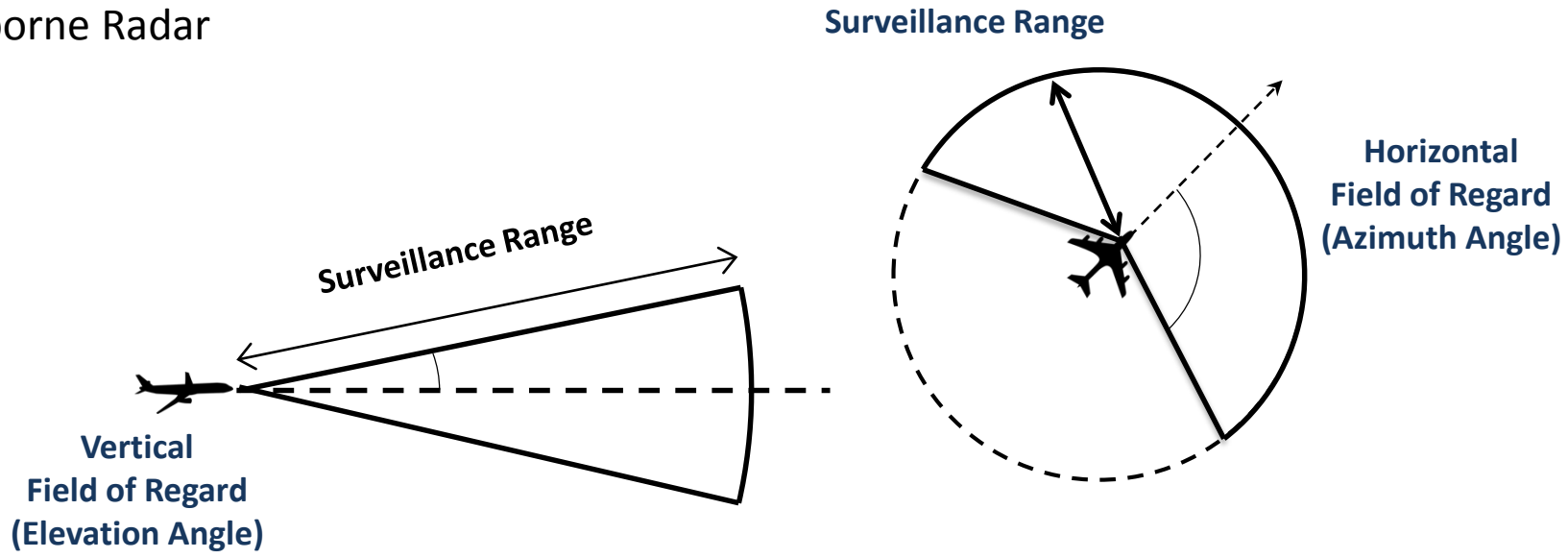
Cleared for public release.

# Detect and Avoid Models

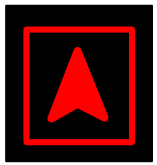
# Surveillance




- Automated Dependent Surveillance – Broadcast (ADS-B)
- Mode S/C Transponder
- Airborne Radar



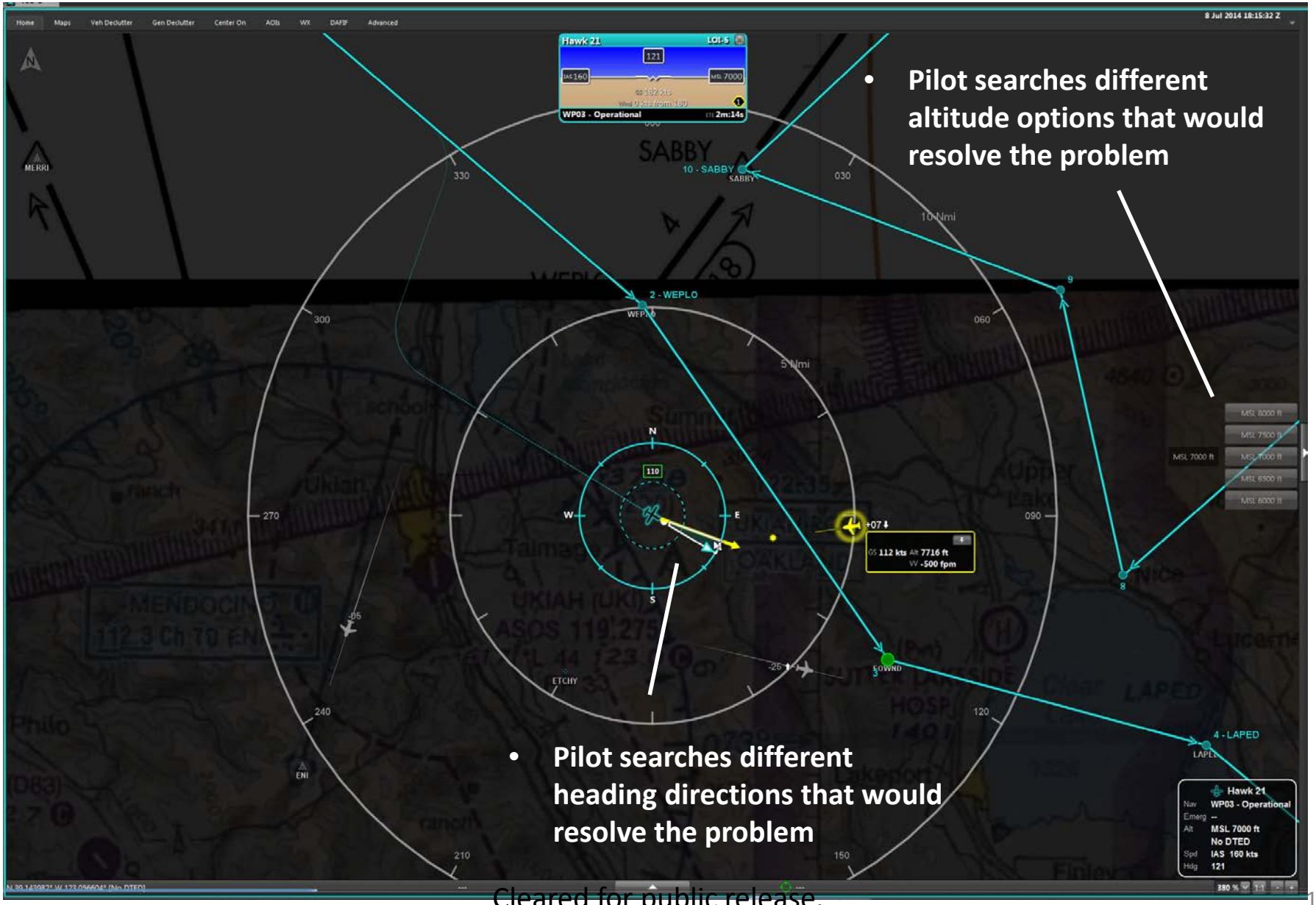
# Alerting

| Symbol | Name | [1]Alert Time | [2]Separation | Pilot Action |
|---|---|---|---|---|
|  | DAA Warning Alert | 25 seconds | Horz: 0.75 nmi<br>Vert: 450 feet<br>Tau: 35 sec | • ***Immediate action required***<br>• Notify ATC as soon as practicable after taking action |
|  | Corrective DAA Alert | 55 seconds | Horz: 0.75 nmi<br>Vert: 450 feet<br>Tau: 35 sec | • On current course, ***corrective action required***<br>• Coordinate with ATC to determine an appropriate maneuver |
|  | Preventive DAA Alert | 55 seconds | Horz: 1.0 nmi<br>Vert: 700 feet<br>Tau: 35 sec | • On current course, corrective action ***should not be required***<br>• Monitor for intruder course changes<br>• Talk with ATC if desired |

1. Alert time is approximately the timeliness prior to predicted loss of well clear an alert is displayed to pilot
2. Separation values are similar well clear separation definition, however small buffers do (can) exist

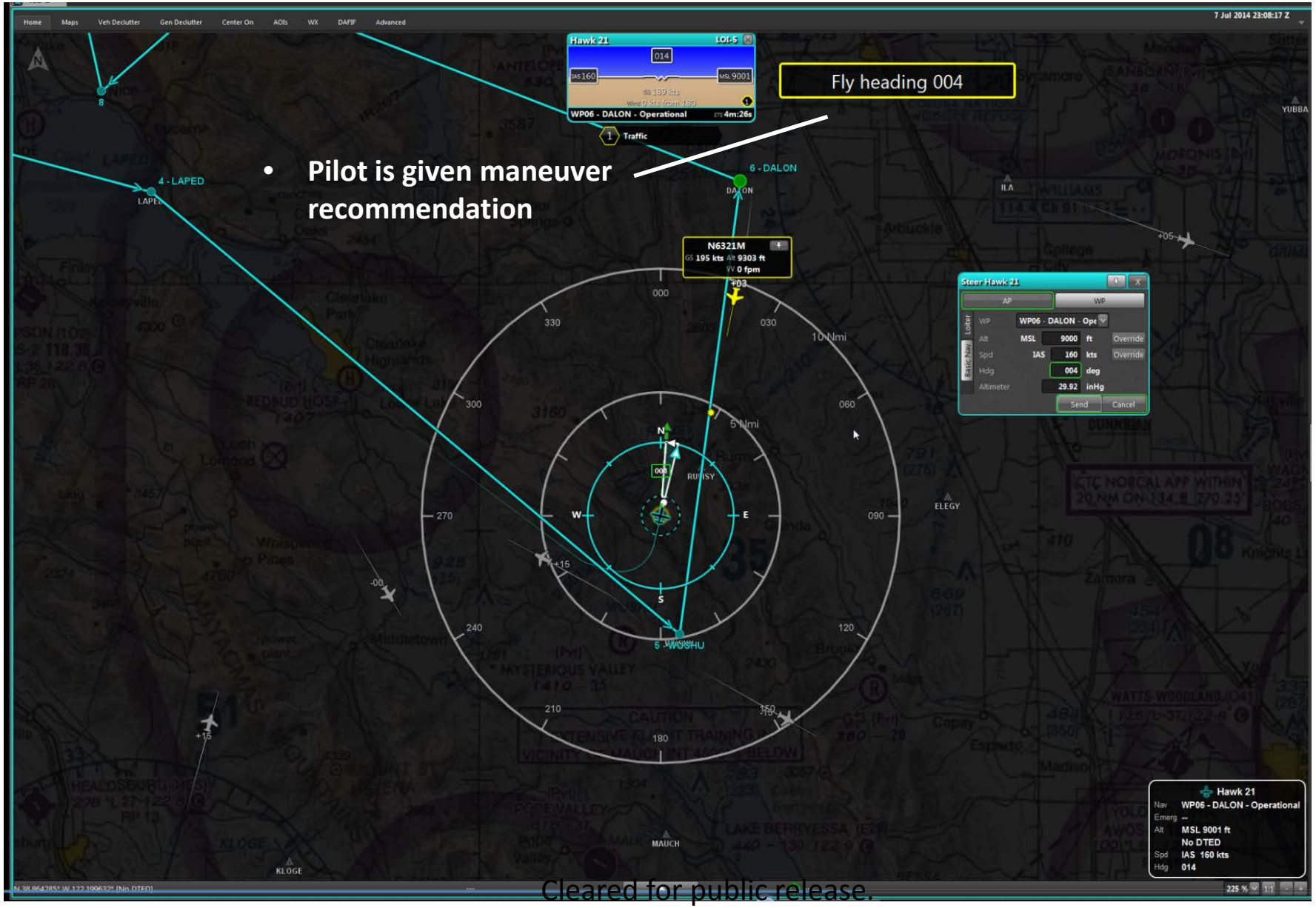
# Detect and Avoid Maneuver Guidance

# Vector Planner

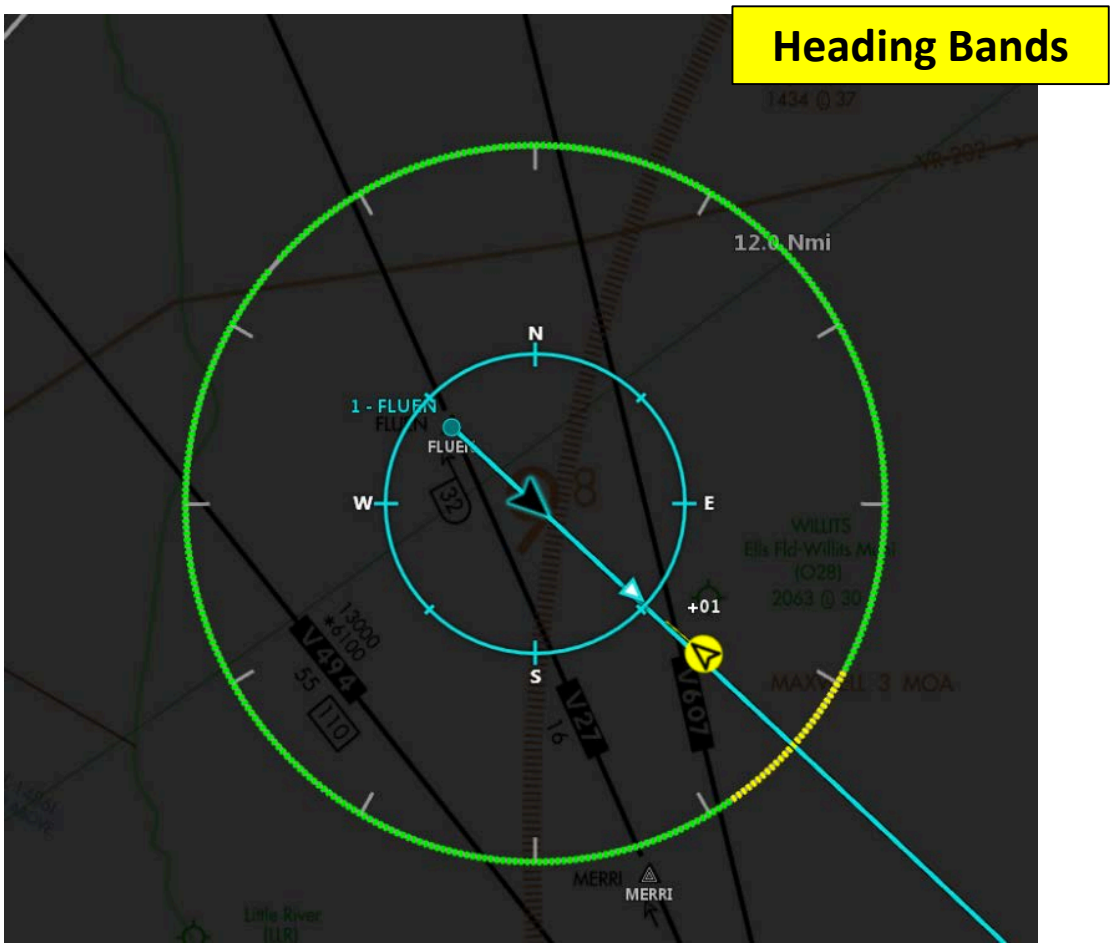


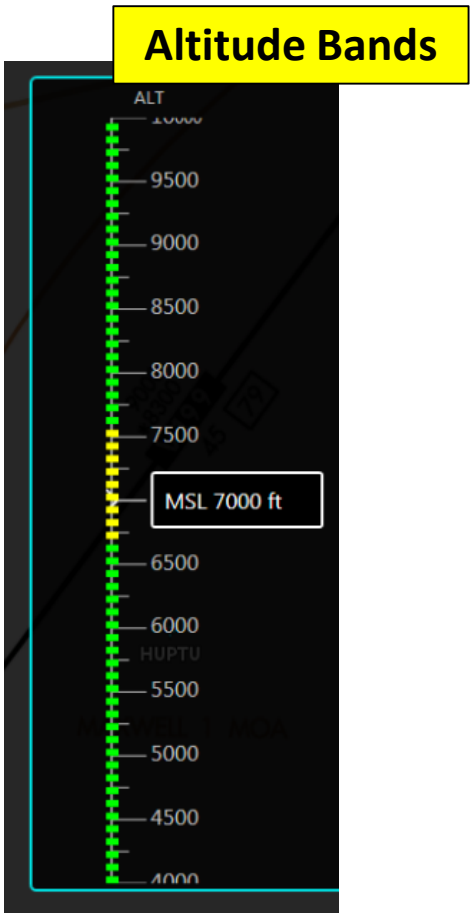

- **Pilot searches different altitude options that would resolve the problem**
- **Pilot searches different heading directions that would resolve the problem**

# Autoresolver



# OmniBands

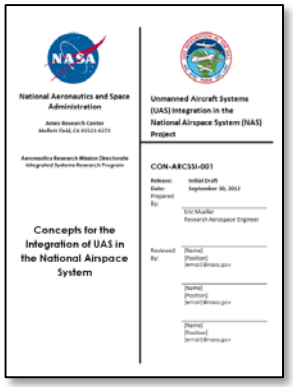



- Pilot receives ranges of heading and altitude maneuvers in which would maintain well clear against alerted traffic (green bands), and which would not (yellow bands)
- OmniBands display is our current baseline for guidance/display requirements

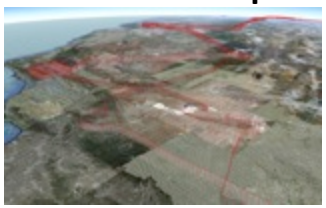
# How All Research Capabilities Tie Together

New UAS-related modeling and simulation capabilities




UAS-NAS integration concepts

**19 UAS mission profiles**

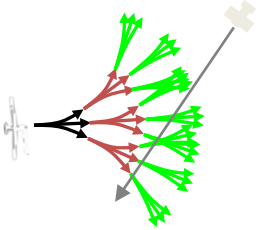


**17 UAS types**

**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

Cleared for public release.

# Results

# Surveillance Requirements (ACES Simulation)

- Research Objective:
  - Analyze the performance of updated sensor (ADS-B, TCAS, and radar) range and fields of regard requirements and sensitivities against Draft MOPS Alerting requirements
  - Assess airborne radar intruder detection frequency against realistic NAS traffic (IFR, cooperative VFR, and non-cooperative VFR) to inform radar tracker requirements

- Results, Conclusions, and Recommendations
  - 5-nm range appears to cover 99% of potential warning alerts DAA system would encounter with non-cooperative VFR providing verification that 5-nmdeclaration range for airborne radar is suitable
  - When UAS had at least one non-cooperative VFR intruder in its field of regard, there were 3 or fewer non-cooperative aircraft 98% of the time

# Integrated Human-in-the-loop Experiment (Test 1)

- Research Objective:
  - Evaluate air traffic controller acceptability of UAS maneuvers in response to detect and avoid advisories and pilot performance for remaining Well Clear

- Results, Conclusions, and Recommendations:
  - Controllers reported maneuvers requested between 60 and 90 seconds until closest point of approach were acceptable, and at 120 seconds were unacceptable.
  - Size of requested maneuvers was frequently judge to be too large, indicating a difference between the separation standard used by UAS pilots to remain Well Clear and manned aircraft.

# Integrated Human-in-the-loop Experiment (Test 2)

- Research Objective:
  - Evaluate the pilot's ability to remain well clear as a function of detect-and-avoid display features and whether the display was stand-alone or integrated within the main traffic display

- Results, Conclusions, and Recommendations:
  - Of all advanced maneuver guidance tested, maneuver recommendations (Autoresolver) were the most effective in aiding the pilots to remain well clear
  - Although non-cooperative aircraft can only be detected at a limited range, most losses of Well Clear can be prevented given alert time of at least 60 seconds to closet point of approach

# DAA Self-Separation Alerting Methods, Performance, and Robustness Study (ACES Simulation)

- Research Objective:
  - Gather data to support development of alerting logic, methods, and performance requirements using cooperative and non-cooperative VFR traffic and the SC-228 definition of Well Clear considering target level of safety and NAS-interoperability

- Interim Results, Conclusions, and Recommendations:
  - DAA Warning Alerts that actually result in a loss of well clear have at least 15 seconds of lead time to LOWC in 83% of cases
  - 72% of DAA Warning alerts resulted in a loss of well clear suggest alerting criteria is within suitable performance bounds
  - Even though a large proportion of false alerts were observed, most of the encounter fall near the well clear boundary, thus trading these false alerts for minimizing missed alerts seemed acceptable
  - Also, given the low frequency of DAA alerts (about 1 every 10 flight hours), these large false alert proportions are minimal

Self-Separation Alerting Requirements for DAA MOPS

# Upcoming: Flight Test 4

## Objectives:

1. Validate DAA requirements in stressing cases that drive MOPS requirements
   - High-speed intruder ( > 500 knots )
   - Low-speed intruder ( ~ 100 knots )
2. Validate collision avoidance/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors
3. Validate well clear recovery guidance when well clear is lost in the presence of realistic sensor, tracking and navigation errors
4. Validate DAA alerting and guidance requirements under normal circumstances in the presence of realistic sensor, tracking and navigational errors

*Key verification and validation activity for RTCA SC-228*

# Questions?

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UAS Integration in the NAS: SSI-ARC Sub-team

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