# Flight Validation of a Time-Critical Autonomous Drone Swarm System

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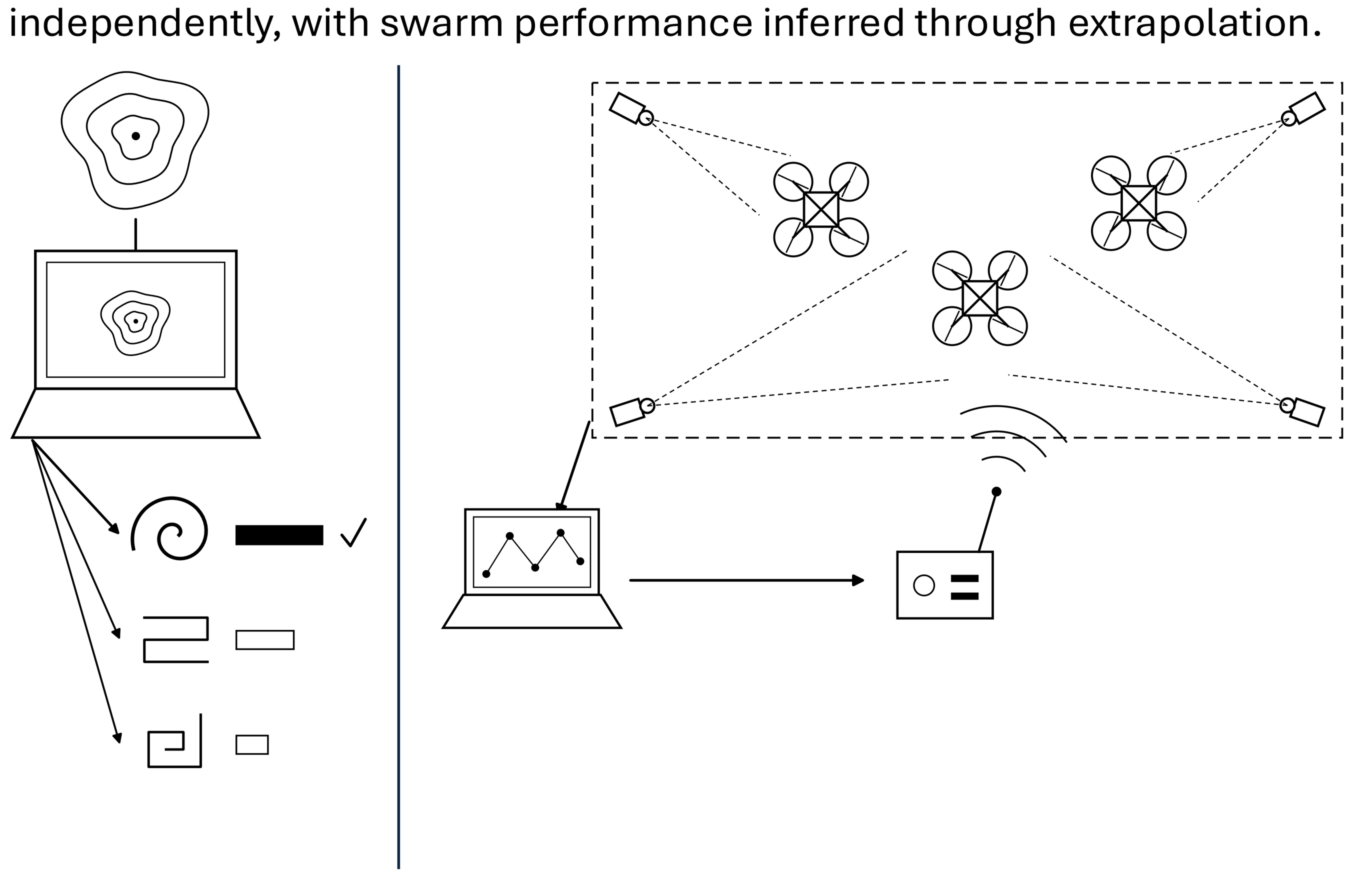
## Abstract

Previous work has characterized multirotor flight in motion-capture arenas with millimeter precision, quantifying trajectory tracking error, and has measured sim-to-real degradation in mission time and area coverage. Both evaluate how a vehicle follows a path, rather than whether the search strategy encoded in that path retains its advantage once flown. A maritime SAR simulation environment was developed to evaluate multiple search algorithms across diverse probability fields and environmental conditions. The resulting performance data were used to train a neural network (MLP) capable of selecting the most effective search strategy for a given scenario. Multiple search strategies were flown repeatedly across a range of belief fields in a motion-capture volume, each flight paired with a simulation of its own plan under identical conditions. The strategy selected in simulation remained the best performer in flight in every environment tested, although execution cost roughly one quarter of absolute survival. This loss was dominated by timing rather than path geometry and shrank measurably as mission scale increased.

## Experiment Setup

An autonomous drone swarm was constructed. It receives instructions via an offboard Python controller that calculates and transmits "setpoints". Although a fully functional three-drone swarm was developed, experimental data were collected using a single drone to eliminate aerodynamic interference caused by the confined indoor test environment. This allowed vehicle performance to be characterized independently, with swarm performance inferred through extrapolation.



## Equations

**Time Dependent Coverage**

$$\mathcal{A} = \frac{1}{\tau}\int_0^{\infty} (R_{\varnothing}(t) - R(t))dt$$

**Bayesian Cell Probability Update Function**

$$b_{t+1}(x) \propto (1 - P_D\, 1_{\text{swept}}(x))\, b_t(x)$$

**PID Controller Equation**

$$u(t) = K_p\, e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}$$

**Total Survivability Scorer**

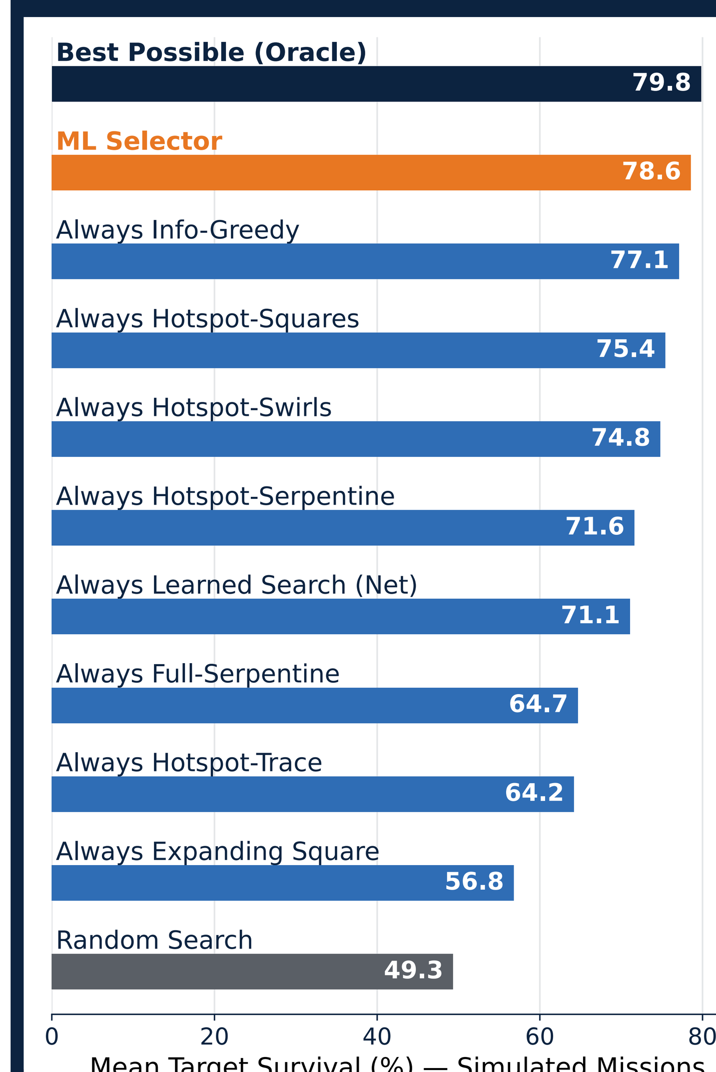
$$S = \frac{1}{N}\sum_{k=1}^{N} e^{-t_k/\tau}$$

Auburn Logo Traced by an Autonomous Drone

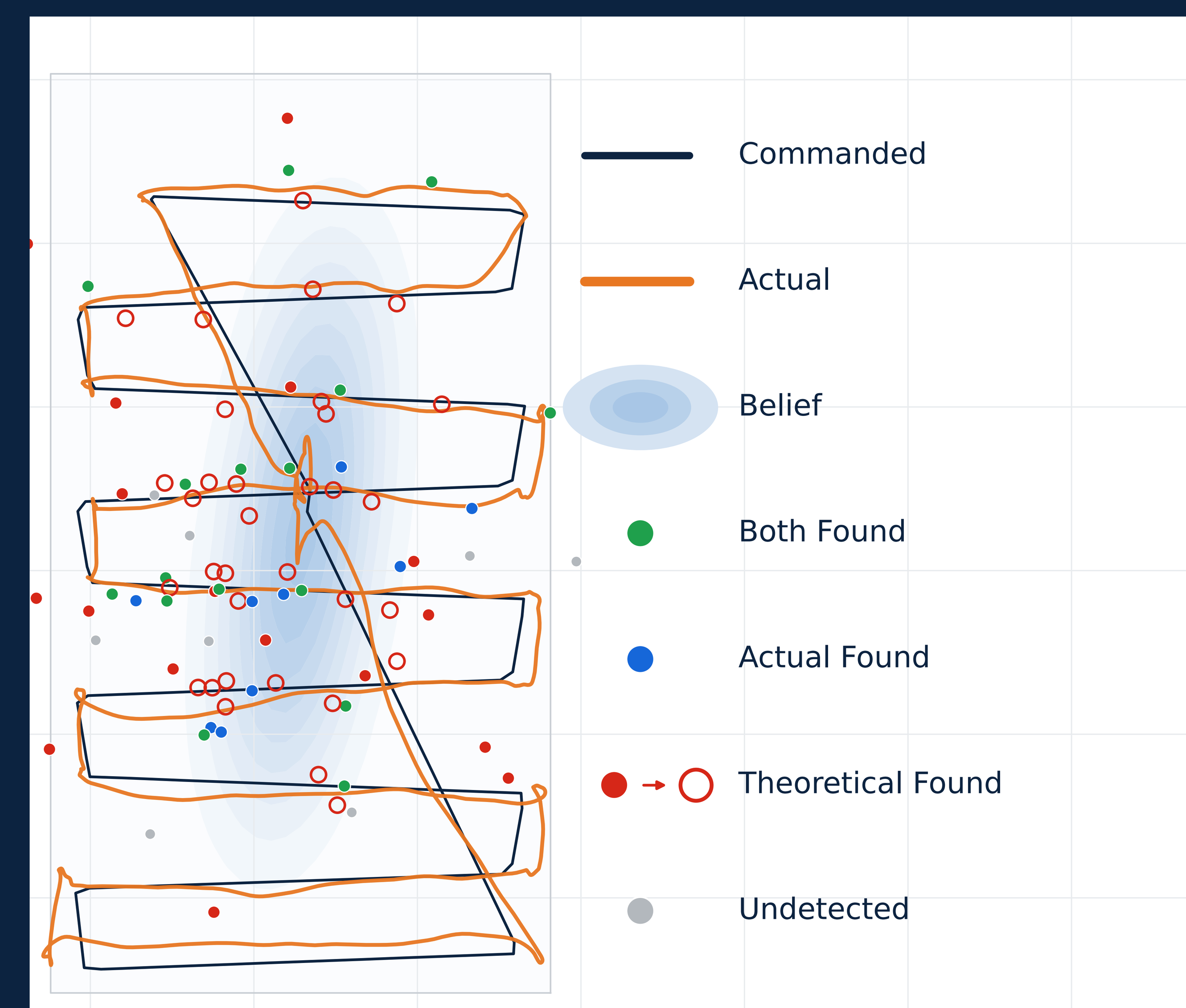
## Methodology

- 176 autonomous flights completed.
- Primary evaluation: 5 distinct probability fields × 6 search strategies × 3 repetitions (90 flights).
- All strategies evaluated on the same field before advancing to the next field to ensure fair comparison.
- Field scaling study: Field size reduced to 100%, 75%, 50%, and 35% using 3 search strategies with 3 repetitions (36 flights).
- Serpentine spacing study: Search line density varied to evaluate its effect on performance.
- All flights conducted above 16.6 V battery voltage for consistent flight conditions.

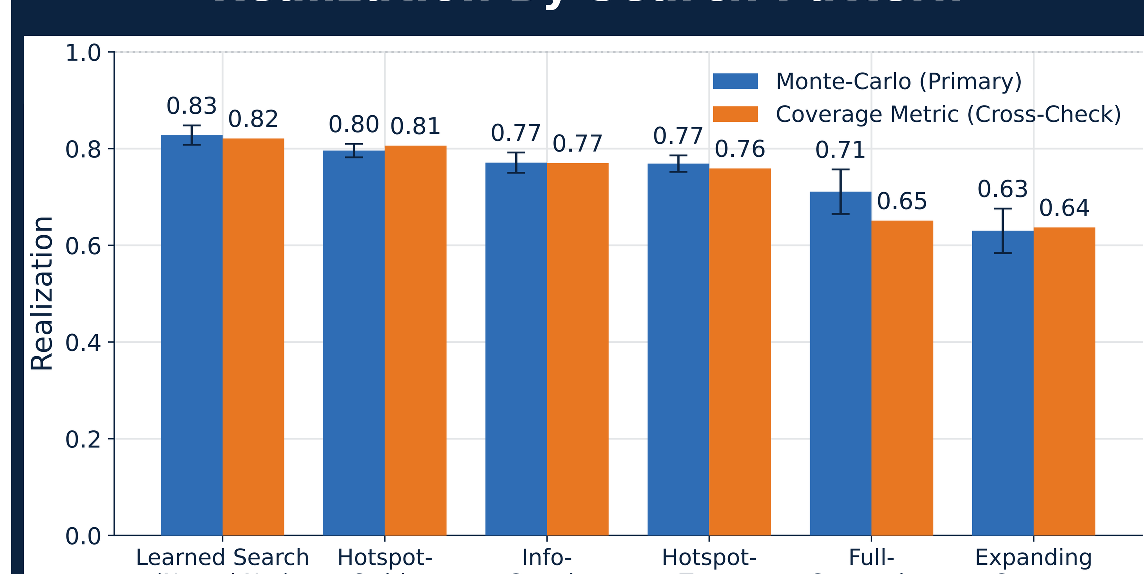
## ML Selector Results



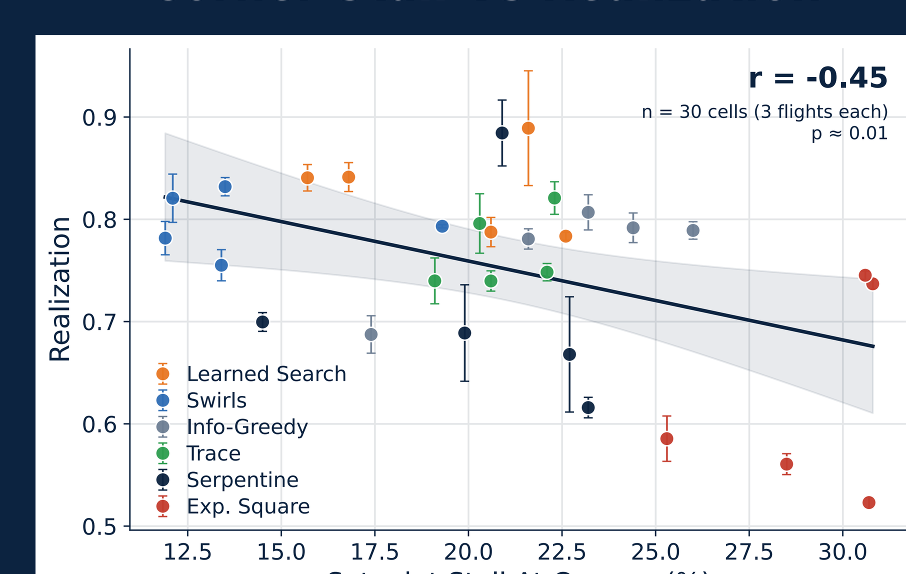

## Retroactive Survival Simulation Of Real Time Flight



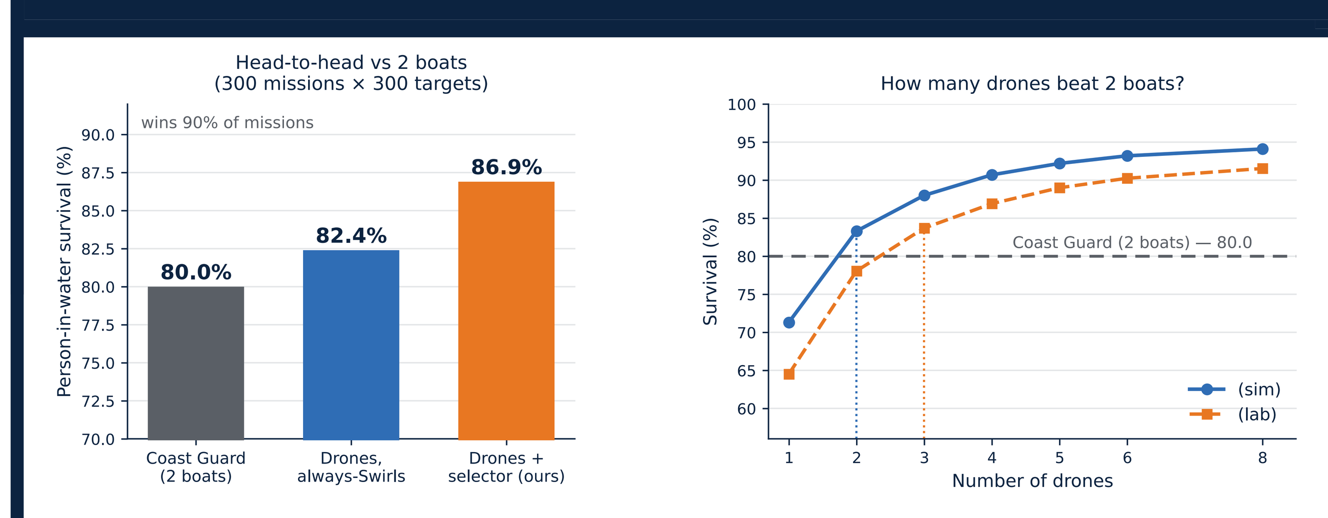

## Realization By Search Pattern



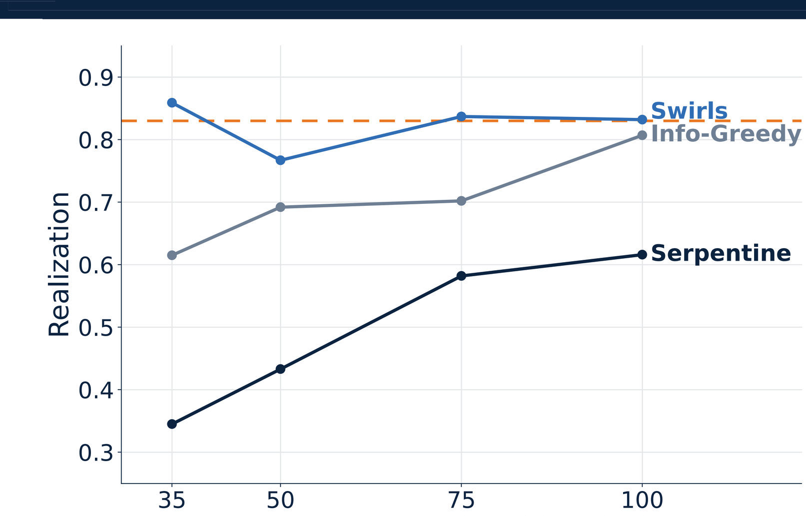

## Corner Stall Vs Realization



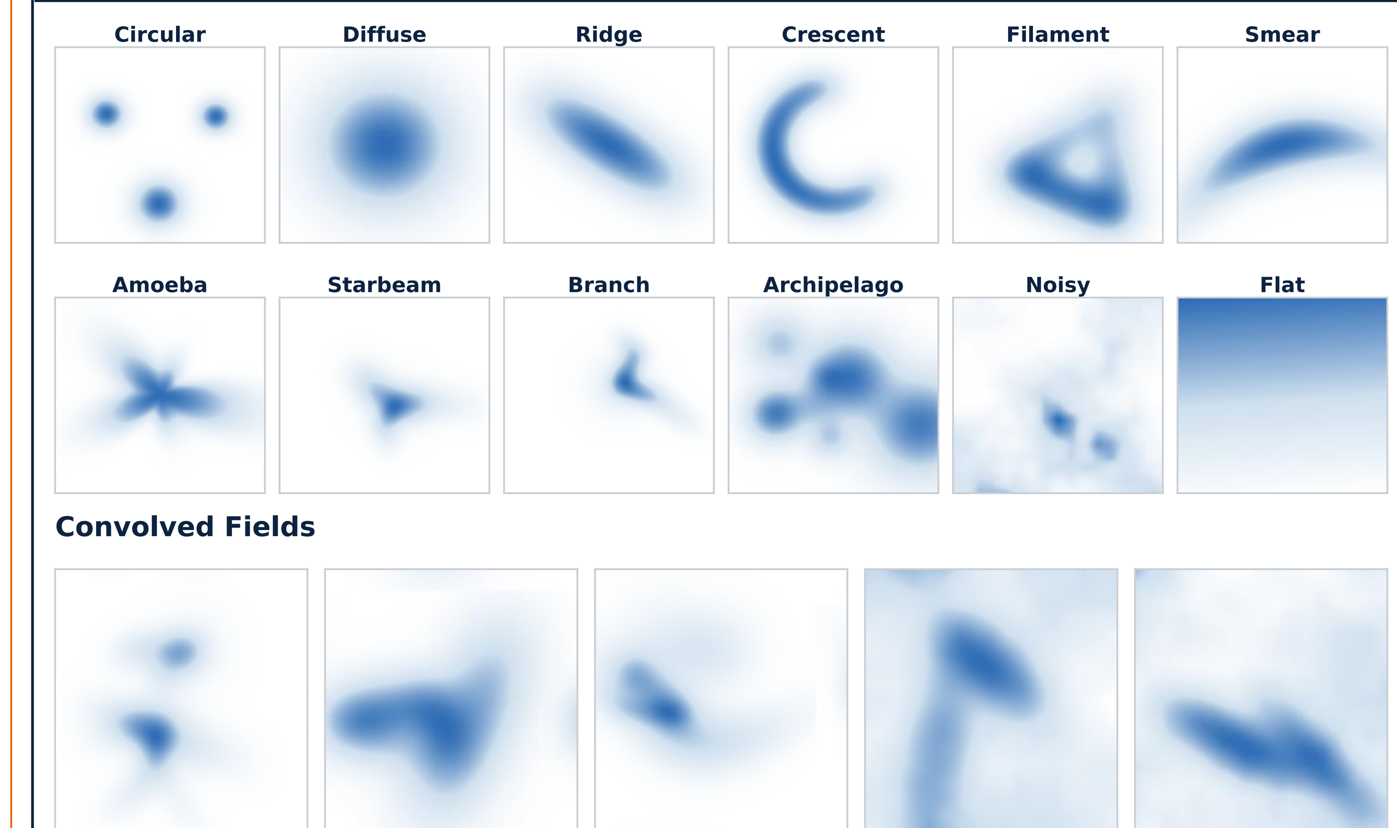

## Drone Swarm Vs The Coast Guard



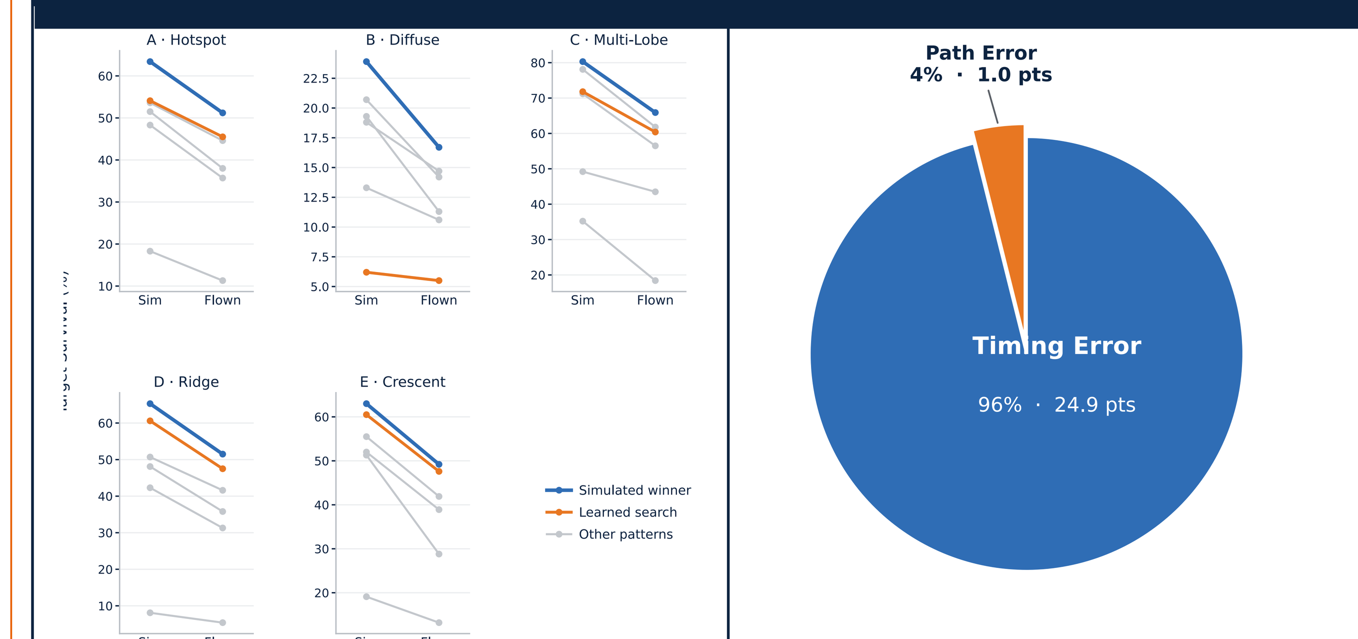

## Realization Vs Mission Scale




## Search-Field Types & Composition



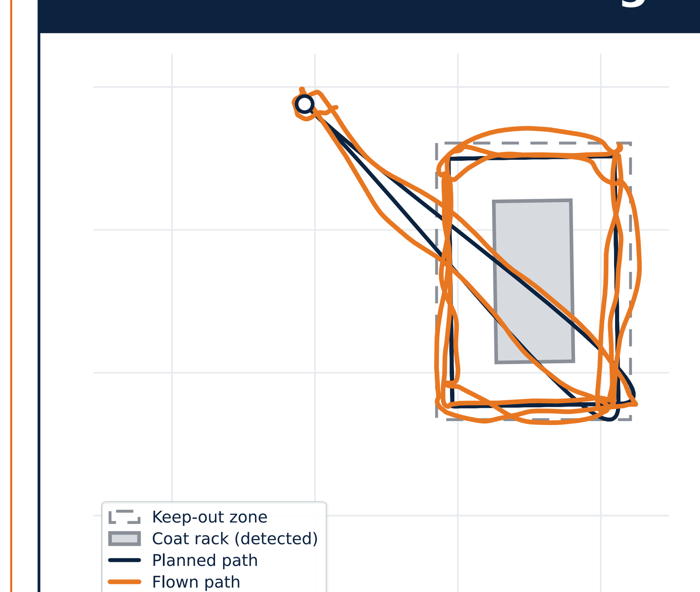

## Realization Loss Characterization



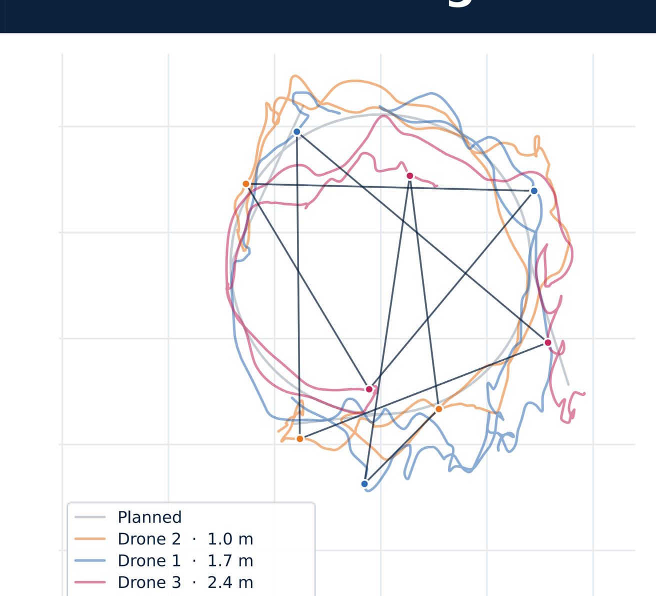

## Future Work & Limitations

This work was validated using a single drone in a controlled indoor environment, with swarm performance inferred through extrapolation. Target detection was simulated rather than performed onboard. Future work will integrate onboard computation, real-time target detection, adaptive replanning, and experimental validation of multi-drone coordination in outdoor maritime environments.

## Detection & Planning




## 3-Drone Flight

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