National Aeronautics and Space Administration

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

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Background and Motivation

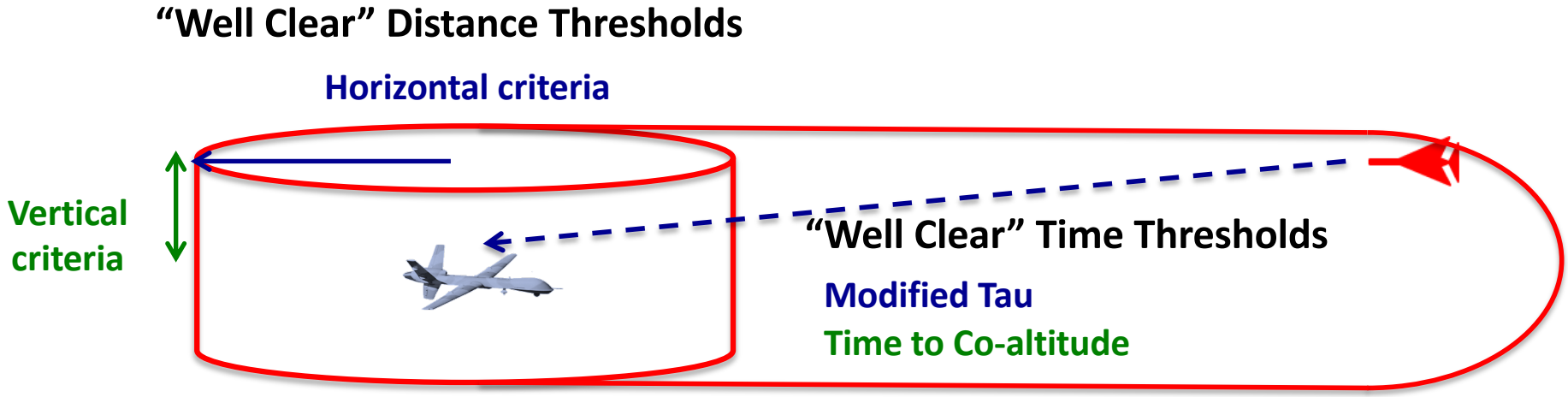
- A Detect-And-Avoid (DAA) capability is required for UAS to meet the requirement in CFR 91.113 to "see and avoid" other aircraft and maintain **"well clear"**.
- RTCA Special Committee 228 is developing Minimum Operational Performance Standards (MOPS) for DAA systems.
- A surveillance system is a critical 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



Definition of Well-Clear Violation

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

and

Vertical Criteria $|\Delta h| \le ZTHR \quad or \quad 0 \le \tau_{vert} \le \tau^*_{vert}$

where R_{xy} : *Horizontal Range*

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

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

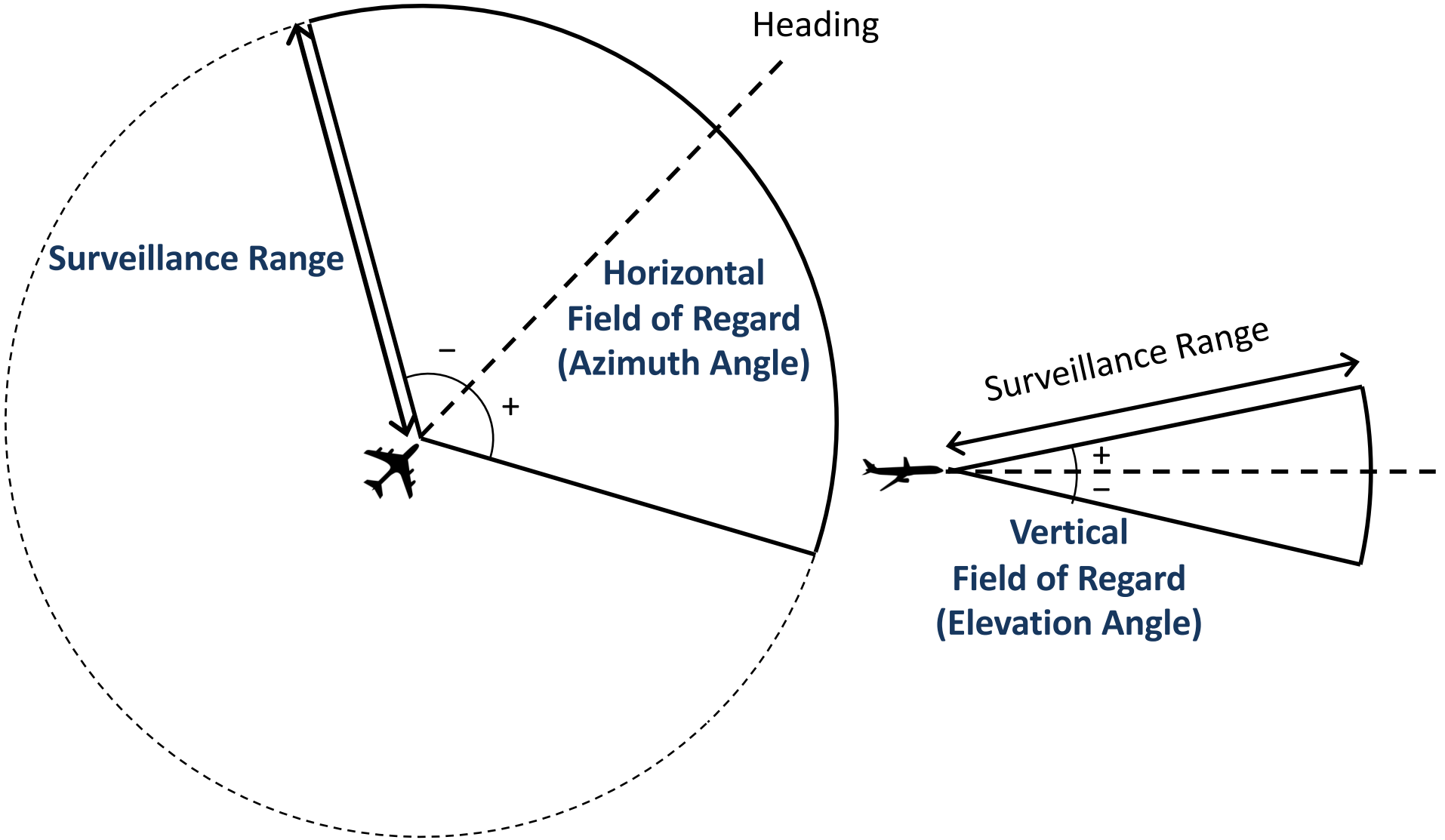
$|\Delta h|$: Altitude Difference

τ_{vert} : Time to Co-Altitude

$DMOD = 6000\,ft \quad HMD = 6000\,ft \quad ZTHR = 475\,ft$

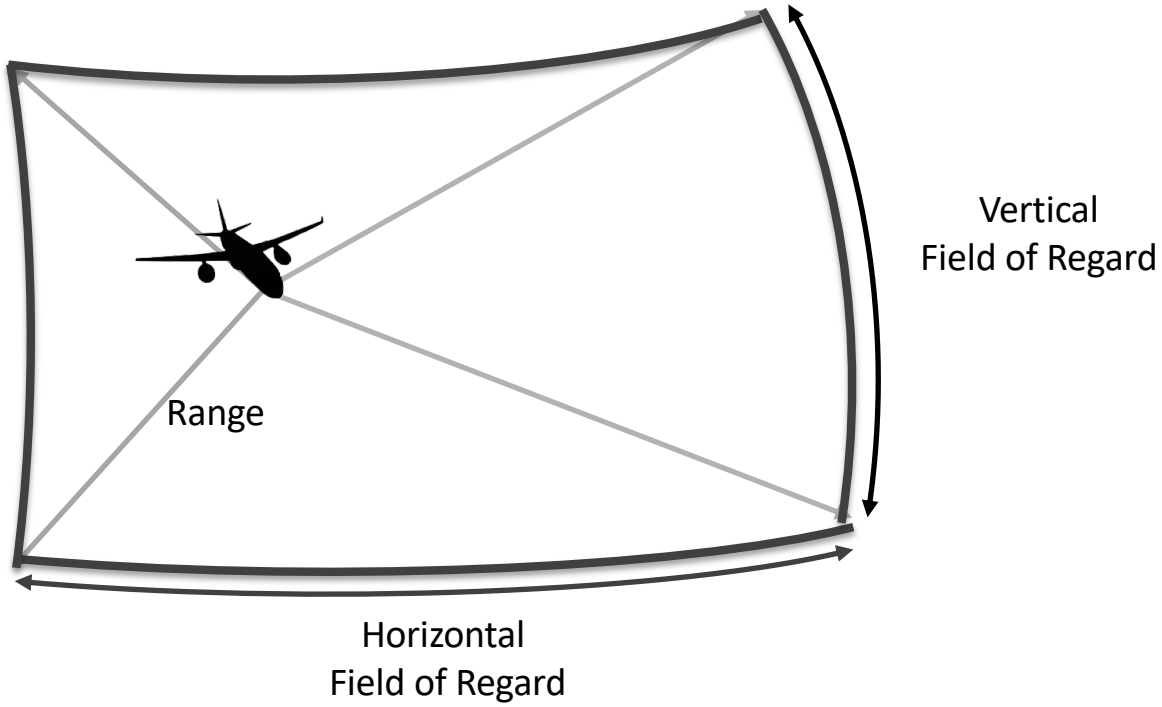
$\tau^*_{mod} = 30\,\text{sec} \quad \tau^*_{vert} = 20\,\text{sec}$

Generic Surveillance Model

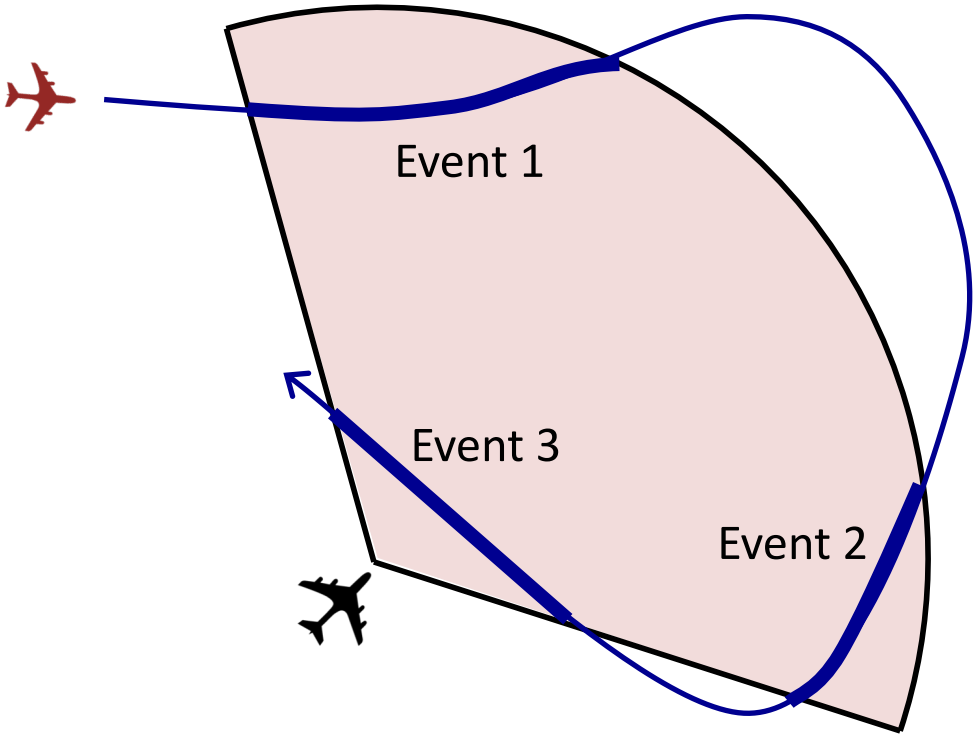


Generic Surveillance Model

Surveillance Volume



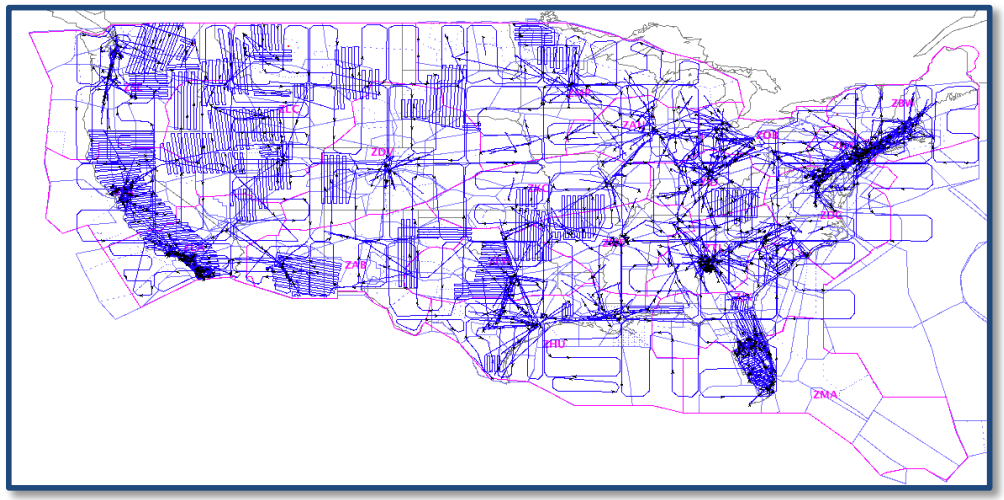
Intruding event, Intruder and Threat



- **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



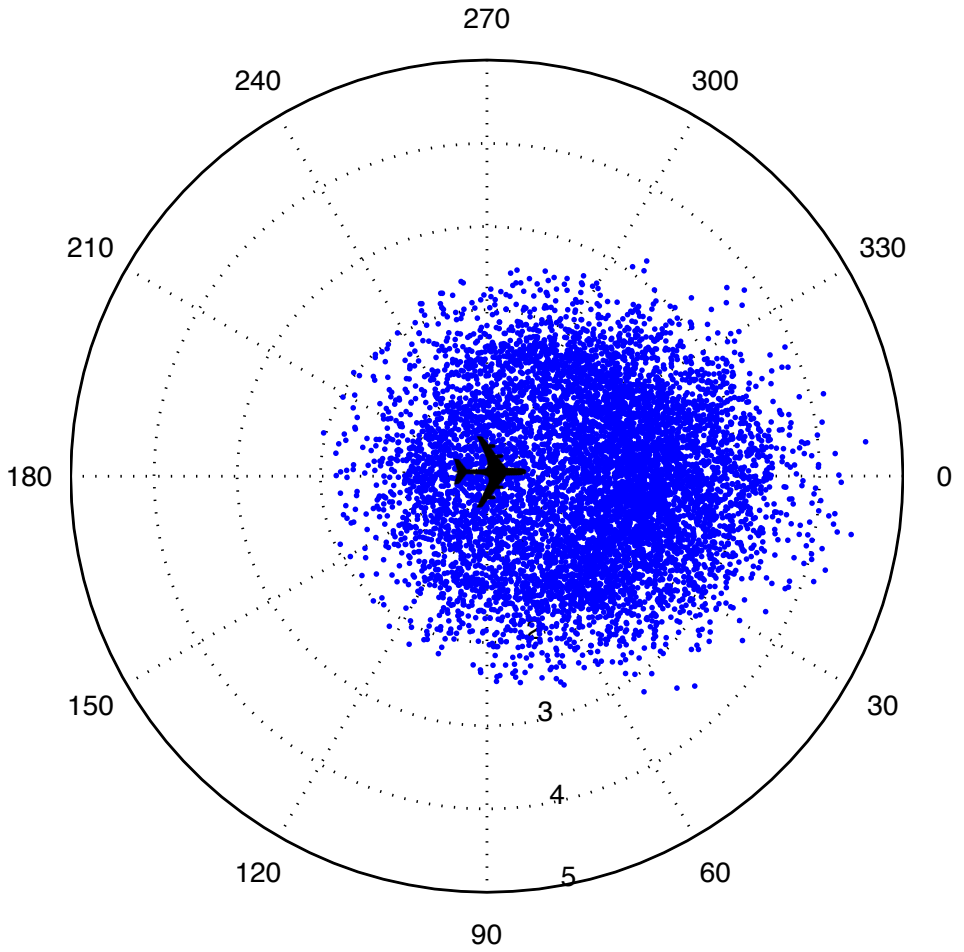
- Traffic scenarios

-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

Simulation and Analysis

Relative Position of Threats

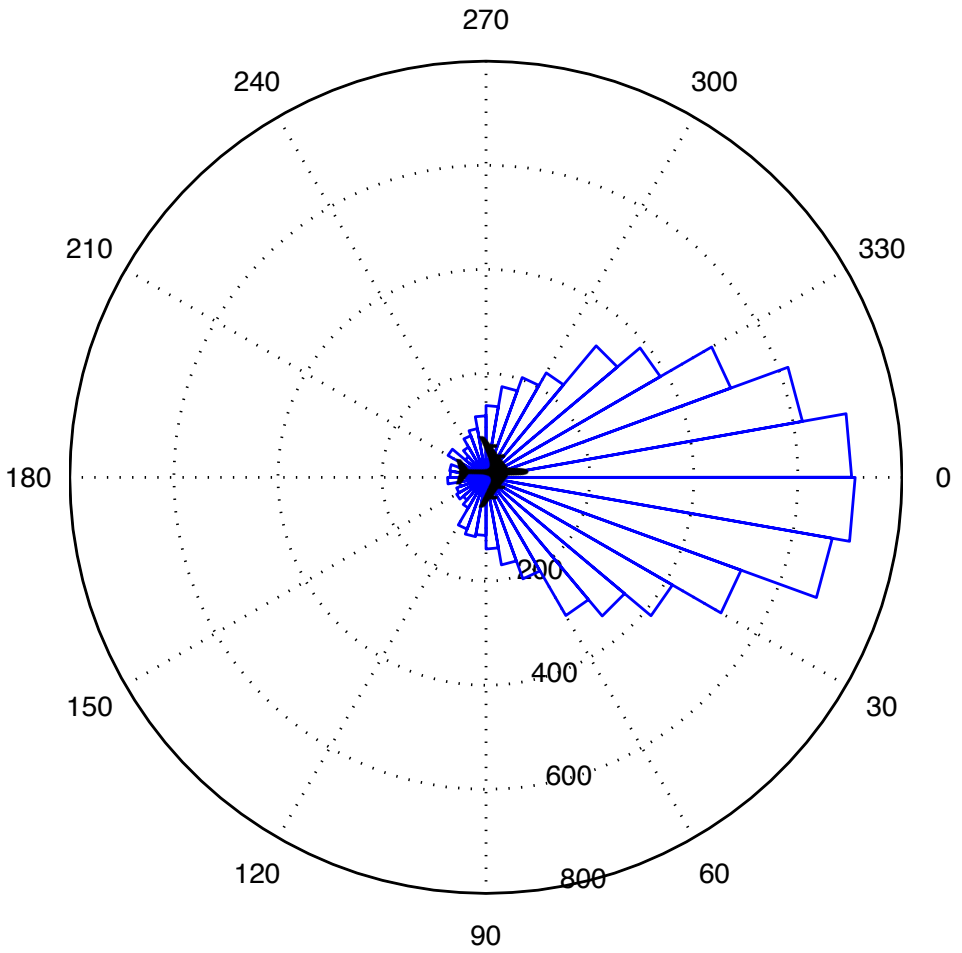


Trailing

Head-on

Relative Position of Threat

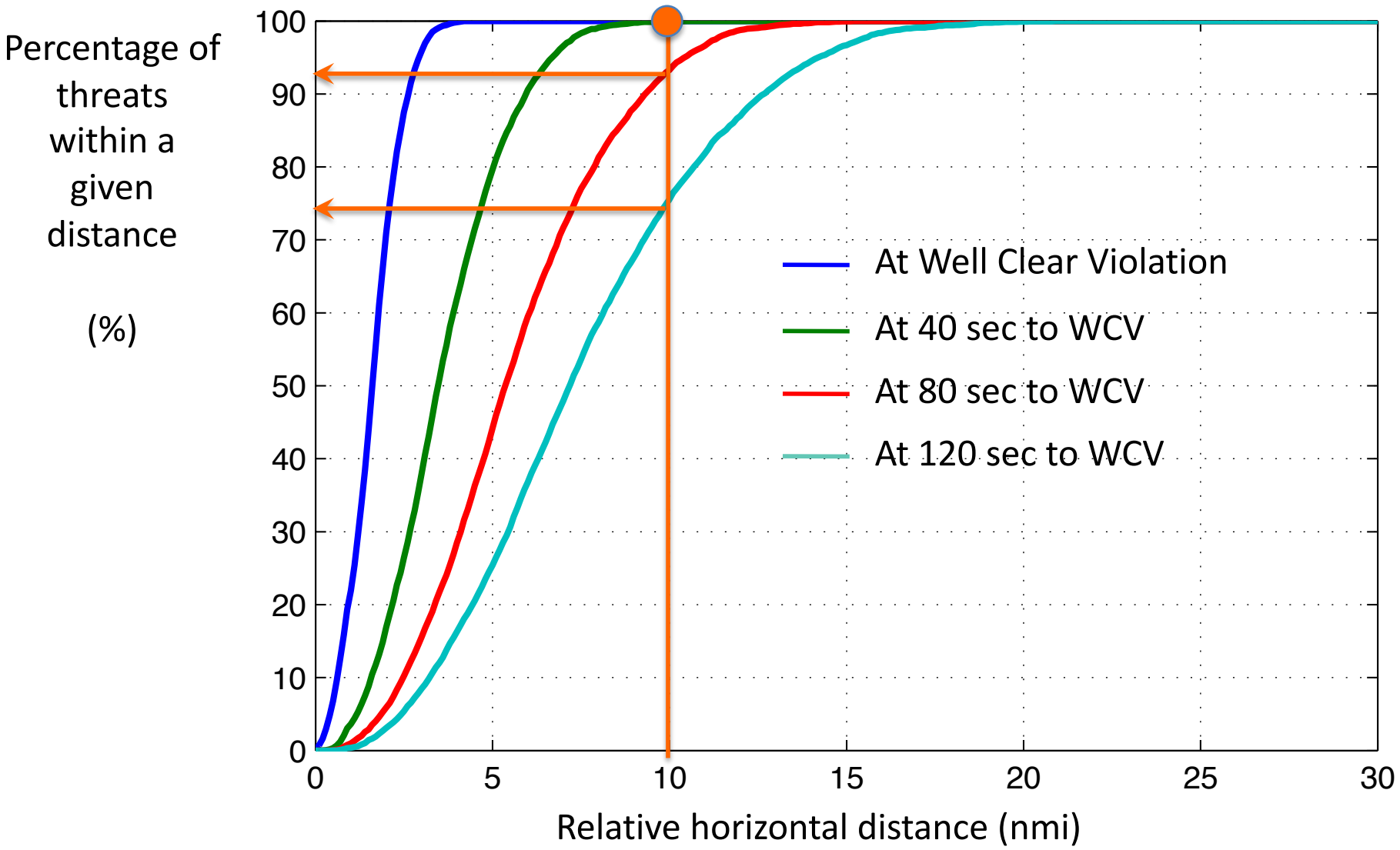
Bearing Angle Distribution at Well-Clear Violation



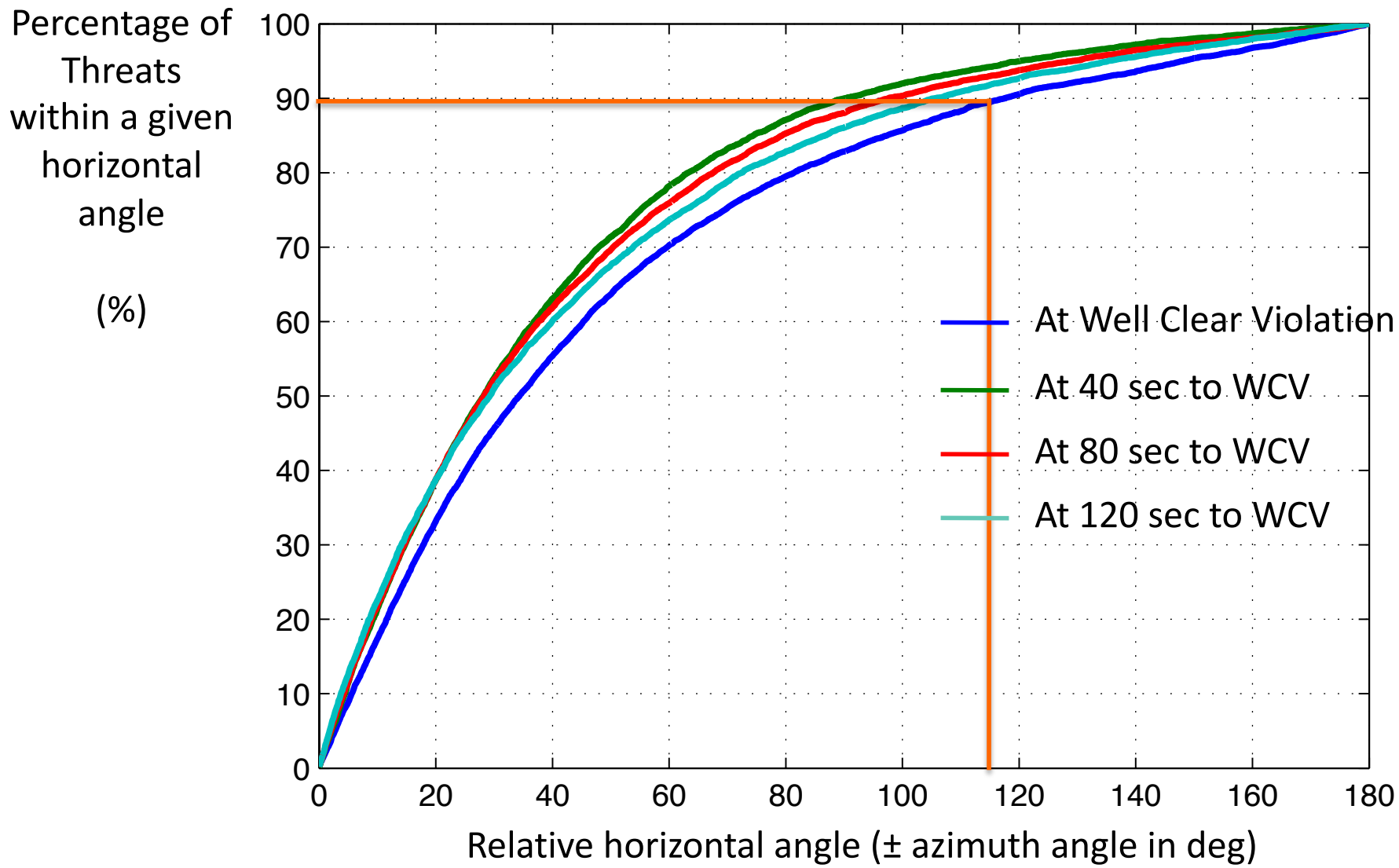
Trailing

Head-on

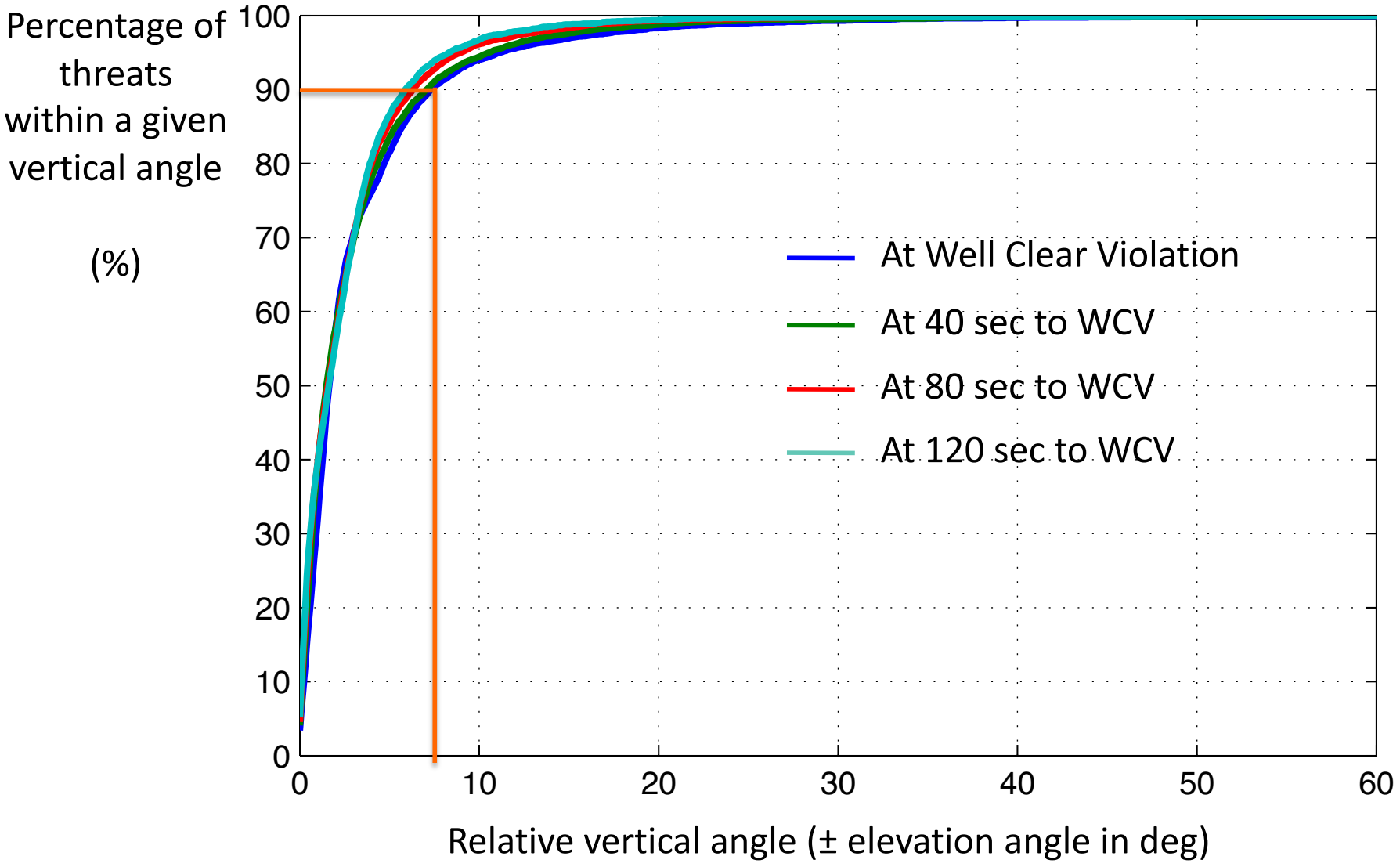
Relative Horizontal Distance of Threats



Relative Horizontal Angle of Threats



Relative Vertical Angle of Threats



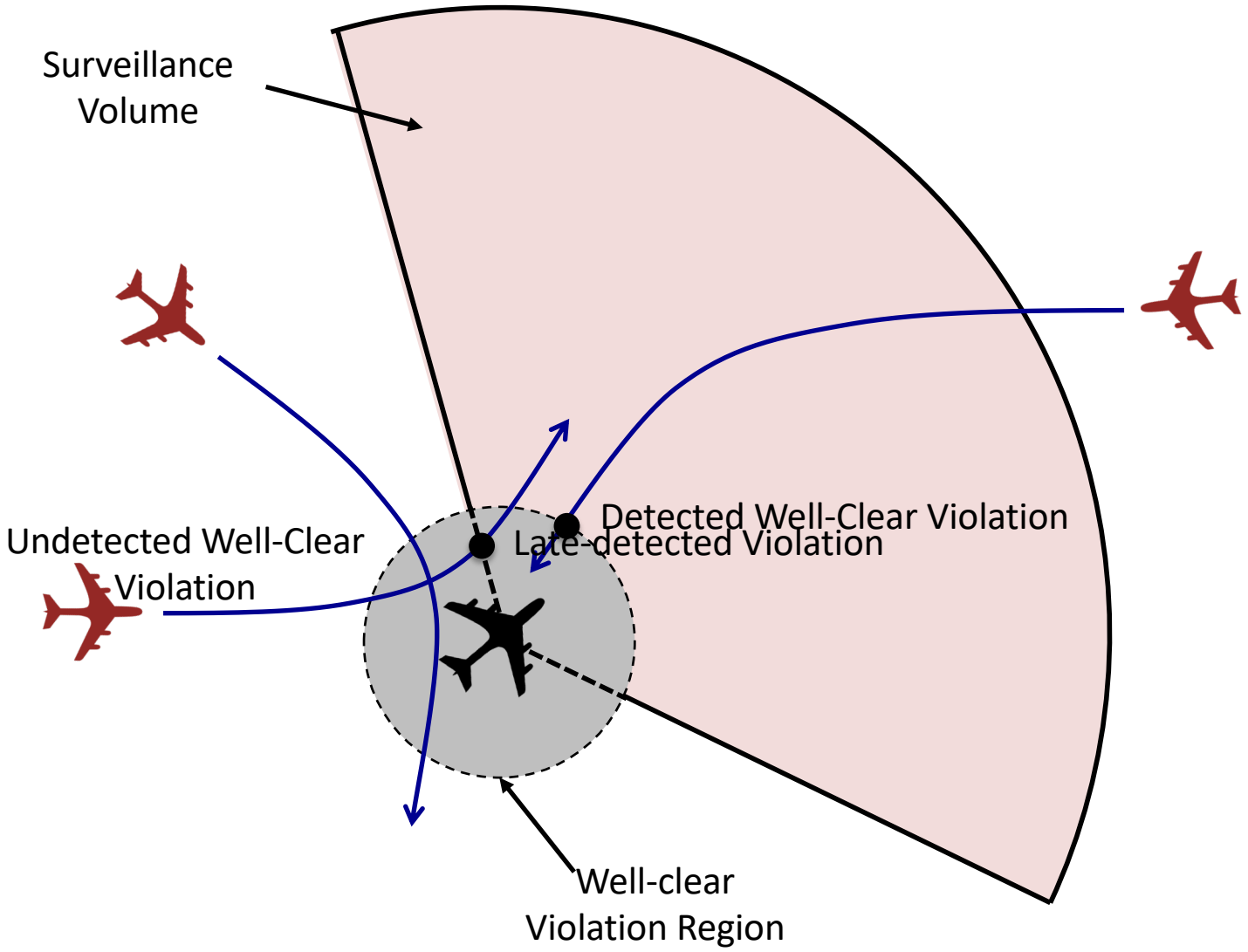
Effects of Surveillance Parameters

- Selected sets of surveillance parameters
  - Surveillance Range: 3, 6, 10, 20 nmi
  - Horizontal Field of Regard: (±) 60, 90, 120, 180 deg
  - Vertical Field of Regard: (±) 20, 40 deg
  - Total 32 sets of surveillance volume (4*4*2)

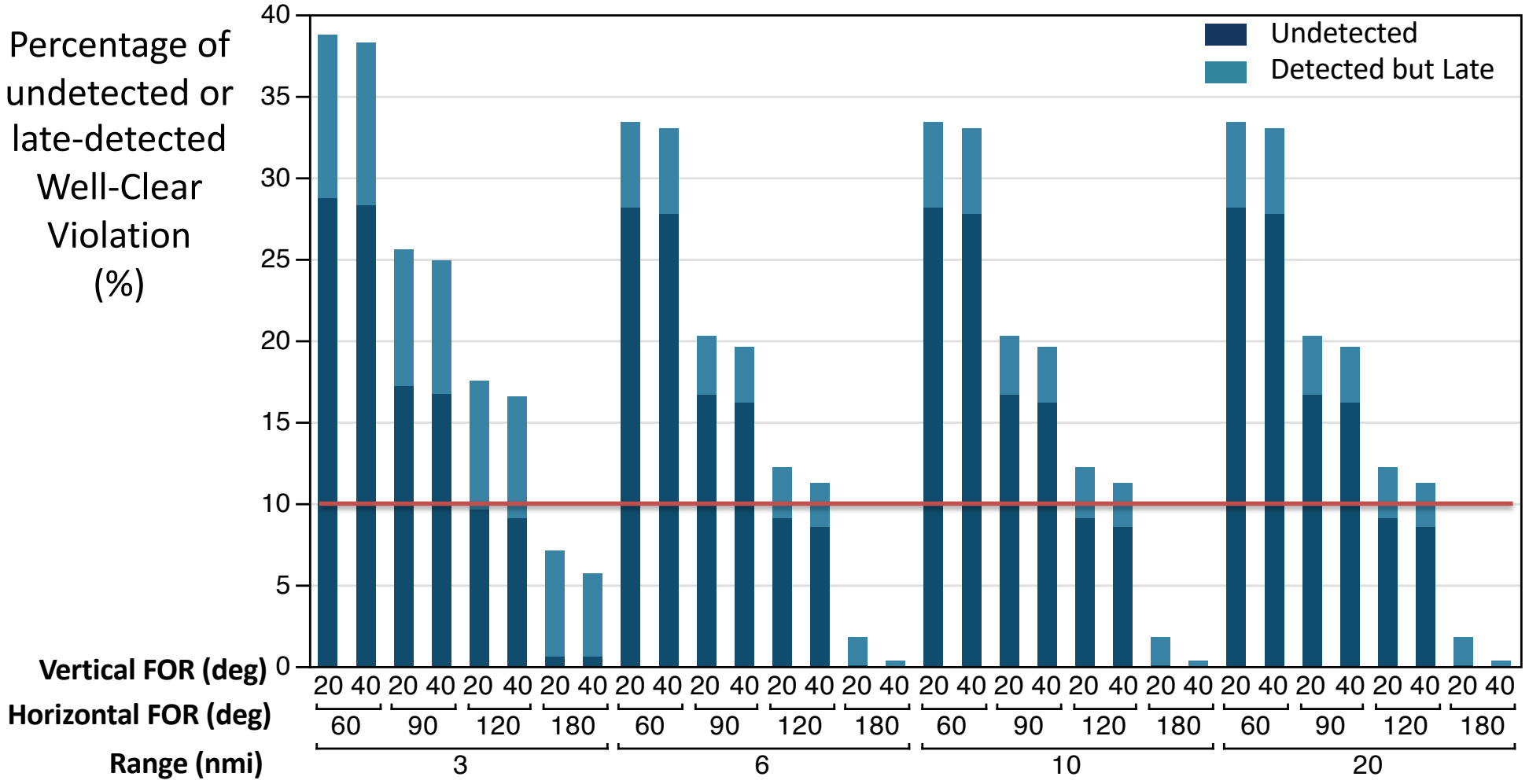
- Analysis for undetected Well-Clear Violation
  - Metric: Ratio of the number of undetected Well-Clear Violations for each surveillance volume

- 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

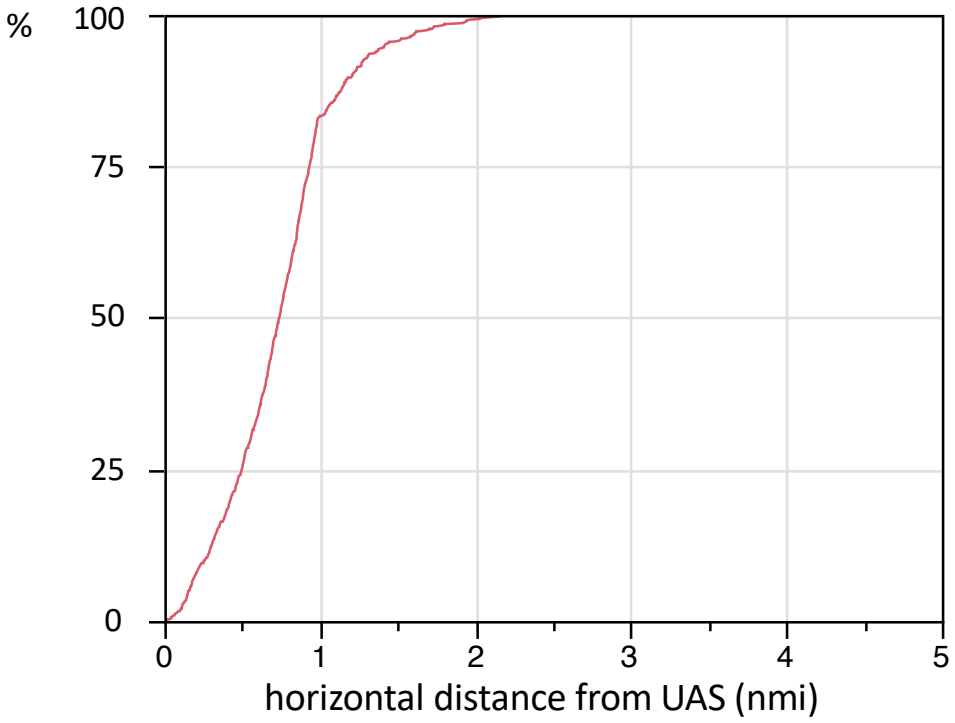


* Percentage of undetected Well-Clear Violations is closely related to horizontal field of regard!

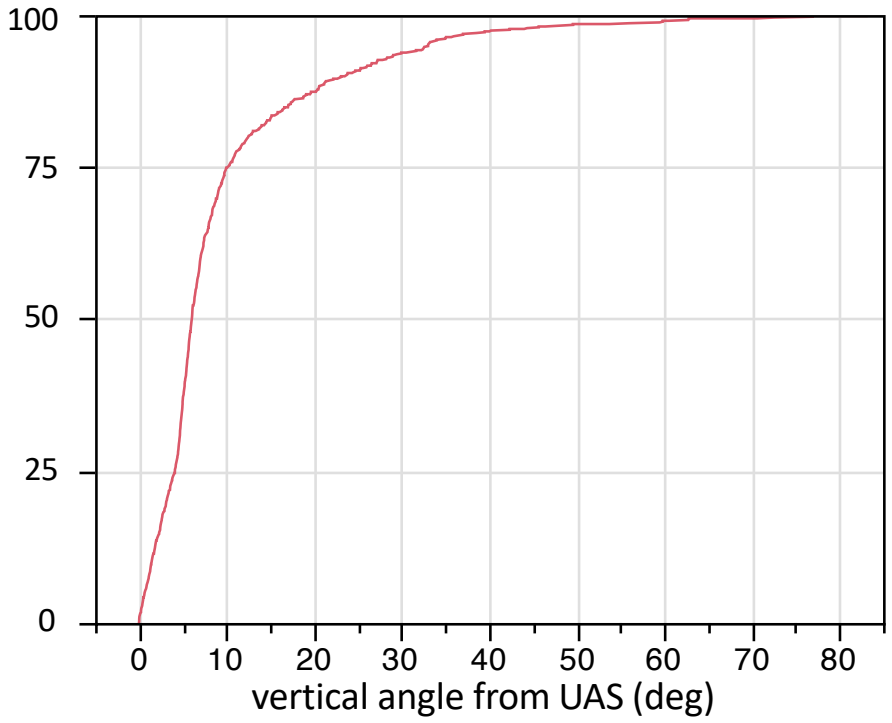
Characteristics of undetected WCVs

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

Cumulative distribution for horizontal distance

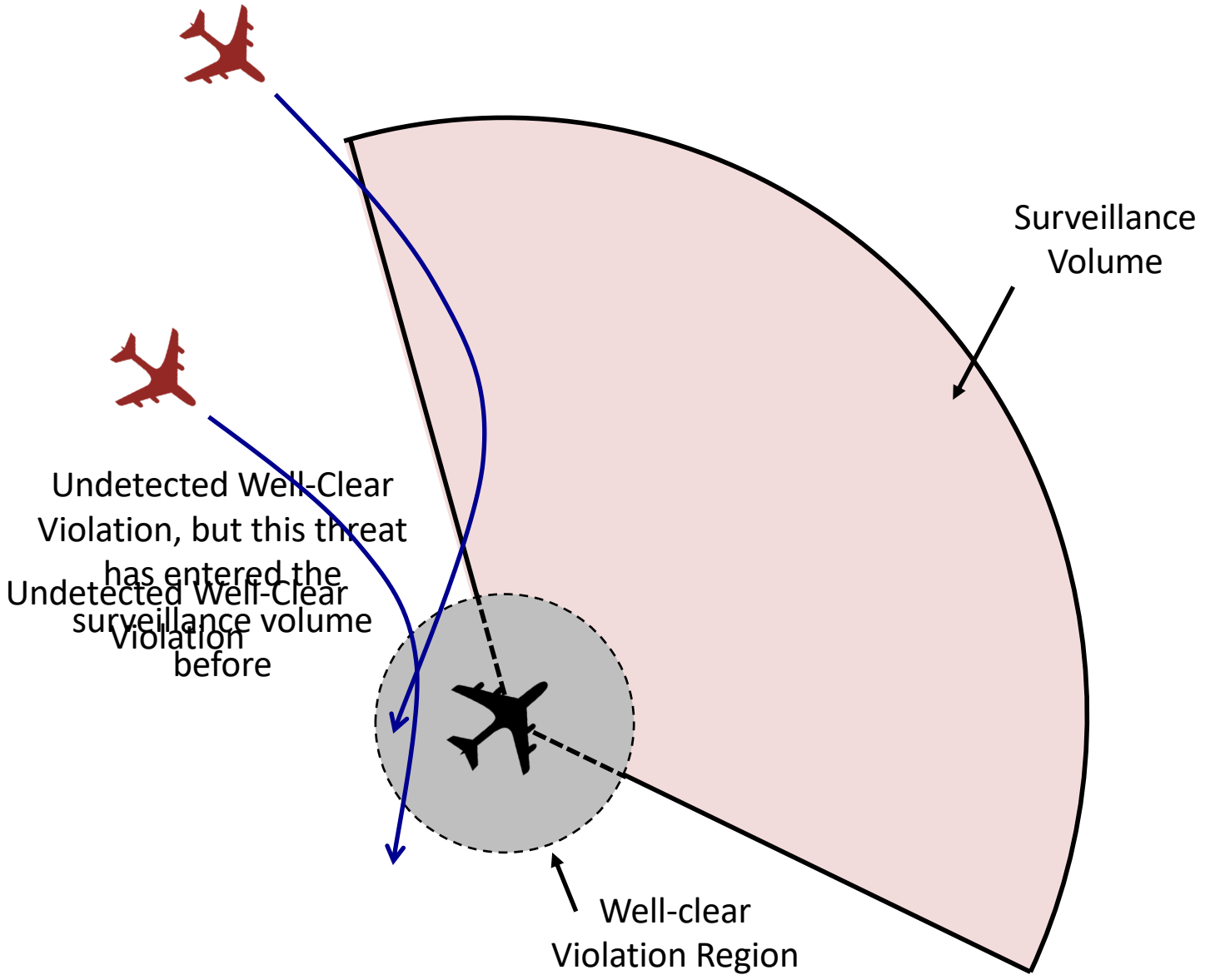


Cumulative distribution for vertical angle

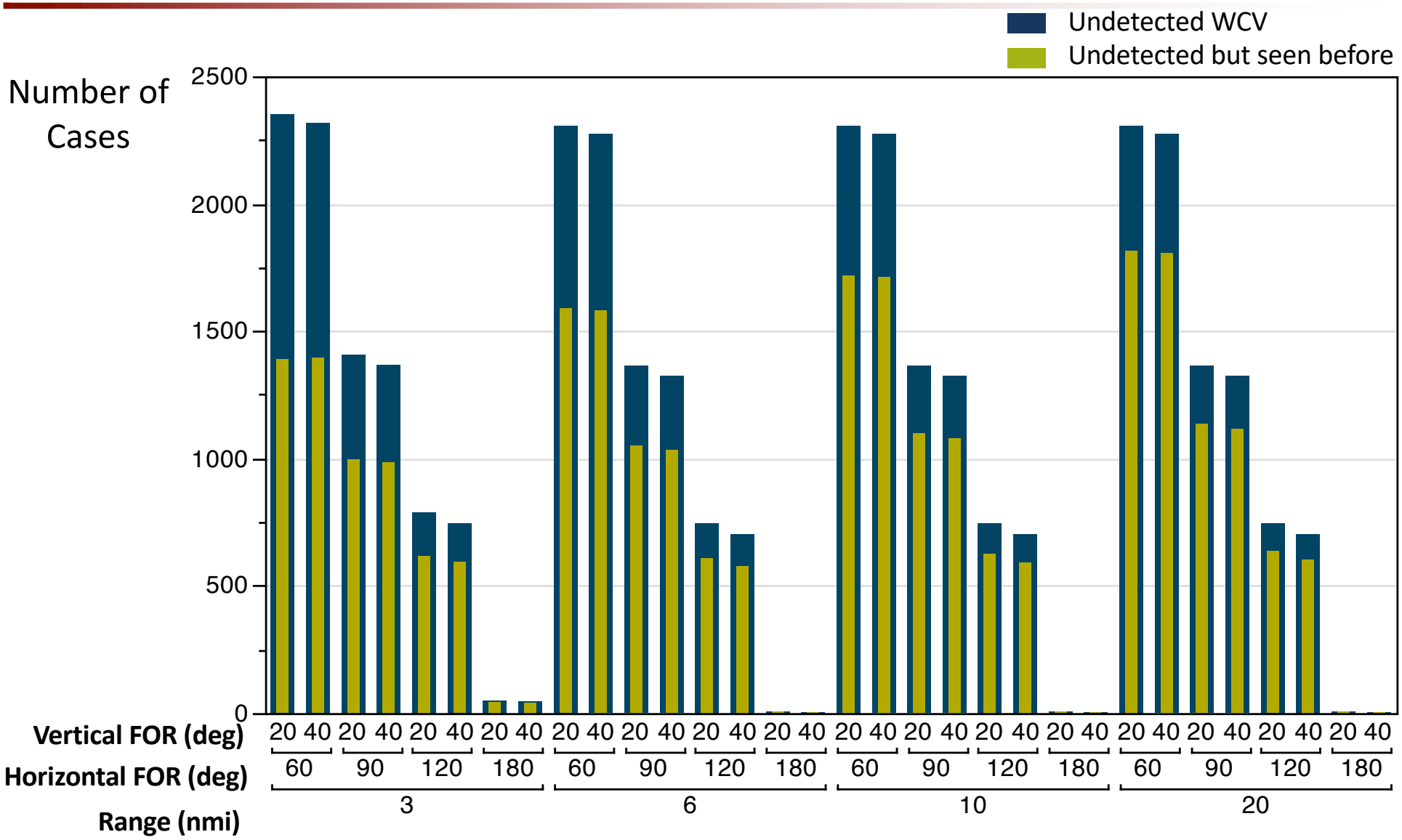


* The undetected WCVs might be detected if UAS is equipped with a secondary sensor having short detection range (~2 nmi) but wide vFOR (~60 deg)

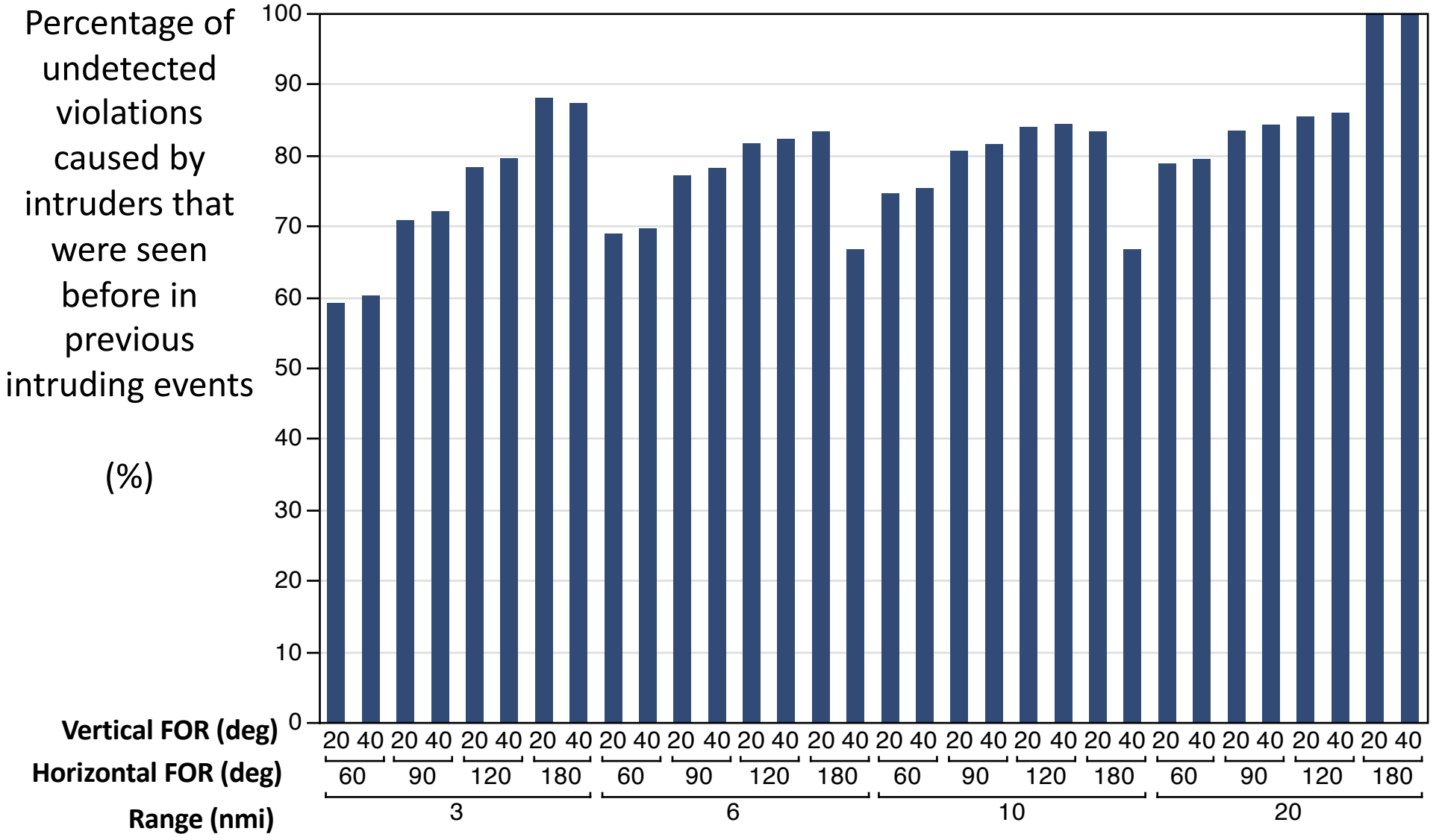
Example:
Undetected but Already Seen Before



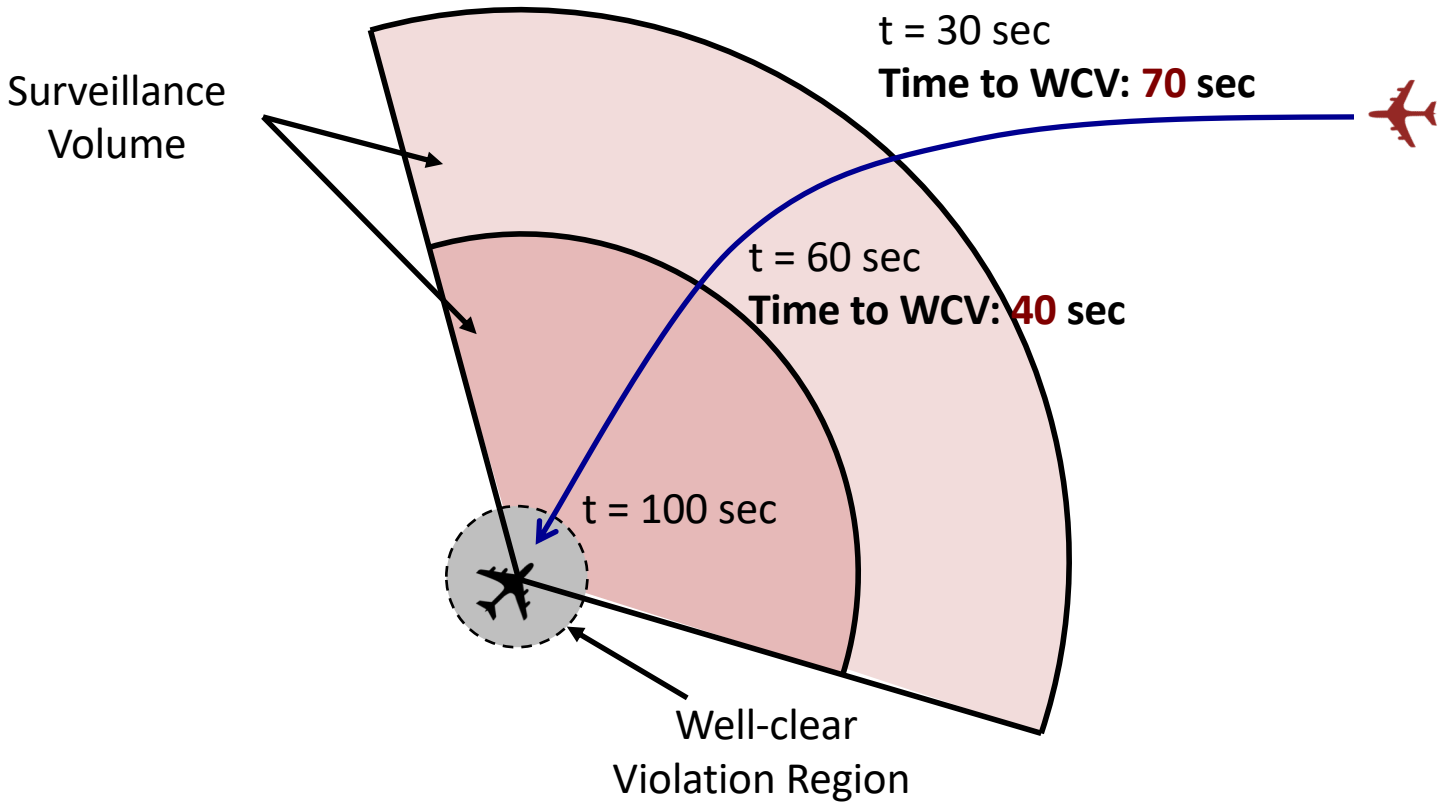
Undetected Well-Clear Violation but the Threat Was Seen Before



Undetected Well-Clear Violation but the Threat Was Seen Before

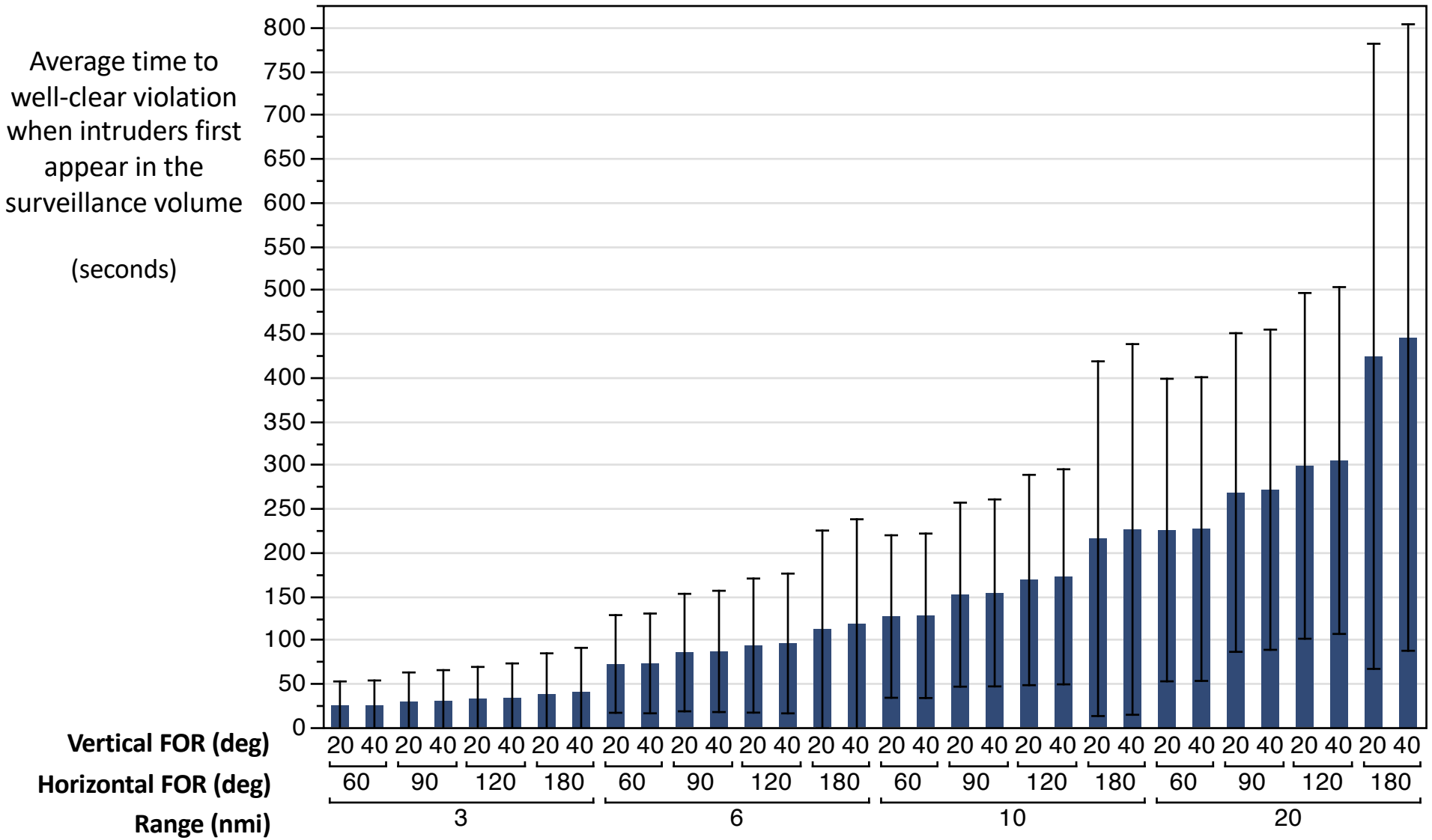


Time until Well-clear Violation at First Appearance in the Surveillance Volume

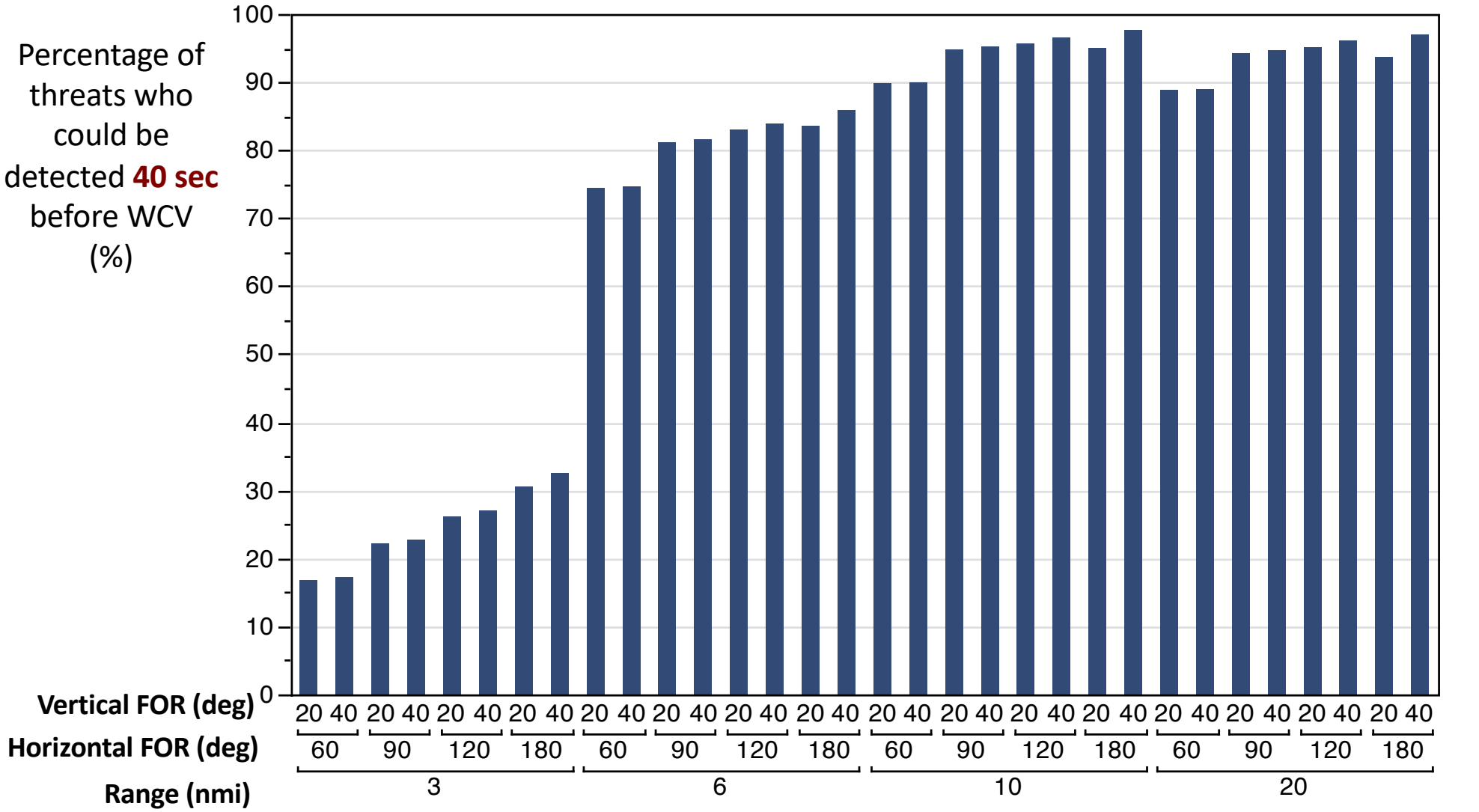


- Time until well-clear violation at the first appearance in the surveillance volume is important since it is time for preparing for avoiding the violation.
- For all threats, collect data at the time when they first appear in each surveillance volume.

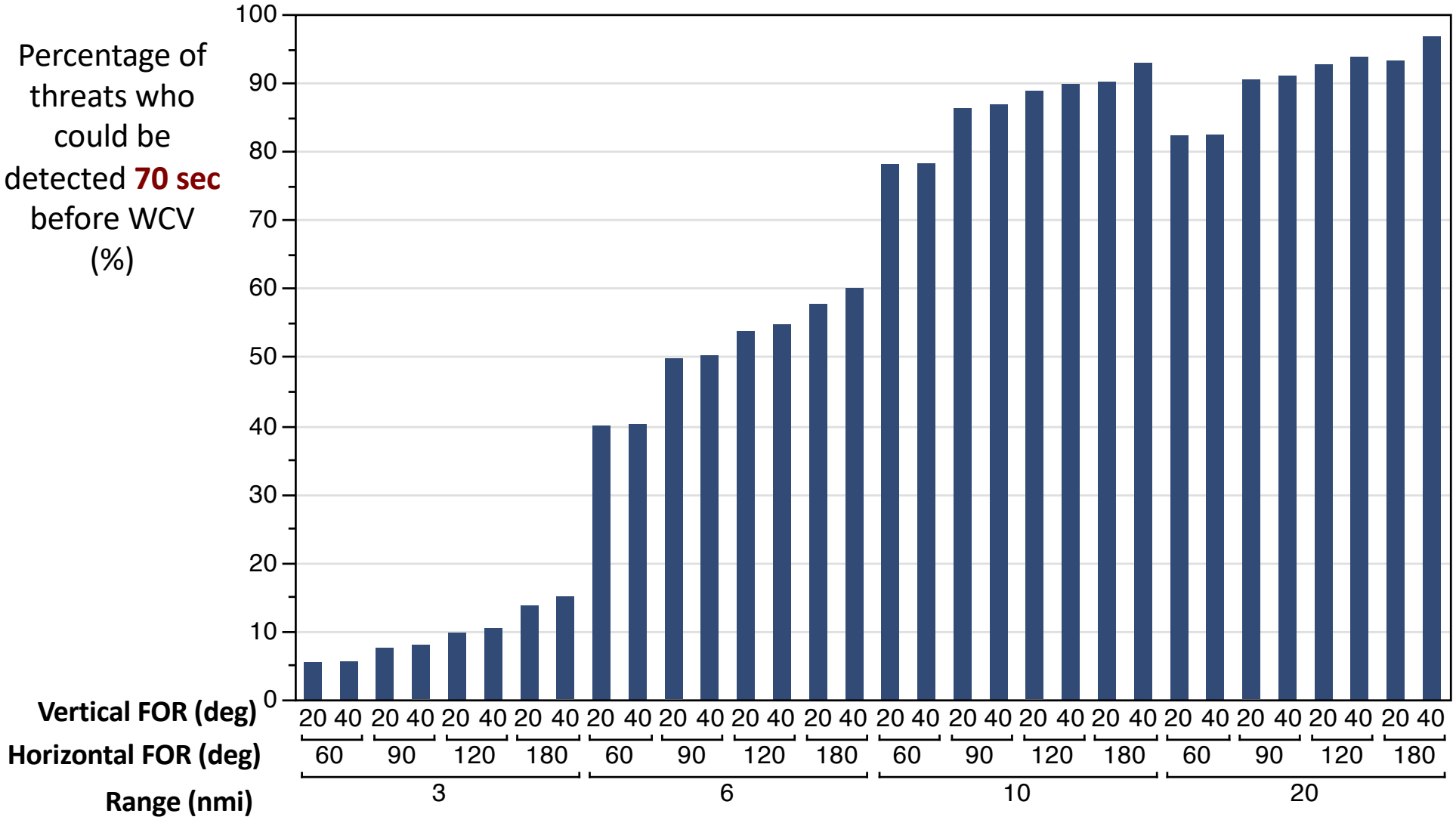
Average Time until Well-Clear Violation at First Appearance in the Surveillance Volume



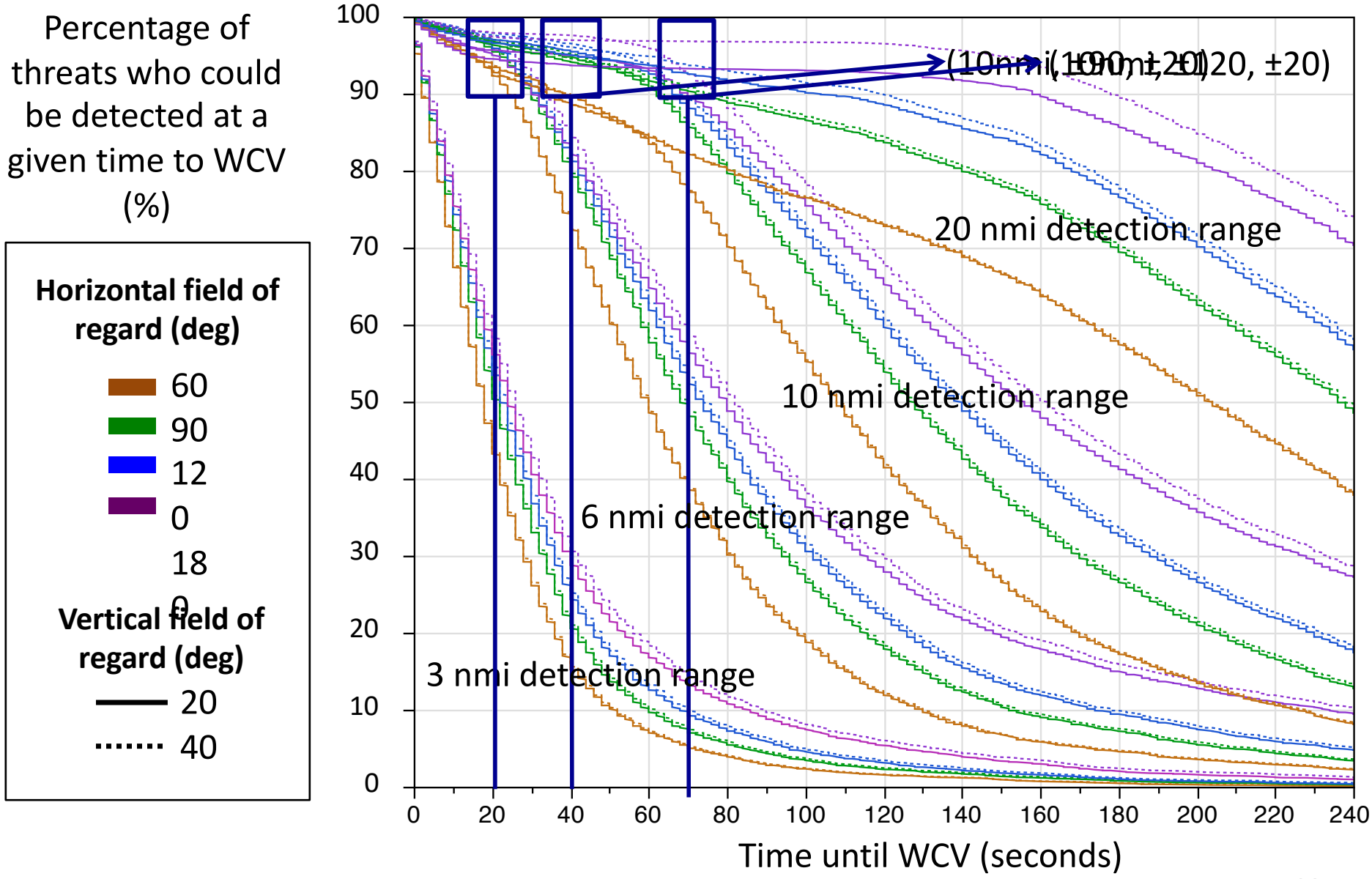
40 sec before Well-clear Violations



70 sec before Well-clear Violations



Analysis of the 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.

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