



Low Size, Weight, and Power (SWaP) ATAR Analysis Results for Appendix C/D Updates



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UAS INTEGRATION IN THE NAS



- Analysis Objectives
- Low SWaP Dataset Overview
- Terminology Sync
- ATAR Analysis Parameters
- Appendix C Analysis
- Appendix D Analysis



- Explore implications of low SWaP sensor Field of Regard (FoR) and Radar Declaration Range (RDR) on ability to detect intruders and maintain well clear separations
- Requirements addressed for low SWaP in DO-366
 - 2.2.6 Radar Field of Regard
 - Azimuth (026) /Elevation Coverage (027)
 - 2.2.7 Radar Tracks
 - 15s Intruder track acquisition time (022)
 - RDR for Small (039), Medium (040), and Large (041) intruders

Encounter characteristics

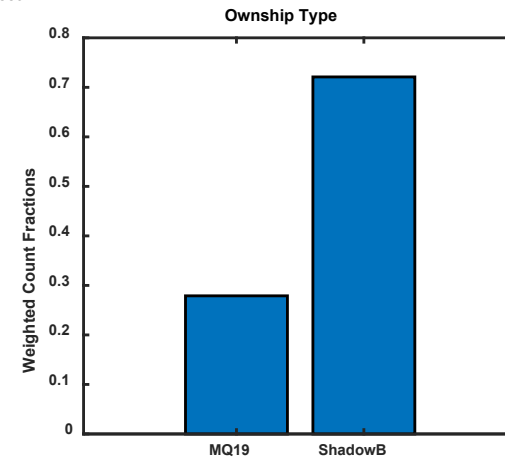
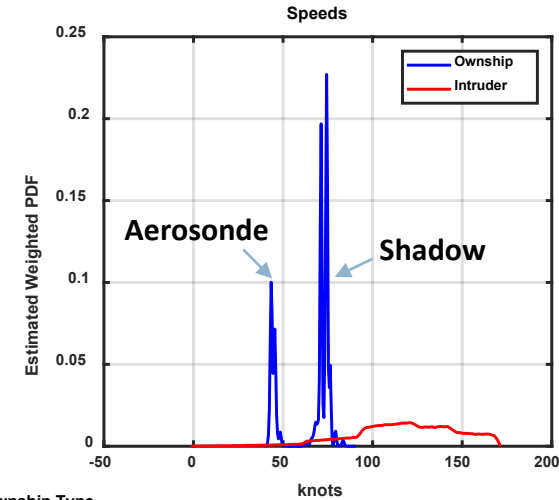
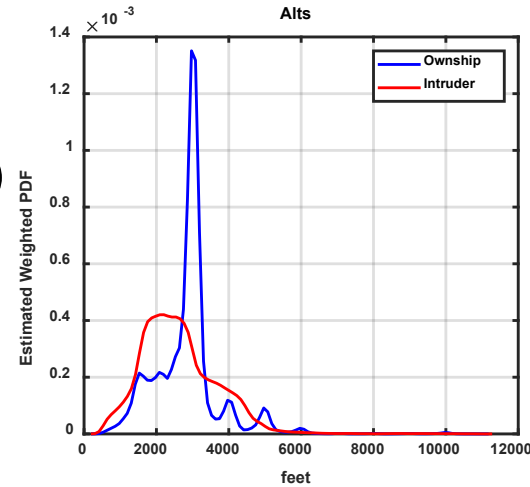
- # of Encounters: 1 Million
- Minimum Separation at Encounter Start: 800 ft (vertically) or 1.5 NM (horizontally)
- Max HMD/VMD: 3 NM / 1500 ft
- Closest Approach: 150 sec
- Encounter duration: 180 sec
 - Extended up to 300 sec if necessary to satisfy initial minimum separation

Airspace classes: E/G

Aircraft characteristics

- Ownship speed: 40-100 kts
- Intruder speed: 0-170 kts
- Ownship/intruder altitude: 500 AGL-10000 ft MSL

Low-SWaP Encounter Characteristics



Encounters not guaranteed to start outside of Radar Declaration Range.

Encounter Set Summary



Encounter Type	Total	Total %	Weighted %
Total # of Encounters	1 Million	100	100
Total Nominal Encounters (No LoWC)	662,008	66.2%	96.0%
Total with Loss of Well Clear (LoWC)*	337,992	33.8%	4.0%
<i>Total of LoWC Resulting in NMAC</i>	65,929	6.6%	0.2%

ATAR Analysis Parameters



- Perform comparative analysis for configurations to understand time margin trades:
 - AZ: 45, 60, 75, 90, 105, 110, 120, 135 deg
 - EL: 5, 10, 15, 20 deg
 - RDR: 2, 2.5, 3, 3.5 NMi
- Candidate* parameters became available as analysis evolved

Intruder Size	Small			Medium			Large		
MIR	1.24 NMi			1.56 NMi			1.98 NMi		
Pilot Response Time	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec
RDR	1.63 NMi	1.87 NMi	2.45 NMi	2.03 NMi	2.27 NMi	2.8 NMi	2.57 NMi	2.86 NMi	3.44 NMi
RDR Correction Factors	RDR-Dependent								
Field of Regard	Azimuth: +/- 110° Elevation: +/- 15°								

* Candidate Radar Declaration Range and Field of Regard Parameters from AAG



Symbol	Parameter	Phase 1	Phase 2, Non-cooperative, Low SWaP
HMD^*	Horizontal Miss Distance Threshold	4000 ft	2200 ft
h^*	Vertical Separation Threshold, Corrective & Warning	450 ft	450 ft
h^*	Vertical Separation Threshold, Preventive	700 ft	700 ft
τ_{mod}^*	Modified Tau Threshold	35 s	0 s
THR_{Late}	Late Threshold, Preventive & Corrective	20 s	20 s
THR_{Late}	Late Threshold, Warning	15 s	15 s
	Minimum Average Alert Time, Preventive & Corrective	55 s	55 s
	Minimum Average Alert Time, Warning	25 s	25 s

Terminology Sync

From [1] ATAR MOPS DO-366, Appendix C:

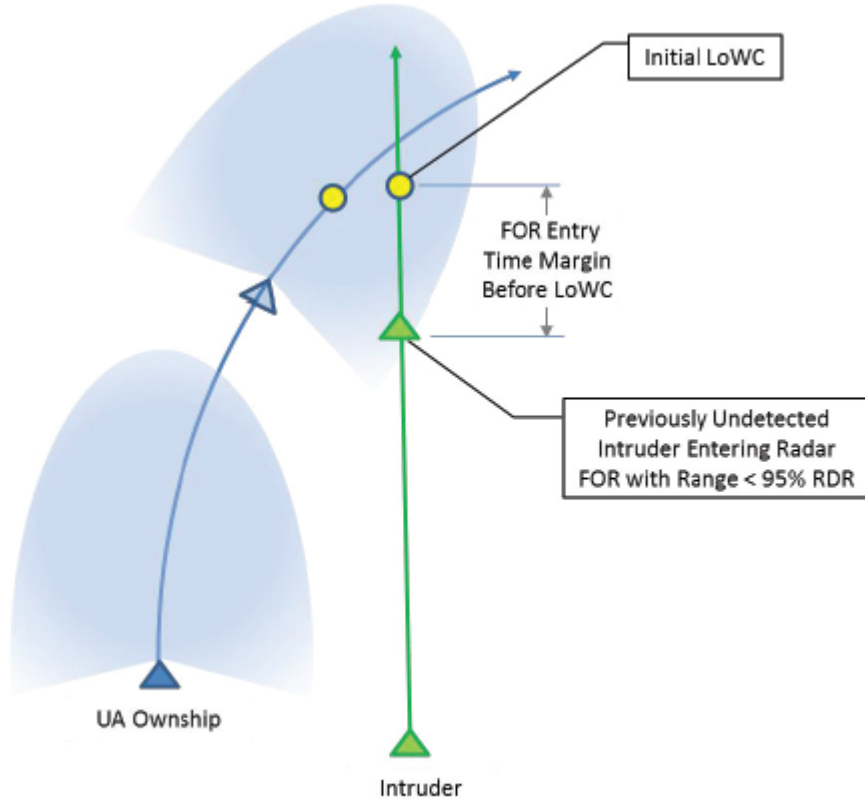


Figure C-2 Capturing the FOR Entry Time Margin

- **Pop-Up Encounters** – When intruders enter the FOR within the RDR
- Pop-Up encounters can be the result of **Ownship Maneuver**, **Intruder Overtake**, and **Vertical Convergence** encounter geometries
- There is less time for the pilot to maintain LoWC in these cases

Appendix C Analysis



- Determine probability of encounters affected by time to track requirement
 - 22. For cases where the intruder enters the FOR within the RDR (cases dominated by ownship maneuvers) the radar shall (050) take no more than 15 seconds 90% of the time to establish a track that meets the accuracy requirements in Paragraph 2.2.8, evaluated 15 seconds from the time the intruder enters the FOR until RCPR or the intruder exits the FOR.
- Investigate encounter geometries impacted by 15s track initiation requirement to identify challenging encounter geometries
- Perform comparative analysis for configurations to understand time margin trades:
 - AZ: 45, 60, 75, 90, 105, 110, 120, 135 deg
 - EL: 5, 10, 15, 20 deg
 - RDR: 2, 2.5, 3, 3.5 NMi

From [1] ATAR MOPS DO-366, Appendix C:

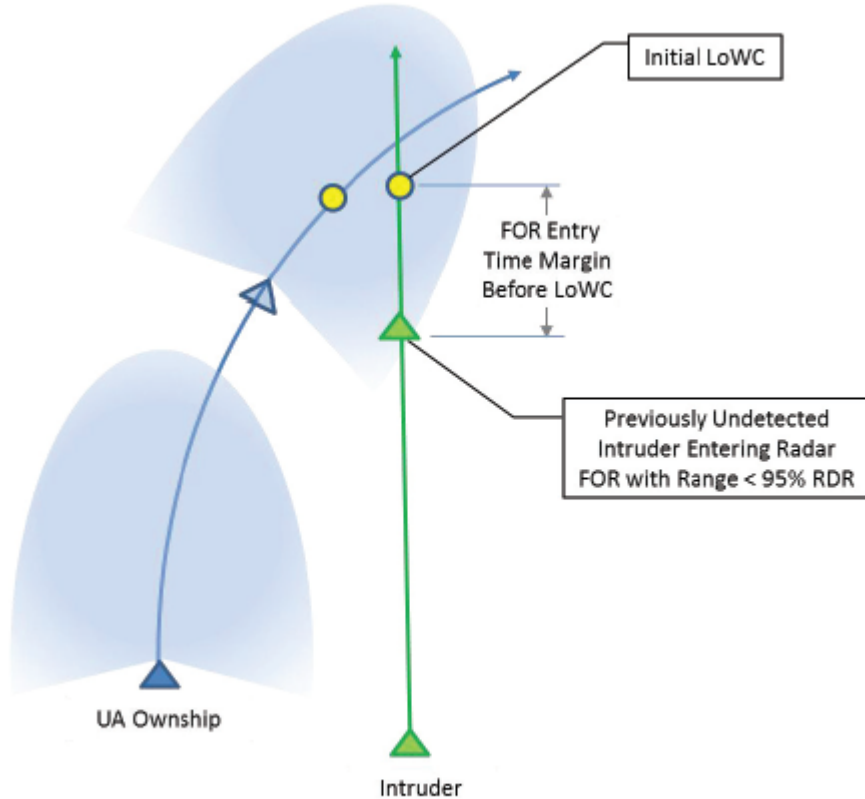
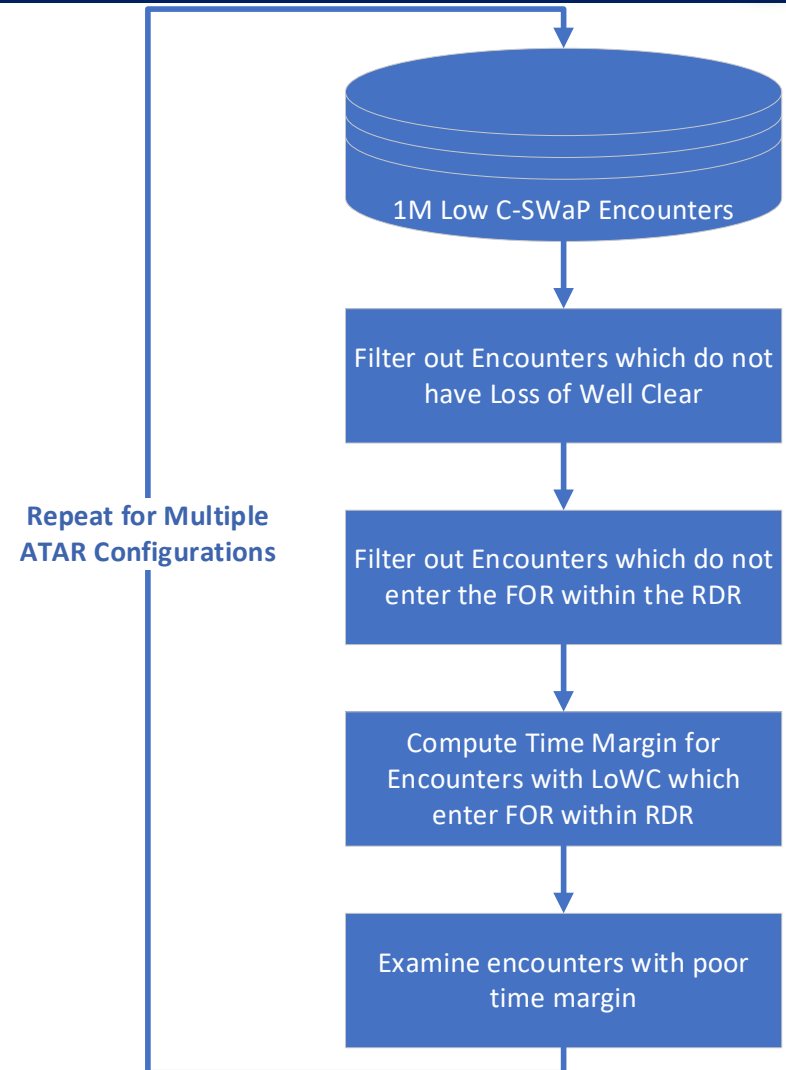


Figure C-2 Capturing the FOR Entry Time Margin

- As a metric to estimate the probability of Pop-Up Encounters, the **Time Margin** is measured
- **Time Margin** – The time between:
 - the intruder entering FOR *and* RDR
 - LOWC
- **Time Margin:**

$$t_{TM} = t_{LOWC} - t_{RDR}$$

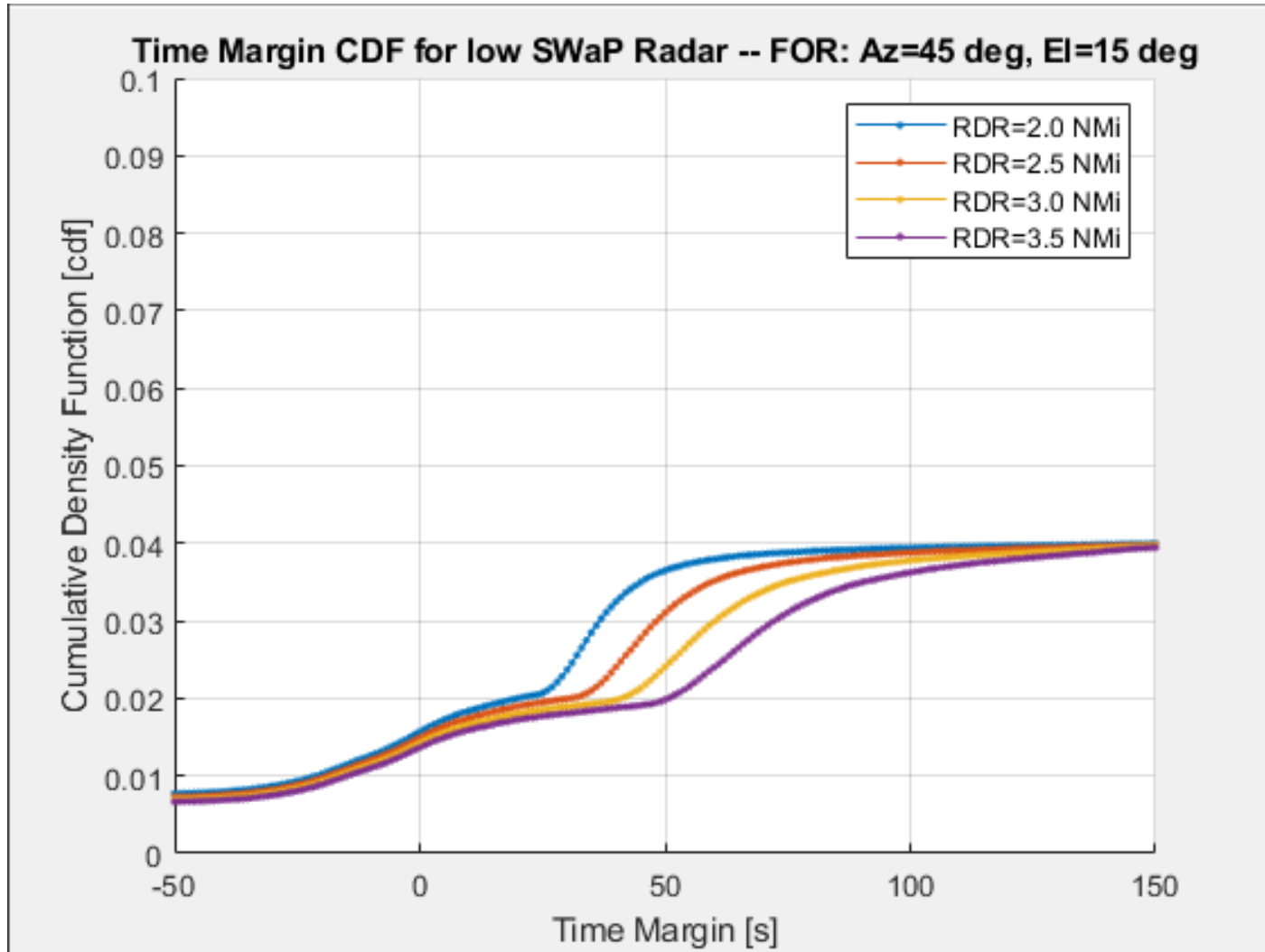
- Data generated for multiple configurations
- Multiple configurations compared to show trades between ATAR FoR and RDR



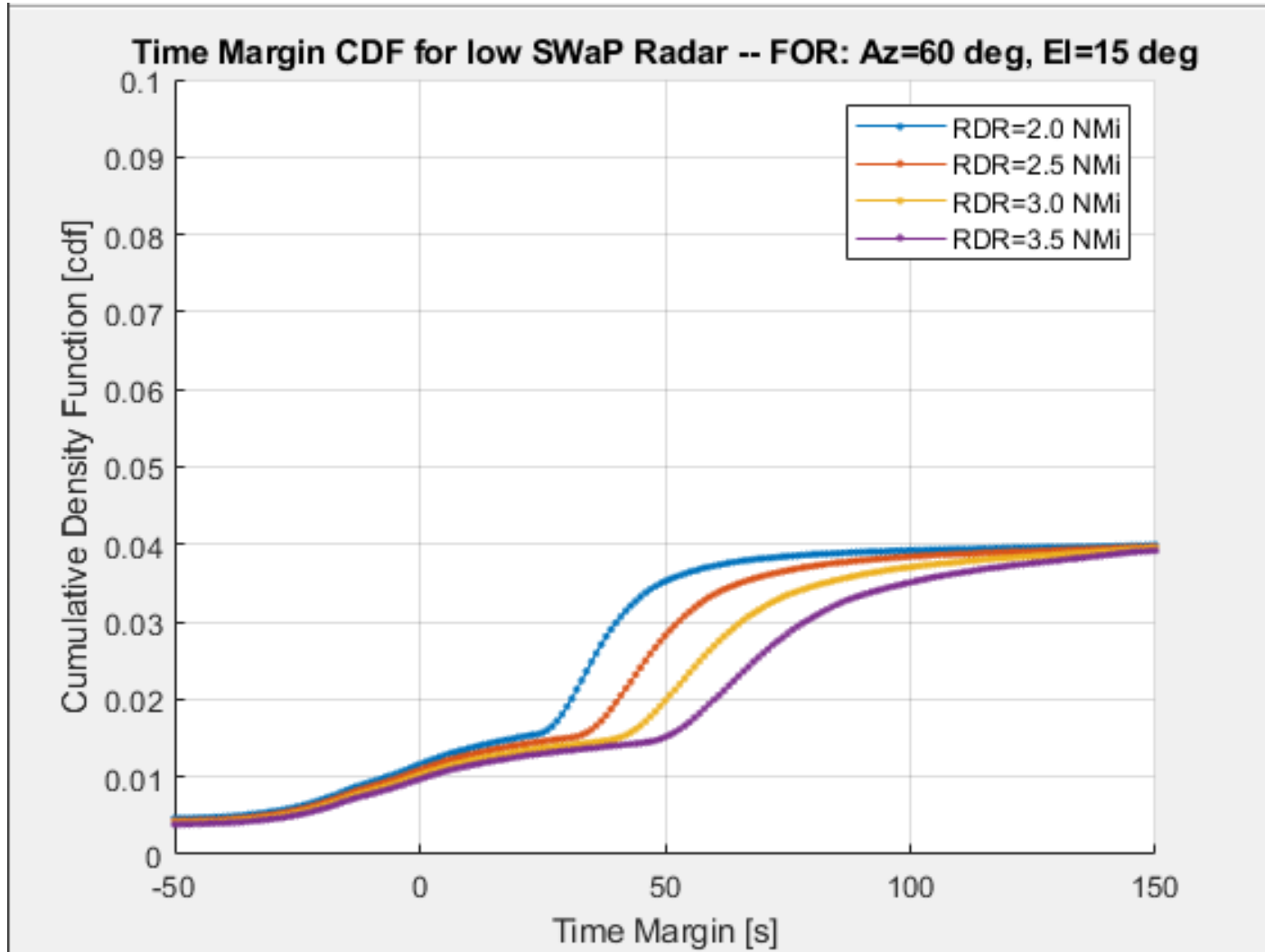
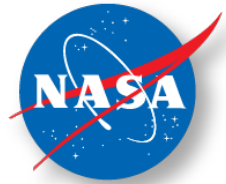


- Time Margin cumulate density function (CDF) results are shown for following configurations:
 - Fixed Elevation FoR
 - 15°
 - Varied Azimuth FoR
 - 45°, 60°, 75°, 90°, 105°, 110°, 120°, 135°
 - Varied RDR
 - 2, 2.5, 3.0, 3.5 NMi

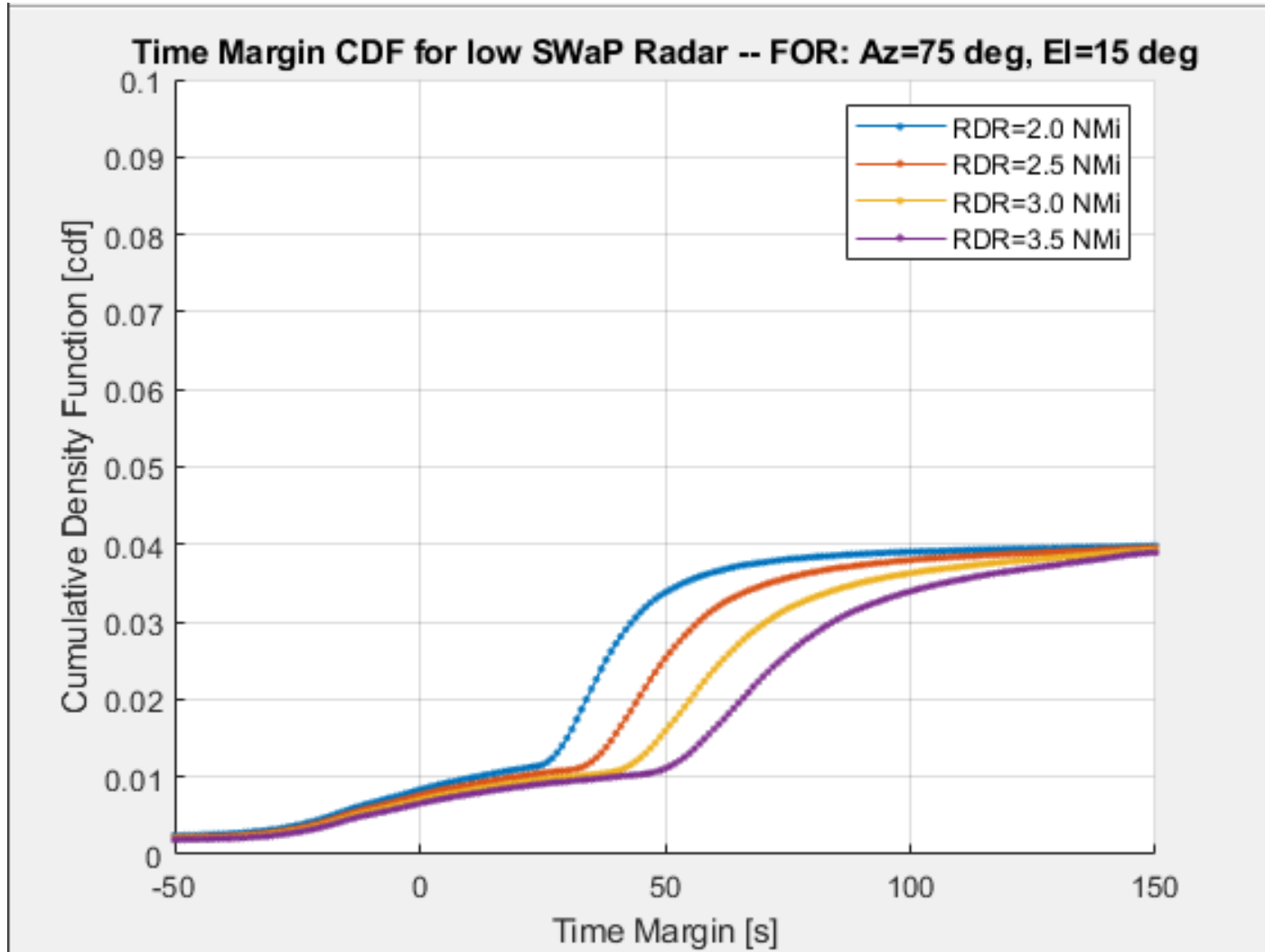
Fixed Elevation Time Margin Results



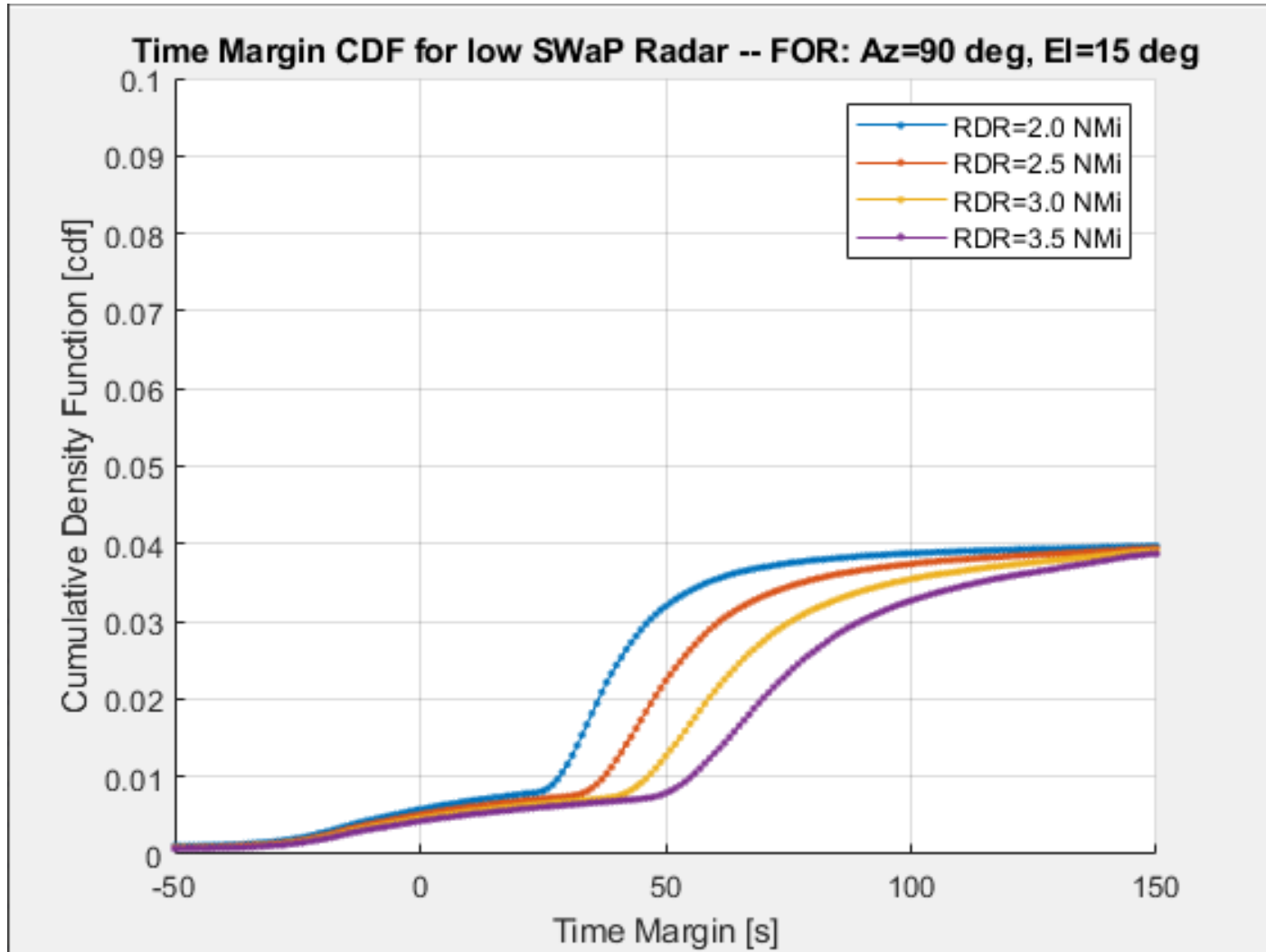
Fixed Elevation Time Margin Results



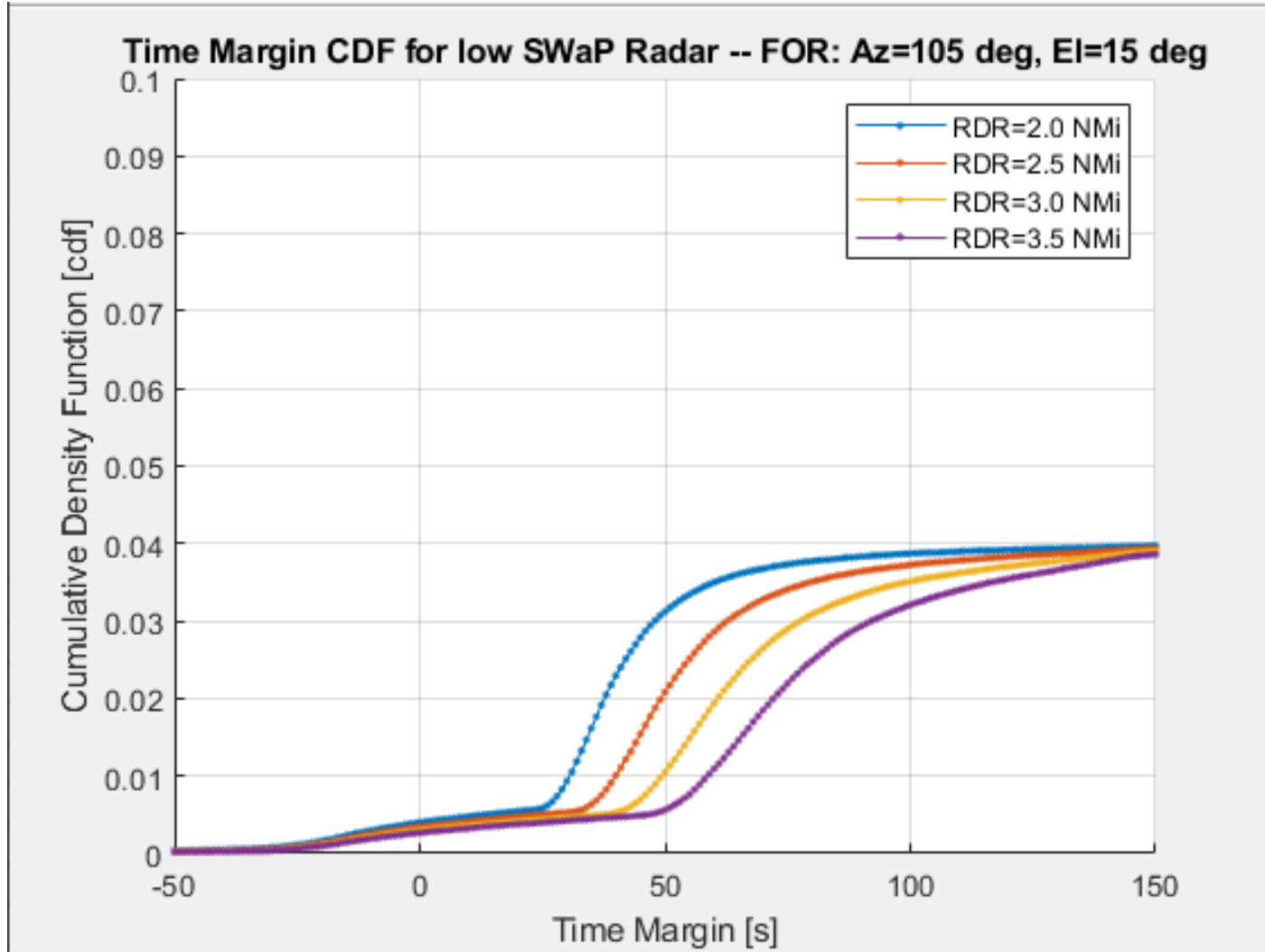
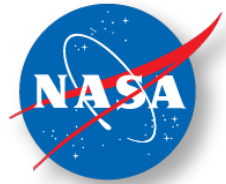
Fixed Elevation Time Margin Results



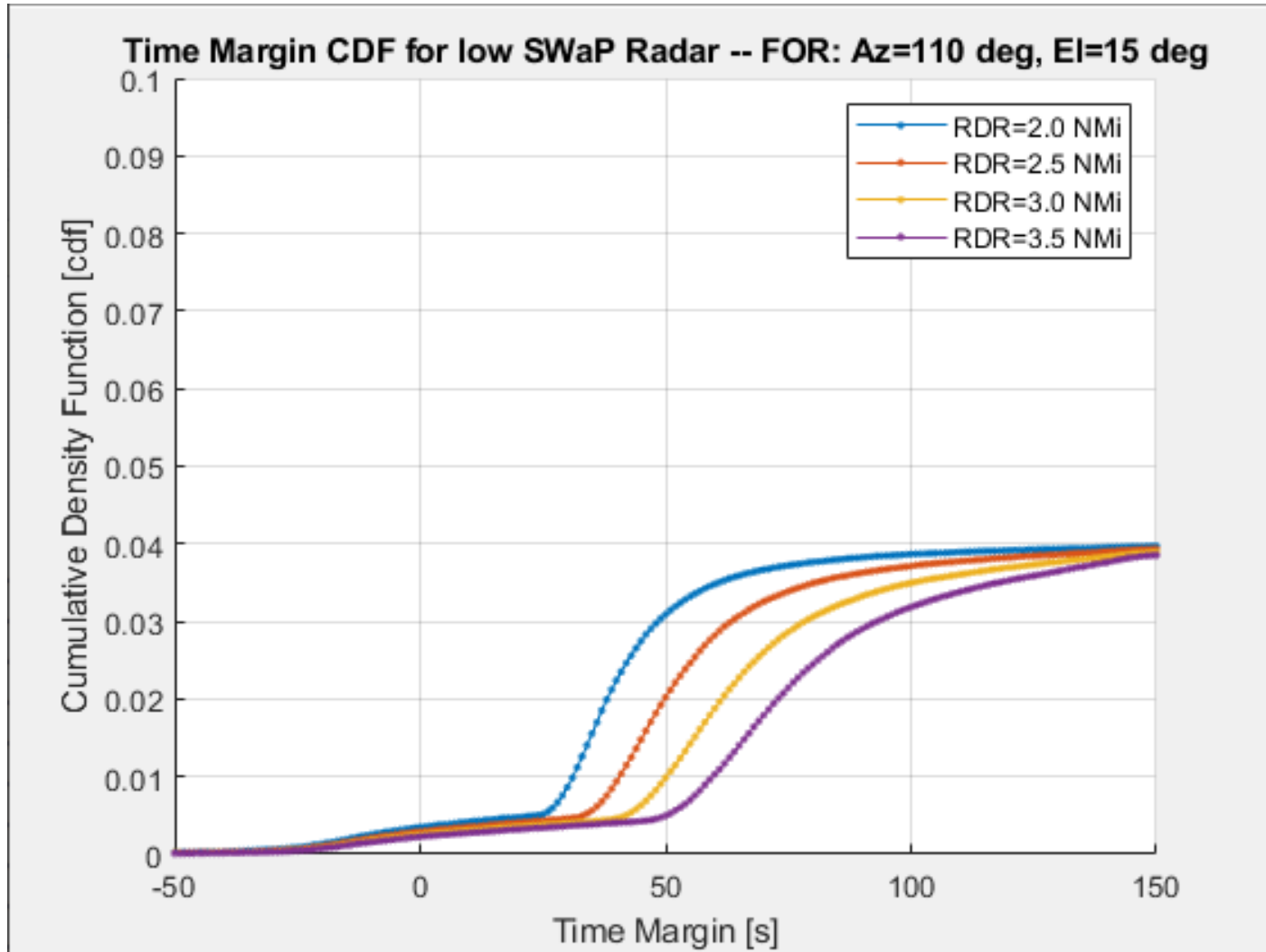
Fixed Elevation Time Margin Results



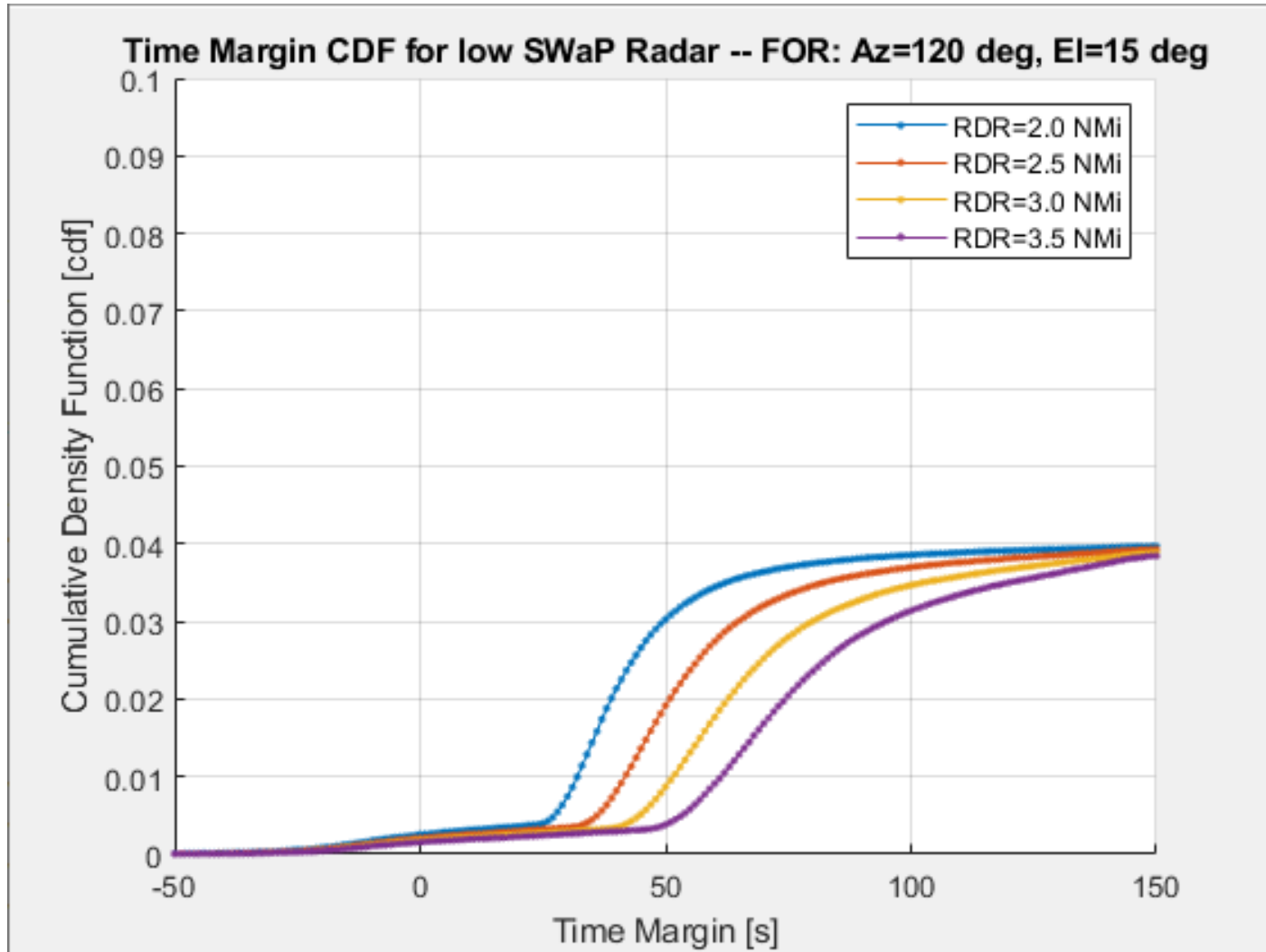
Fixed Elevation Time Margin Results



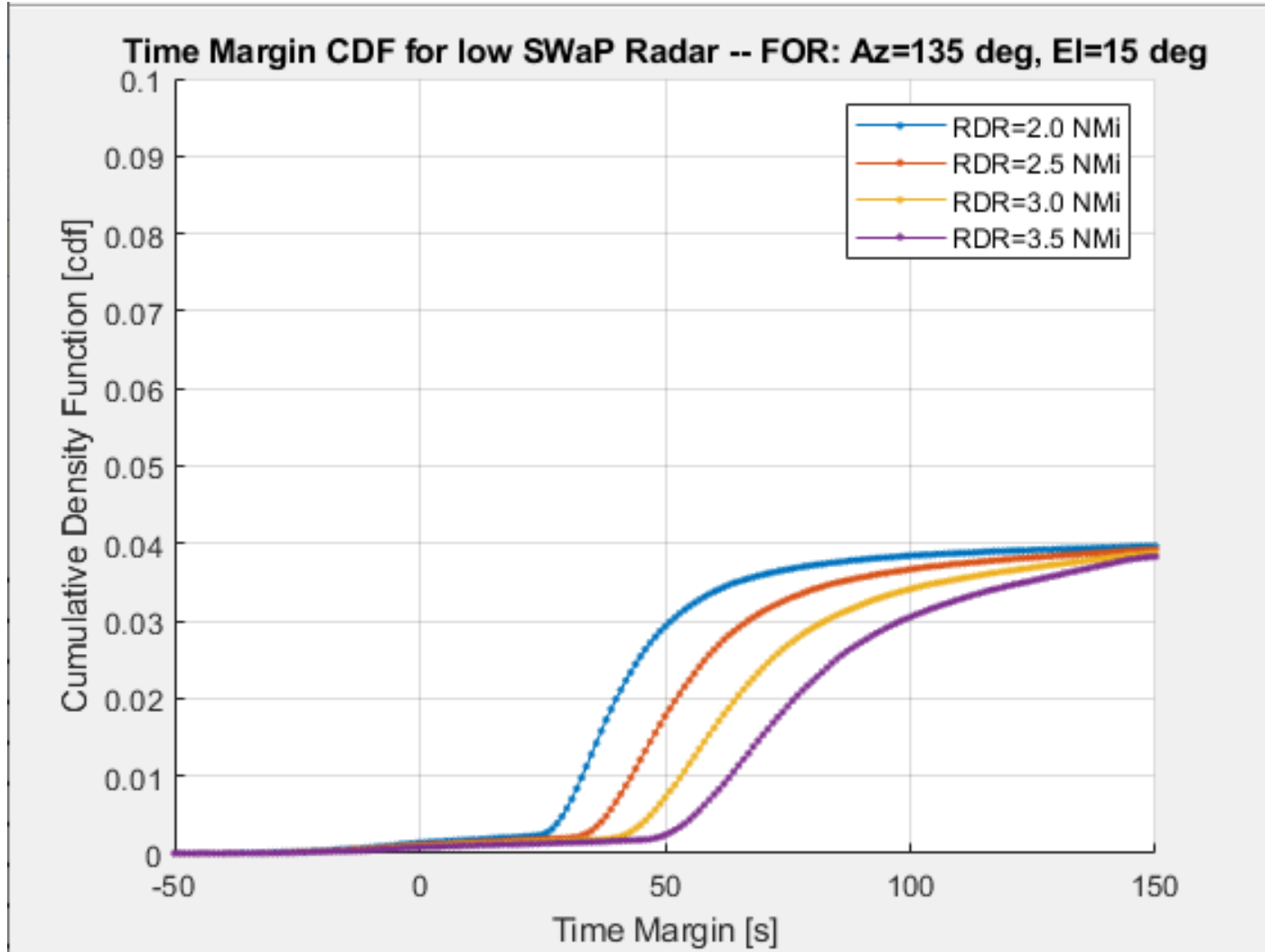
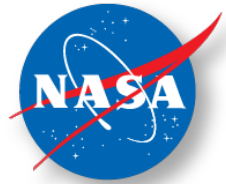
Fixed Elevation Time Margin Results



Fixed Elevation Time Margin Results



Fixed Elevation Time Margin Results



Config Summary

- Increased RDR has limited impact on pop-up encounters but improves overall time margin
- Increased AZ FoR reduces likelihood of pop-up and undetected intruders
 - Ownship Maneuver
 - Intruder overtake
 - Vertical Convergence



Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.0126	0.0120	0.0115	0.0110
AZ: 60 deg	0.0093	0.0088	0.0082	0.0078
AZ: 75 deg	0.0066	0.0060	0.0055	0.0051
AZ: 90 deg	0.0044	0.0039	0.0035	0.0032
AZ: 105 deg	0.0030	0.0025	0.0022	0.0019
AZ: 110 deg	0.0025	0.0021	0.0018	0.0016
AZ: 120 deg	0.0017	0.0014	0.0012	0.0010
AZ: 135 deg	0.0008	0.0006	0.0005	0.0004

Weighted probability that intruder is not detected at 10s after LoWC.

Results show that range (RDR) can be traded for increased azimuth (FoR) coverage.



Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.0237	0.0199	0.0189	0.0181
AZ: 60 deg	0.0191	0.0150	0.0141	0.0134
AZ: 75 deg	0.0150	0.0108	0.0100	0.0094
AZ: 90 deg	0.0116	0.0075	0.0068	0.0063
AZ: 105 deg	0.0093	0.0053	0.0047	0.0042
AZ: 110 deg	0.0086	0.0046	0.0040	0.0036
AZ: 120 deg	0.0074	0.0034	0.0029	0.0026
AZ: 135 deg	0.0058	0.0020	0.0016	0.0014

Weighted probability that intruder is not detected 30s before LoWC.

Results show that range (RDR) can be traded for increased azimuth (FoR) coverage.

Total Density of Encounters Impacted by 15s Requirement

Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.0110	0.0079	0.0074	0.0071
AZ: 60 deg	0.0097	0.0062	0.0059	0.0056
AZ: 75 deg	0.0084	0.0048	0.0045	0.0043
AZ: 90 deg	0.0071	0.0036	0.0033	0.0031
AZ: 105 deg	0.0064	0.0028	0.0025	0.0023
AZ: 110 deg	0.0061	0.0025	0.0022	0.0021
AZ: 120 deg	0.0057	0.0021	0.0018	0.0016
AZ: 135 deg	0.0051	0.0014	0.0011	0.0009

All (but one) configurations have < 1% of encounters impacted by 15s requirement.

Total Density of Encounters Impacted by 15s Requirement

Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.2760	0.1980	0.1860	0.1764
AZ: 60 deg	0.2430	0.1562	0.1471	0.1400
AZ: 75 deg	0.2099	0.1208	0.1117	0.1064
AZ: 90 deg	0.1786	0.0890	0.0823	0.0779
AZ: 105 deg	0.1596	0.0697	0.0627	0.0583
AZ: 110 deg	0.1528	0.0628	0.0560	0.0517
AZ: 120 deg	0.1428	0.0513	0.0445	0.0395
AZ: 135 deg	0.1266	0.0344	0.0284	0.0237

Weighted by LoWC.

Most configurations are higher than Phase 1 results (3.3% Weighted)

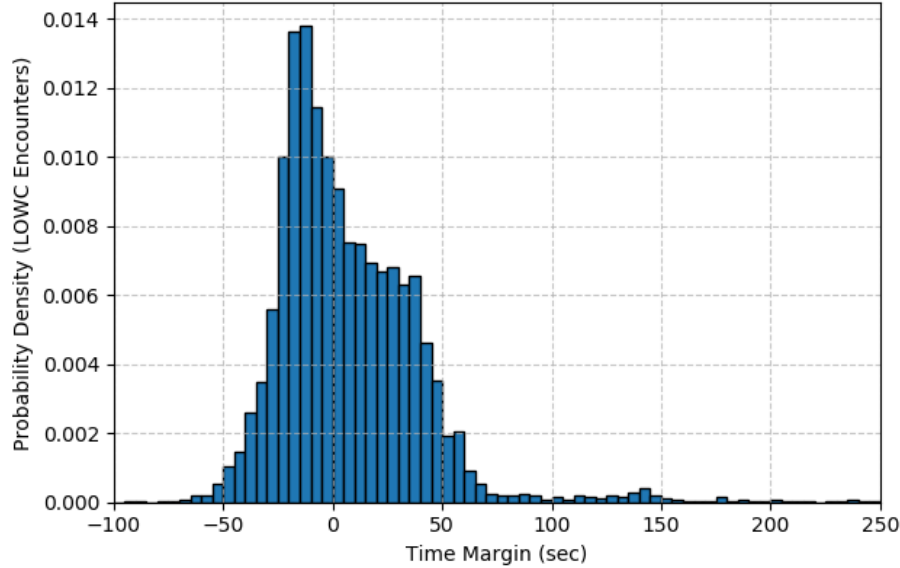


Pilot Response Time	10 sec	15 sec	25 sec
Prob. Of Popup Enc. (LOWC)	0.154	0.152	0.158
Prob. Affected by 15 sec Track Delay (LOWC)	0.065	0.061	0.055
Prob. Of Popup Enc. (All)	0.006	0.006	0.006
Prob. Affected by 15 sec Track Delay (All)	0.003	0.002	0.002
Initial FoR Candidate	Azimuth: +/- 110° Elevation: +/- 15°		

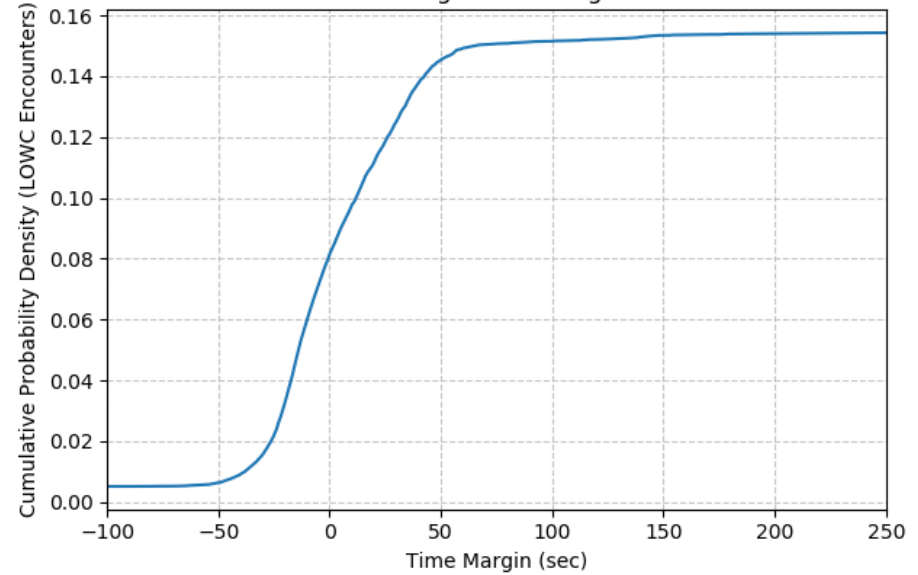
Candidate configurations are higher than Phase 1 results (3.3% Weighted)

$$t_{RDR} = t_{MIR} + 10 \text{ sec (Pilot Response)}$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR



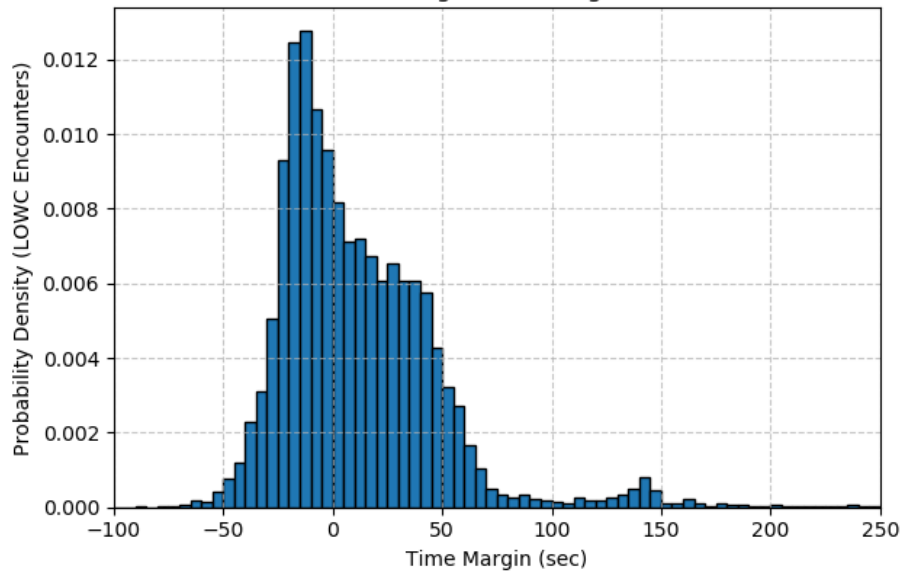
Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR



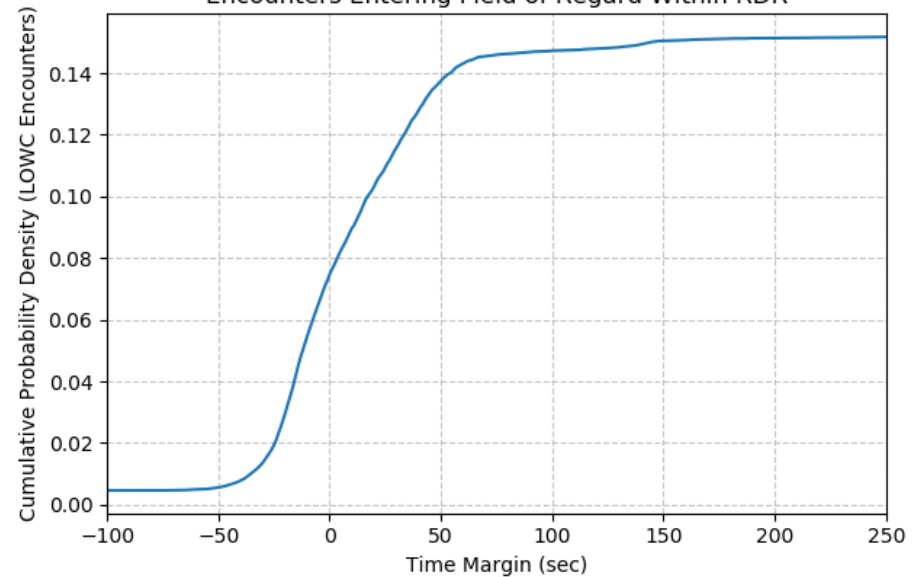


$$t_{RDR} = t_{MIR} + 15 \text{ sec (Pilot Response)}$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR

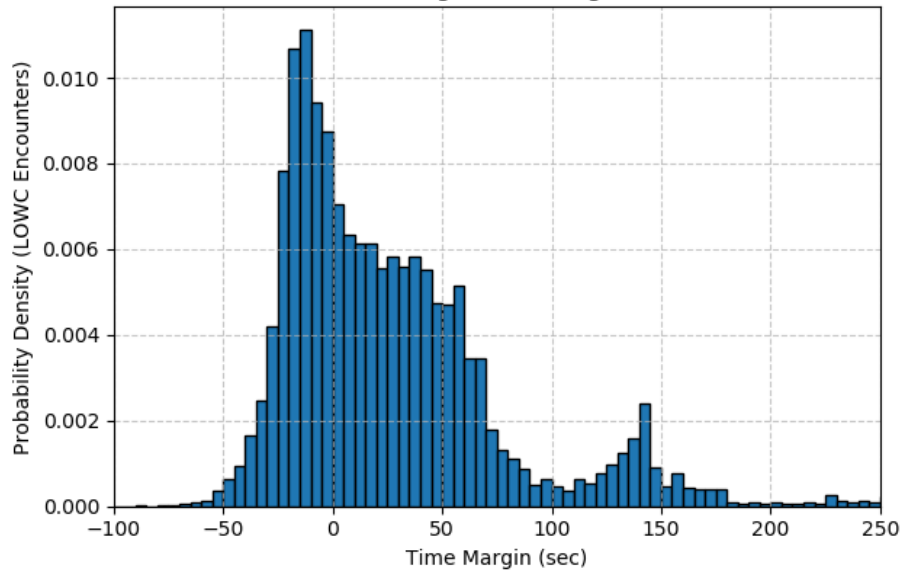


Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR

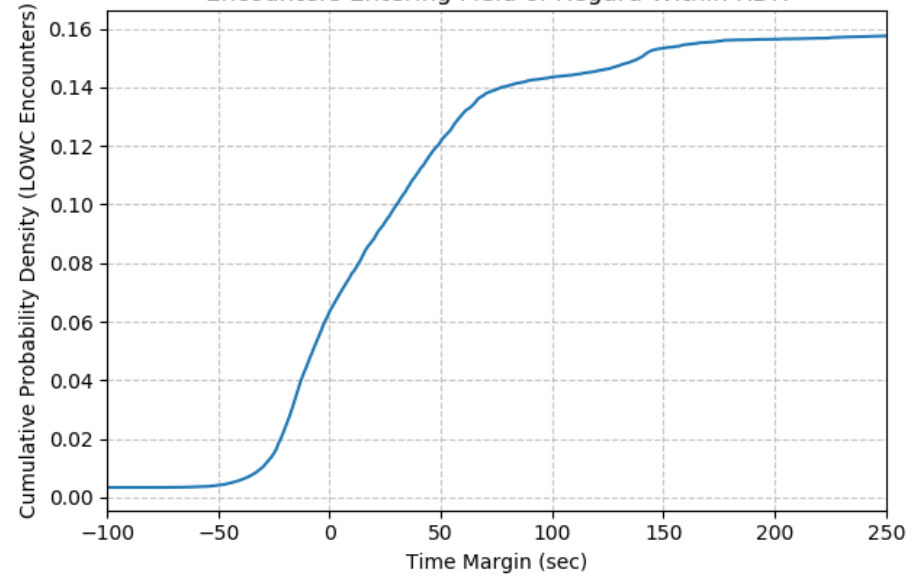


$$t_{RDR} = t_{MIR} + 25 \text{ sec (Pilot Response)}$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$
Encounters Entering Field of Regard Within RDR



Appendix D Analysis

Appendix D

Technical Objectives



- Validate RDR/FOR candidates against DAA alerting requirements
 - Minimum Average Alert Time
 - Late Threshold
- Compare the number of late detected intruders from various RDR/FOR configurations and alert times
- Categorize encounters (Ownship Maneuver, Intruder Overtake, Vertical Convergence, 'Enters FOR within RDR') to find how many late detected intruders are safe to ignore

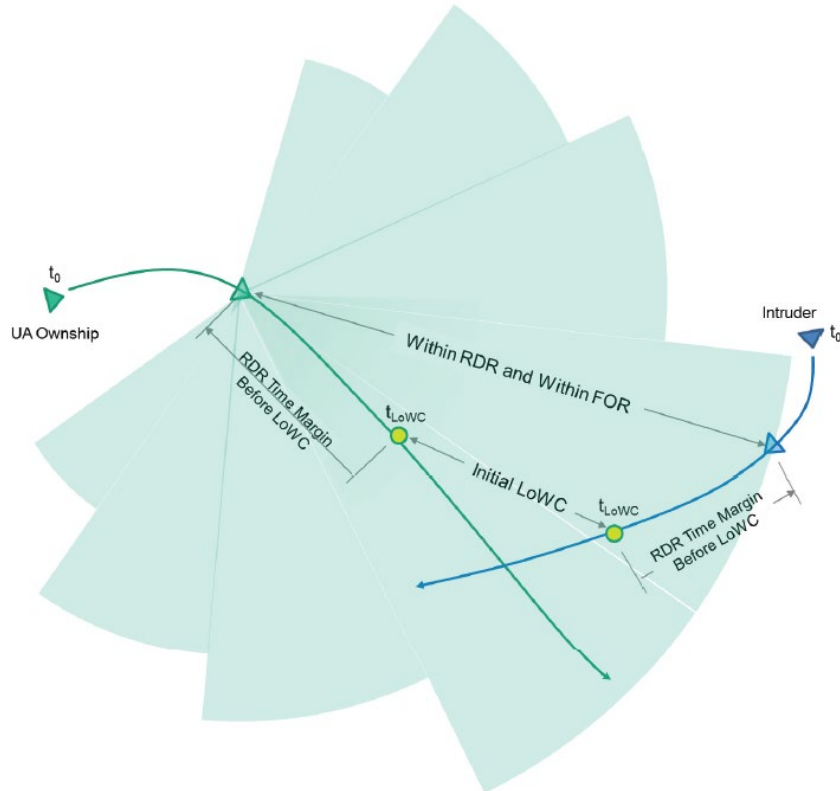


Figure D-1 RDR Time before LoWC against Corrective Alerting Requirements

From [1], DO-366 Appendix D.

- For each encounter, the RDR Time Margin is compared against DAA alerting requirements

$$t_{TM} = t_{LOWC} - t_{RDR}$$

- Time Margin Statistics are compared against alerting requirements:
 - On average, Time Margin should be greater than the **Minimum Average Alert Time**.
 - Time Margin should always be greater than the **Late Threshold**.



- Encounters were categorized to understand the detection / maneuver initiation responsibilities between ownship and intruder for small / negative time margin encounters
- Encounters with small/negative time margins are almost entirely “Pop-up” encounters
 - Ownship Maneuver
 - Intruder Overtake
 - Vertical Convergence
- For Ownship Maneuver and Intruder Overtake encounters, it is typically the intruder’s responsibility to see and avoid

Results

Configuration Summary

- Elevation FoR
5°, 10°, 15°, 20°
- Azimuth FoR
90°, 105°, 110°, 120°, 135°
- 3x Candidate RDR per Intruder Size:

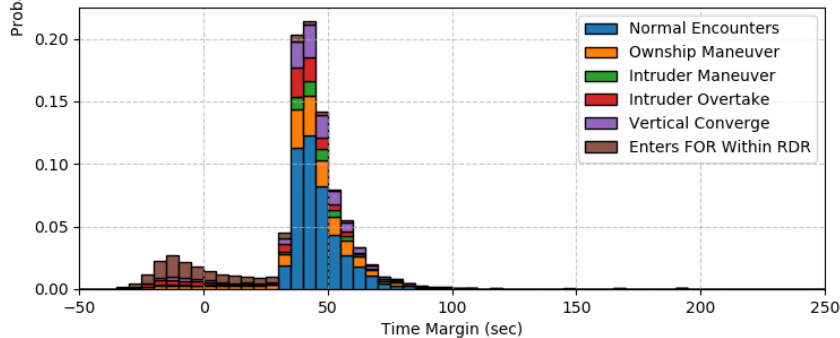
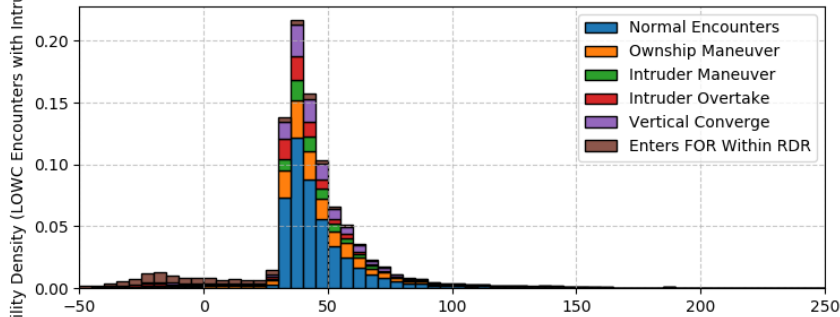
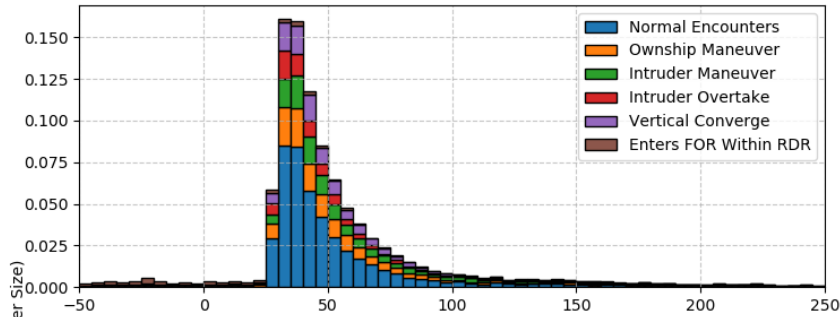
Intruder Size	Small			Medium			Large		
MIR	1.24 NMi			1.56 NMi			1.98 NMi		
Pilot Response Time	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec
RDR	1.63 NMi	1.87 NMi	2.45 NMi	2.03 NMi	2.27 NMi	2.8 NMi	2.57 NMi	2.86 NMi	3.44 NMi
RDR Correction Factors	RDR-Dependent								
Initial FoR Candidate	Azimuth: +/- 110° Elevation: +/- 15°								

Time Margin Distributions

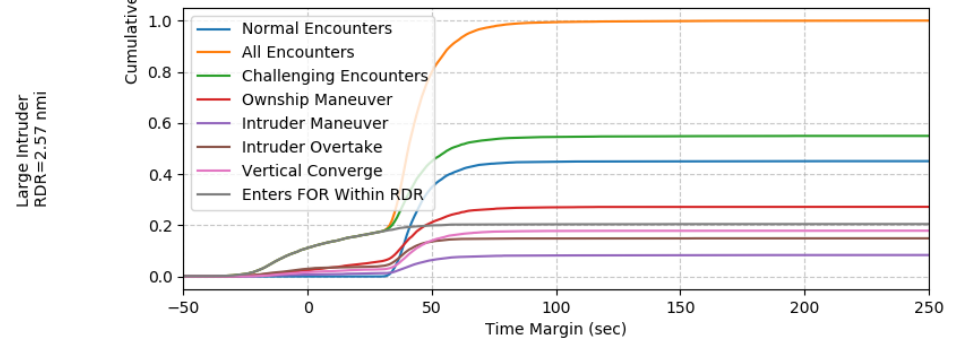
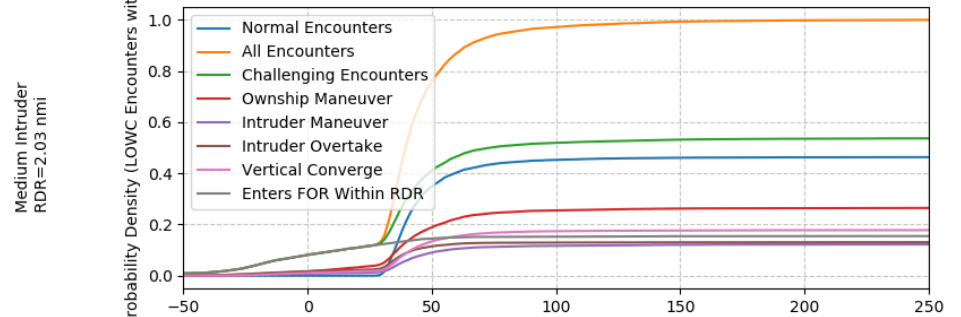
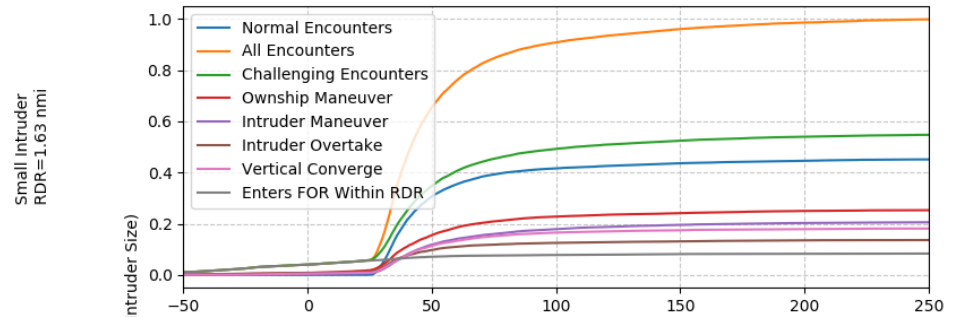


$$t_{RDR} = t_{MIR} + 10 \text{ sec} *$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



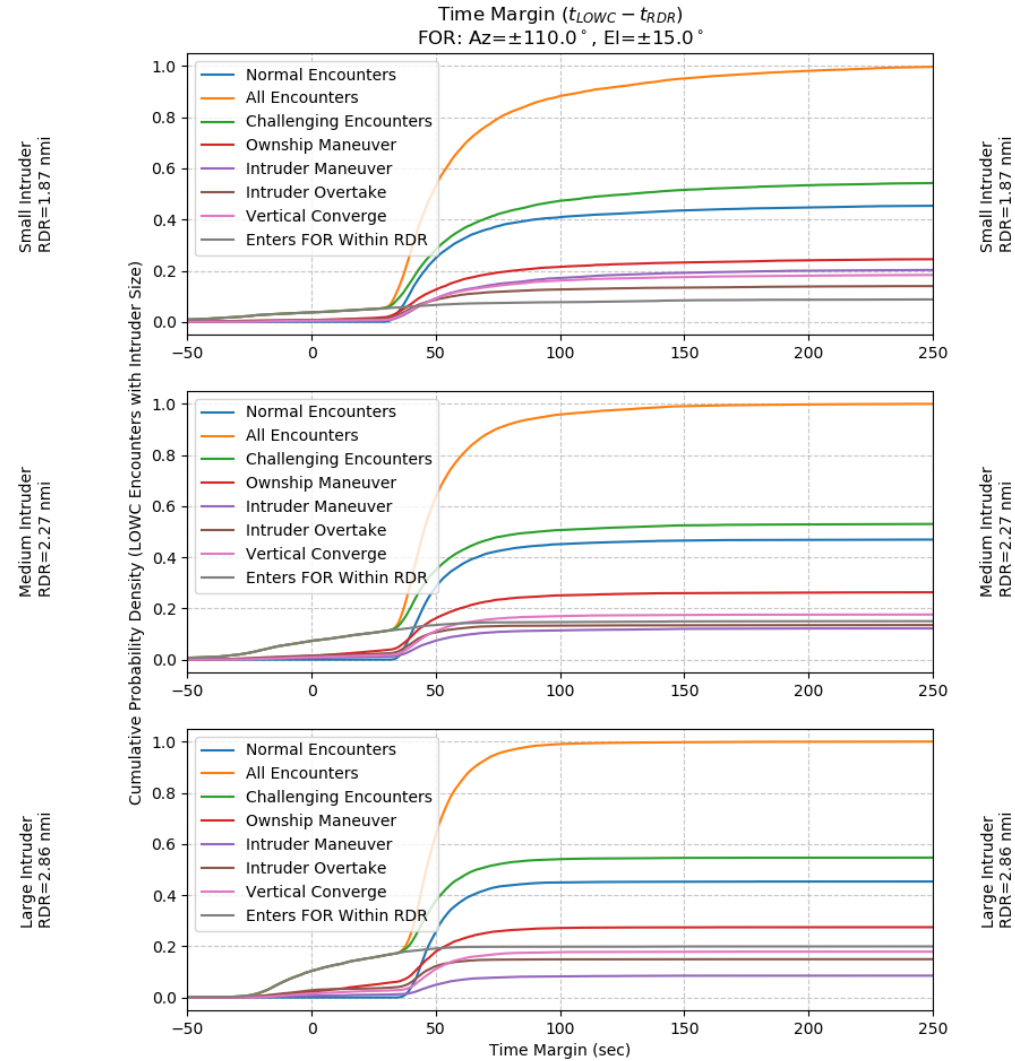
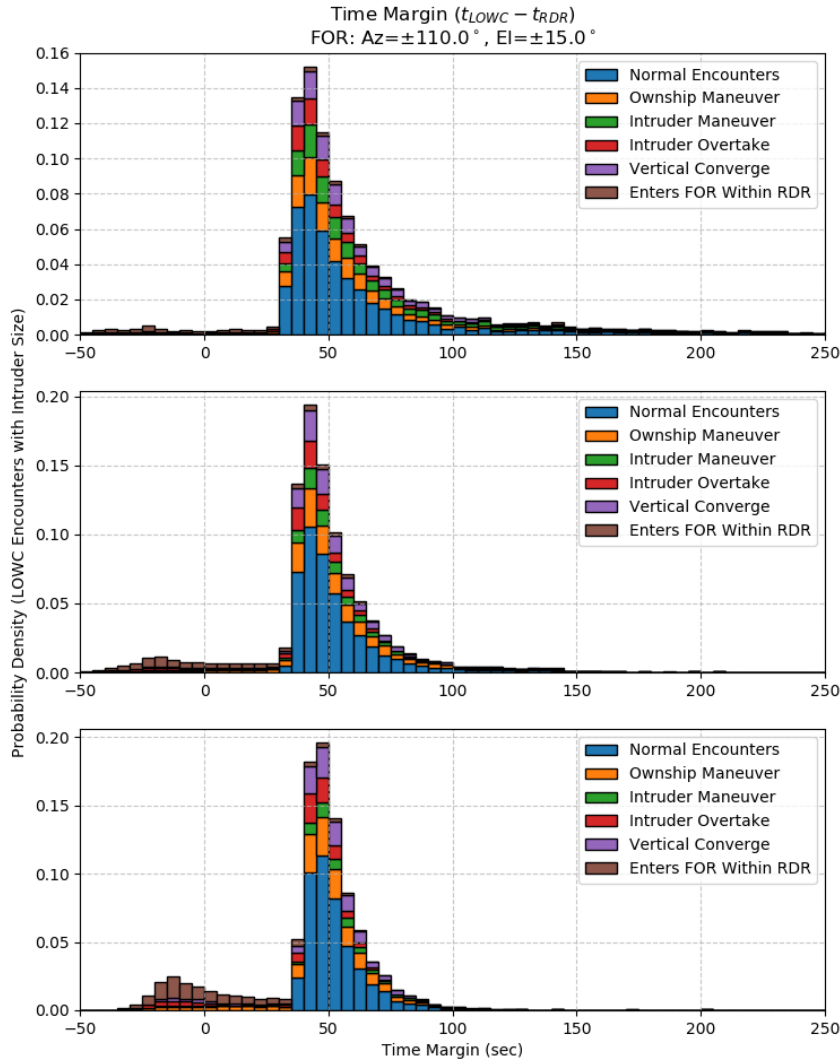
Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



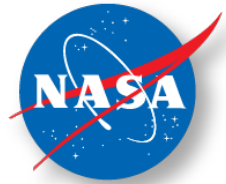
Time Margin Distributions



$$t_{RDR} = t_{MIR} + 15 \text{ sec} *$$

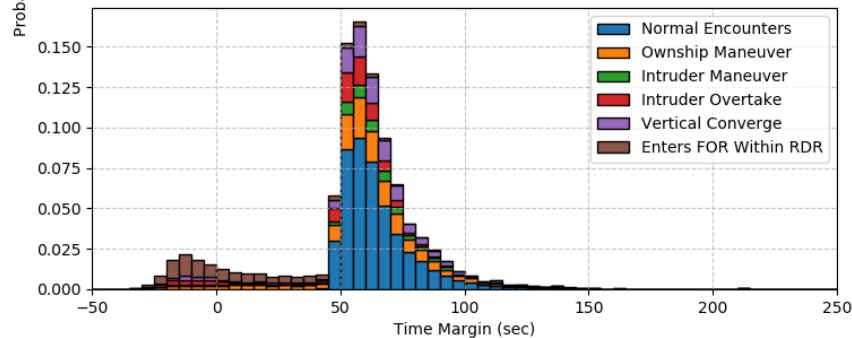
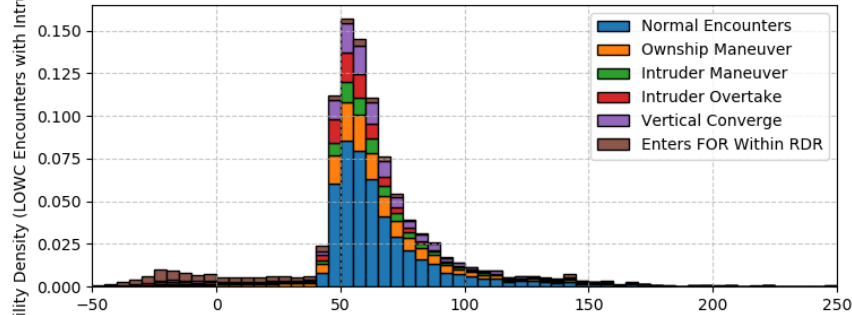
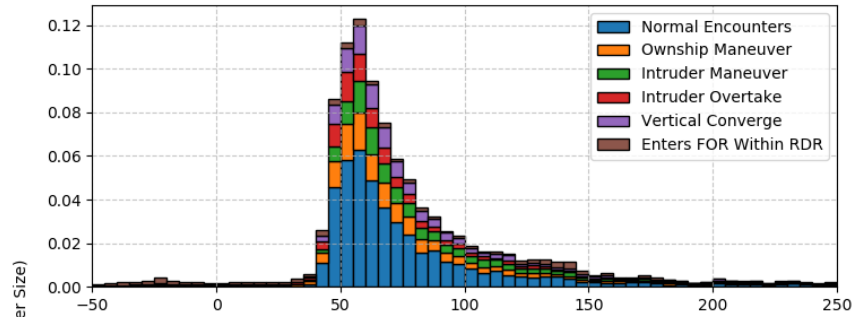


Time Margin Distributions

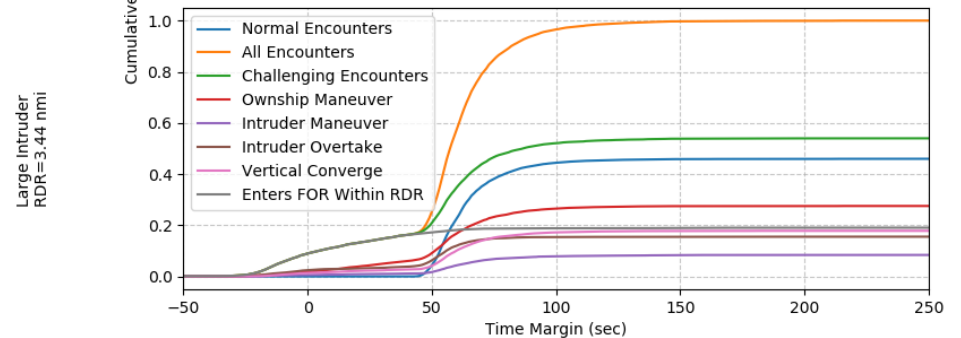
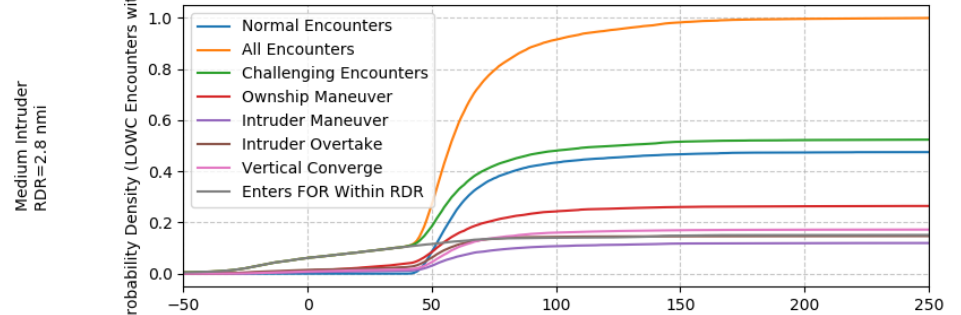
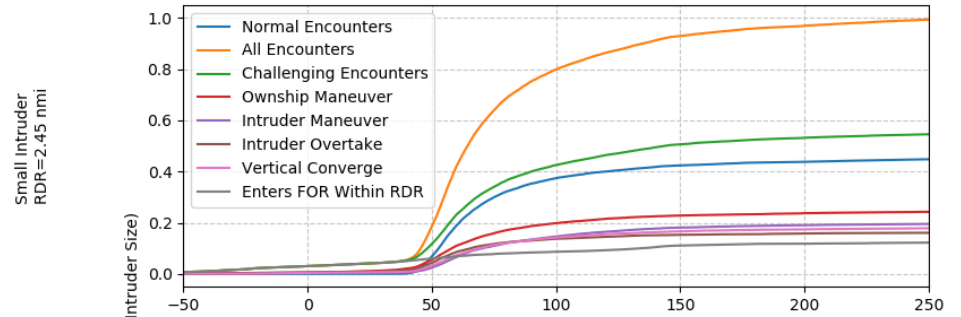


$$t_{RDR} = t_{MIR} + 25 \text{ sec} *$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$

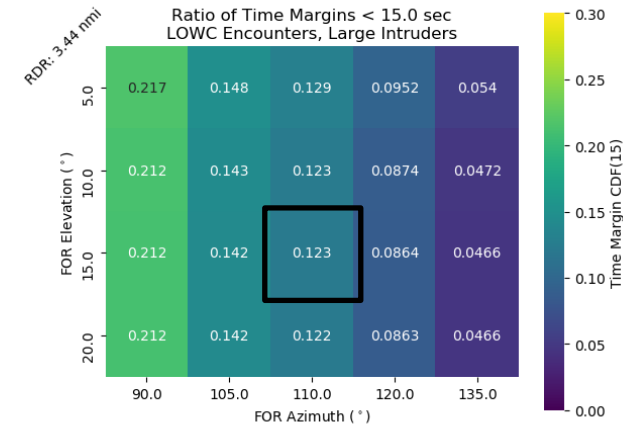
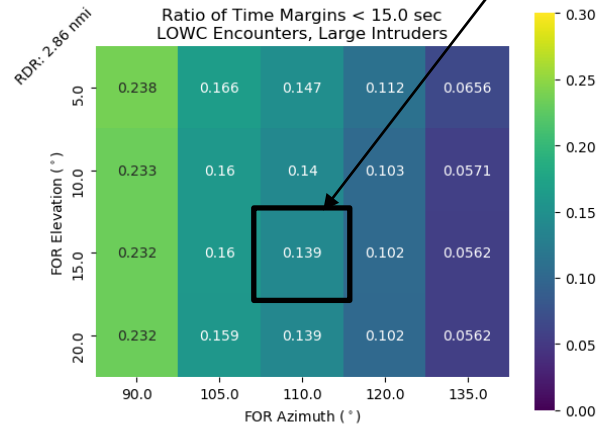
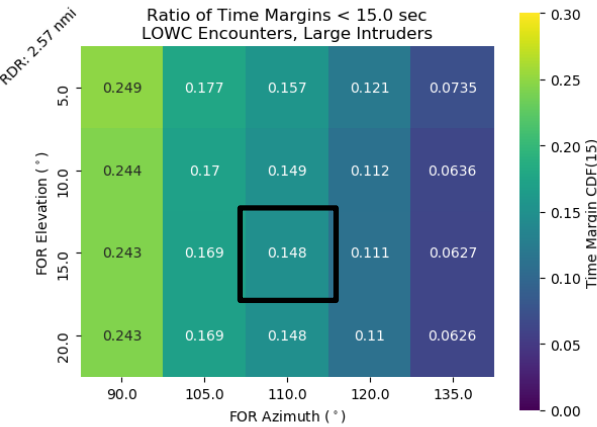


Time Margin CDF at (Warning) Late Threshold



Ratio of intruders detected after the Late Threshold (i.e. 15 sec before LOWC). Candidate low SWaP RDR/FOR configuration outlined.

Large Intruders



RDR = 2.57 NMi
($t_{RDR} = t_{MIR} + 10$ sec)

RDR = 2.86 NMi
($t_{RDR} = t_{MIR} + 15$ sec)

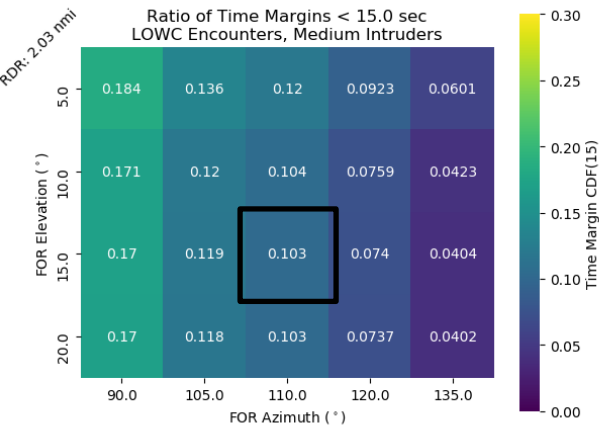
RDR = 3.44 NMi
($t_{RDR} = t_{MIR} + 25$ sec)

- Results for candidate low SWaP ATAR Configuration
 - FOR: +/- 110.0° Az, +/- 15.0° El
- Approximately **12 - 15%** of **LoWC encounters** with large intruders were detected after the late threshold
 - **0.48 - 0.58%** of **all encounters** with large intruders

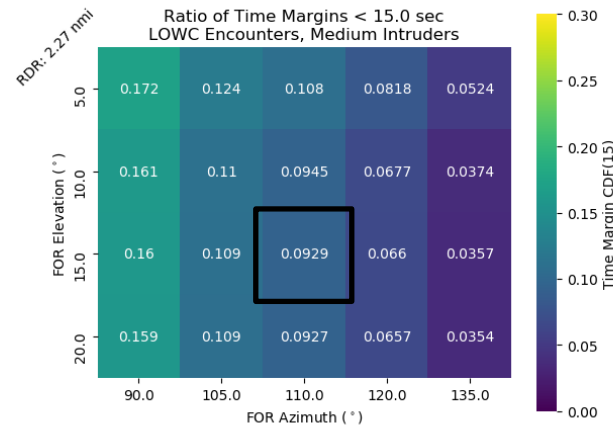
Time Margin CDF at (Warning) Late Threshold



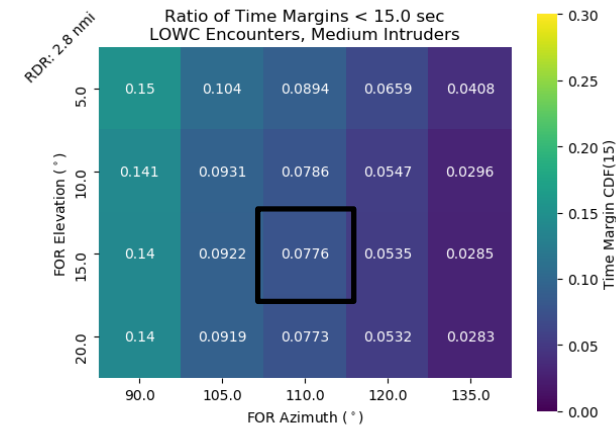
Medium Intruders



RDR = 2.03 NMi
($t_{RDR} = t_{MIR} + 10$ sec)



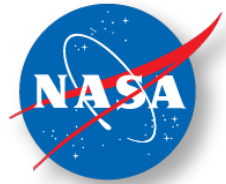
RDR = 2.27 NMi
($t_{RDR} = t_{MIR} + 15$ sec)



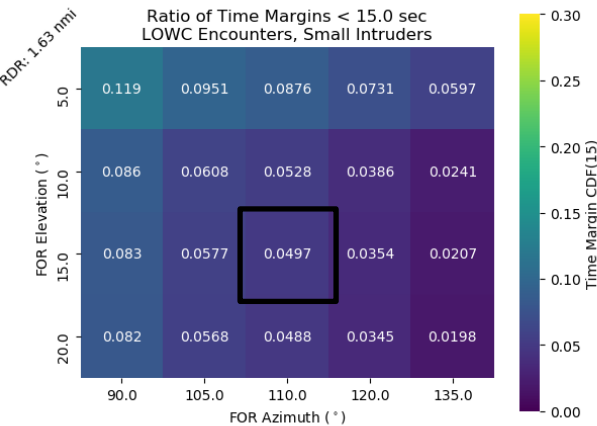
RDR = 2.8 NMi
($t_{RDR} = t_{MIR} + 25$ sec)

- Results for candidate low SWaP ATAR Configuration
 - FOR: +/- 110.0° Az, +/- 15.0° El
- Approximately 7.8 - 10% of LoWC encounters with medium intruders were detected after the late threshold
 - 0.31 - 0.42% of all encounters with medium intruders

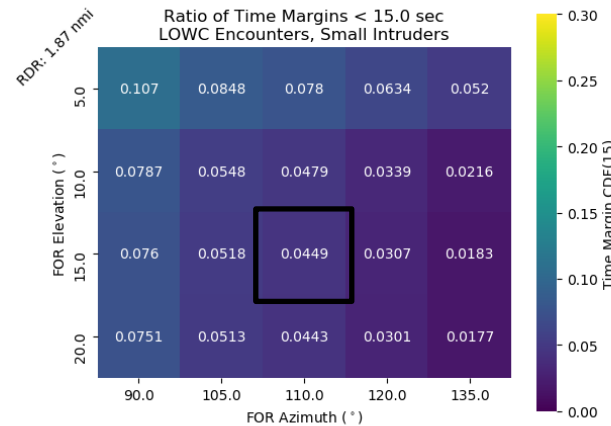
Time Margin CDF at (Warning) Late Threshold



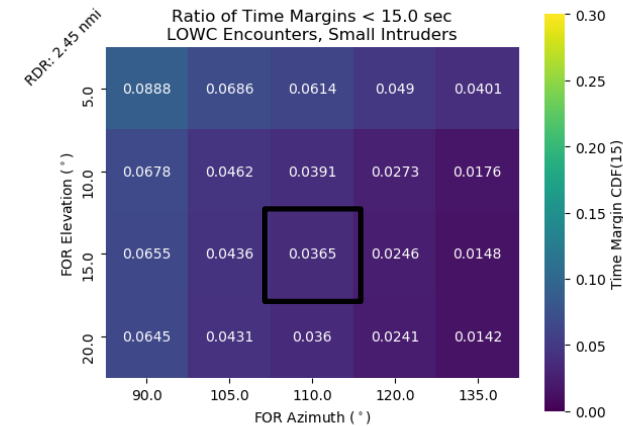
Small Intruders



RDR = 1.63 NMi
($t_{RDR} = t_{MIR} + 10$ sec)



RDR = 1.87 NMi
($t_{RDR} = t_{MIR} + 15$ sec)



RDR = 2.45 NMi
($t_{RDR} = t_{MIR} + 25$ sec)

- Results for candidate low SWaP ATAR Configuration
 - FOR: +/- 110.0° Az, +/- 15.0 ° El
- Approximately **3.7 - 5 %** of **LoWC encounters** with small intruders were detected after the late threshold
 - **0.15 - 0.21%** of **all encounters** with small intruders

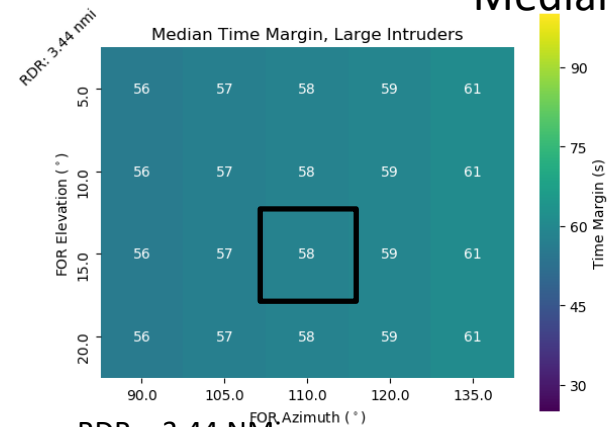
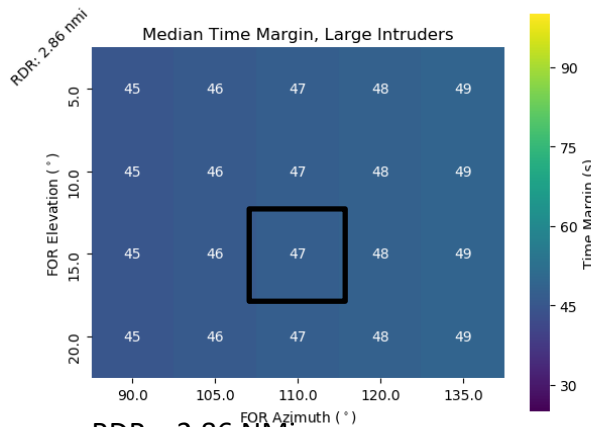
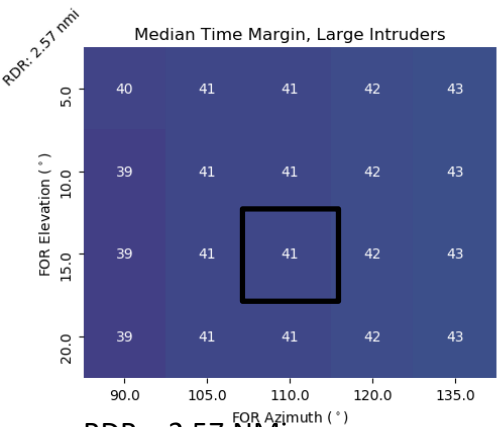
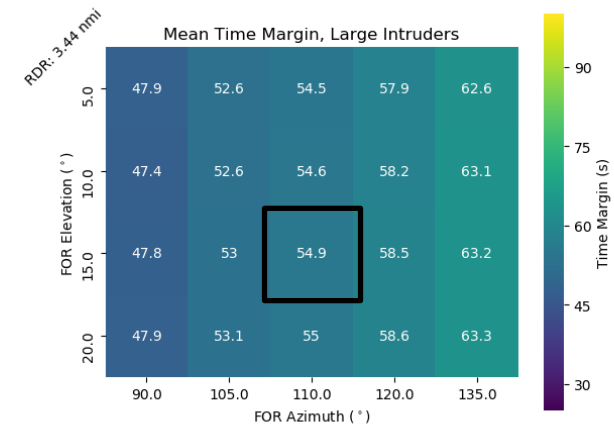
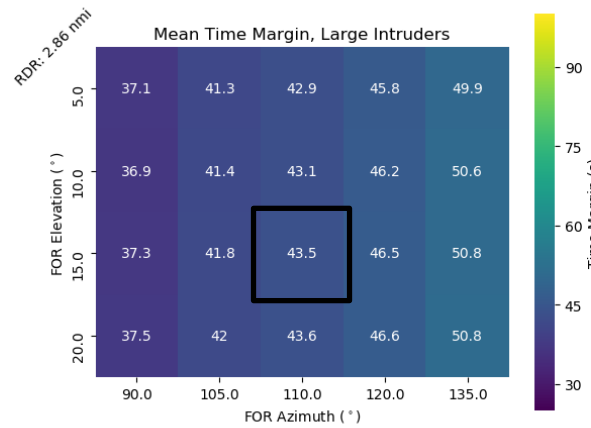
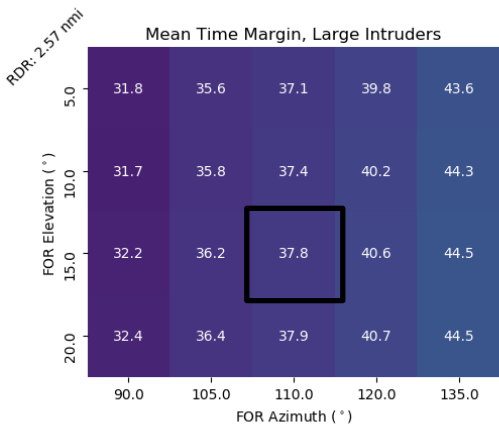
Time Margin Mean/Median vs. Minimum Average Alert Time



Large Intruders

Min. Avg. Alert Times: **55 sec** (Corrective), **25 sec** (Warning)

Mean



Median

RDR = 2.57 NMI
($t_{RDR} = t_{MIR} + 10$ sec)

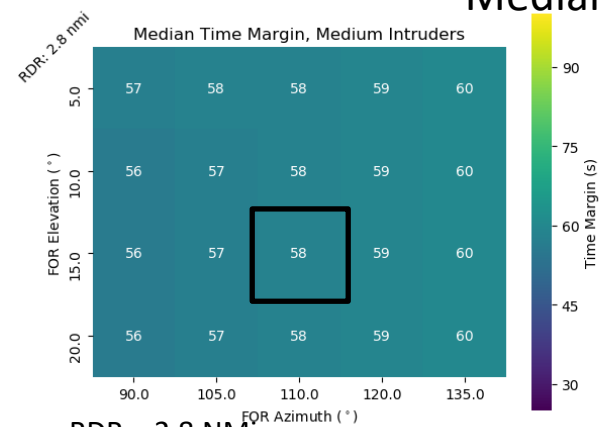
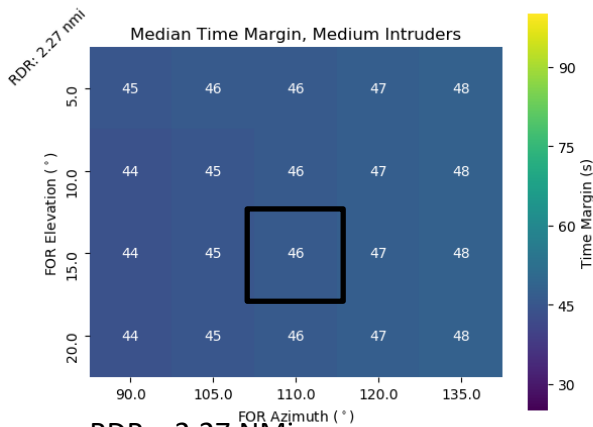
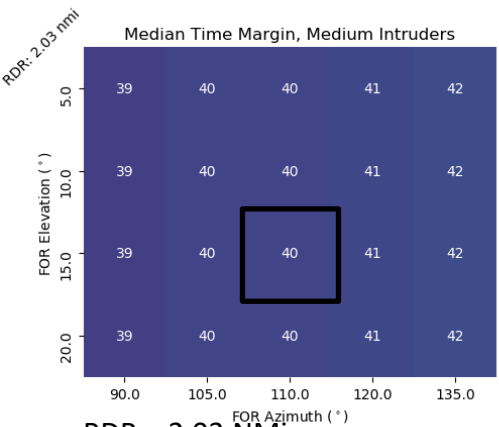
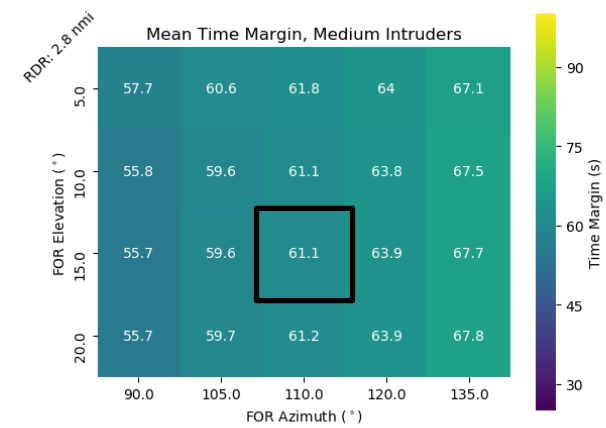
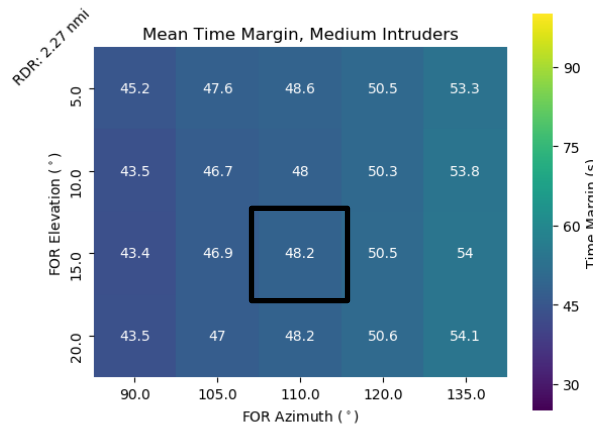
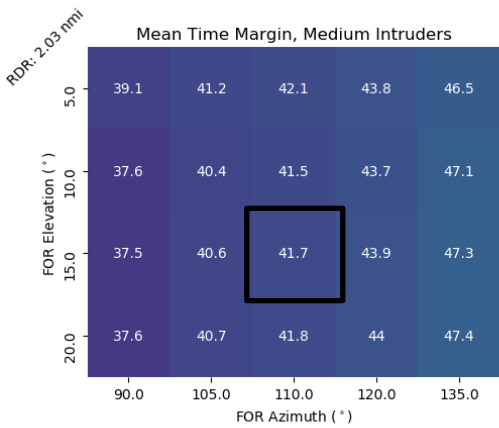
RDR = 2.86 NMI
($t_{RDR} = t_{MIR} + 15$ sec)

RDR = 3.44 NMI
($t_{RDR} = t_{MIR} + 25$ sec)

Time Margin Mean/Median vs. Minimum Average Alert Time



Medium Intruders Min. Avg. Alert Times: 55 sec (Corrective), 25 sec (Warning) Mean



RDR = 2.03 NMI
($t_{RDR} = t_{MIR} + 10$ sec)

RDR = 2.27 NMI
($t_{RDR} = t_{MIR} + 15$ sec)

RDR = 2.8 NMI
($t_{RDR} = t_{MIR} + 25$ sec)

Median

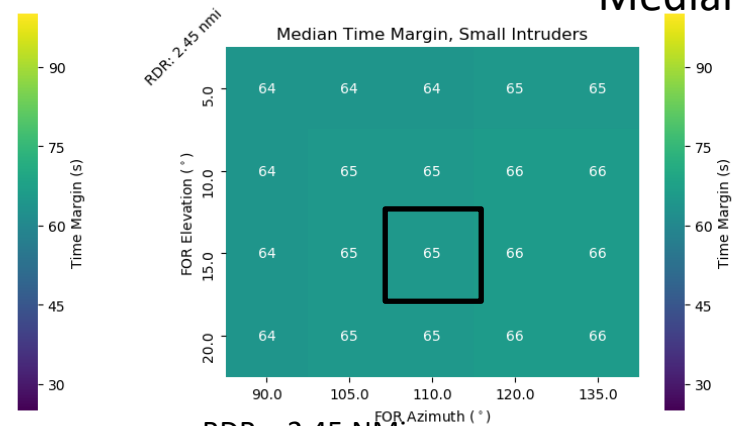
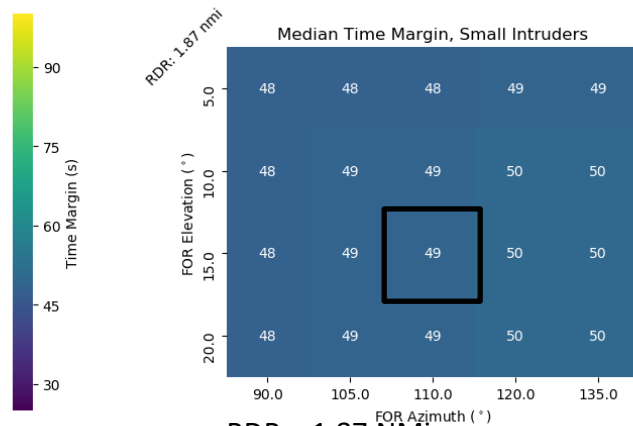
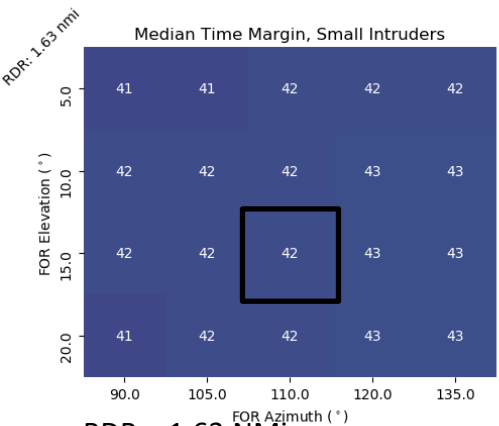
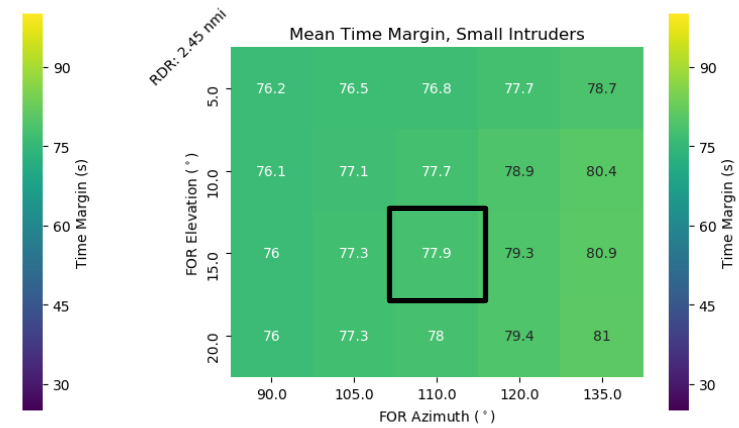
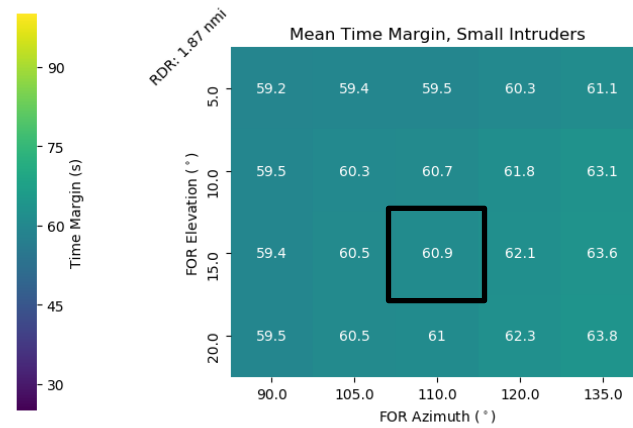
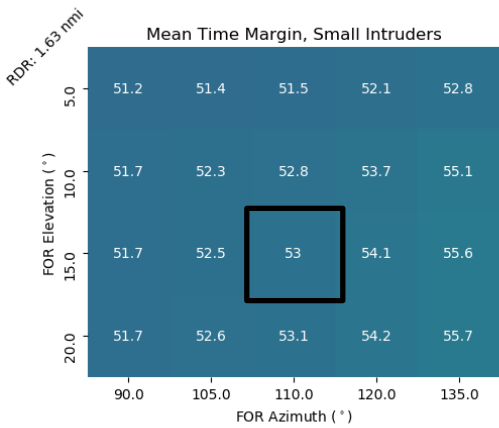
Time Margin Mean/Median vs. Minimum Average Alert Time



Small Intruders

Min. Avg. Alert Times: **55 sec** (Corrective), **25 sec** (Warning)

Mean



RDR = 1.63 NMI
($t_{RDR} = t_{MIR} + 10$ sec)

RDR = 1.87 NMI
($t_{RDR} = t_{MIR} + 15$ sec)

RDR = 2.45 NMI
($t_{RDR} = t_{MIR} + 25$ sec)

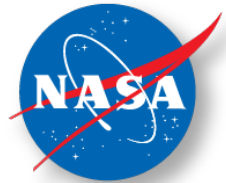
Median

Summary of Time Margin Statistics vs. Alert Requirements



Intruder Size	Small			Medium			Large		
	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec
Pilot Response Time	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec	10 sec	15 sec	25 sec
RDR	1.63 NMi	1.87 NMi	2.45 NMi	2.03 NMi	2.27 NMi	2.8 NMi	2.57 NMi	2.86 NMi	3.44 NMi
Mean TM	53	60.9	77.9	41.7	48.2	61.1	37.8	43.5	54.9
Median TM	42	49	65	40	46	58	41	47	58
TM CDF(15s) LOWC Enc.	0.050	0.045	0.037	0.103	0.093	0.078	0.148	0.139	0.123
TM CDF(15s) All Enc.	0.002	0.002	0.002	0.004	0.004	0.003	0.006	0.005	0.005

- FOR Configuration: Az = 110 deg, El = 15 deg
- All average Time Margins are > than the (**Warning**) Minimum Average Alert Time: 25 sec.
- The cases with 25 sec pilot response time, had average Time Margins >= the (**Corrective**) Minimum Average Alert Time: 55 sec (highlighted).



- Draft Appendix Writeup: 11/01/2019
- External Review Completed: 11/29/2019
- Final Draft Completed: 12/31/2019



- Want external feedback from committee members on Appendix Writeups
 - Volunteers?

Backup

References



- [1] RTCA Inc., "Minimum Operation Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance, DO-366," 2017.
- [2] RTCA Inc., "Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems, DO-365," 2017.

From [1] ATAR MOPS DO-366, Appendix C:

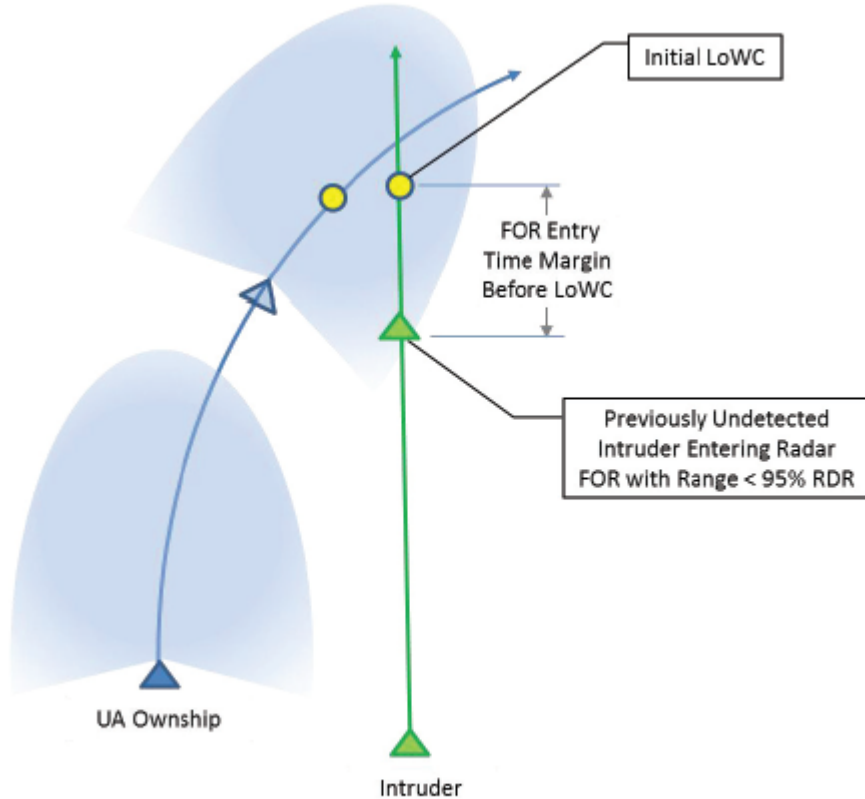


Figure C-2 Capturing the FOR Entry Time Margin

- Pop-Up encounters can be the result of **Ownship Maneuver**, **Intruder Overtake**, and **Vertical Convergence** encounter geometries.
- Appendix C addresses the probability...
 - of Pop-Up encounters
 - that a 15 sec delay in track accuracy prevents maintenance of LOWC, in Pop-Up encounters.*

*See [1] 2.2.7.22 for the 15 sec track accuracy requirement.

- For a good FOR / RDR candidate, we want to see:
 - ✓ Mean and Median RDR Time Margin is > 55 sec, (Corrective) Minimum Average Time of Alert.
 - ✓ The Time Margin CDF is low at 20 sec, (Corrective) Late Threshold, i.e., there are very few encounters with Time Margins less than 20 sec.
 - ✓ The Time Margin CDF is very low at 15 sec, (Warning) Late Threshold.
 - ✓ Of the encounters that do have a Time Margin < Late Threshold, most of them can be classified as ownship maneuver, intruder overtake, or vertical convergence.

Table 2-21 Parameters for DAA Alerting Requirements

Alert Type →		Preventive Alert	Corrective Alert	Warning Alert
Alert Level →		Caution	Caution	Warning
Hazard Zone Alert Times	Minimum Average Time of Alert (Seconds)	55	55	25
	Late Threshold (THR_{Late}) (Seconds)	20	20	15
	Early Threshold (THR_{Early}) (Seconds)	75	75	55

From [2], DO-365 2.2.4.3.4 (zones omitted).

Inputs:

Az FOR: +/- 90, 105, 110, 120, 135 °

EI FOR: +/- 5, 10, 15, 20 °

RDR: 2.0, 2.5, 3.0, 3.5 NMi

Minimum Average Alert Time (Warning): 25 sec

Late Threshold (Warning): 15 sec

RDR Correction Factors*:

Intruder Size	$0^\circ < \theta \leq 30^\circ$	$30^\circ < \theta \leq 60^\circ$	$60^\circ < \theta \leq 90^\circ$	$90^\circ < \theta \leq 135^\circ$
Small	1.0	0.92	0.68	0.48
Medium	1.0	0.94	0.79	0.52
Large	1.0	0.94	0.86	0.63

Outputs: Weighted RDR Time Margin Statistics:

PDF: The simplest way to visualize the Time Margin Distribution. Shown as a histogram.

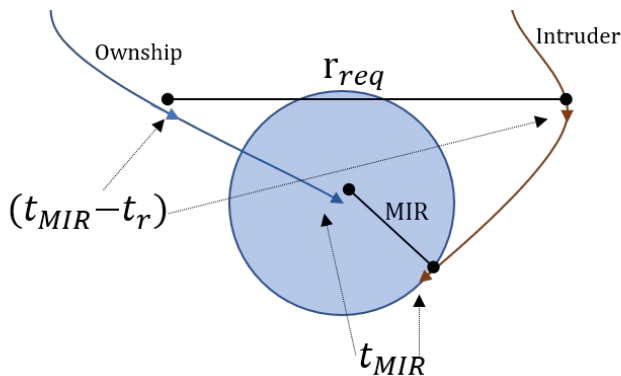
CDF: Shows probability of undetected intruders at Late Threshold, or other times before LOWC. Shown as a line plot.

Mean: Compared to the Min Average Alert Time.

Median: Compared to the Min Average Alert Time, but less affected by outliers.

*These are the mean of each correction factor from AAG's analysis 8/22/2019, using a 25 sec pilot response time .

- RDR is validated with range statistics, based on MIR.
- The Required Range is the range at t_r seconds before t_{MIR} .



t_{MIR} : The time at which the intruder is within the Maneuver Initiation Range (MIR) .

t_r : The Pilot Response and Air-Traffic Control Coordination Time.

r_{req} : The required range.

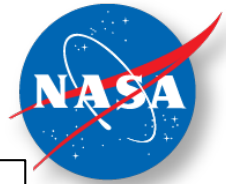
$$r_{req} = r(t_{MIR} - t_r)$$

- This approach differs from Phase 1 analysis in which the required range was defined as 40 sec before LOWC. 40 sec = DAA Execution Threshold (DET) 15 sec + Pilot Response and ATC coordination time 25 sec.*
- Previously: $r_{req} = r(t_{LOWC} - t_{DET} - t_r)$

Time Margin Distributions

- The next three slides show the low side of the Time Margin distributions, for the three candidate RDR sets.

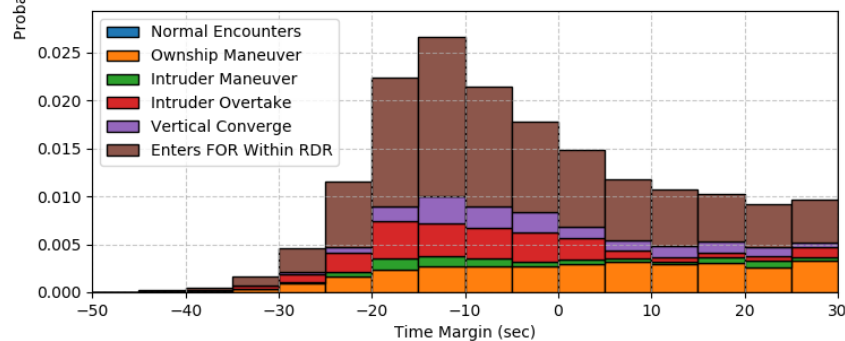
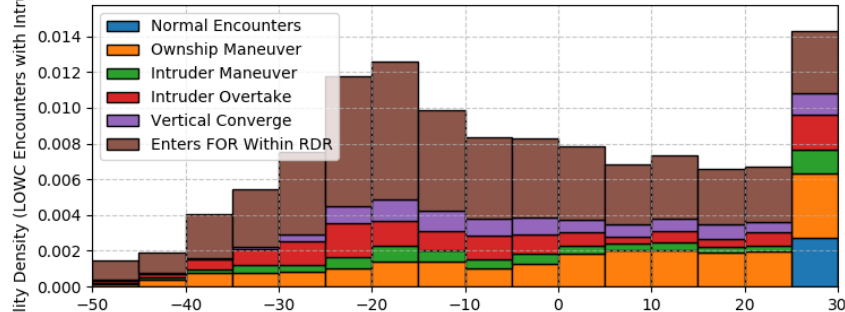
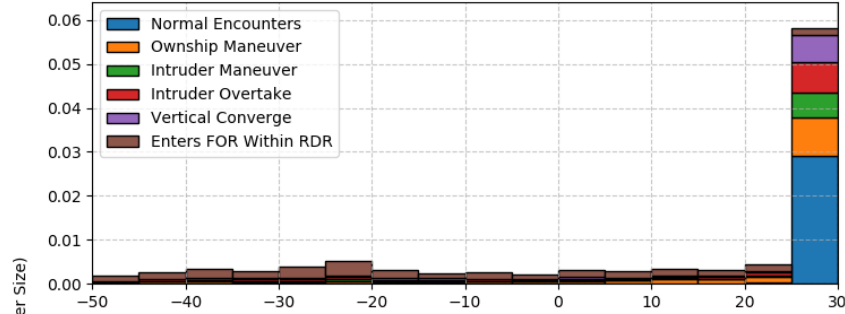
Time Margin Distributions



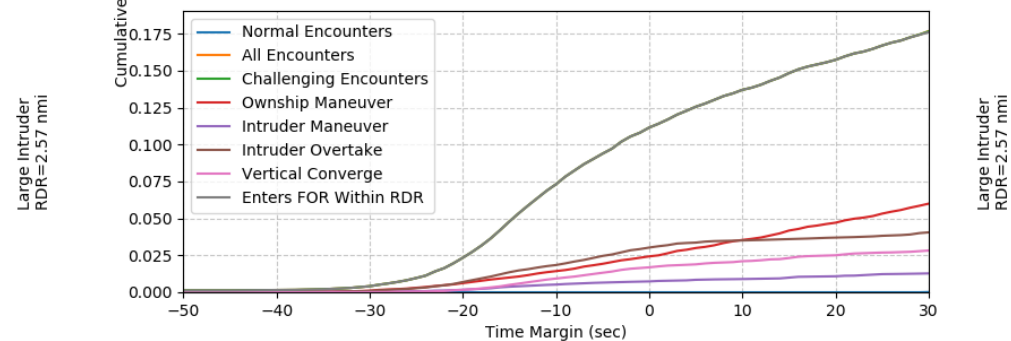
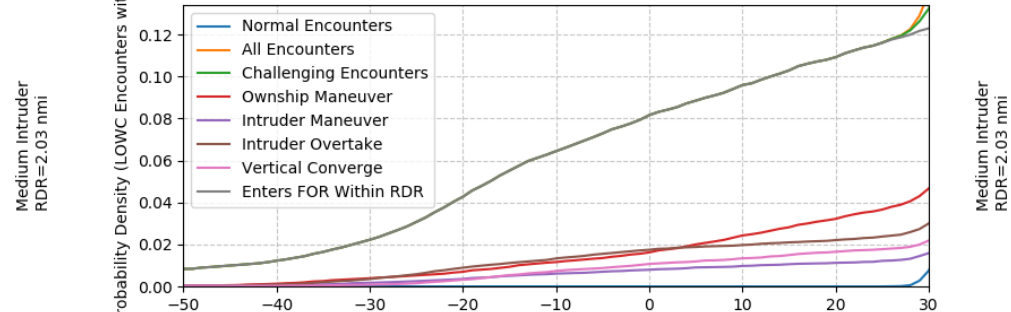
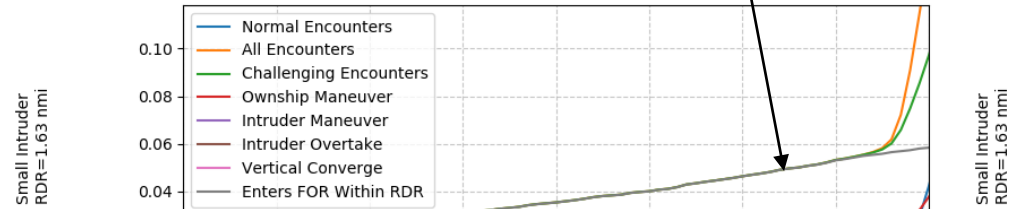
$$t_{RDR} = t_{MIR} + 10 \text{ sec}$$

All detections <15 sec (i.e. after the late Threshold) "Entered FOR Within RDR"

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$

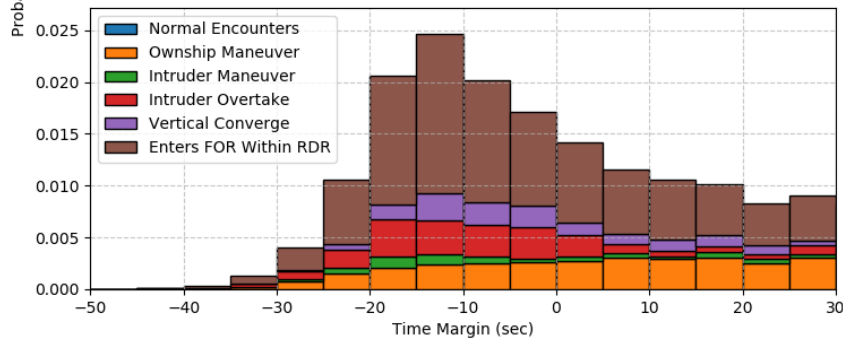
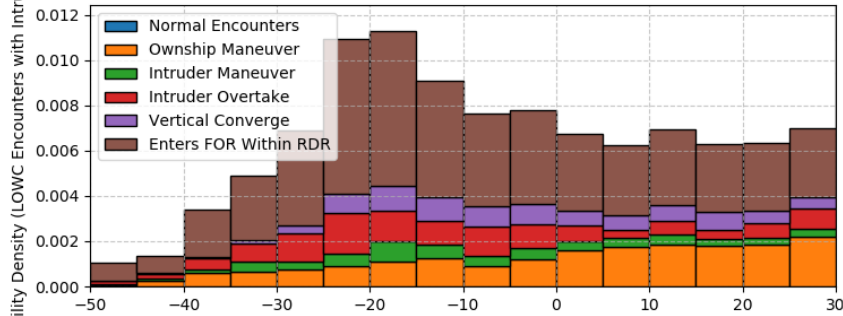
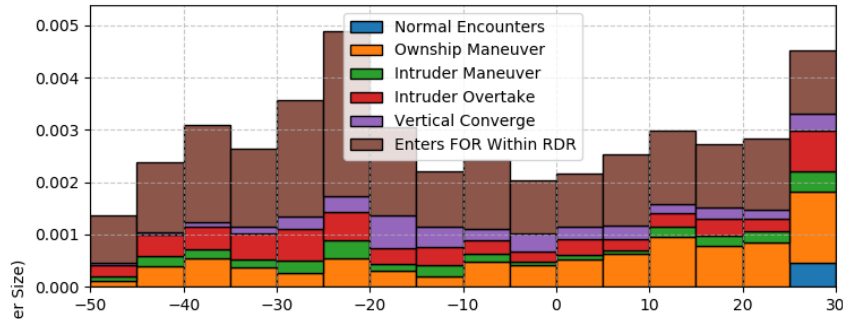


Time Margin Distributions

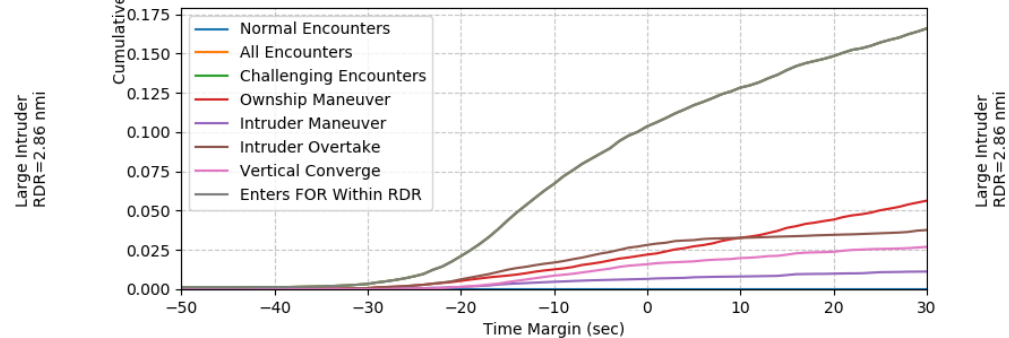
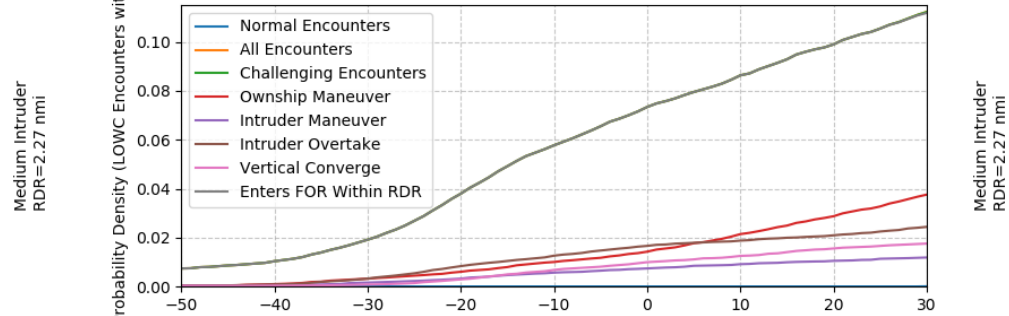
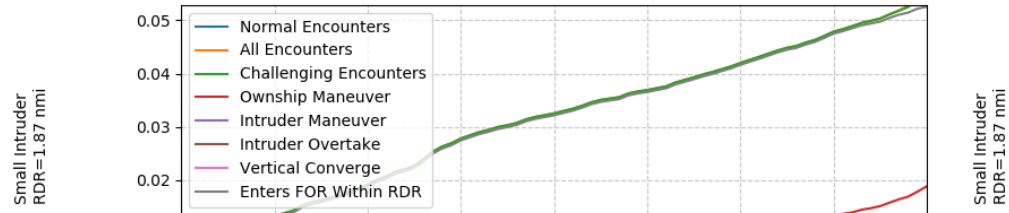


$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$

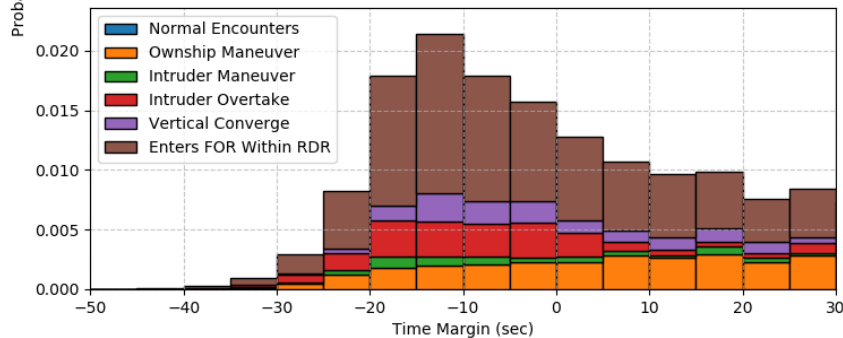
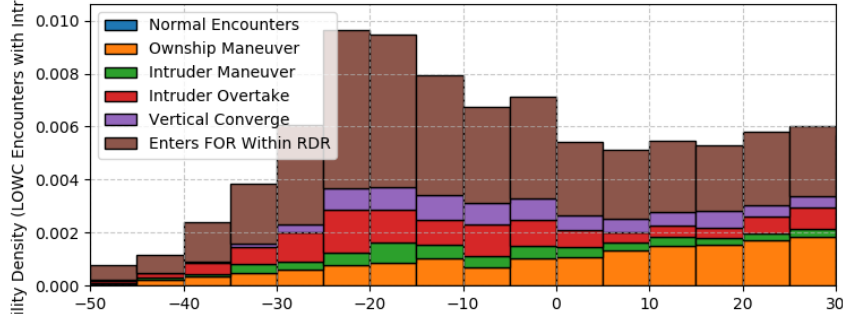
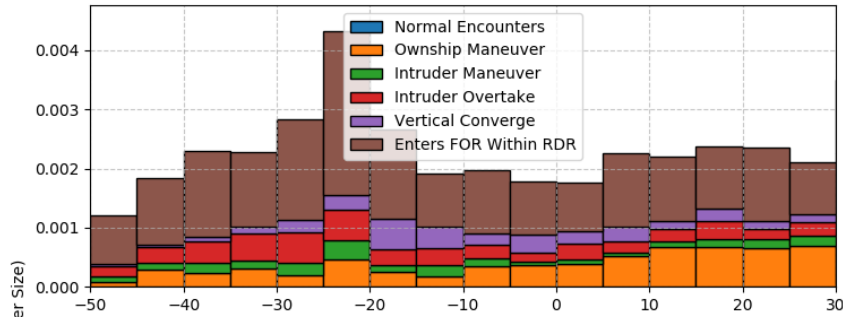


Time Margin Distributions

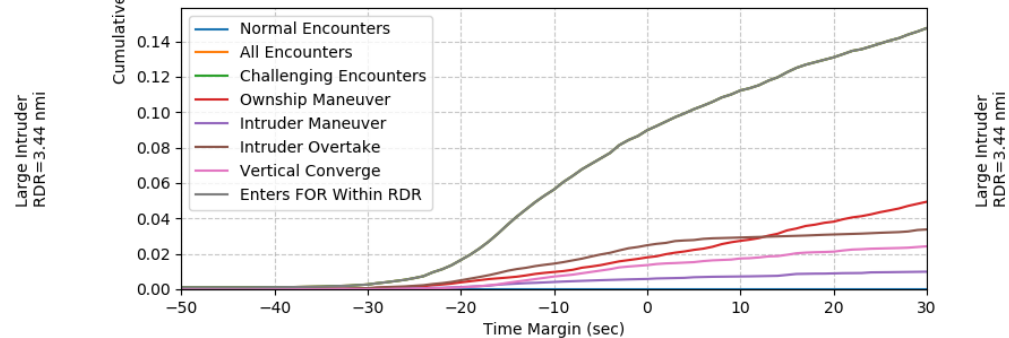
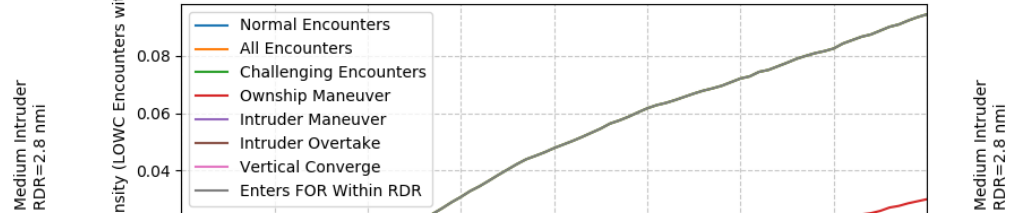
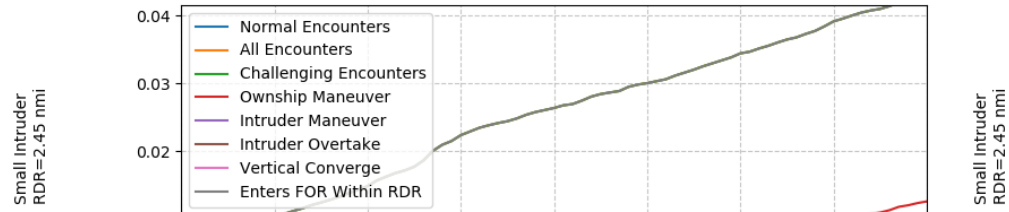


$$t_{RDR} = t_{MIR} + 25 \text{ sec}$$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$





Inputs:

MIR (per intruder size): 1.24 NMi (small), 1.56 NMi (medium), 1.98 NMi (large).*

Pilot Response / ATC Coordination Time: 25 sec

Outputs: Weighted Required Range Statistics

PDF: Shows the required range distributions as histograms per intruder size.

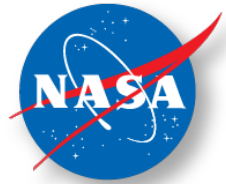
CDF: Shows the probability of detecting intruder at 25 sec before reaching MIR.

*These are the largest MIR values per intruder size, from AAG's results 8/22/2019 .



- The next three slides show the affect of increasing Azimuth Coverage on Time Margin.

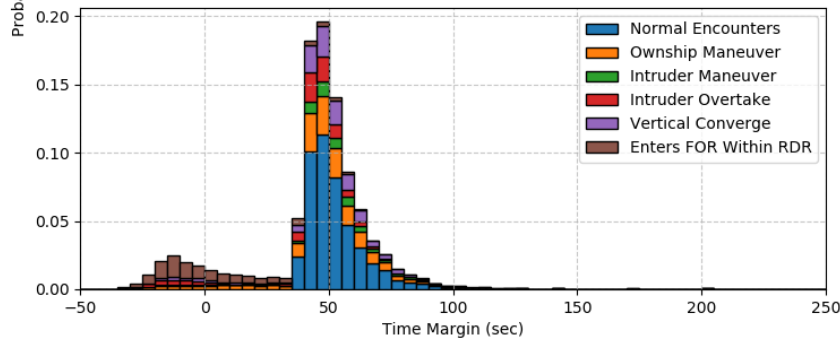
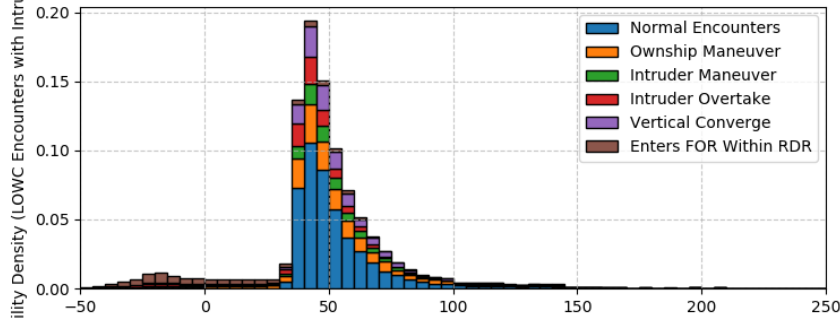
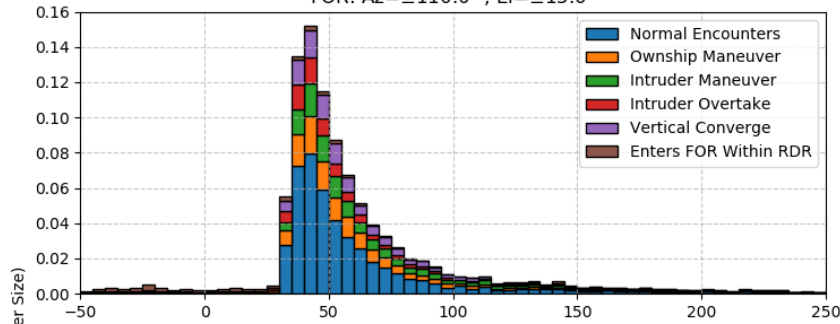
Time Margin Distributions



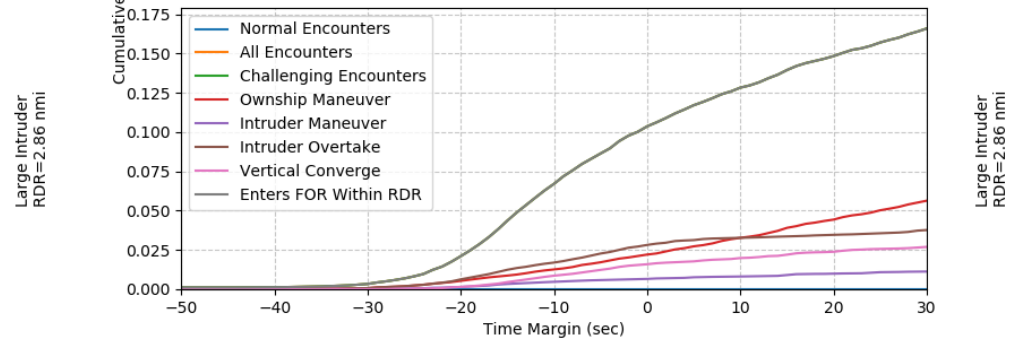
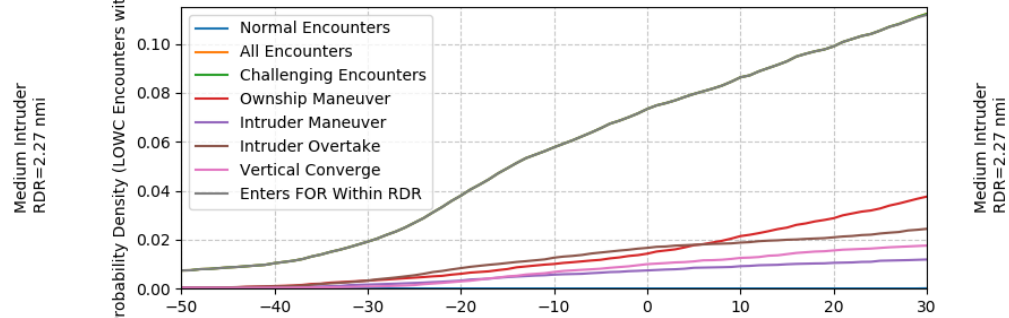
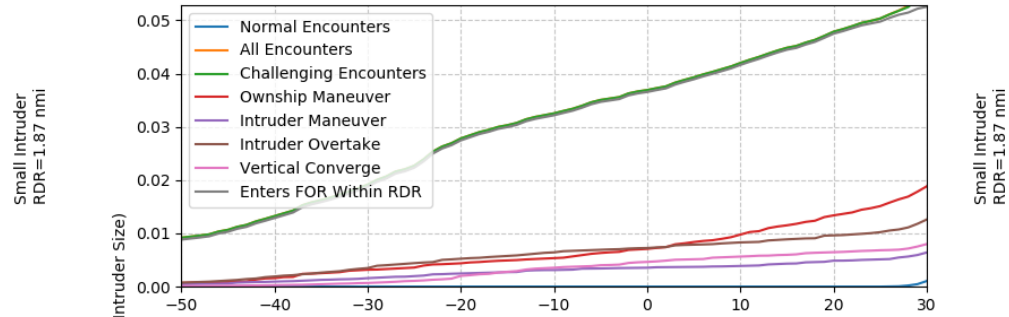
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

Az Coverage: $\pm 110.0^\circ$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



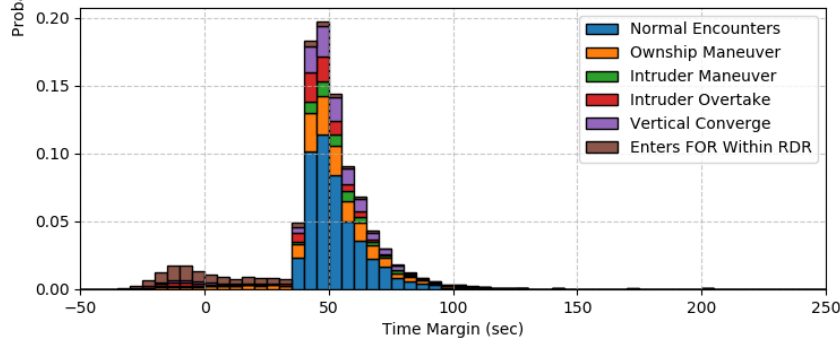
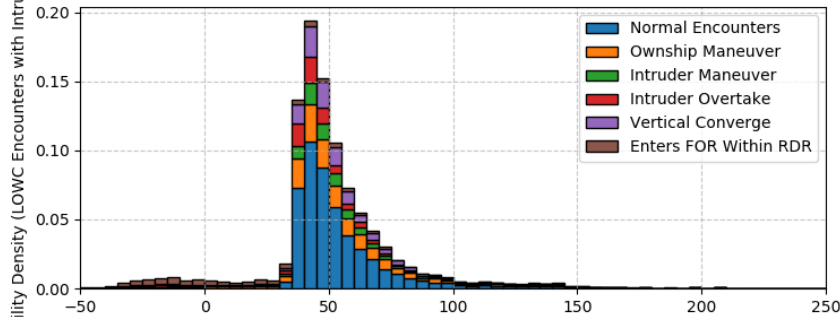
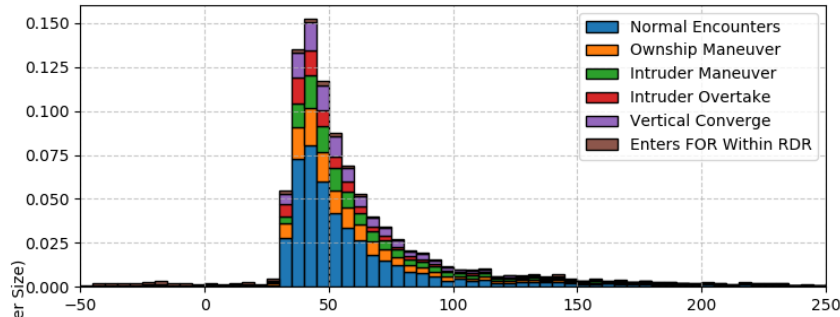
Time Margin Distributions



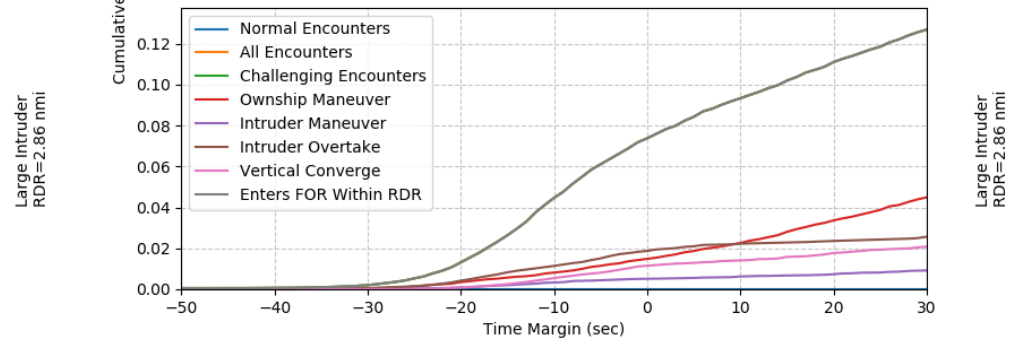
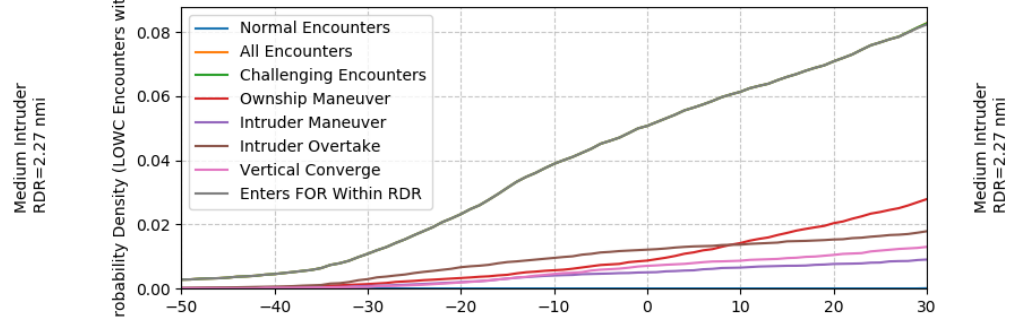
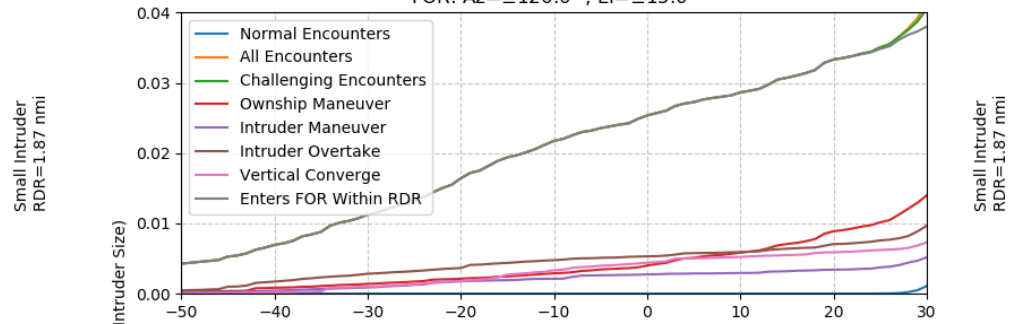
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

Az Coverage: $\pm 120.0^\circ$

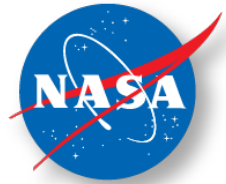
Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 120.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 120.0^\circ$, El= $\pm 15.0^\circ$



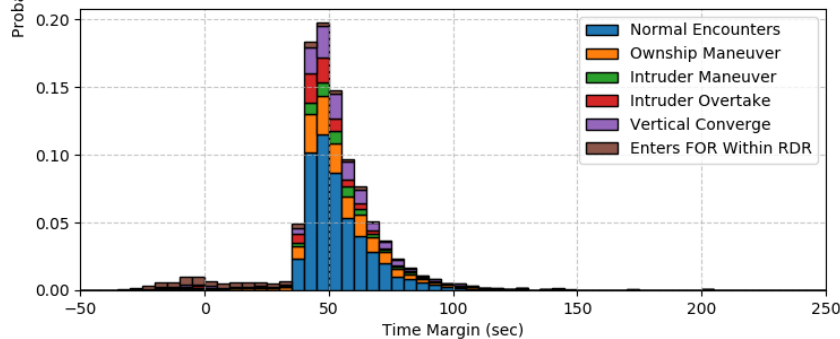
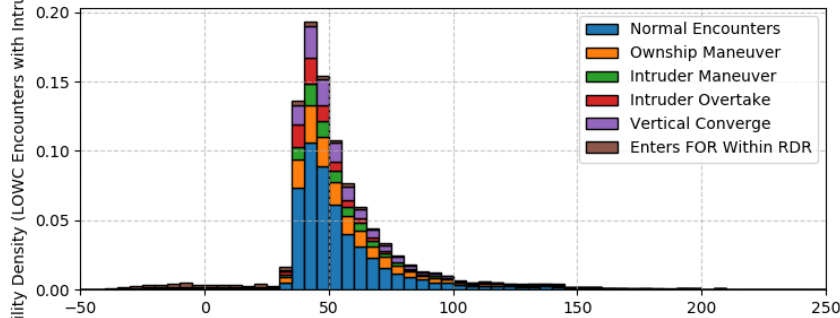
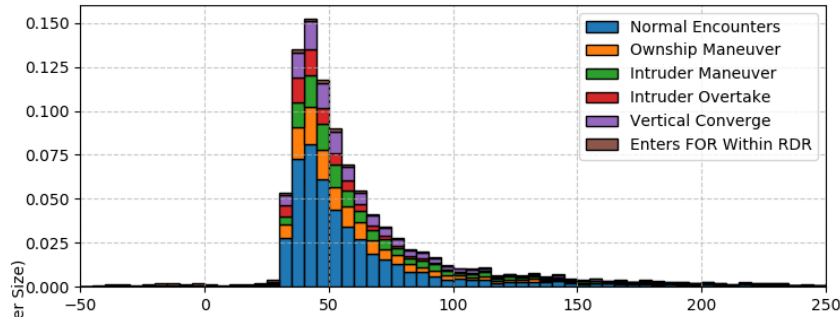
Time Margin Distributions



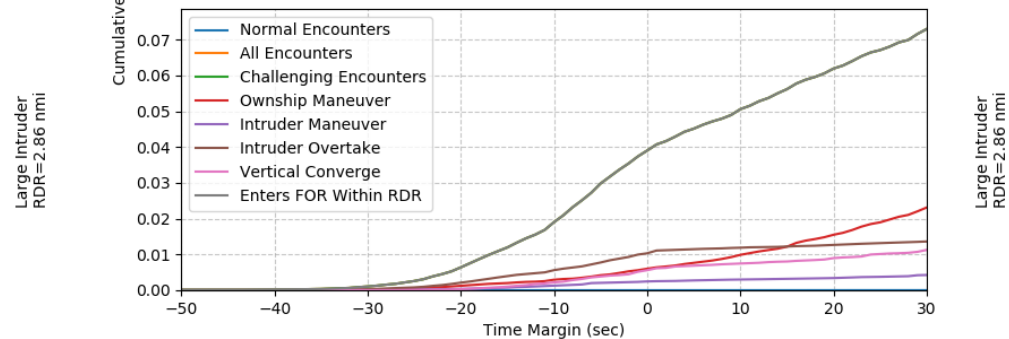
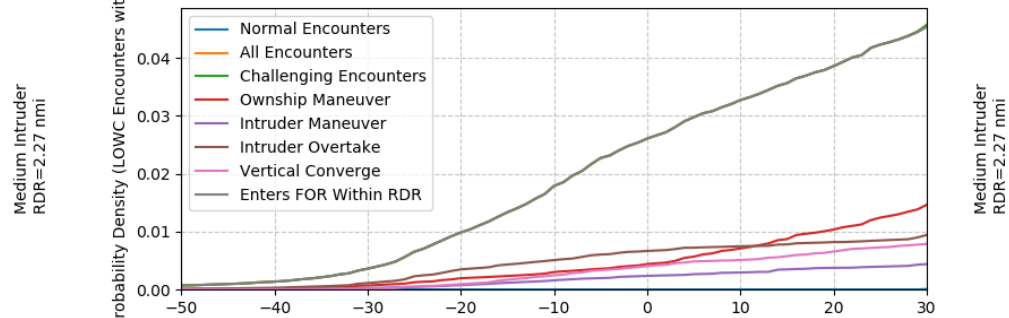
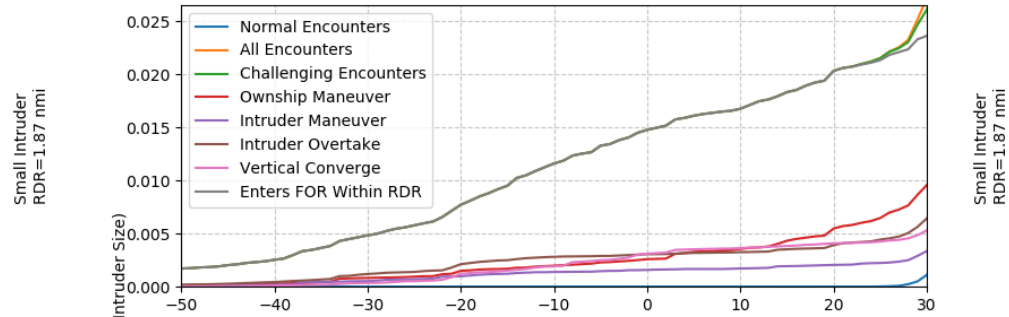
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

Az Coverage: $\pm 135.0^\circ$

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 135.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 135.0^\circ$, El= $\pm 15.0^\circ$





- The next three slides show the affect of increasing Elevation Coverage on Time Margin.

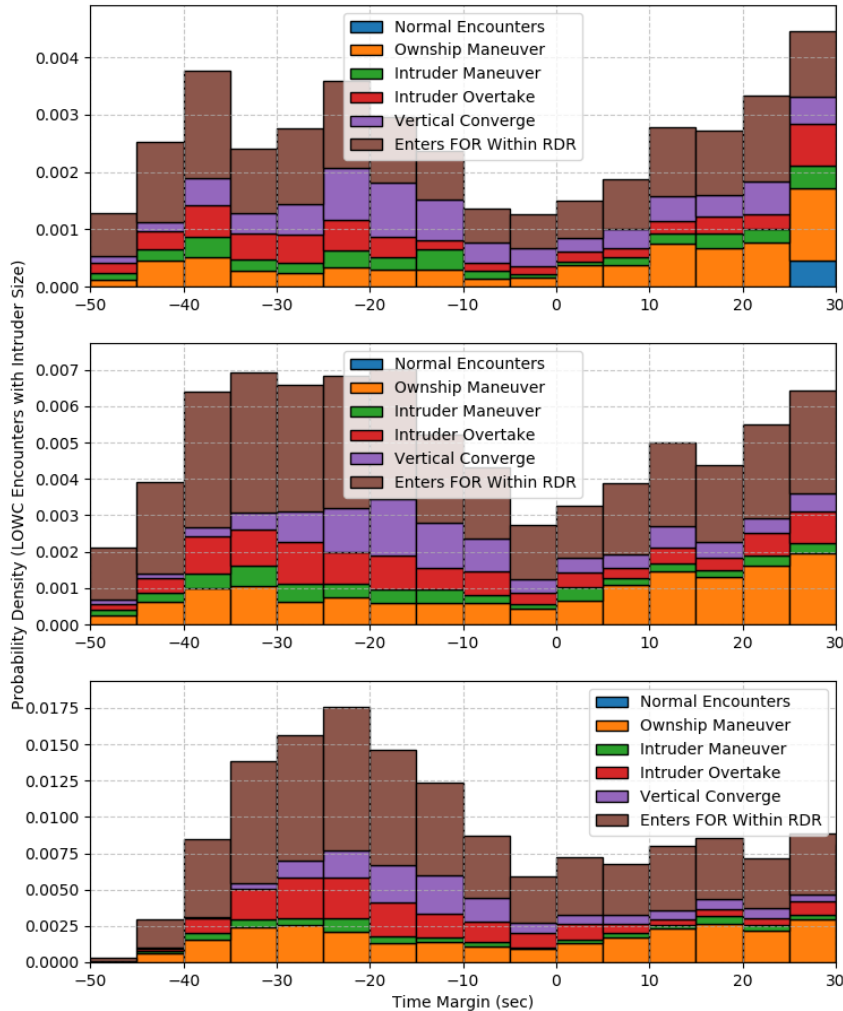
Time Margin Distributions



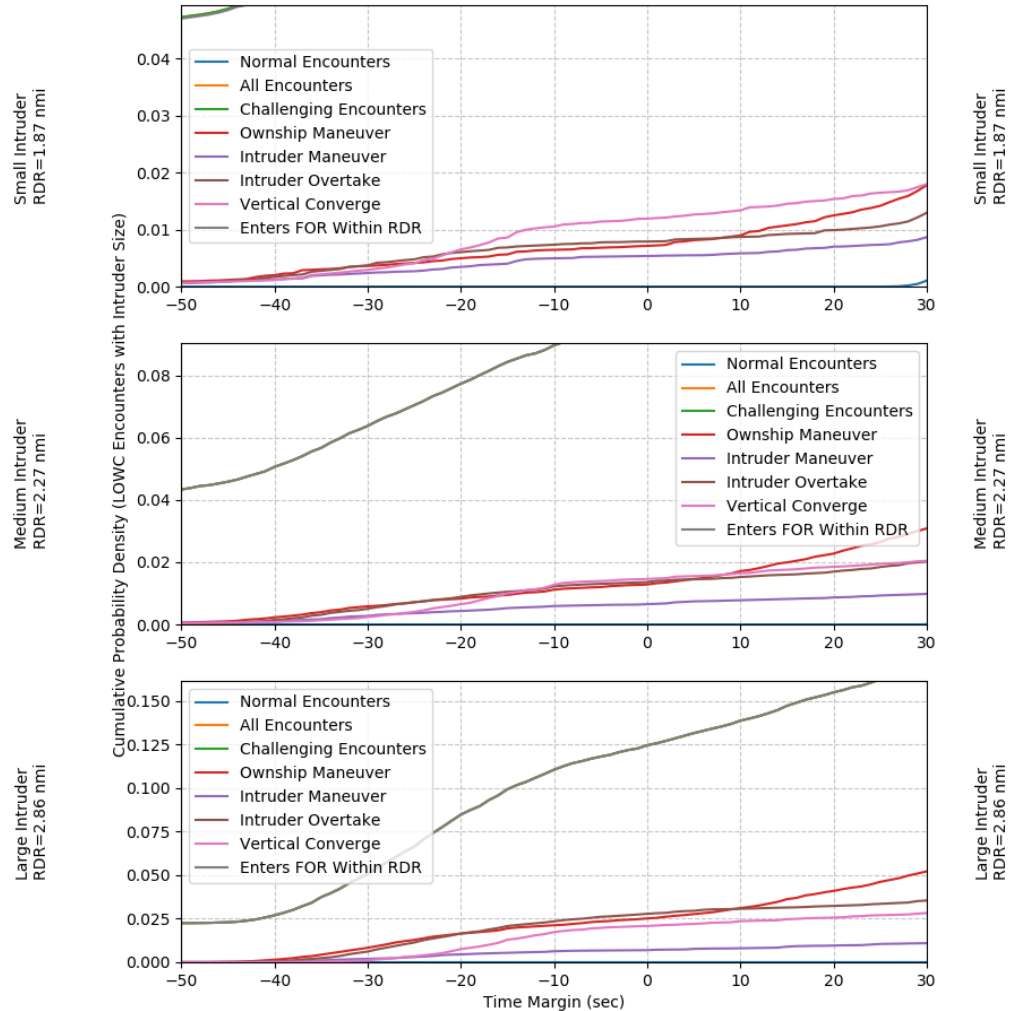
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

El Coverage: +/- 5.0°

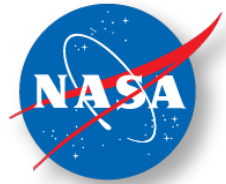
Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 5.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 5.0^\circ$



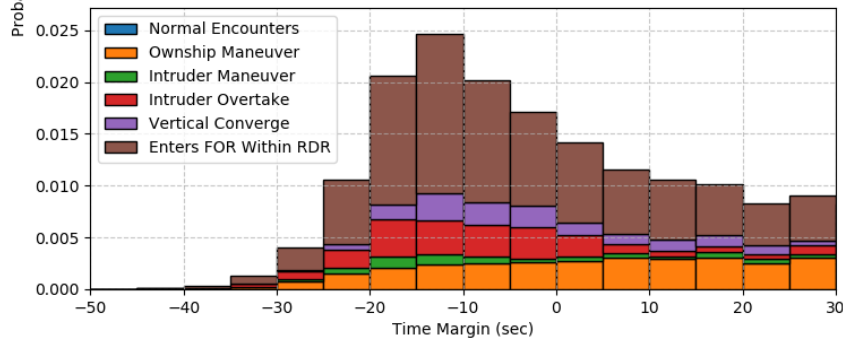
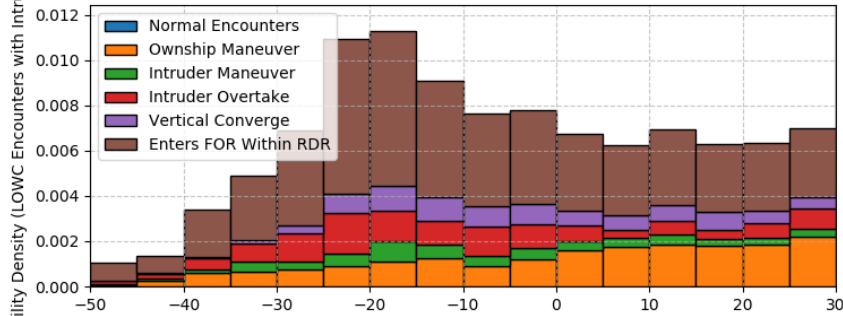
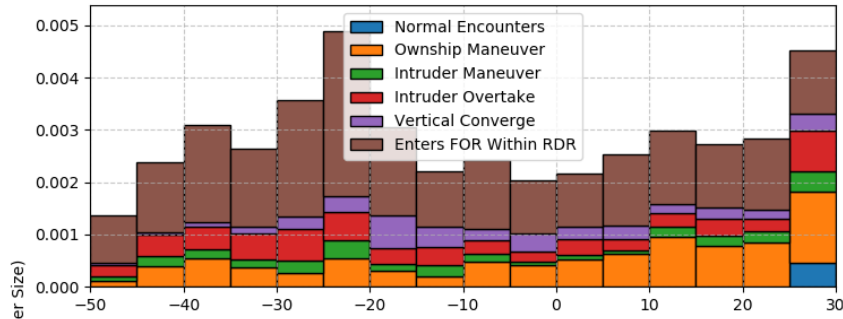
Time Margin Distributions



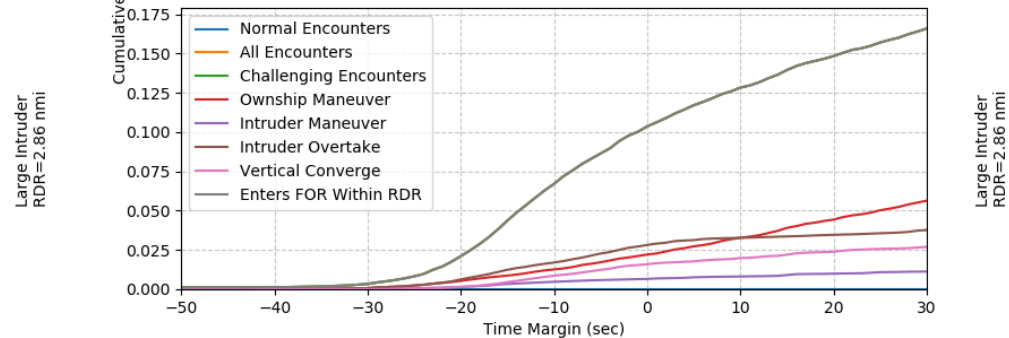
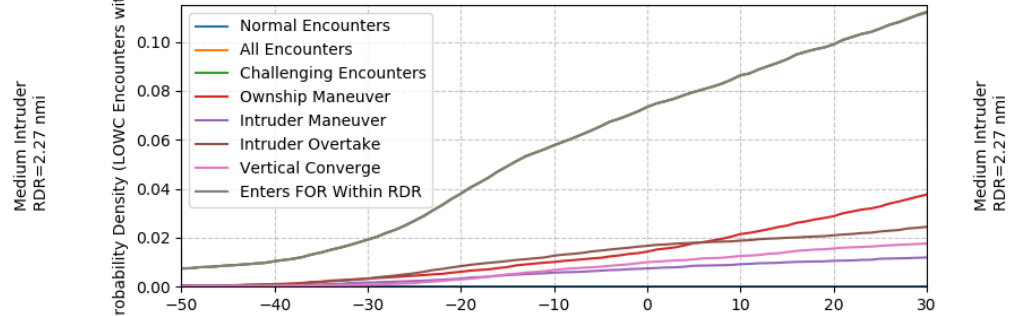
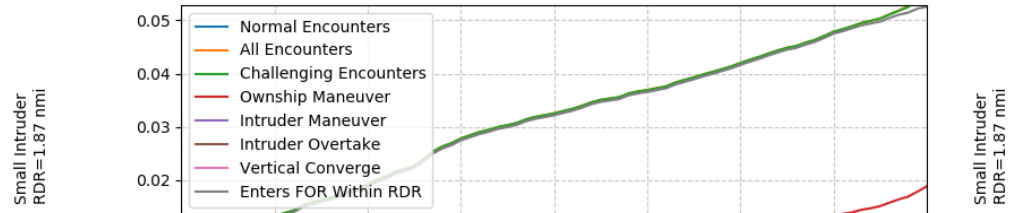
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

El Coverage: +/- 15.0°

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 15.0^\circ$



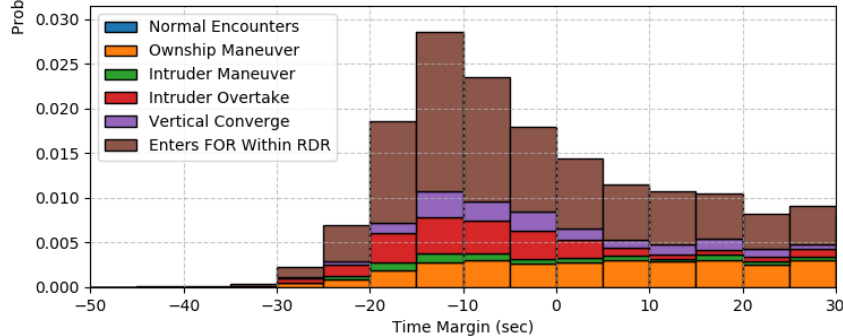
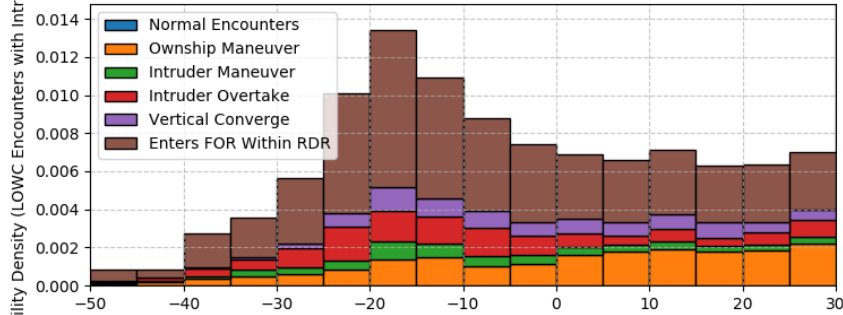
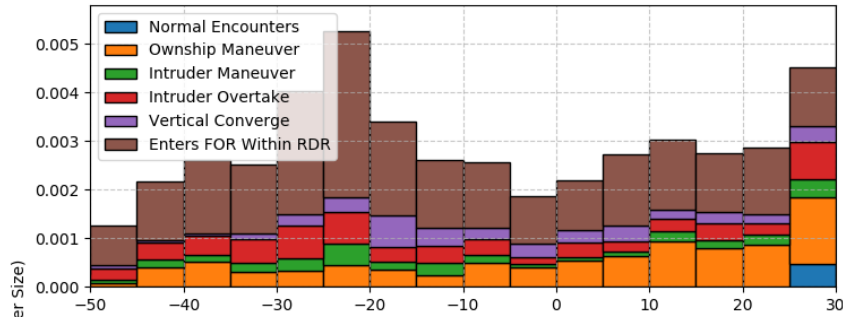
Time Margin Distributions



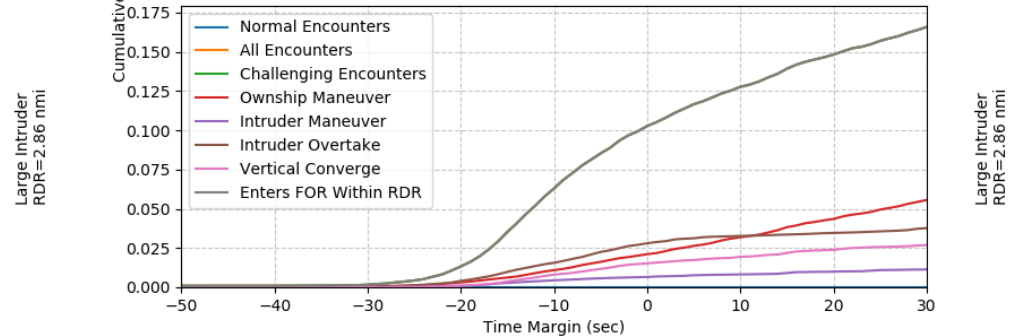
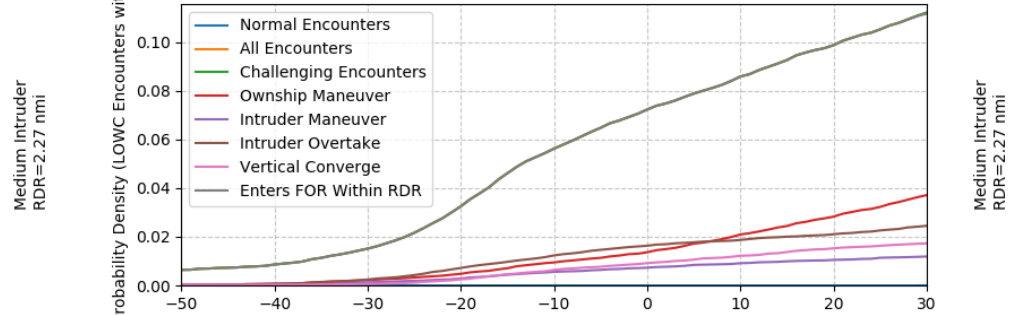
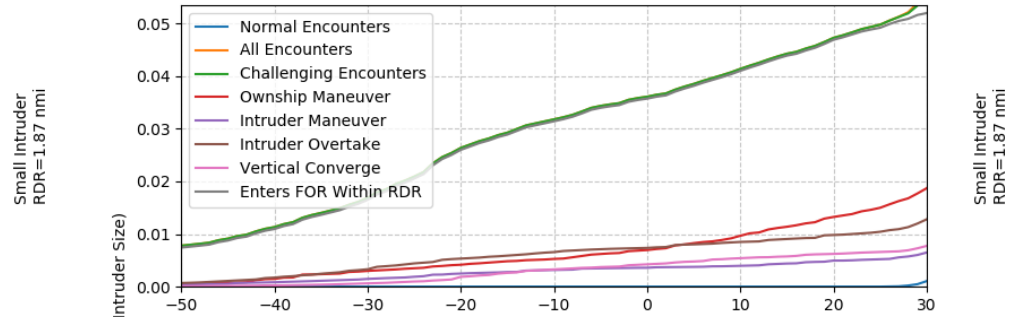
$$t_{RDR} = t_{MIR} + 15 \text{ sec}$$

El Coverage: +/- 20.0°

Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 20.0^\circ$



Time Margin ($t_{LOWC} - t_{RDR}$)
FOR: Az= $\pm 110.0^\circ$, El= $\pm 20.0^\circ$





Defined as:

$$\text{abs} \left(\frac{d}{dt} (\text{Ownship Heading}) \right) > (+) \text{Threshold}$$

$\text{Heading} := \tan^{-1} \left(\frac{\dot{y}}{\dot{x}} \right)$, counter-clockwise from +x

- Angles are “unwrapped” prior to applying $\frac{d}{dt}$, to prevent $\text{abs}(\text{heading rates}) > 180^\circ/\text{s}$.
- This detects large changes in Ownship Heading.

Defined as:

$$\frac{d}{dt} \text{abs}(\text{Relative Azimuth}) < (-) \text{Threshold}$$

$\text{Azimuth} := \tan^{-1} \left(\frac{y_{rel}}{x_{rel}} \right) - \tan^{-1} \left(\frac{y_{intr} - y_{own}}{x_{intr} - x_{own}} \right)$, counter-clockwise from +x.

$\text{Relative Azimuth} := \text{Azimuth} - \text{Ownship Heading}$, counter-clockwise from Ownship Heading.

- Relative Azimuth is unwrapped prior to applying abs().
- This detects large changes in Relative Azimuth from +/- 180° towards 0°.

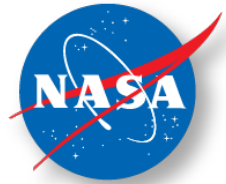


Defined as:

$$\frac{d}{dt} (\textit{Vertical Range}) < (-)\textit{Threshold}.$$

$$\textit{Vertical Range} := \text{abs}(z).$$

- This detects large vertical closure rates.



Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.0157	0.0149	0.0142	0.0136
AZ: 60 deg	0.0116	0.0109	0.0103	0.0097
AZ: 75 deg	0.0083	0.0077	0.0070	0.0066
AZ: 90 deg	0.0058	0.0051	0.0046	0.0043
AZ: 105 deg	0.0040	0.0034	0.0030	0.0027
AZ: 110 deg	0.0035	0.0029	0.0025	0.0022
AZ: 120 deg	0.0025	0.0021	0.0018	0.0016
AZ: 135 deg	0.0014	0.0011	0.0009	0.0008

Weighted probability that intruder is not detected at time of LoWC.

Results show that range (RDR) can be traded for increased azimuth (FoR) coverage.



Field of Regard	RDR: 2.0 NMi	RDR: 2.5 NMi	RDR: 3.0 NMi	RDR: 3.5 NMi
AZ: 45 deg	0.0200	0.0190	0.0181	0.0173
AZ: 60 deg	0.0151	0.0141	0.0132	0.0126
AZ: 75 deg	0.0110	0.0100	0.0092	0.0087
AZ: 90 deg	0.0077	0.0068	0.0062	0.0058
AZ: 105 deg	0.0055	0.0047	0.0042	0.0038
AZ: 110 deg	0.0048	0.0041	0.0036	0.0032
AZ: 120 deg	0.0036	0.0030	0.0026	0.0022
AZ: 135 deg	0.0021	0.0017	0.0014	0.0012

Weighted probability that intruder is not detected 20s before LoWC.

Results show that range (RDR) can be traded for increased azimuth (FoR) coverage.

ATAR MOPS DO-366

Req. 2.2.7.22



22. For cases where the intruder enters the FOR within the RDR (cases dominated by ownship maneuvers) the radar shall (050) take no more than 15 seconds 90% of the time to establish a track that meets the accuracy requirements in Paragraph 2.2.8, evaluated 15 seconds from the time the intruder enters the FOR until RCPR or the intruder exits the FOR.

Note: *It is shown in Appendix C that the probability of an intruder entering the FOR within the RDR is low, and these cases are mainly in two classes; those with the ownship maneuvering, which are covered by this requirement, and those with the intruder overtaking the ownship, . When the ownship is being overtaken by an intruder the responsibility for “See and Avoid” falls on the pilot of the intruder aircraft since the ownship is in the intruder pilot’s field of view.*