

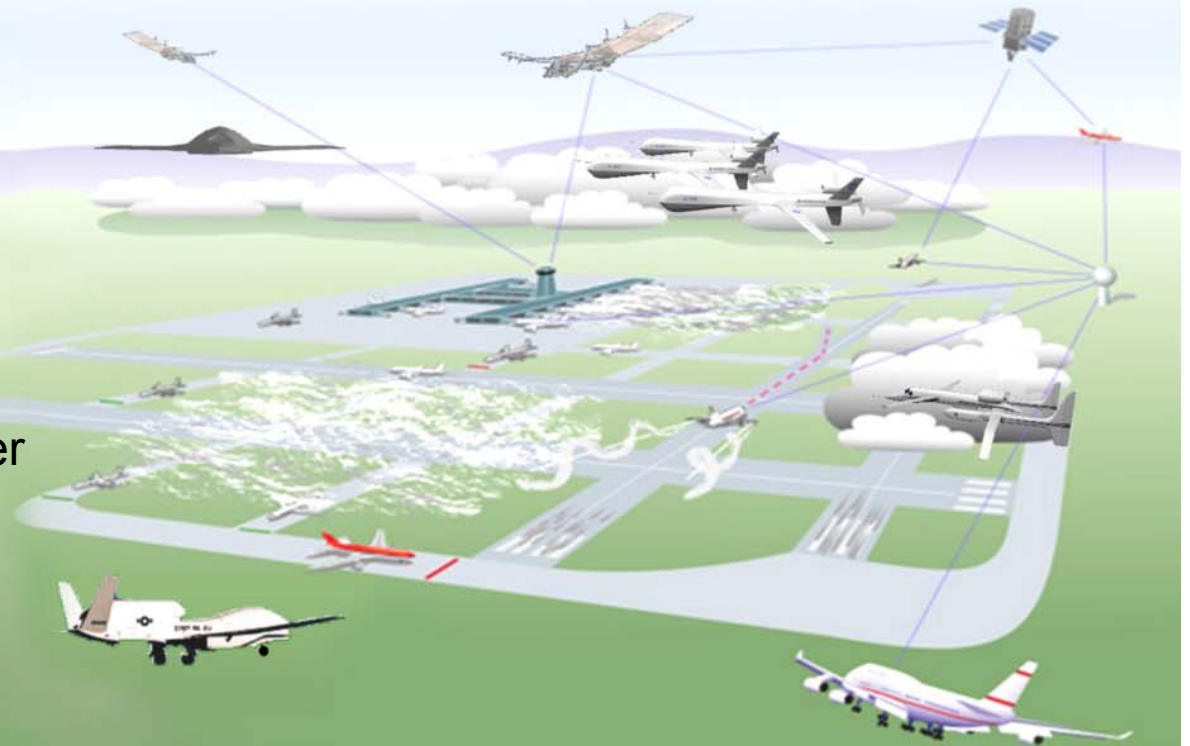
UAS Integration in the NAS

***Crew Systems & Aviation Operations Peer Review
Hampton, VA
January 28, 2016***

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Operations Branch
NASA Langley Research Center
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Content to be covered



- **Background and Motivation**
- **Research Objectives**
- **Organization**
- **Research Approach and Results**
- **Partnerships/collaborations**
- **Team Composition**
- **Future research**

Acronyms



AFRC	Armstrong Flight Research Center
ARC	Ames Research Center
ATC	Air Traffic Control
CAS	Controller Acceptability Study
CPA	Closest Point of Approach
DAA	Detect and Avoid
DAIDALUS	Detect and Avoid ALerting for Unmanned Systems
DPMf	Deputy Project Manager for
GRC	Glenn Research Center
HITL	Human-in-the-loop
HMD	Horizontal Miss Distance
HSI	Human System Integration
IT&E	Integrated Test and Evaluation
LaRC	Langley Research Center
LoWC	Loss of Well Clear
NAS	National Airspace System
OV-1	Operational View 1
UAS	Unmanned Aerial System
SAA	Sense and Avoid
SS	Self-Separation
SSI	Separation Assurance-Sense and Avoid Integration
SSV	Self-Separation Volume
TC	Technical Challenge
TCAS	Traffic alert and Collision Avoidance System
UTM	UAS Traffic Management
WC	Well Clear

Most Helpful

DAA	Detect and Avoid
SAA	Sense and Avoid
SS	Self-Separation
SSV	Self-Separation Volume
WC	Well Clear
SSI	Separation Assurance-Sense and Avoid Integration
DAIDALUS	Detect and Avoid ALerting for Unmanned Systems
LoWC	Loss of Well Clear

UAS Background

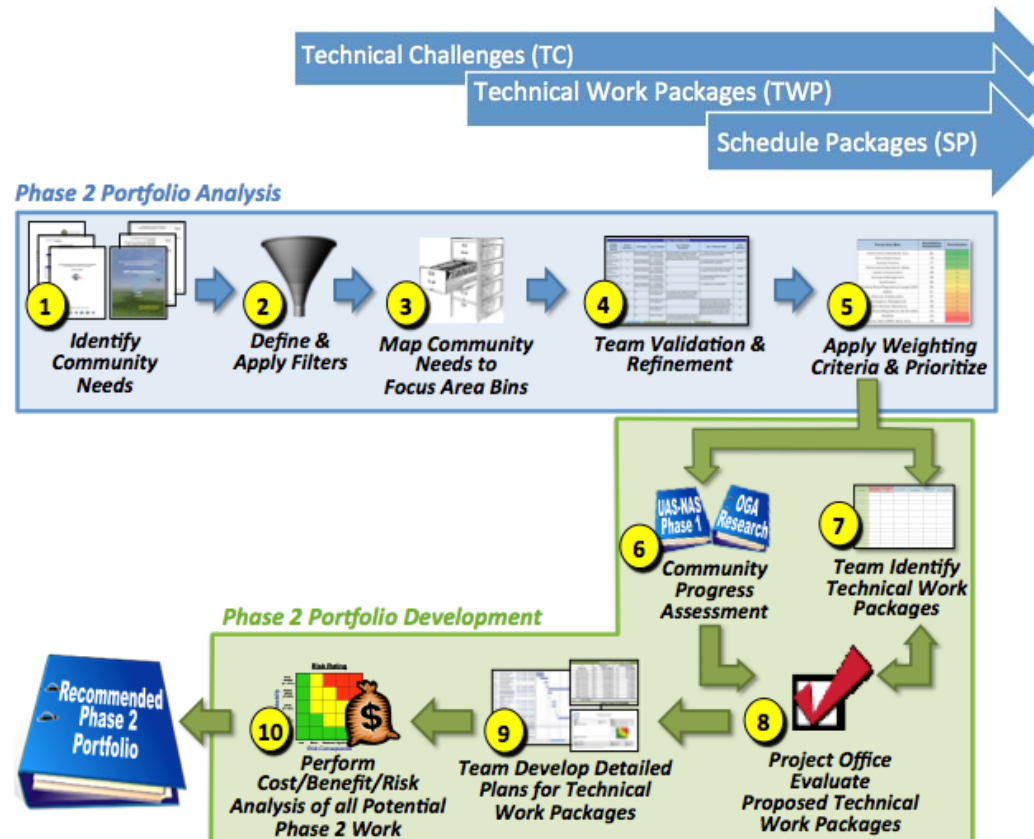


- UAS operate today under many restrictions
 - Certificate of Authorization or Waiver (COA) for public use
 - Experimental certificate for civil use
- Goal is to move toward more routine access
- UAS span a wide range of size and performance
 - Small UAS (<55 lbs.) will be covered by separate rulemaking
 - Our research interest is in larger UAS, interacting with air traffic services in non-segregated airspace
- Routine access will require new equipage, standards, rules, procedures, etc., and supporting research

Community Needs Influence on Project Portfolio and Technical Challenges



- **Content Decision Process (CDP) included:**
 - technical needs of the UAS Community
 - Community Progress Assessment
 - Focus Area Bins
 - Cost/benefit/risk analysis

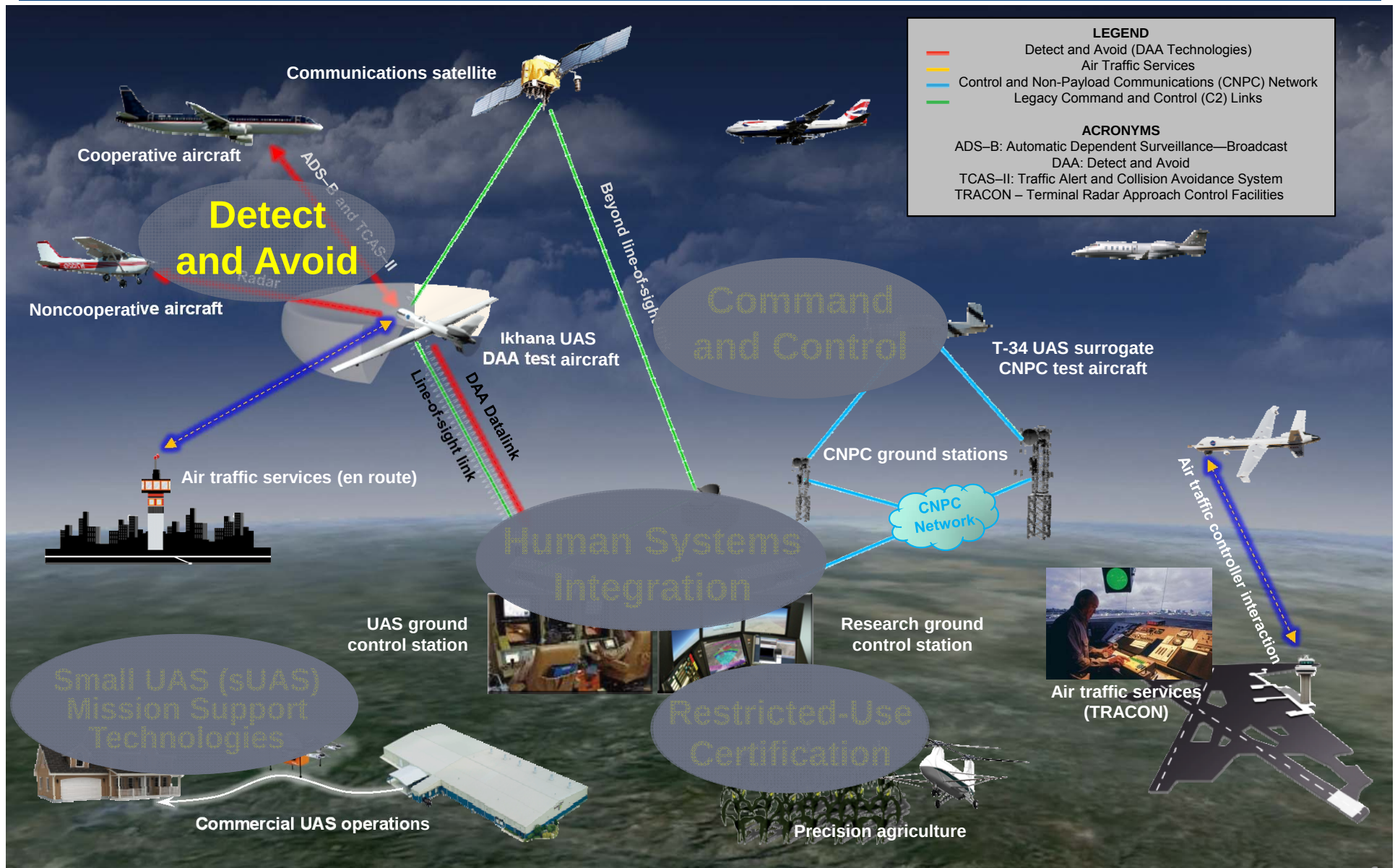
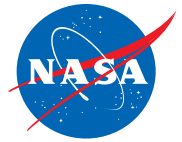


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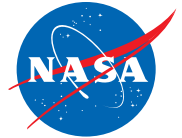
Apply Weighting Criteria & Prioritize

Focus Area Bins	Quantitative Assessment	Prioritization
Performance Standards (C2)	81	H
Test Infrastructure	81	H
Performance Standards (SAA)	80	H
Human Factors	78	H
Certification Criteria & Methods of Compliance	59	M
Airspace Management Policies & Procedures	59	M
Levels of Automation	58	M
Operating Rules/Regulations (Large UAS)	54	M
Safety Criteria & Methods of Assessment	51	M
Operating Rules/Regulations (Small UAS)	47	M
External Collaboration	47	M
Contingency Management	46	M
Airport Surface Operations	45	M
Weather	34	L
Security (Non-CNPC items only)	28	L

UAS-NAS Project



NASA Strategic Plan Flow Down to UAS-NAS Project



STRATEGIC GOAL

2: Advance understanding of Earth and develop technologies to improve the quality of life on our home planet

OBJECTIVE

2.1: Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research

PERFORMANCE GOAL *UAS-NAS*

2.1.6: Support transformation of civil aircraft operations and air traffic management through the development, application, and validation of advanced autonomy and automation technologies, including addressing critical barriers to future routine access of Unmanned Aircraft Systems (UAS) in the National Airspace System, through the development and maturation of technologies and validation of data.

Annual Performance Indicators (APIs) *UAS-NAS*

AR-14-8: Conduct a human-in-the-loop (HITL) simulation where unmanned aircraft are mixed with manned aircraft and subjected to a range of test conditions

AR-15-7: Deliver data, analysis, and recommendations based on integrated simulations and flight tests to the RTCA Special Committee on Minimum Operational Performance Standards (MOPS) for UAS to support preliminary MOPS development.

ARMD Strategic Plan Flow Down to UAS-NAS Project



AERONAUTICS STRATEGIC THRUST

Thrust 6: Enable Assured Machine Autonomy For Aviation

AERONAUTICS OUTCOME

Outcome (2015 – 2025): Initial Autonomy Applications with Integration of UAS into the NAS

UAS-NAS Project Goal

Goal: Provide research findings to reduce technical barriers associated with integrating Unmanned Aircraft Systems into the National Airspace System utilizing integrated system level tests in a relevant environment

UAS-NAS Research Themes

Research Theme 1: UAS Integration - Airspace integration procedures and performance standards to enable UAS integration in the air transportation system

Research Theme 2: Test Infrastructure - Test infrastructure to enable development and validation of airspace integration procedures and performance standards

UAS-NAS Technical Challenges



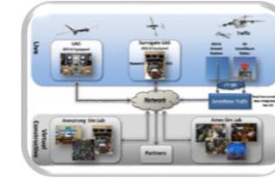
TC-SAA:
Sense and Avoid
Performance Standards



TC-C2:
Command & Control
Performance Standards



TC-HSI:
Human
Systems
Integration



TC-ITE:
Integrated
Test & Evaluation

NASA Langley DAA Research in support of the UAS in the NAS Project



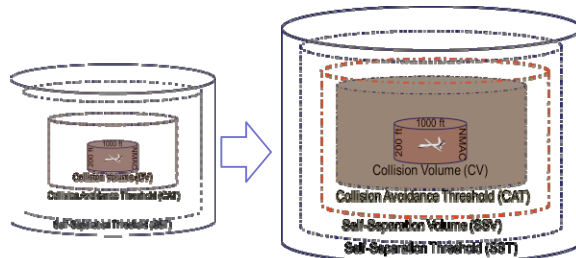
July 2012

March 2013

May-June 2014

July 2014

Concept of integration for UAS operations in the NAS,
Proceedings of the 28th International Congress of the Aeronautical Sciences (ICAS 2012), 2012.



Well Clear concept expanded to include a Self Separation Volume (SSV)

- Mathematical Model for Well-Clear.
- Implemented the WC definition in the DAA prototype capability known as Stratway+ (DAIDALUS)
- Developed bands-based SS pilot maneuver guidance
- Developed the HITL simulation environment to support the CAS series of experiments

1. Controller Acceptability Study (CAS1) HITL
2. Integrated-HITL

CAS2 Results

- A horizontal miss distance (HMD) of ~1.5 nmi and a 500' IFR-VFR vertical separation appears to be optimal for ATC

I-HITL Results

- First long-haul connectivity
- First look at TCAS interoperability

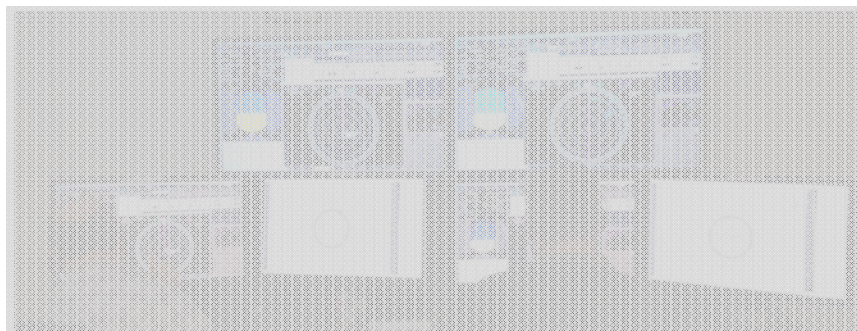
1. CAS2 HITL
2. Comm Gen2 Flight Test

CAS2 Results

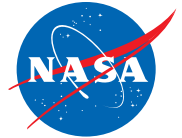
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FT Results

- First flight systems test
- Discovered & corrected software and connectivity issues



The Detect and Avoid (SAA) Challenge for UAS

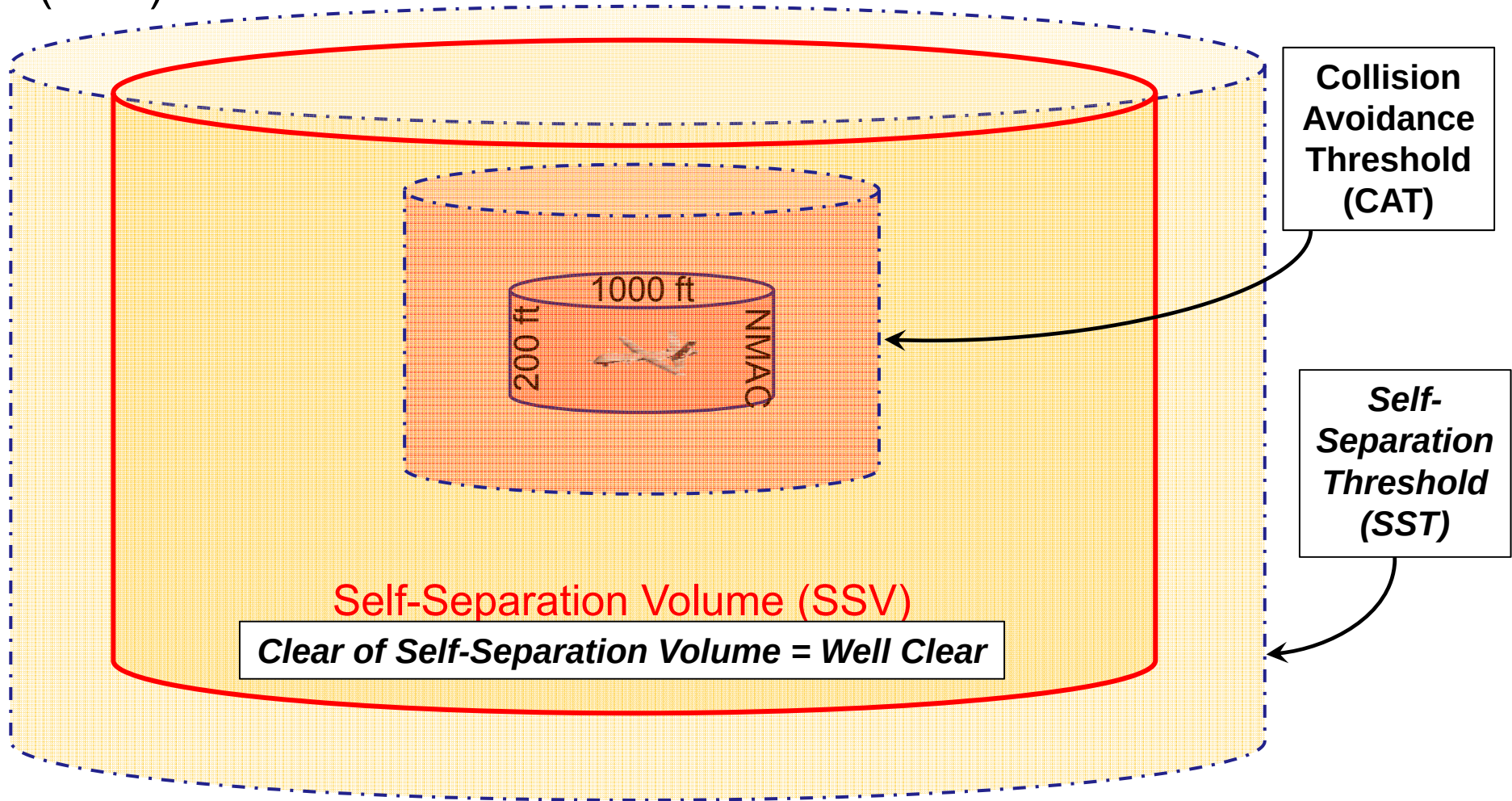


- Pilots are required to see and avoid other aircraft
 - 14CFR 91.111 (a) No person may operate an aircraft so close to another aircraft as to create a collision hazard.
 - 14CFR 91.113 (b) *General*. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.
- DAA-equipped UAS should seamlessly interoperate with other aircraft, air traffic services and existing collision avoidance technologies

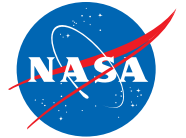
CV, CAT, SSV, SST and “Well Clear”



Workshop Model with NASA SAA Concept's Self-Separation Volume (SSV):



Note: CAT, SSV and SST boundaries are notional and generally not cylindrical



Self Separation Volume (SSV) Considerations

- SSV size should be large enough to avoid:
 - Corrective RAs for TCAS-equipped intruders
 - Safety concerns for controllers
 - Undue concern for proximate see-and-avoid pilots
- SSV size should be small enough to avoid:
 - Unnecessarily large maneuvers
 - Disruptions to traffic flow
 - Inefficient use of airspace
- SSV size should vary appropriately with operational area (airport vicinity, en route, etc.)

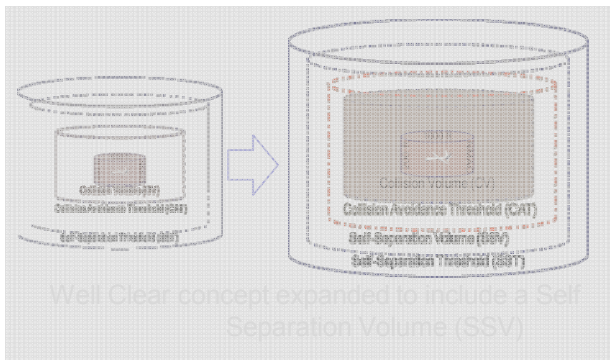
Determination of minimum and maximum operationally acceptable SSV sizes will inform the design space for required SAA surveillance accuracy

NASA Langley DAA Research in support of the UAS in the NAS Project



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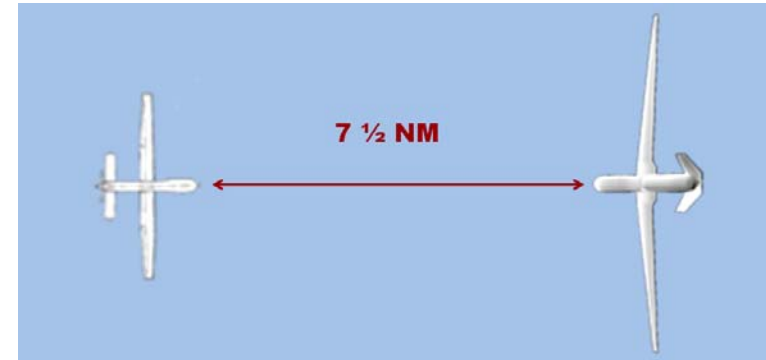
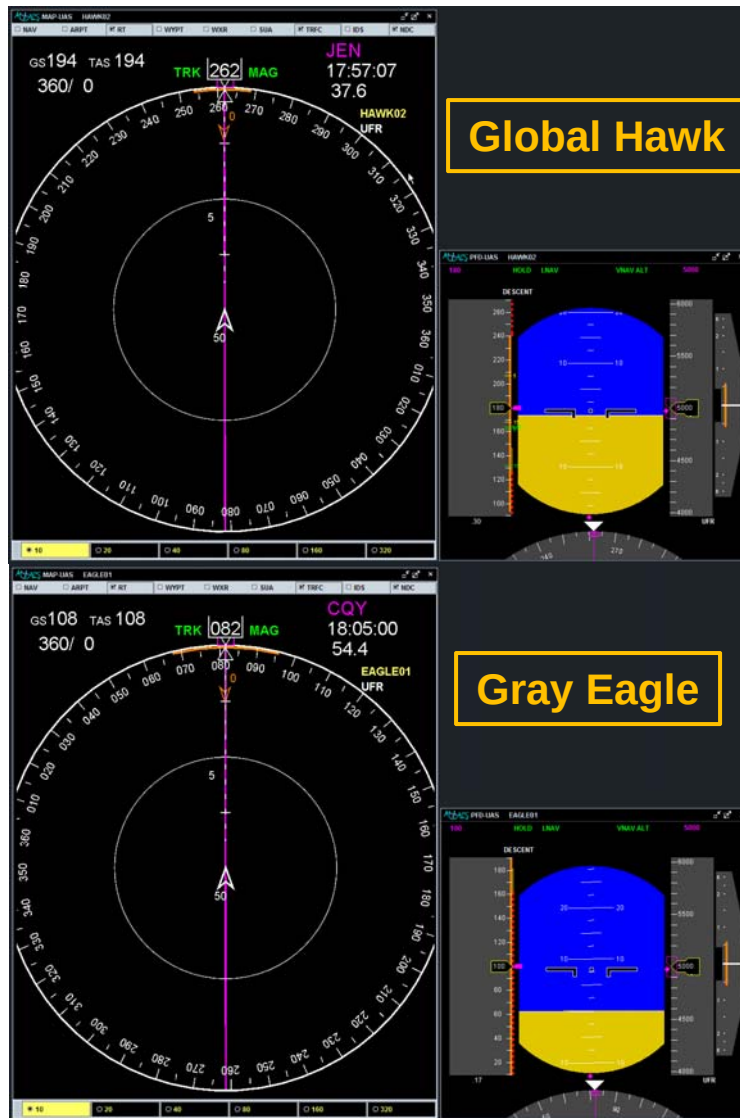
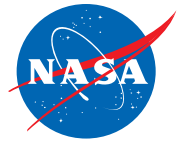
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Self Separation Bands Example



Self Separation Bands Example - 2



Head-On Encounter:

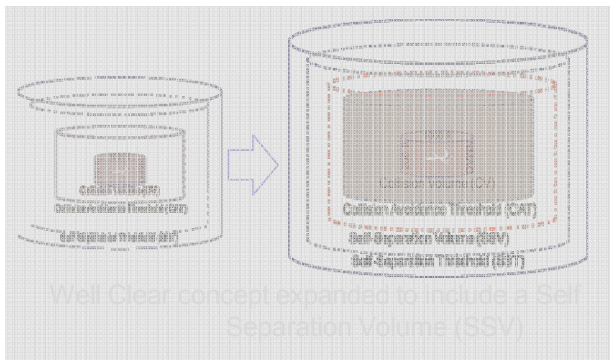
- “Global Hawk” (194 kts, 3 deg/sec turn)
- “Gray Eagle” (108 kts, 1 deg/sec turn)
- Declaration Time = 120 secs
- “TCAS Bands” (20 sec tau, .35 nmi HMD)
- Different Performance = Different Bands

NASA Langley DAA Research in support of the UAS in the NAS Project



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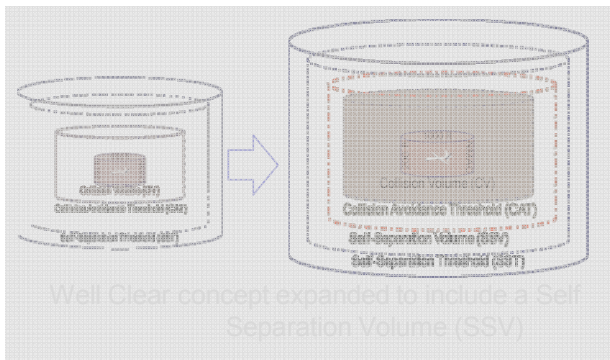


NASA Langley DAA Research in support of the UAS in the NAS Project



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LaRC DAA Research (Cont.)

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GA-FAA-NASA Flight Test	PT5 HITL	1. CASSAT HITL 2. Flight Test 3	Final Phase I MOPS research and support
LaRC Contribution: DAIDALUS SS maneuver guidance provided to pilot-in-command of Ikhana UAS	LaRC Contribution: DAIDALUS SS guidance integrated with the “Vigilant Spirit” Displays.	Collision Avoidance/Self Separation and Alerting Times (CASSAT) Integration of TCAS ii with DAIDALUS Studying minimum and maximum acceptable alerting times for projected well clear losses, from the perspectives of both ATC and the pilot-in-control.	Sensor Uncertainty Mitigation Characterize and mitigate effects of real-world sensor noise and uncertainty
Results - Verified stability of DAIDALUS with real sensor input - pilot feedback on guidance positive - Reduced risk for FT3 & FT4	Results: Bands-based guidance better than Info-Only and Vector-Based - Fewer Losses of Well Clear - Less severe - Faster reaction	Flight Test 3 Validation of DAA SS maneuver guidance algorithm with actual sensor suite input and actual TCAS-equipped intruders in pair-wise encounters	End-to-End V&V V&V of MOPS-representative DAA system from detection to avoidance (CPA) Flight Test 4 Validate DAIDALUS and sensor mitigation performance in flight environment DAIDALUS V&V Formal V&V of example DAA algorithm in MOPS



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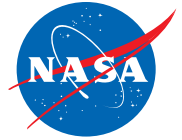
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Partnerships and Collaborations



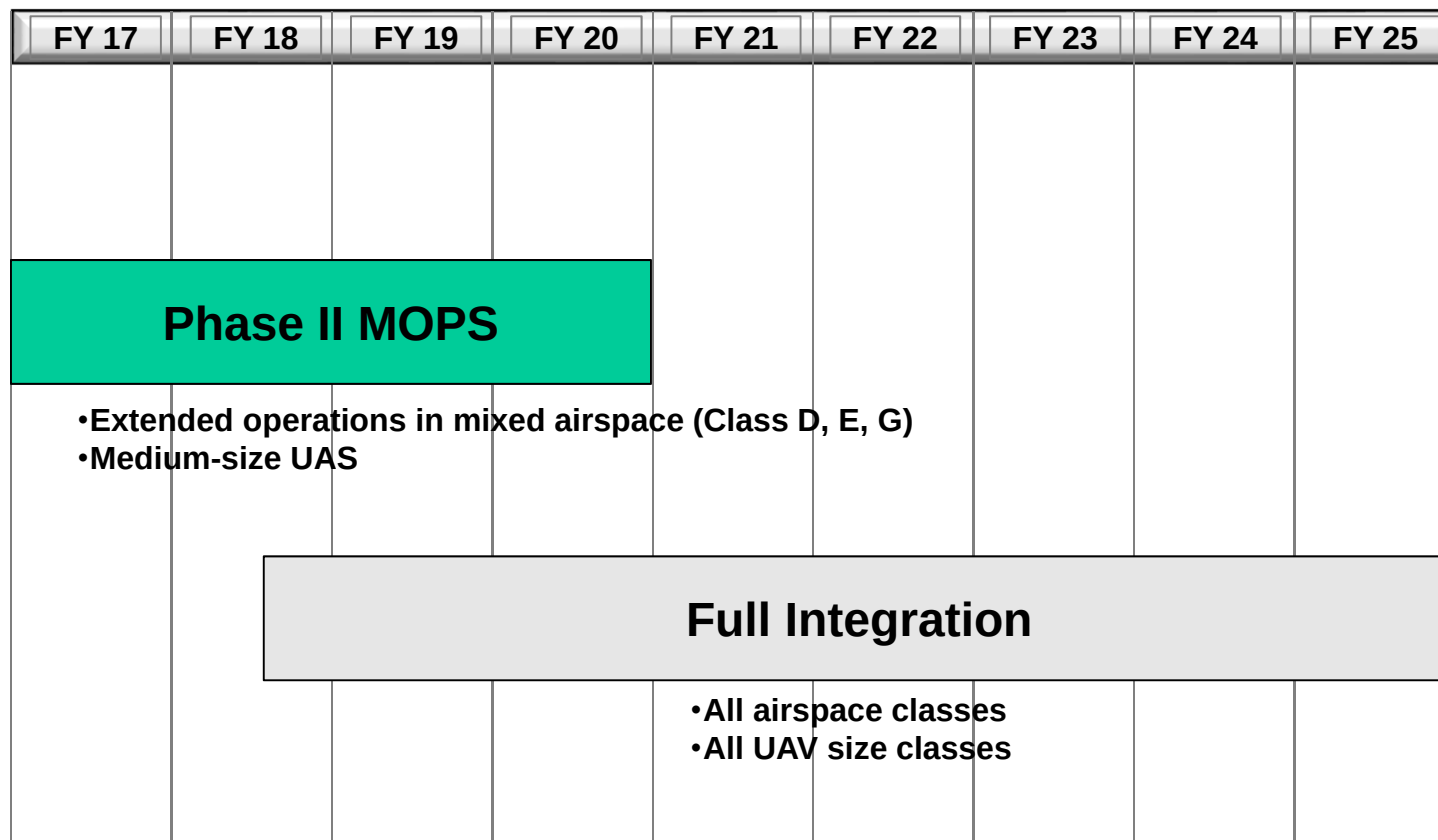
- **FAA**
- **RTCA SC228, subgroup leadership**
- **SAA SARP**
- **General Atomics ASI**
 - **Due Regard Radar**
 - **Conflict Prediction and Display System (CPDS)**
 - **LaRC initiated partnership for Project**
- **Honeywell**
 - **DAA Target Tracker**
- **AFRL & support contractors**
- **MIT LL**
- **Mitre**

Team Composition



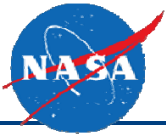
- Air Traffic Management
 - Airspace operations
 - Aviation operation concept and procedure development
 - Avionics systems & architectures
 - Crew/vehicle interaction technologies
 - Flight management
 - Human-Systems Integration
 - Simulation and modeling
 - Flight testing
 - Software development
 - Formal methods
 - Radar and surveillance sensors
 - Trajectory generation in the airspace system
- Workforce
 - 6.5 FTE
 - 8 WYE (supporting research activities, automation development, and simulation infrastructure development)

Future Research



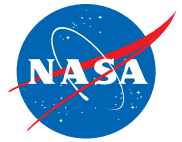
Opportunities:

- *DAIDALUS as single DAA approach for all UAS/airspace classes*
- *Expand DAIDALUS for VTOL, revolutionary aircraft*
- *Integrate UTM (UAS Traffic Mgmt) capabilities, concepts, community*
- *Utilize & grow SMARTNAS Testbed*
- *Integrate Autonomous Flight Rules (AFR) concepts, capabilities*



Questions?



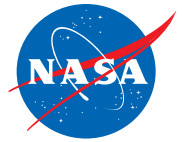


Self Separation and Collision Avoidance

From the SAA Workshop Final Report:*

- Self Separation (SS) Function
 - SS is “essential” and “could be the only function” of SAA
 - Intended as a means to remain “well clear”
 - “Normal/operational, non obtrusive maneuvers”
 - Maneuvers made early enough to avoid CA activation
- Collision Avoidance (CA) Function
 - CA engages “when all other modes of separation fail”
 - Intended as a means to avoid Near Mid-Air Collisions (NMACs)
 - CA maneuvers made “within a relatively short time horizon before closest point of approach [CPA]”

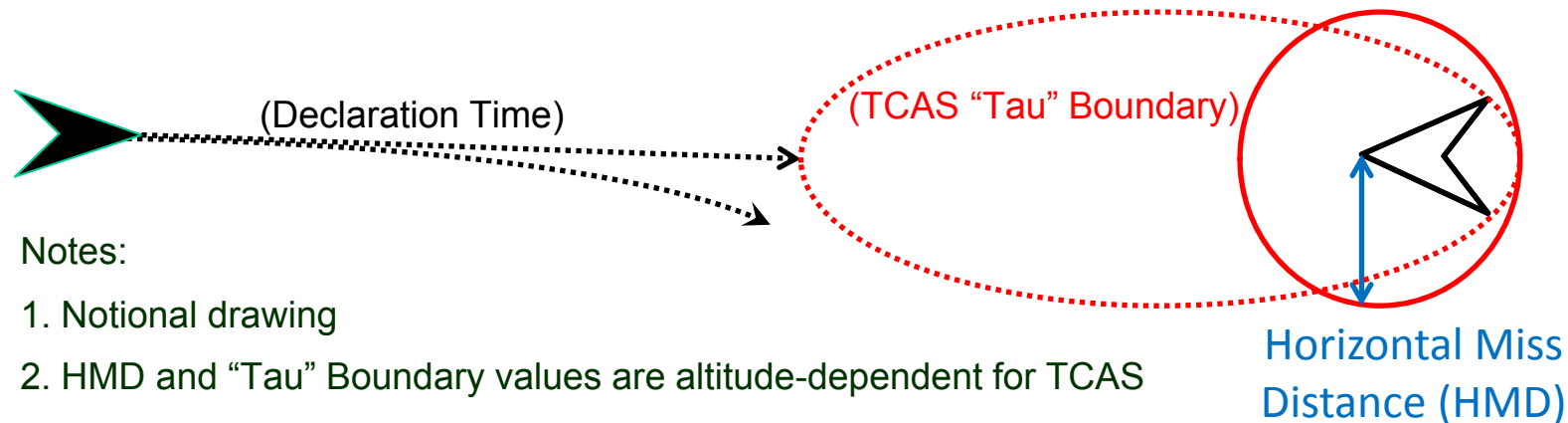
* Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS). Prepared by: FAA Sponsored Sense and Avoid Workshop, October 9, 2009.



TCAS-Compatible SSV and SS Algorithm

- UAS-NAS SSI East has developed a TCAS-compatible SSV and SS concept:
 - Consiglio M., Chamberlain J., Muñoz C., and Hoffler K. Concept of Integration for UAS Operations in the NAS. 28th International Congress of the Aeronautical Sciences, Brisbane, Australia, 23-28 September 2012
- SSI East has also developed a SS algorithm (Stratway+) to implement this SSV and concept:
 - César Muñoz, Anthony Narkawicz, and James Chamberlain, A TCAS-II Resolution Advisory Algorithm. Proceedings of the AIAA Guidance, Navigation, and Control Conference (GNC), AIAA-2013-4622, Boston, Massachusetts, August 2013
 - Anthony Narkawicz, César Muñoz, Jason Upchurch, James Chamberlain, and María Consiglio, A Well-Clear Volume Based on Time to Entry Point. Technical Memorandum, NASA/TM-2014-218155, January 2014
- Stratway+ provides a range of pilot guidance to remain well clear of other detected aircraft within a specified time

SAA “Self Separation Bands” Concept



Notes:

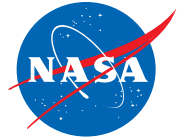
1. Notional drawing
2. HMD and “Tau” Boundary values are altitude-dependent for TCAS
3. Drawing assumes insufficient vertical separation (e.g., co-altitude)

If Ownship trajectory will pass within HMD laterally of intruder then

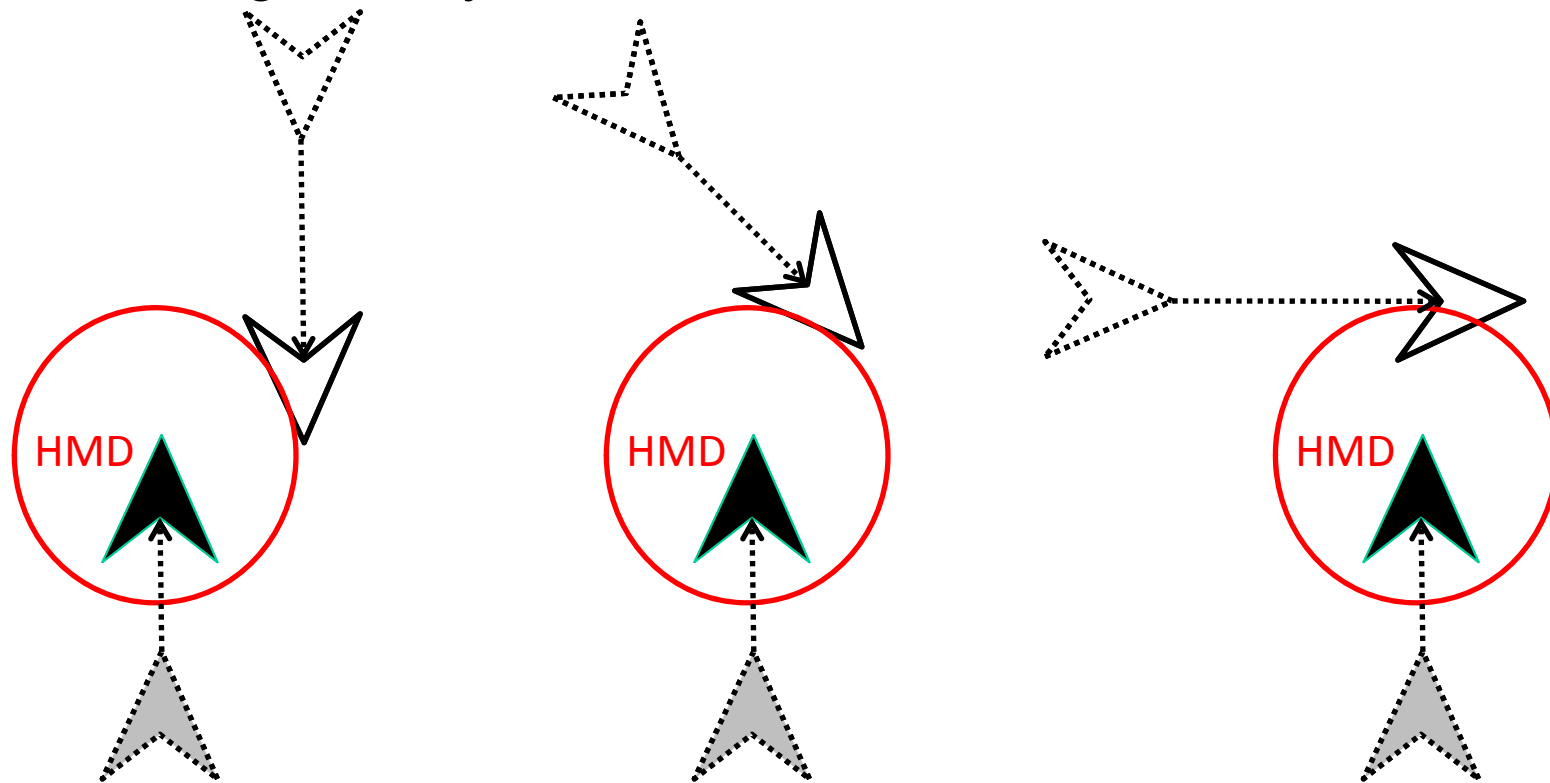
- “Self Separation Bands” will appear on Ownship trajectory when within specified declaration time of the Tau boundary
- Pilot will need to negotiate a trajectory change outside of Bands

No Bands will appear on trajectory if it will pass outside of HMD

HMD versus Encounter Geometry



- TCAS will not activate an RA if HMD is cleared, regardless of encounter geometry:

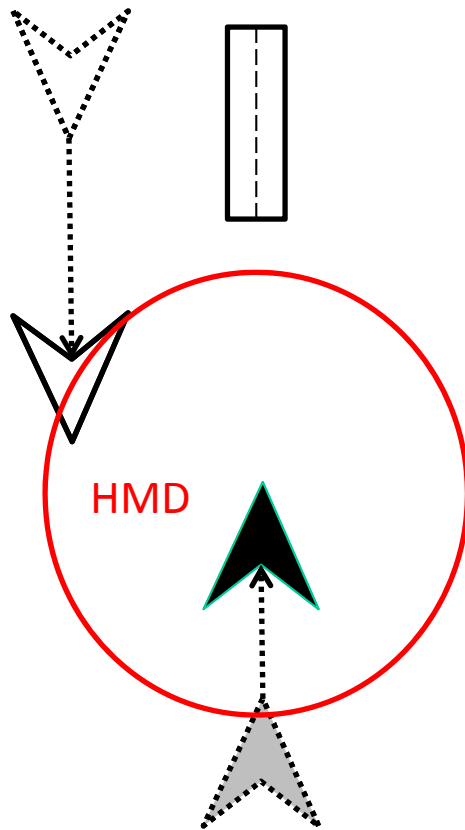


- Air traffic controllers and proximate manned aircraft pilots may desire more than TCAS HMD, especially for crossing geometries

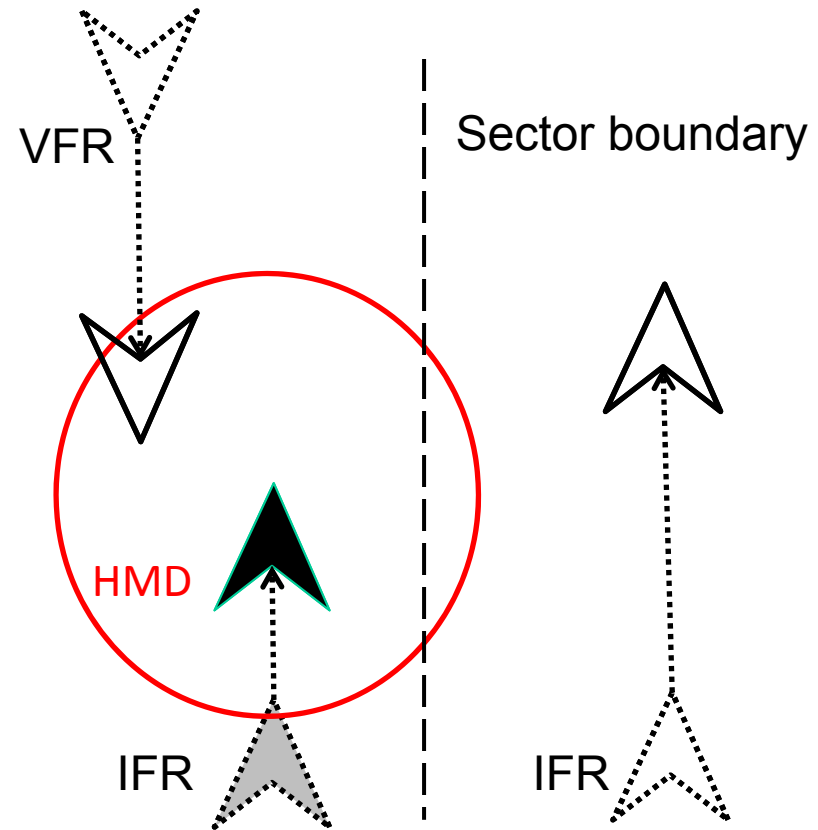
Unacceptably Large HMD



- Excessive lateral displacements will be disruptive to traffic flow:



UAS on final approach,
intruder on downwind leg



UAS "well clear" deviation
causes secondary conflicts

HMD = Horizontal Miss Distance

CAS1 Assumptions for UAS



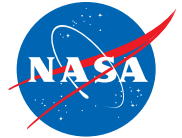
- A future environment where appropriate certified equipment, operational approvals, rules and procedures are in place to enable IFR “file and fly” access for UAS
- Today’s ATC environment and equipage with small changes to procedures and phraseology for UAS
- Nominal operations
 - No lost comm, lost command/control link, equipment failures
 - Pilot always in the loop (no autonomous operations)
 - Consistent ATC communication with minimal delays
- Trained UAS pilots with access to “sense and avoid” guidance

CAS1 Research Questions



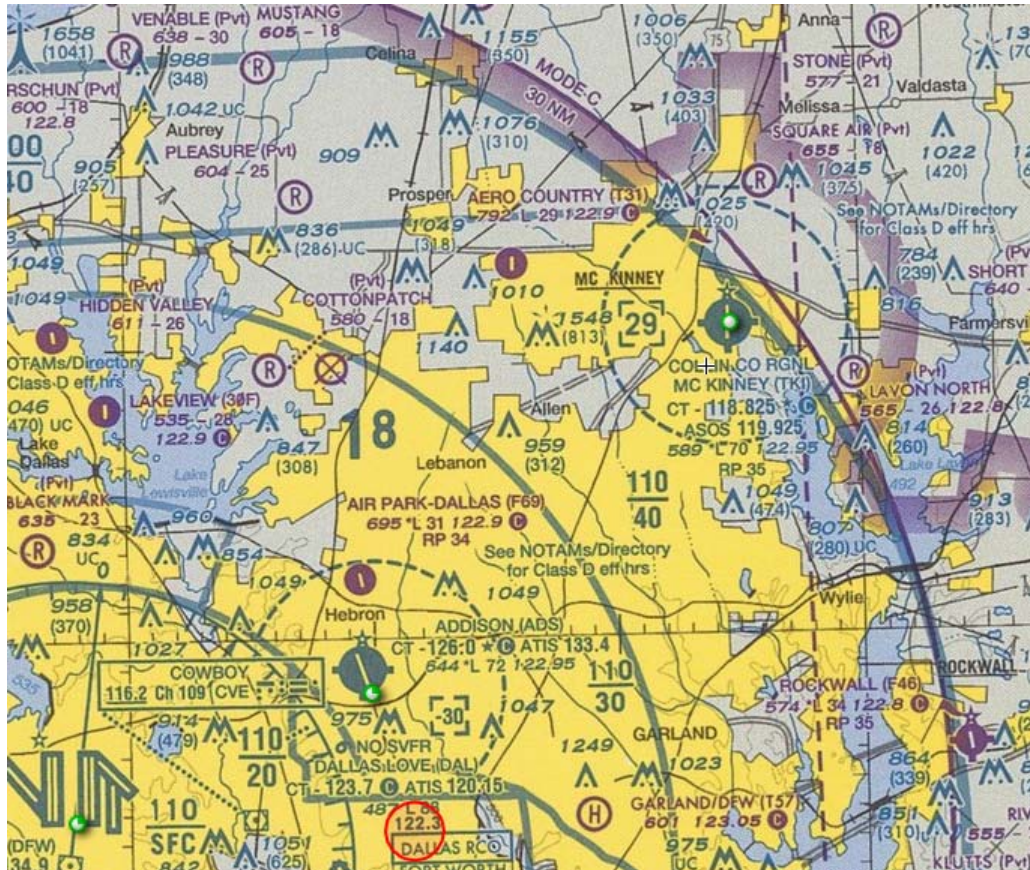
1. What SAA SS horizontal maneuvers are too small, resulting in issuance of traffic safety alerts or controller perceptions of unsafe conditions?
2. What SAA SS horizontal maneuvers are too large (excessive “well clear” distances), resulting in behavior the controller would not expect and/or disruptions to traffic flow?
3. Is there a range of acceptable SAA horizontal miss distances that can be applied to the development of SAA algorithms? Is this range affected by encounter geometry and/or speed differential, and if so, how?

CAS1 Research Approach



- **Construct a set of simulated “well clear encounters”**
 - Different miss distances, encounter geometries, relative speeds
- **Embed these encounters into simulated background traffic scenarios representative of moderate-workload TRACON traffic (IFR and VFR) on a calm, clear-weather day**
- **Ask a series of ATC volunteers to “control” the simulated traffic scenarios, and measure the results**
 - Direct query after each encounter
 - Workload and performance measures throughout
- **Perform statistical analysis of all data afterward to assess the range(s) of acceptable horizontal miss distances**

CAS1 Traffic Scenario Area



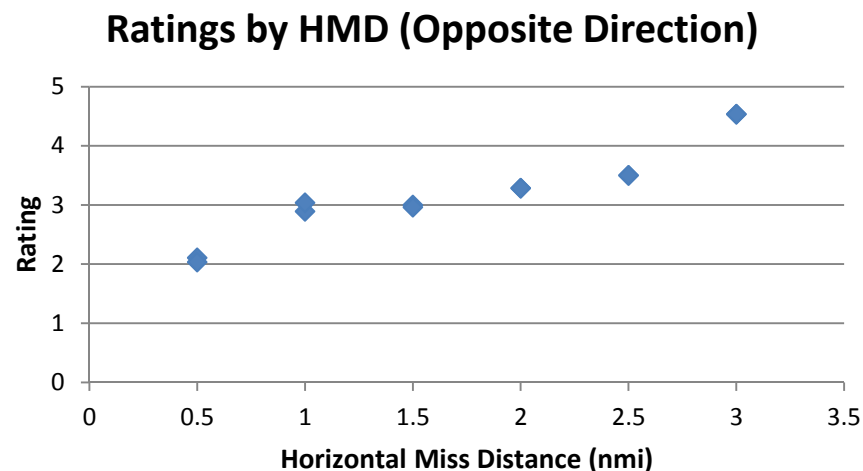
Scenarios focused on ATC sector handling arrivals to Collin County Regional (McKinney – TKI), ~28 nmi NE of DFW

Feature-rich airspace:

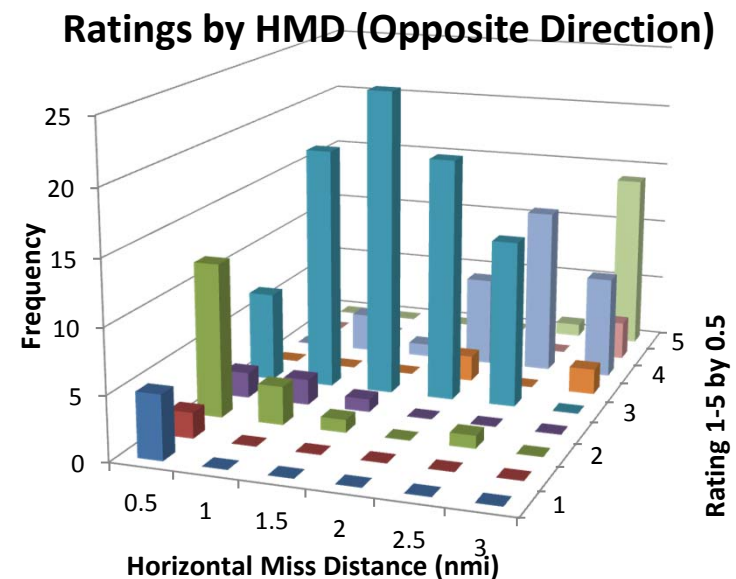
- Class B, 4000-11000' above TKI
 - VFR & IFR aircraft all under positive control, all cooperative
- Class D, SFC-2900' around TKI
 - VFR & IFR cooperative aircraft receiving Class D ATC services
- ❖ Class E, 700' or 1200' up to FL180 and outside Class B and D
 - IFR aircraft
 - VFR aircraft, some receiving ATC services, some not
 - Some non-cooperative traffic outside of 30 nmi Mode C veil
- Class G, SFC to overlying airspace
- Nearby non-towered airports

Ratings for Opposite Direction encounters

Mean of 14 ATC subjects for each encounter



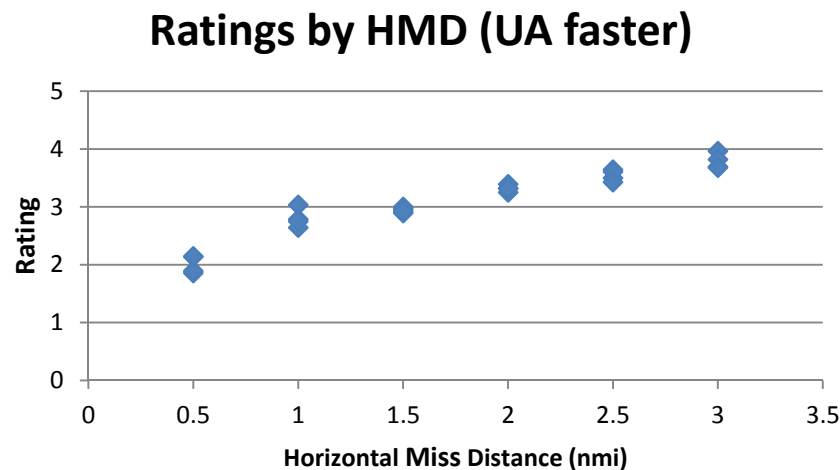
The plot above shows Mean Ratings for **opposite direction** encounters.



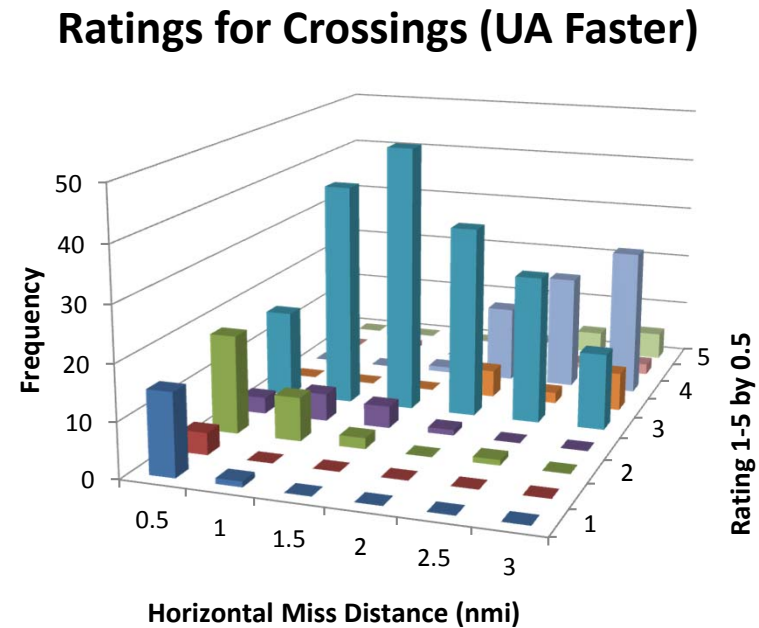
Plot of frequency of Rating responses for **opposite direction** encounters.

Note: All Horizontal Miss Distances required a UAS lateral maneuver (initially a collision course)

Ratings for UA faster than encounter aircraft Mean of 14 ATC subjects for each encounter



The plot above includes only **Crossing** encounters where the UA was **faster** than the encounter aircraft.



Plot of frequency of Rating responses when UA was **faster** than the encounter aircraft.

Note: Horizontal Miss Distances > 1.5 nmi required a UAS lateral maneuver



Initial Conclusions

- A horizontal miss distance (HMD) of ~1.5 nmi appears to be optimal for ATC acceptability (away from the airport vicinity)
- HMD of 1.5 nmi is >150% larger than the TCAS RA HMD for all airspace below Class A, and 136% larger in Class A
- 500' IFR-VFR vertical separation (with no vertical closure rate) was universally acceptable during debrief sessions (some controllers were ok with less)
- Controllers think the SAA integration concept as presented is viable
 - “definitely viable”
 - “absolutely viable”
 - “really impressed, way beyond expectations” [from before seeing it]
 - [worked] “surprisingly well”
 - “impressed with it”
 - “don’t see any controller having an issue with” [concept as seen]

Formal Analysis

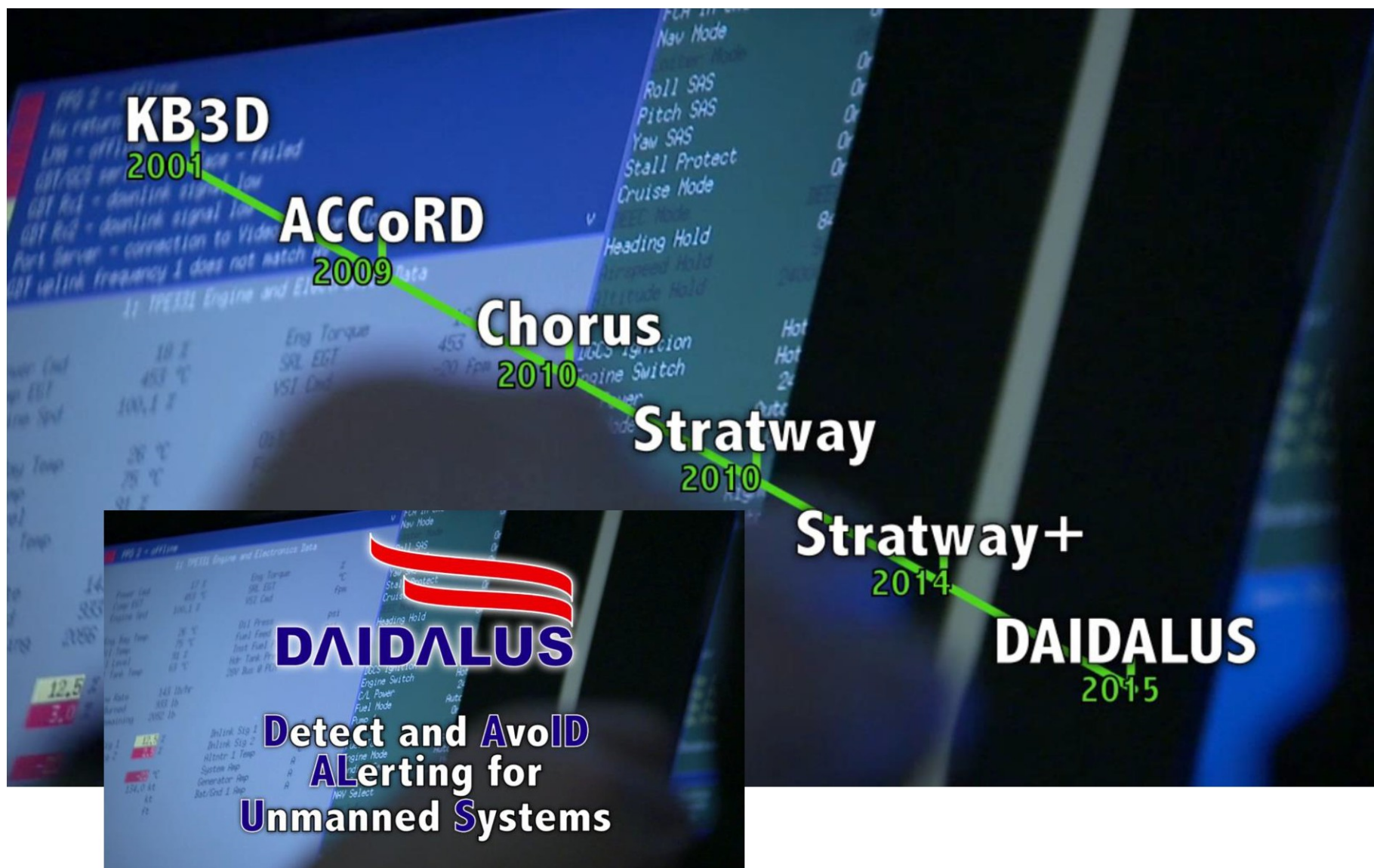
Required Properties of Well Clear Volume Definitions



- ▶ Demonstrated three properties of WCV definitions:
 - ▶ Inclusion: For a given set of parameters, T_{EP} is the most conservative volume definition of the well clear concept family
 - ▶ Symmetry: Ownship and intruder aircraft have the same perception of being well clear (or not)
 - ▶ Local Convexity : It is never the case that an ownship in a linear trajectory goes from a well-clear violation to being well clear to a well-clear violation.



History of Aircraft Separation Algorithms



DAIDALUS

Self-Separation and Alerting Algorithm for UAS



- At the core of the DAIDALUS logic there is a mathematical definition of a well-clear concept
- The implementation of the WC concept is fully parameterized to enable evaluation experiments and refinement studies
- DAIDALUS includes algorithms for:
 - Determining the current well-clear status between two aircraft
 - Predicting a well-clear violation within a look-ahead time.
- Self-Separation Guidance for the pilot-in-command
- Conflict Alerting Symbolology coordinated with maneuver guidance

- DAIDALUS Self-Separation Guidance Display



SS Bands Example: Crossing, No Conflict (yet)



- SS Bands Example: Crossing, With Conflict





SS Bands Example: Overtake, Well Clear







CAS1 Conclusions

- A horizontal miss distance (HMD) of ~1.5 nmi appears to be optimal for ATC acceptability (away from the airport vicinity)
- 500' IFR-VFR vertical separation (with no vertical closure rate) was universally acceptable as noted during debrief sessions (some controllers were Ok with less)
- Controllers think the SAA integration concept as presented is viable
 - “definitely viable”
 - “absolutely viable”
 - “really impressed, way beyond expectations” [from before seeing it]
 - [worked] “surprisingly well”
 - “impressed with it”
 - “don’t see any controller having an issue with” [concept as seen]
- 1.5 nmi HMD matches controller separation standards between VFR and large/turbojet IFR aircraft in Class B airspace

Based on 14 ATC Test Subjects, 1176 Horizontal Miss Distance Acceptability Ratings



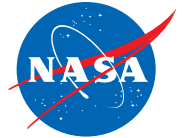
CAS2 Findings

- Traffic Density - *“Rate the realism of the Traffic Density of the simulation during the preceding hour,”*
 - 66.7% of responses were *“Traffic Density was about the same as would be found in real world operations”*
 - 31.0% of the responses were *“Traffic Density was somewhat lower than real world operations.”*
- Wind – No issues or performance differences attributable to the “low” and “moderate” wind conditions
- Communications Delays – no differences in HMD or workload ratings, however comments reflected the difficulties that long delays caused.

Based on 7 ATC Test Subjects, 588 Horizontal Miss Distance Acceptability Ratings



- **Initial Phase 1 MOPS flight testing and validation of simulation results**
- **Successful test of DAIDALUS in operational flight test conditions with real aircraft and sensors operating in real time.**
- **Initial Aircrew Observations Positive**
- **Flight Test 3 continues the DAA Flight Test Campaign adding multi-intruder encounters, vertical geometries, high speed aircraft to fully inform and validate the DAA MOPS creation**



CAS-3 Objectives

- This experiment will address minimum and maximum acceptable declaration times for projected well clear losses, from the perspectives of both the air traffic controller and the UA pilot, i.e.,
 - what declaration times are excessive, leading to nuisance alerts for controllers and UA pilots and
 - what times are too short providing insufficient time to query/negotiate maneuvers with ATC and execute them before triggering TCAS RAs
 - Integration of CA&SS functions Stratway+ with TCAS as a CA capability for the UA



Research Questions

- Given a projected well clear loss, what is the minimum acceptable declaration time?
- Given a projected well clear loss, what is the maximum acceptable declaration time?
- Which, if any, of the declaration times are too excessive leading to nuisance alerts for the controllers and UA pilots?
- Which, if any, of the declaration times are too short providing insufficient time to query/negotiate maneuvers with ATC and execute said maneuvers before triggering TCAS RAs?
- Is there an interaction between Alerting Time and Horizontal Miss Distance?
- Given the TCAS alerting symbology sets, does the change in display icons (between caution and warning) affect the saliency of alert levels to the UA pilot?
- In Vertical encounters, does prediction of time to co-altitude (TCOA) affect acceptability of the Alert?



Scenario Environment

- Similar to CAS-1 and CAS-2, the scenarios will be focused on the ATC sector handling arrivals to Collin County Regional (now known as McKinney National – KTKI), which is approximately 28 nmi NE of Dallas/Fort Worth (DFW), and the surrounding airspace and airports
- Traffic in the scenario includes 14 encounters per hour between GA aircraft that are transponding but not in voice communications with ATC, and UAS (large).
- In addition there are approximately 45 additional aircraft per hour (Background traffic) in the same airspace that are also in communications with the subject Controller.



CAS3 (CASSAT) Methodology

Two-part study based on CAS1 and CAS2 methodology

(1)UAS ground control station pilots as subjects, ATC is part of experimental team; varied Alerting Times and Horizontal Miss Distances

- 12 pilots total; 6 UAS pilots and 6 IFR pilots
- Pilots will fly multiple-UAS each hour in the DFW area using MACS interface with additional alerting symbology incorporated

(2)ATC subjects rating acceptability of UAS encounters with non-communicating (with ATC; but transponding) aircraft when UAS self-separate with varied alerting times (Variable of interest, fixed levels)

- 10 active ATC (experience at DFW a plus, but training on the sector for all)
- Similar to CAS1 and CAS2 except additional sector traffic to boost workload and addition of several vertical traffic encounters per hour



CAS3 (CASSAT) Methodology (2)

- Independent Variables
 - Horizontal Miss Distance (0.7, 1.0 and 1.5 nmi)
 - Alerting Times (used by DAIDALUS algorithms)
 - 30 sec, 45 sec, 75 sec
 - Time to Co-altitude (TCOA) for vertical encounters (used by DAIDALUS algorithms)
 - 0 and 20 sec
 - Vertical Rates 1000 and 3000 feet per minute (between encountering aircraft)
- Variables from CAS1 and CAS2 being held Constant
 - Wind – only medium wind profile for all encounters
 - Communications delay – 400 msec for all UAS voice communications
 - Pilots will rate candidate alerting symbology sets
 - For pilot subject runs, will require triggering TCAS on some encounters to see full range of symbology



Summary and Impact of Work

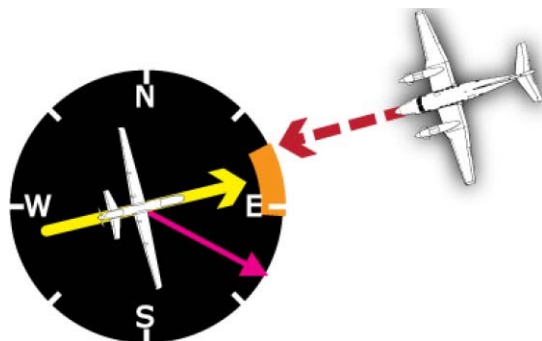
- Three years of work ranging from concept development, algorithm development, software implementation, formal analysis, testing, verification and validation, HITL and batch experiments
- Close collaboration with the stakeholder community: Industry (recent General Atomics/NASA FT), FAA, Academia, SARP
- All work done in support of RTCA-SC228 WG1-DAA:
 - Preliminary white papers in preparation for the upcoming DAA MOPS are fundamentally based on NASA's integration concept work
 - NASA's WC concept adopted
 - NASA's developed pilot guidance adopted
 - NASA's developed DAIDALUS code was requested to be part of the MOPS document
- Results of upcoming experiments are expected and required for MOPS V&V. FAA offered that we use active ATC for the next controller in the loop experiment

Observations

DAIDALUS Display at Time of Maneuver

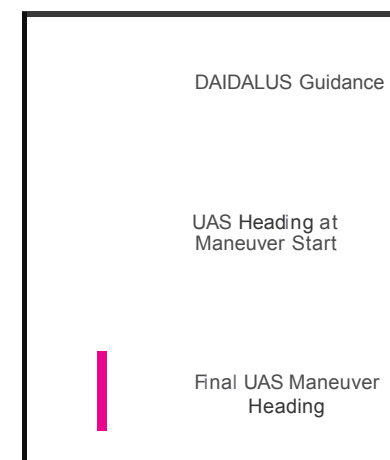
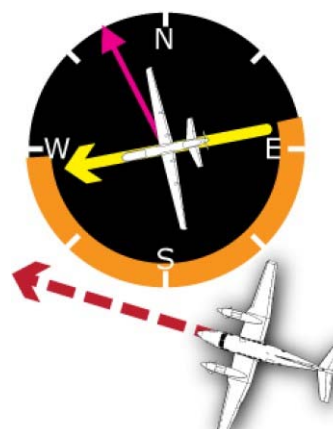
Encounter S12

- Sensor: Radar+ADS-B
- Encounter Type: 00
- CPA Offset: In m
- Aircraft Distance at Maneuver: 9.18nm
- Estimated time to CPA at Maneuver: 102.5 seconds



Encounter S54

- Sensor: Radar+ADS-B
- Encounter Type: 135°
- CPA Offset: Onm
- Aircraft Distance at Maneuver: 2.32nm
- Estimated time to CPA at Maneuver: 73.4 seconds

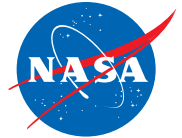


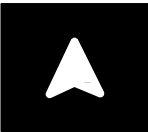
UAS Operator Time to Maneuver from Start of Guidance

, ... : Encounter 512 (0°): 36 Seconds : --.....,

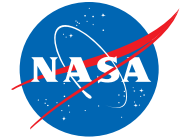


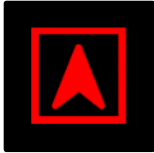
PT5 Alert Structure



Alert Level	Name	Pilot Action	DAA Separation Criteria	Alert Time (Time Until Penetrating Separation Criteria)	Symbology	Aural Alert Verbiage
4	Self Separation Warning Alert	Immediate action required to avoid a well clear violation, notify ATC as soon as practicable after taking action	HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec DMOD = 0.75 nmi	25 sec (TCPA approximate: 60 sec)		"Traffic, Maneuver Now"
3	Corrective Self Separation Alert	Action to remain well clear will be necessary if the encounter does not change, coordinate with ATC to determine an appropriate maneuver	HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec DMOD = 0.75 nmi	75 sec (TCPA approximate: 110 sec)		"Traffic, Separate"
2	Preventive Self Separation Alert	Action to remain well clear will be necessary only if one or both aircraft make both a horizontal and vertical maneuver, do not climb/descend or turn into the intruder and be prepared to respond if the intruder begins climbing/descending or turning towards you. You may want to coordinate with ATC about the intentions of the intruder.	HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec DMOD = 0.75 nmi	75 sec (TCPA approximate: 110 sec)		"Traffic, Monitor"
1	Self Separation Proximate Alert	No action necessary to avoid this aircraft, but its presence should be considered when determining a resolution maneuver to avoid other aircraft.	HMD = 1.5 nmi ZTHR = 1200 ft modTau = 35s DMOD = 0.75 nmi	85 sec (TCPA approximate: 120 sec)		N/A
0	None (Target)	No action necessary, There is an aircraft within your sensor range, but it is not expected to present a threat.	Within surveillance field of regard	X		N/A

CASSAT Alert Structure



Alert Level	Name	Maneuver guidance-Pilot Action	DAA Separation Criteria	Alert Time (Time Until Penetrating Separation Criteria)	Symbology	Aural Alert Verbiage
3	Warning Self Separation Alert	Follow maneuver guidance. Notify ATC as soon as feasible after taking action	HMD = DMOD = 4000 feet ZTHR = 450 ft modTau = 35 sec	50 sec to CPA		"Traffic, Maneuver Now"
2	Corrective Self Separation Alert	Corrective (solid) bands intersect the ownship path. Follow maneuver guidance coordinating with ATC		35-75 sec to WCV (Experimental Variable)		"Traffic, Separate"
1	Preventive Self Separation Alert	Preventive (solid) bands do not intersect the ownship path. No maneuver required at this point, just monitor traffic		Same as Corrective		"Traffic, Monitor"
0	None (Target)	N/A	N/A	N/A		N/A

1. When TCAS is integrated with the SS TCAS RA symbols and aural alerts will be presented at the appropriate times.
2. TCAS TA's will not be shown.
3. If well clear separation is lost (or about to be lost) "Recovery" (dashed) maneuver bands will continue to provide guidance to the pilot



When DMOD < HMD...

- The time variable Taumod **increases to infinity** before CPA.
- The time variable Taumod is **less** conservative than Tcpa.
- Taumod and Tcpa time variables are plotted for the following geometry (aircraft are co-altitude):

so = (-2.00 [nmi], 0.98 [nmi])

vo = (90.00 [deg], 350.00 [kn])

si = (0.00 [nmi], 0.00 [nmi])

vi = (90.29 [deg], 200.00 [kn])

DMOD = 0.75 [nmi]

The following information is computed for that scenario:

TAUMOD = 35 [s]

Range at time 0: 2.23 [nmi]

Range at TAUMOD: 1.13 [nmi]

Tcpa: 48 [s]

Dcpa: 0.99 [nmi]

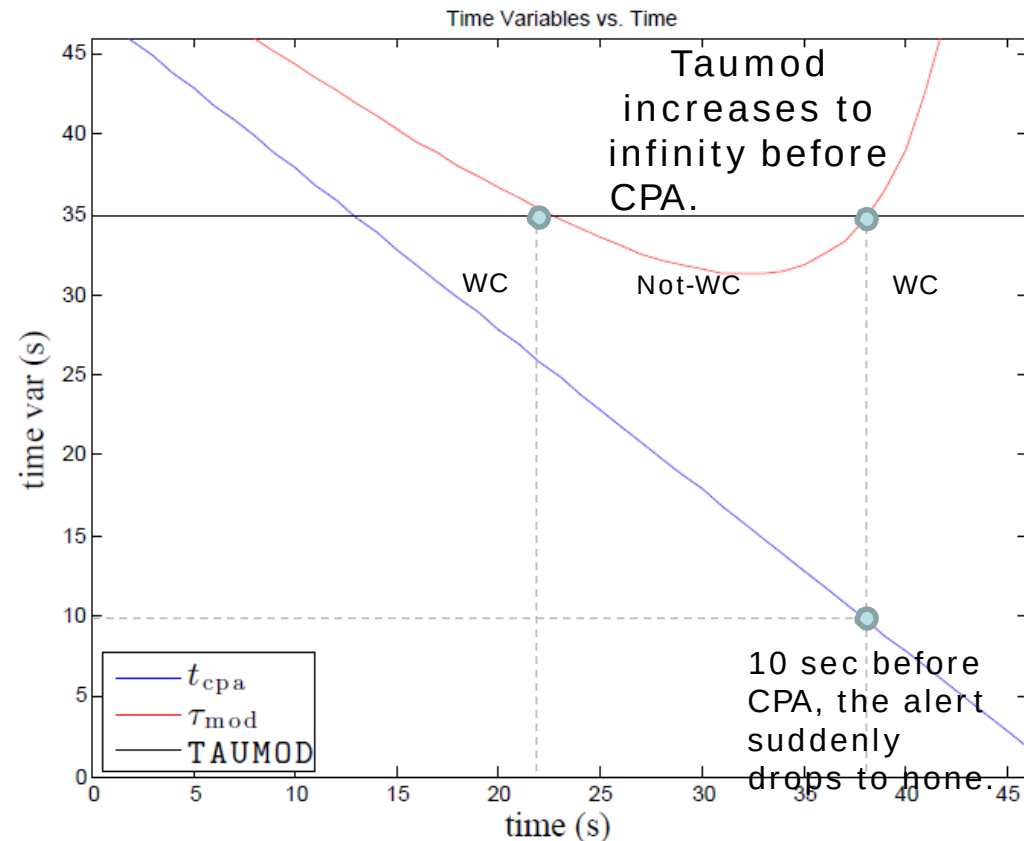
Time of first crossing

of TAUMOD: 23 [s]

Time of second crossing of

TAUMOD: 38 [s]

(time to CPA: 10s) The worst case for an alert to disappear is 17.5 seconds before CPA (Taumod/2)





When $DMOD > (or =) HMD...$

- The time variable Taumod **decreases to zero** before CPA.
- The time variable Taumod is **more** conservative than Tcpa.
- Taumod and Tcpa time variables are plotted for the following geometry (aircraft are co-altitude):

so = (-2.00 [nmi], 0.50 [nmi])
vo = (90.00 [deg], 350.00 [kn])
si = (0.00 [nmi], 0.00 [nmi])
vi = (90.29 [deg], 200.00 [kn])

DMOD = 0.75 [nmi]

The following information is
computed for that scenario:
TAUMOD = 35 [s]

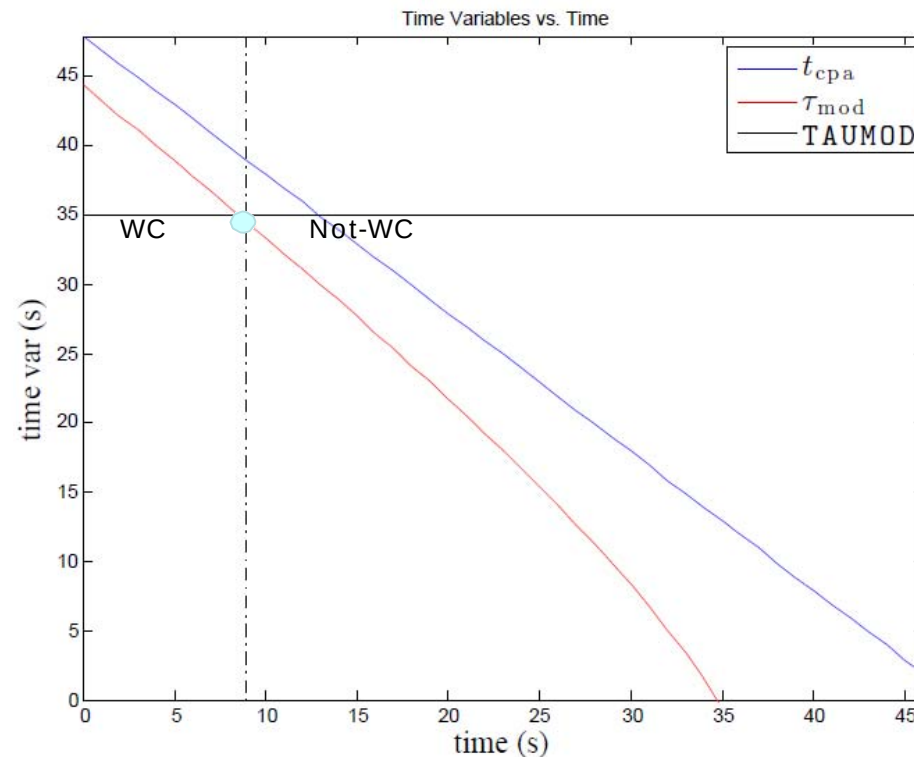
Range at time 0: 2.06 [nmi]

Range at TAUMOD: 0.74 [nmi]

Tcpa: 48 [s]

Dcpa: 0.51 [nmi]

Time of crossing of TAUMOD: 9
[s]





Gaps in PT5 Alerting Structure

- Since in PT5 alert levels 1 and 2 use a value of $HMD > DMOD$, in the following case an **alert level 2 drops to NO ALERT 16 seconds before TCPA**.

$so = (-8.98 \text{ [nmi]}, 0.98 \text{ [nmi]})$
 $vo = (90.00 \text{ [deg]}, 335.00 \text{ [kn]})$
 $si = (-4.17 \text{ [nmi]}, 0.02 \text{ [nmi]})$
 $vi = (90.29 \text{ [deg]}, 200.00 \text{ [kn]})$
 $DMOD = 0.75 \text{ [nmi]}$

The following information is computed for that scenario:
 $TAUMOD = 35 \text{ [s]}$

Range at time 0: 4.91 [nmi]

Range at $TAUMOD$: 3.63 [nmi]

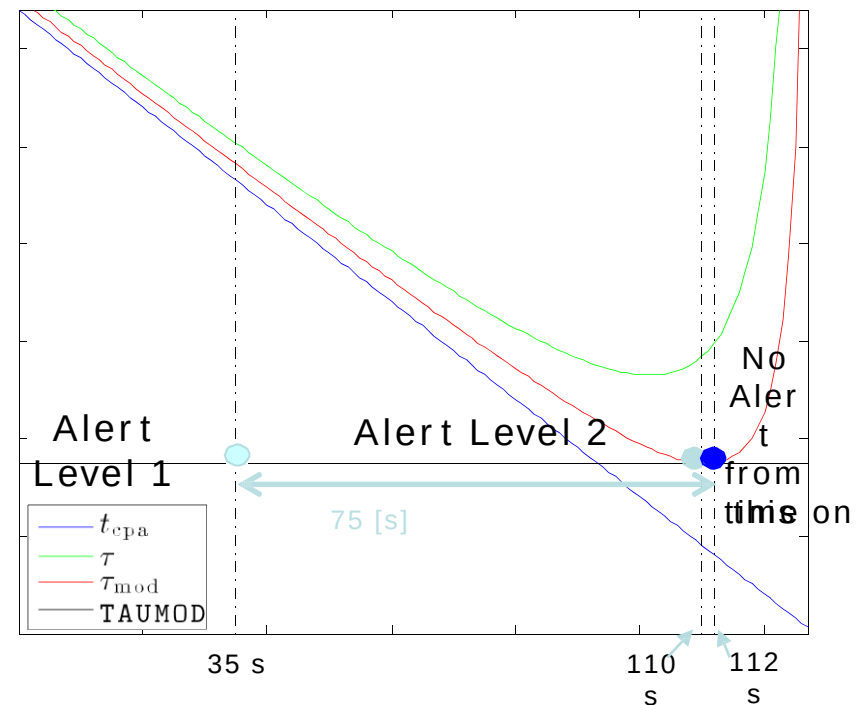
T_{cpa} : 128 [s]

D_{cpa} : 0.99 [nmi]

Time of first crossing of $TAUMOD$:
 110 [s]

Time of second crossing of
 $TAUMOD$: 112 [s] (time to CPA: 16 [s])

Alert 2 at time 35 [s]





Meet the SSI LaRC Team

- **Pierre Beaudoin**
- **Jim Chamberlain**
- **Ray Comstock**
- **Maria Consiglio**
- **Anna Dehaven**
- **Rania Ghatas**
- **Mike Guminsky**
- **George Hagen**
- **Keith Hoffler**
- **Steve Hylinski**
- **Joel Ilboudo**
- **Kristen Mark**
- **Robb Meyer**
- **Cesar Munoz**
- **Anthony Narkawicz**
- **Gaurev Sharma**
- **Jim Sturdy**
- **Dimitrie Tsakpinis**
- **Jason Upchurch**
- **Paul Volk**

How we got here

- First Challenge: Build a HITL Simulation Capability to:
 - Design, test, evaluate SAA concepts and technologies
 - Research impact of SAA equipped UAS on the NAS
 - Maintain compatibility with other existing simulation platforms
 - Reuse and leverage existing software and functionality



How we got here



- Second Challenge
 - Develop a concept of UAS integration in the NAS for vehicles equipped with SAA systems that would support the GCS pilots to perform SAA functions that are acceptable to ATC and minimize airspace disruptions.
 - Implement prototype systems that can be used to generate experimental data in HITL experiments
 - Disseminate concept and logic in the community to inform and influence the development of SAA (DAA) MOPS
 - Complete the planned series of studies to ensure that the necessary data will be available to inform the SC228 MOPS development

GA-FAA-NASA Flight Test Objectives



**Initial Self Separation Flight Test: SS Algorithm - DAIDALUS(*)
(formerly Stratway+)**

Objectives:

- **Verify stability of DAIDALUS with real sensor data**
- **Receive pilot feedback on DAIDALUS display**
- **Flight Test 3 Risk Reduction**

Ikhana UAS – King Air Intruder - 17 Total trials

- **Head on, 20, 45, 90, 135 degree**
- **Sensor varied between Radar only and Radar + ADS-B**
- **Closest point of approach (CPA) offset between 0 and 1.5nm**
- **Only 1 UAS operator**

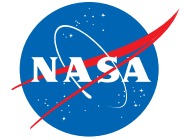
(*) Detect and Avoid Alerting for Unmanned Systems

GA-FAA-NASA Flight Test Results



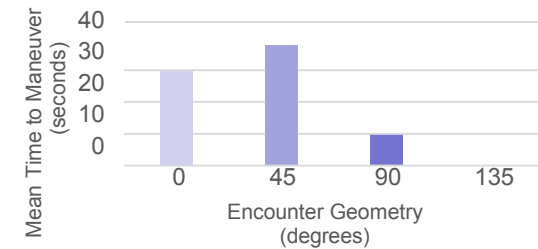
- **Sensor Test**
 - Self-separation guidance from DAIDALUS was effective
 - DAIDALUS was stable with real sensor data
 - Sensors performed as expected – no outstanding or new issues
- **Operator feedback**
 - Operator was able to use the DAIDALUS guidance to maneuver
 - Display was usable, understandable
- **Risk Reduction**
 - Lessons learned have driven decisions for Flight Test 3 and CASSAT
 - Allowed Team to mature data collection capability

GA-FAA-NASA Flight Test Observations

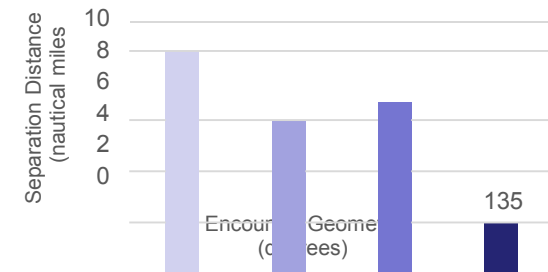


- Alerting time afforded by DAIDALUS reflected in operator behavior
- The operator reacted more quickly in 90 and 135 degree encounters
 - Perceived as more urgent
- DAIDALUS guidance allowed the operator to stay well clear in the challenging 135 degree encounters
- The operator made more dramatic maneuvers than needed
 - Operator “primed” by collision avoidance trials
 - More timely training planned for FT3

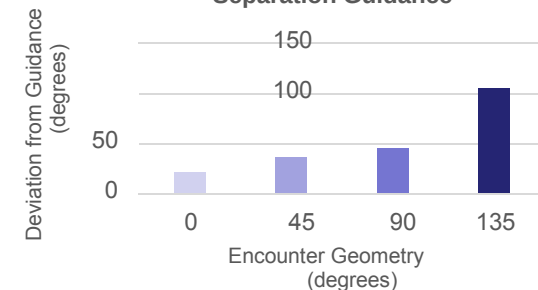
Mean Operator Time to Maneuver from First DAIDALUS Self-Separation Guidance



Mean Aircraft Separation Distance at Time of Maneuver



Pilot Maneuvers Using DAIDALUS Self-Separation Guidance



UAS Integration in the NAS Project

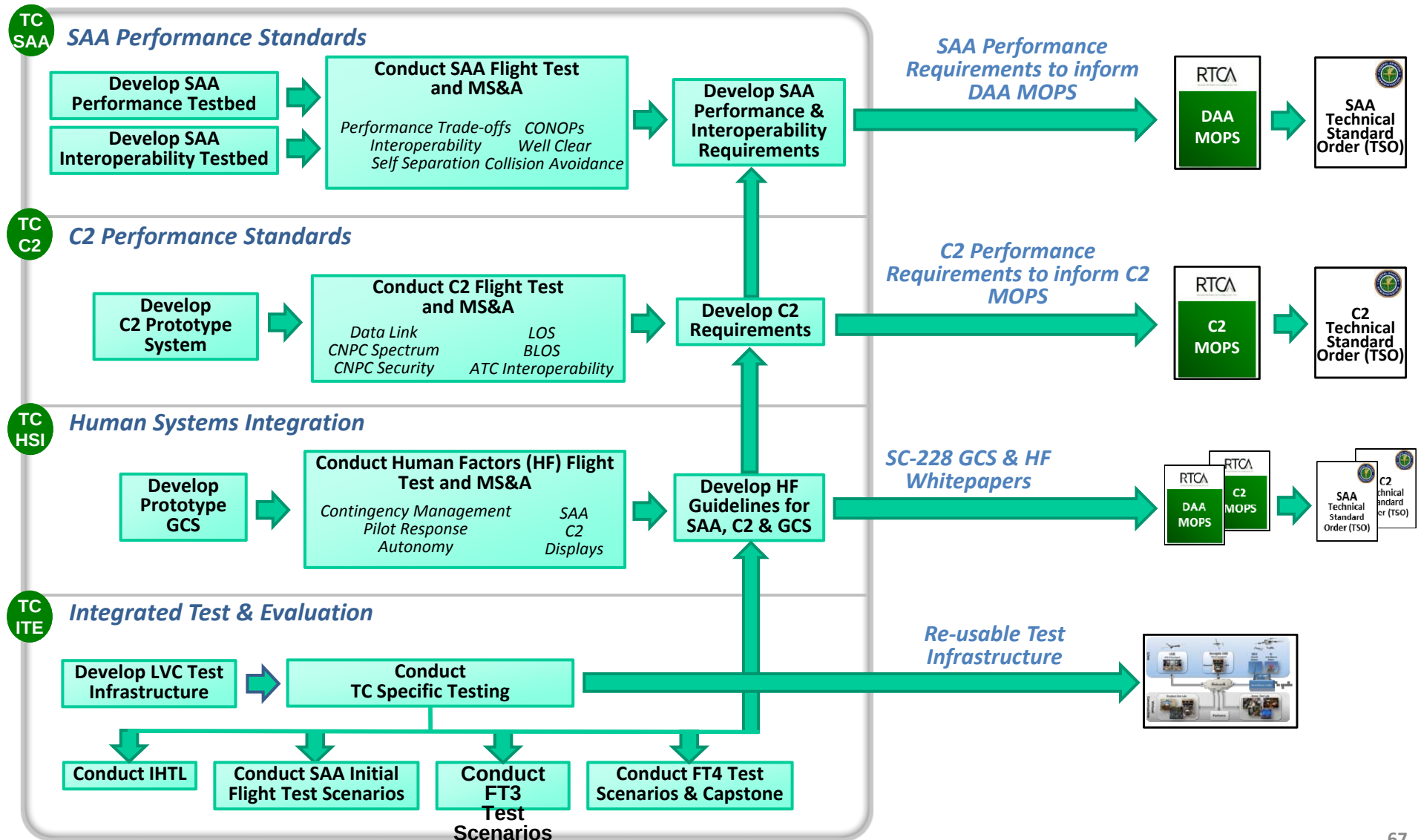
Value Proposition Flow Diagram



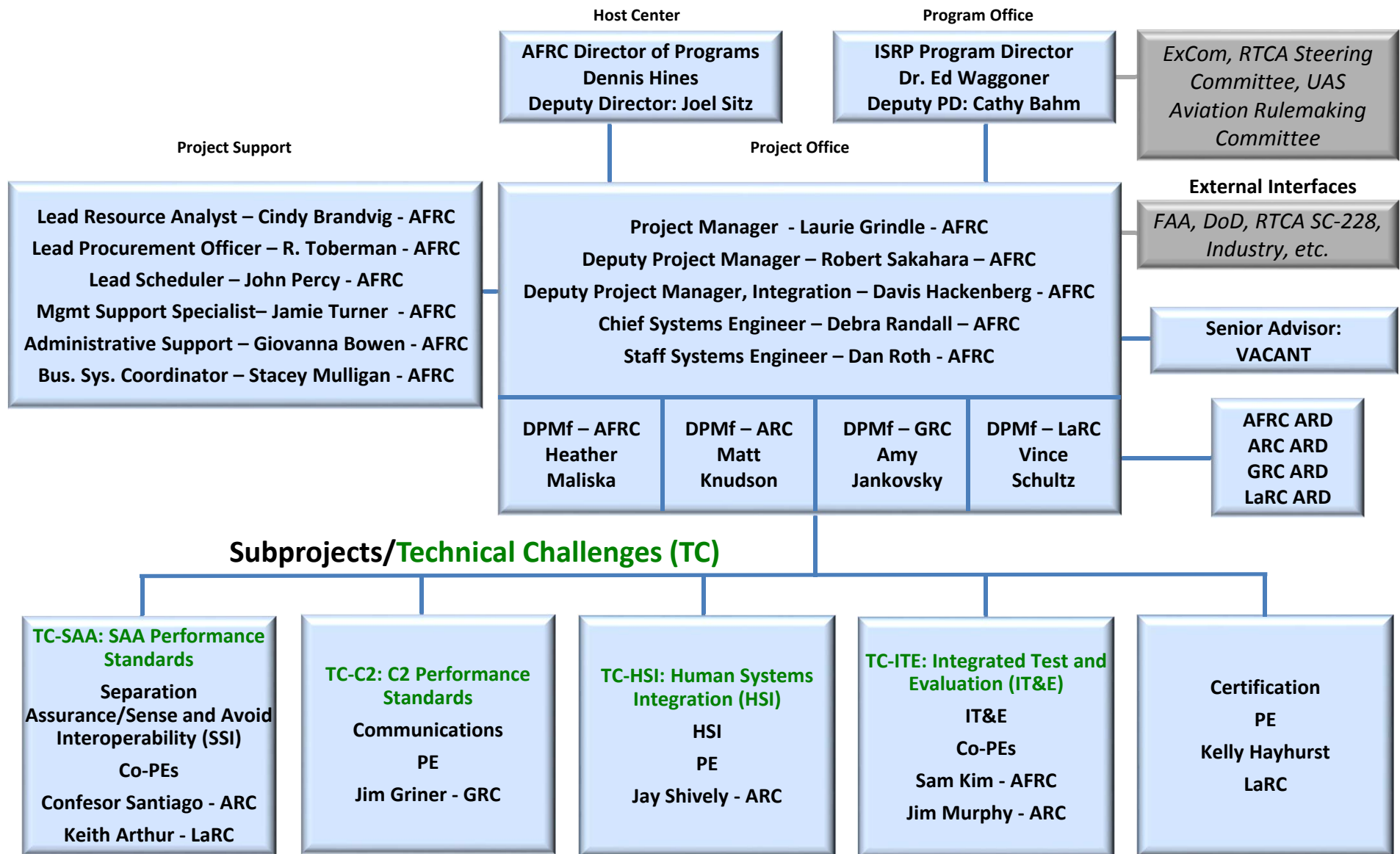
NASA UAS-NAS Project Activities

Key Products

Resultant Outcomes



UAS Integration in the NAS Organizational Structure



PE: Project Engineer, DPMf: Deputy Project Manager for