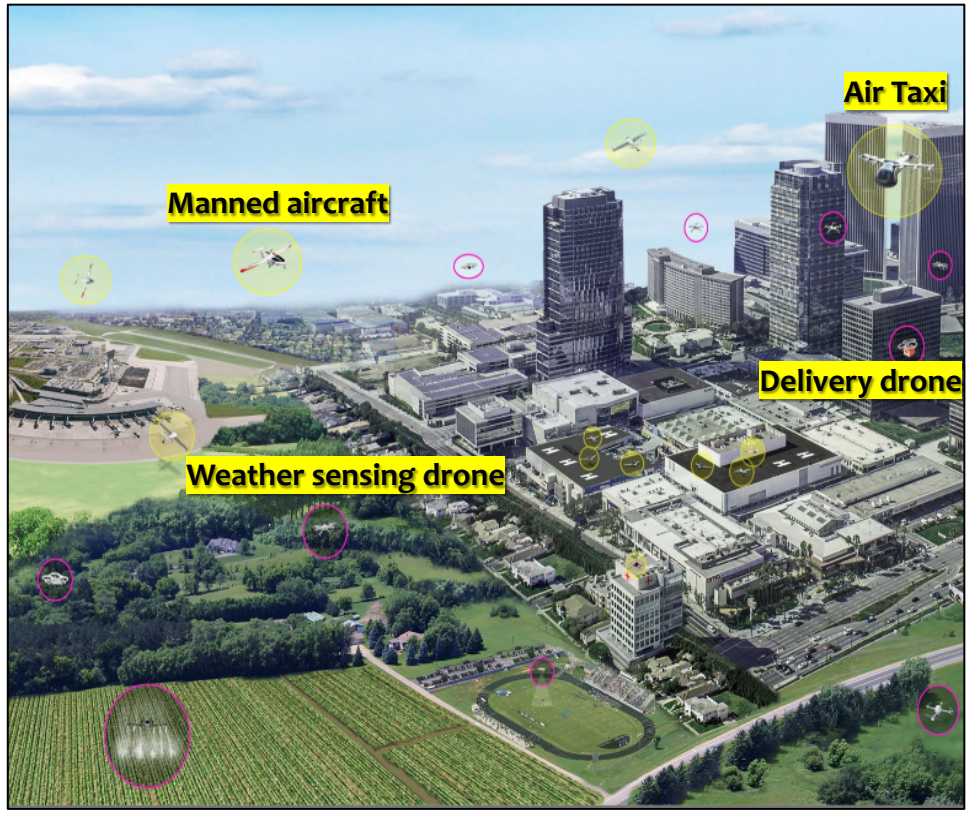
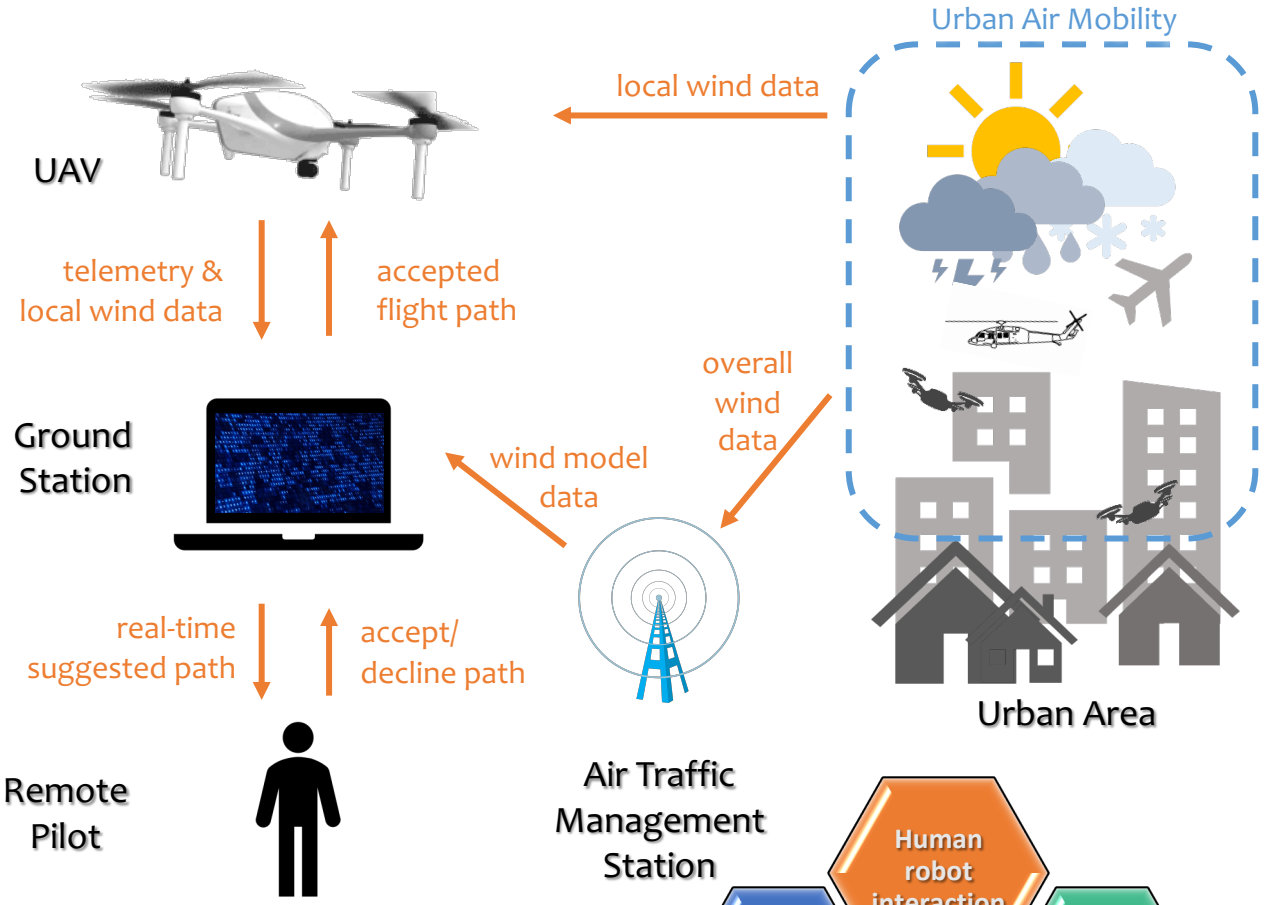
NRI INT: Safe Wind-Aware Navigation for Collaborative Autonomous Aircraft in Low Altitude Airspace

MAE: *Dr. Bai, Dr. Kamalapurkar, Dr. Jacob, Dr. Kara*, **Aviation Education:** *Dr. Vance*, **Oklahoma State University**



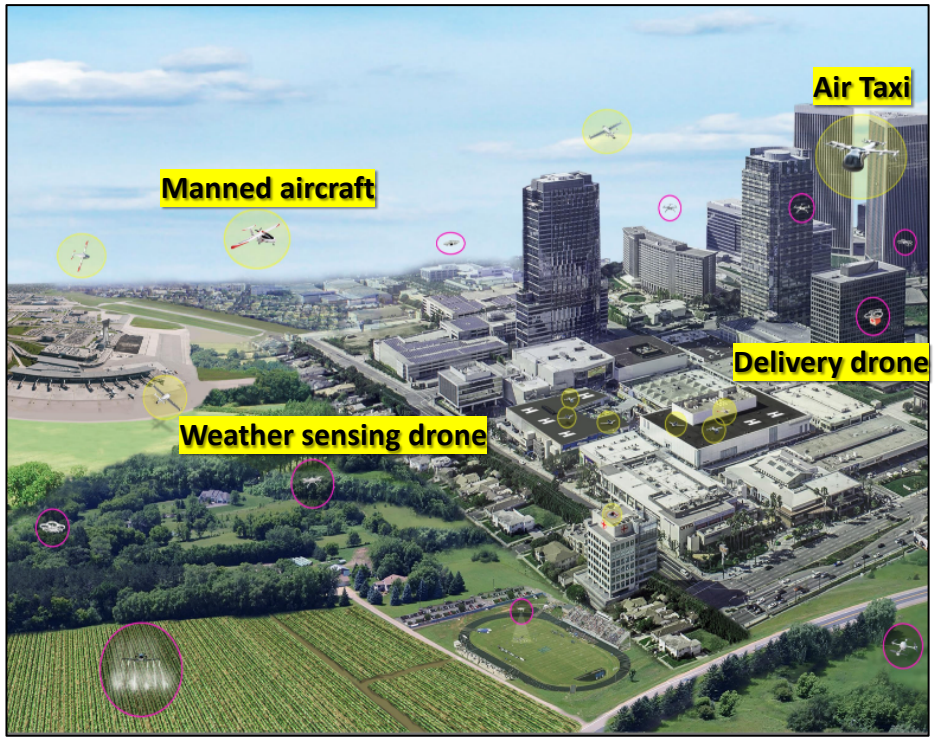


Hypothesis: 'in-time' or 'real-time' wind field information communicated effectively to pilots and traffic management can enhance safety, efficiency and robustness of future sUAS operations in low-altitude airspace.

Period: 2020-23

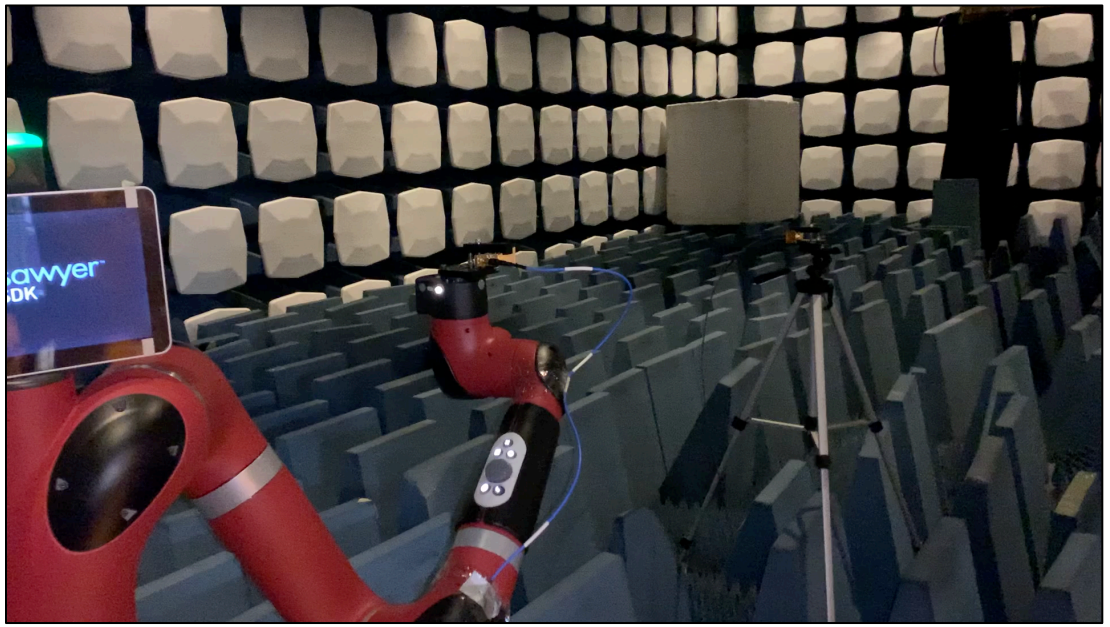
Poster #: 10

Broad impacts:



- Integration of sUAS with challenging urban environment
- Sensing and contribution of wind data for users in future aviation networks

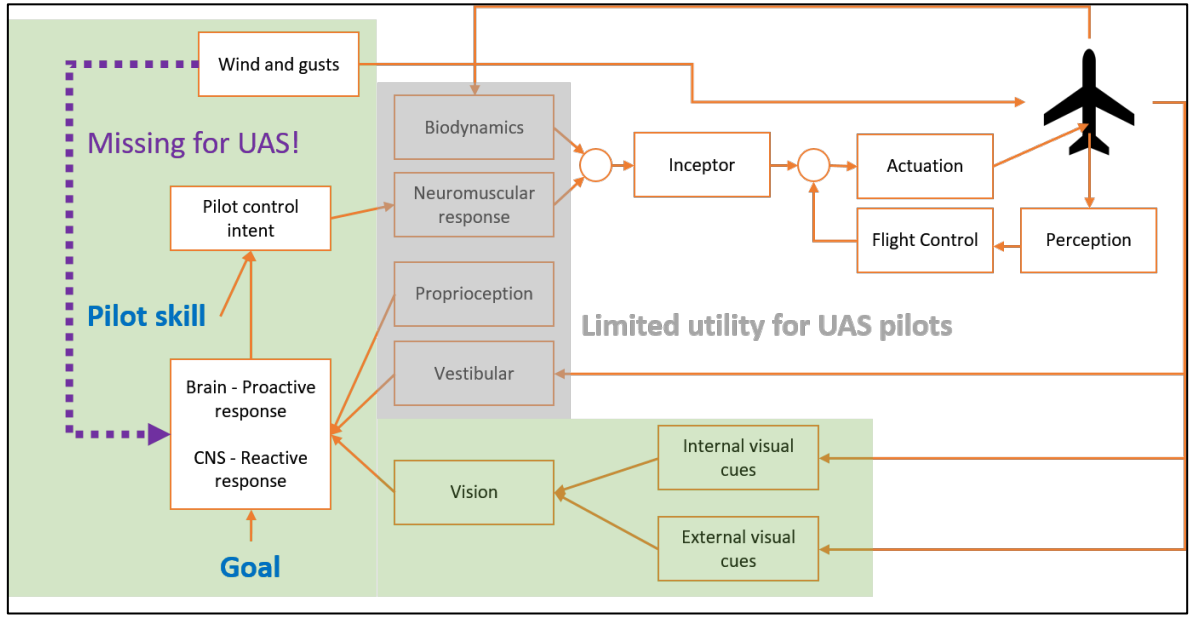
- American Meteorological Society, FAA
- Channel modeling for sUAS-assisted wireless communication

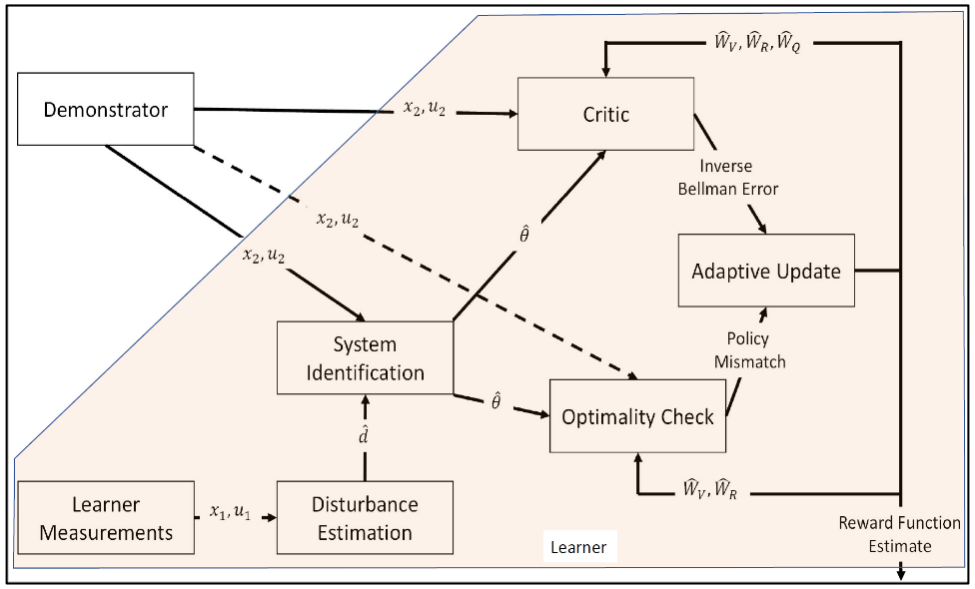


Kachroo, Amit, et al. “Emulating UAV Motion by Utilizing Robotic Arm for mmWave Wireless Channel Characterization”. Accepted by IEEE Transactions on Antennas and Propagation, 2021.

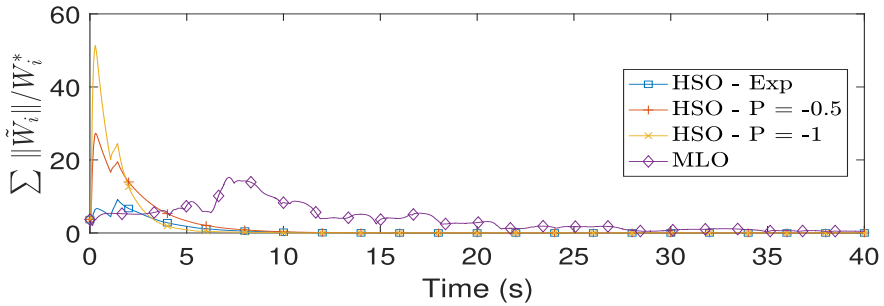
Jacob, Jamey, et al. “Utilizing UASs to Assist in Weather Hazard Detection for Urban Air Mobility and Unmanned Traffic Management”, American Meteorological Society, Jan. 2020.

Progress: Pilot intent modeling





- Developed inverse reinforcement learning (IRL) techniques for pilot intent modeling



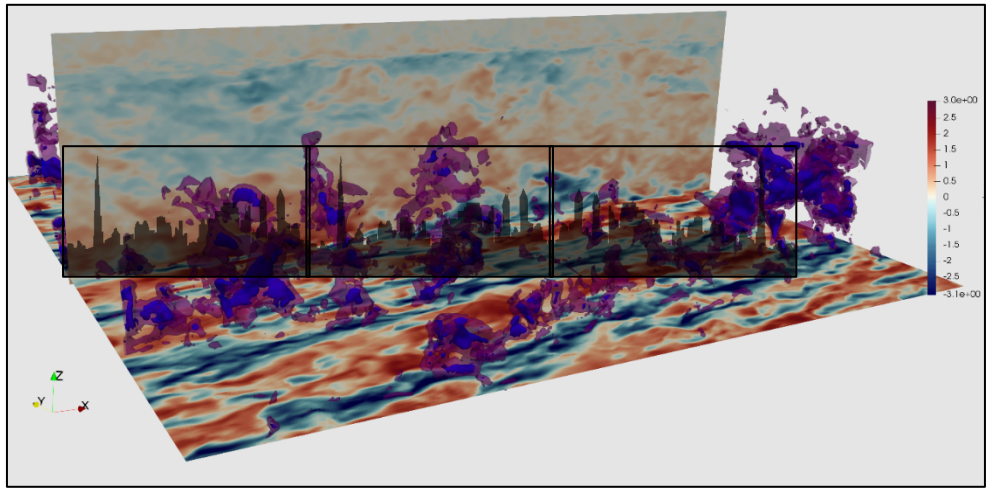
- Preparation for human-in-the-loop experiments
  - Surveyed UI for manned aircraft
  - Integrated joystick control in ROS-Gazibo simulator for human-in-the-loop experiments

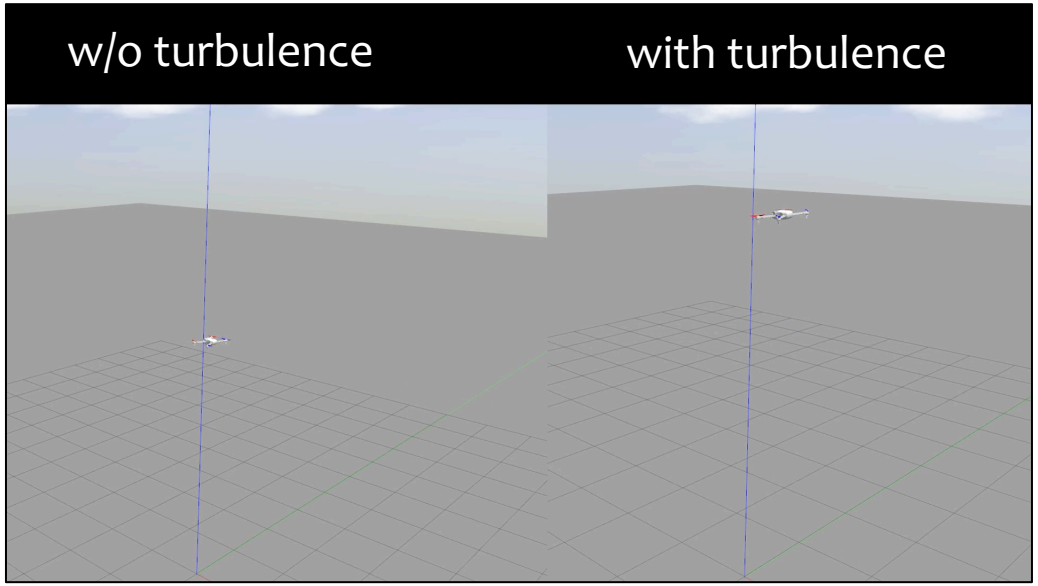
R. Self, K. Coleman, H. Bai, and R. Kamalapurkar. "Online Observer-Based Inverse Reinforcement Learning." IEEE Control Systems Letters, 2020.

R. V. Self, S. M. N. Mahmud, K. Hareland, and R. Kamalapurkar, "Online inverse reinforcement learning with limited data." Proc. IEEE Conf. Decis. Control, 2020.

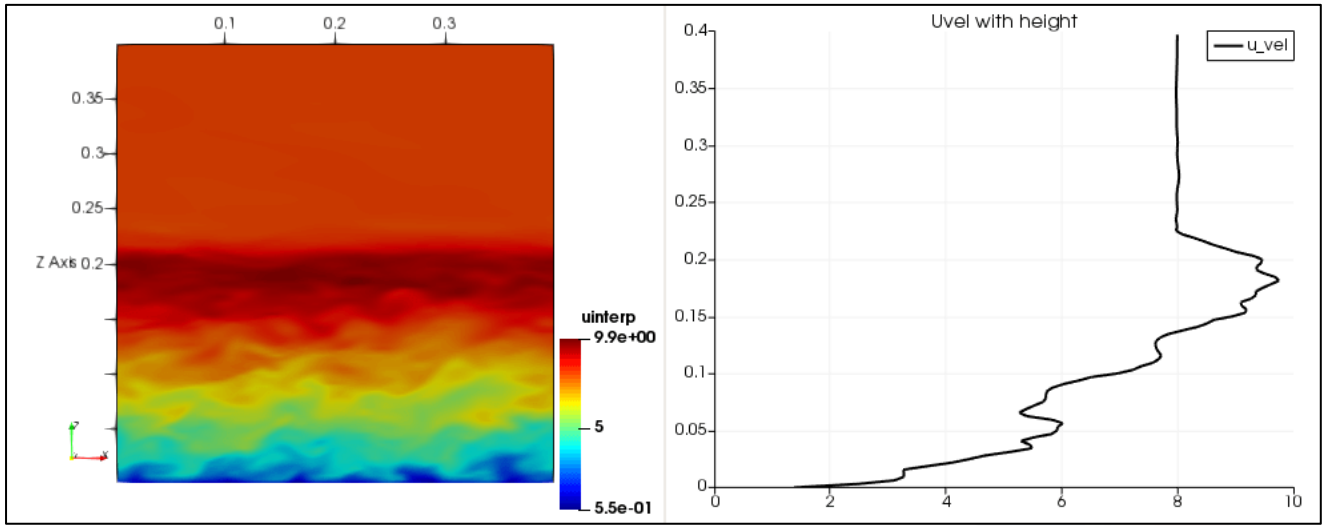
R. Self, M. Abudia, and R. Kamalapurkar, "Online inverse reinforcement learning for systems with disturbances." Proc. Am. Control Conf., pp. 1118-1123, 2020.

Progress: Low-altitude wind modeling and simulation





- Turbulence modeling & simulation
  - Low altitude airspace in the Atmospheric Boundary Layer (ABL)
  - Turbulence (gust) modeling in the ABL through Large-Eddy Simulations (LES)



- LES dynamic wind data integrated into quadcopter dynamics in ROS

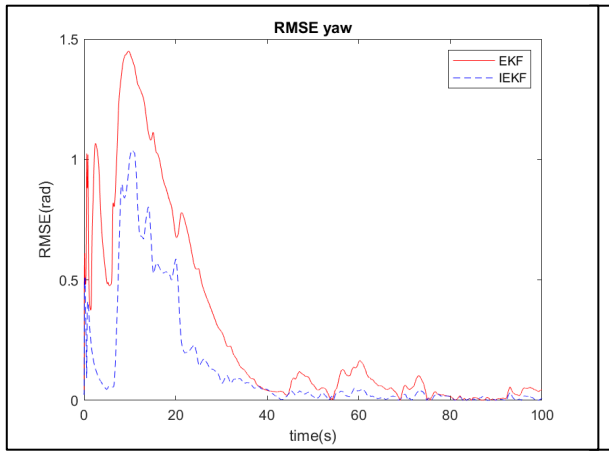
R. K.S. Vuppala and K. Kara, “Large-Eddy Simulation of Atmospheric Boundary-Layer Gusts for Small Unmanned Air Systems.” 73rd Annual Meeting of the APS Division of Fluid Dynamics, November 22–24, 2020.

Progress: Wind sensing and estimation

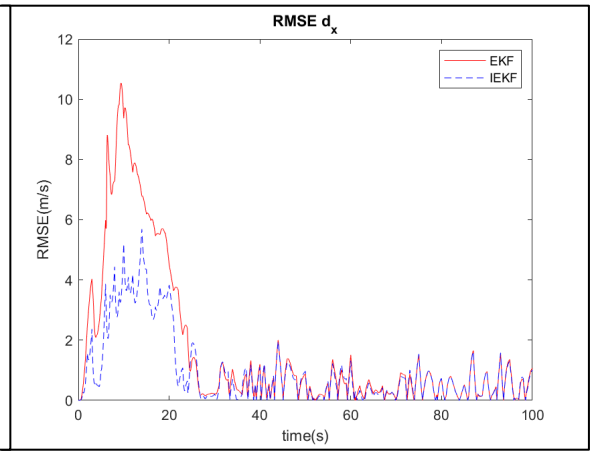
M600 with gimbal mounted
Ultra-Sonic Anemometer

Nano-Talon with 3-D
printed 5-Hole probe

- Experimental development
  - 5-hole probe for fixed-wing UAVs
  - Multi-rotor setup for wind data collection
- Wind estimation algorithm
  - Model-based Invariant EKF for simultaneous wind and state estimation



The RMSE of yaw estimates
between EKF and IEKF



The RMSE of wind estimates
between EKF and IEKF

Hickman, Kyle T., et al. "Development of Low Cost, Rapid Sampling Atmospheric Data Collection System: Part 1--Fully Additive-Manufactured Multi-Hole Prob." *AIAA Scitech 2021 Forum*. 2021.

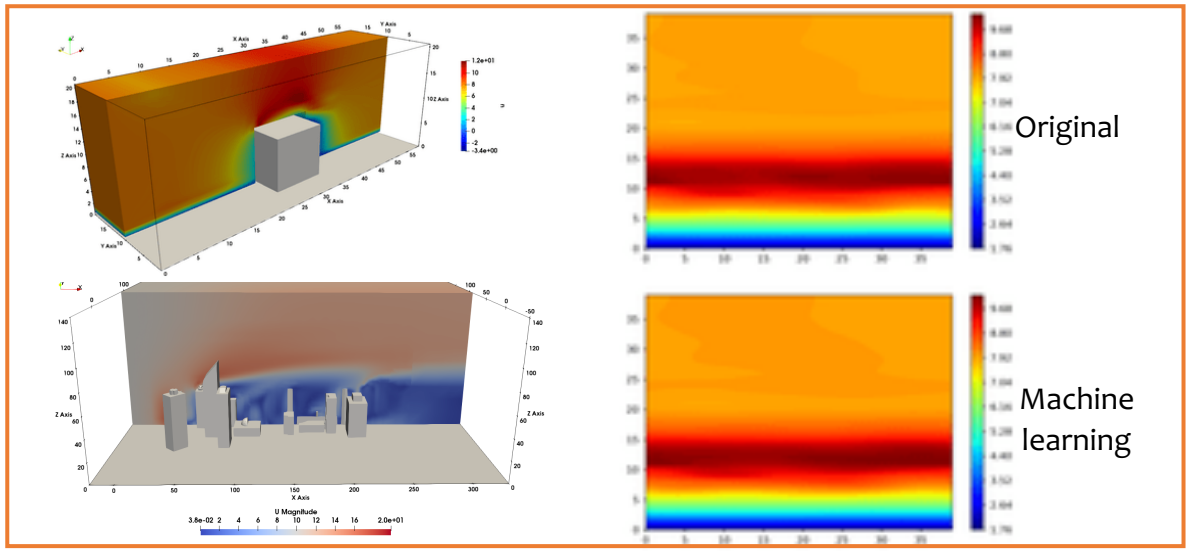
Ross, Andrew L., et al. "Development of Low Cost, Rapid Sampling Atmospheric Data Collection System: Part 2-Sensor & System Integration." *AIAA Scitech 2021 Forum*. 2021.

Hickman, Kyle, James Brenner, and Jamey Jacob. "Five Hole Probe Sweeping Wake Surveys." *Bulletin of the American Physical Society* (2020).

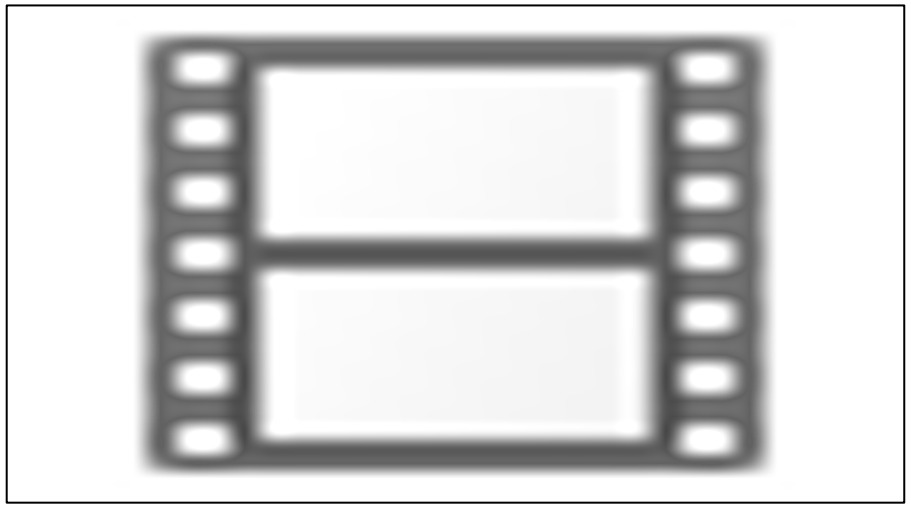
Brenner, James, Kyle Hickman, and Jamey Jacob. "Experimental Assessment of Multi-Rotor Downwash Interaction." *Bulletin of the American Physical Society* (2020).

K. Coleman, H. Bai, and C. N. Taylor, ”Extended Invariant-EKF Designs for State and Additive Disturbance Estimation.” Automatica 125 (2021): 109464.

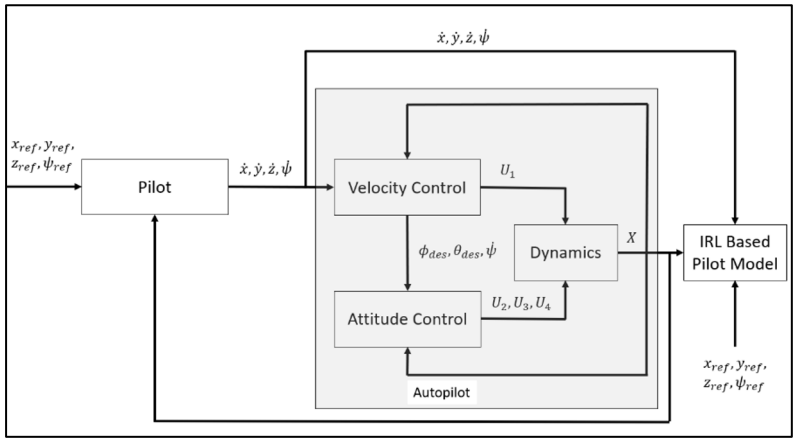
- Wind modeling with complex terrains and data assimilation to predict wind

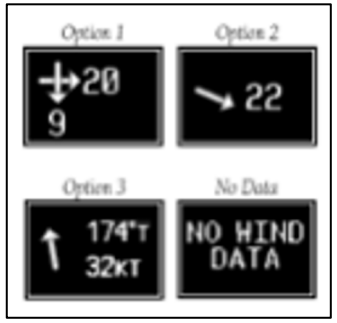


- Experimental validation of wind estimation algorithms

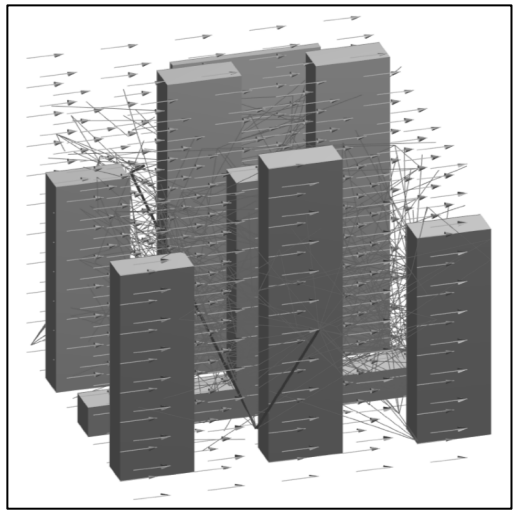


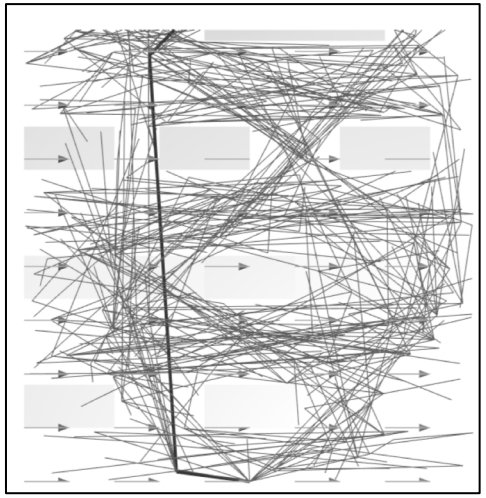
- Preparing and conducting pilot-in-the-loop experiments for pilot intent modeling





- Sampling-based algorithms for wind-aware path planning





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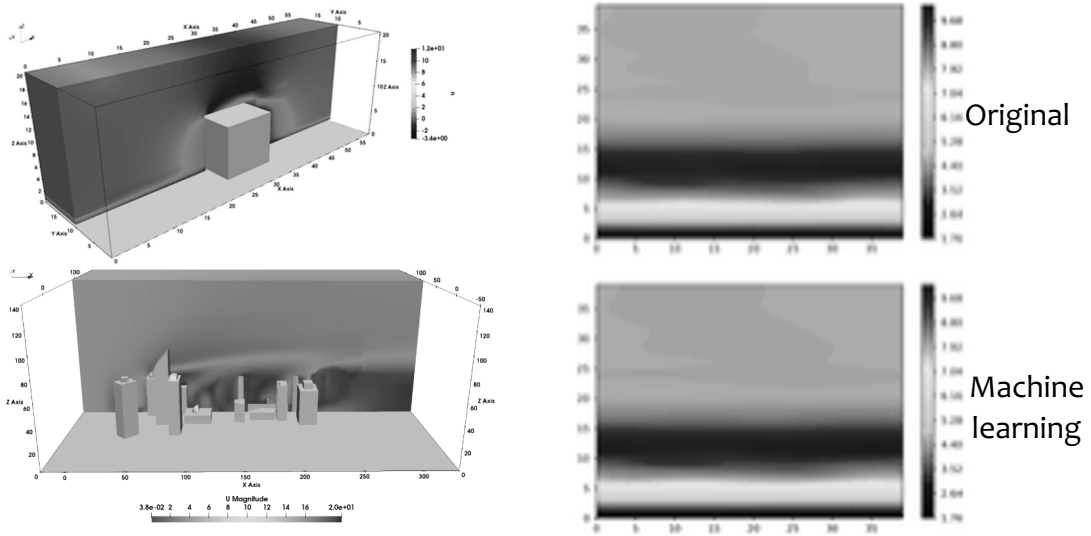

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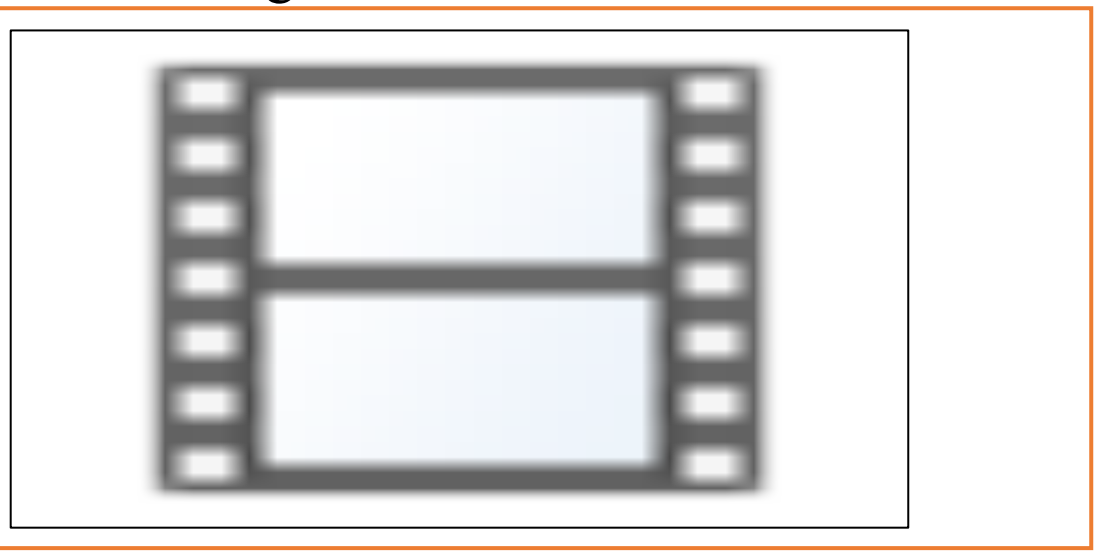

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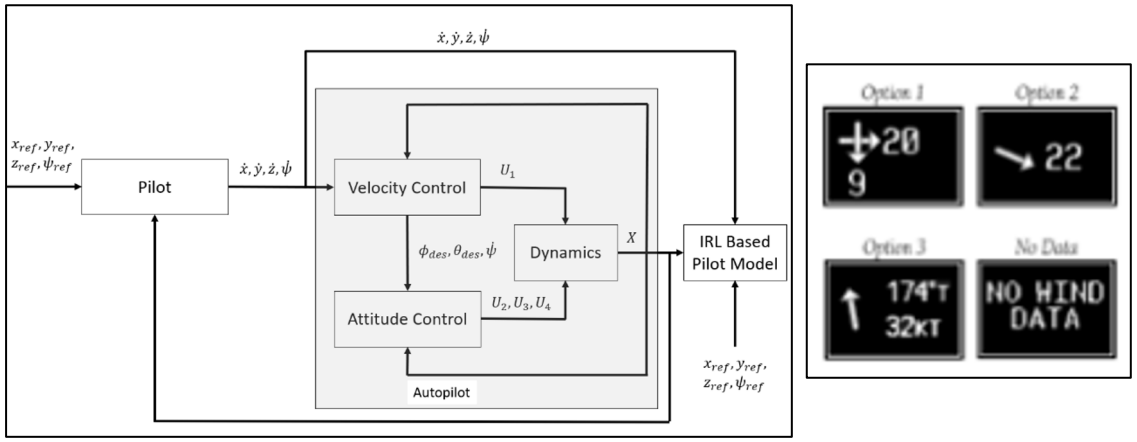

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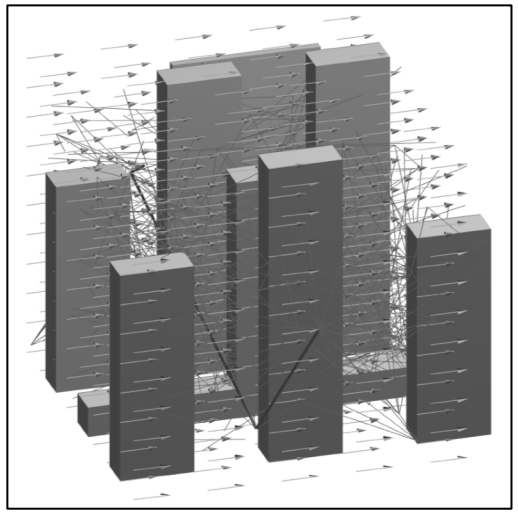

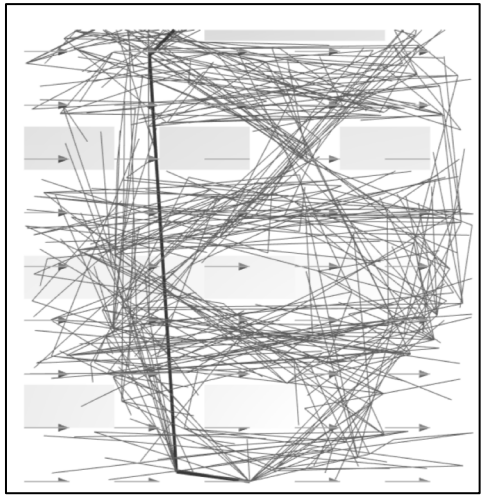

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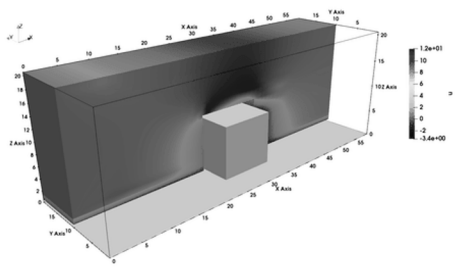

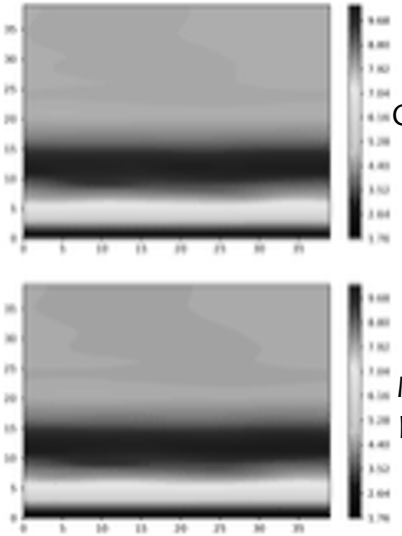

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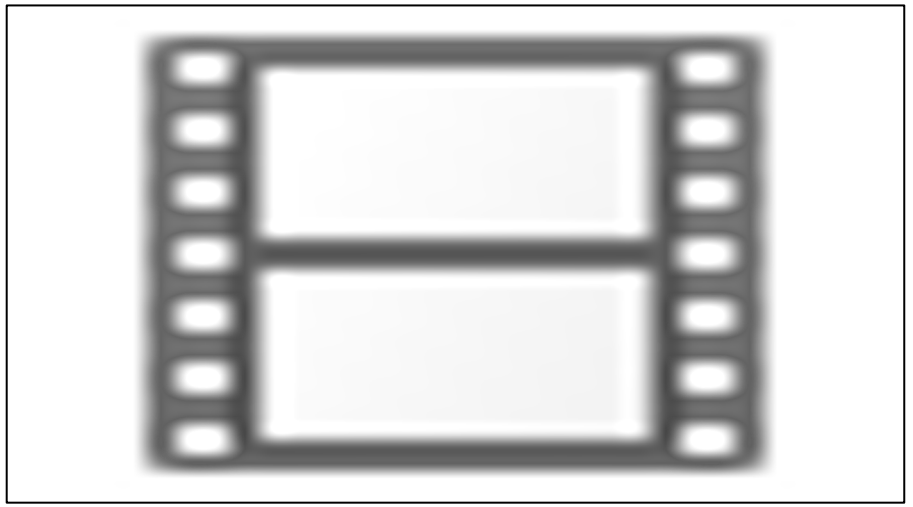

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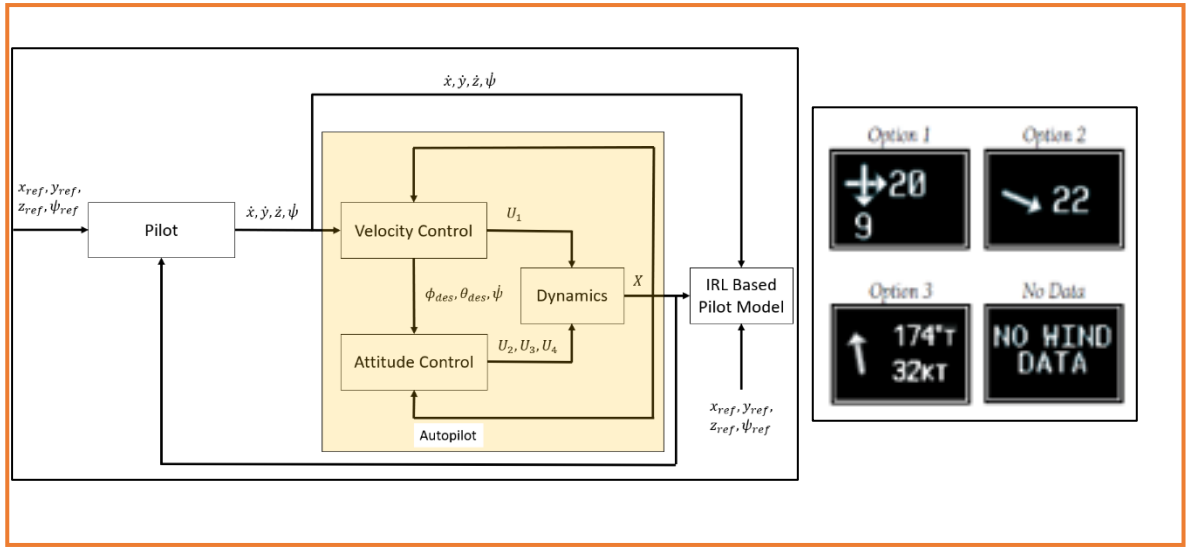

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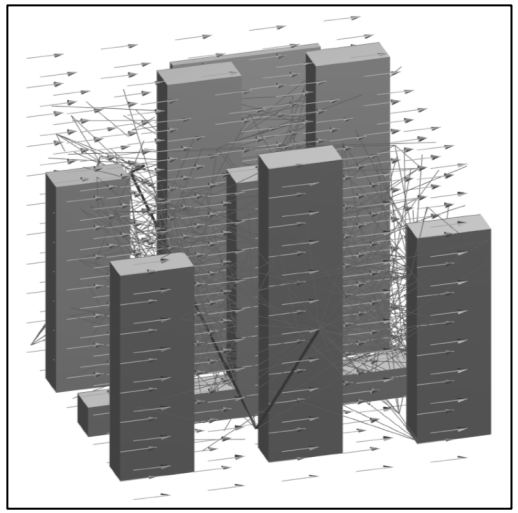

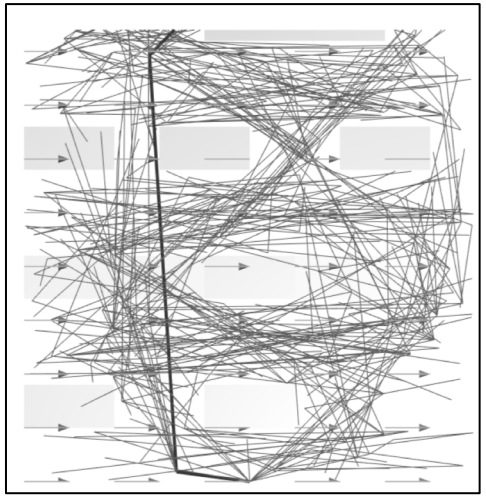

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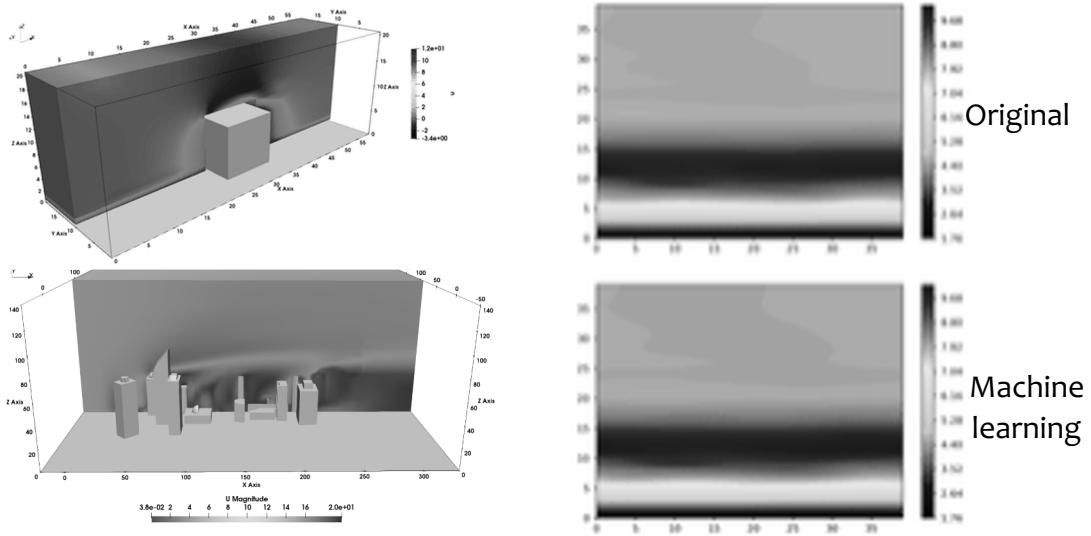

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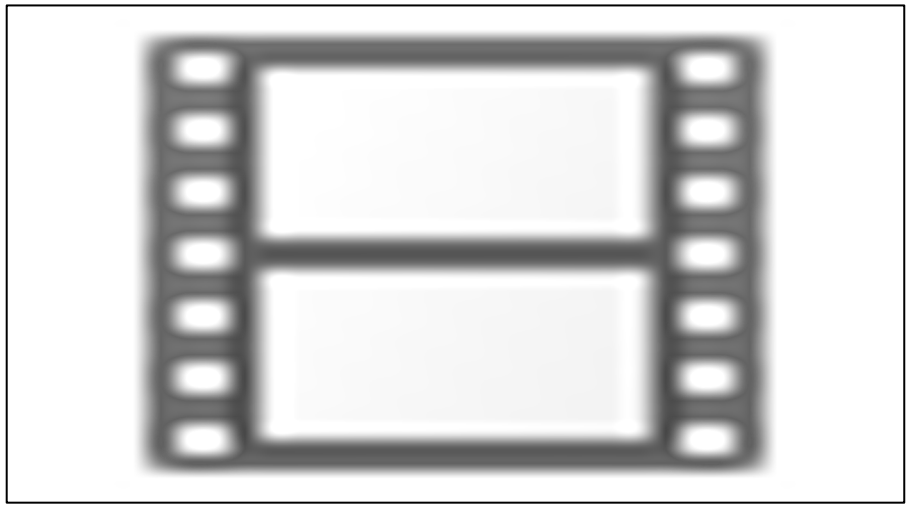

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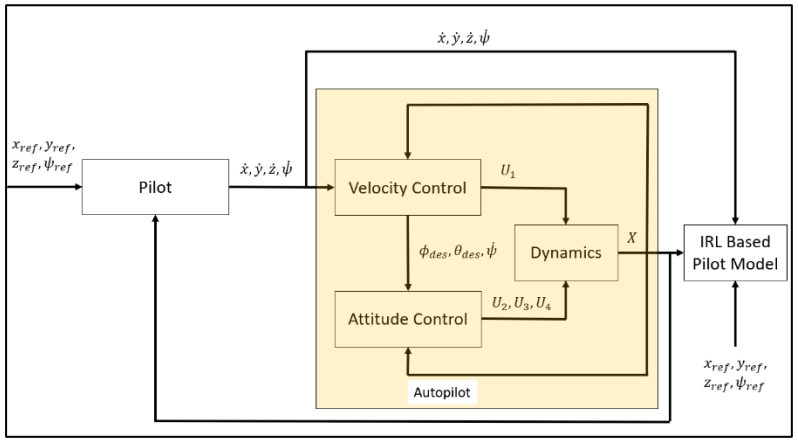

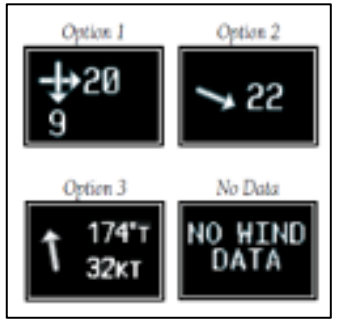

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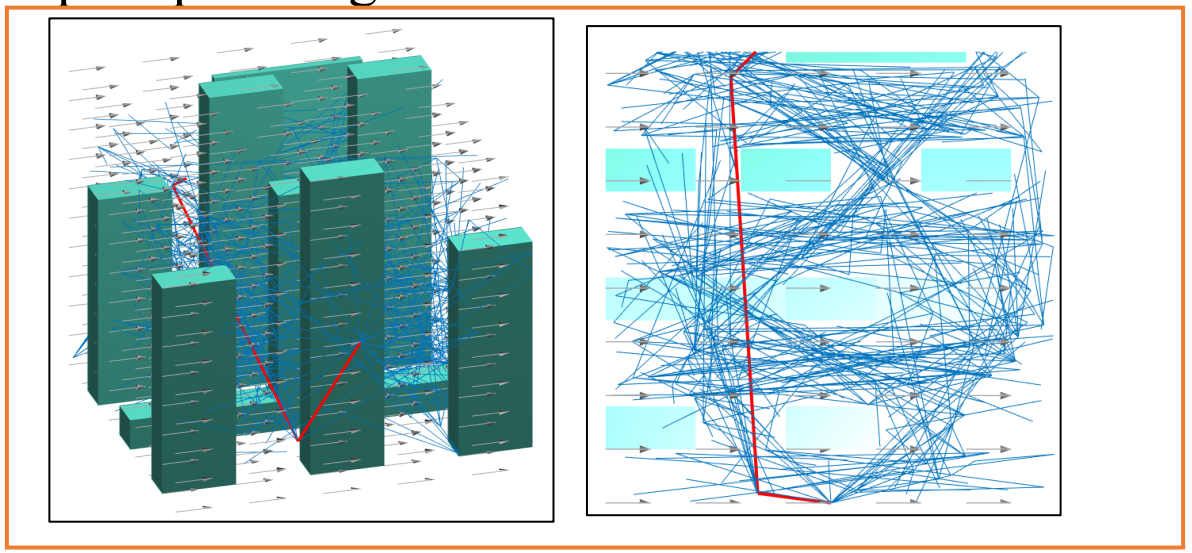


Acknowledgement

Faculty members:

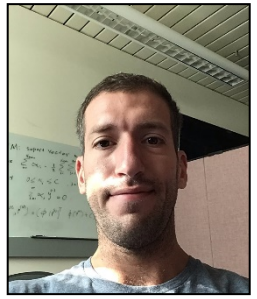




Graduate students:





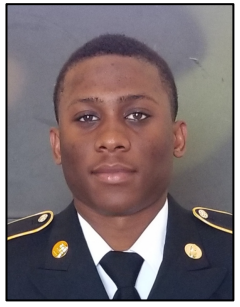
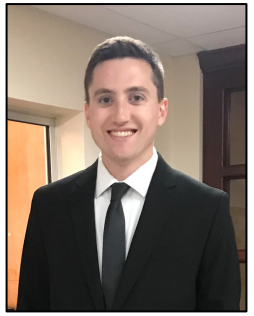










Undergraduate students:

sUAS pilots:

ENG/CMMI:
Dr. Irina Dolinskaya

Award #: 1925147

Dr. Atkins (UMich), Dr. Woolsey (VT),
Dr. Xue (NASA)

Session: 2 Poster #: 10