Air Mobility Trajectory Anomaly Detection and Operational Advancement

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SCHOOL OF COMPUTING
THE UNIVERSITY OF UTAH

Advanced Air Mobility

How do we automate air traffic control for autonomous aircraft?

UAS Traffic Management (UTM)

for

Advanced Air Mobility (AAM)

A problem for government agencies such as *NASA*, the *FAA,* and *Departments of Transportation (DOT)*

Project Goals

1. The impact of configurations of virtual highways (lanes)
2. The impact of tactical contingency response on the lane system
3. An investigation into trajectory anomaly detection within the lane-based approach.

NASA's Advanced Air Mobility National Campaign

GeoRq™

Advanced Air Mobility National Campaign Partners

Advanced Air Mobility, with its many vehicle concepts and potential uses in both local and intraregional applications, is shown in this illustration.

To integrate air taxis, cargo delivery aircraft, and other new vehicle concepts into the National Airspace System, NASA's Advanced Air Mobility (AAM) National Campaign needs to partner with industry, state government, and other government agencies to be successful.
The team also is closely working with the Federal Aviation Administration to provide testing data and determine which current aviation standards need to evolve. The ongoing effort aims to help integrate new aircraft into the skies.

Developmental Test partners (NC-DT)

The developmental testing phase ended in 2021 after flights with Joby's air taxi vehicle. These activities were designed to allow aircraft and airspace management service providers to demonstrate their systems with real-world operations and in simulated situations. The goal of DT was to prepare for NC-1, which is slated to occur in 2022.

Developmental Flight Testing - Industry partner provided a vehicle to fly in the NC-DT and demonstrated key integrated operational Urban Air Mobility or UAM scenarios.

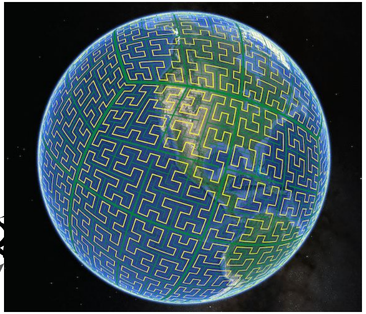
- Joby Aviation of Santa Cruz, California

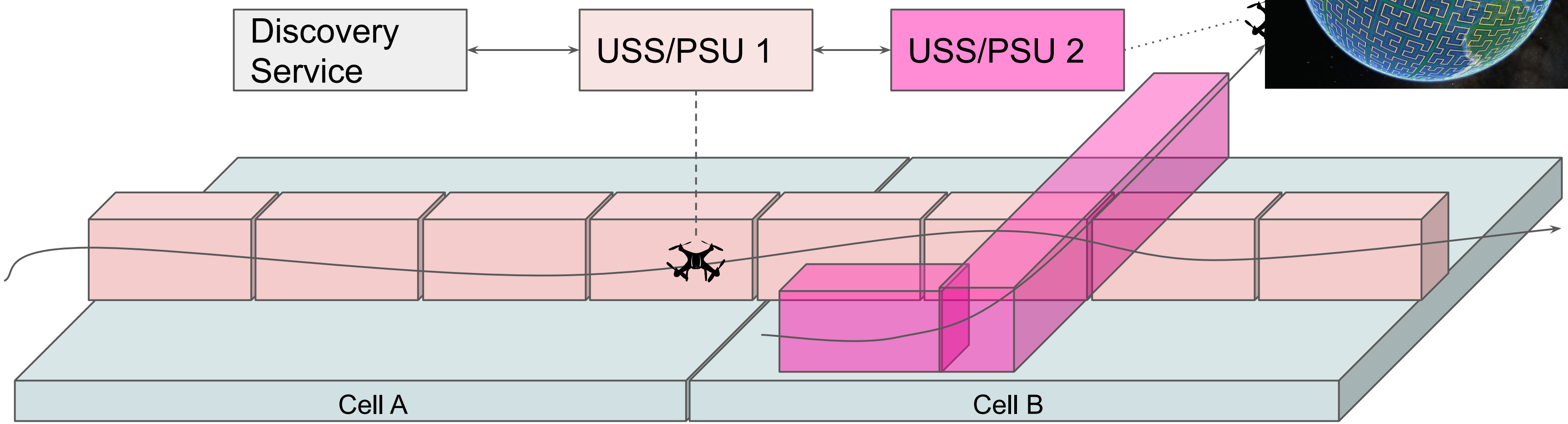
Developmental Airspace Simulation - Industry partner tested its UAM traffic management services in NASA-designed airspace simulations and demonstrated key integrated operational UAM scenarios.

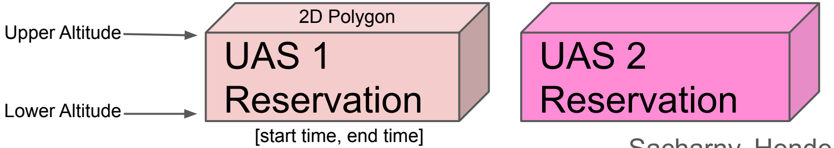
- AirMap, Inc. of Santa Monica, California
- AiRXOS, Part of GE Aviation, of Boston, Massachusetts
- ANRA Technologies, Inc. of Chantilly, Virginia
- ARINC Inc. of Cedar Rapids, Iowa
- Avision, Inc. of Santa Monica, California
- Ellis & Associates, Los Angeles, CA, a wholly-owned subsidiary of Lacuna Technologies, Palo Alto, CA
- GeoRq LLC of Holladay, Utah
- Metron Aviation, Inc. of Herndon, Virginia
- OneSky Systems Inc. of Exton, Pennsylvania
- Uber Technologies, Inc. of San Francisco, California

Strategic Deconfliction

The FAA/NASA method (and the current standard)







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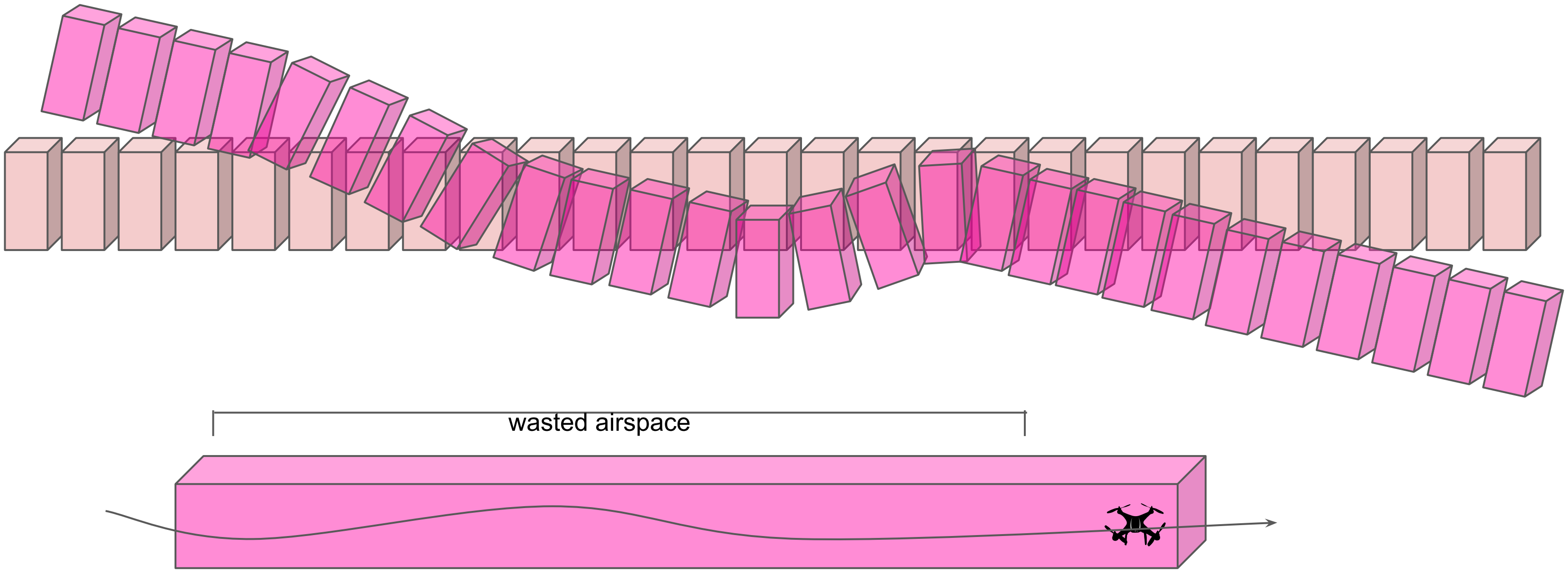


Solution

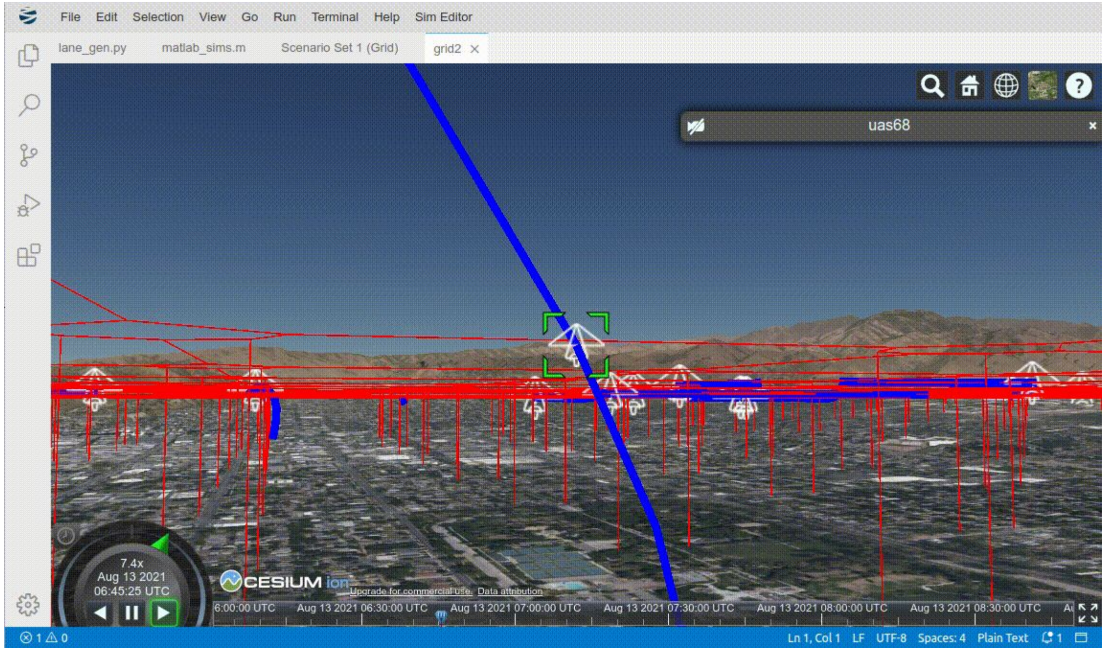
Airspace Structures

that support

Dense Operations

and

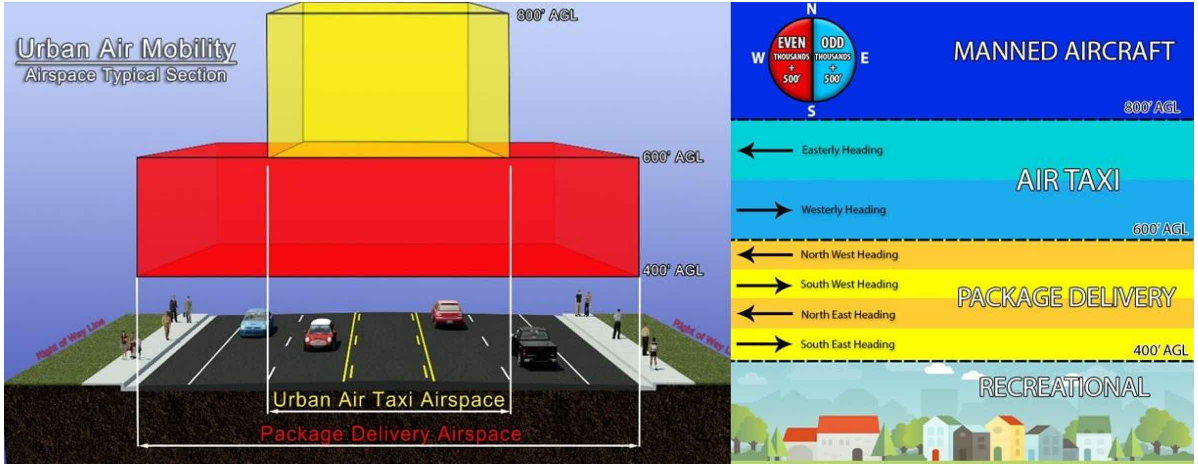
Efficient Strategic Deconfliction



Inspiration

Working Group Meetings with UDOT Aeronautics

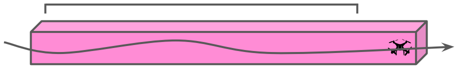
- Raised questions about airspace capacity and infrastructure
- Desire to restrict operations over private property
- Dual-Altitude airspace design discussed



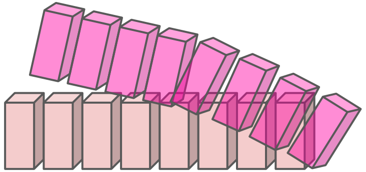
Addressed by the Lane-Based Approach

FAA/NASA

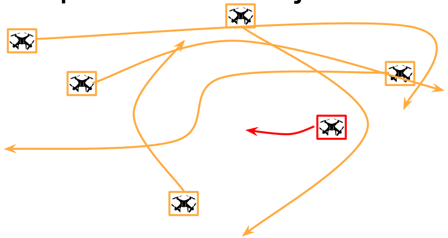
Inefficient airspace usage



Inefficient deconfliction

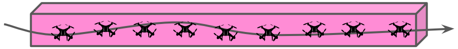


Unpredictable trajectories

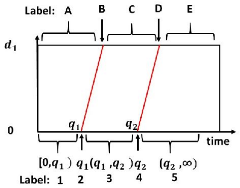


Lane-Based

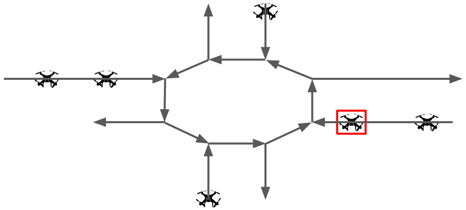
Efficient airspace usage



Efficient deconfliction



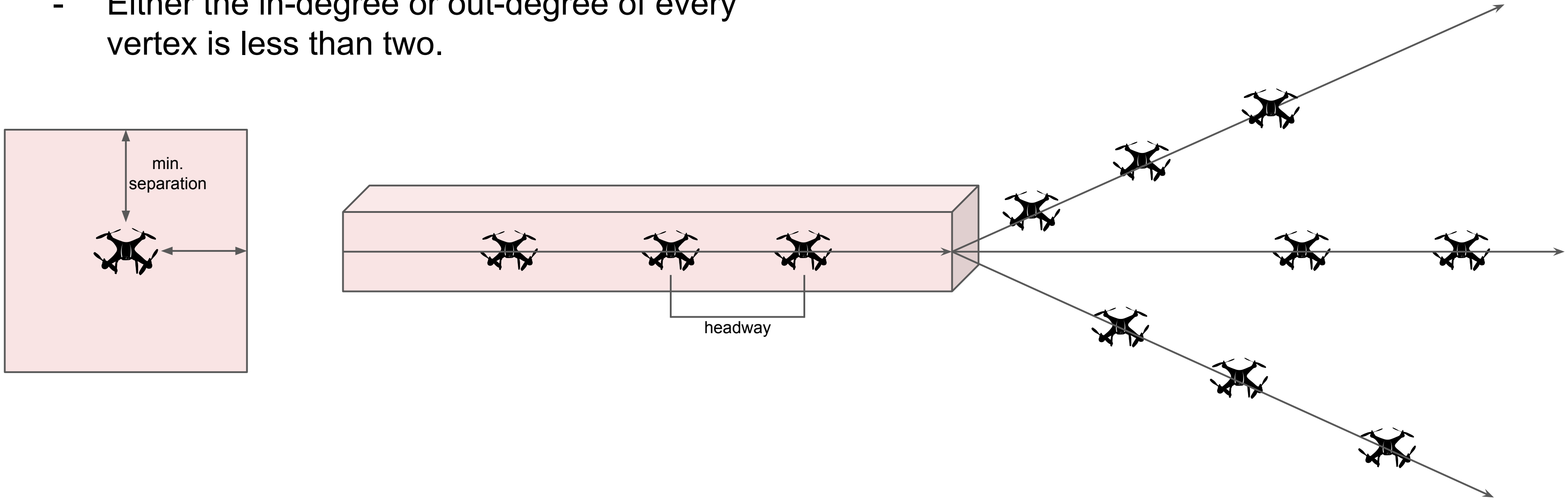
Predictable trajectories



What are Lanes?

Lanes are edges in a directed graph

- Not restricted to straight lines
- Disjoint lanes separated by minimum distance
- Either the in-degree or out-degree of every vertex is less than two.

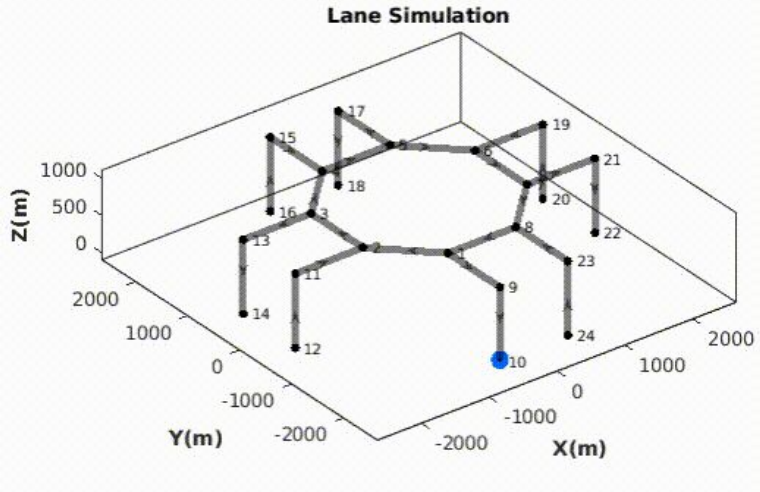


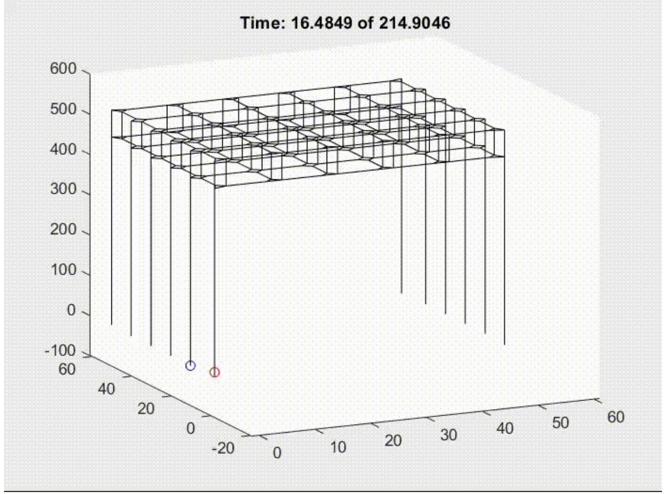
Strategic Deconfliction

The Lane-Based Approach

The basics:

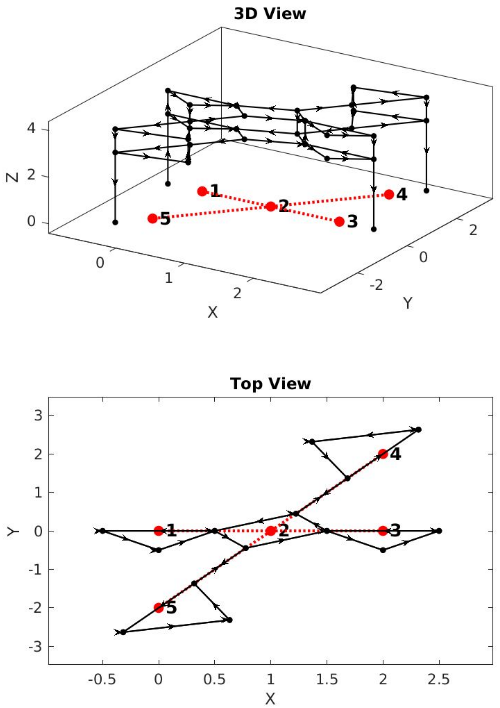
1. Choose a path through the system (Dijkstra, A*, etc.)
2. Request a launch time

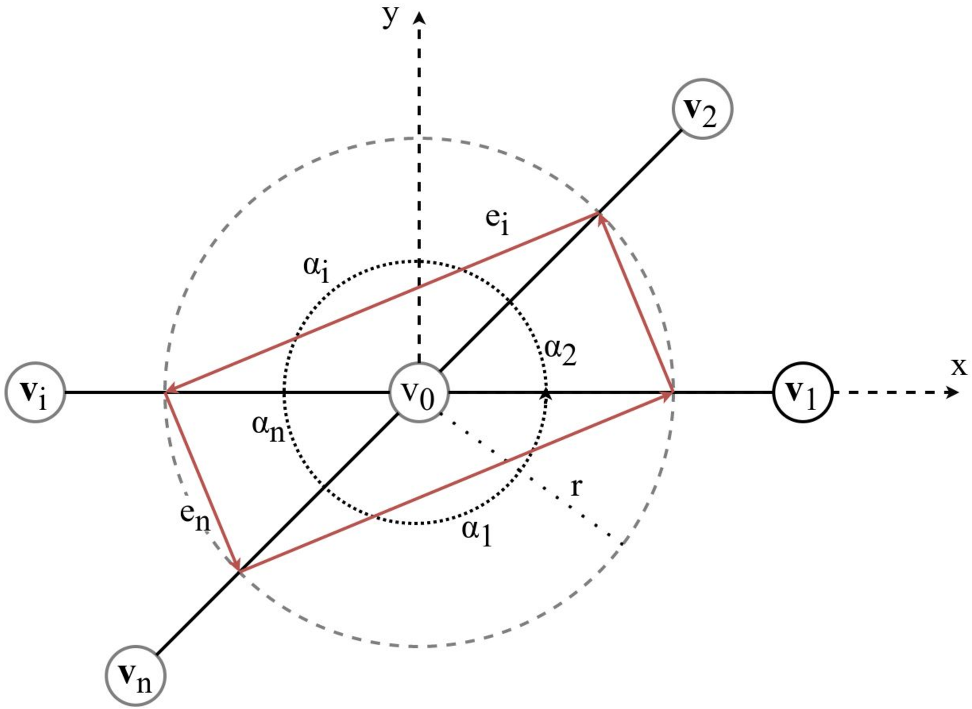




Constructing Lanes

The Lane-Based Approach





Constructing Lanes

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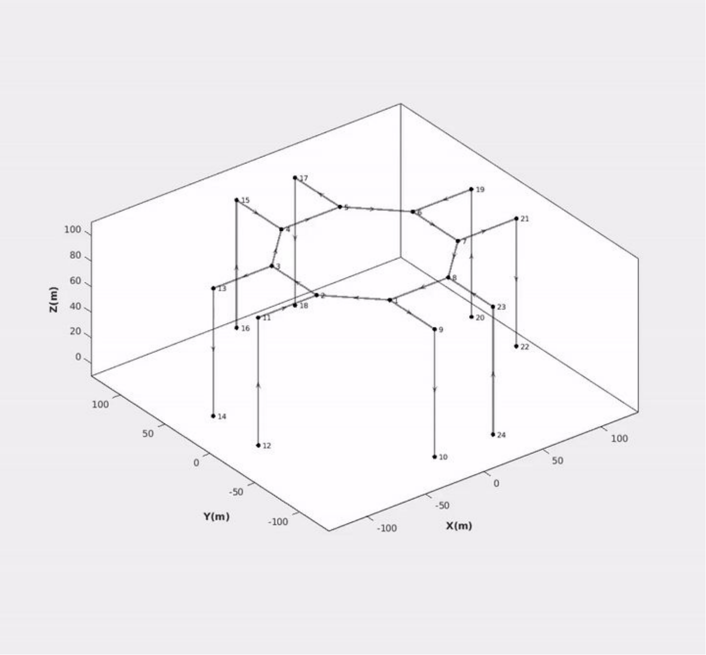
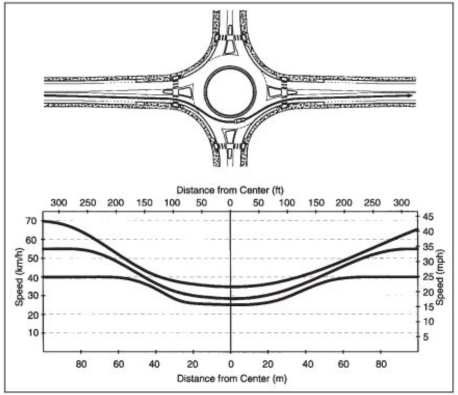


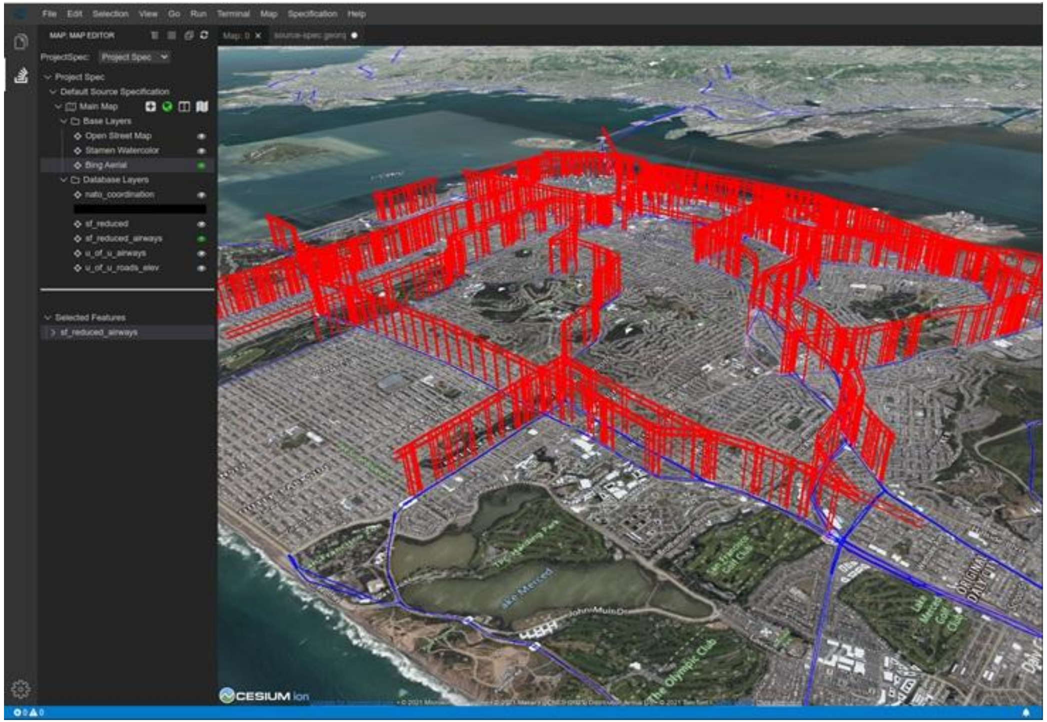


Recommended maximum entry design speeds for roundabouts at various intersection site categories are provided in Exhibit 6-4.

Site Category	Recommended Maximum Entry Design Speed
Mini-Roundabout	25 km/h (15 mph)
Urban Compact	25 km/h (15 mph)
Urban Single Lane	35 km/h (20 mph)
Urban Double Lane	40 km/h (25 mph)
Rural Single Lane	40 km/h (25 mph)
Rural Double Lane	50 km/h (30 mph)

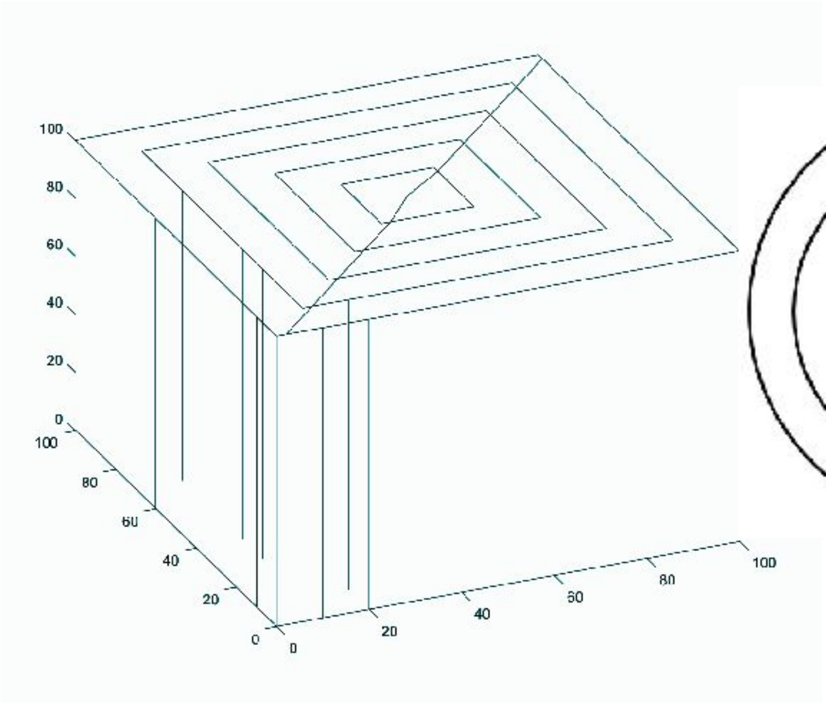
Constructing Lanes

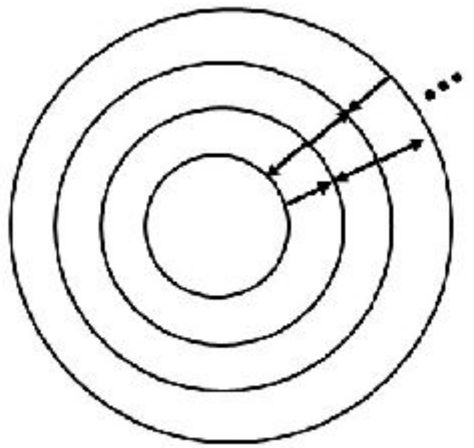
Two-Altitude Lanes over San Francisco

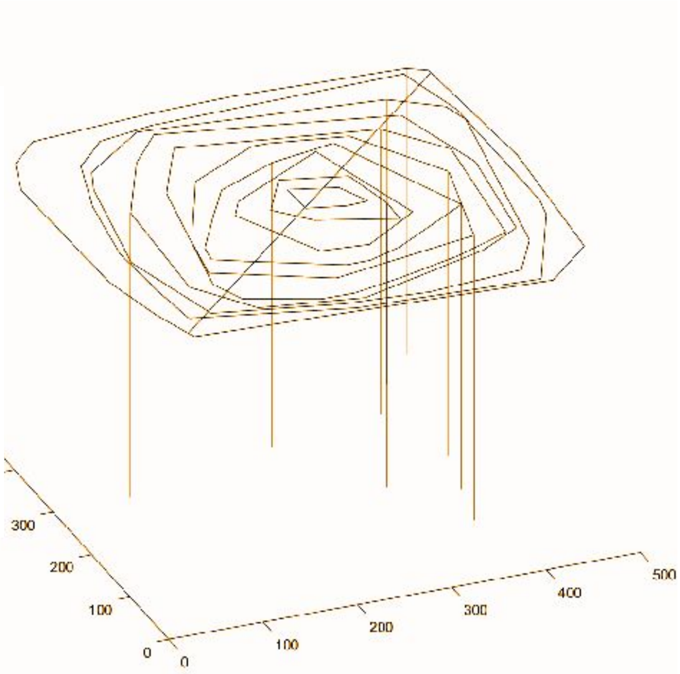


Constructing Lanes

Single-Altitude Lane System







Constructing Lanes

Lane System in Dubai

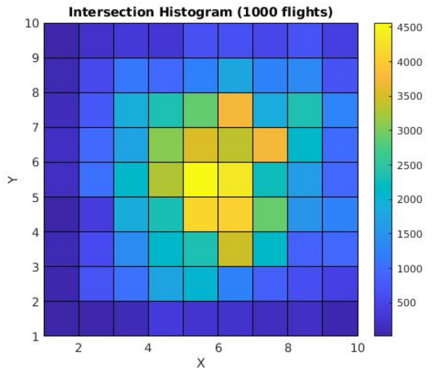
Lane-Based Approach over Salt Lake

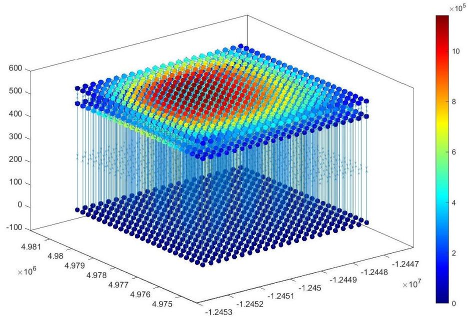
STRUCTURE AND COMPARISON

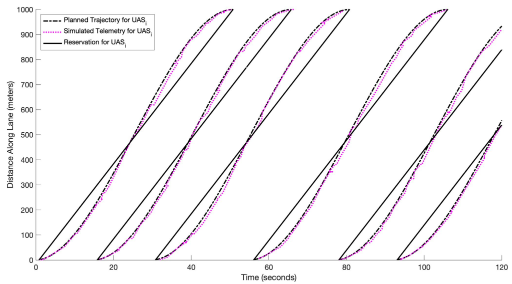
Tools for Analyzing Lane Systems and Comparisons to the Current Approach

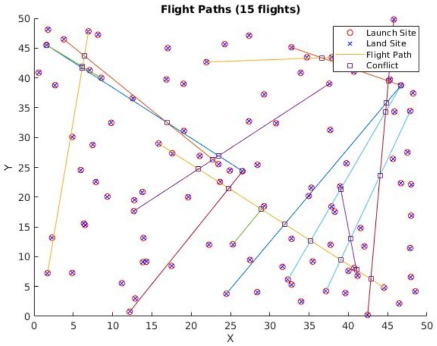
Spatial Network Measures

The lane-based approach supports a static analysis through spatial network measures more commonly used to describe ground transportation systems.



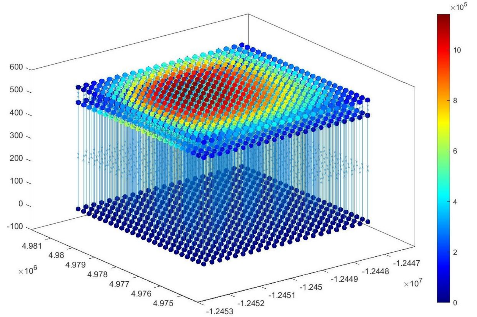


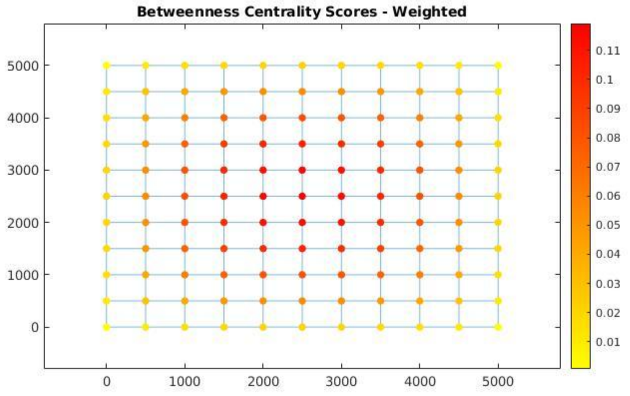


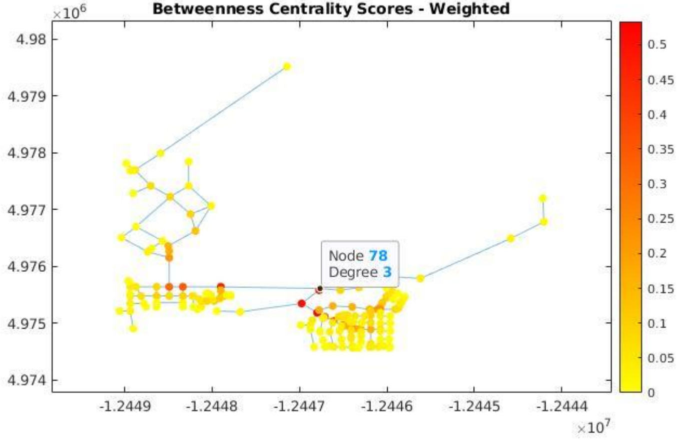


Spatial Network Measures

The lane-based approach supports a static analysis through spatial network measures more commonly used to describe ground transportation systems.

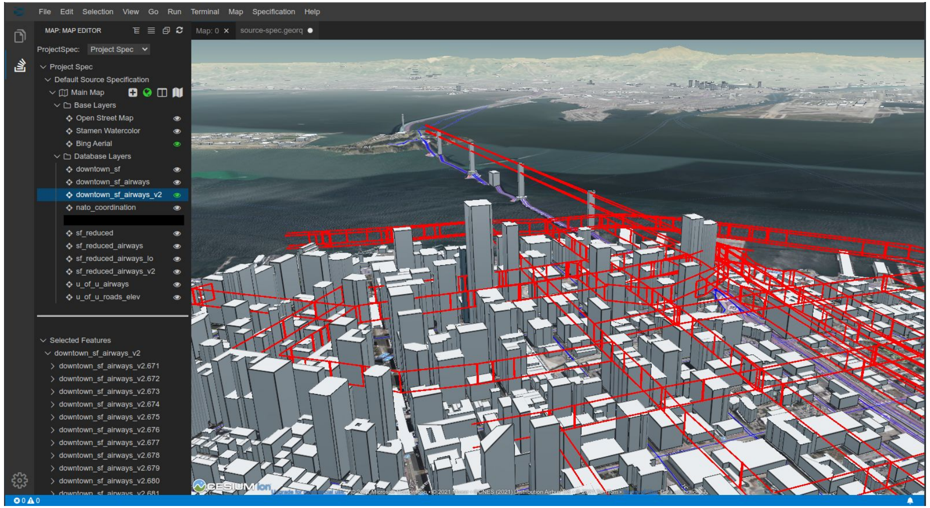






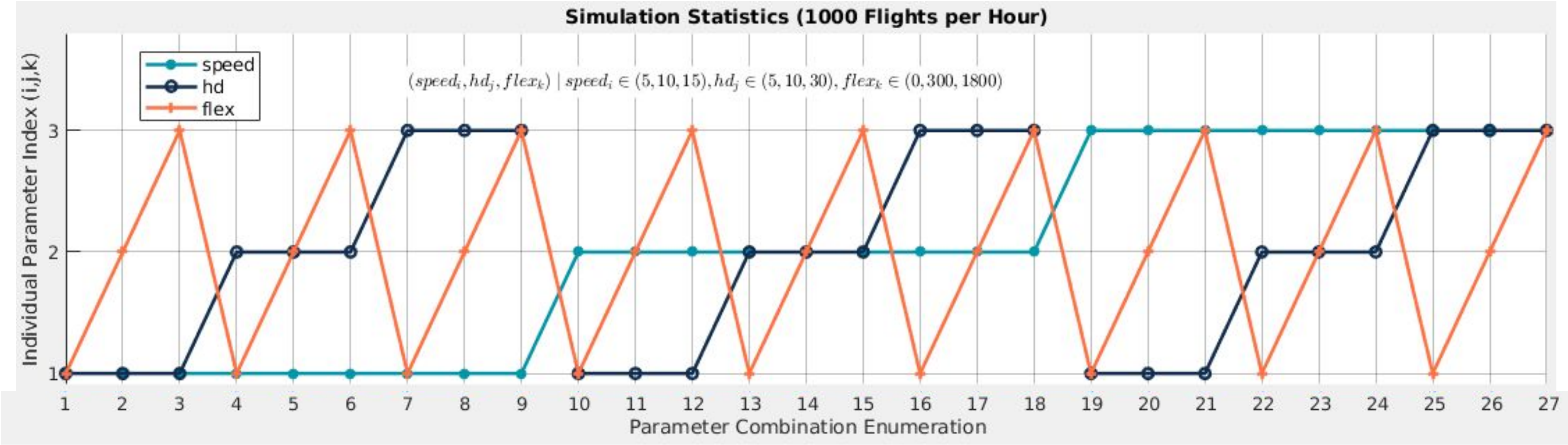
How is UTM Behavior Measured?

- Failed Flights
  - Number of flights that desire a schedule but are denied due to space/time/safety constraints
- Delay
  - How much time between when a vehicle wants to launch and when it is allowed to launch
- Deconfliction Time
  - How much time is required to plan a trajectory



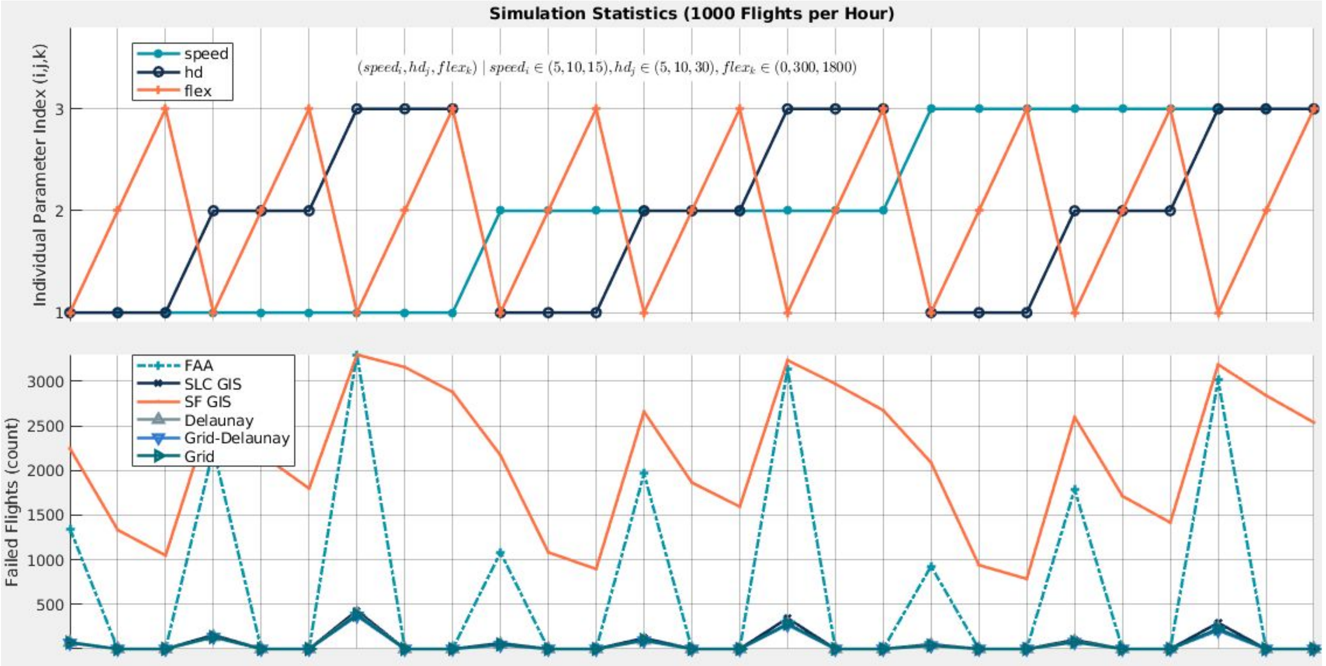
UTM Comparison

27 combinations of UTM parameters tested, 10 simulation runs each, 4 hour sim time



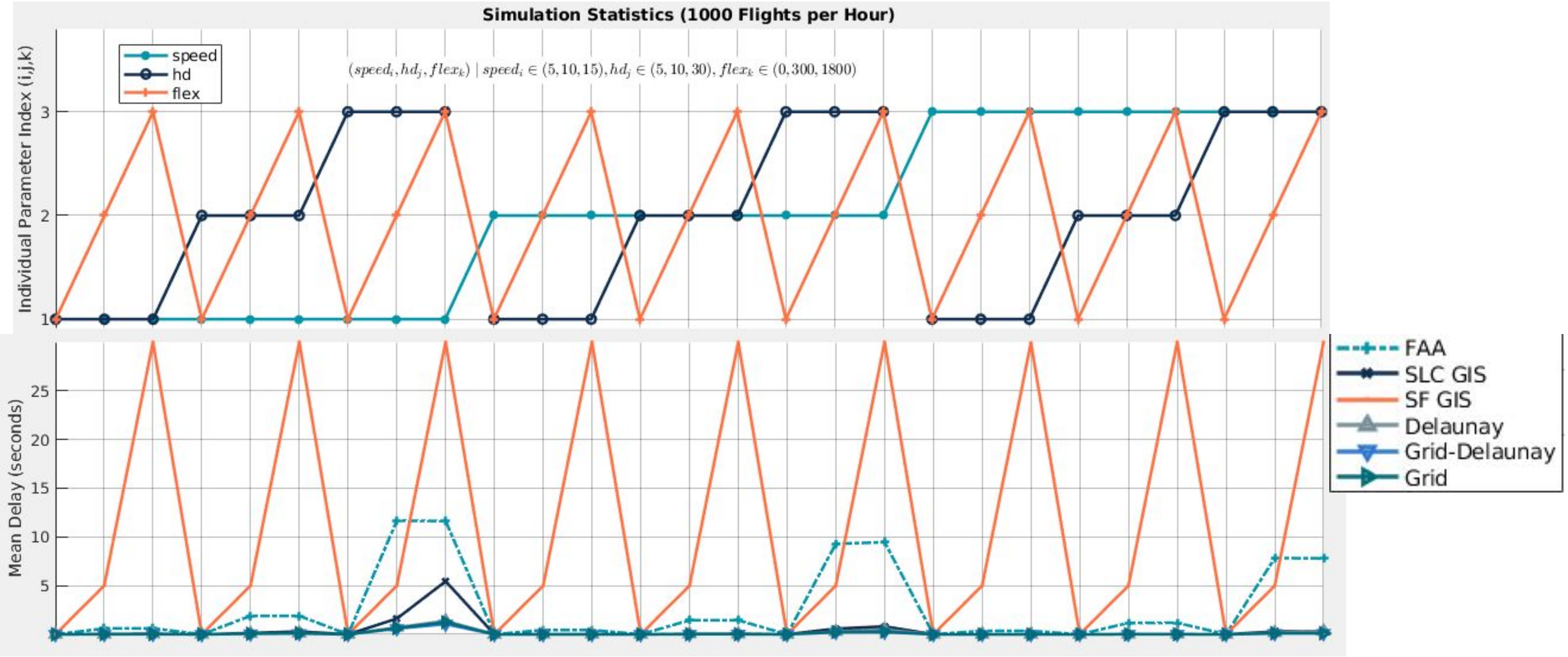
UTM Comparison

Failed flights count operations that could not be scheduled



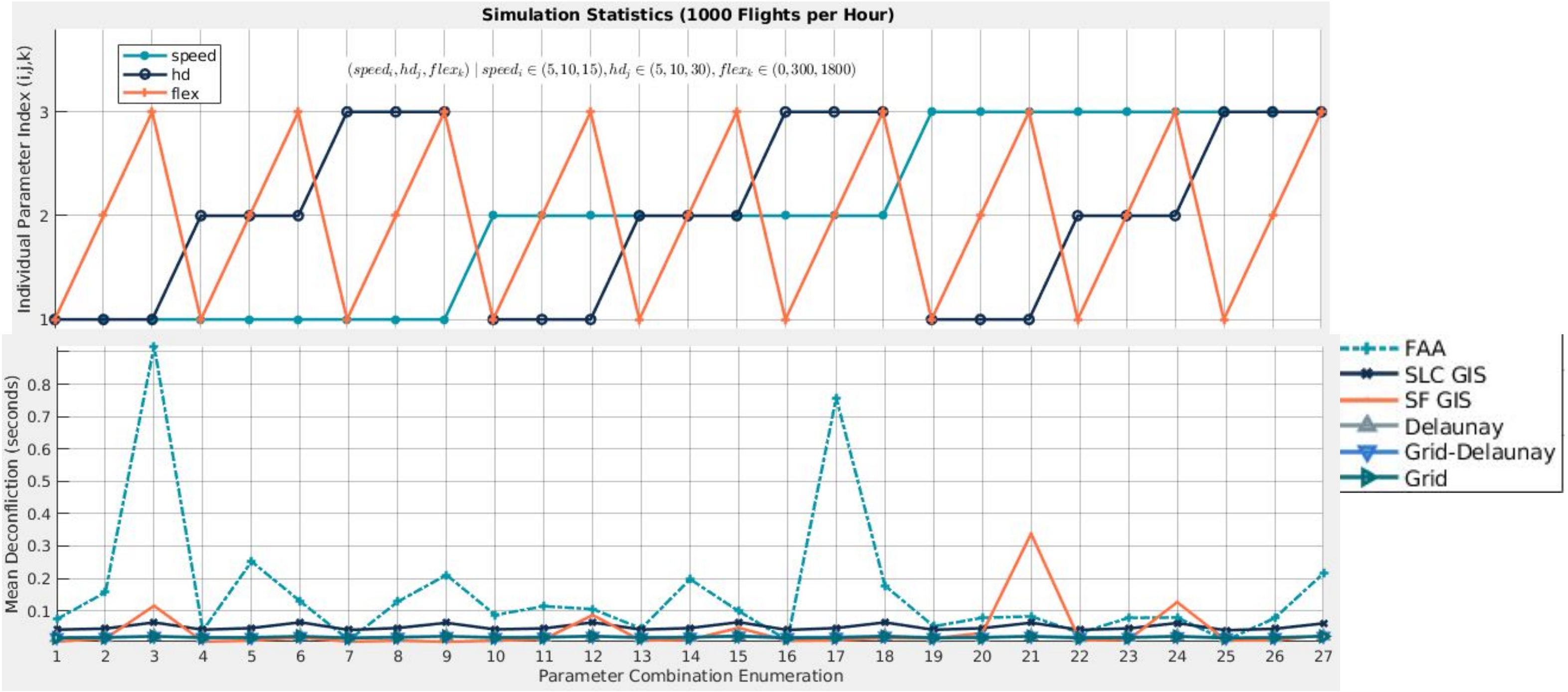
UTM Comparison

Mean delay



UTM Comparison

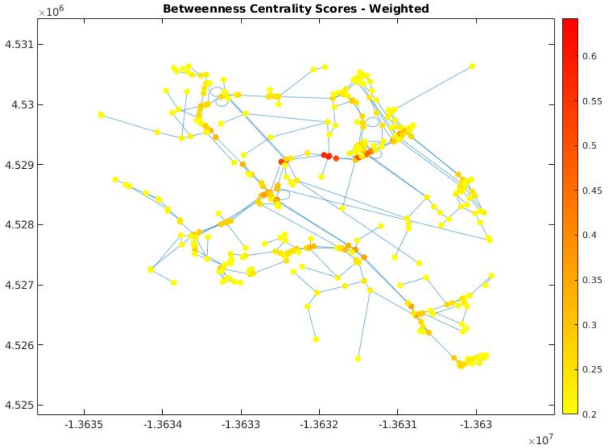
Mean Deconfliction Time (wall clock)



UTM Comparison

Low flex, low speed, high headway → more failed flights (less airspace capacity)
- FAA and SF most sensitive
- Many SF choke points (high betweenness centrality)

Structured airspace deconfliction time lower on average



CONTINGENCIES

UAS Behaviors and UTM Policies

Contingencies

UTM Policies (CPAD)

Algorithm 1: Closest Point of Approach

∀ active flight, f
if f enters a new lane
    OR a neighboring flight has slowed
    OR f has reduced speed on its own
then call Deconflict_Pair for all flights in neighboring lanes
if f has reduced speed
then f broadcasts this information.

Deconflict_Pair

while conflict(f_1,f_2)
    reduce speed, s_1, of f_1
    if $s_1 < s_{min}$
    then flight f_1 fails

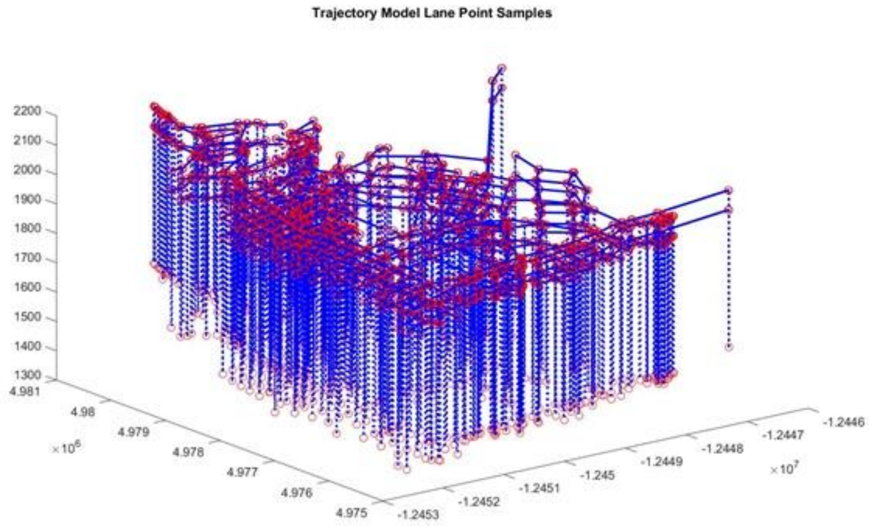
Table 1: Delays and Failures in Experimental Simulations

t_{max}	n_f	s_{max}	Wait	Fly	Done	Fail	Avg Speed	Delays
100	100	5	1	18	81	0	4.98	2
			2	12	86	0	4.98	2
			0	15	85	0	4.99	1
			0	11	89	0	4.98	2
			1	18	81	0	4.96	4
	means		0.8	14.8	84.4	0	4.98	2.2
100	100	9	0	11	89	0	8.98	1
			1	8	91	0	8.94	2
			0	12	88	0	8.99	0
			0	6	94	0	8.99	0
			0	11	88	1	8.98	0
	means		0.2	9.6	90	0.2	8.98	0.6
200	200	5	0	14	186	0	4.96	6
			0	11	189	0	4.97	8
			0	17	183	0	4.98	6
			1	13	186	0	4.99	10
			0	6	194	0	4.96	9
	means		0.2	12.2	187.6	0	4.97	8.6
200	200	9	0	7	193	0	8.96	4
			1	6	193	0	8.97	2
			0	8	192	0	8.97	4
			0	7	193	0	8.98	3
			0	4	196	0	8.97	2
	means		0.2	6.4	193.4	0	8.97	3

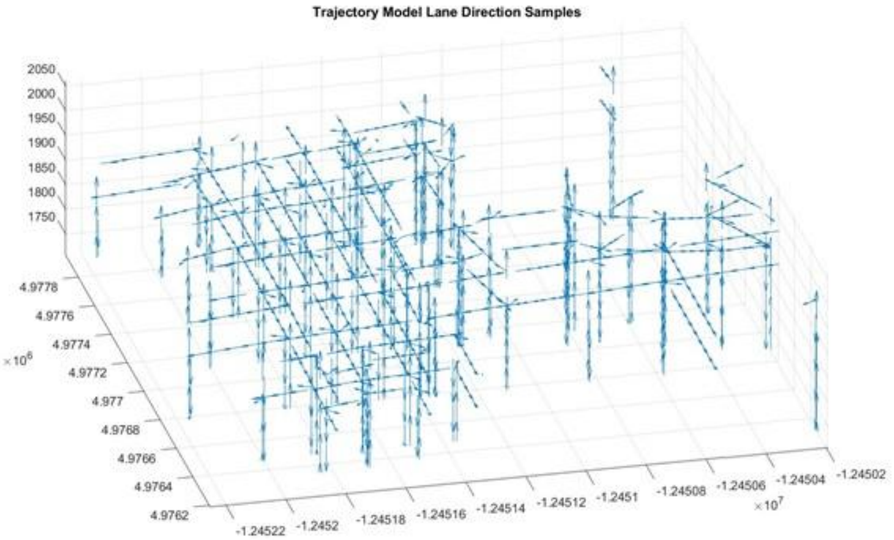
MONITORING THE AIRSPACE

Detecting Anomalies and Rogue Aircraft

Lane-Based Trajectory Model



Lane Point Samples

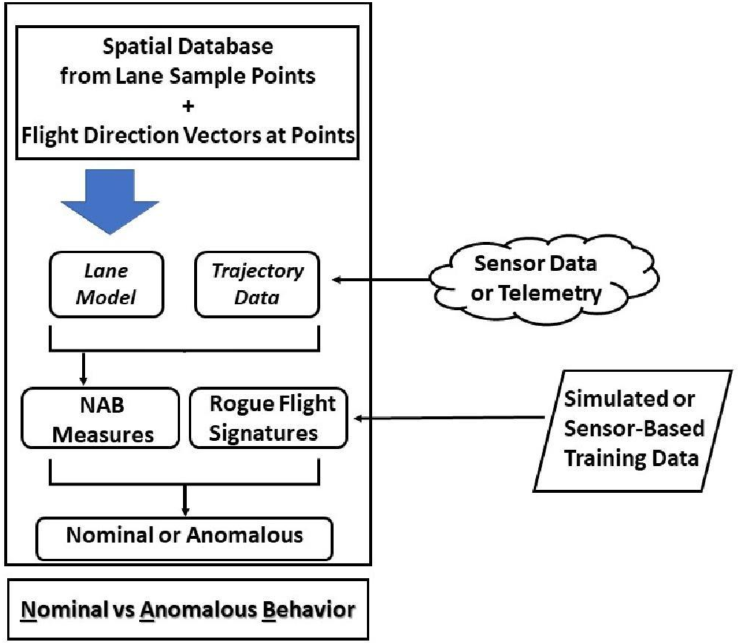


Lane Direction Samples

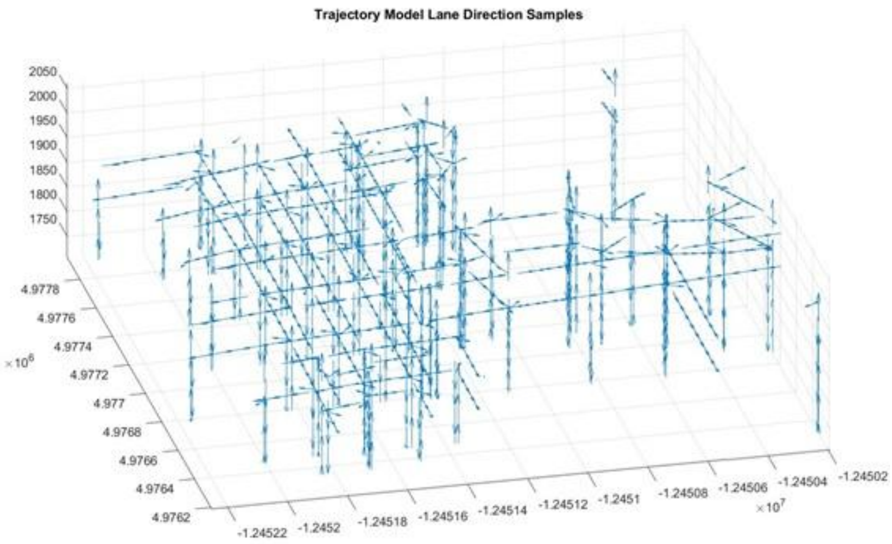
Detecting Anomalies

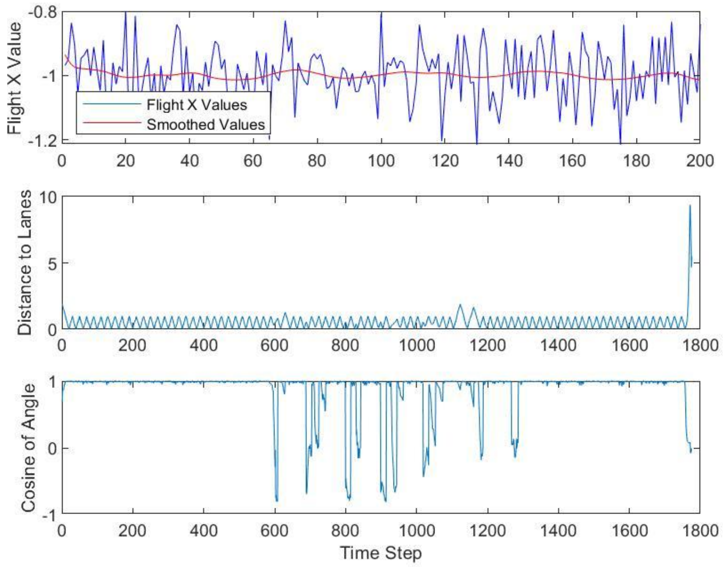
Nominal vs. Anomalous Behavior or (NAB)

- A system for detecting, tracking, and characterizing airspace traffic
- Can detect rogue, hobbyist, and conforming aircraft
- Output can be fed into neural nets for further classification



Nominal Trajectory Behavior





Anomalous Trajectory Behavior

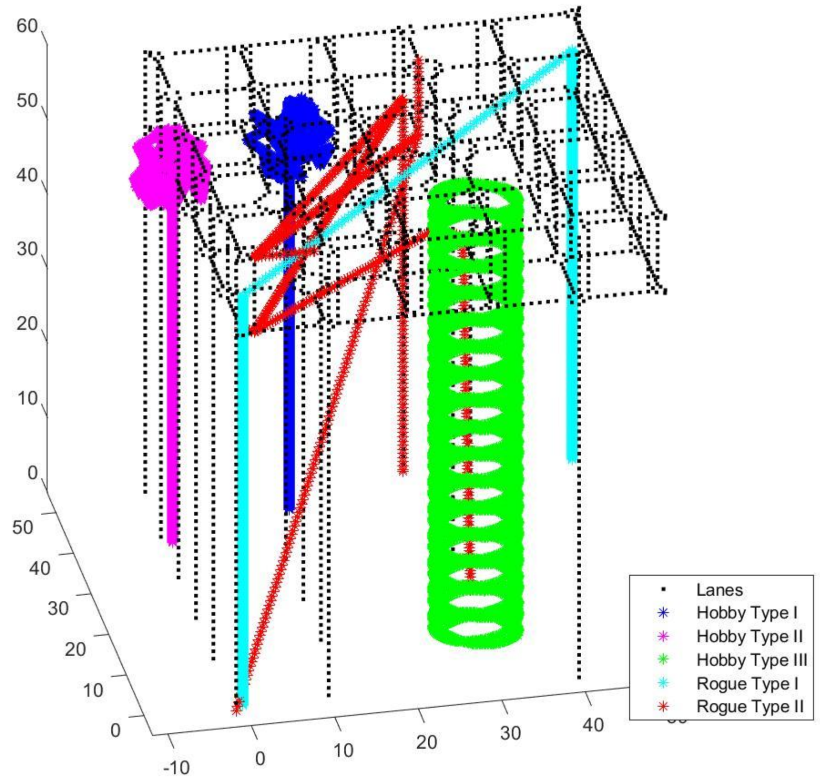
Hobbyist Type I: Flies up from one place and makes a few moves above the launch site, then eventually lands at the same site.

Hobbyist Type II: Flies up from one place and makes a few moves above the launch site, hovers after each move, then eventually lands at the launch site. –

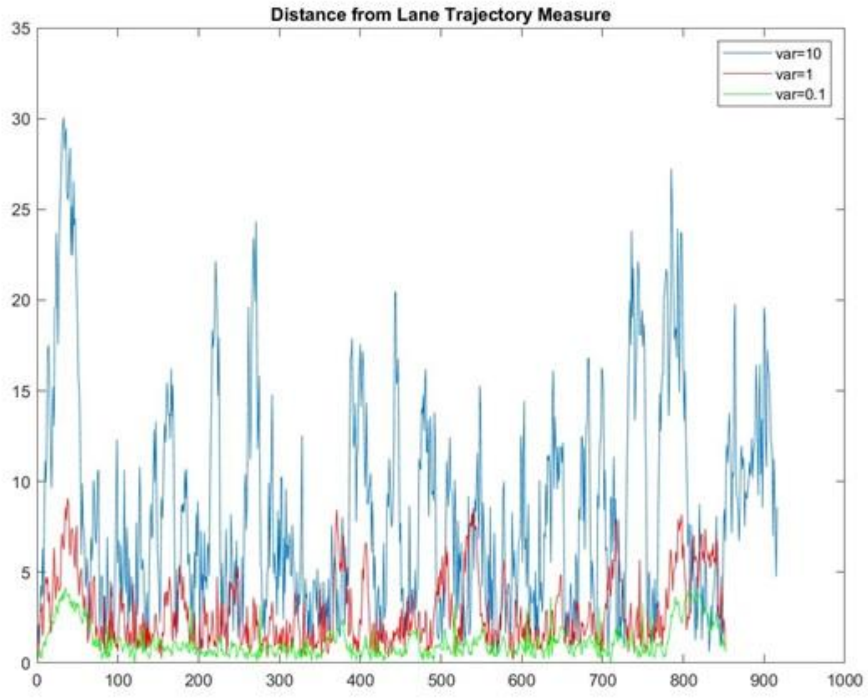
Hobbyist Type III: Flies up in a circular motion to some highest point then flies down in a circular motion to land.

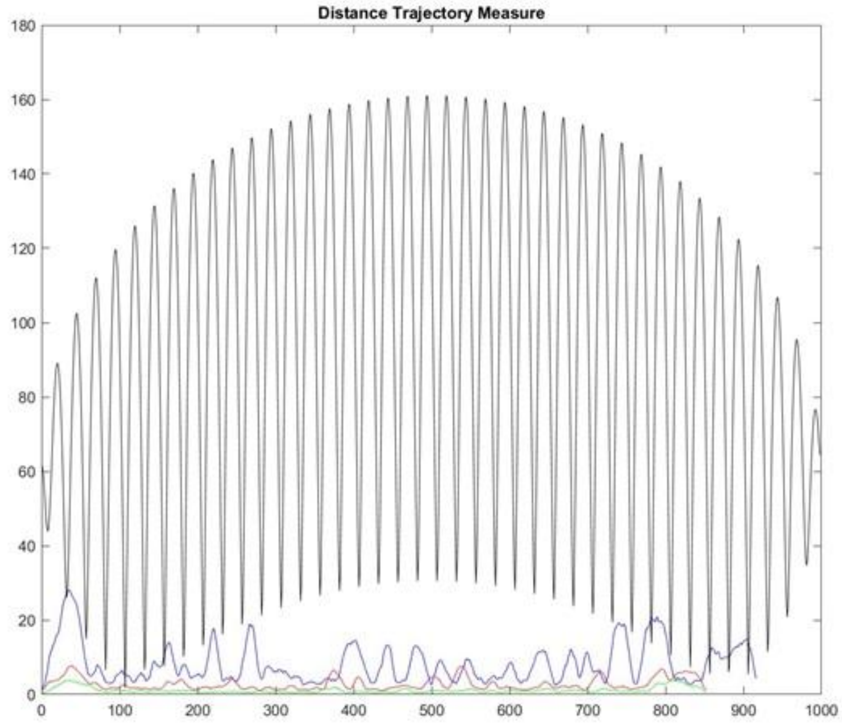
Rogue Type I: Flies up over and down as for a delivery.

Rogue Type II: Flies up to a lane, flies along the lane to the end, then flies to another lane (not necessarily connected), and eventually flies down to land.



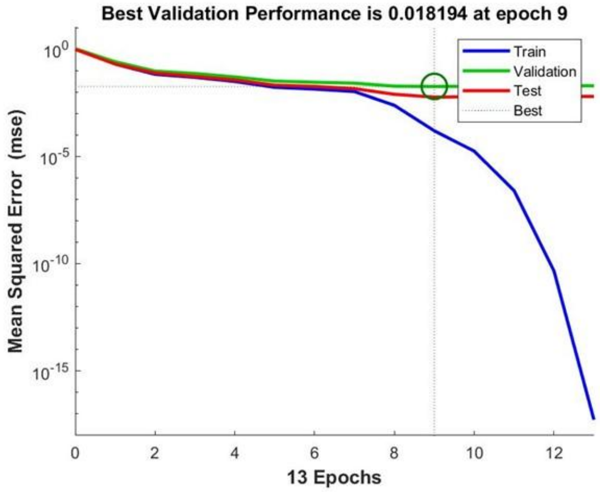
Anomalous Trajectory Behavior

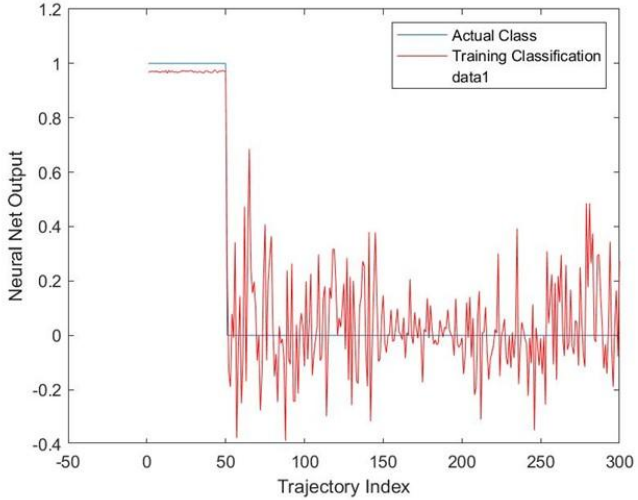




Classifying Anomalies

Simple feed-forward network classification of nominal/anomalous





Cyber Security

The Attack Landscape

		Attacked Asset	
		Physical	**Cyber**
Attack Type	**Physical**	*Physical Attacks* - Sabotage of infrastructure - Physical weapons to disable UAS - Coercion of authorized persons	*Cyber-Physical Attacks* - Radio signal jamming - Compromising unattended sensors - EM radiation-based attack on security keys
	Cyber	*Cyber-Physical Threats* - ADS-B/GNSS spoofing - Sensor data manipulation - Telemetry data/link manipulation	*Cyber Attacks* - Malware insertion - Network traffic analysis - Data theft and corruption - Identification spoofing - Cryptanalysis

The Attack Landscape

Likelihood Level	Quantification of Likelihood
Extremely Improbably	Zero-day exploit available; multi-lateral staged attack; +$10M in cost
Improbable	$1M-$10M in cost; complex mission planning with staff; bot herder, fleet of bots
Remote	Multi-thousand to millions of dollars in cost; sophisticated malware, ransomware, phishing, etc.
Occasional	Unsophisticated malware
Frequent	Low cost or free; pay-for-hire

Conclusion

Conclusion

Is the system for managing UAMs moving in this direction?

Airspace Structure Definition Service (ASDS)!

Continuing/Future Work

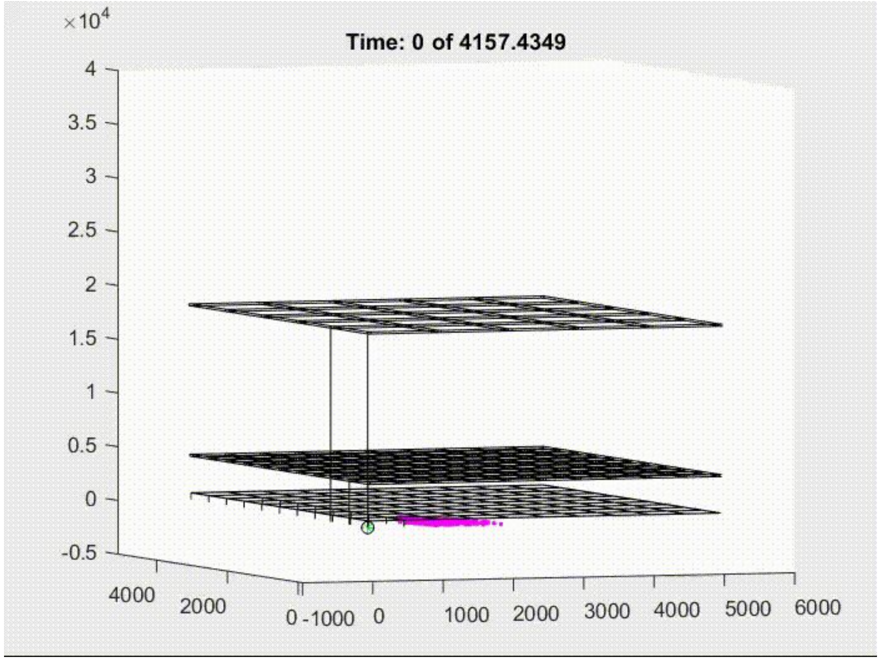
Utah Advanced Air Mobility Simulator (UAAMS)

AFWERX Phase II

- Multi-Domain Deconfliction
- Department of Defense Applications

Continuing Research

- Incorporating Vehicle Models
- More Contingency Modeling



Thank You