DO-366 Appendix-C&D Update for High and Medium UA Speed Ranges

Prepared for

RTCA F2F

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Background and Objectives

- DO-366 Appendices C and D document analyses of the air-to-air radar (ATAR)'s field of regard (FOR) in terms of alerting times before a loss of DAA well clear (LoDWC)

- These analyses are to be repeated because
  - SC-228 Phase 2 work selects an alternative non-cooperative DWC
    - 2200 ft horizontal distance
    - 450 ft vertical distance

  - The one radar category in DO-366 will be expanded to 3 categories characterized by varying UA speed ranges
    - **High speed UA from 100 to 291 KTAS**
    - **Medium speed UA from 100 to 200 KTAS**
    - Low speed UA from 40 to 110 KTAS (not analyzed in this work)

ATAR Field of Regard (FOR) Requirements

- Radar Declaration Range (RDR) Requirement (computed by Adaptive Aerospace Group and NASA)
  - It is dependent on:
    - The bearing angle of the intruder aircraft to the ownship UAS
    - The size of the intruder aircraft which is based on the intruder aircraft speed
    - The speed of the ownship UAS
    - Assumed FOR angular ranges: $\pm$ 110° azimuth, $\pm$15° altitude
- Radar Closest Performance Range (RCPR) Definition
  - 4000 ft
- Track declaration time
  - 15 seconds track delay when the intruder enters the FOR within the RDR

High Speed UAS

Intruder Size	Nominal RDR [nm]
Small ($s_{int} \leq 100$ KTAS)	4.9
Medium ($100 < s_{int} \leq 130$ KTAS)	5.2
Large ($130 > s_{int}$ KTAS)	5.7

Intruder Bearing Angle	RDR Correction Factor		
	Small	Medium	Large
$\|angle\| < 30$	1	1	1
$30 \leq \|angle\| < 60$	0.59	0.67	0.76
$60 \leq \|angle\| < 90$	0.33	0.51	0.66
$90 \leq \|angle\| < 110$	0.17	0.25	0.40

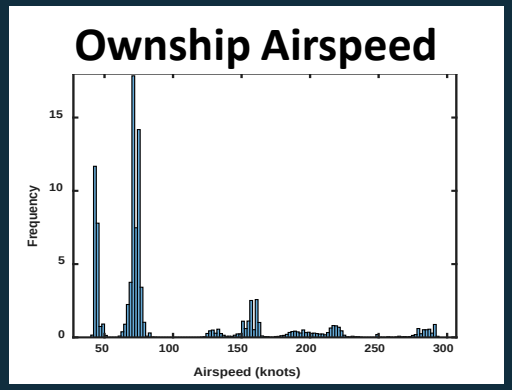
Medium Speed UAS

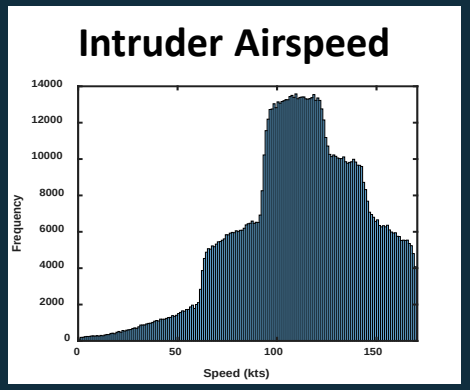
Intruder Size	Nominal RDR [nm]
Small ($s_{int} \leq 100$ KTAS)	4.1
Medium ($100 < s_{int} \leq 130$ KTAS)	4.5
Large ($130 > s_{int}$ KTAS)	5.0

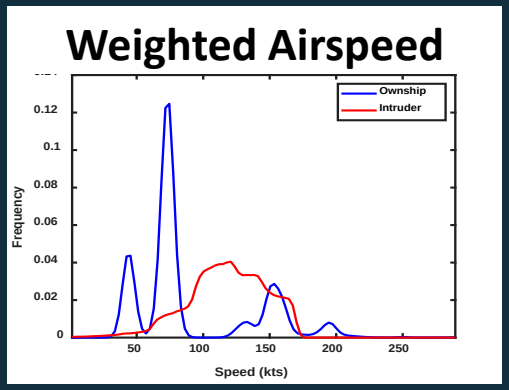
Intruder Bearing Angle	RDR Correction Factor		
	Small	Medium	Large
$\|angle\| < 30$	1	1	1
$30 \leq \|angle\| < 60$	0.70	0.78	0.84
$60 \leq \|angle\| < 90$	0.39	0.59	0.76
$90 \leq \|angle\| < 110$	0.20	0.30	0.45

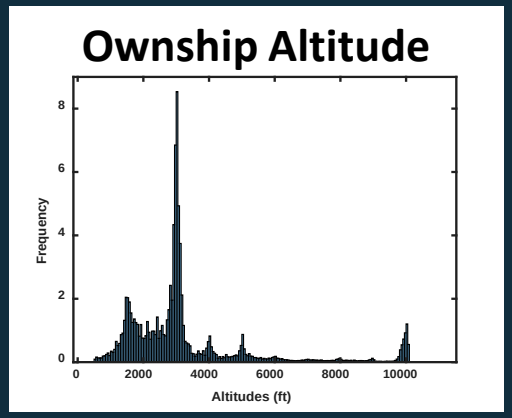
Full Encounter Set

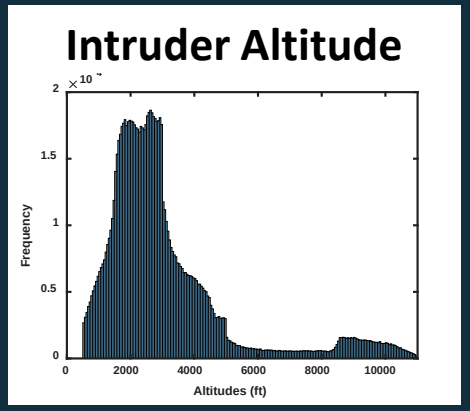
- 1 million encounters are created overlaying NASA UAS trajectories with VFR trajectories sampled from MIT Lincoln Lab's uncorrelated encounter model
- Weighted distributions represent the frequency at which the encounters actually occur
  - Trajectories with high ownship speeds occur infrequently in the original NASA UAS track data; trajectories with lower ownship speeds have longer track durations

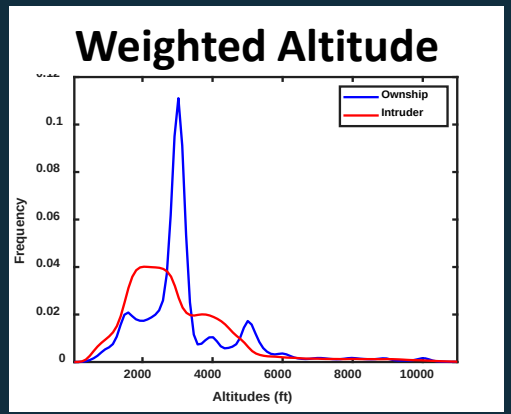












Encounter Set Stats

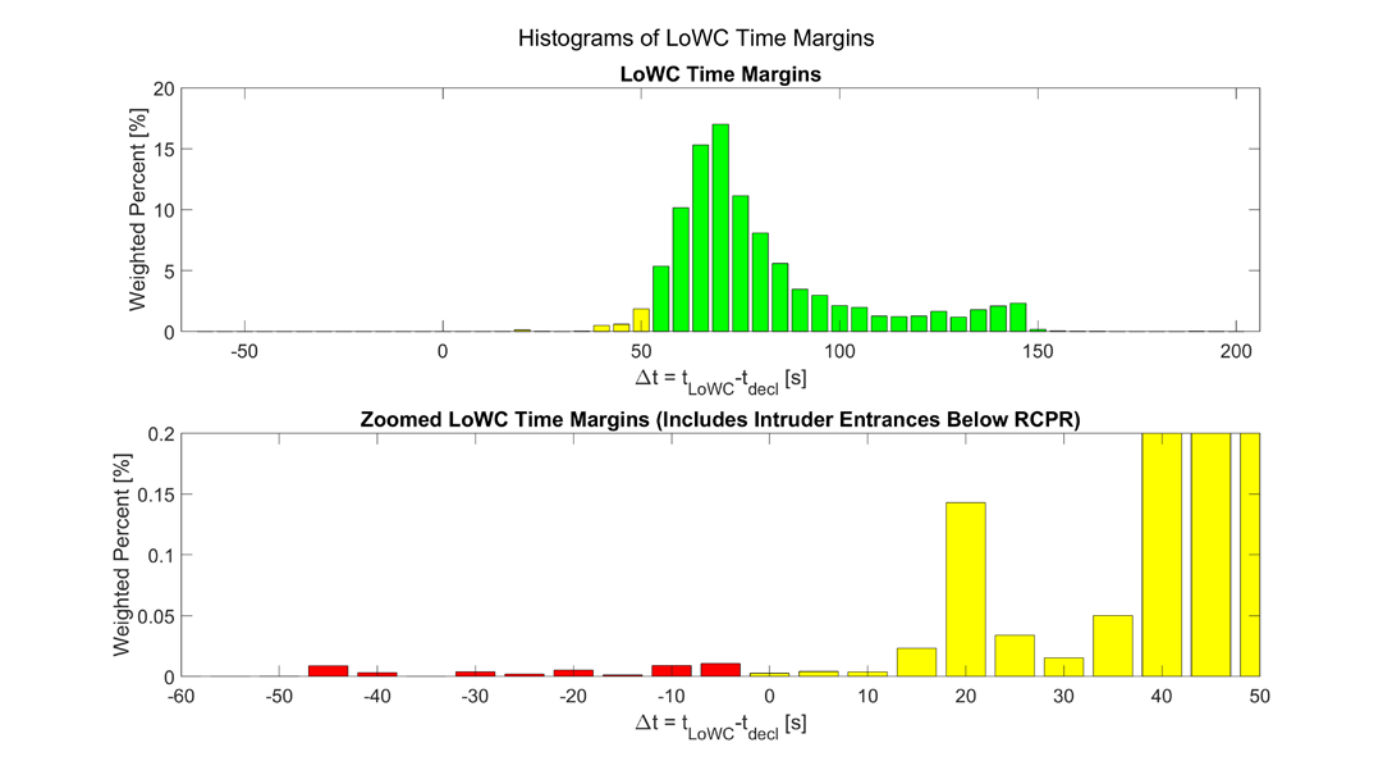
- The 1 million encounters were filtered to a set that includes only those encounters that are strictly within the speed bounds for High Speed UAS
  - 100 KTAS to 291 KTAS
  - This includes all Medium Speed UAS encounters as well
    - 100 KTAS to 200 KTAS
  - High Speed UAS set includes 247,827 encounters
  - Medium Speed UAS set includes 157,299 encounters

	High Speed UAS (247,827 encs)			Medium Speed UAS (157,299 encs)		
	# of Encs	% of Encs	Weighted % of Encs	# of Encs	% of Encs	Weighted % of Encs
LoWC	79,949	32.26	3.98	48,480	30.82	3.79
NMAC	12,252	4.94	0.20	7,849	4.99	0.19

Appendix D Definitions and Goals

- App Goal: Compare RDR Time Margin to corrective alert requirements
- Definition: time margin $\Delta t = t_{LoWC} - t_{decl}$
  - t_{LoWC} = the time of first loss of well clear (LoWC)
  - t_{decl} = the time of track declaration
- Average corrective alert time: 55 seconds
- Late Alert time: 20 seconds

High Speed LoWC Time Margin Data



- Green has a time margin of $\Delta t \geq 55\ s$
- Yellow has a time margin of $0\ s \leq \Delta t < 55\ s$
- Red has a time margin of $\Delta t < 0\ s$
- This includes ALL of the data. All of the Red and many of the smaller valued Yellow data are intruders that entered the FOR below the RCPR ($< 4000\ ft$).

Appendix D Preliminary Results

Δt Bracket [s]	High Speed UAS (79,949 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
$\Delta t > 55$	69,555	86.99	95.16
$20 < \Delta t \leq 55$	10,352	12.95	4.61
$\Delta t \leq 20$	42	0.05	0.22

Δt Bracket [s]	Medium Speed UAS (48,480 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
$\Delta t > 55$	41,092	84.76	86.42
$20 < \Delta t \leq 55$	7,347	15.15	13.34
$\Delta t \leq 20$	41	0.08	0.23

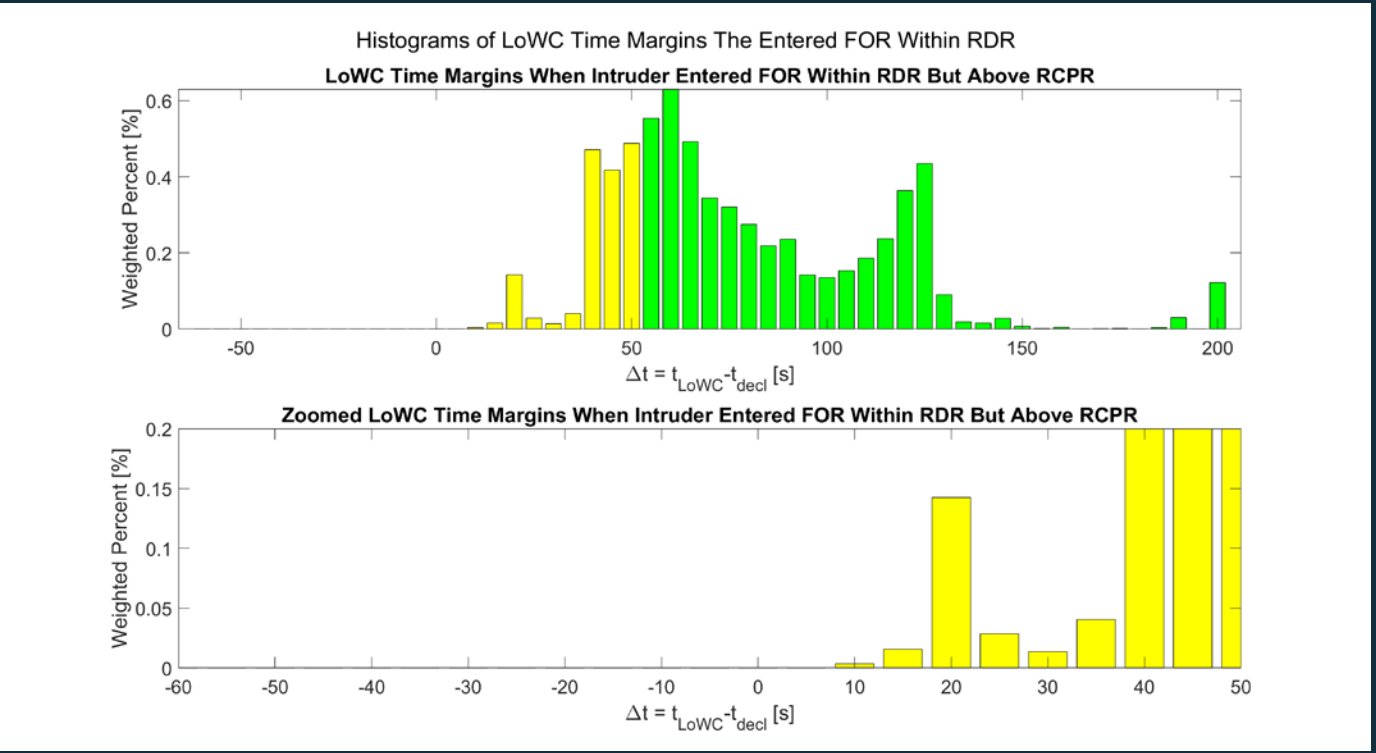
App D Preliminary Results Comments and Questions

- Late alert % is very low. It appears that the RDR may be too conservative
- Possible differences due to 1.5 deg/s turn vs 3 deg/s
  - 3 deg/s results in RDR that is roughly 0.7-0.85 the RDR at 1.5 deg/s
- Rounding up in the way RDR definition:
  - Using worst case bearing across the bearing range (e.g. using 0 deg bearing for all of 0 to 30 deg)
  - Taking the largest RDR across ownship speed range
  - Using 1.5 deg/s turn rate
  - Rounding up at each stage may push RDR too far out

Appendix C Definition and Goals

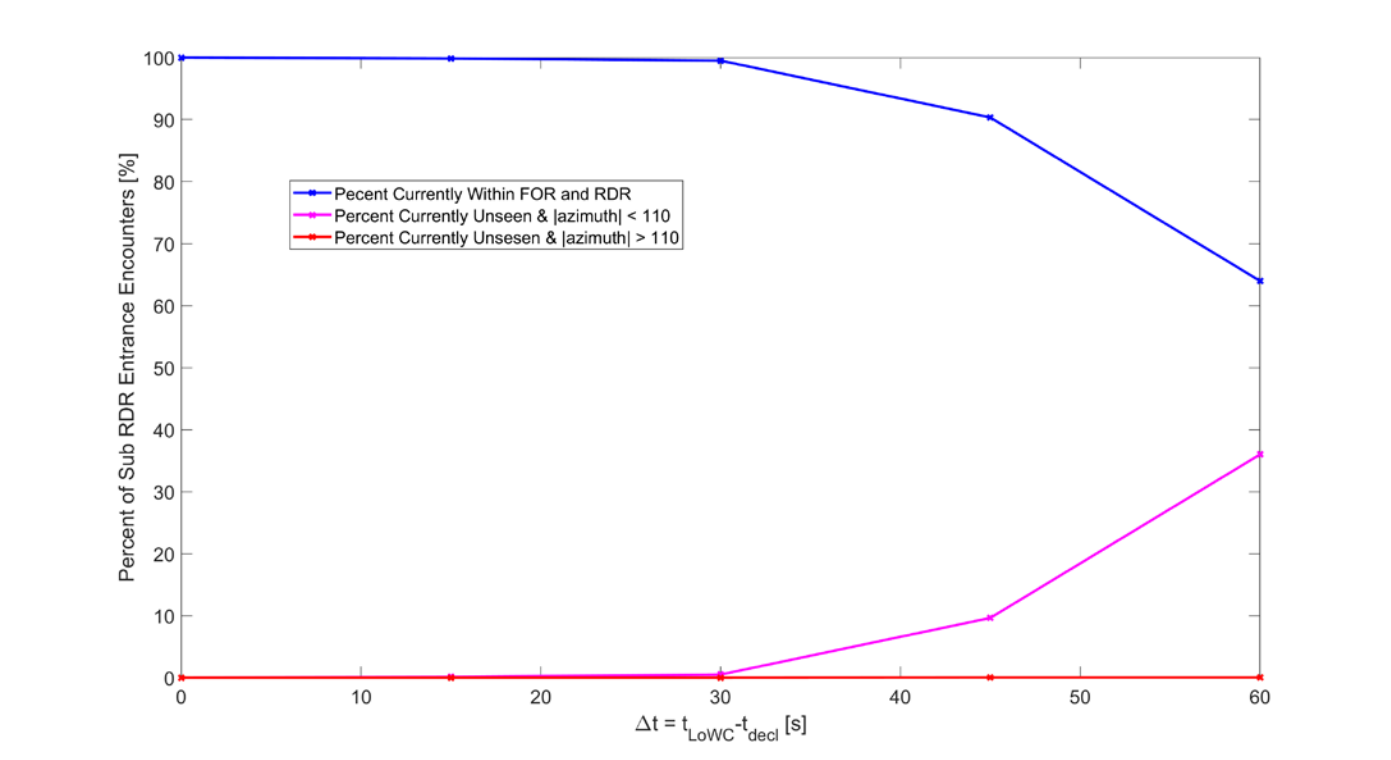
- App Goal: Determine effect of 15 second track delay when intruder enters FOR within RDR
- Definition: time margin $\Delta t = t_{LoWC} - t_{decl}$
- We want to find the percentage (and weighted percentage) of LoWC encounters entering the FOR below RDR that results in a $\Delta t \leq 30$ seconds
  - For a encounter first observed within RDR, a 15 second delay is considered for track declaration time.
- We also want to ignore any cases below the RCPR
  - RCPR defined as 4,000 ft horizontal distance

High Speed LoWC Time Margin Data When Intruder Entered FOR Within RDR



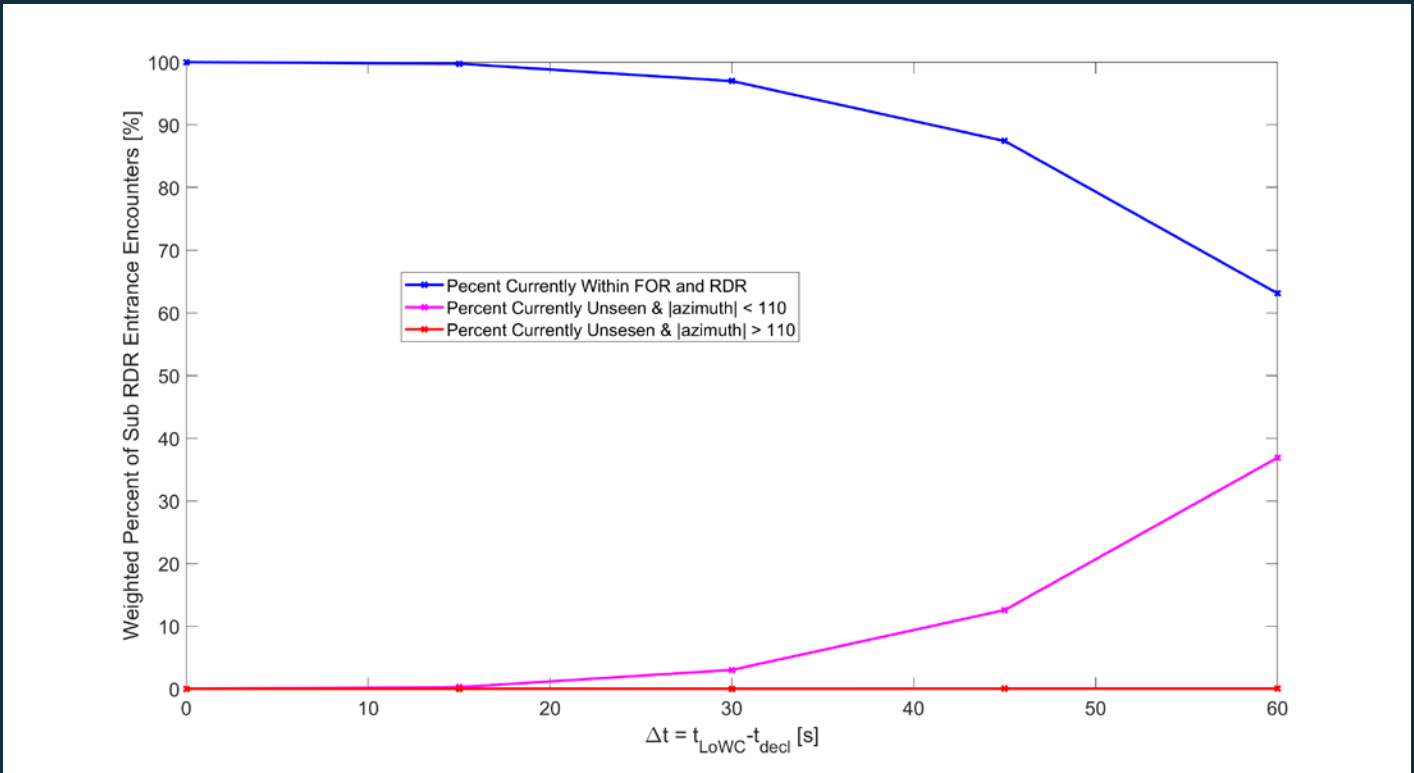
- Same color convention as before
- Removal of sub-RCPR FOR entrance data and only considering the cases where the intruder entered within the RDR.
- No more Red data.

Percent of Sub-RDR Encounters Currently with the FOR relative to Δt for High Speed UAS



- By $\Delta t = 30$ seconds, nearly all of the Sub-RDR entrance encounters are within the FOR

Weighted Percent of Sub-RDR Encounters Currently with the FOR relative to Δt for High Speed UAS



- These weights are calculated for only the subset of Sub-RDR Entrance encounters

Appendix C Preliminary Results

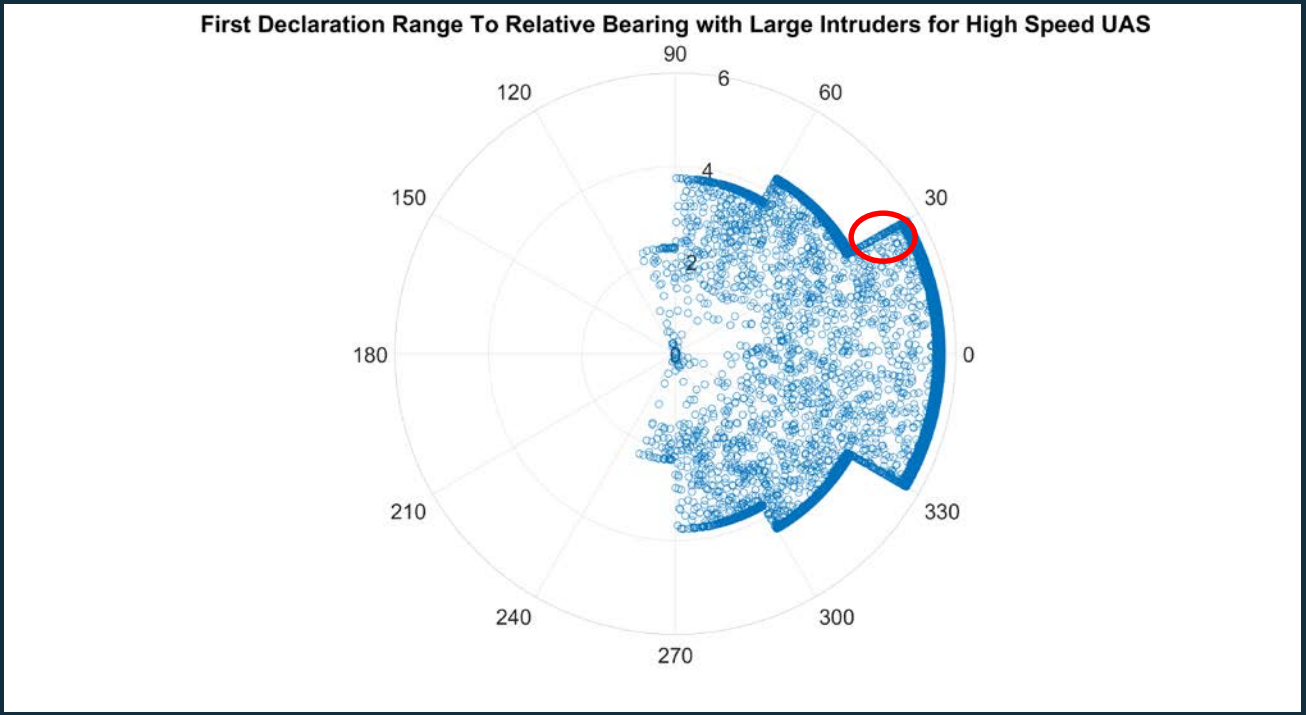
Where the intruder entered the FOR	High Speed UAS (79,949 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
Within RDR but above RCPR	3,642	4.55	6.57
Within RDR but above RCPR with $\Delta t \leq 30$ seconds (cases impacted by 15 second track delay)	18	0.02	0.20
Below RCPR	40	0.05	0.06

Where the intruder entered the FOR	Medium Speed UAS (48,480 total)		
	# of Encs	% of LoWC Encs	Weighted % of LoWC Encs
Within RDR but above RCPR	2,852	5.88	6.68
Within RDR but above RCPR with $\Delta t \leq 30$ seconds (cases impacted by 15 second track delay)	14	0.03	0.20
Below RCPR	39	0.08	0.06

App C Preliminary Results Comments and Questions

- There are some significant changes in percent values from the previous work
- E.g. previously, 3527 encounters (3.3%, 2.1% weighted) of LoWC events could be affected by 15 sec delay where as current work suggests only 18 (0.02%, 0.2% weighted) encounters of the current set are impacted.
- This could be explained by differences in the set and our analysis parameters (no τ factor, >100 KTAS ownship, HMD is 2200 from 4000 last time).

Are the RDR Requirements and Definitions Suitable?



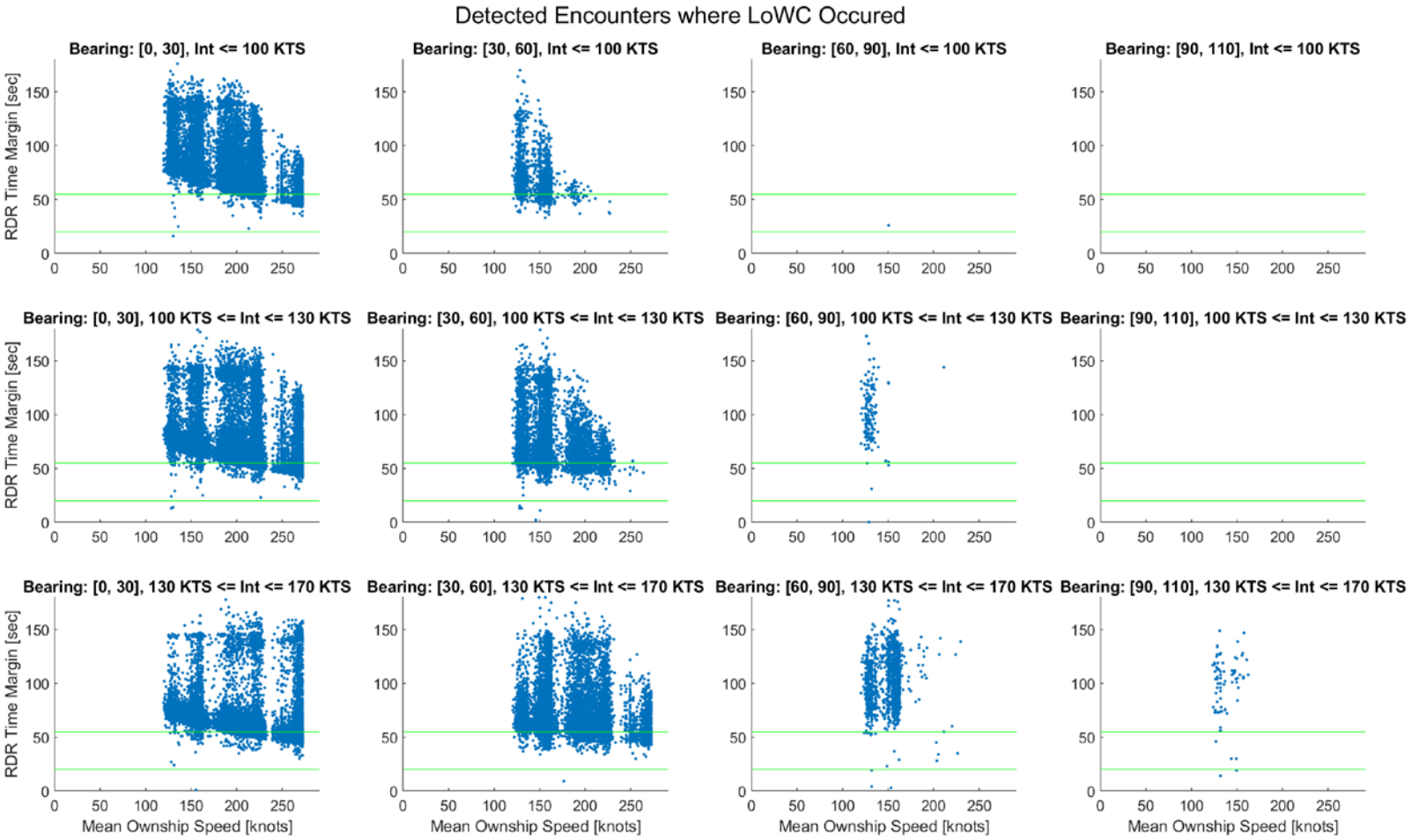
- Interesting cases to consider
  - Entrance in to the RDR through any of the radial faces (like what is circled in red)
  - What happens when the intruder enters the FOR at $1.01 \times RDR$ for a given bearing?
  - Is there a different definition or functional version of RDR that might make sense (i.e. something without the range discontinuities)?

Backup slides

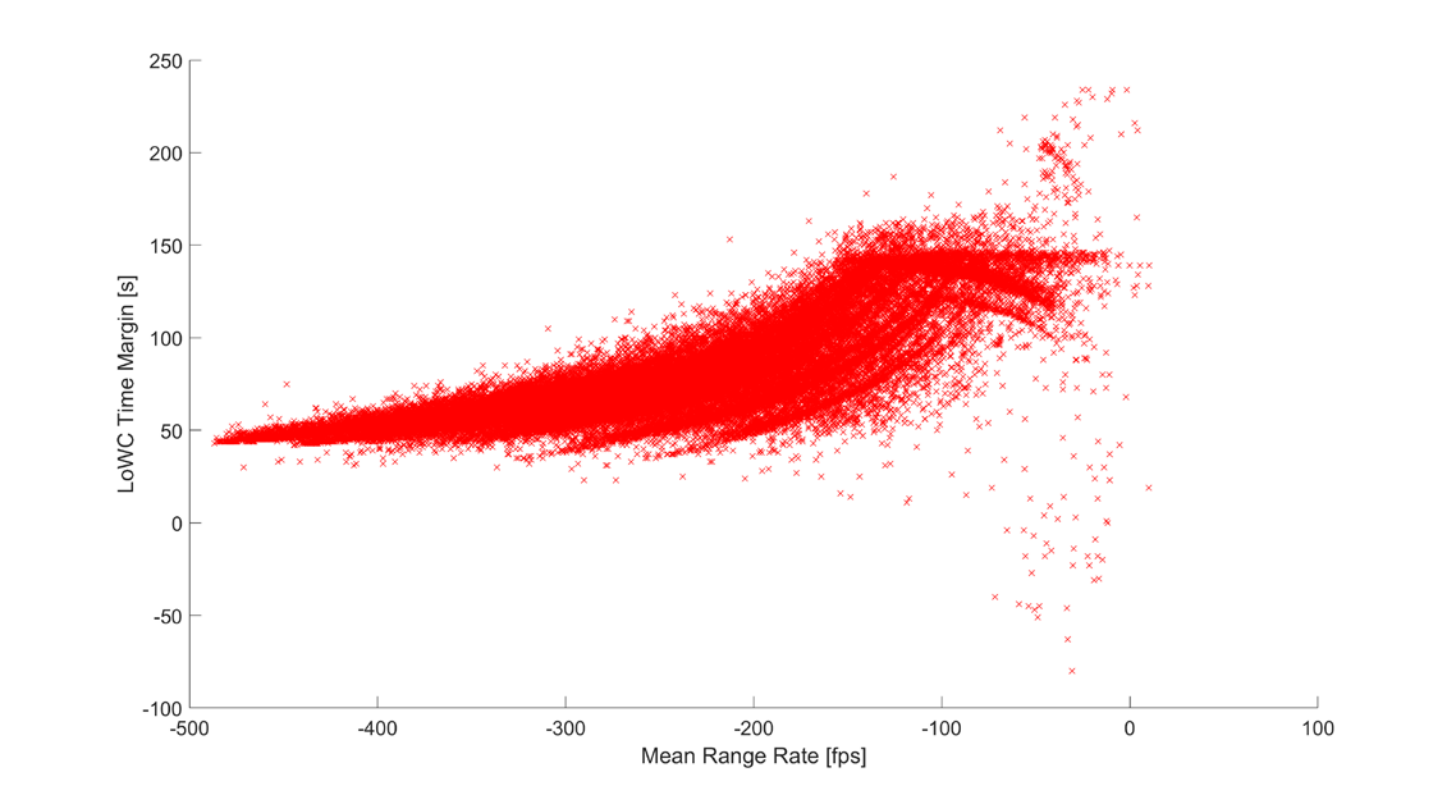
Appendix C Preliminary Results Cont.

- Of the 3642 encounter entering the FOR below RDR
  - 1566 are cases where the ownship is non-maneuvering (43.0% of below RDR encounters, 3.86% weighted for LoWC encounters)
  - 1746 are cases where the ownship is climbing/descending (47.94%, 1.35% weighted)
  - 180 are cases where the ownship is turning (4.94%, 1.23% weighted)
  - 150 are cases where the ownship is both turning and climbing/descending (4.12%, 0.12% weighted)

All High Speed Detected LoWC Encounters



High Speed LoWC Time Margins Compared to Mean Range Rate



It appears that the high valued LoWC time margin points (high on the vertical axis) have a low magnitude (i.e. a slow) mean closing speed.