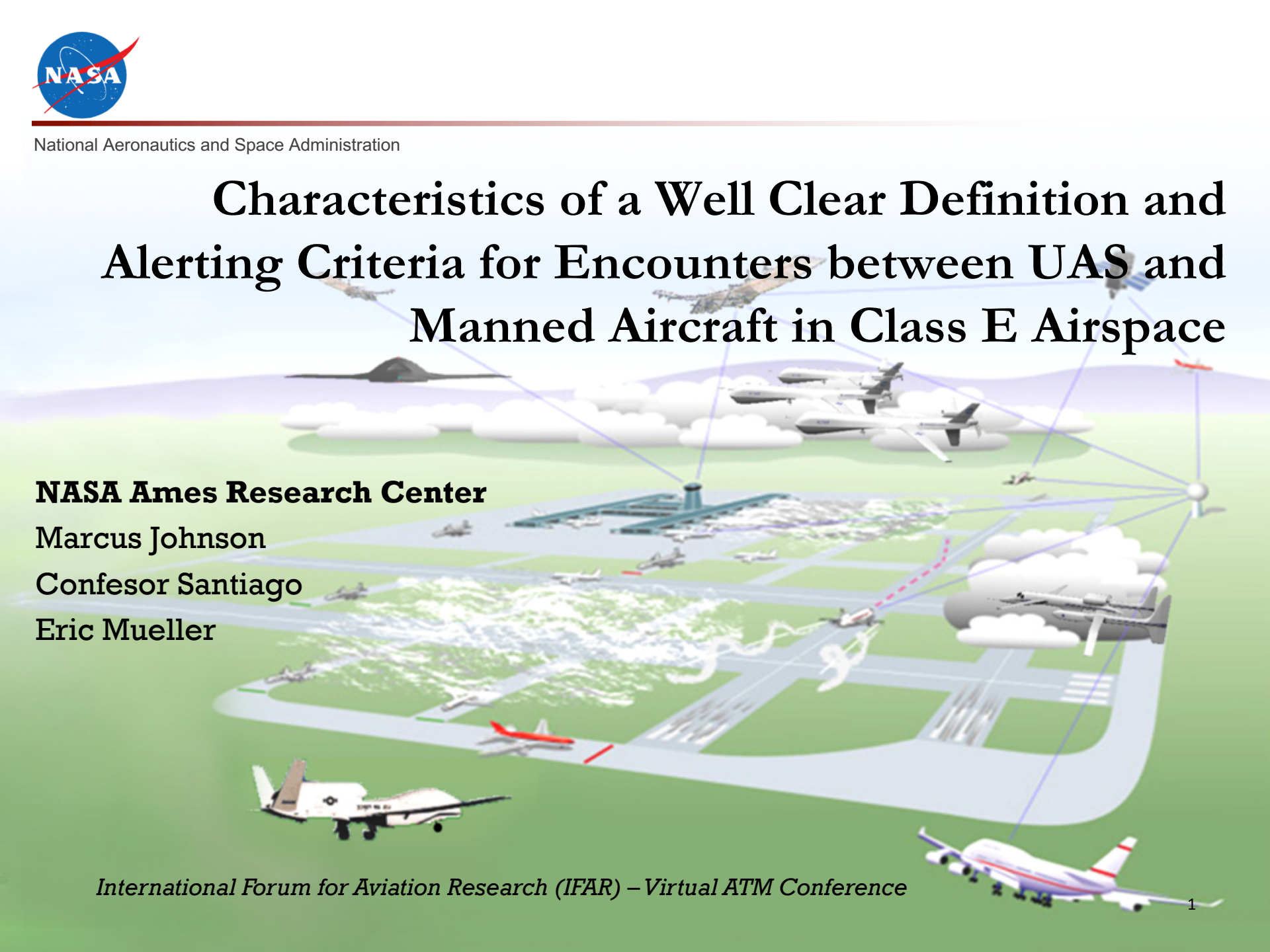
National Aeronautics and Space Administration

Characteristics of a Well Clear Definition and Alerting Criteria for Encounters between UAS and Manned Aircraft in Class E Airspace



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International Forum for Aviation Research (IFAR) – Virtual ATM Conference

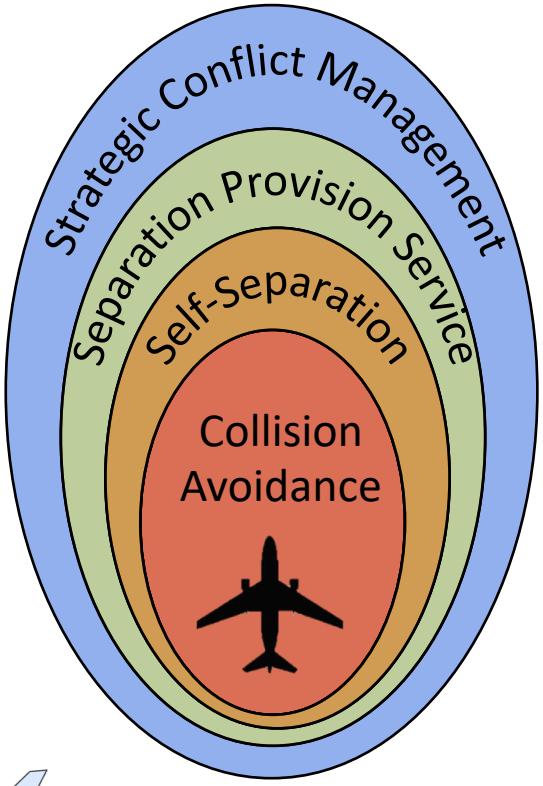
Outline

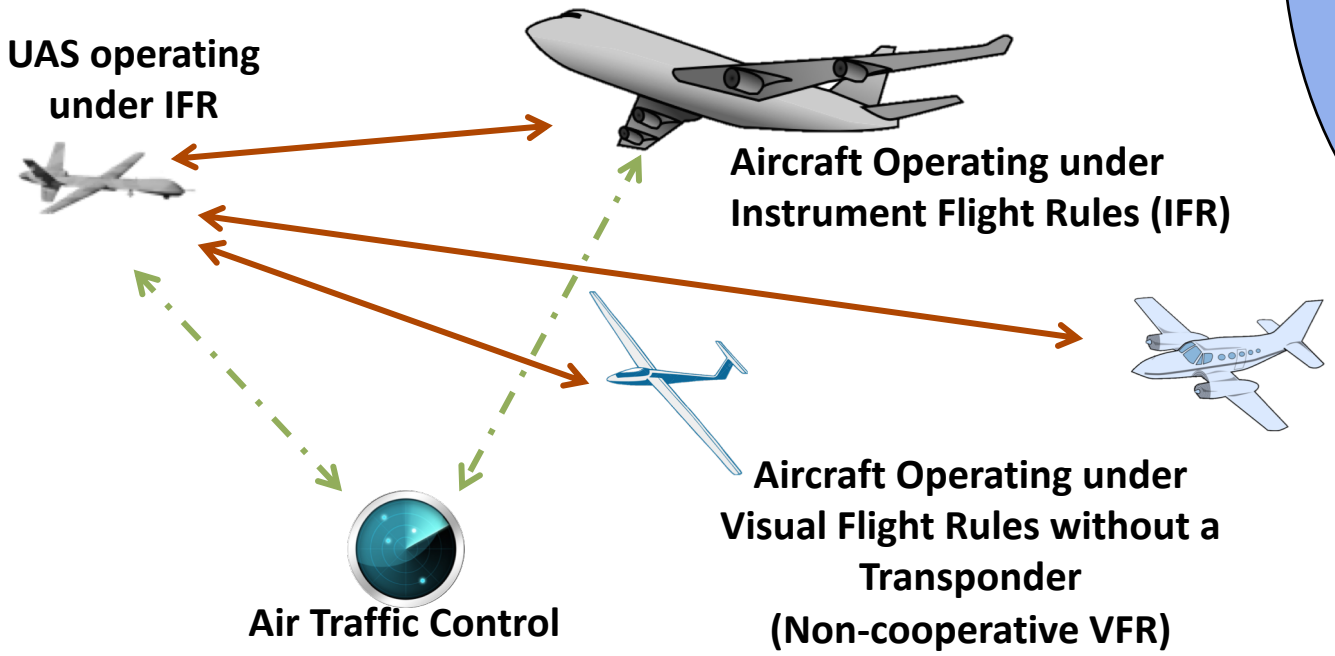
- Research and Motivation
- Analysis Overview and Definitions
- Simulation Setup
  - Traffic Scenarios
  - UAS Missions
- Fast-Time Simulation Study Results
  - Analysis 1: Characterizing Encounters at Well Clear Boundary
  - Analysis 2: Evaluating Alerting Criteria
- Conclusions

Background

14CFR Part 91, § **91.113**

…vigilance shall be maintained by each person operating an aircraft so as to **see and avoid** other aircraft…pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless **well clear**.



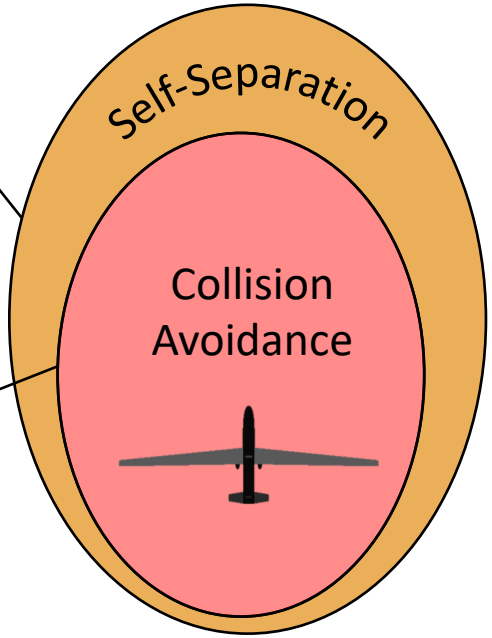


Background: Detect and Avoid

Manned Aviation

Analysis 2:
Alerting the UAS Operator

Analysis 1:
Loss of Well Clear



Unmanned Aviation

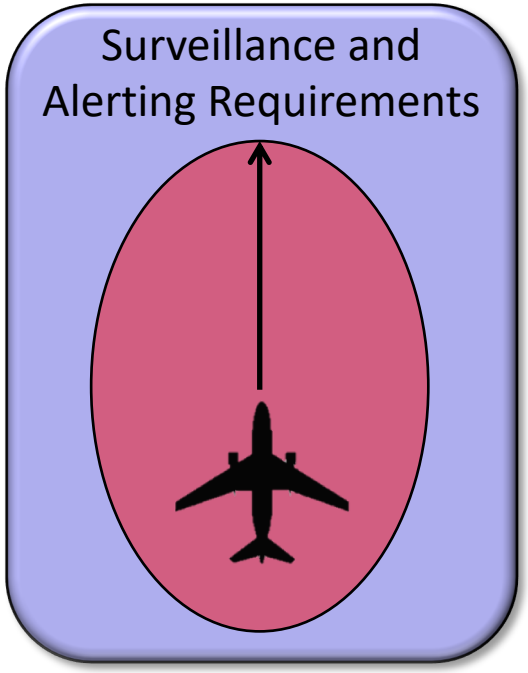
See and Avoid
Traffic Collision Avoidance System (TCAS)

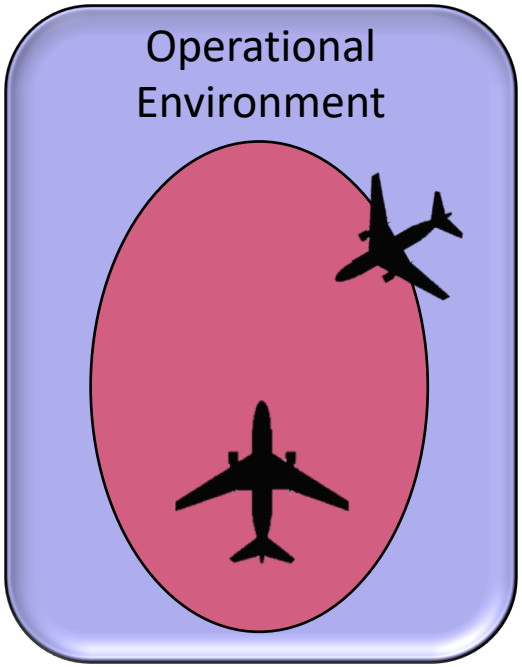
Detect and Avoid
Collision Avoidance Function
(TCAS/ACAS/etc.)

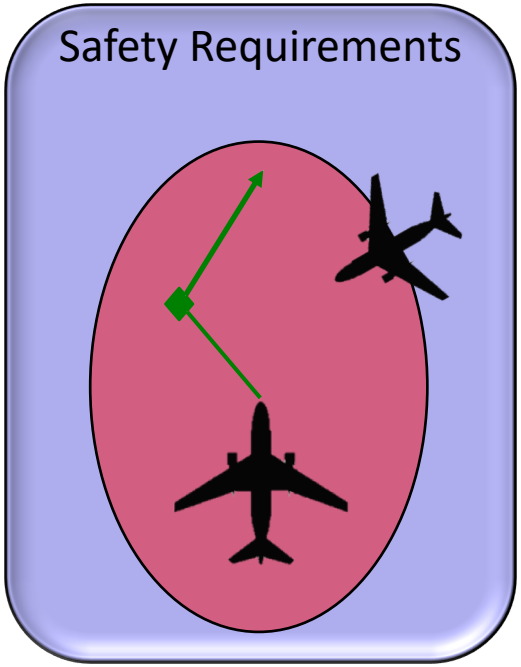
Motivation

RTCA

Special Committee 228 Minimum Operational Performance Standards for Unmanned Systems







Analysis Overview

- **Analysis 1: Characterizing encounters at well clear boundaries.**
  - Objective:
    - Investigate implications of using Well Clear Definitions proposed from the UAS community in terms of surveillance requirements and safety.
  - Metrics:
    - Rate of Losses of Well Clear per UAS Flight Hour
    - Relative State information at the Loss of Well Clear (LoWC)
- **Analysis 2: Evaluating the alerting criteria.**
  - Objective:
    - Investigate implications of an alerting scheme as suggested from the UAS community in terms of surveillance requirements and safety.
  - Metrics:
    - Rate of Alerts per Flight Hour
    - Percentage of Nuisance Alerts
    - Relative State Information at First Alert
    - Time to Loss of Well Clear

Unmitigated Encounter Rate Evaluation

Capabilities

UAS Models

UAS Mission Profiles

VFR Traffic from Air Defense Radar Data

US National Airspace Simulation

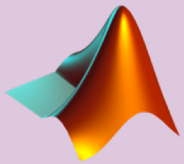
Airspace Concept Evaluation System (ACES)

Metrics

Loss of Well Clear

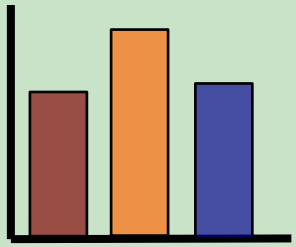
Self Separation Conflict Alerting

Analysis



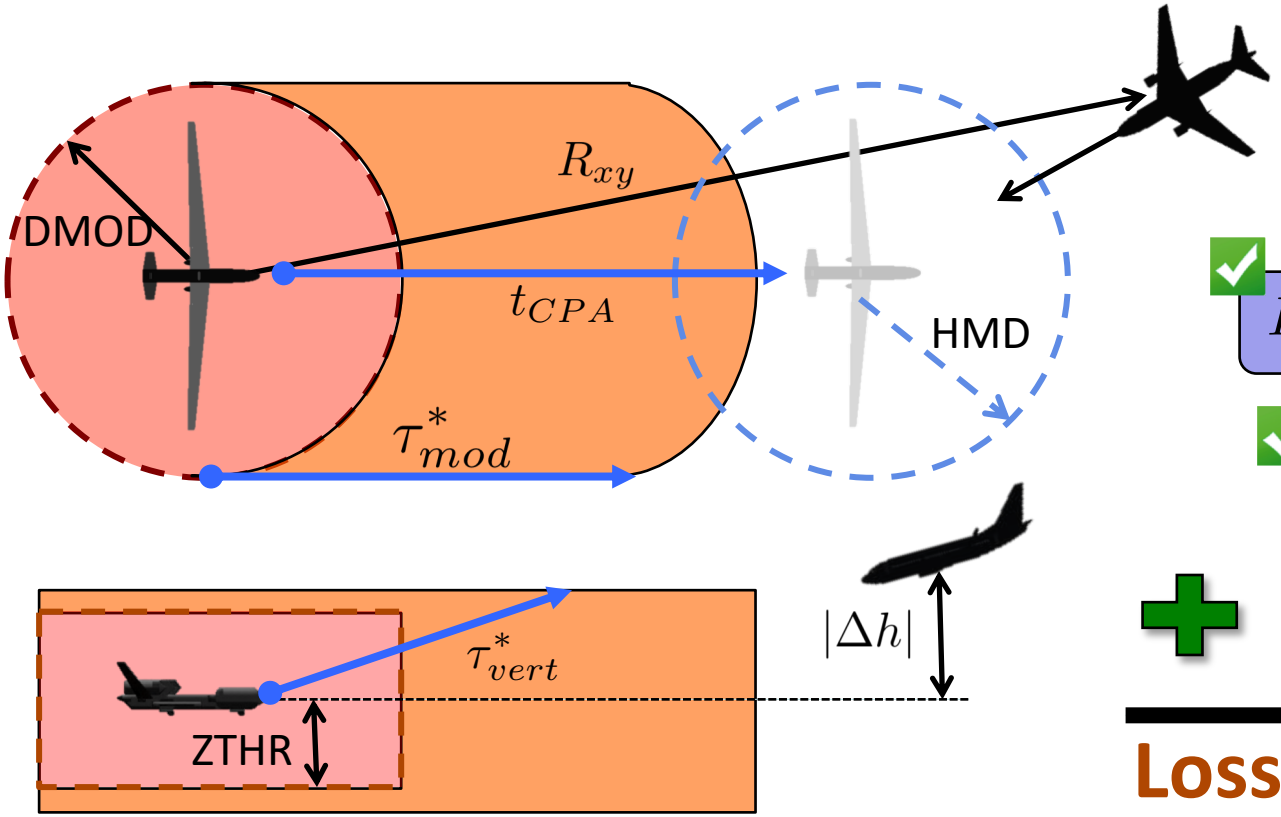
Results

Losses of Well Clear per UAS Flight Hour



Altitude

Loss of Well Clear



$0 \leq \tau_{mod} \leq \tau^*_{mod}$

$R_{xy}(t_{CPA}) \leq HMD$

$0 \leq \tau_{vert} \leq \tau^*_{vert}$
OR
$|\Delta h| \leq ZTHR$

Loss of Well Clear

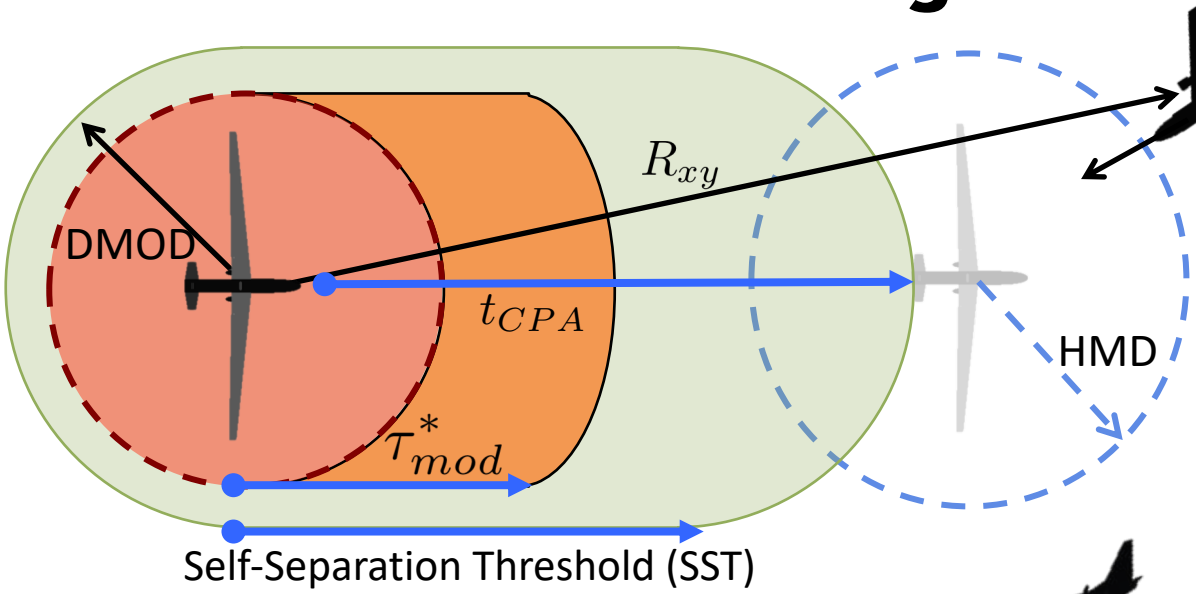
Note: DMOD value = HMD value

$$\tau_{mod} = -\frac{R_{xy}^2 - DMOD^2}{\dot{R}_{xy} R_{xy}}$$

t_{CPA} Time at Closest Point of Approach

$$\tau_{vert} = -\frac{\Delta h}{\dot{\Delta h}}$$

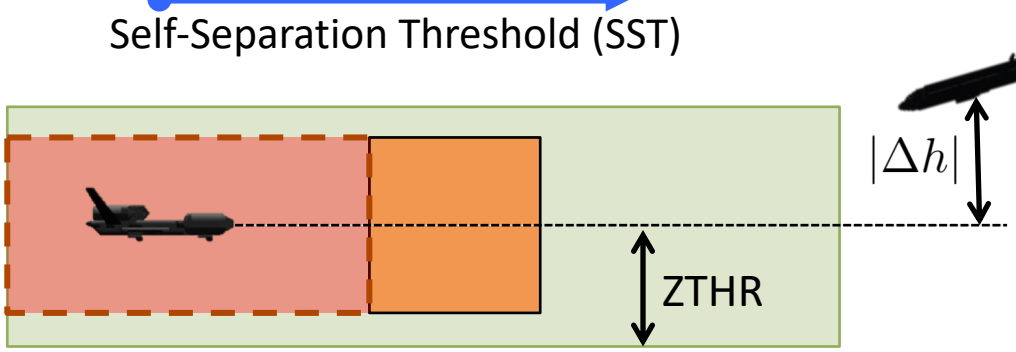
Alerting Criteria



$0 \leq \tau_{mod} \leq SST$

$R_{xy}(t_{CPA}) \leq HMD$

$|\Delta h| \leq ZTHR$



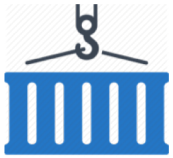
Self-Separation Conflict Alert

$$\tau_{mod} = -\frac{R_{xy}^2 - DMOD^2}{\dot{R}_{xy} R_{xy}}$$

t_{CPA} Time at Closest Point of Approach

UAS Missions Overview

Air Quality Monitoring



Cargo Transport

Flood Mapping

Atmospheric Sampling

Wildfire Detection and Reconnaissance

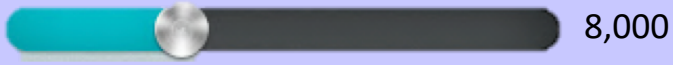
On-Demand Air Taxi

Overall Mission Characteristics

UAS Size

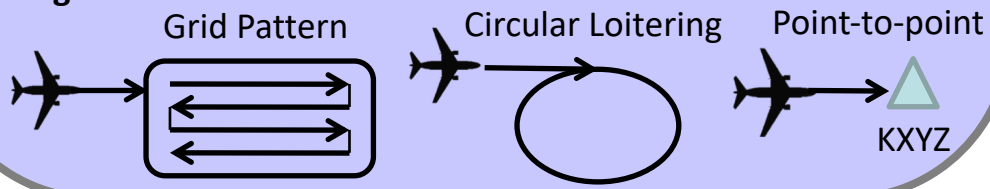
Flight Duration

Flights Per Day



Cruise Altitude

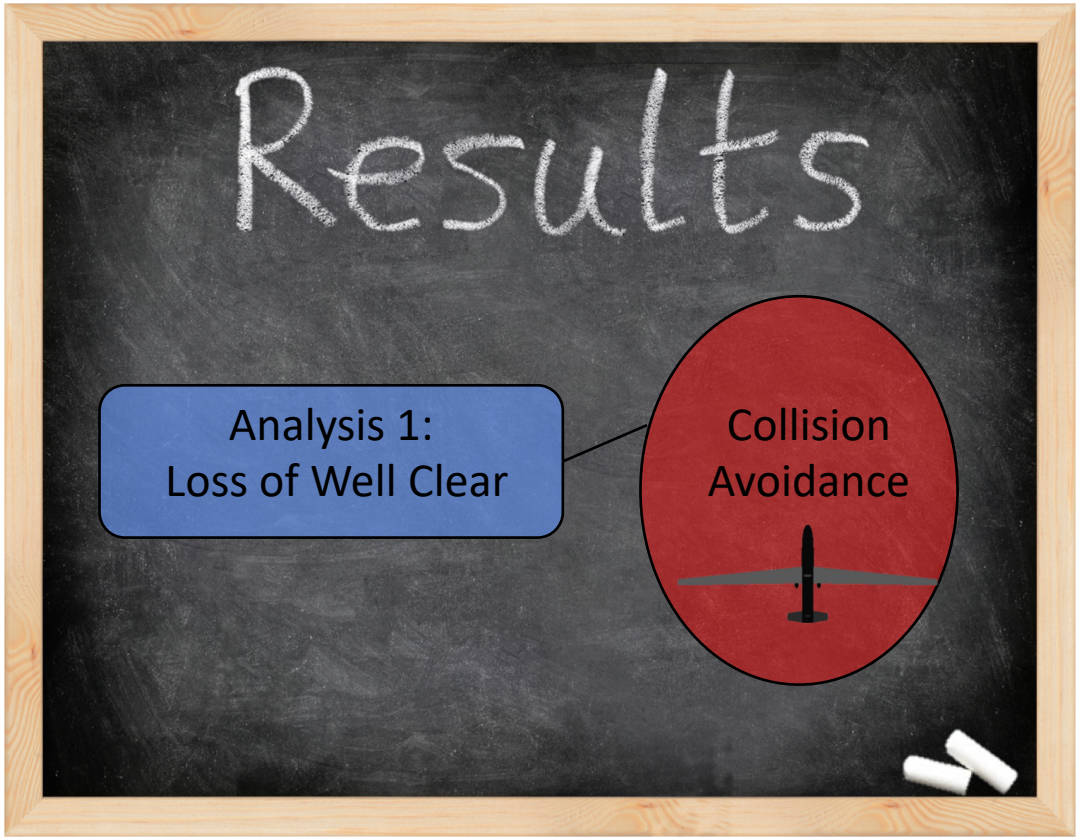
Flight Pattern



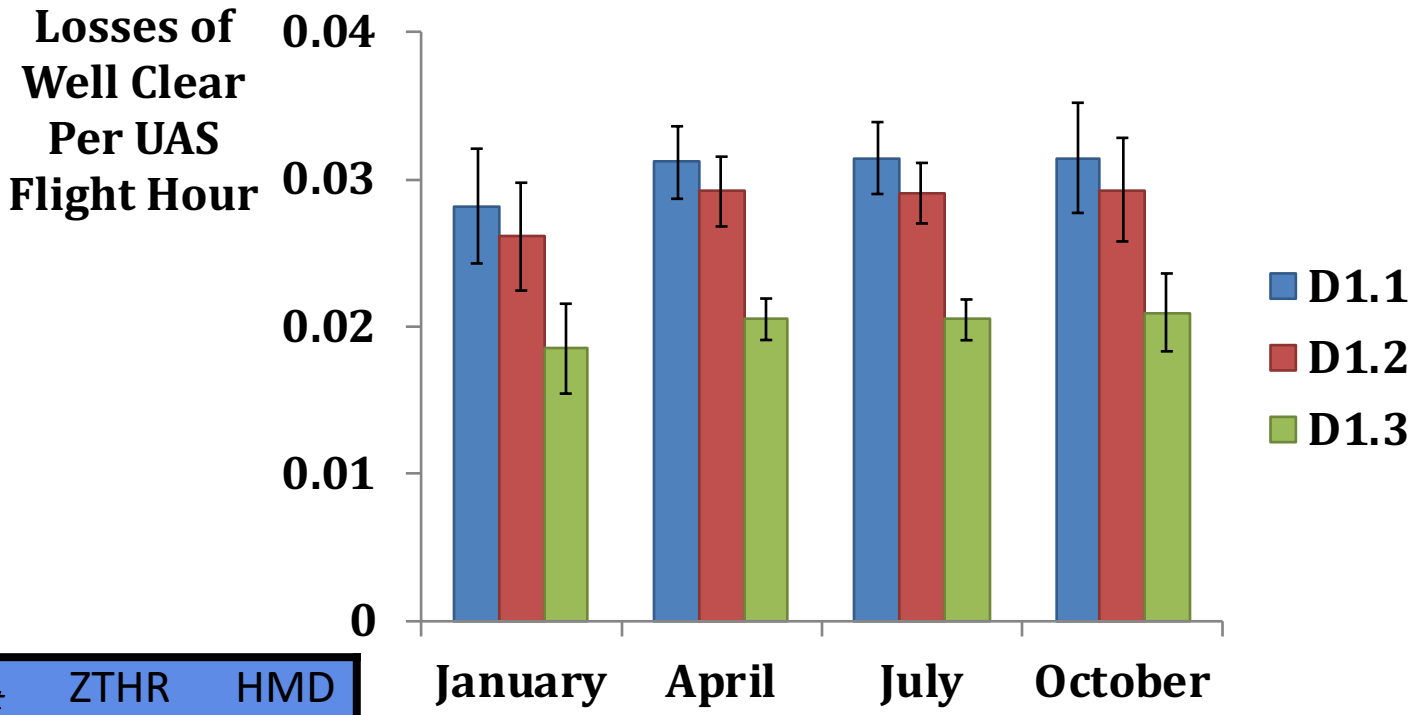
Simulation Configuration

- There are 24 different simulation runs
  - 1 simulation run is a single day in the US national airspace system (NAS)
- Each simulation had
  - UAS: 9 Different Proposed Missions
    - Total of 18,000 UAS flights in data set (~26,000 flight hours)
    - Variety of aircraft performance, mission profiles, geographic areas of operation
  - Traffic: Cooperative VFR Traffic (secondary radar returns)
    - Derived from 84th squadron air defense radar data
    - Varying volume of traffic (20-28k flights)
    - Days are spread over 4 seasons in 2012 (24 days total)
  - No Separation mitigation
    - Metrics only collected for UAS vs. VFR conflicts
    - No Detect and Avoid System was present

Analysis 1: Characterizing Encounters at Well Clear Boundaries



Rate of Losses of Well Clear by Month

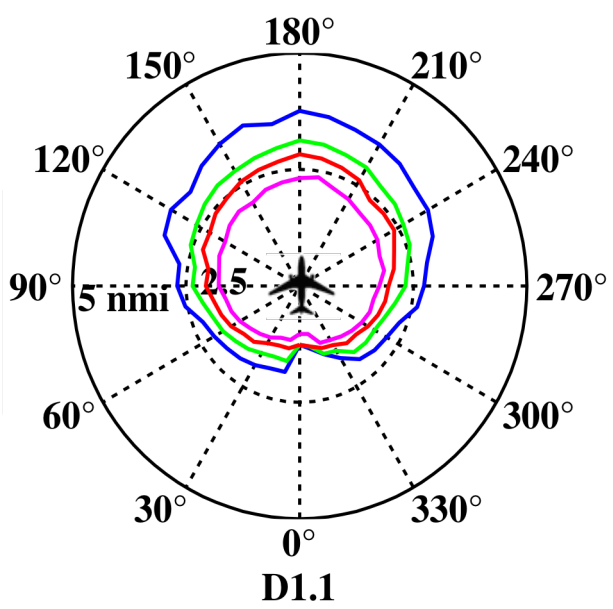


	τ^*_{mod} [s]	τ^*_{vert} [s]	ZTHR [ft]	HMD [ft]
D1.1	30	20	475	6000
D1.2	35	0	700	4000
D1.3	35	0	450	4000

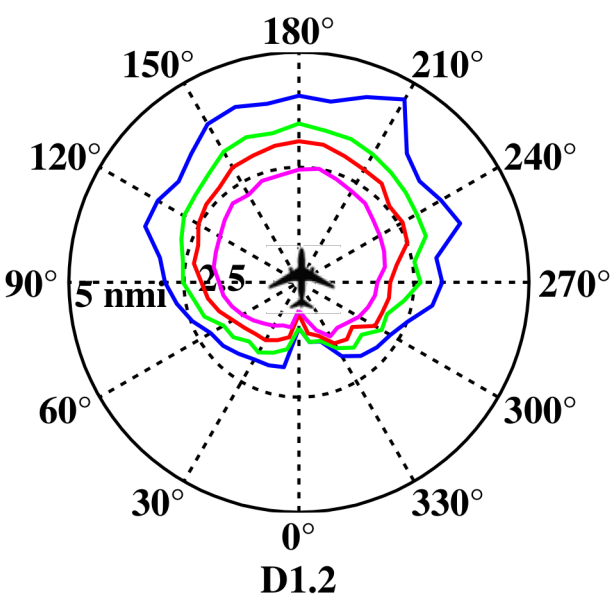
SARP Proposed Definitions

RTCA Proposed Definition

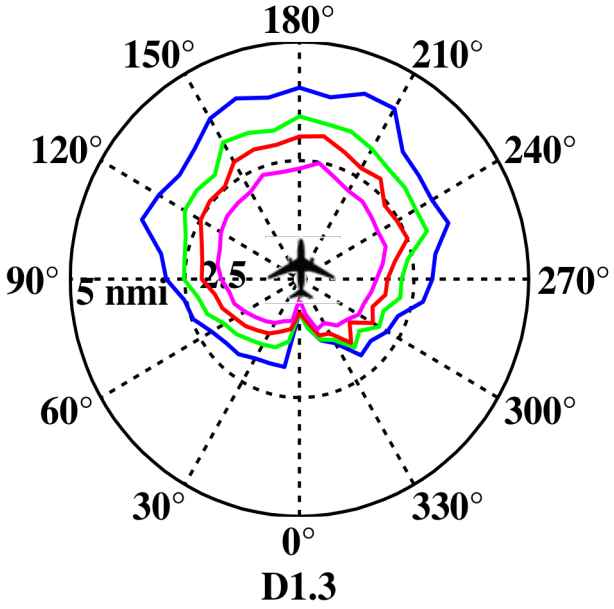
Relative Heading and Distance at LoWC



D1.1

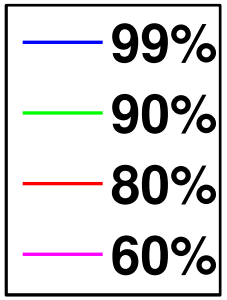


D1.2

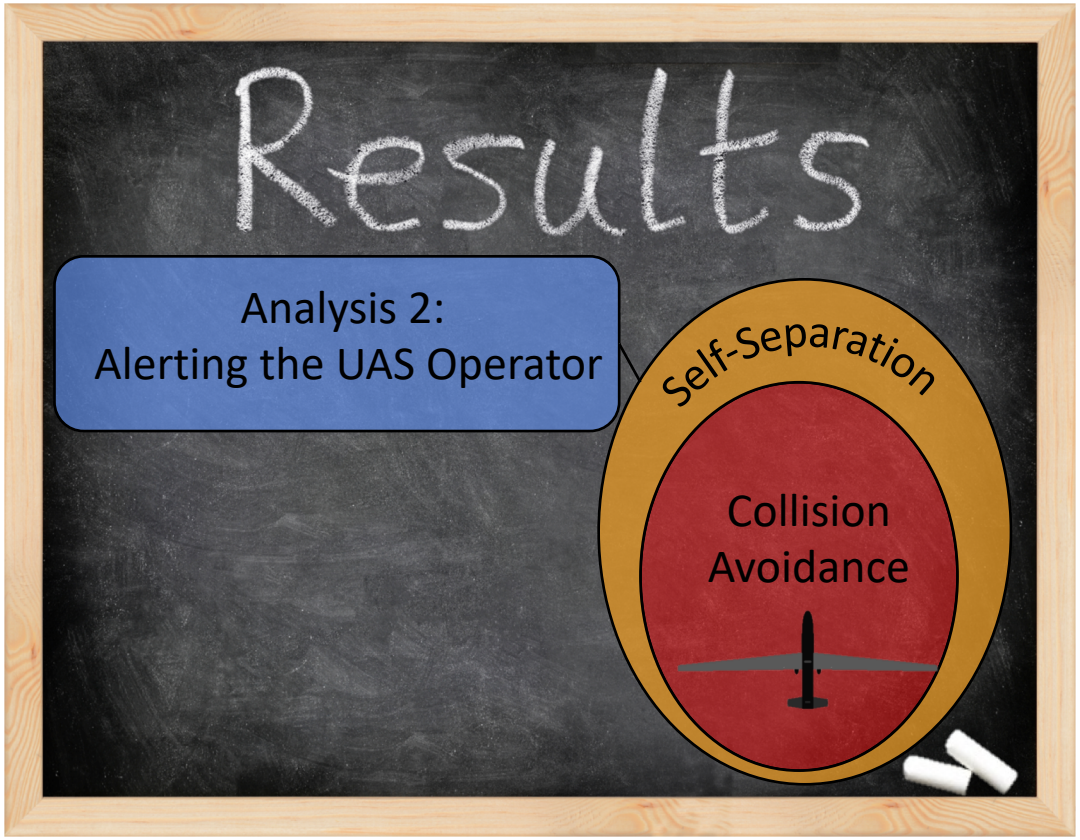


D1.3

	τ^*_{mod} [s]	τ^*_{vert} [s]	ZTHR [ft]	HMD [ft]
D1.1	30	20	475	6000
D1.2	35	0	700	4000
D1.3	35	0	450	4000



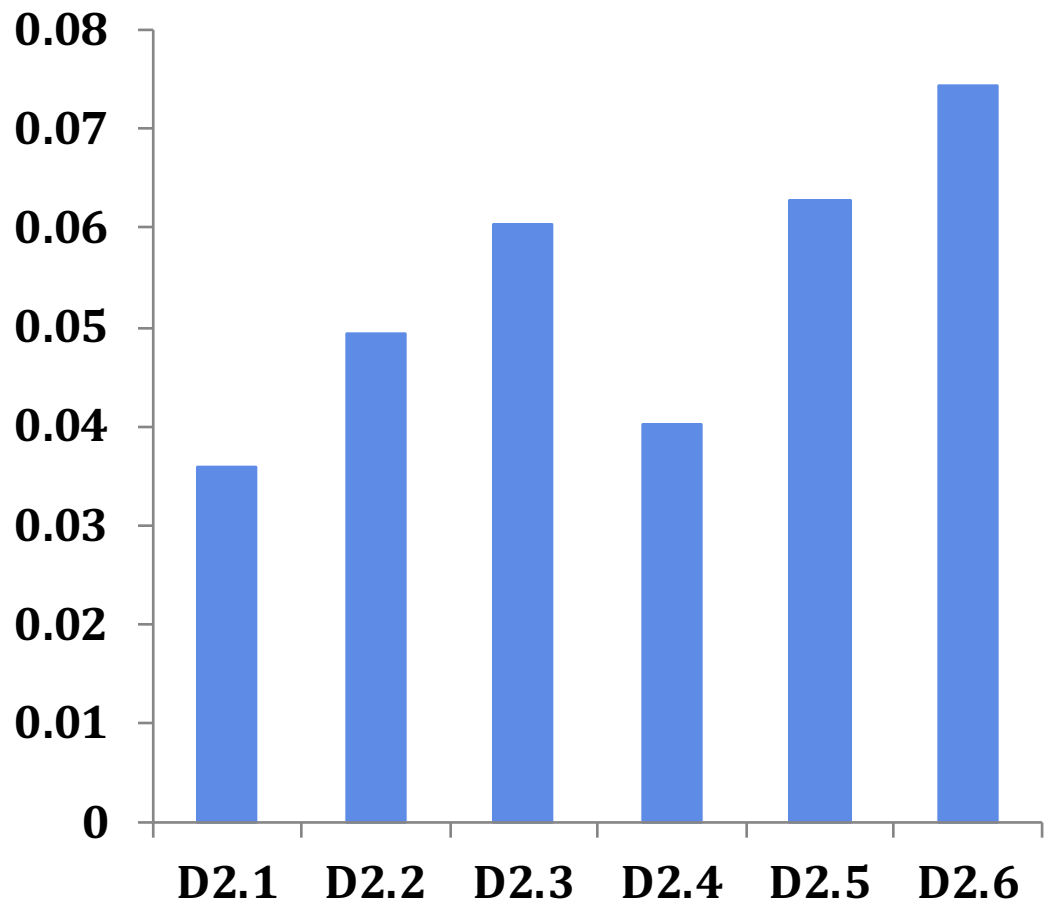
Analysis 2: Evaluating the Alerting Criteria



Rate of Self Separation Alerts

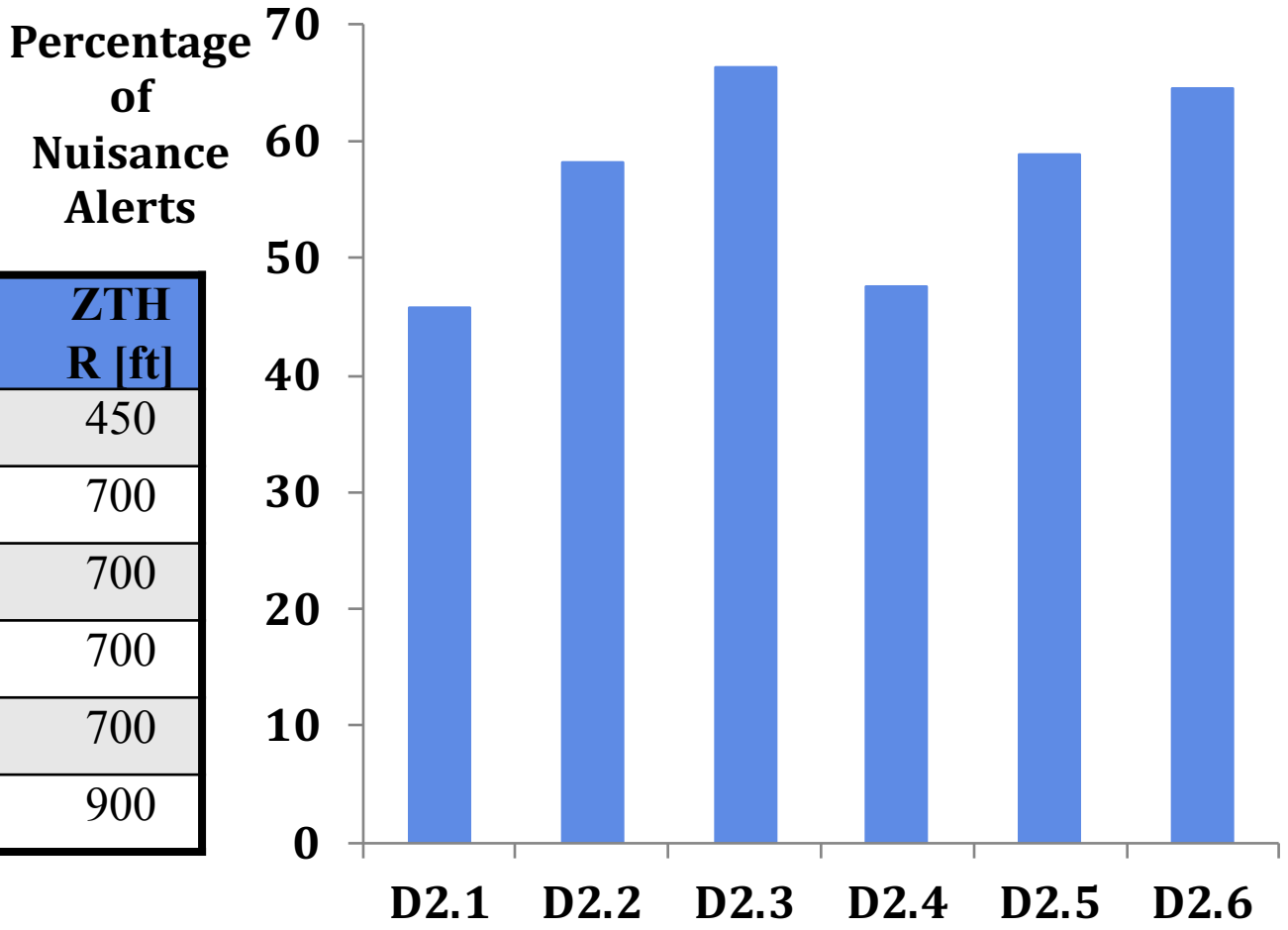
	SST [s]	HMD [ft]	ZTHR [ft]
D2.1	90	4000	450
D2.2	90	4000	700
D2.3	110	4000	700
D2.4	70	4000	700
D2.5	90	6000	700
D2.6	90	6000	900

Note: Definitions Based on D1.3 (RTCA Proposed Well Clear Definition)

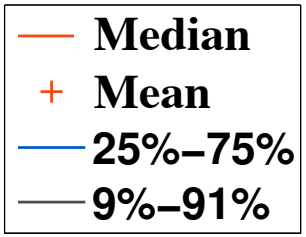


Percentage of Nuisance Alerts

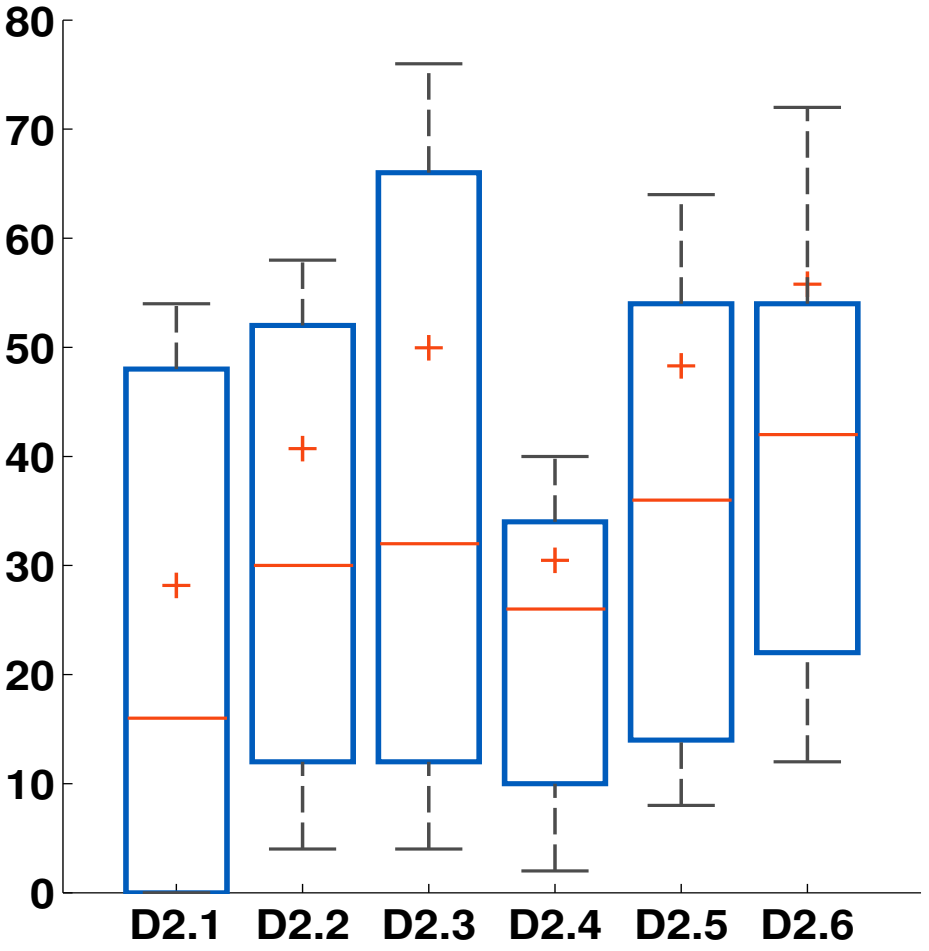
	SST [s]	HMD [ft]	ZTHR [ft]
D2.1	90	4000	450
D2.2	90	4000	700
D2.3	110	4000	700
D2.4	70	4000	700
D2.5	90	6000	700
D2.6	90	6000	900



Time to LoWC at First Self Separation Alert



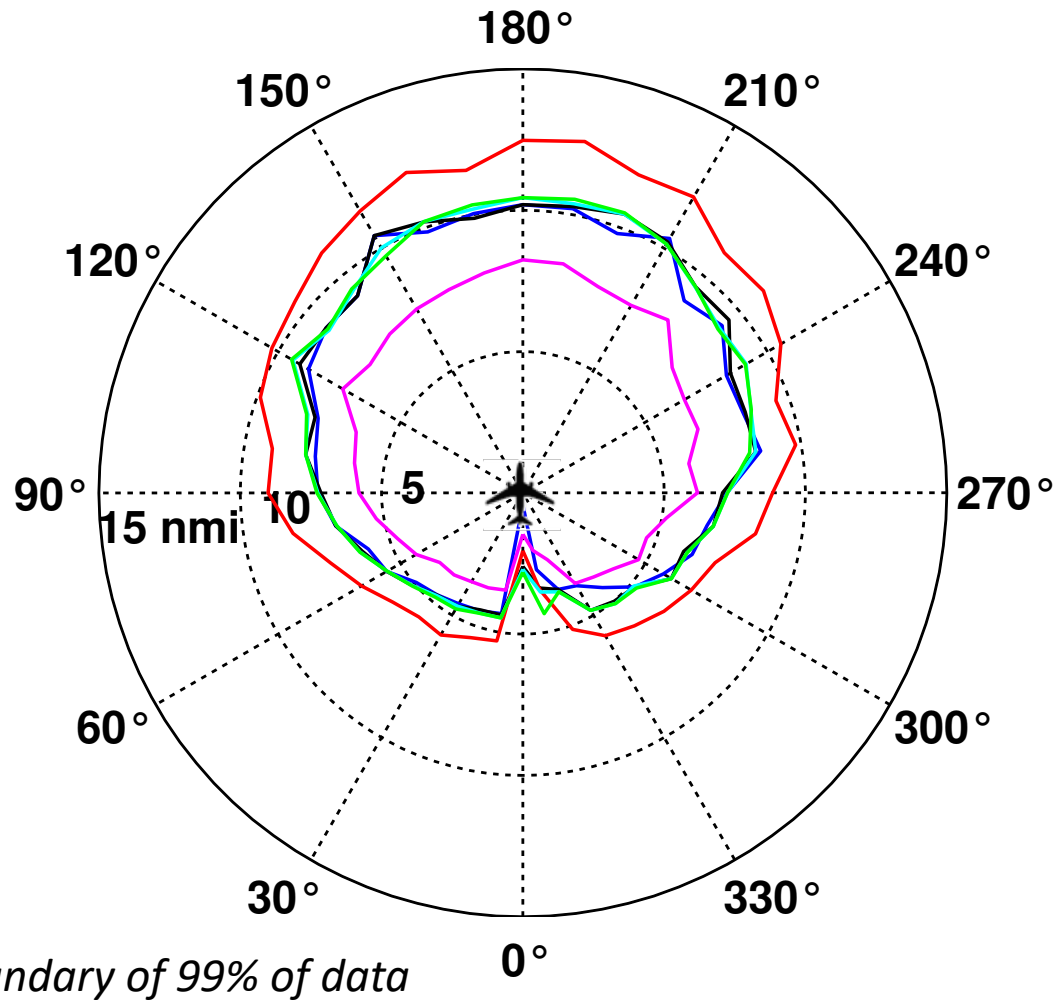
Time to LoWC [sec]



	SST [s]	HMD [ft]	ZTHR [ft]
D2.1	90	4000	450
D2.2	90	4000	700
D2.3	110	4000	700
D2.4	70	4000	700
D2.5	90	6000	700
D2.6	90	6000	900

Note: D1.3 is used to define a LoWC (RTCA Proposed Well Clear Definition)

Relative Heading and Distance at First Self Separation Alert



	SST [s]	HMD [ft]	ZTHR [ft]
D2.1	90	4000	450
D2.2	90	4000	700
D2.3	110	4000	700
D2.4	70	4000	700
D2.5	90	6000	700
D2.6	90	6000	900

Note: All contours represent max boundary of 99% of data

Conclusions and Recommendations

- Surveillance and Alerting Guidelines:
  - DAA system would want a surveillance range of 4-5 nmi
  - Using the proposed alerting criteria the surveillance range would nominally need to be 10 nmi to alert the UAS operator to take action
  - There is a trade-off between time to loss of well clear and percentage of nuisance alerts
    - The larger the alerting volume ➔ More time before loss of well clear and larger percentage of nuisance alerts.

- Recommendations:
  - Consider buffers for alerting criteria
  - Include ownship intent in alerting criteria
  - Consider multiple layers of alerting

Questions

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