



National Aeronautics and Space Administration

# Investigating Detect-and-Avoid Surveillance Performance for Unmanned Aircraft Systems

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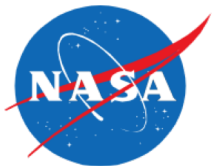




# Background and Motivation



- A Detect-And-Avoid (DAA) capability is required for UAS to meet the requirement in CFR 91.113 to “see and avoid” other aircraft and maintain “**well clear**”.
- RTCA Special Committee 228 is developing Minimum Operational Performance Standards (MOPS) for DAA systems.
- A surveillance system is a critical component of DAA system to detect and track intruder aircraft. Thus, the MOPS will include surveillance system requirements.
- Encounter characteristics of “well-clear” violations between UAS and manned aircraft have not been investigated.



# Objectives



- Investigate geometric encounter characteristics of well-clear violations between UAS and VFR aircraft in Class E airspace
- Investigate the relationship between encounters and surveillance system characteristics in terms of detection range and field of regard (FOR)
- Generate a database for encounters between UAS and VFR aircraft and a knowledge base that helps surveillance system designer



# Concept of Well-Clear Violation



- Airborne separation standard
- Time and distance-based definition of “Well-Clear Violation (WCV)”
  - When two aircraft are within distance thresholds
  - When the projected closest point of approach (CPA) of two aircraft is within a distance-based volume in particular time thresholds

## “Well Clear” Distance Thresholds

Horizontal criteria





# Definition of Well-Clear Violation



Horizontal Criteria  $R_{xy} \leq DMOD$  or  $\{ R_{xy}(t_{CPA}) \leq HMD$  and  $0 \leq \tau_{mod} \leq \tau_{mod}^* \}$

and

Vertical Criteria  $|\Delta h| \leq ZTHR$  or  $0 \leq \tau_{vert} \leq \tau_{vert}^*$

where  $R_{xy}$  : Horizontal Range

$R_{xy}(t_{CPA})$  : Predicted horizontal range at time of closest point of approach

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

$|\Delta h|$  : Altitude Difference

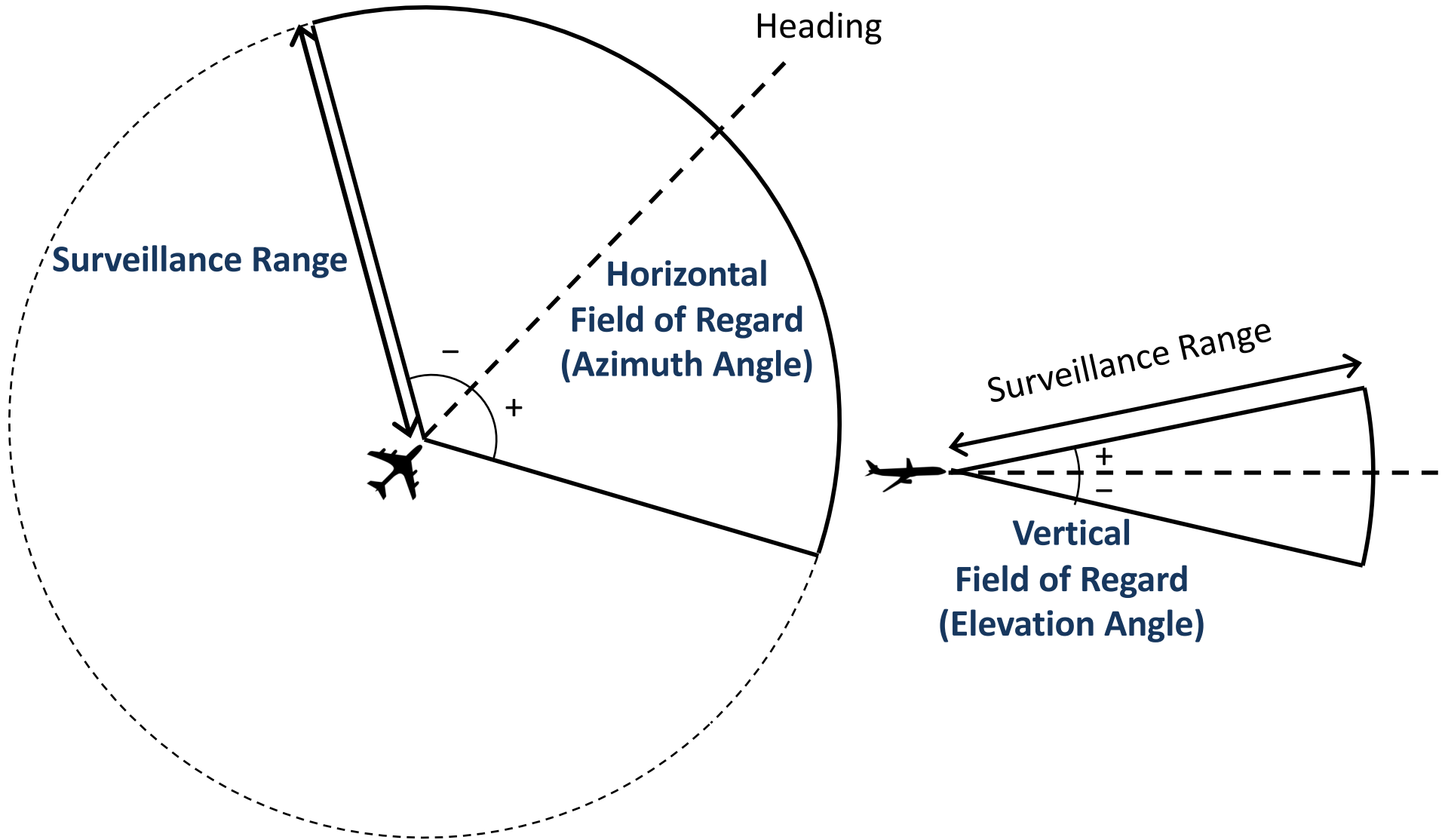
$\tau_{vert}$  : Time to Co-Altitude

$$DMOD = 6000 \text{ ft} \quad HMD = 6000 \text{ ft} \quad ZTHR = 475 \text{ ft}$$

$$\tau_{mod}^* = 30 \text{ sec} \quad \tau_{vert}^* = 20 \text{ sec}$$



# Generic Surveillance Model

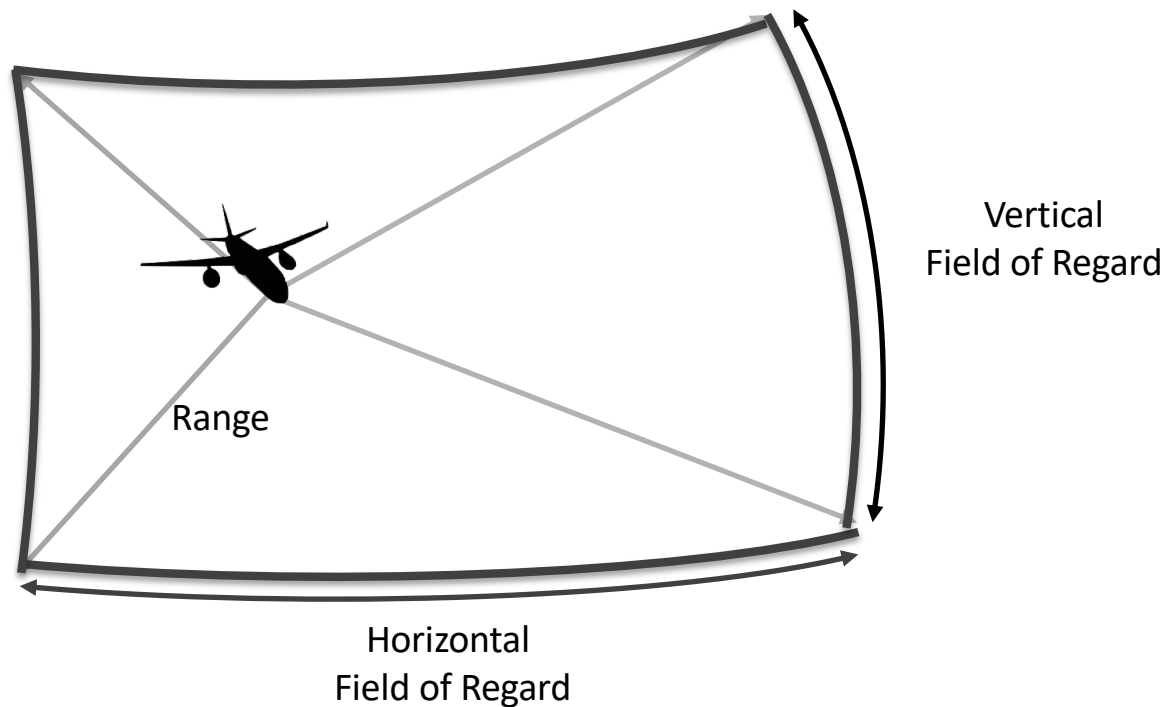




# Generic Surveillance Model

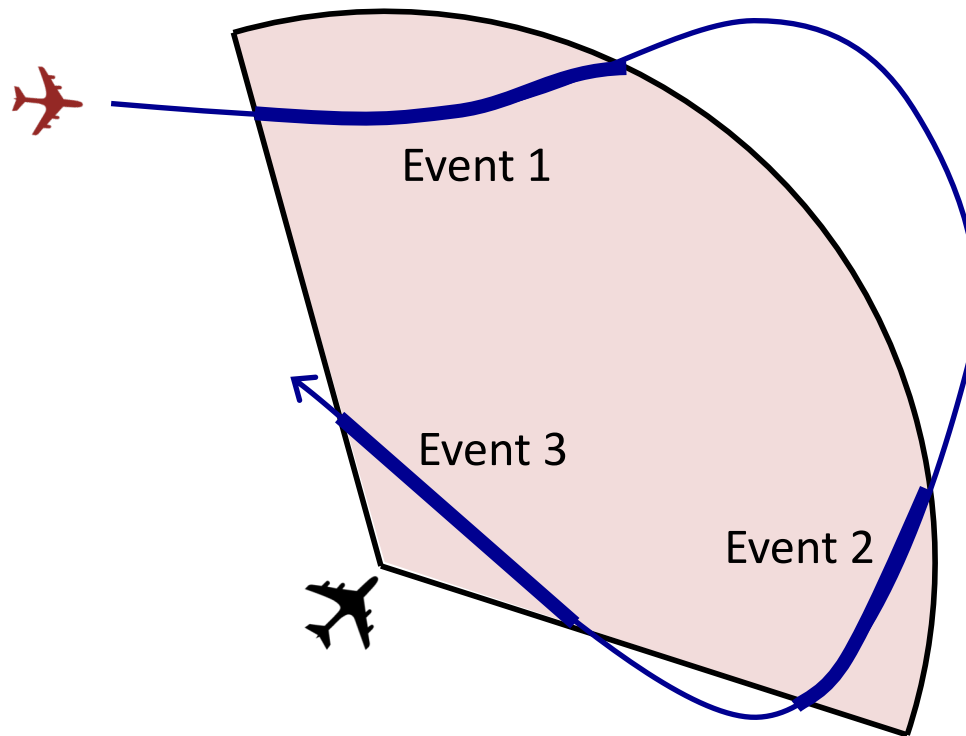


## Surveillance Volume





# Intruding event, Intruder and Threat



- **Intruding event:** Each intrusion into the ownship's surveillance volume
- **Intruder:** Aircraft that causes intruding events
- **Threat:** An intruder that finally causes well-clear violation

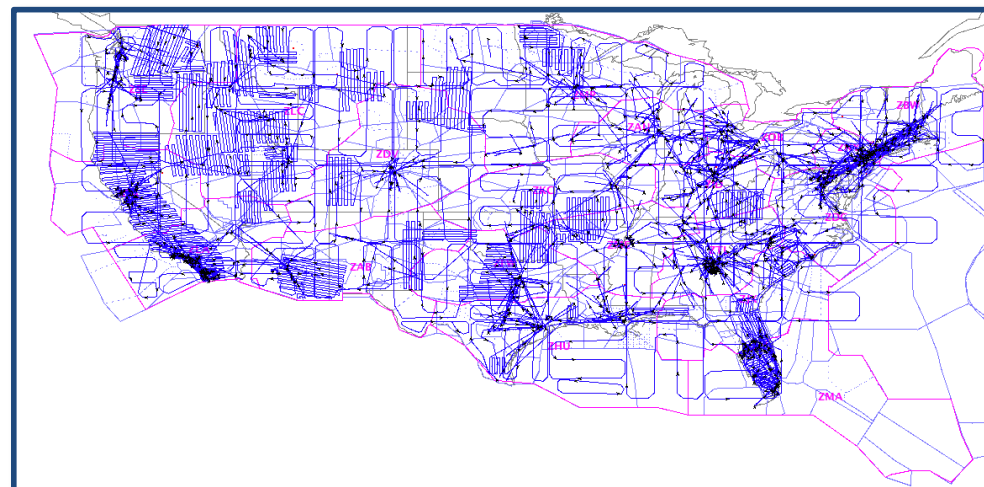




# NAS-Wide Air Traffic Simulation



- Airspace Concept Evaluation System (ACES)
  - Simulate NAS-wide air traffic operations and unmitigated encounters between UAS and VFR traffic

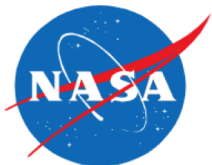


- Traffic scenarios
  - Proposed UAS flights
    - Various types of UAS missions generated by Intelligent Automation Inc.
    - Total 18,262 flights, 18,900 flight hours
  - Historical cooperative VFR traffic
    - Extracted from Air Defense radar data on 2012
    - Selected 7 days: 1/5, 4/6, 4/21, 7/2, 7/22, 7/25, and 10/16
    - Each day: 20,439 – 26,770 flights, 16,515 – 24,838 flight hours

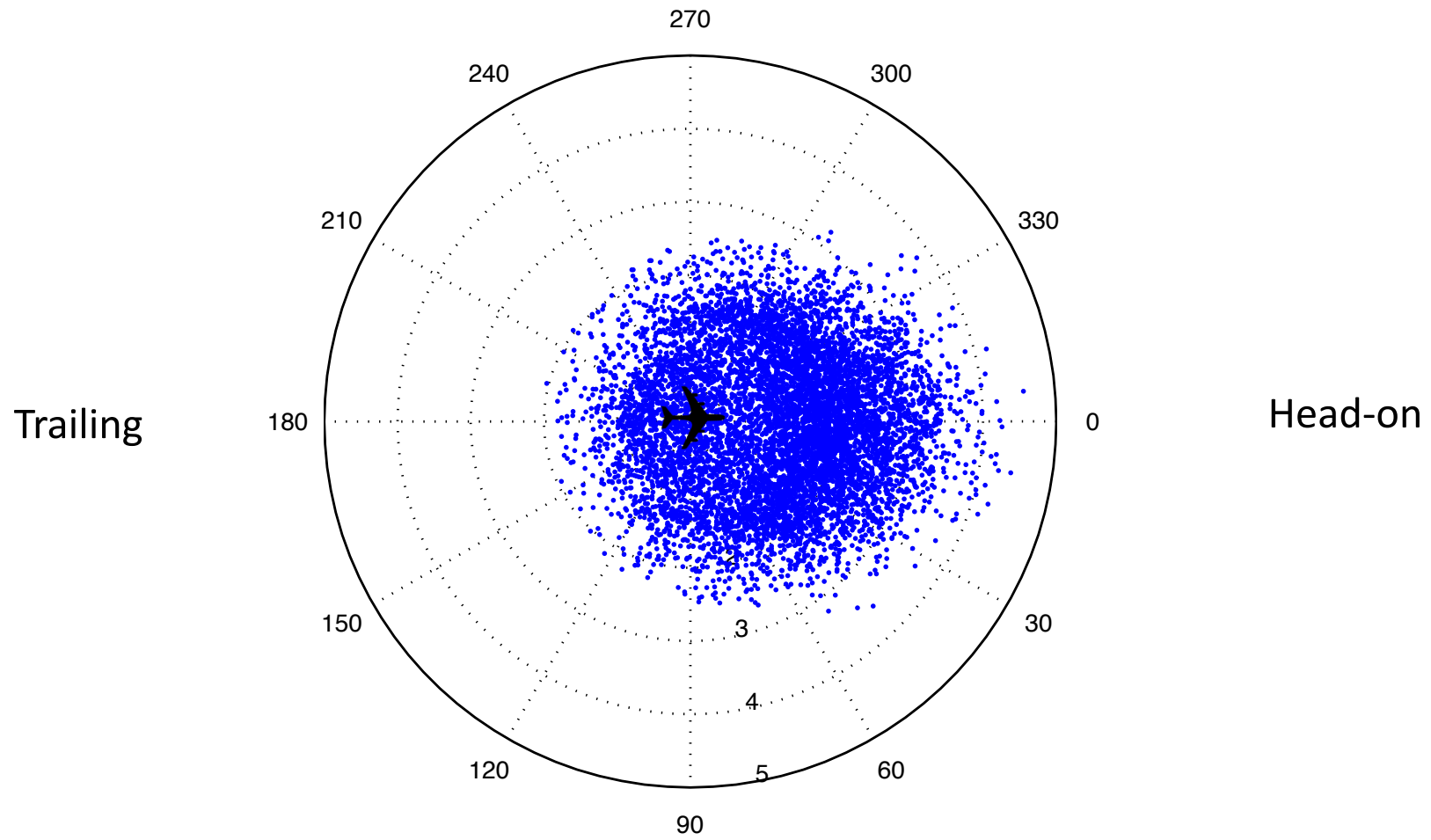


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# Simulation and Analysis



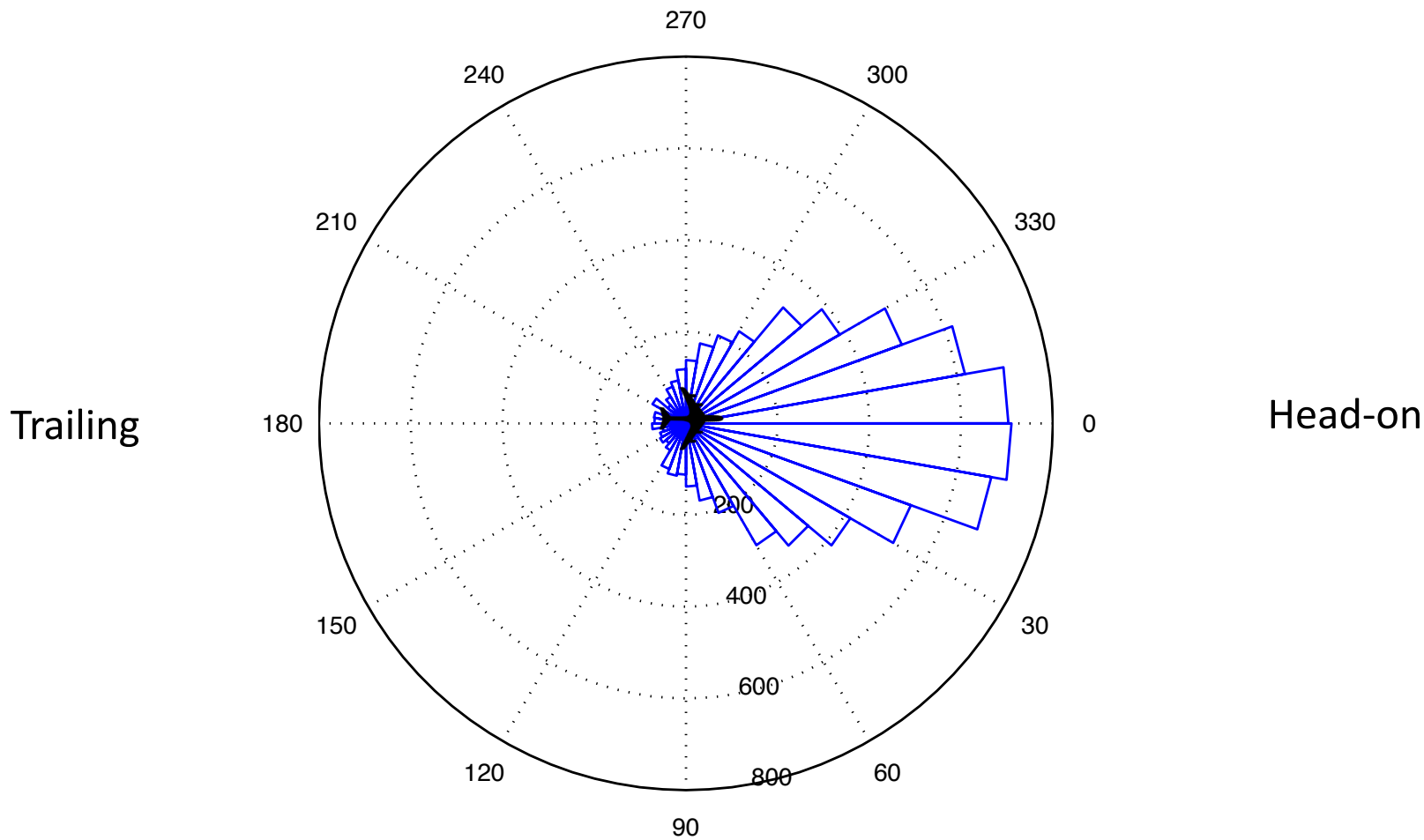
# Relative Position of Threats



Relative Position of Threats at 2000 ft Altitude

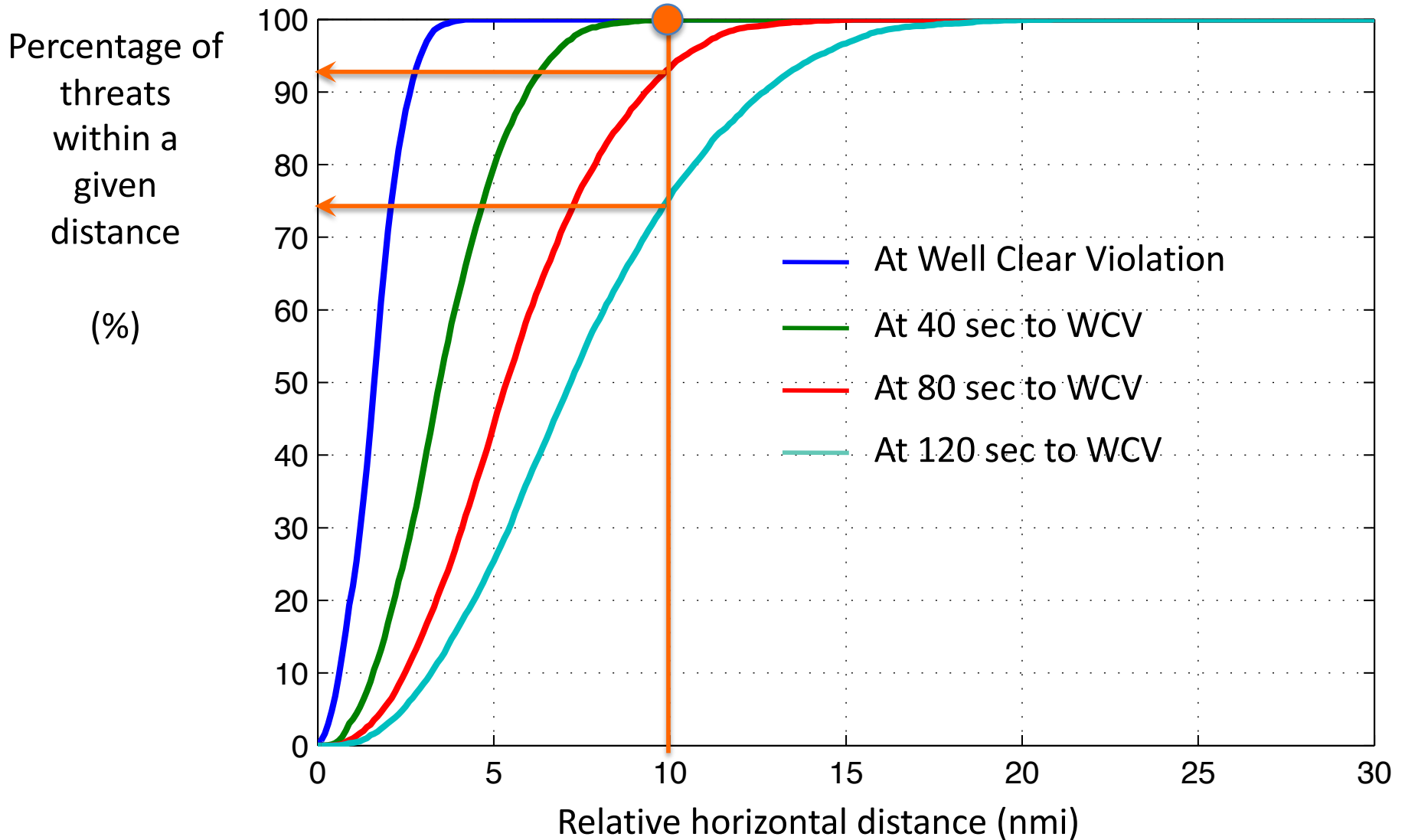


# Bearing Angle Distribution at Well-Clear Violation



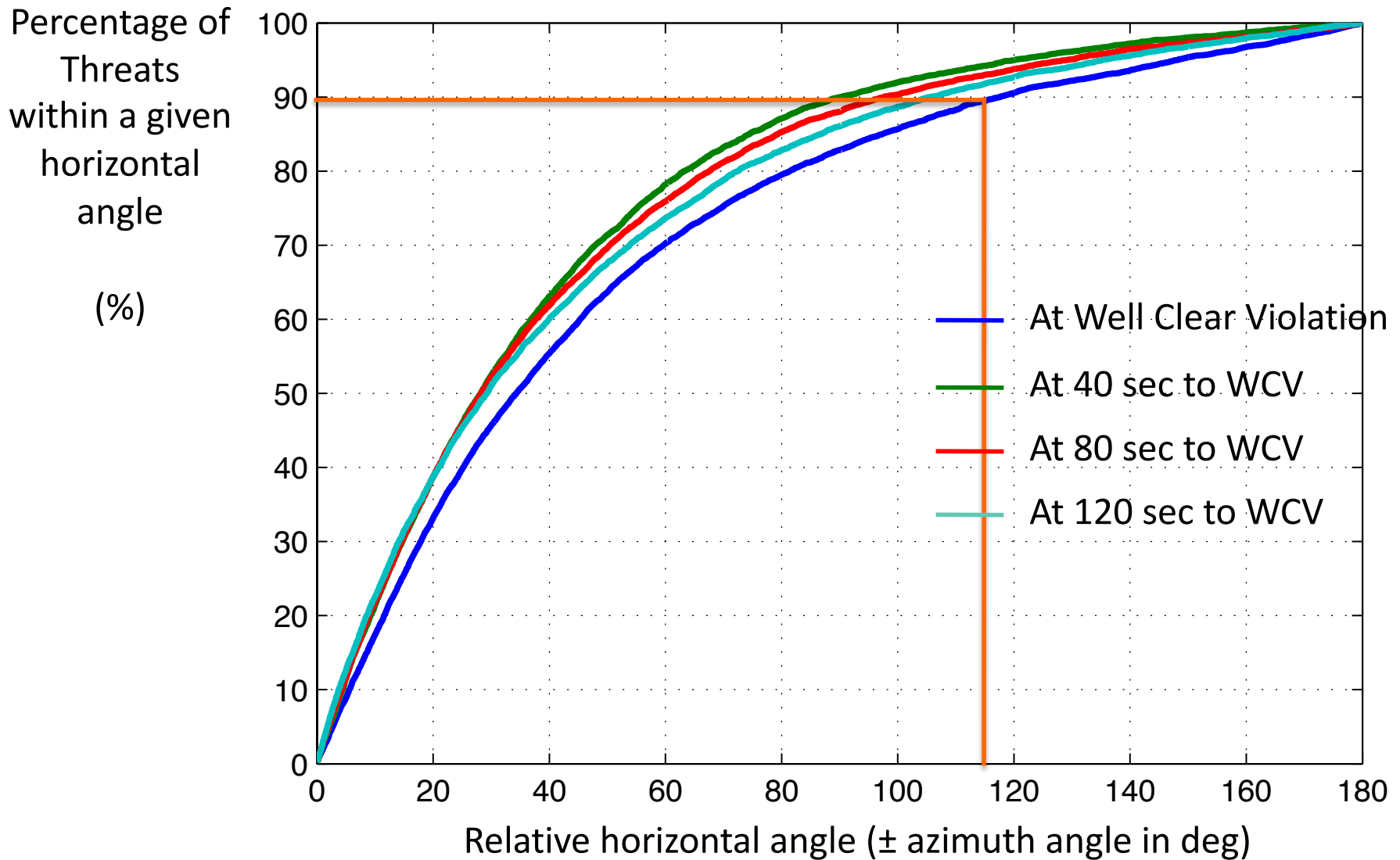


# Relative Horizontal Distance of Threats



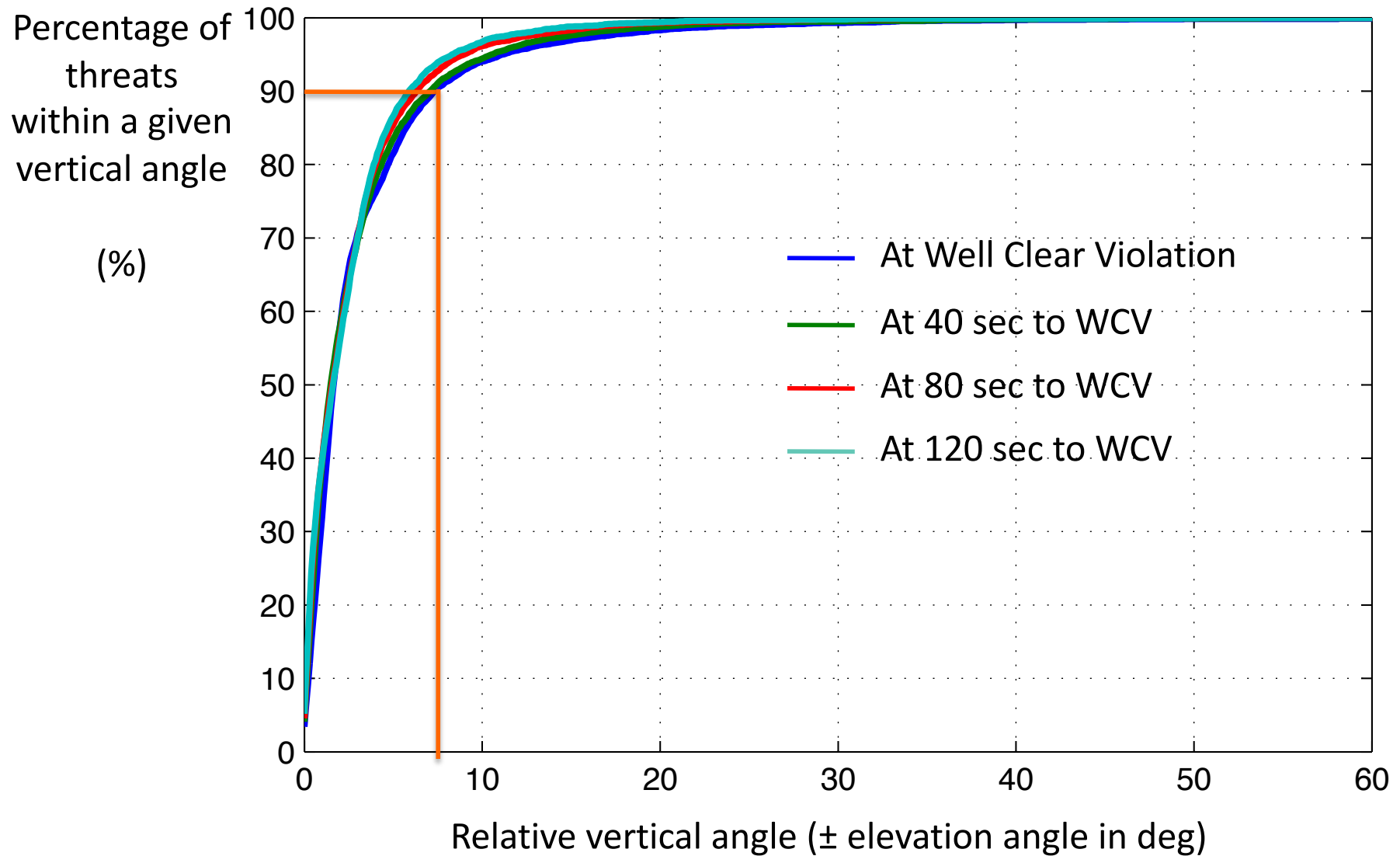


# Relative Horizontal Angle of Threats





# Relative Vertical Angle of Threats





# Effects of Surveillance Parameters

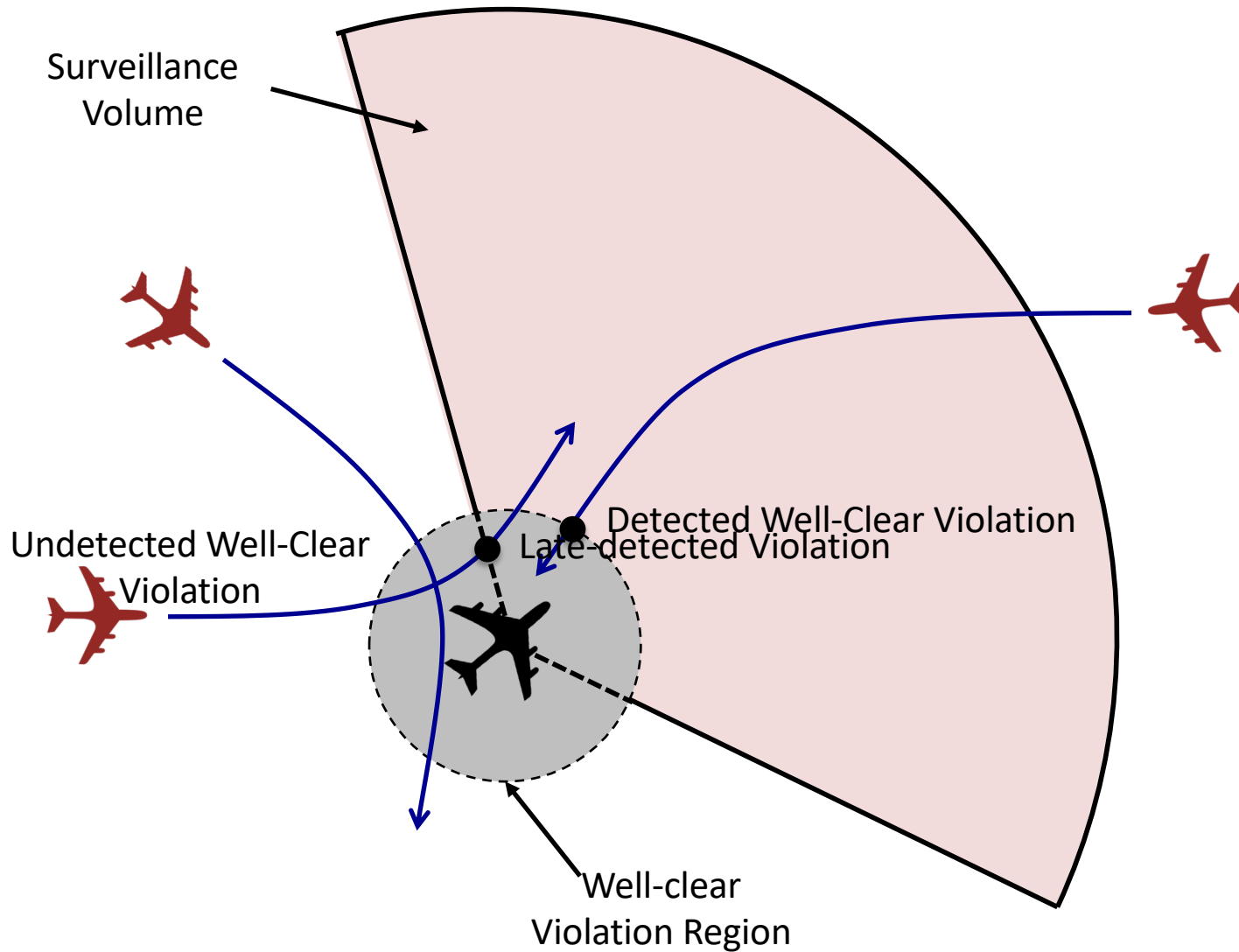


- Selected sets of surveillance parameters
  - Surveillance Range: 3, 6, 10, 20 nmi
  - Horizontal Field of Regard: ( $\pm$ ) 60, 90, 120, 180 deg
  - Vertical Field of Regard: ( $\pm$ ) 20, 40 deg
  - Total 32 sets of surveillance volume ( $4 \times 4 \times 2$ )
- Analysis for undetected Well-Clear Violation
  - Metric: Ratio of the number of undetected Well-Clear Violations for each surveillance volume
- Analysis for detected Well-Clear Violation
  - Metric: Time to Well-Clear Violations of threats at their first appearance in each surveillance volume



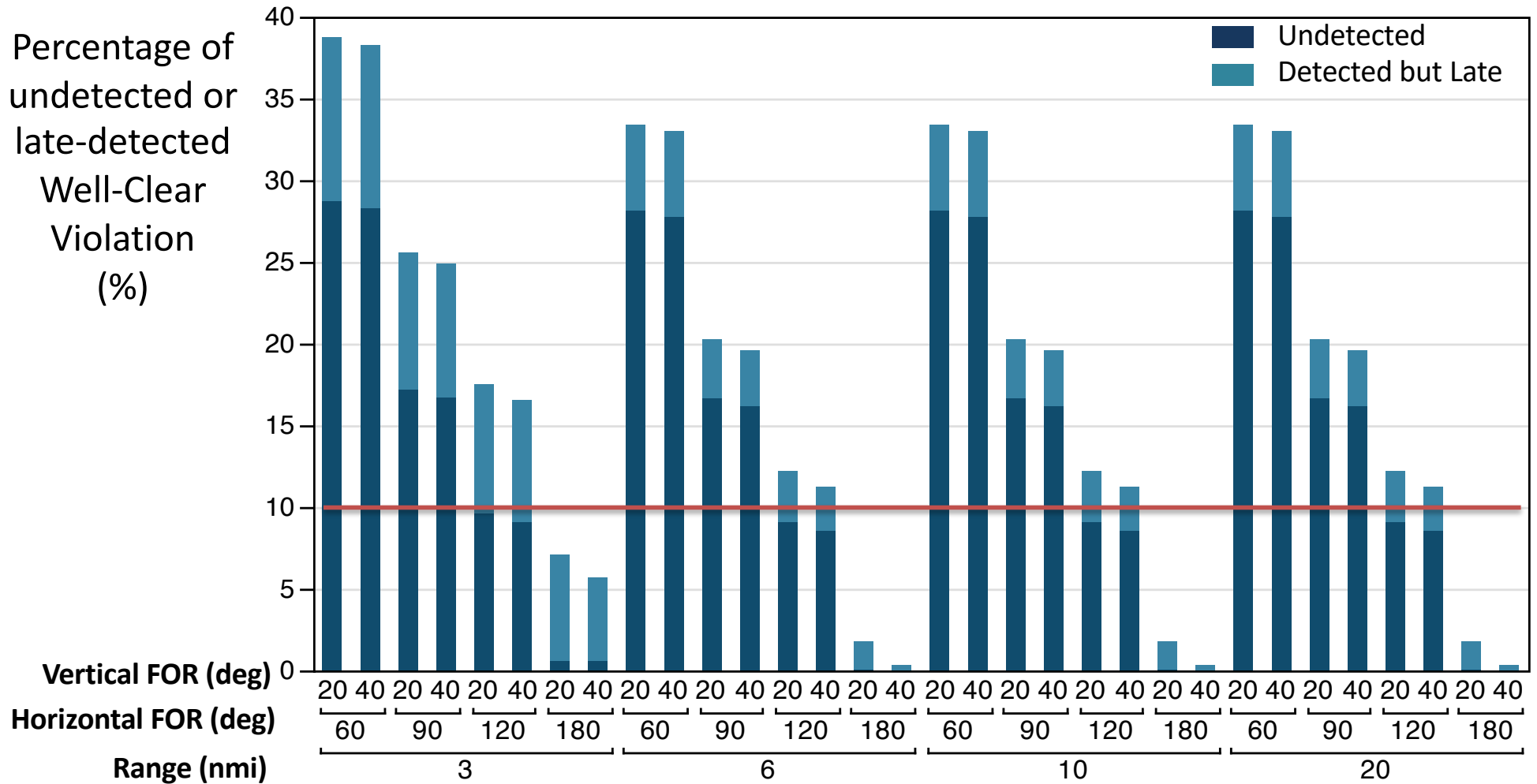


# Detected / Undetected / Late-Detected Well-Clear Violations





# Ratio of Undetected and Late-detected Well-Clear Violations



\* Percentage of undetected Well-Clear Violations is closely related to horizontal field of regard!

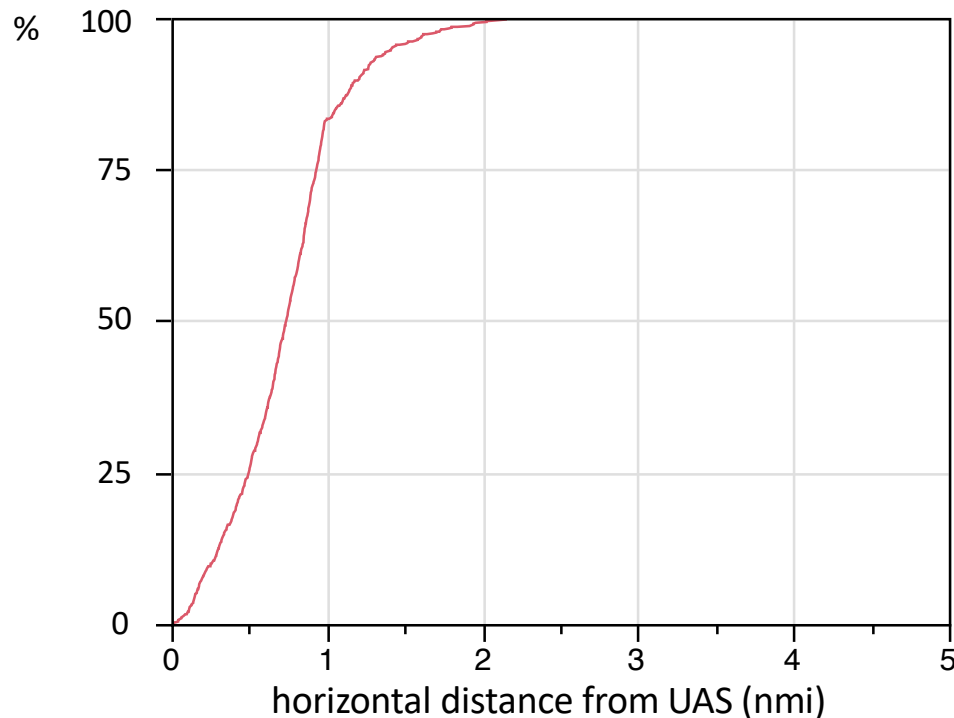


# Characteristics of undetected WCVs

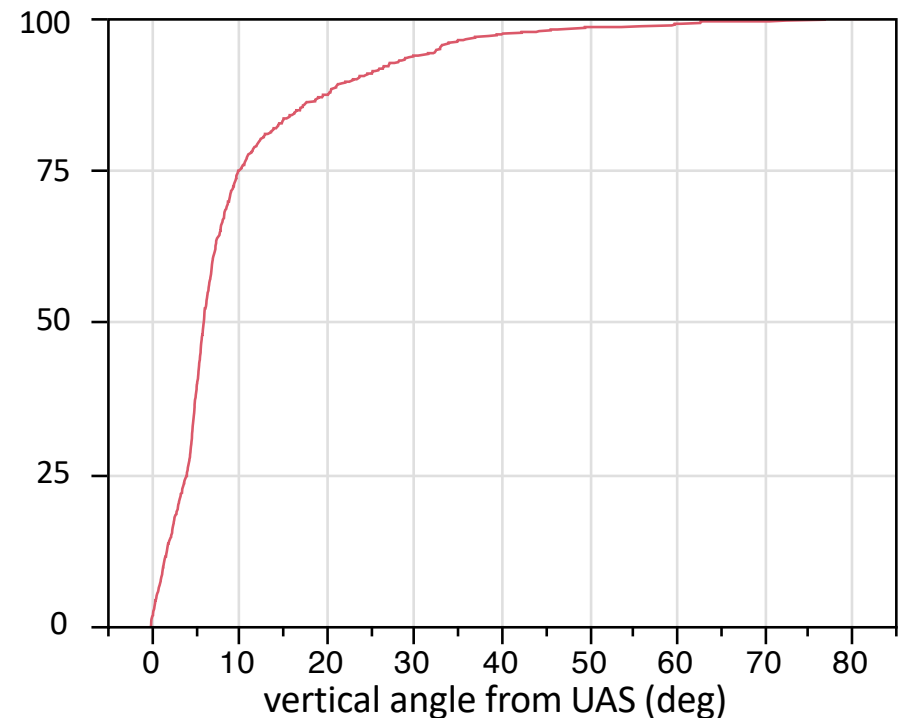


- When range=10 nmi, HFOR=120 deg, VFOR=20 deg

Cumulative distribution for horizontal distance



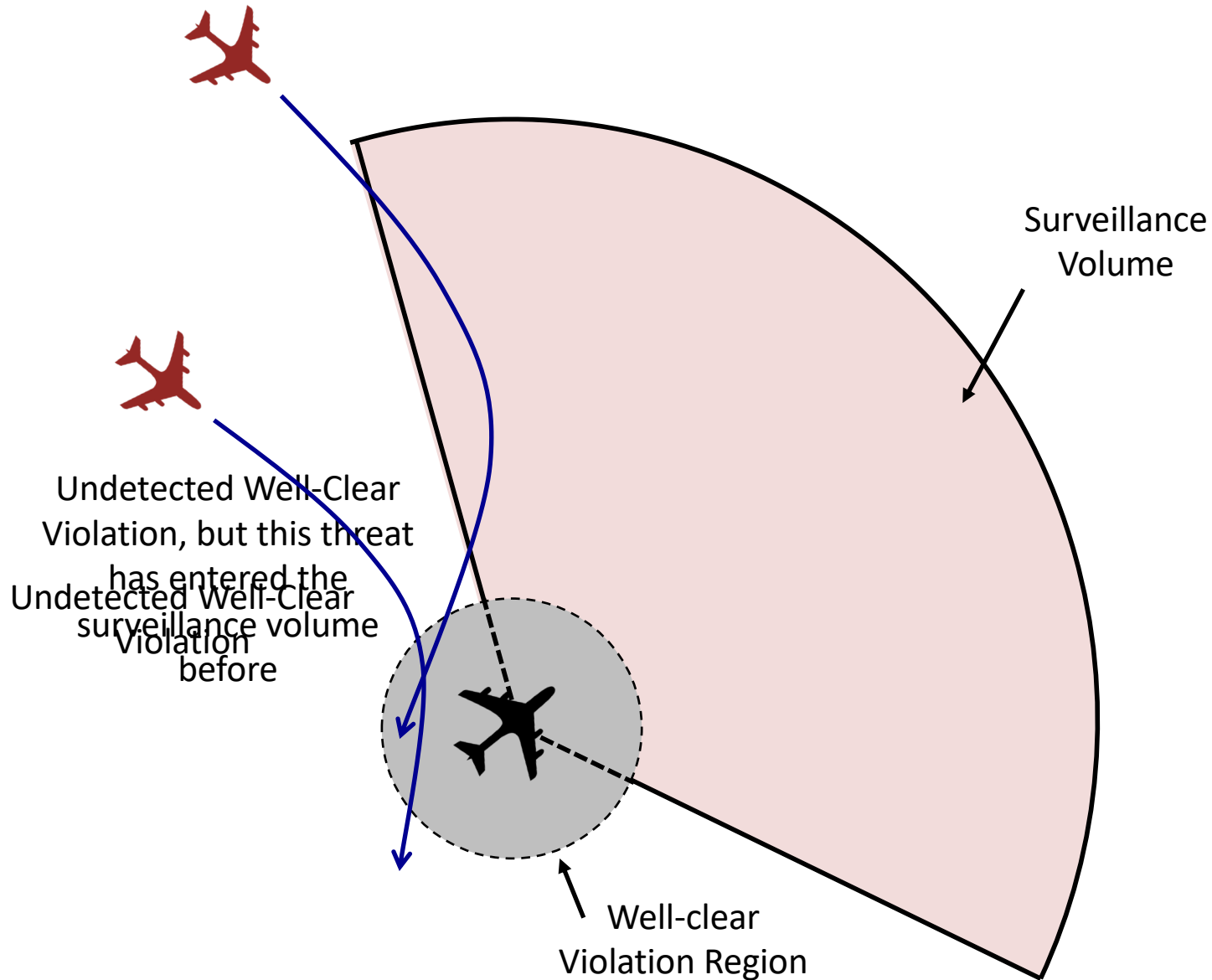
Cumulative distribution for vertical angle



\* The undetected WCVs might be detected if UAS is equipped with a secondary sensor having short detection range (~2 nmi) but wide vFOR (~60 deg)

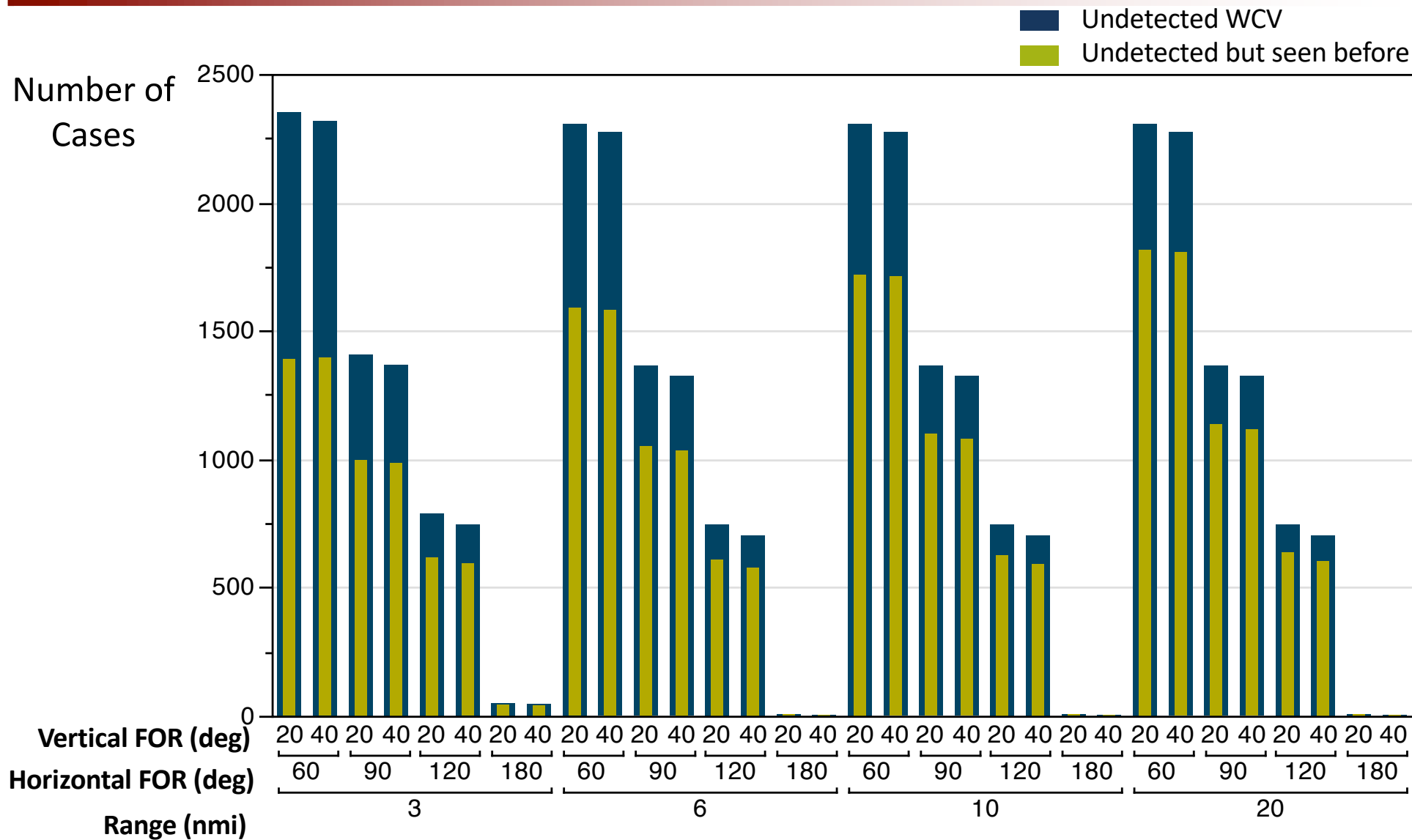


# Example: Undetected but Already Seen Before



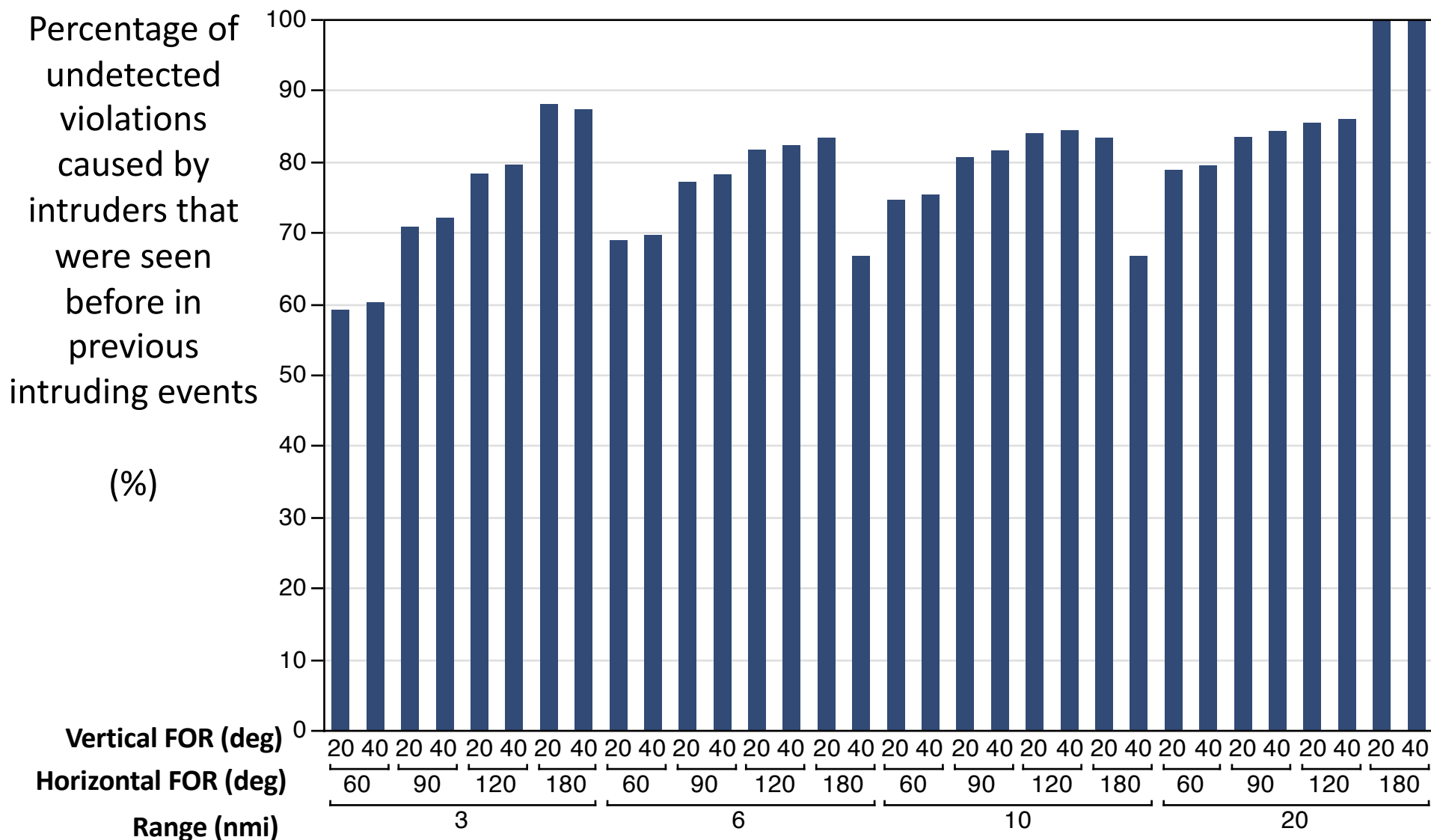


# Undetected Well-Clear Violation but the Threat Was Seen Before



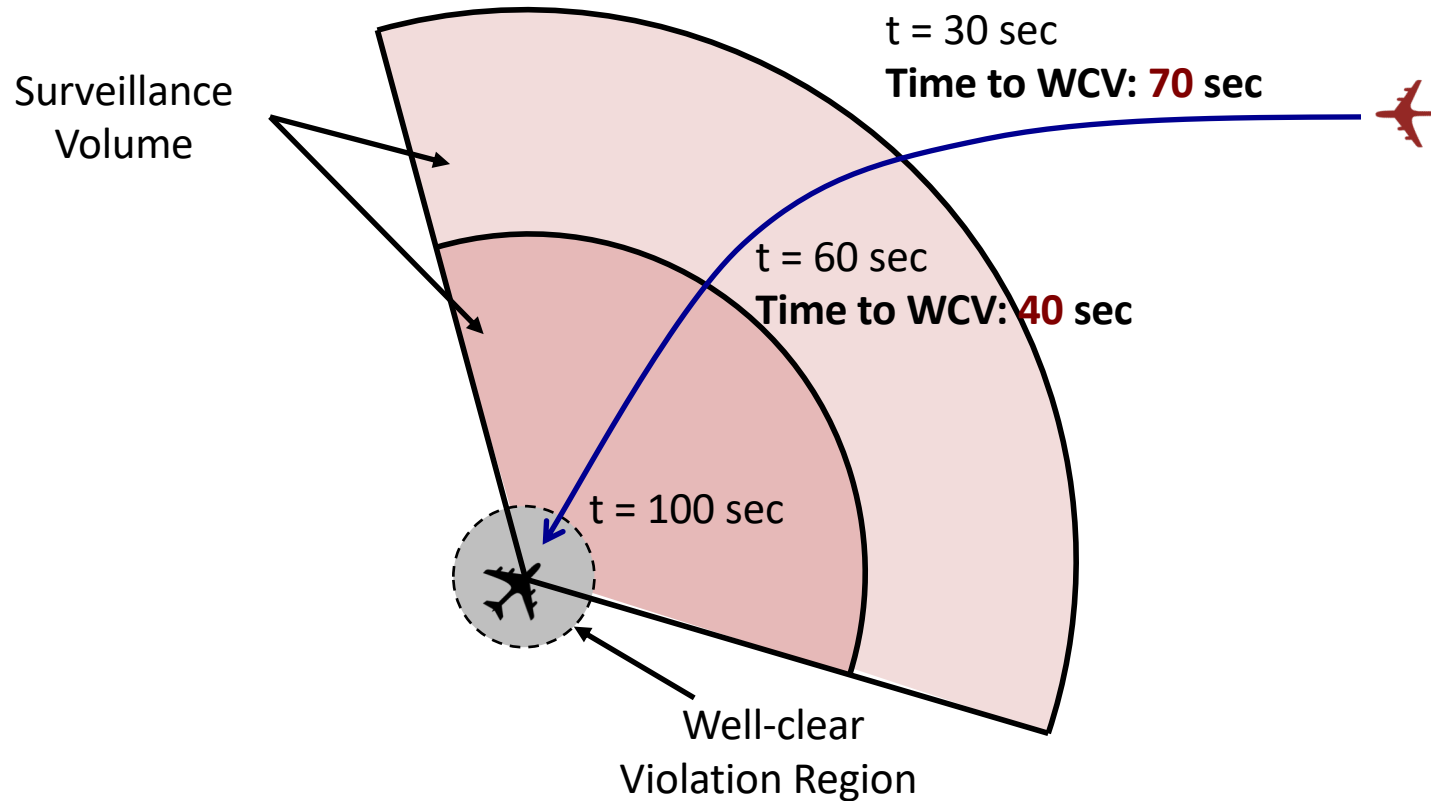


# Undetected Well-Clear Violation but the Threat Was Seen Before





# Time until Well-clear Violation at First Appearance in the Surveillance Volume



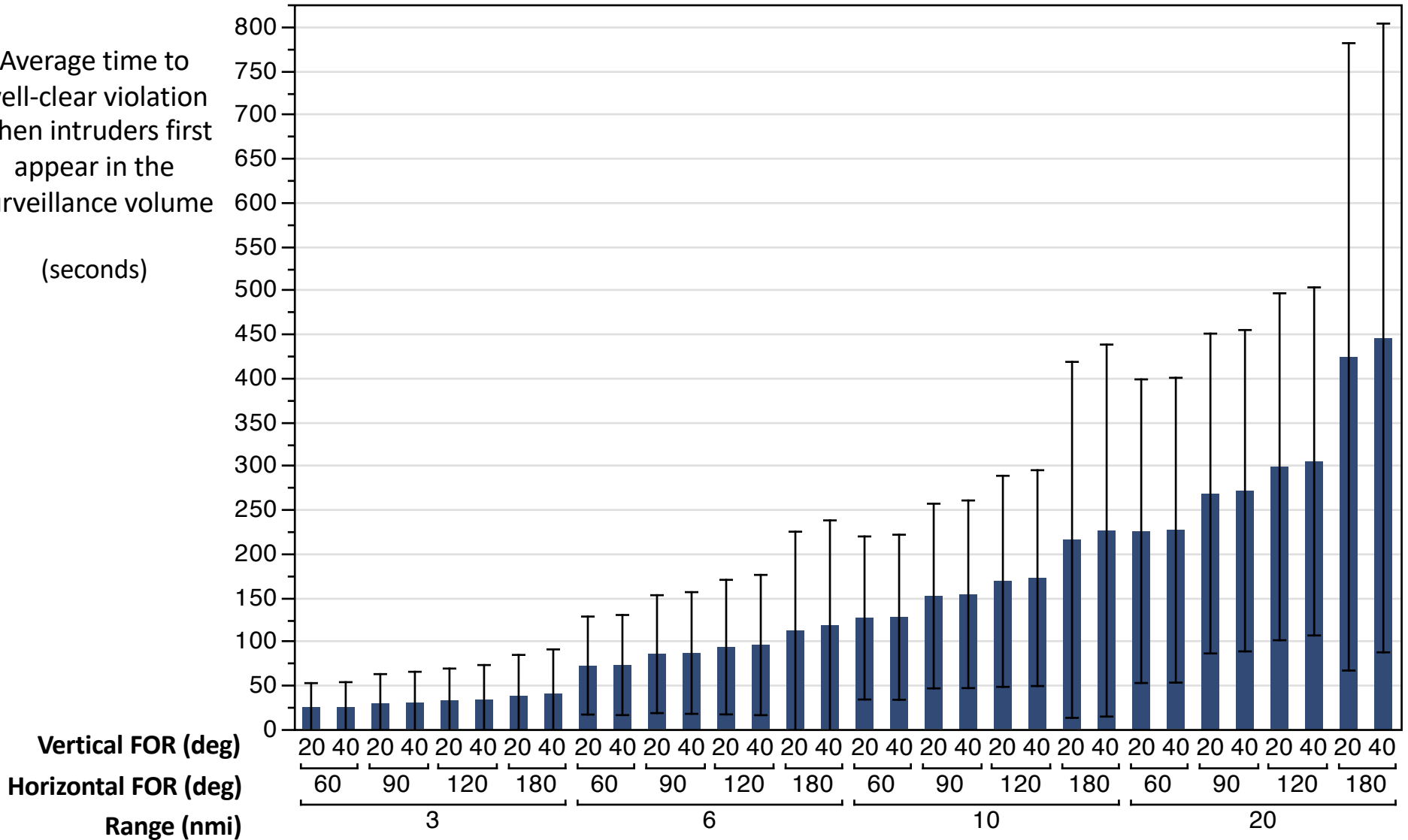
- Time until well-clear violation at the first appearance in the surveillance volume is important since it is time for preparing for avoiding the violation.
- For all threats, collect data at the time when they first appear in each surveillance volume.



# Average Time until Well-Clear Violation at First Appearance in the Surveillance Volume



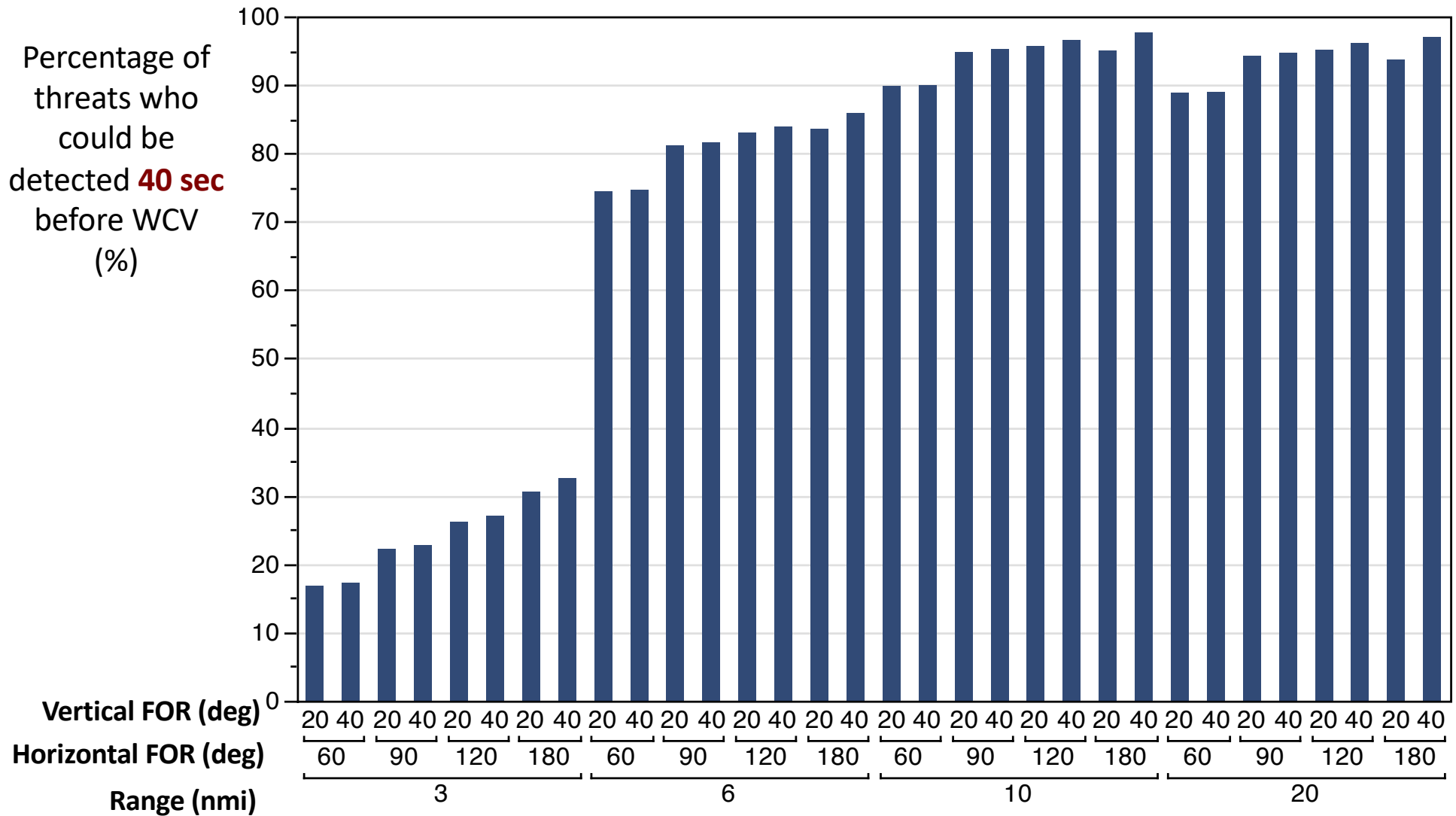
Average time to well-clear violation when intruders first appear in the surveillance volume (seconds)





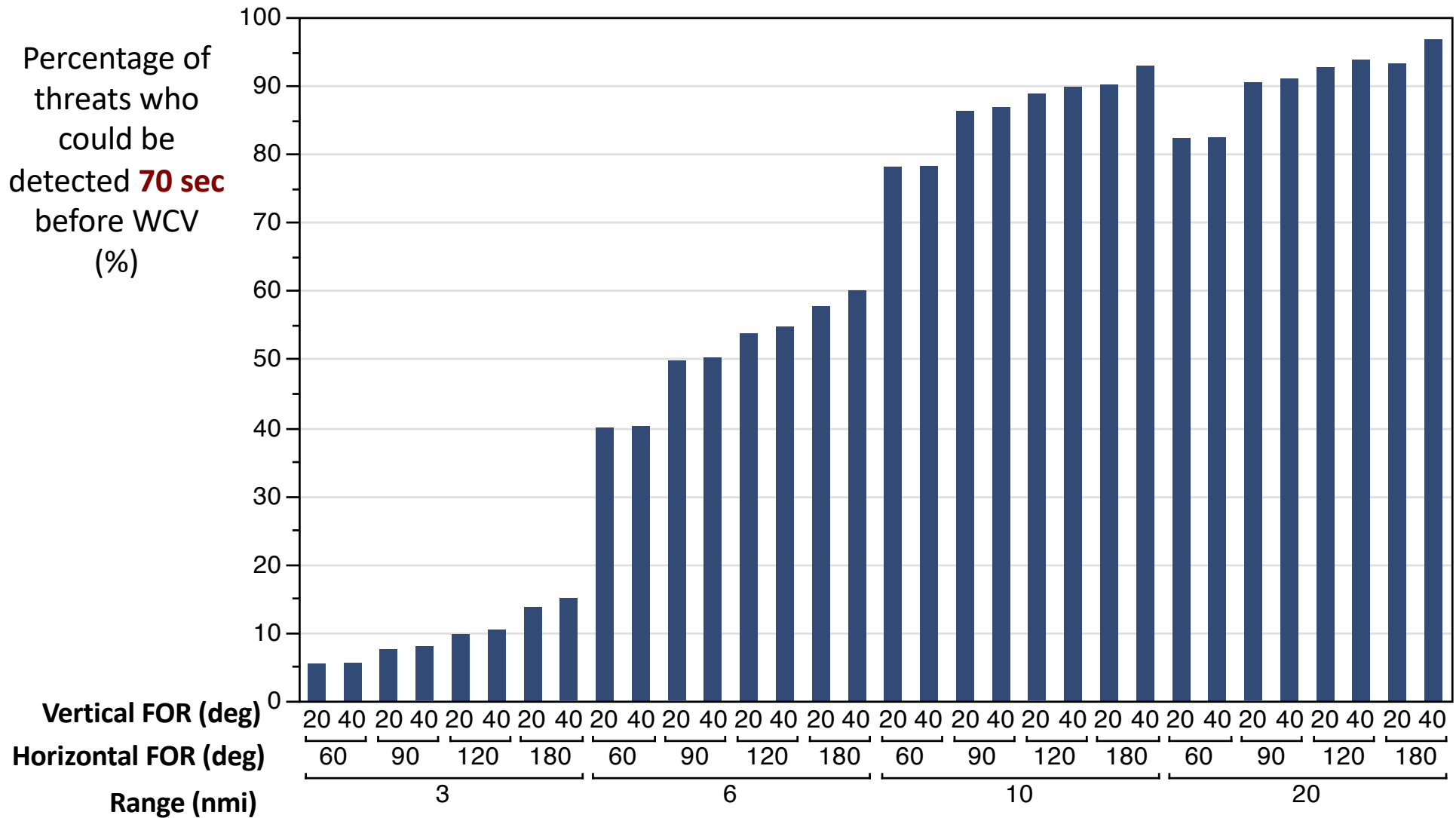


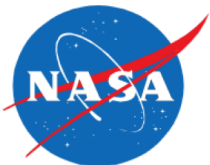
# 40 sec before Well-clear Violations





# 70 sec before Well-clear Violations

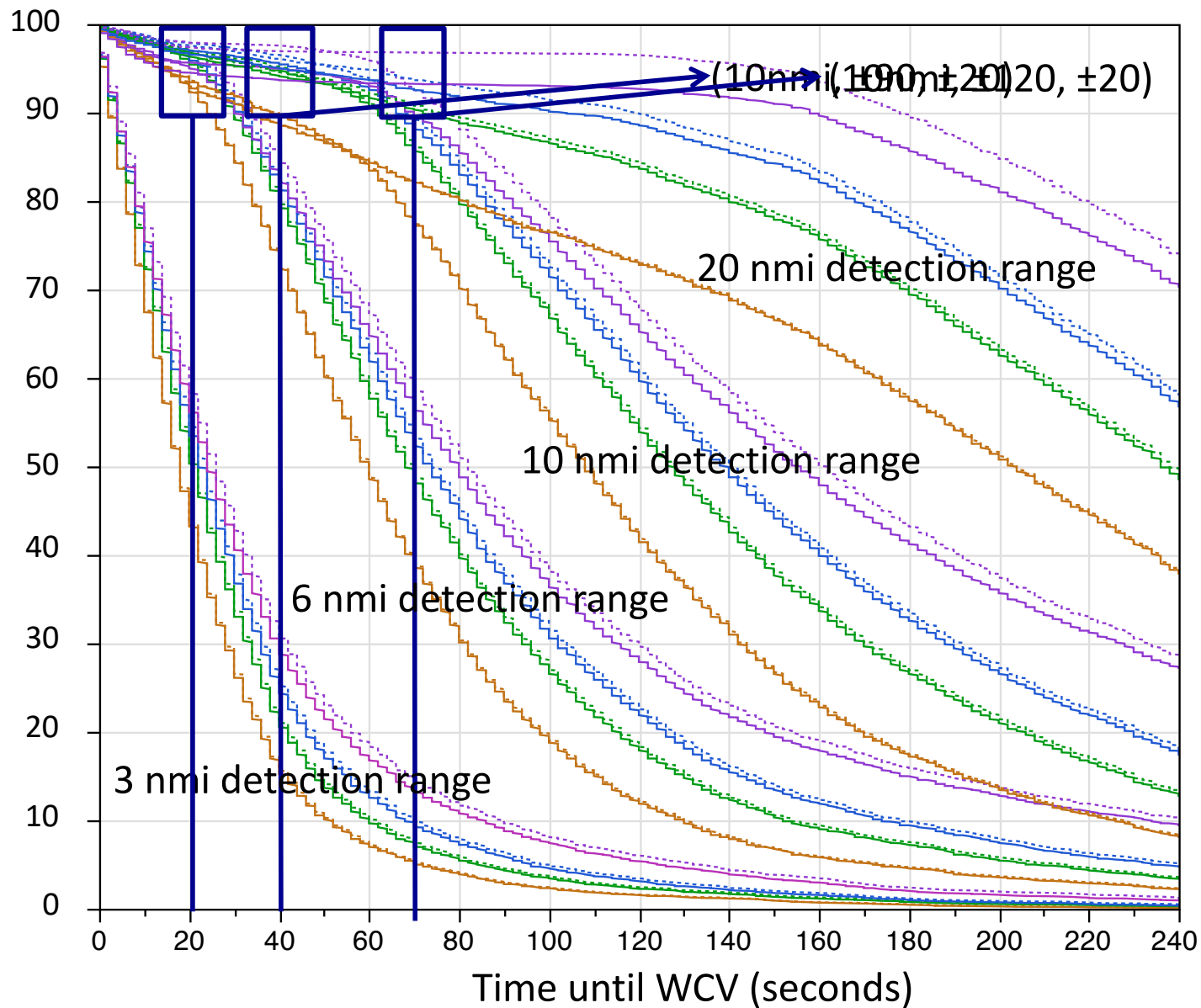
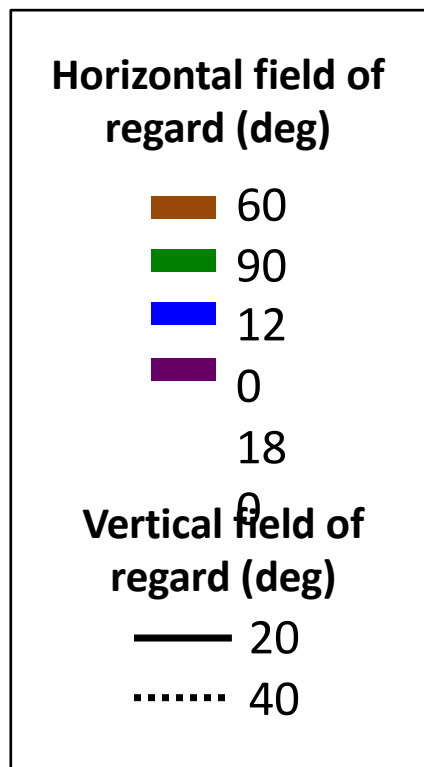




# Analysis of the Time to WCV



Percentage of threats who could be detected at a given time to WCV (%)

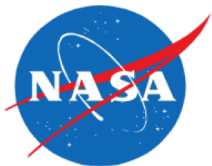




# Concluding Remarks



- Analyzed and built a database for well-clear violations between UAS and VFR traffic
  - Provide system designers a method to conduct trade space analysis among surveillance parameter values to meet overall system safety metrics
- Observed from a database of this study that
  - The ratio of undetected Well-Clear Violations was substantially affected by horizontal field of regard
  - More than 60% of undetected well-clear violations were incurred by the intruders that were seen in the surveillance volumes before
  - The time to Well-Clear Violations was most sensitive to surveillance detection range



# Future Research



- Extend the current unmitigated surveillance study by
  - Using high-fidelity sensor models
  - Running ACES simulations with non-cooperative VFR flights and different UAS missions
  - Investigating the effect of the SARP-recommended definition of well-clear separation standard
- Conduct mitigated surveillance study with a Detect-and-Avoid system



# Questions?



- Chunki Park, Seung Man Lee, and Eric Mueller, “Investigating Detect-and-Avoid Surveillance Performance for Unmanned Aircraft Systems”, Proceedings of 14th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Atlanta, GA, June 2014.

## Contact Information

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