



# Alternative Surveillance Fast Time Simulation with Sensor Uncertainties and Mitigation: Preliminary Results



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# Background

- SC-228 selected a Detect-and-Avoid (DAA) Well Clear (DWC) for non-cooperative aircraft for additional studies
  - The non-coop DWC and Phase 1 DWC yield comparable safety metrics such as the NMAC risk ratio and loss of DWC ratio
  - Simulations were based on
    - Truth aircraft states
    - Phase 1 pilot response model in a deterministic mode
    - Version 1.0 of the DAIDALUS algorithm

DWC	$\Gamma_{mod}$ (sec)	HMD* (ft)	h* (ft)
Non-Coop	0 sec	2200 ft	450 ft
Phase 1	35 sec	4000 ft	450 ft



# Objectives

- Investigate the effect of realistic radar noise on alerting and guidance performance
- Evaluate the ability of the sensor uncertainty mitigation (SUM) feature of the DAIDALUS algorithm to improve alerting and guidance
- Evaluate sensitivity of alerting and guidance performance to pilot response model turn buffer



# Fast Time Simulation Coverage

Simulation Type		Low C-SWaP Operations	Phase 1 Operations
Unmitigated	Truth Tracks	NASA Briefing Mar. 2019	NASA Briefing May 2019
	Noisy Tracks	TBD	
Mitigated	Truth Tracks with a Phase 1 Pilot Model	Lincoln Lab (LL) Briefing Mar. 2019	Cal Analytics (CAL) Briefing Mar. 2019
	Noisy Tracks with a Phase 1 Pilot Model	NASA Nov.. 2019	TBD



# Performance Metrics

- Safety Metrics

- Loss of DWC (LoDWC) ratio
- Near-mid-air-collision (NMAC) risk ratio

- Operational suitability metrics

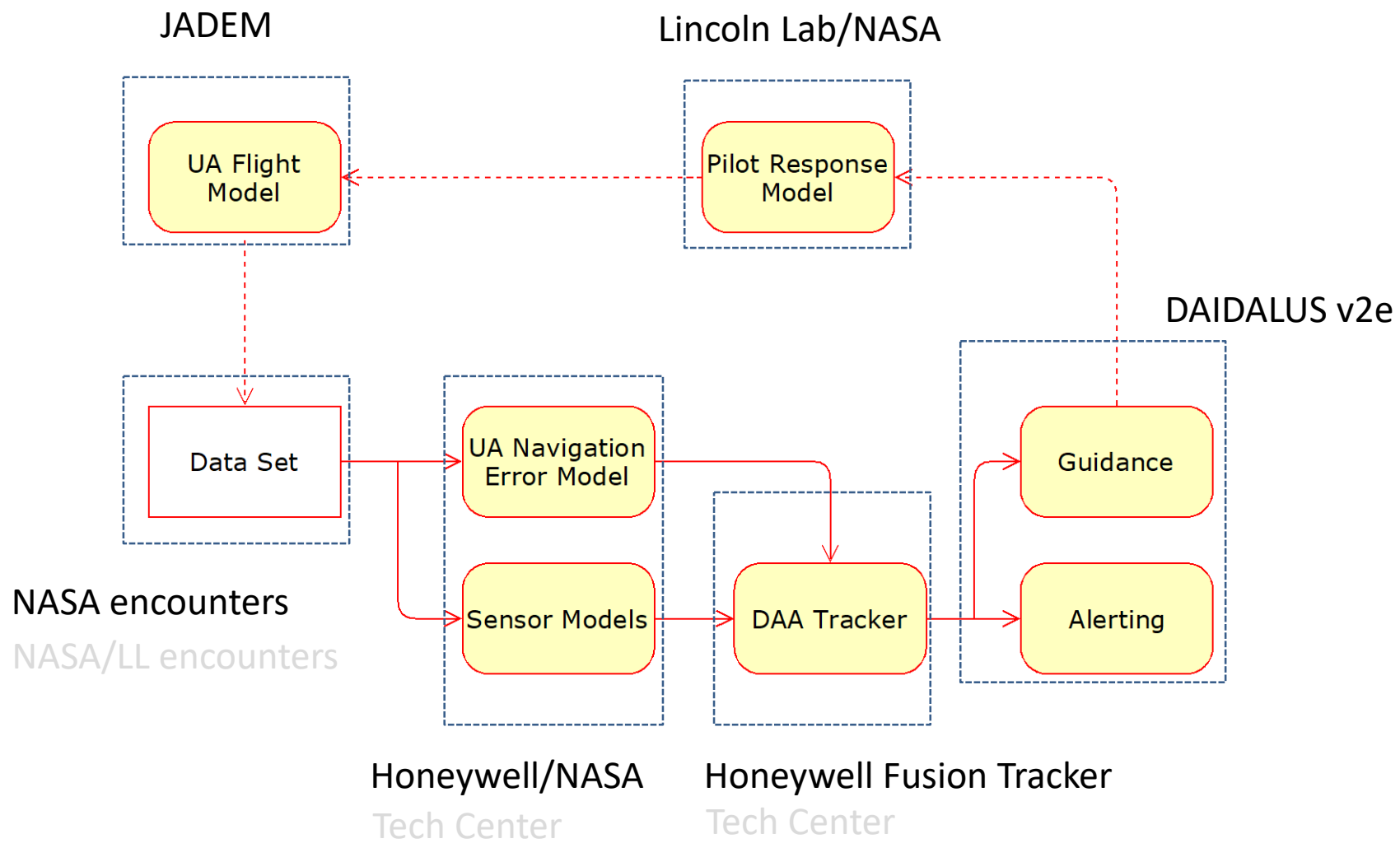
- Alert ratio:  $\frac{\# \text{ encounters with alerts}}{\# \text{ encounters with unmitigated LoDWCs}}$

- Maneuver workload:

$$\frac{\# \text{ maneuvers in all encounters}}{\# \text{ encounters with unmitigated LoDWCs}}$$



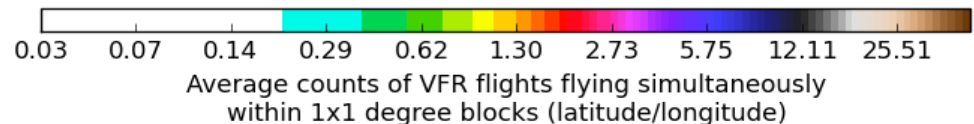
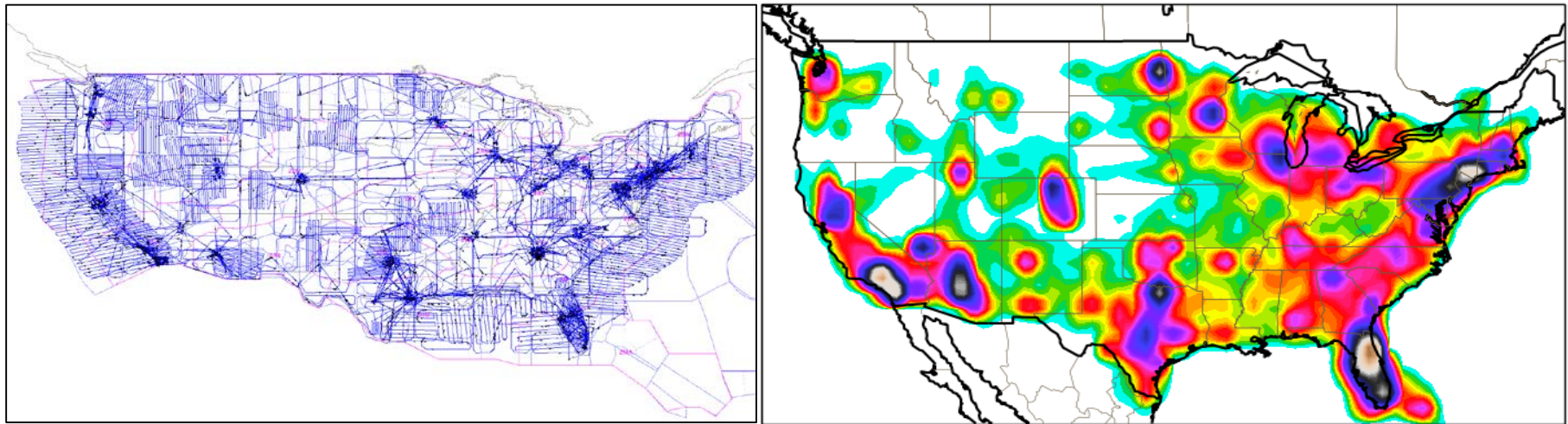
# Simulation Architecture





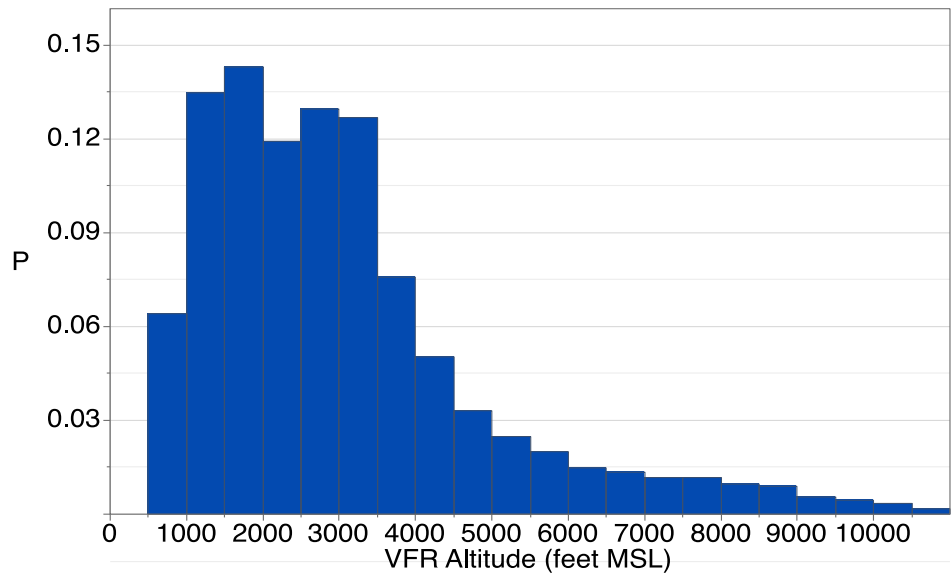
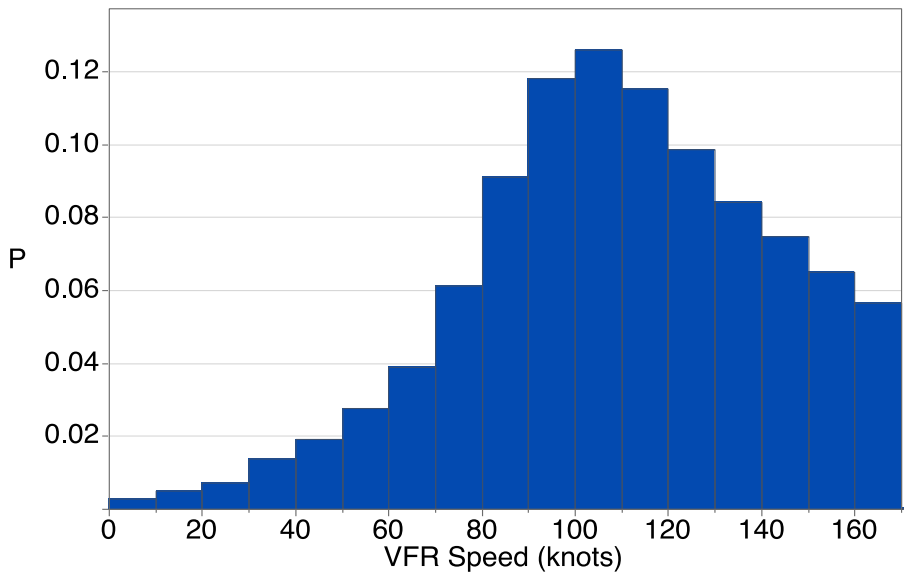
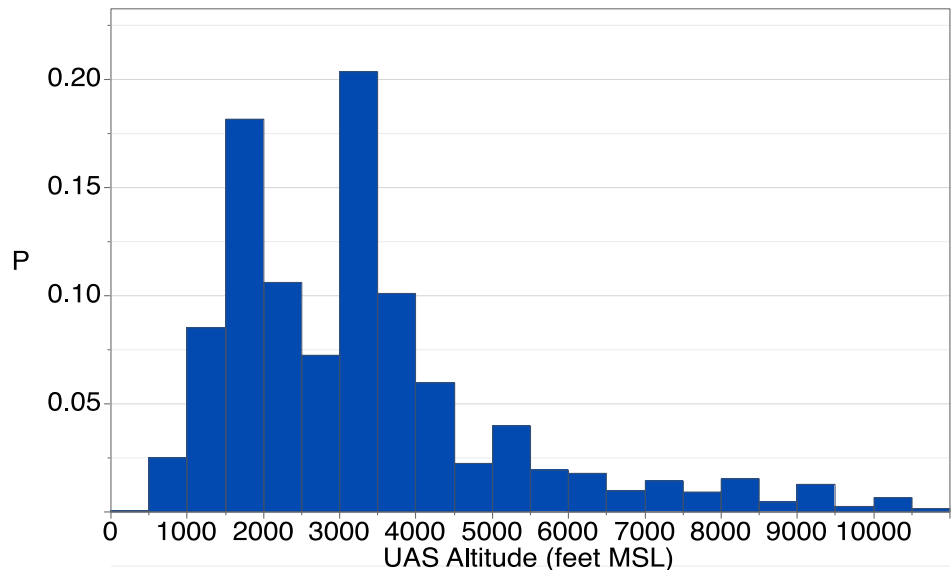
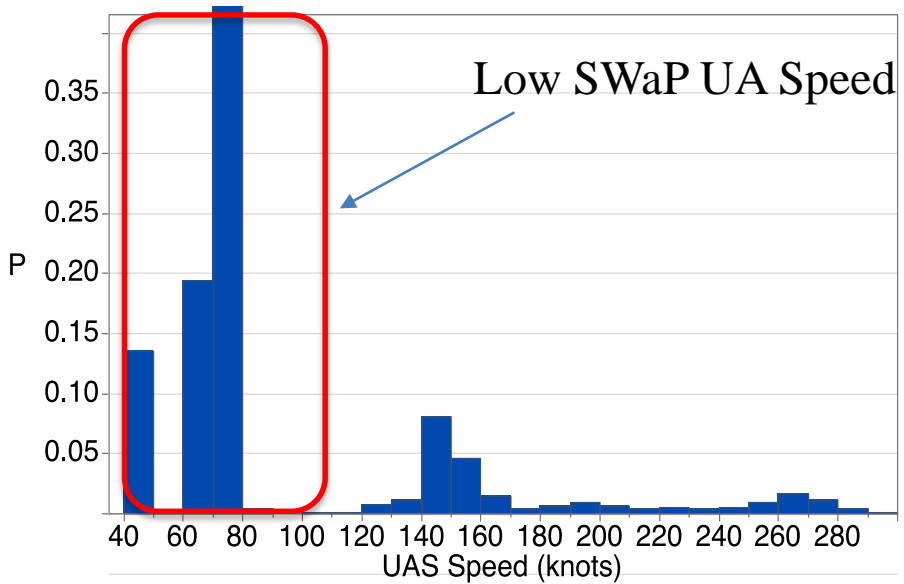
# Encounter Set

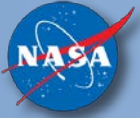
- 20,000 hours of projected UAS mission trajectories in one day overlaid with each of 21 days' radar recorded visual flight rules (VFR) traffic
- Subset selected for UAS missions with low size, weight, and power (SWaP) sensors
  - UA speed between 40 and 110 KTAS
  - Non-cooperative intruder speed between 0 and 170 KTAS
  - Between 500 ft AGL and 10,999 ft MSL





# Speed and Altitude of UAS and VFR Traffic





# Sensor and Tracker Models

- Radar model

- Field of Regard: 8 NM slant range,  $\pm 90^\circ$  elevation and  $\pm 180^\circ$  azimuth
- Uncertainty (Accuracy) parameters

### Radar measurement accuracy parameters in terms of bias and error

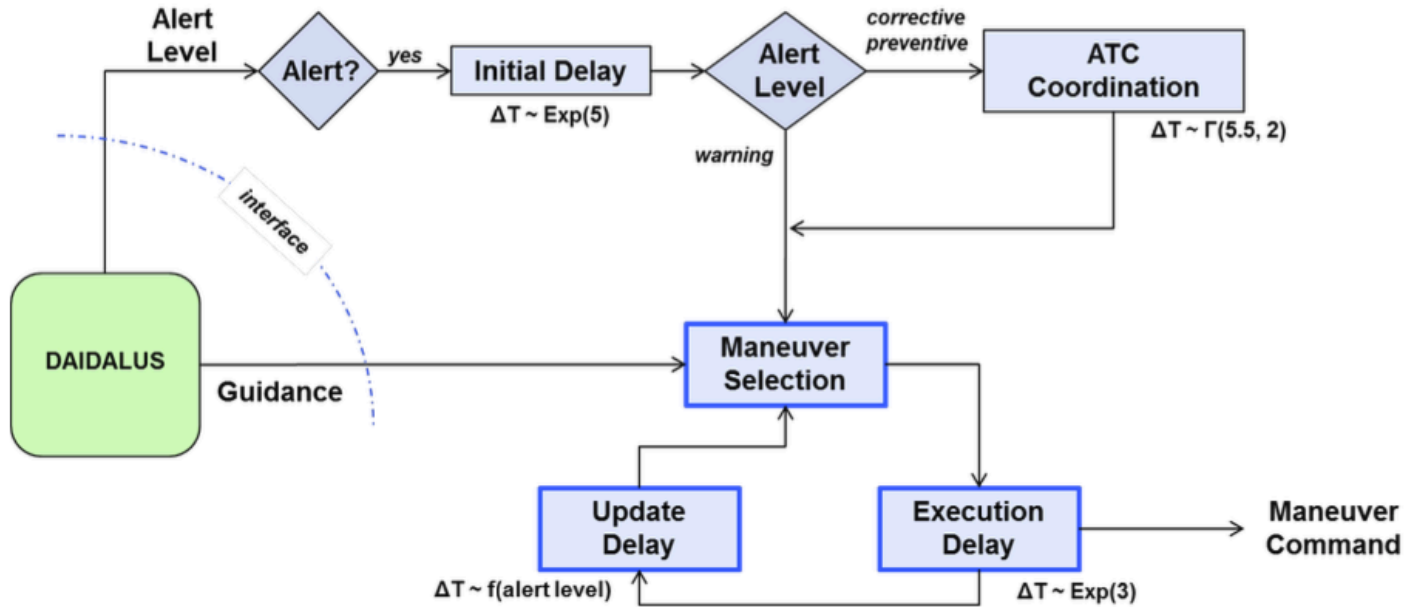
Configuration	Range (m)	Azimuth ( $^\circ$ )	Elevation ( $^\circ$ )	Velocity (m/s)
Sensor Noise (SN)	$5.5 \pm 10$	$0 \pm 0.4$	$0 \pm 0.4$	$0 \pm 2$
Large Sensor Noise (LSN)	$15 \pm 21$	$0.5 \pm 1.0$	$0.5 \pm 1.0$	$0 \pm 2$

- Honeywell Fusion tracker

- Used in NASA flight tests
- Provides track accuracy information



# Pilot Response Model



Alert Condition	Decision Update Period (s)
No Alert	12
Preventive Alert	9
Corrective Alert	6
Warning Alert	6
Regain-DWC Guidance	0

Turn Buffer: None or 5 °  
Horizontal maneuver only



# DAIDALUS Parameters

## Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS)

- SUM parameters:

- Horizontal values chosen to result in comparable well clear recovery start time to a run without SUM
- Vertical values chosen to achieve some level of alert stability

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Name	Horizontal Position	Horizontal Velocity	Vertical Position	Vertical Velocity
value	1.0	1.0	2.5	2.5

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- Other parameters

- Warning alert: 30 seconds before alerting volume
- Corrective alert: 60 seconds before alerting volume
- Alerting volume
  - For non-SUM runs, the horizontal miss distance threshold (HMD\*) buffered (2,200 ft x 1.519)
  - For SUM runs, no HMD\* buffer (2,200 ft)
- Turn rate is  $7^\circ$  /sec



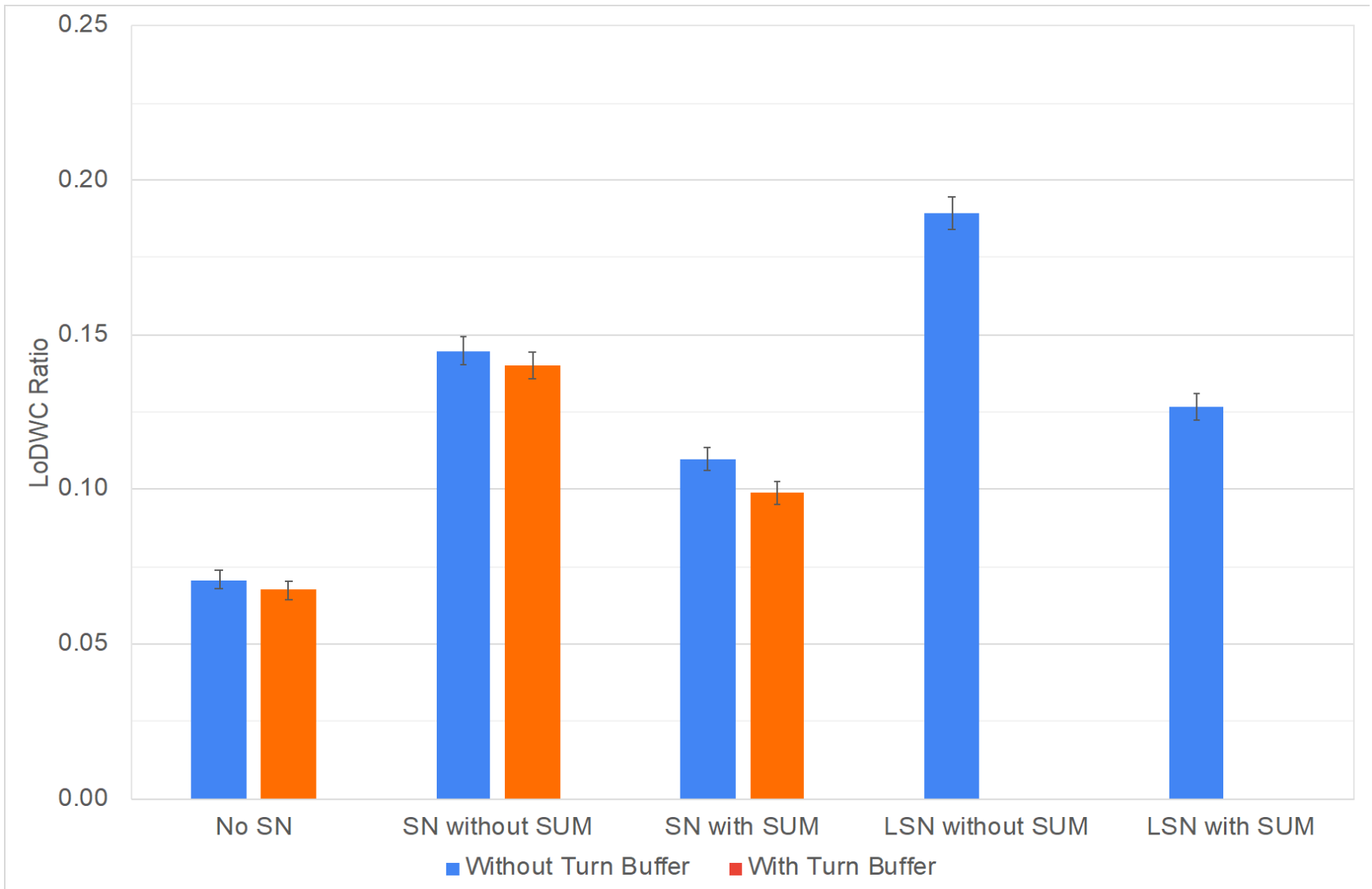
# Results

- One unmitigated simulation and eight mitigated simulations analyzed
- 8167 LoDWCs and 420 NMACs in the unmitigated run

Simulation	No Sensor Noise		Sensor Noise (SN)		Large Sensor Noise (LSN)	
	No	Yes	No	Yes	No	Yes
5° Turn Buffer	No	Yes	No	Yes	No	Yes
Unmitigated	0					
Mitigated without SUM	0	0	0	0	0	
Mitigated with SUM			0	0	0	

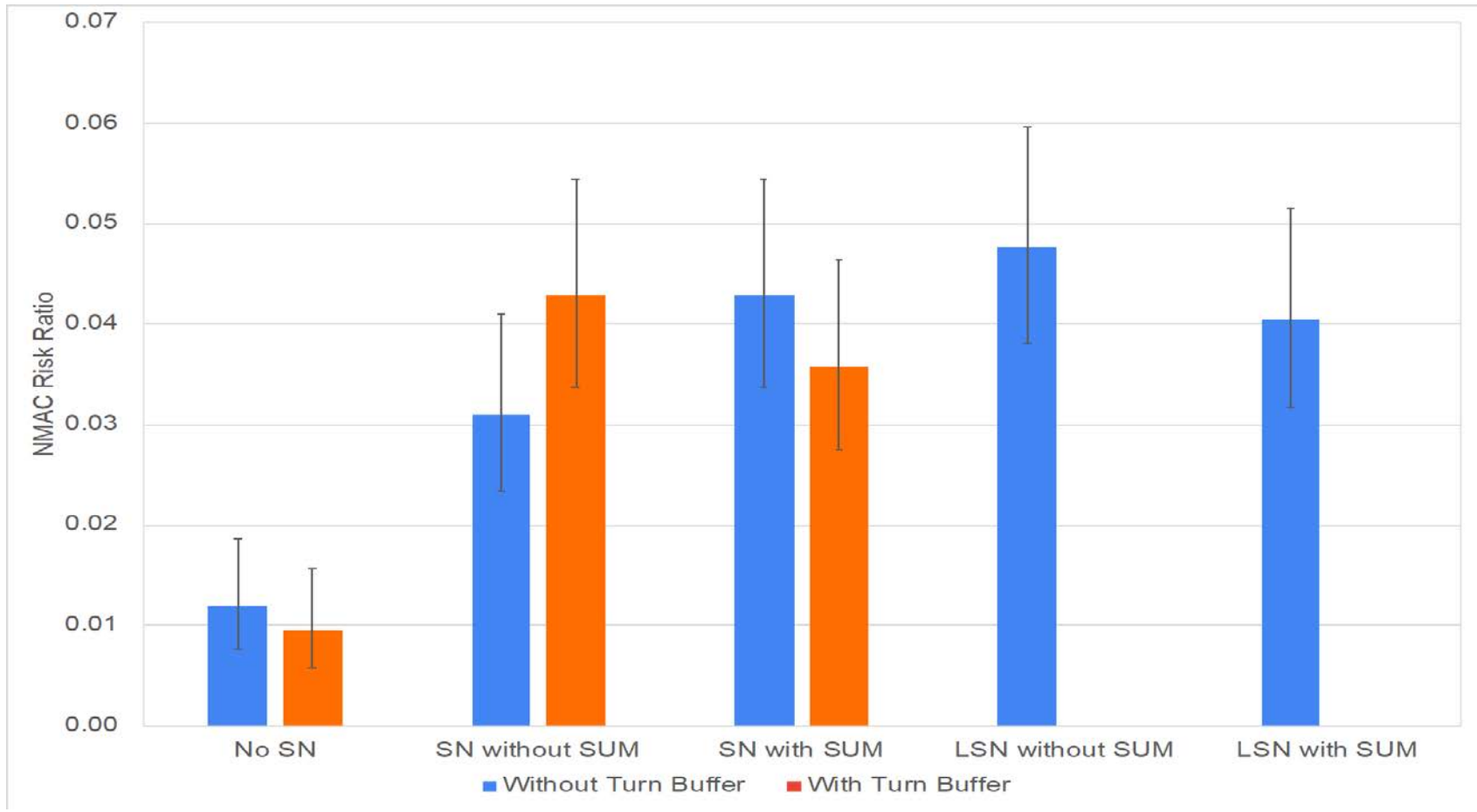


# LoDWC Ratio



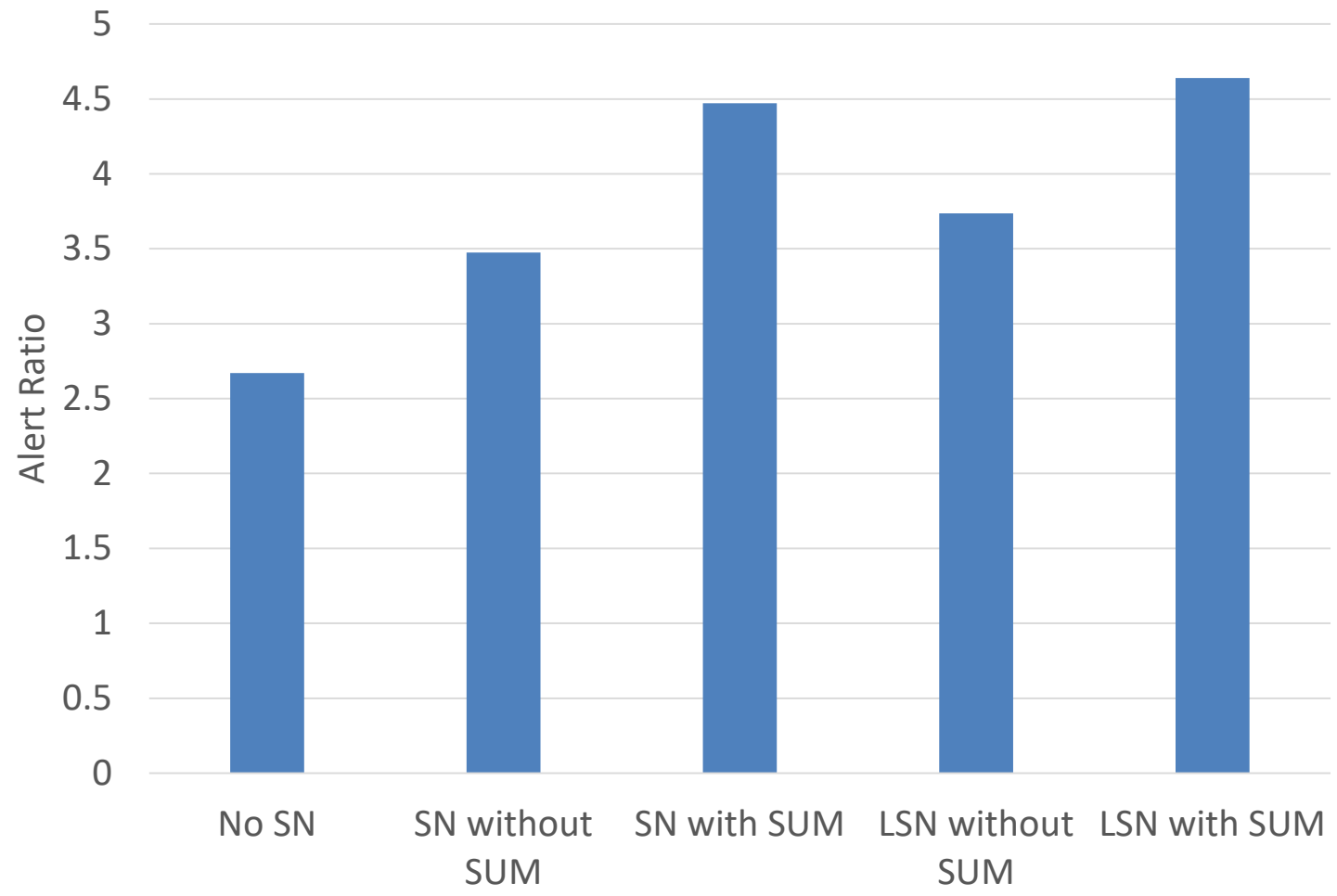


# NMAC Risk Ratio



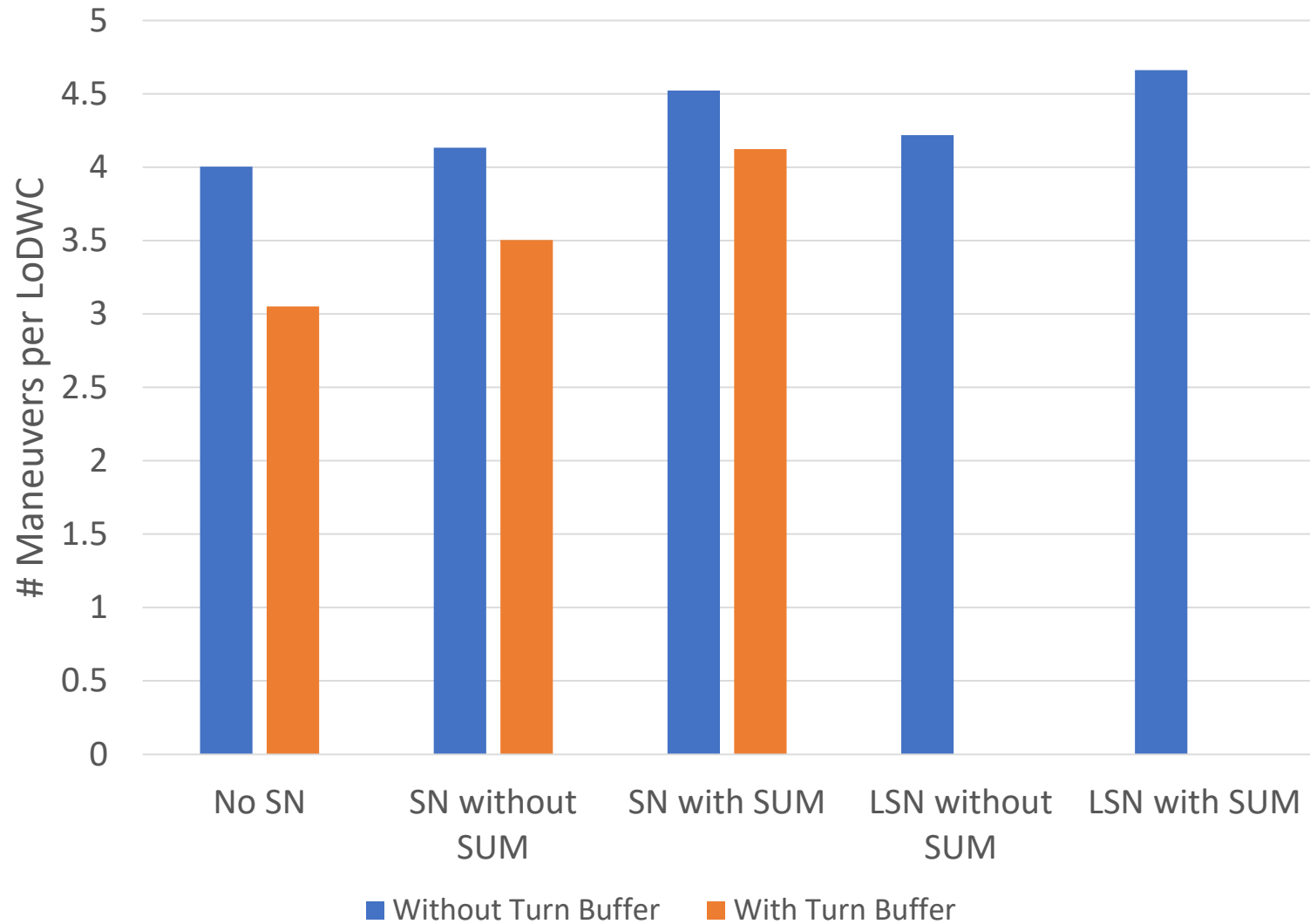


# Alert Ratio





# Maneuver Workload





# Results Summary

- Radar noise impacts all the performance metrics
  - Increasing from SN to LSN increases the LoDWC ratio and alert ratio, but has little effect on the NMAC risk ratio and the maneuvers workload
- SUM improves the LoDWC ratio (from 14% to 11%) at a slight cost of maneuver workload (0.3 # maneuver per LoDWC)
- Turn buffer of 5 ° reduces maneuver workload
  - Benefit seems to diminish with radar noise and SUM on



# Additional Work

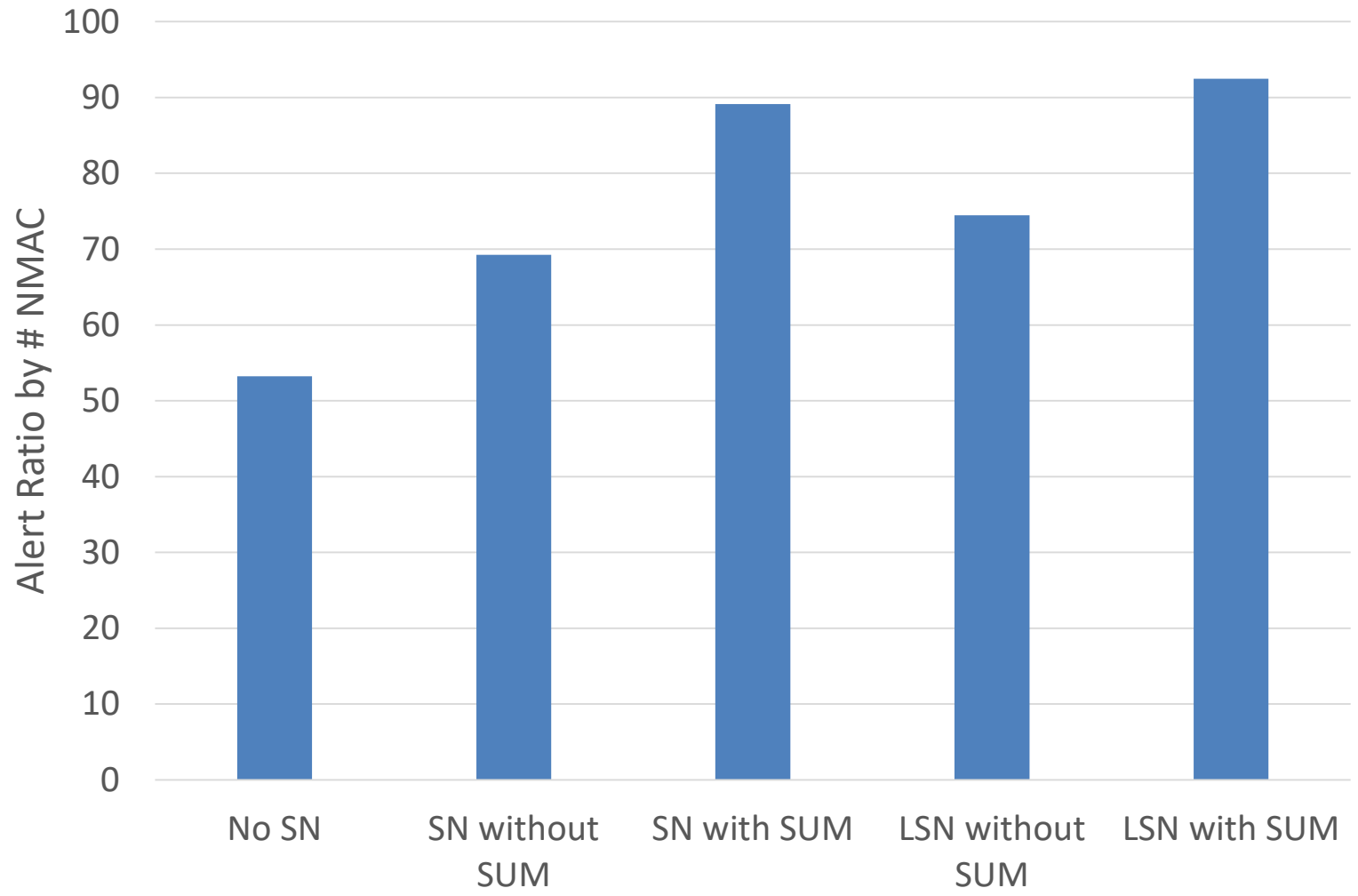
- Extended scope
  - Include medium and high-speed UA encounters
  - Include more encounters to improve NMAC risk ratio statistics
- Modeling options
  - Tech center sensor and tracker models
  - Finite surveillance volume
  - Updated SUM parameters
  - Going beyond deterministic mode in pilot response model
- End-to-end simulation support



# Backup Slides



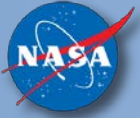
# Alert Ratio by # NMAC





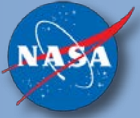
# Analysis of Safety Metrics

	# of LoDWC	# of NMAC
Unmitigated Simulation	8167	420
Mitigated Simulation without Sensor Noise and without DAIDALUS SUM	578	5
Mitigated Simulation with Sensor Noise but without DAIDALUS SUM	1183	13
Mitigated Simulation with Sensor Noise and DAIDALUS SUM	898	18
Sensor Noise with Turn Buffer, and without DAIDALUS SUM	1145	18
Sensor Noise with Turn Buffer, and with DAIDALUS SUM	807	15
No Sensor Noise and No DSUM, but with Turn Buffer	551	4
Larger Sensor Noise without SUM	1546	20
Larger Sensor Noise with SUM	1036	17



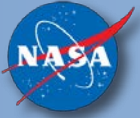
# Analysis of Safety Metrics

	LoDWC Ratio	NMAC Risk Ratio
Unmitigated Simulation	0.0708	0.0119
Mitigated Simulation without Sensor Noise and without DAIDALUS SUM	0.1449	0.0310
Mitigated Simulation with Sensor Noise but without DAIDALUS SUM	0.1100	0.0429
Mitigated Simulation with Sensor Noise and DAIDALUS SUM	0.1402	0.0429
Sensor Noise with Turn Buffer, and without DAIDALUS SUM	0.0988	0.0357
Sensor Noise with Turn Buffer, and with DAIDALUS SUM	0.0675	0.0095
No Sensor Noise and No DSUM, but with Turn Buffer	0.1893	0.0476
Larger Sensor Noise without SUM	0.1269	0.0405
Larger Sensor Noise with SUM	0.0708	0.0119



# UAS Missions

Number	Mission Types	Airspace	UAS Group	Cruise Altitude	Cruise Speed (KTAS)	Flight Pattern
1	Aerial Imaging and Mapping	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Aerosonde Mk 4.7	3000 ft. AGL	44 to 51	Radiator-grid pattern or circular pattern
2	Air Quality Monitoring	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Shadow-B (RQ7B)/NASA Sierra	4k, 5k, and 6k ft AGL	74 to 89	Radiator-grid pattern
3	Airborne Pathogen Tracking	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Shadow-B (RQ7B)/NASA Sierra	3,000 ft., 5,000 ft. and 10,000 ft. AGL	72 to 97	Radiator-grid pattern
4	Flood Inund. Mapping	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, Mode C Veil, E, and G	Aerosonde Mk 4.7	4,000 ft. AGL	46 to 51	Grid pattern
5	Flood Stream Flow	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, Mode C Veil, E, and G	Aerosonde Mk 4.7	4,000 ft. AGL	46 to 51	Grid pattern and/or along stream direction
6	Law Enforcement	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Aerosonde Mk 4.7	3,000 ft. AGL	44 to 51	Three types of pattern: 1) grid pattern, 2) random, 3) outward spiral
7	Point Source Emission	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, Mode C Veil, E, and G	Shadow-B	3,000 ft. AGL	72 to 80	Grid pattern and/or along stream direction
8	Spill Monitoring	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, Mode C Veil, E, and G	Shadow-B/Sierra	3,000 ft. to 13,000 ft. AGL	72 to 93	Up and down-wind flights in a radiator-grid pattern, Round-the-clock
9	Tactical Fire Monitoring	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	ScanEagle/Shadow-B	3,000 ft. AGL	72 to 75	Circular flight path following the perimeter of a wildfire
10	Traffic Monitoring	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Shadow-B	1,500 ft. AGL	58 to 84	Geo-spatial monitoring flight path
11	Wildlife Monitoring	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, Mode C Veil, E, and G	Aerosonde Mk 4.7	3,000 ft. AGL	44 to 51	Radiator-grid pattern
12	News Gathering	Flights depart from and return to a regional airport located within 40 nmi. of OEP 35 airports; Class D, E, and G (including Mode C Veil) with Class B or C transition	Aerosonde Mk 4.7	1,500 ft. to 3,000 ft. AGL	44 to 51	Random-path: e.g., police-chase; Circular orbit:



# Encounter Statistics

- Total number of pairwise encounters with 21 days of traffic
  - 94,081
- Total number of NMAC: 505 Near Mid-Air Collisions

UA Speed Range (KTAS)	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
# Encounters	72667	9062	7040	5312

- Total number of LoDWCs
  - Non-coop DWC: 9958
  - Phase1 DWC: 24809



# Number of LoDWC

