National Aeronautics and Space Administration

Simulation and Flight Test Data Collection to Support Phase 1 Detect-and-Avoid MOPS

Ames Research Center

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Separation Assurance/Sense and Avoid Interoperability

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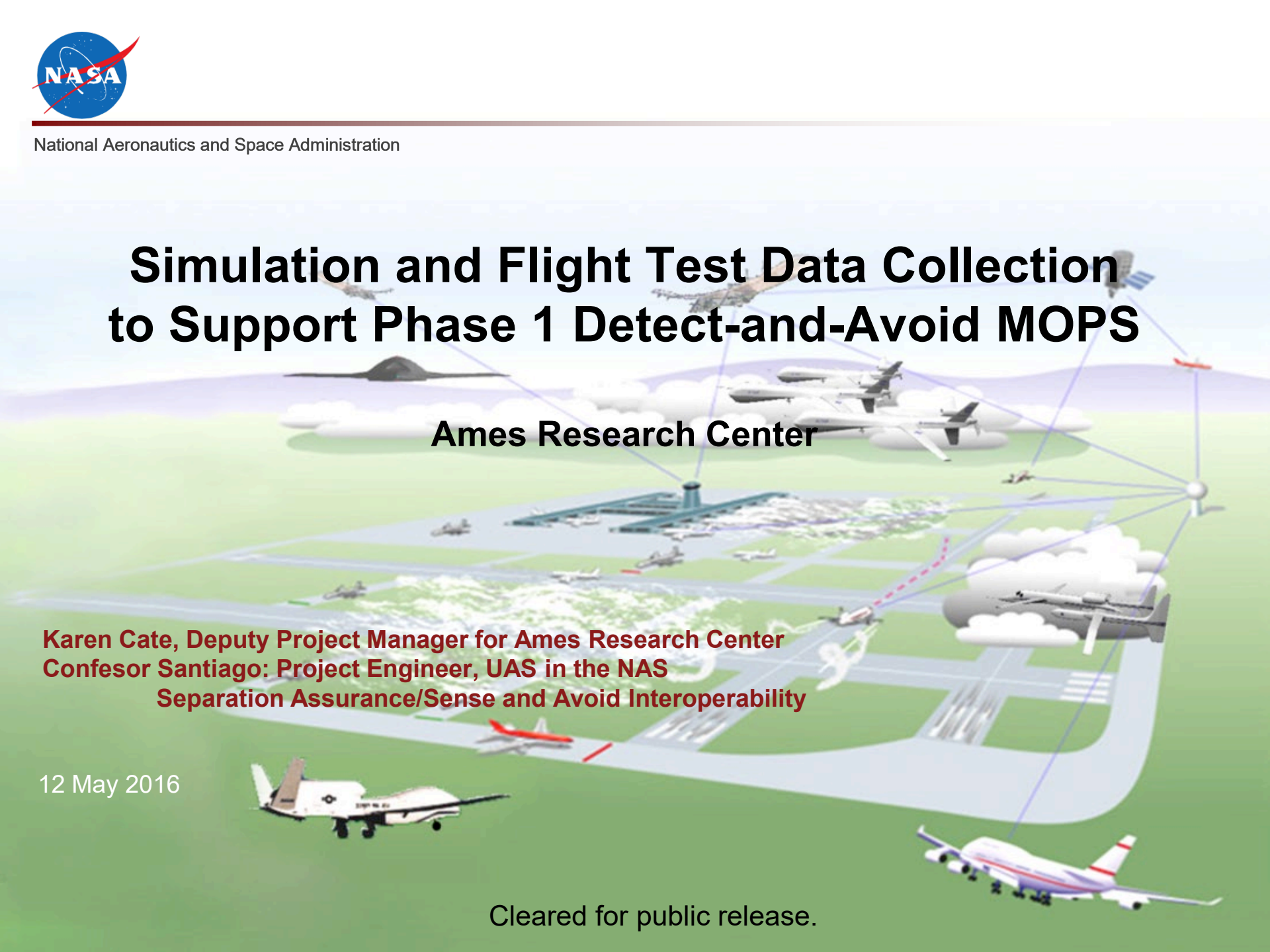


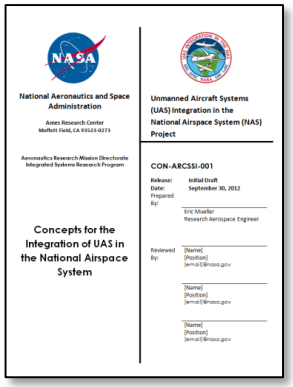
Cleared for public release.

Challenges to Integrating UAS into the NAS

- What's the impact on current traffic in the NAS
  - Encounter rates and geometries?
  - How would UAS interact with existing traffic, i.e. VFR.
- Surveillance requirements?
- Alerting requirements?
- Maneuver guidance?

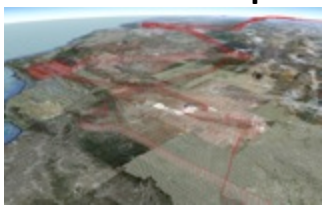
How Our Research Capabilities Tie Together

New UAS-related modeling and simulation capabilities



UAS-NAS integration concepts

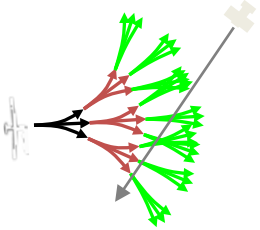
19 UAS mission profiles



17 UAS types

UAS models, comm. link models

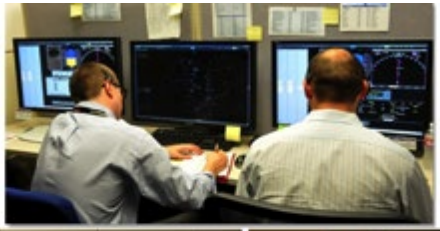
DAA algorithms



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

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-nm declaration 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

Non-Cooperative Sensor Surveillance Requirements for DAA MOPS

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
  - Evaluate 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.
  - Controllers judged that requested maneuvers were frequently too large
    - indicates a difference between the separation standard controllers use for manned aircraft and that used by UAS pilots to remain Well Clear.

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
    - 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
  - Most losses of Well Clear can be prevented given an alert lead time of at least 60 seconds prior to closest point of approach. This is not always possible when non-cooperative aircraft are involved, due to the short range at which they can be detected.

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 resulted in a loss of well clear providedat least 15 seconds of lead time to LOWC in 83% of cases
  - 72% of DAA Warning alerts resulted in a loss of well clear. This suggests that alerting criteria is within suitable performance bounds
  - Even though a large proportion of false alerts were observed, most of the encounters fall near the well clear boundary. 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 proportion of false alerts is considered 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

Definition of Success and Evaluation Criteria

- **Objective 2: Validate TCAS/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors: (e) level-level TCAS RA encounters (mitigated TCAS RA maneuver, >10kft)**
- Success Criteria:
  - A timely (corrective initially) DAA alert is provided to the UAS pilot
    - 'Time of DAA corrective alert' is assessed to be reasonable and timely by the test engineer.
  - A corrective TCAS RA is generated for the primary intruder and the UAS pilot complies with TCAS RA guidance
    - Test engineer observes UAS pilot receipt of, and compliance with, TCAS RA for primary intruder.
  - Data collected: LVC log file, SAAProc log files, TCAS log files for ownship and intruder, SAAP file
- Evaluation Criteria:
  - UAS pilot receives DAA corrective alert with associated guidance
    - First 'time of DAA corrective alert' coincides (within TBD s) with ('yellow band guidance' on UA's current heading AND altitude) AND (horizontal ANDOR altitude 'green band guidance' indicating viable UA maneuvers to remain well clear): derived from alert and guidance time histories in JADEM csv file
  - Vertical DAA guidance indicates no viable vertical maneuvers in temporal proximity to TCAS RA
    - 'Red band guidance' displayed for all altitudes for DAA vertical guidance from TBD s prior to initial ' time of corrective TCAS RA' until expiration 'time of corrective TCAS RA'.
  - DAA alerting and guidance for the primary intruder are removed while a TCAS RA is present for the primary intruder
  - UAS pilot promptly evaluates (and complies with) TCAS RA guidance and avoids NMAC.
    - 'Ikhana maneuver time' is within TBD s of initial 'time of corrective TCAS RA'
    - 'commanded/observed maneuver' consistent with sense of TCAS RA ('climb' or 'descent')
    - No 'NMAC' recorded in analysis of DGPS truth data
  - DAA alert(s) and guidance are removed once the ownship is clear of threat
    - DAA alert status 'none' at some point after CPA and remaining 'none' until ***test termination***

FT4 TEST OBJECTIVES – SSIWest.2.e

Objective 2: Validate TCAS/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors: (e) level-level TCAS RA encounters (mitigated, >10kft).	**MOPS Sections 2.2.4.2.4 Alerti 2.2.4.3 Determine Processing, Collision Avoidance Interopera**

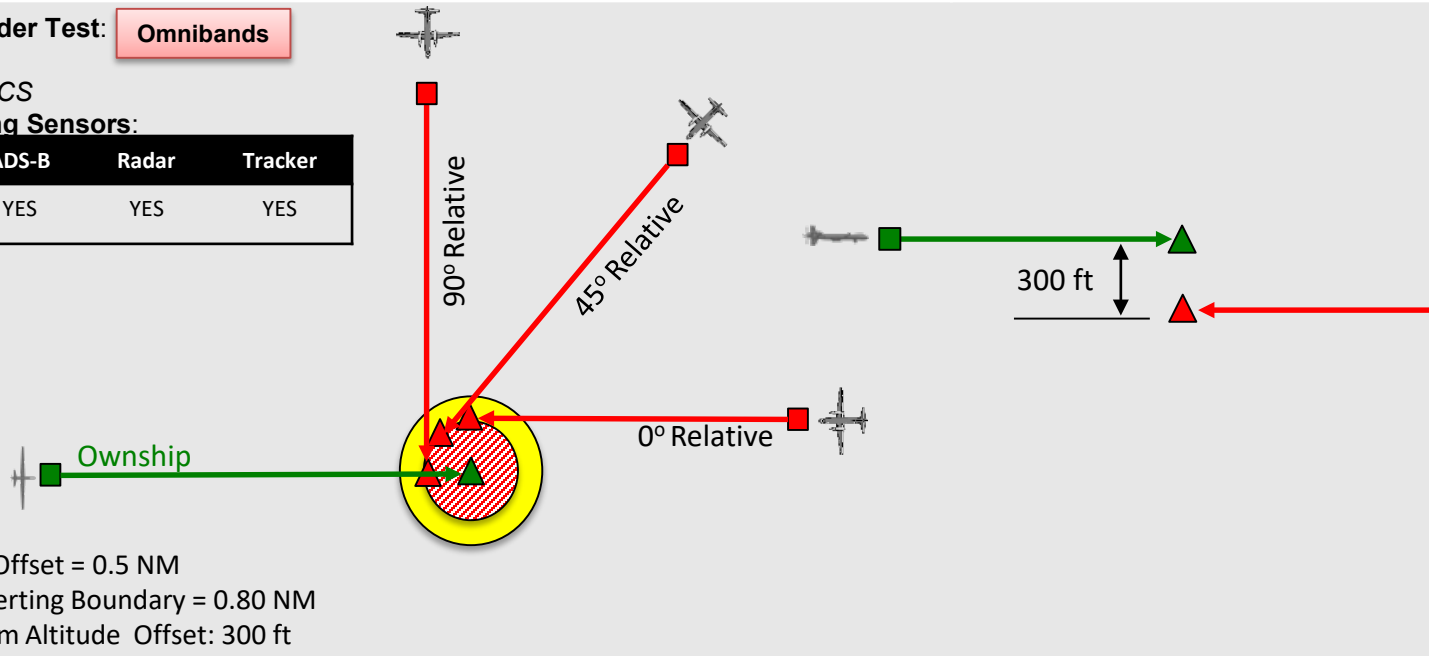
Configuration

System Under Test: Omnibands

Display: *VSCS*

Contributing Sensors:

TCAS	ADS-B	Radar	Tracker
YES (S)	YES	YES	YES



Test Objectives (TO)

1. Validate DAA alert timing allows pilot sufficient time to assess options and maneuver to remain well clear.
2. Validate DAA guidance to UAS pilot is appropriate (reasonable, timely & responsive).
3. Validate DAA alerting and guidance do not interfere with UAS pilot's ability to assess and follow TCAS RA guidance.

Success Criteria (retest if criteria not met)

1. A timely (corrective initially) DAA alert is provided to the UAS pilot.
2. A corrective TCAS RA is generated for the primary intruder and the UAS pilot complies with TCAS RA guidance.
3. Data collected: LVC log file, SAAProc log files, TCAS log files for ownship and intruder, SAAP file ('raw' surveillance data).

Test Method

- MANUEVER: Pilot disregards DAA guidance and follows TCAS guidance if consistent with test constraints.
- Aircraft speeds (non-accelerating): Ownship 150 KGS, Intruder 150/180/210 KGS
- Encounter Length: 1 min (IP to CPA)
- Stable Conditions: stable at the IP (1 minutes prior to CPA)
- Test Termination Criteria: targets diverging, range > 0.75 nmi., no DAA alerts displayed.
- Climb/Roll/Pitch Rates: Ownship 0/0/0, Intruder -2500 FPM/0/0
- Tolerance: ± 8 sec, ± 5 kts at IP crossing.

Summary of SSI-Ames FT4 Scenarios

- 72 Total Scenarios Planned:
  - Objective 1: 18
  - Objective 2: 29
  - Objective 3: 9
  - Objective 4: 16

- 2 Flights, 41 (57%) Scenarios Completed
  - Objective 1: 6 (4/29)
  - Objective 2: 12 (4/26) + 16 (4/29)
  - Objective 3: 3 (4/29)
  - Objective 4: 4 (4/26)

- 2 Planned Flights Remaining

- 1 Additional SC-228/Ames Flight Remaining

Questions?

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