Detect-and-Avoid Alerting Performance for High-Speed UAS and Non-Cooperative Aircraft

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Background

- Unmanned Aircraft Systems (UAS)
- Phase 1
- Phase 2
- Reevaluate

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  - Required to Detect-and-Avoid other aircraft and remain “well clear”

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  - VFR aircraft provide the primary challenge
  - Cooperative VFR aircraft have a Mode S or Mode C transponder, and may be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) system
  - Non-Cooperative VFR aircraft either do not have a transponder equipped or have their transponder turned off

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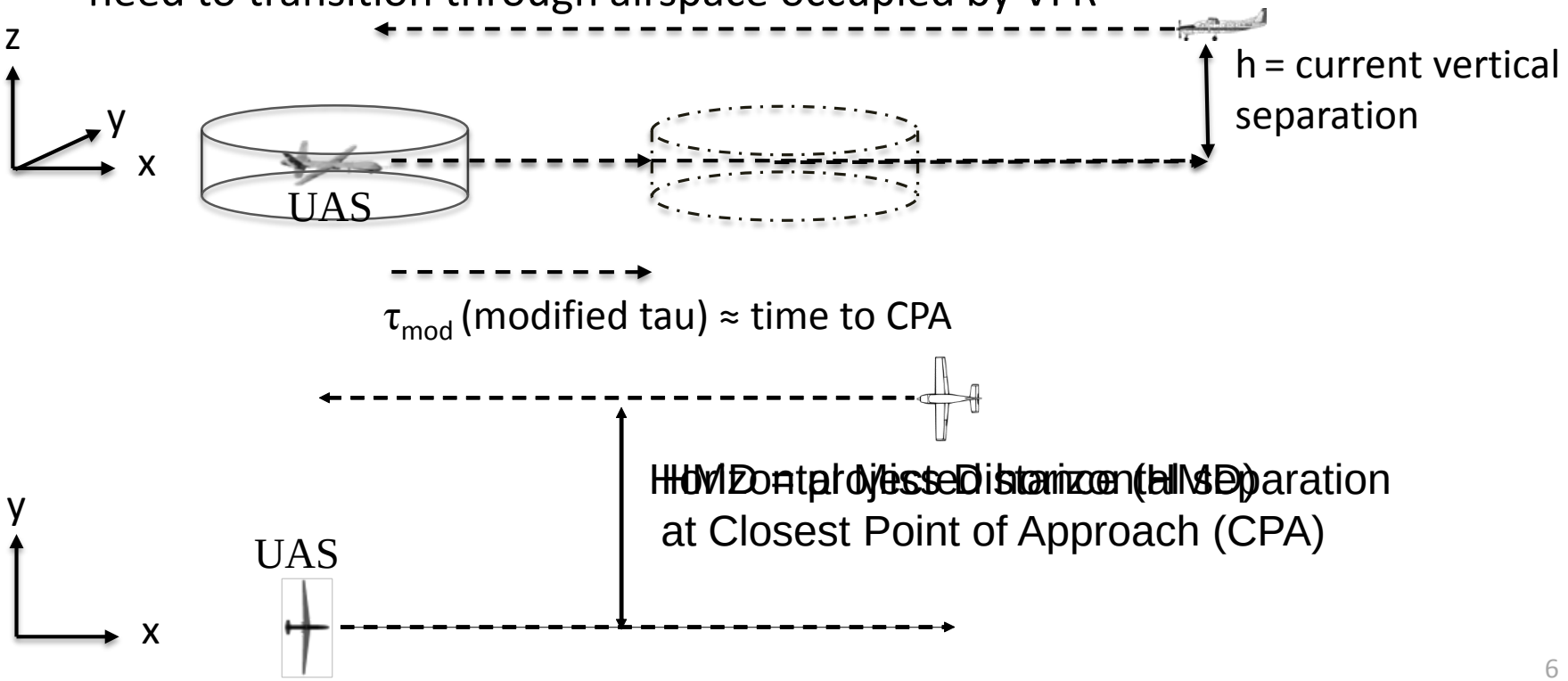

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- Phase 2 work extends operations, including to smaller vehicles operating at lower altitudes
  - UAS whose primary mission is between 500 ft AGL and 10,000 ft MSL
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  - Assumed lower speeds to allow a shorter range radar
  - Created new, smaller DWC for encounters with non-cooperative VFR
- Reevaluate Phase 1 UAS encounters with non-cooperative VFR
  - Can the smaller Phase 2 DWC be used for these encounters?
  - Will this allow Phase 1 UAS to safely equip a smaller radar?
  - Will this allow Phase 1 UAS to safely fly faster than the current limit of 200 kts TAS below 10,000 ft MSL?

Big Picture Goals

- Can Phase 1 UAS with Phase 1 radar safely use the Phase 2 DWC definition for encounters with non-cooperative VFR aircraft?

- Can the Phase 1 radar range requirement and/or the Phase 1 true airspeed limit be relaxed by using a smaller DWC definition for encounters with non-cooperative VFR aircraft?

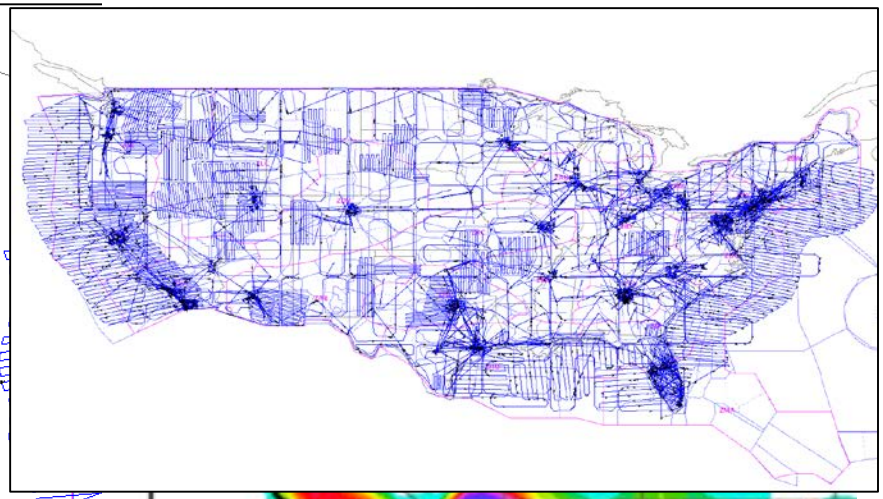
Simulation Study Objectives

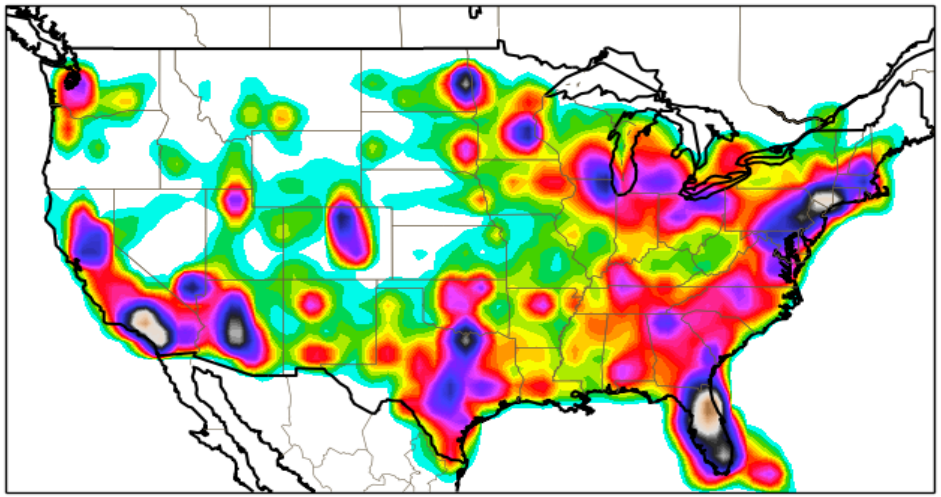
- Run unmitigated study to test effect of a smaller DWC on alerting
- Run a study with mitigation to test effect on safety metrics
- Test sensor uncertainty and pilot effects

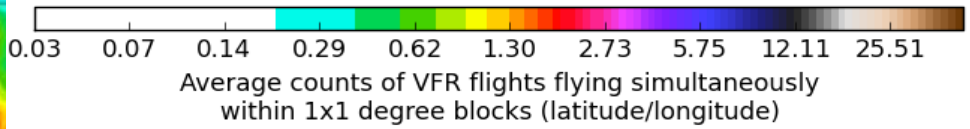
Unmitigated Study Experiment Plan

- Simulate multiple encounters between a single UAS and a single non-cooperative VFR intruder
- Evaluate the alerting performance of the Phase 1 DWC and a selection of potential alternative DWCs
- Rerun the tests using multiple potential radar ranges to test the effect of radar range

Encounter Generation



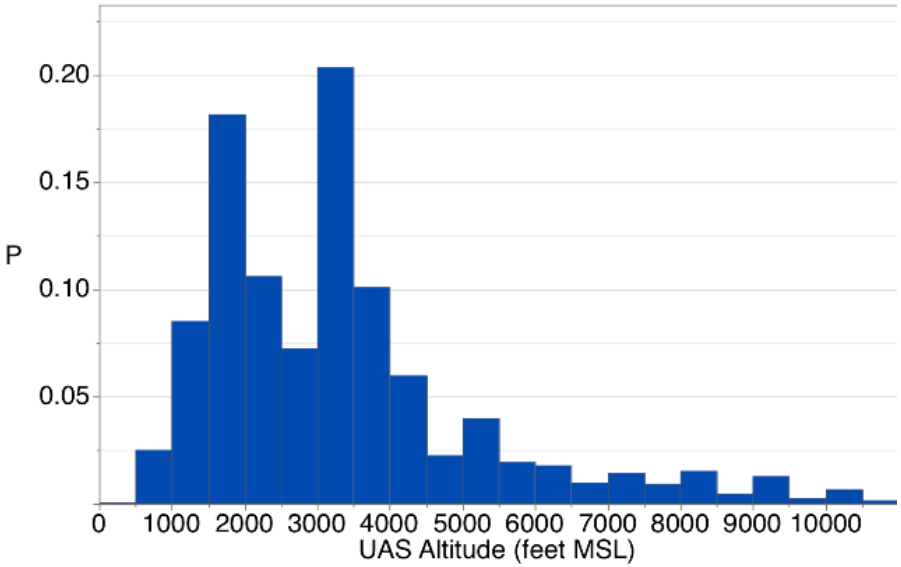


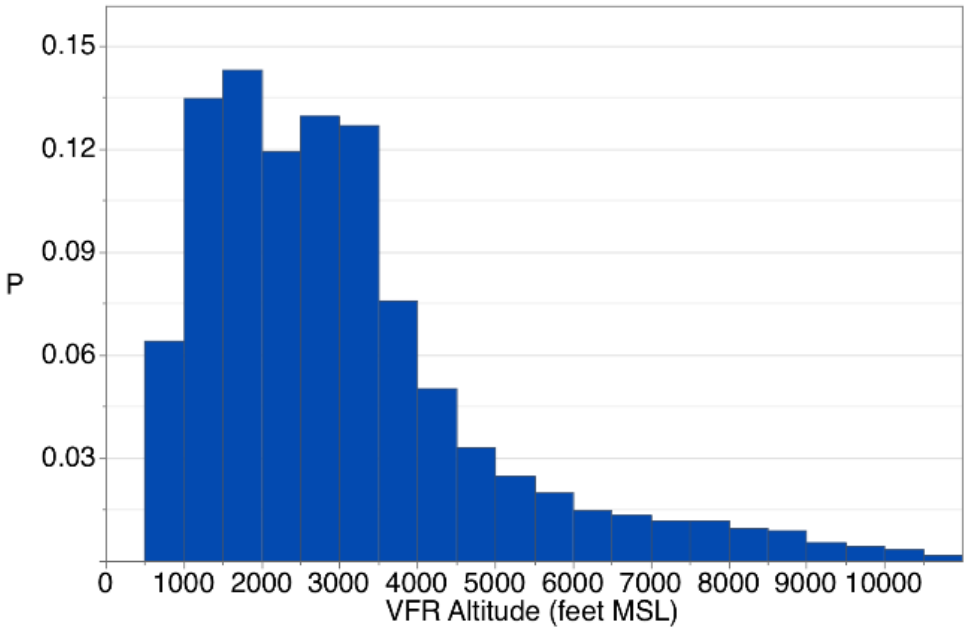


Heat map of historical VFR traffic locations

- 3.3 million encounters between projected UAS trajectories and recorded VFR traffic from 21 non-consecutive days in year 2012
- Encounters filtered to meet altitude and airspeed constraints
- Only encounters that lead to an unmitigated Loss of DWC between a UAS and a non-cooperative VFR are included in the metrics

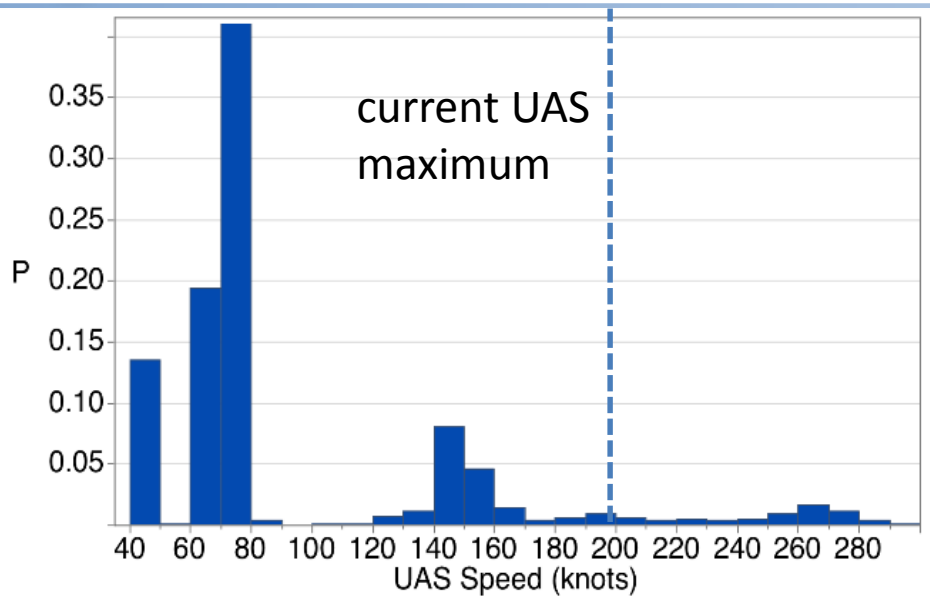
UAS and Intruder Altitude Distribution

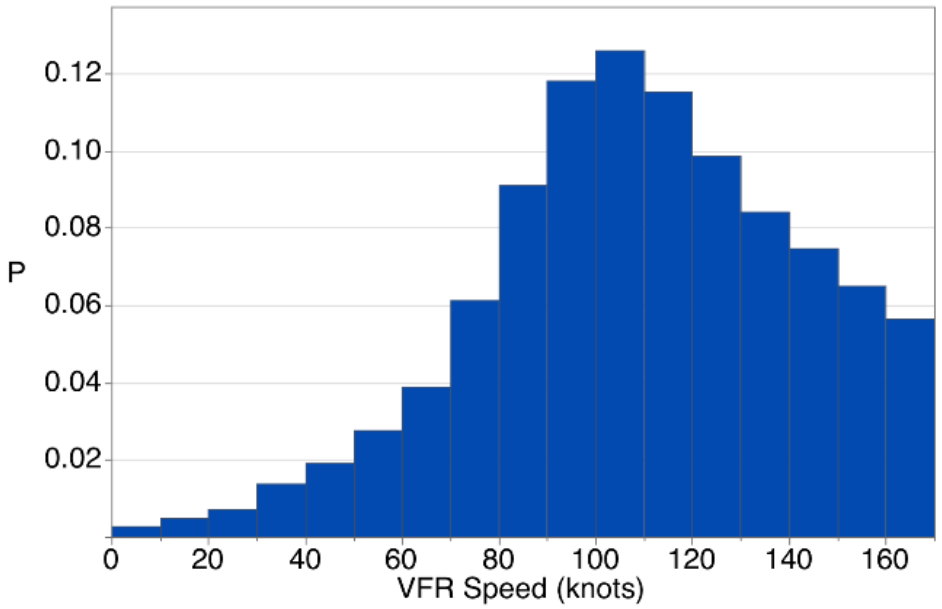




Only aircraft flying between 500 feet AGL and 10,999 feet MSL are considered for this study

UAS and Intruder Speed Distribution





- UAS speed ranges tested (All speeds in knots TAS):
  - 40 to 99.9 (Phase 2 UAS speed range)
  - 100 to 149.9
  - 150 to 199.9
  - 200 to 291 (Extension of Phase 1 UAS speed range)
- Only encounters that have intruder speeds at or below 170 knots TAS are considered

Tested DAA Well Clear Definitions

DAA Well Clear Label	HMD threshold (ft)	τ_{mod} threshold (s)	*h* threshold (ft)
Phase 1 DWC	4000	35	450
DWC 1	2000	15	450
DWC 2	2200	0	450
DWC 3	1500	15	450
DWC 4	2500	25	450

Simulation Test Matrix

Test Parameter	Units	Tested values
DWC Type	n/a	Phase 1 DWC, DWC1, DWC2, DWC3, DWC4
RADAR declaration range	nautical miles	4, 6, 8
Horizontal field of regard	degrees	+/-110, +/-180
Vertical field of regard	degrees	+/-15, +/-90

Evaluation Metrics

- Average Alerting time
- Required radar range
- Required horizontal field of regard for radar
- Required vertical field of regard for radar

Average Alert Times

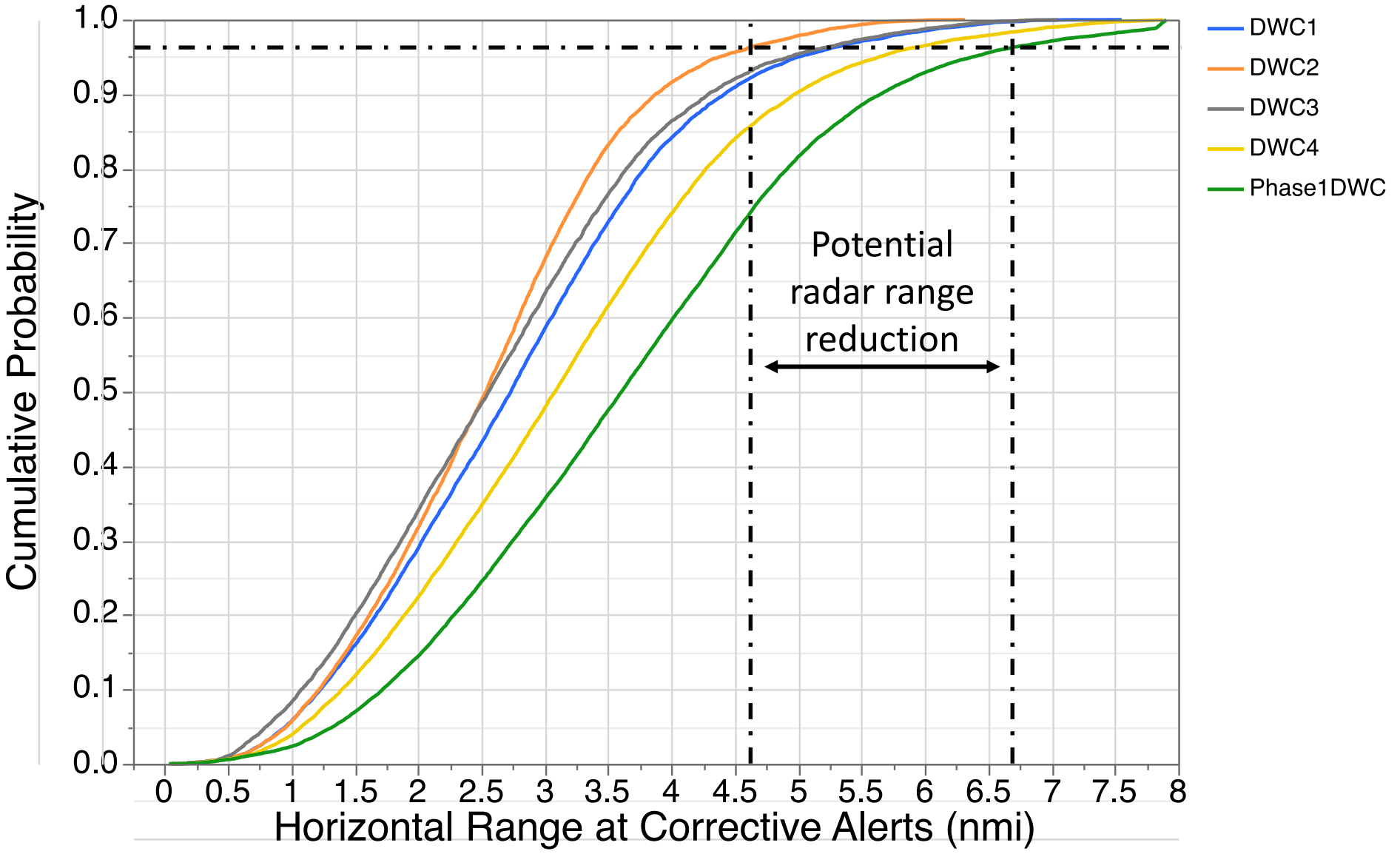
Range (nmi)	DWC Label	Corrective Alert Time (s)	Warning Alert Time (s)
4	Phase1DWC	48.04	34.01
4	DWC1	51.89	32.65
4	DWC2	57.54	35.27
4	DWC3	49.30	30.81
4	DWC4	49.36	32.39
6	Phase1DWC	56.00	35.28
6	DWC1	54.05	32.65
6	DWC2	58.41	35.27
6	DWC3	51.15	30.80
6	DWC4	53.53	32.69
8	Phase1DWC	57.00	35.28
8	DWC1	54.15	32.65
8	DWC2	58.41	35.27
8	DWC3	51.22	30.80
8	DWC4	53.89	32.69

Alerting Requirement:

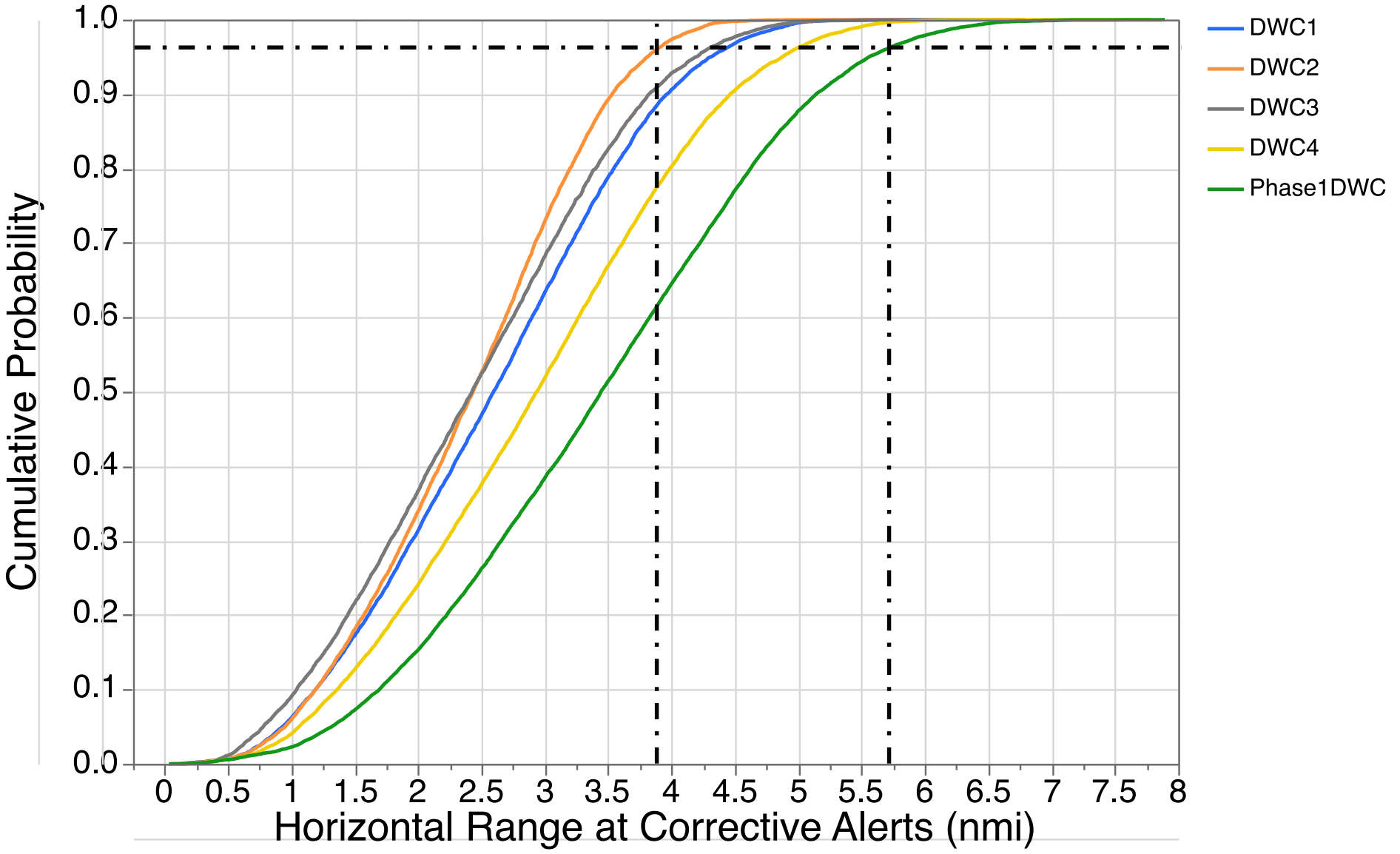
Corrective Alert
> 55.00

Warning Alert
> 25.00

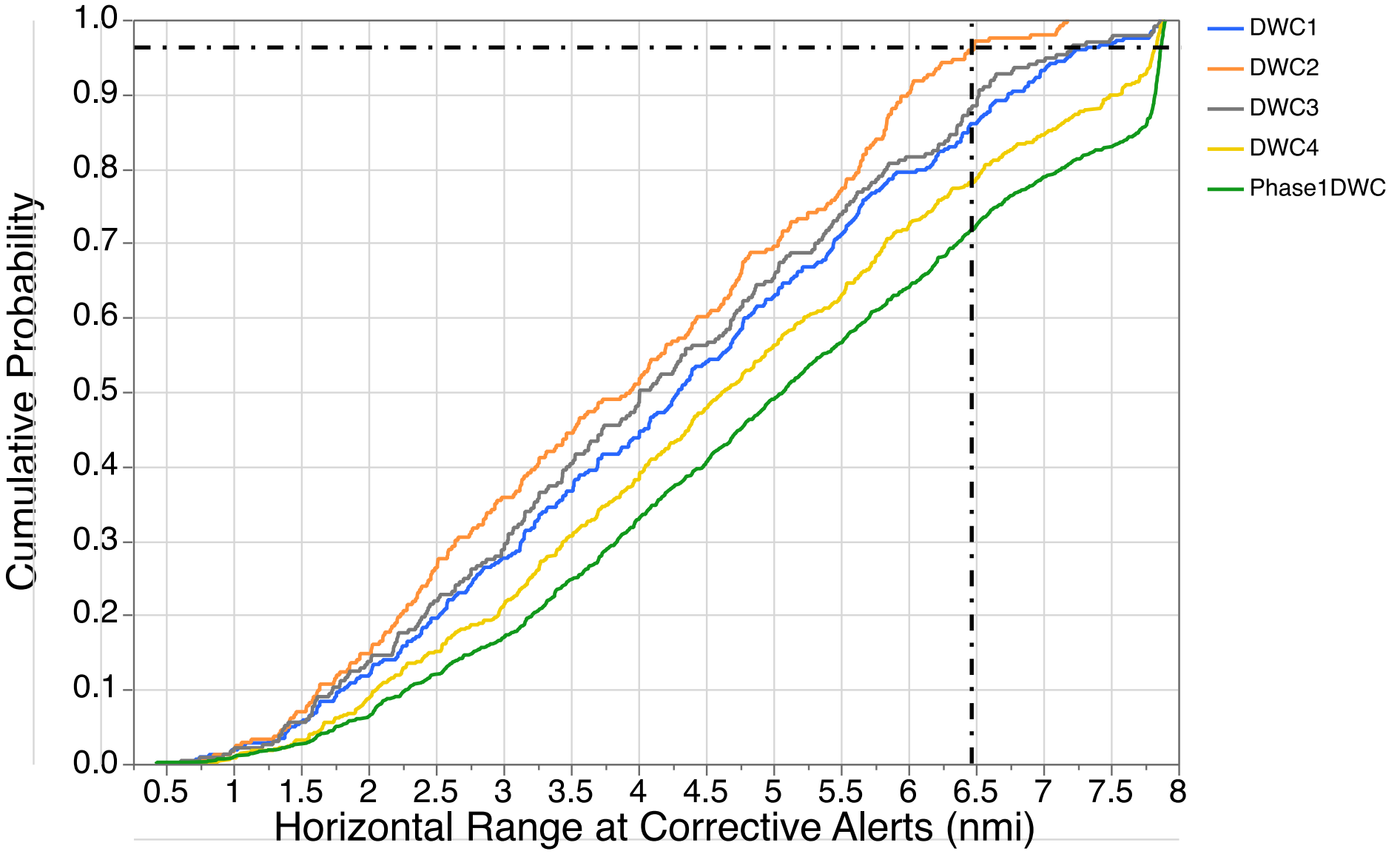
Radar Range for Corrective Alert (40 to 200 kts TAS)



Radar Range for Corrective Alert (40 to 100 kts TAS)



Radar Range for Corrective Alert (200 to 300 kts TAS)



Concluding Remarks

- DWC2 met the alerting time requirements of the Phase 1 MOPS
- Results imply that DWC2 could allow **Phase 1 UAS** to carry smaller radar and/or fly closer to the 250 KIAS airspeed limit imposed by the FAA for aircraft under 10,000 feet MSL
- In March 2019, DWC2 formally accepted by RTCA SC-228 as the DWC definition for **Phase 2 UAS** in encounters with non-cooperative VFR aircraft outside of the terminal area

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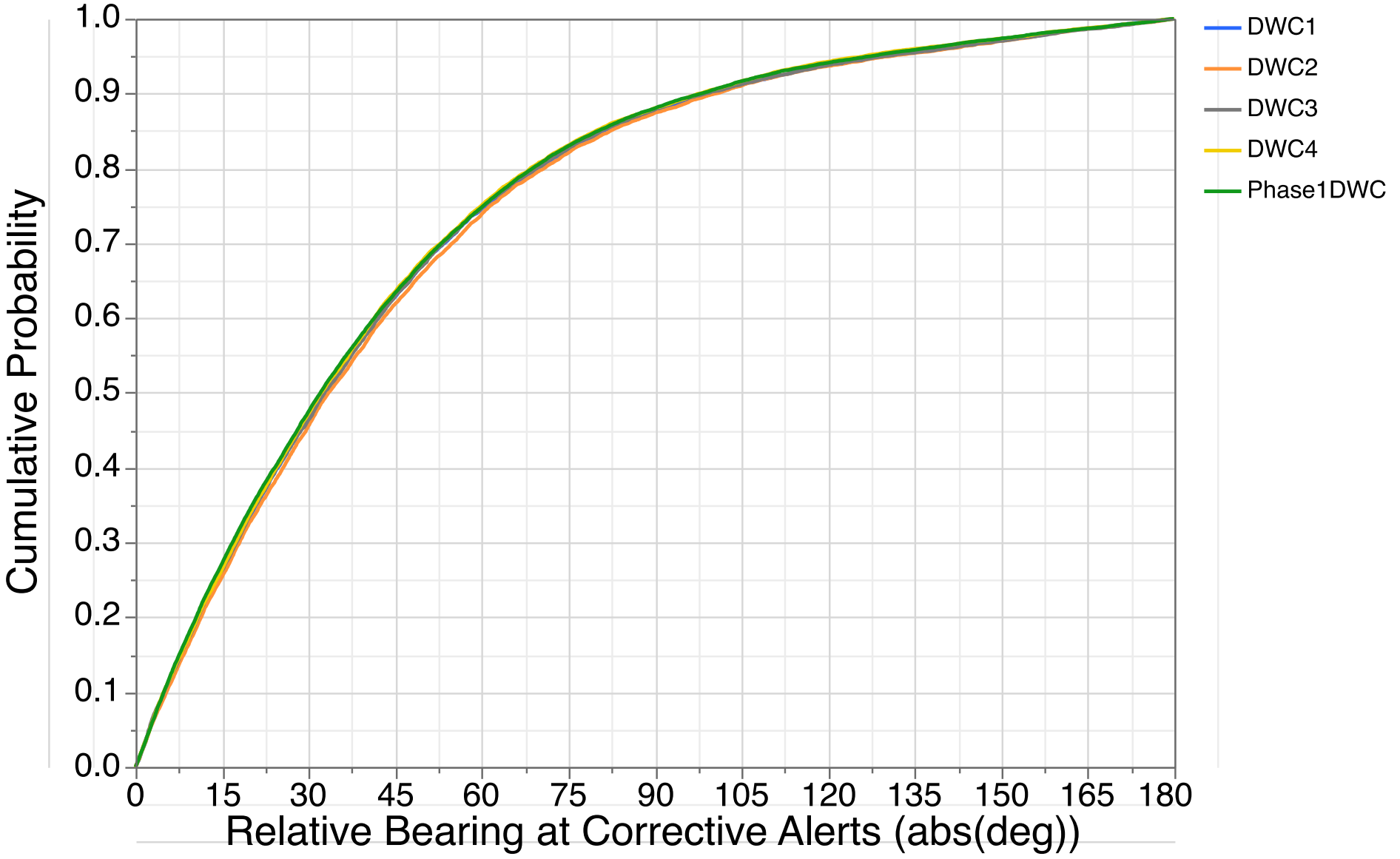
Horizontal Field of Regard (40 to 200 kts TAS)

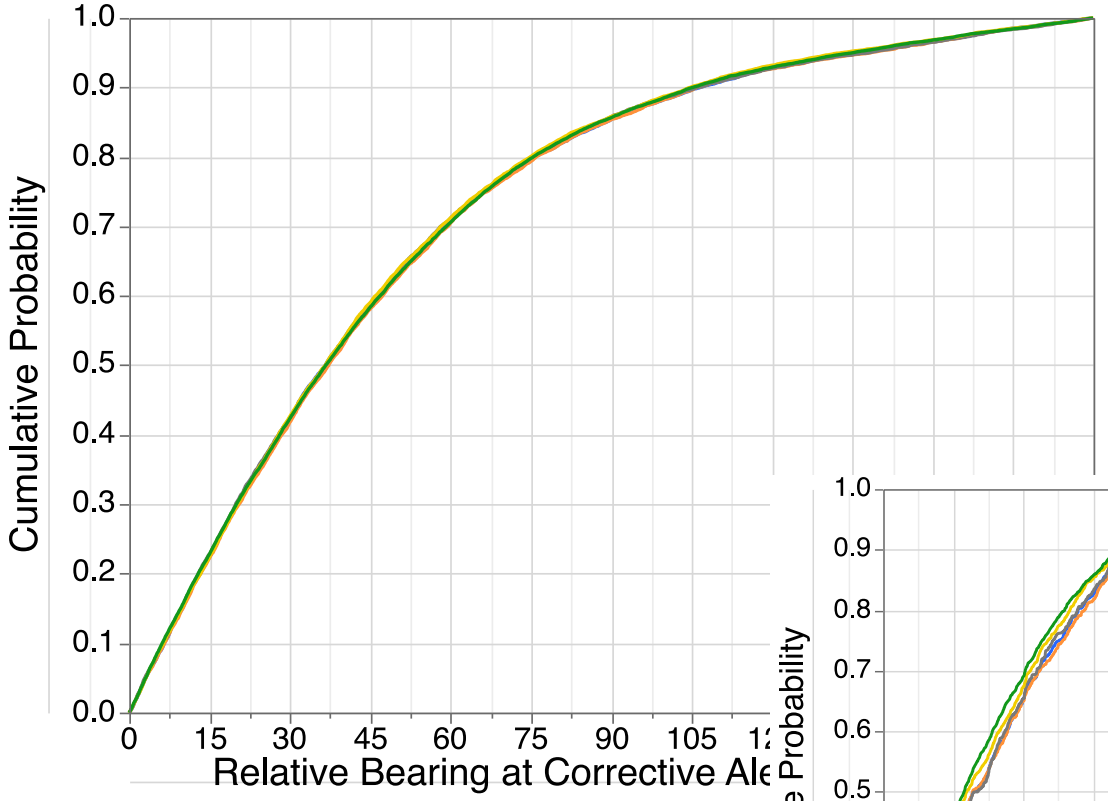


- Desire to interoperate with TCAS led to some of the sizing of the Phase 1 DWC. It was important that DAA alerts trigger before TCAS RA's so tha ta pilot would not be distracted by a DAA alert for an intruder while attempting to execute a TCAS maneuver for that same aircraft. Daa wa allowed to provide guidance for non-cooperative intruders while the pilot was flying a TCAS maneuver.

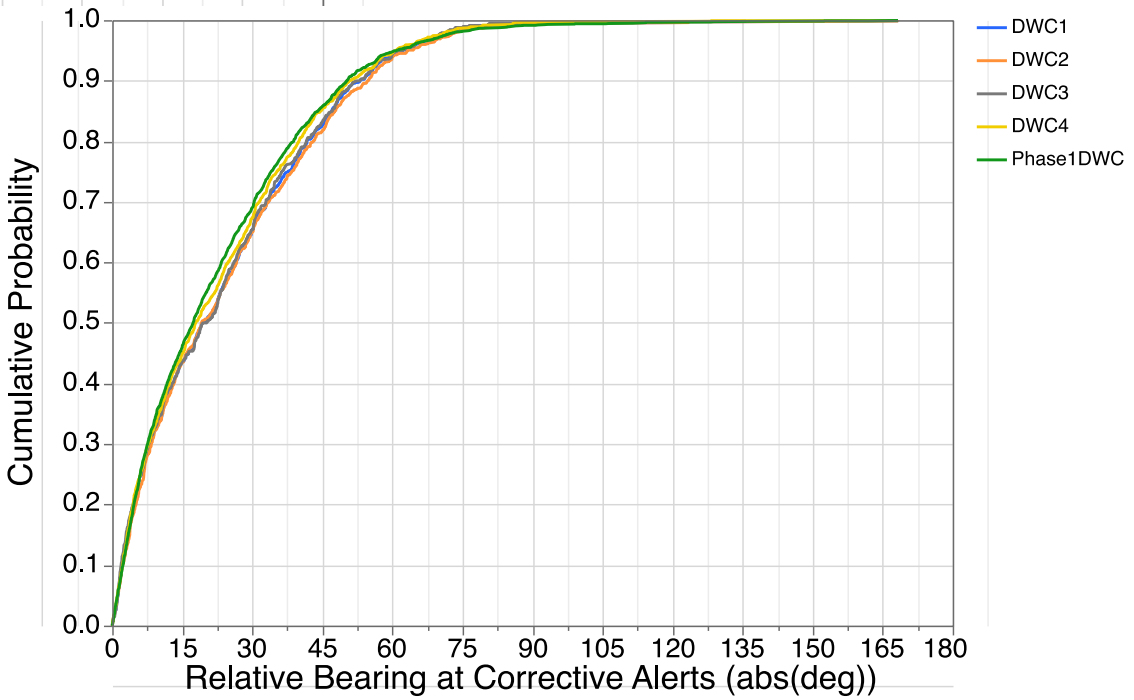
- For those non-cooperative VFR intruders, a radar or other surveillance that did not require a beacon or was reliant on intruders broadcasting info was required

- However, there was only one DAA Well Clear def, and that was sized by the TCAS requirements. This led to a requirement for a radar that could declare intruders at 6.7 nmi. There is also a speed restriction in place (under 200 kts TAS) that is more strict than the FAA requirement at altitudes near 10,000 feet MSL

Horizontal Field of Regard (Speed Bins)



UAS between 40 and 100 kts TAS



UAS between 100 and 150 kts TAS

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