Likelihood of Unmitigated Collision Risks for Unmanned Aircraft Systems (UAS) in Defined Airspace Volumes

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Agenda

- Objective – The Safe Integration of UAS into the National Airspace System (NAS)
- Likelihood of Unmitigated Collision Risks (UCR) for UAS in Defined Airspace Volumes
    - Quantitative Airborne Collision Risk Assessment
    - Statistical Procedure Walkthrough
- Summary

Objective - The Safe Integration of UAS into the NAS

- UAS are becoming key resources in areas such as tourism, real estate, recreational/competitive use, and others
  - With this broad range of applications in mind, the risk associated with these operation types must be considered

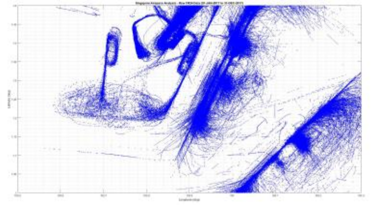
- Key Questions
  - How do we assess the risk of integrating UAS into the NAS?
  - Can we quantify the collision risk between UAS and manned aircraft?
  - How can we use statistical techniques to compare collision risks between different volumes of airspace?

Quantitative Airborne Collision Risk

Airborne Collision Risk Assessment Workflow

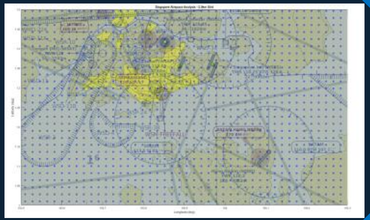
Query Traffic Database

- Threaded Track historical traffic database is queried for the region of interest
- Enough historical traffic data for statistical significance and relevance
- Spans CONOPS airspace
- Characterize the airspace



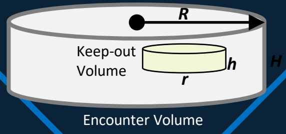
Define Grid Points of Interest

- Based on CONOPS
- Defined by airspace and altitude
- Defined by the resolution needed for the assessment



Define Encounter and Keep-out Geometry

- Defined by UAS operational parameters
- Keep-out based on assessment type (collision)



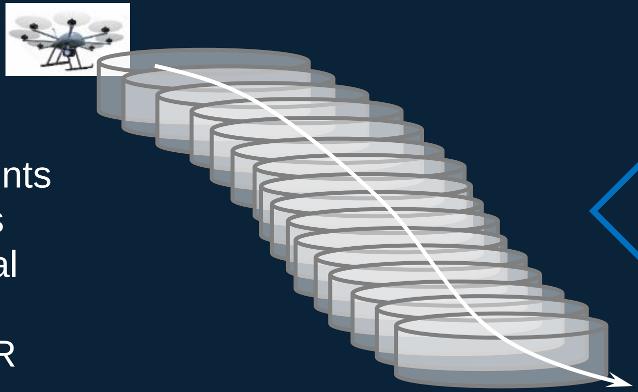
Volumetric Collision Risk Methodology

Calculate UCR for the Grid Points of Interest

- Filter air traffic data to discrete points
- Evaluate the rate that filtered traffic hits a keep-out volume
- The result is an unmitigated collision rate (UCR) is associated with any 4-D (lat/lon/alt/time-of-day) when sufficient historical traffic data is available

Map UCRs from Grid to UAS Trajectory

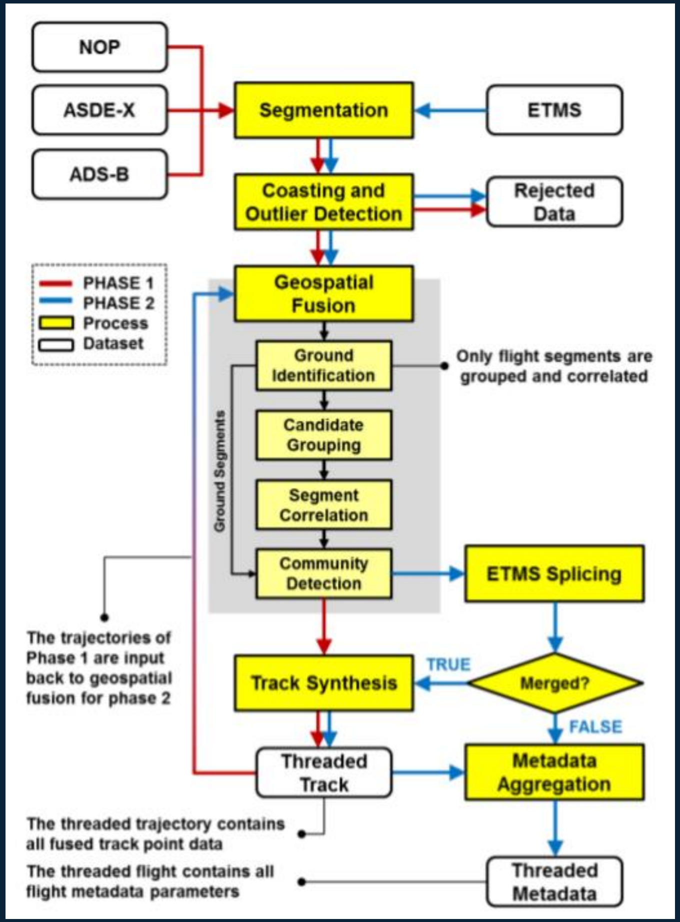
- If CONOPS specifies a trajectory, map flight path points to closest grid location UCRs
- If CONOPS specifies a lateral area and altitude, review corresponding grid point UCR values



Threaded Track & Flight Story (TTFS)

- Historical analysis of aviation systems often requires aircraft flight trajectories that traverse multiple regions of coverage, preferably in high fidelity gate-to-gate measurements
  - MITRE began the development of the Threaded Track which is the compilation of all available surveillance sources into a synthetic trajectory that represents an optimal representation of an aircraft's end-to-end trajectory
  - Developed, verified, and validated a robust and efficient methodology to associate data from distinct surveillance sources simply by examining spatial and temporal proximity

Threaded Track Process Workflow

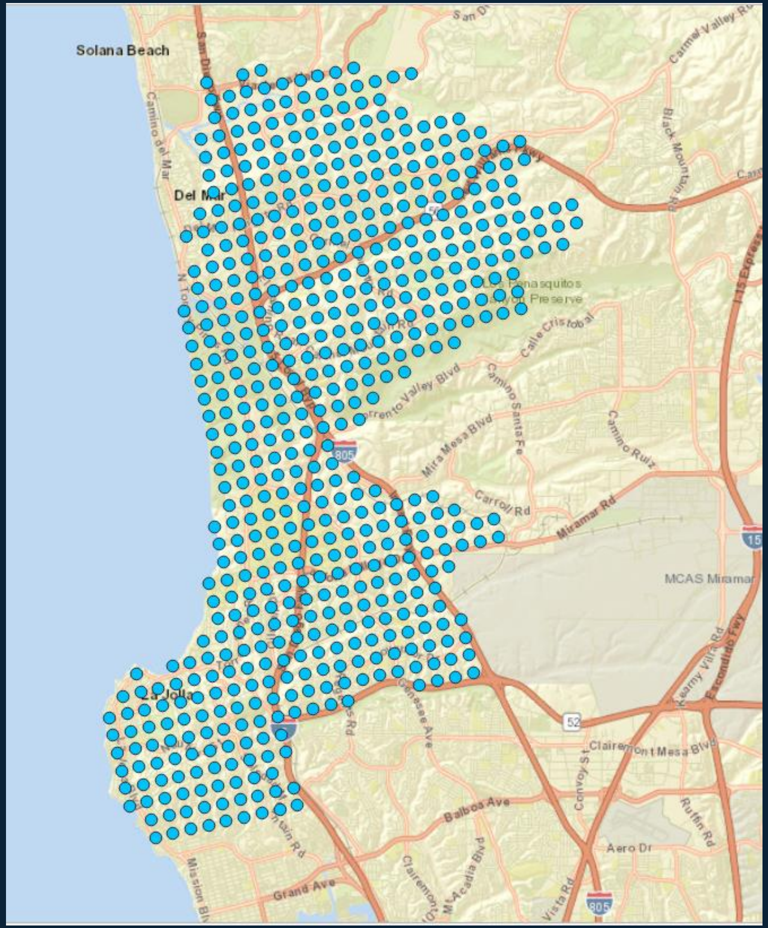


* https://www.mitre.org/sites/default/files/publications/pr-17-3649-geospatial-data-threaded_track.pdf

Defining Grid-Points of Interest

- A grid is generated within the polygon to perform an airborne collision risk analysis
  - Polygons can be defined as, but are not limited to
    - Custom operational areas
    - Class of airspace definitions
    - ARTCC boundaries
- Grid location(s) define the center of the *Encounter Volume(s)*
- Defining a grid allows the analyst to measure the variation in airborne collision risk throughout the polygon
  - The resolution of the grid is tunable based on the desired granularity

Example Gridded Polygon



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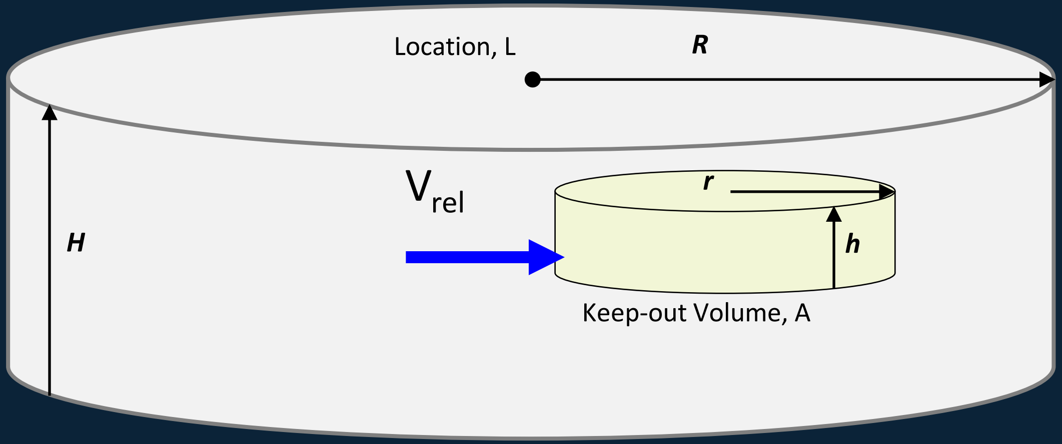
Defining the Encounter Volume

- The operational area is divided into cylinders of airspace called Encounter Volumes
- The probability based on collected air traffic data for the area under investigation

Example Dimensions

- H: Operational Airspace (1000’)
- R: 5 NM
- A: Keep-out volume (NMAC)
  - r: 500’
  - h: 200’

Encounter Volume, B



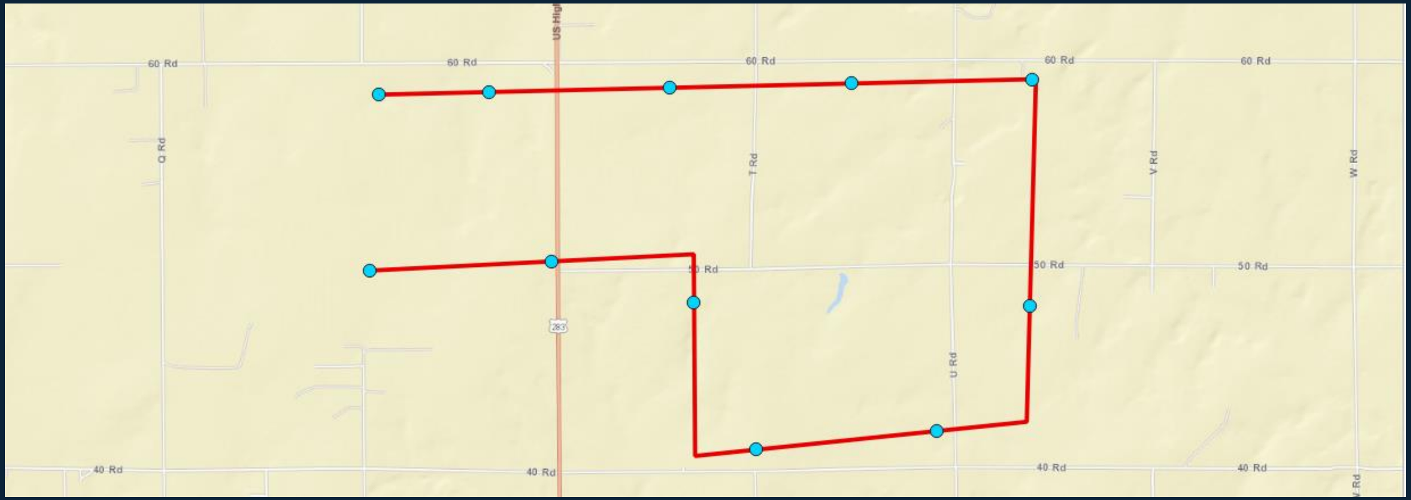
Calculating Unmitigated Collision Rate

- The calculation uses a modified Endoh gas-model
  - Instead of using the randomness of a gas-model, this model considers directionality and the time-variant nature of the airspace density
    - Historical air traffic data is filtered to the bounds of encounter volume
    - Relative vertical and horizontal velocities between the manned aircraft and the UAS are analyzed
    - Occupancy time is measured for each manned aircraft within the encounter volume
- Result is an unmitigated collision rate (UCR) per flight hour
  - Calculated for each coordinate within a gridded polygon
  - Partitioned by hour of the day (UTC)

UCRs Along a Trajectory

- A trajectory analysis is performed using two techniques
  - In a pre-defined grid, assessing the grid locations closest to the trajectory
  - Performing the analysis on a “segmentized” path
    - Segmentizing a path creates equally spaced waypoints along a trajectory
    - For example, a 5NM route is analyzed at 1NM-spaced waypoints

Example Segmentized Trajectory – 1NM Spacing



Statistical Procedure Walkthrough

With Class-D Example

Assessing Unmitigated Collision Risk Distributions

- Compare the distributions of UCRs across multiple georeferenced polygons
  - Leverage hypothesis testing to detect statistically significant differences between the means
  - Pinpoint which distributions of UCRs displayed significant differences
  - Measure the strength of these differences

Prepare Hypothesis Test

- The hypothesis test begins with an assumption
  - All samples of Class D UCRs come from the same population distribution with a true mean, μ, and true variance σ^2
  - Therefore, all samples must have the same true mean and variance
- With respect to Class D Airspaces, we are hypothesizing that the true mean UCR for all Class D Airspaces is equal (The Null Hypothesis, H_0)

$$H_0: \mu_1 = \mu_2 = \cdots = \mu_\mathrm{h}$$

$$H_a: not\ all\ \mu_i\ are\ equal$$

Where,

h: $the\ number\ of\ Class\ D\ Airspaces$

i: $the\ index\ of\ a\ particular\ Class\ D\ Airspace\ UCR\ sample\ distribution$

Assess the Results

- After performing the test, we obtain a p-value
  - Defines if we can reject our claim that all true means are equal, or if we have insufficient evidence to prove that claim
  - For this example, p-values less than 5% signify statistically significant evidence
- If we obtain a p-value less than 5%
  - We have statistically significant evidence that at least one of the Class D distributions of UCRs has a different true mean
  - With a different true mean, this distribution cannot come from the same population
- If we do not obtain a p-value less than 5%
  - We do not have sufficient evidence to say that the true means of the class D sample distributions are different

Analyzing the Differences

- If we find that there is a statistically significant difference, we must now find out which distribution of UCRs had the difference
- Perform a Post-Hoc test
    - Analyzes pair-wise differences across groups to find which group(s) caused us to reject the null hypothesis while minimizing family-wise error

Example Pair-wise Comparison

$$\mu_1 = \mu_2$$

$$\mu_2 = \mu_3$$

$$\mu_3 \neq \mu_4$$

$$\vdots$$

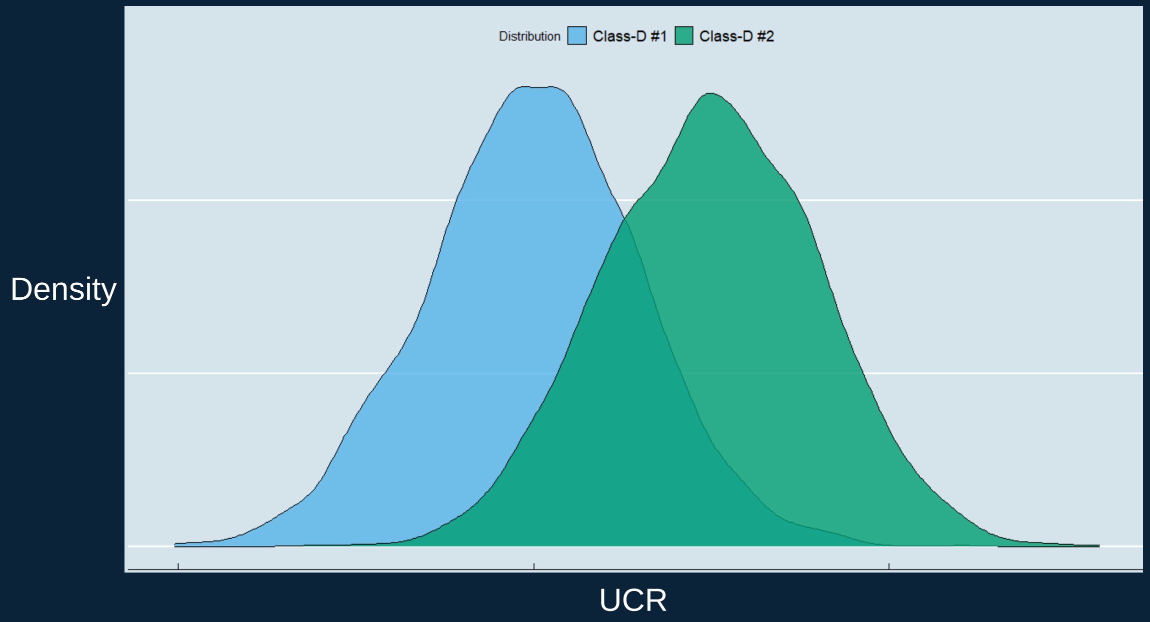
$$\mu_1 \neq \mu_4$$

The Post-Hoc test tells us exactly which pairs are different. We will use this information to build our future subcategories.

Measuring the Magnitude of Differences

- Having too large of a sample size can be misleading
  - Hypothesis tests are sensitive to large sample sizes
  - May reject H_0 when we shouldn’t due to over-sensitivity
- Calculate the effect size for each pair that showed a difference
  - Effect size tells us how strong the relationship was between two variables while accounting for sample size

Pairwise Comparison of UCR Sample Distributions



Summary

What Have We Learned?

- Defined a quantitative methodology to assess the unmitigated collision rate between the UAS and many manned aircraft in a defined volume of airspace
  - Replaces subjective estimations of risk with quantitative measurements
  - Establishes a repeatable, data-driven methodology based on historical manned traffic data
- Discussed a methodology to analyze the UCR distributions
  - Quantifies “how different” volumes of airspace are in terms of collision risk

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Thank you!

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