AEROcAST

Advanced Exploration of Reliable Operation at low Altitudes:
meteorology, Simulation, and Technology

AAM Weather Technical Interchange Meeting

November 2, 2023

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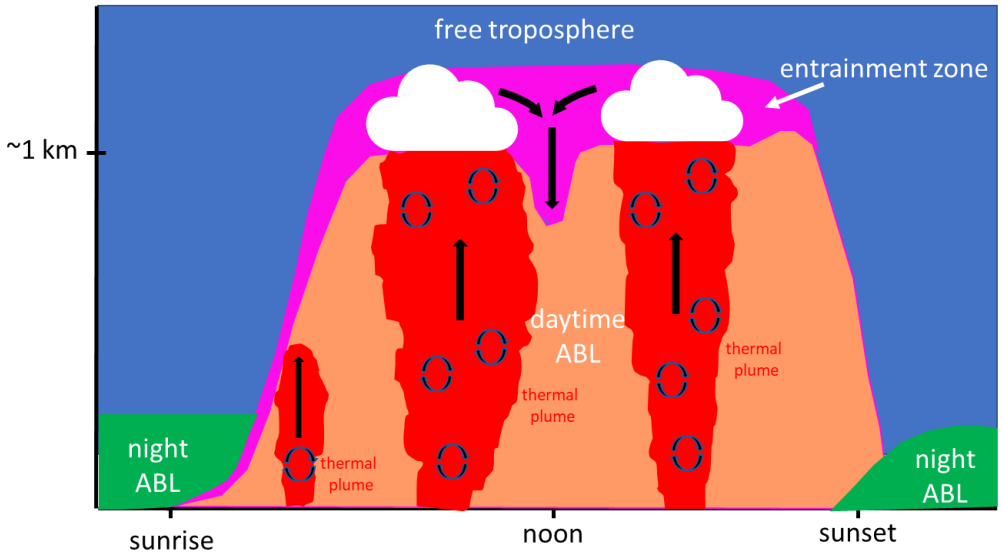
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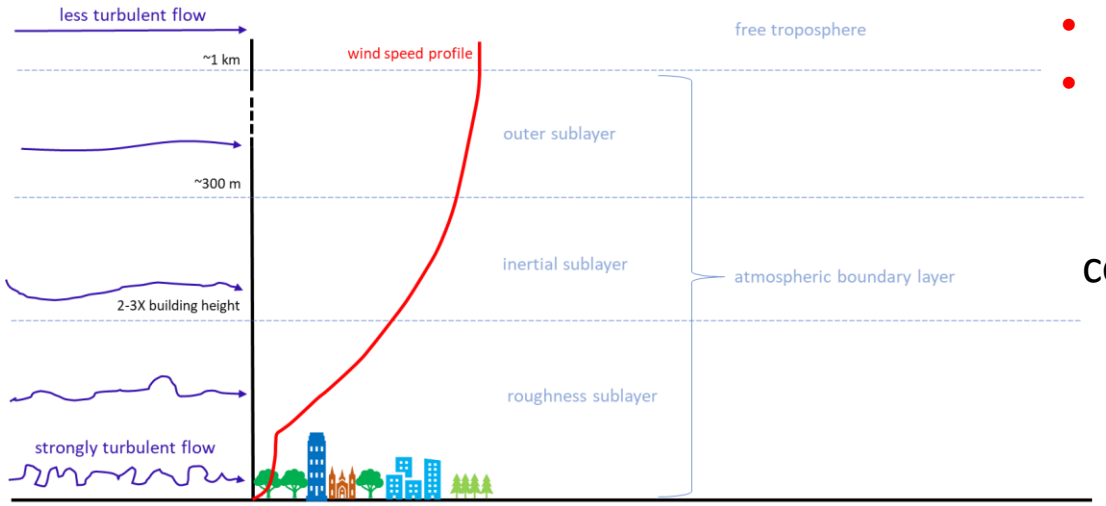
Weather Tolerance for Advanced Air Mobility



Wind in the Atmospheric Boundary Layer (it's complicated)



complexity in daily cycling



Effects on Advanced Air Mobility:

- safety
- operational efficiency
- ride quality
- passenger comfort
- vehicle wear and tear

complexity in height layering

Development Areas

- Innovative wind sensing technologies
- Data aggregation
- Modelling and Estimation
- Reasoning
- Flight campaigns

Innovative Wind Sensing Technologies: Dual-Doppler Lidar

- Key Barrier: High-resolution (< 1 m spatial, < 1 minute temporal, < 1 m/s speed) wind measurements around buildings or structures.
- Problem Space: Characterize the wind flow around a building :
  - Identify, procure, and install technology to meet measurement requirements
  - Gather long-term (> 1 month) data of wind measurements
  - Build database of wind measurements for dissemination
  - Create means to quantify changes in wind flow after installation of moderation design
- Activities:
  - Identified technology of dual-Doppler lidar to meet measurement requirements
  - Procured two commercial wind lidars
  - First implemented at Virginia Tech test site
  - Implemented at AFRC for extensive measurement campaign (see following slide)



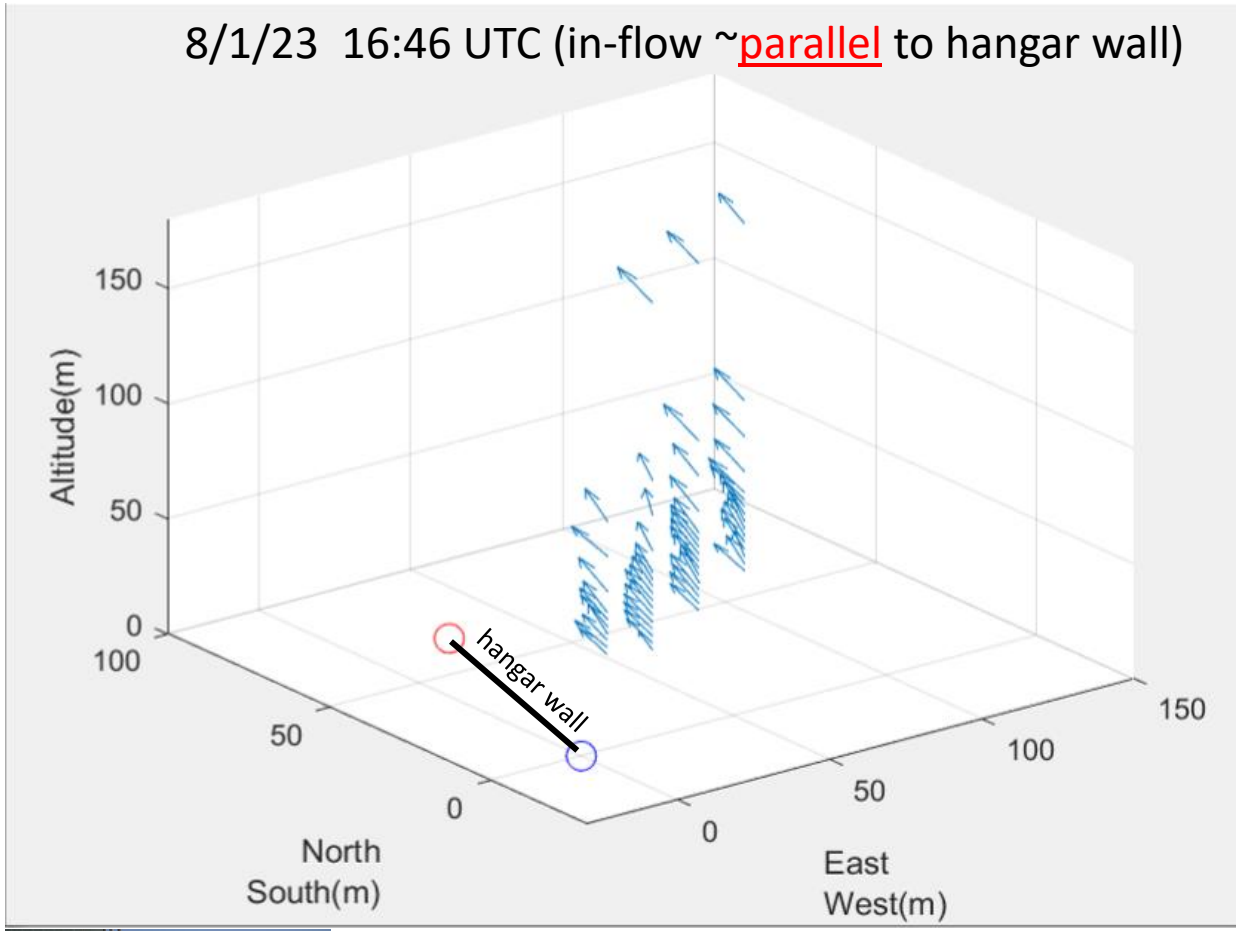
lidar setup at AFRC



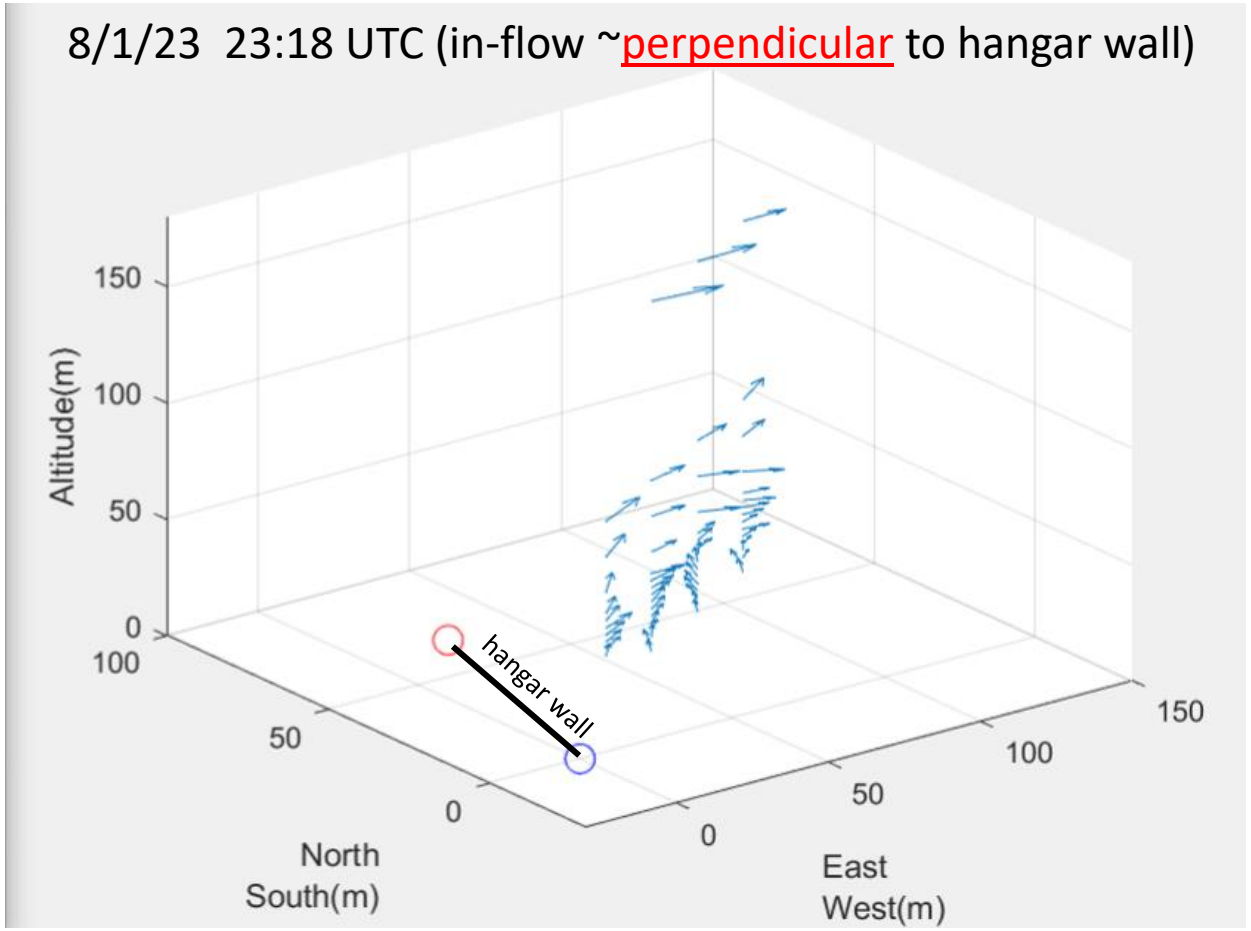
lidars

Dual-Doppler Virtual Tower Results: Parallel vs Perpendicular In-Flow

8/1/23 16:46 UTC (in-flow ~parallel to hangar wall)



8/1/23 23:18 UTC (in-flow ~perpendicular to hangar wall)

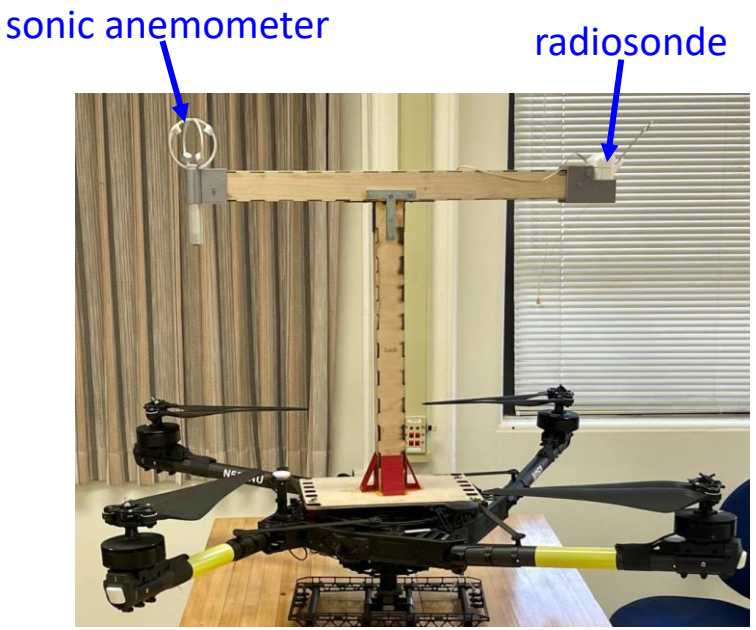




wind speed aloft ~ 8 m/s in both cases

Innovative Wind Sensing Technologies: Vehicle-Based Sensing

- Key Barrier: Sample wind in the atmospheric boundary layer
- Problem Space: Measure wind from vehicles while in flight and stream data in real time.
- Activities:
  - Identified low-cost payload of low SWaP 3D sonic anemometer
  - Adapted radiosonde (traditionally used on weather balloons) for combined weather data and data link
  - Implemented on AltaX vehicle
  - Tested at LaRC CERTAIN with comparison against wind lidar
  - Used at AFRC for extensive measurement campaign

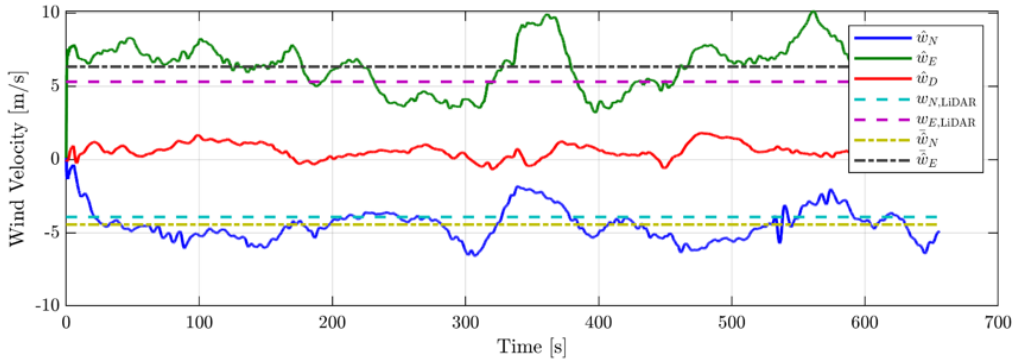




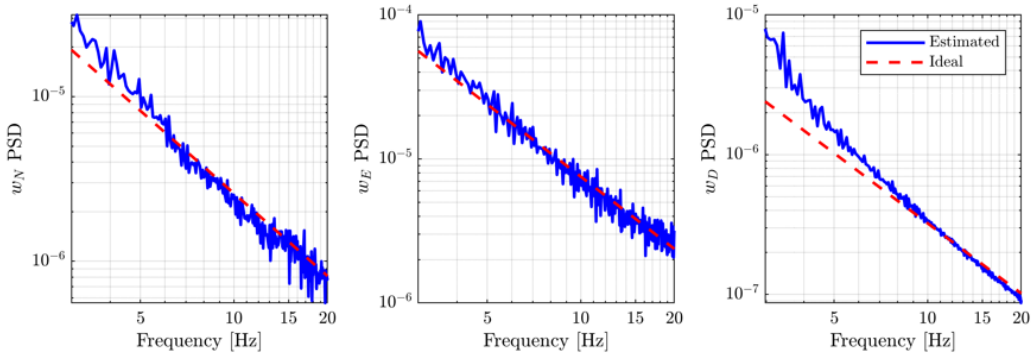
Flight test at LaRC CERTAIN

Innovative Wind Sensing Technologies: Wind Through Navigation Data

- Key Barriers: Sample wind in the atmospheric boundary layer
- Problem Space: Measure wind from vehicles while in flight and stream data in real time.
  - Reduce cost and complexity of measurement by deriving wind from vehicle navigation data
  - Using both rotorcraft and fixed-wing vehicles
- Activities:
  - Collaborated with WINDMAP UI project and Virginia on latest technology
  - Developing flight dynamics models of two candidate aircraft
  - Run one flight test with results compared to wind lidar
  - Extensive flight test this summer



Comparison at 122-m height between rotorcraft-based wind measurement and lidar show excellent agreement,



and indicate rotorcraft-based turbulence measurements are possible, not just wind vector!

Altruistic Weather Scout

- Key Barrier: Weather data in extreme conditions
- Problem Space: Instantly deployable weather station system
  - Shifting conditions of micro-weather will require quick-response sensors for deployment in harsh weather.
  - Operational needs will require increased resolution in local micro-weather or fill gaps due to power outages, damage, weather, etc.
  - Ability to react to changes of the weather monitoring network in real-time under extreme conditions is key to minimize operational downtime.
- Activities:
  - Designed and tested concept
    - Integration with existing networks
    - Deployable on portable systems (e.g. dedicated UAS or manual deployment)
  - Preparations for demonstrations in the field and environmental chamber testing

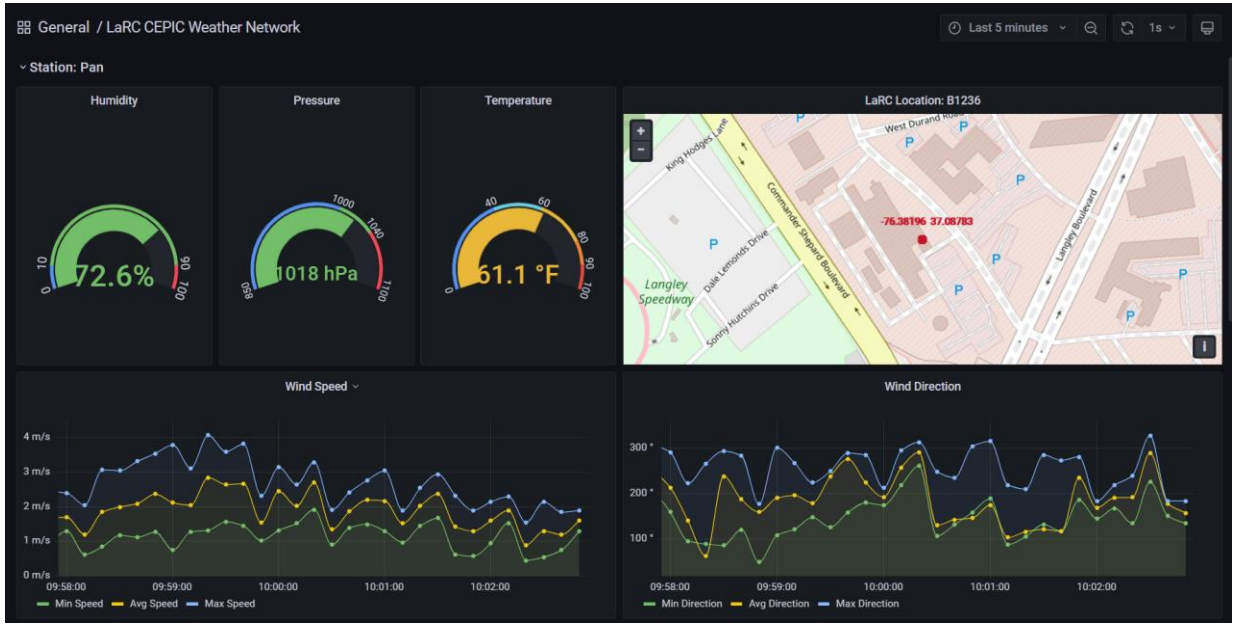






Data Aggregation

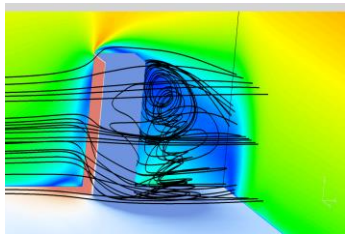
- Key Barriers:
  - Rapid distribution of wind data for modeling and decision making
  - Better use of existing sensors
  - Integrated ubiquitous weather sensing system-of-systems
- Problem Space: Aggregate weather data from a variety of sensors and link to a network with low latency
  - Ingest data from existing and custom weather sensors
  - Develop data link and streaming capability
- Activities:
  - Collaborated with System Wide Safety to aggregate data from LaRC CEPIC weather stations



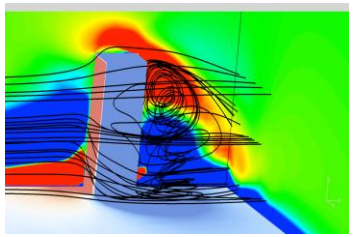
Real-time data from LaRC sensor network—works on any NASA-connected computer

Modeling Activities: CFD

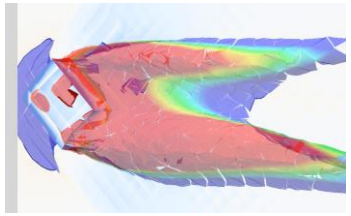
- Key Barrier:
  - Gap of NASA experience simulating flight environment in windy (multi-speed and multi-direction), turbulent urban atmospheric boundary layer (ABL)
  - Lack of best practices for ABL comparisons when combining CFD, wind tunnel testing, and outdoor experimental data
- Problem Space: Simulations of AFRC Area A buildings with a focus on the Shuttle Hangar wake
  - Understanding roles of RANS and LES CFD models for ABL sims
  - Best practices for generating useful ABL-immersed water and wind tunnel tests
- Activities:
  - CFD benchmarking with focus on ABL recreation
  - Digital model creation for AFRC Area A
  - Water tunnel testing
  - Wind tunnel testing



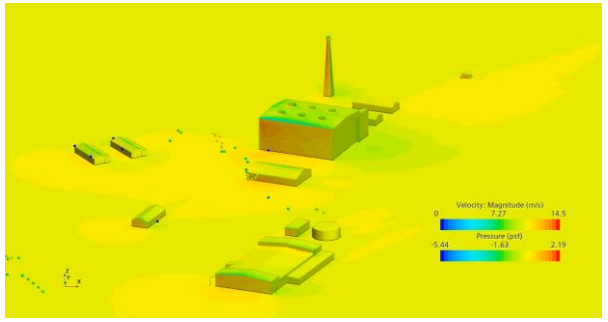
Flowfield



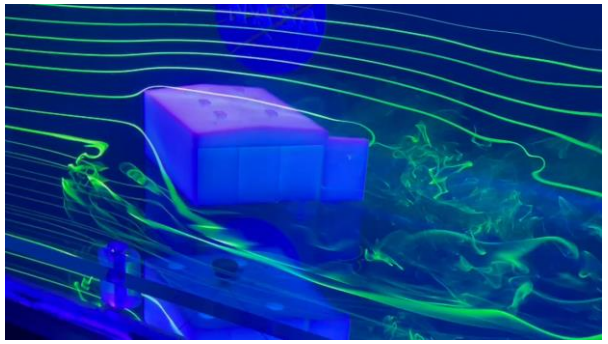
Axial force adjoint



AFRC Hangar Wake



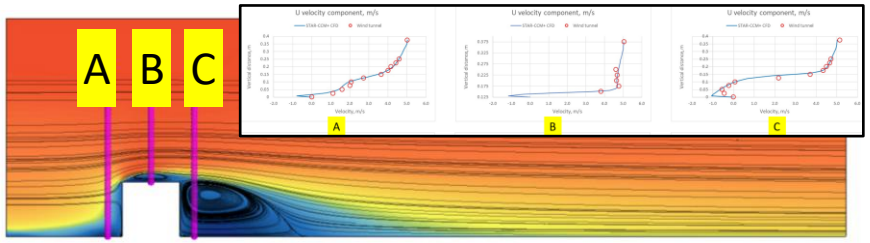
CFD animation

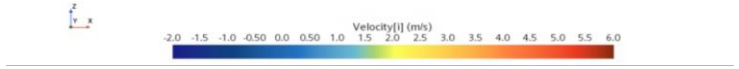


Water Tunnel Testing

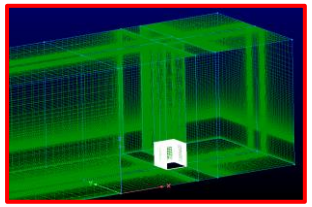


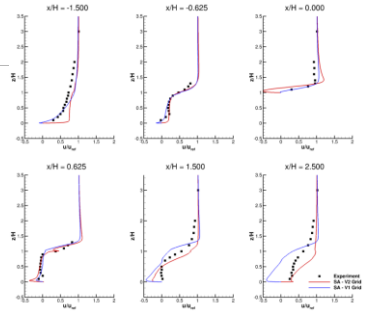
AFRC Area A digital model positioned on USGS Terrain





"Simple" validation simulations



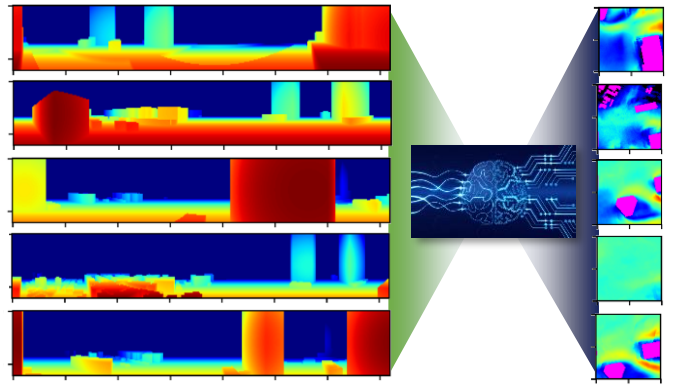


MAESTRO and Virtual Wind Sock

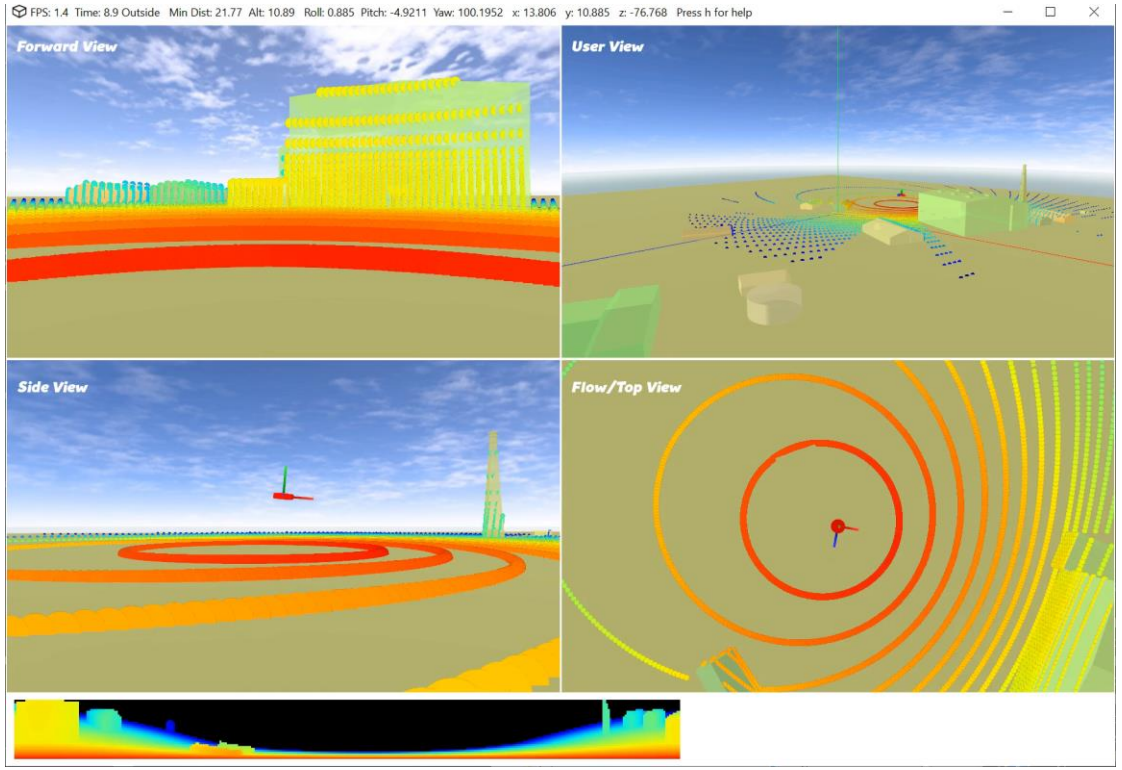
- Key Barrier:
  - 1) On-board estimation of surrounding wind environment within urban cityscape; 2) real-time LZ wind estimations
- Problem Space: 1) Demonstration of MAESTRO prototype at AFRC Area A with current LiDAR (Velodyne) and MLM trained using CFD
  2) Demonstration of Virtual Wind Sock (VWS) MLM for fast wind predictions in the LZ using surrounding sensors
- Activities:
  - Creation of synthetic environment generator for LIDAR dataset at Area A
  - Resurrection of 2017 MAESTRO Neural Network software and trial dataset
  - Applied new image-based convolutional NN architecture to 2017 dataset
  - Lab and outdoor testing of Velodyne Ultra Puck LiDAR
  - Investigation of FB "Prophet" prediction toolset and comparison with XGBOOST and conventional SARIMA tools for VWS



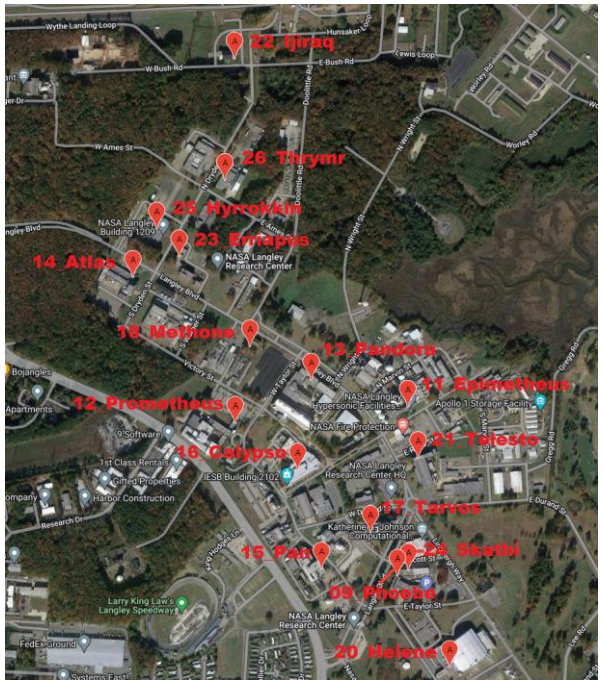
Ultra Puck
(Velodyne.com)



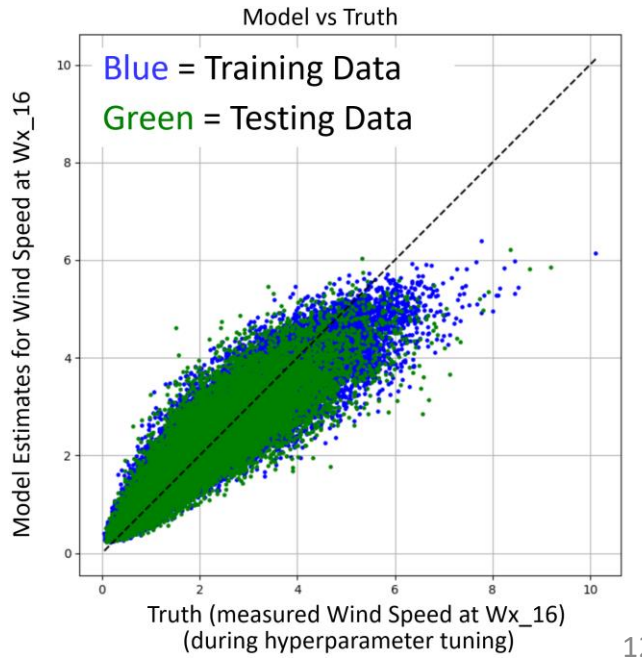
LiDAR Image Input ➡ MAESTRO ➡ Wind Output



Synthetic Surround LiDAR environment at AFRC Area A (MAESTRO)

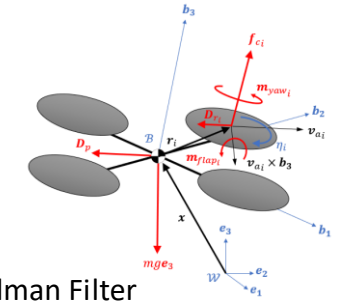


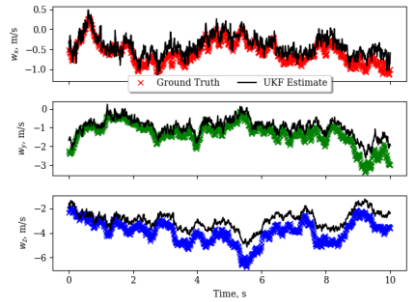
LaRC Rooftop Network (VWS)

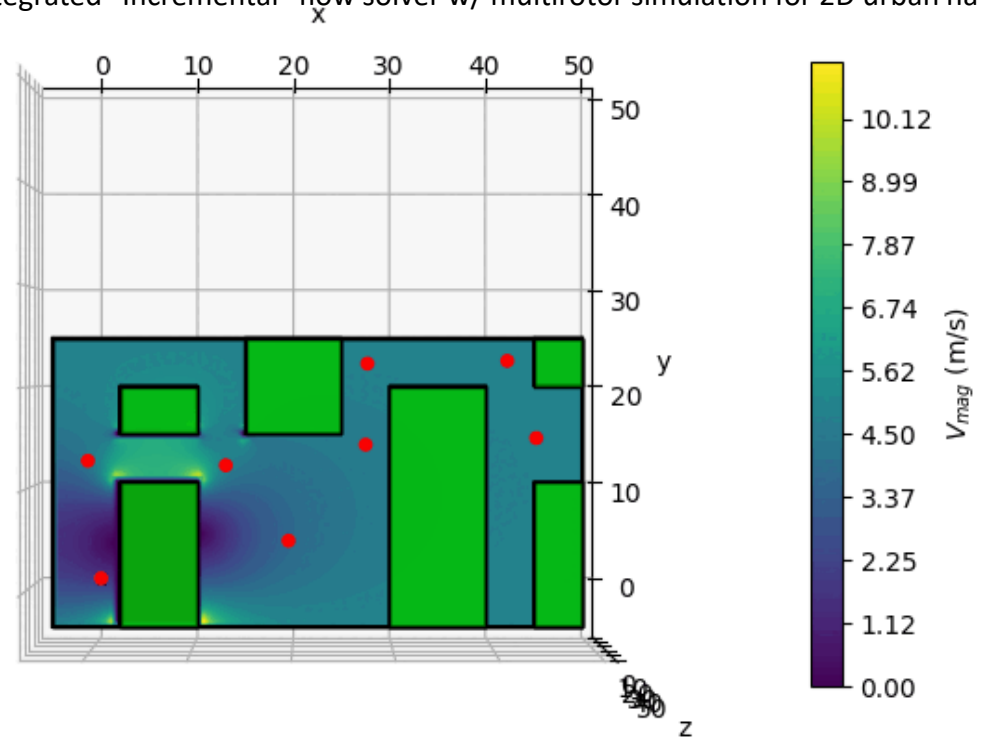


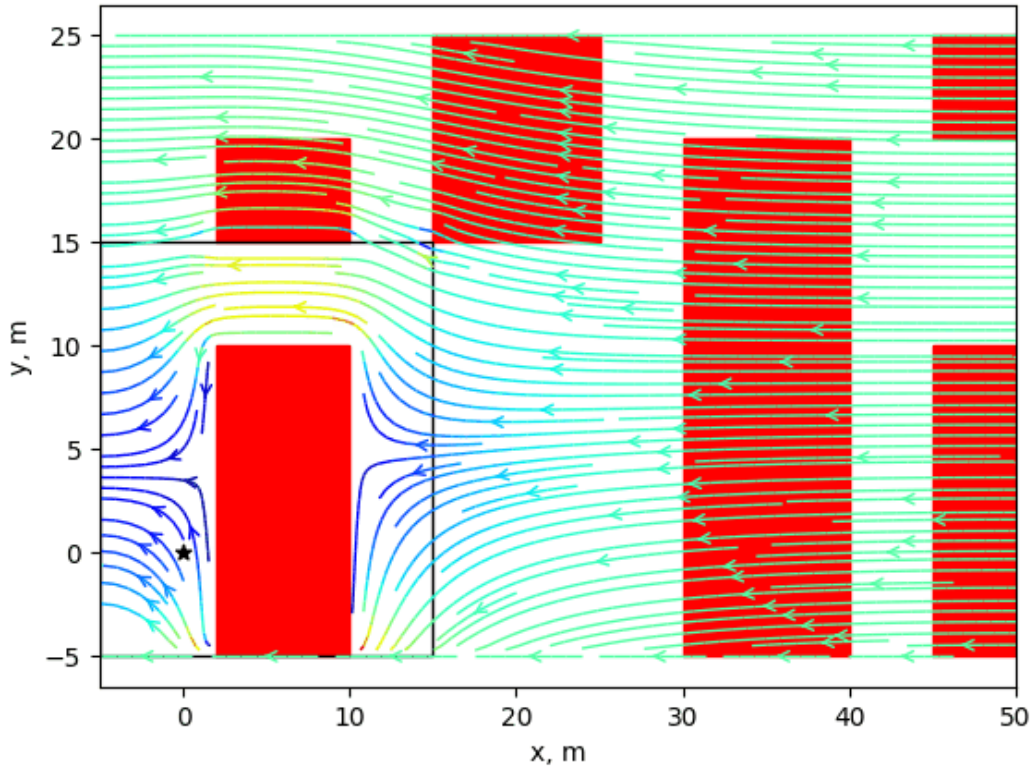
Winds from Vehicle Motion Research

- Key Barrier:
  - High-resolution wind and gust estimation using onboard IMU and advanced control theory
  - Path planning strategies in windy urban environments
- Problem Space: Enable cost-effective airborne weather sensing
  - Evaluate new wind-through-GNC techniques
  - Demonstrate through simulation, lab, and flight testing
- Activities:
  - Spencer Folk, NASA Pathways at U Penn: “Proprioceptive” wind estimation using navigational sensors and an unscented Kalman Filter
  - Integrated “Incremental” flow solver w/ multirotor simulation for 2D urban navigation (analogue to MAESTRO)









As vehicle ★ traverses between waypoints ● …

…surrounding flow solution (wind model) updates as cityscape is revealed

WindShape

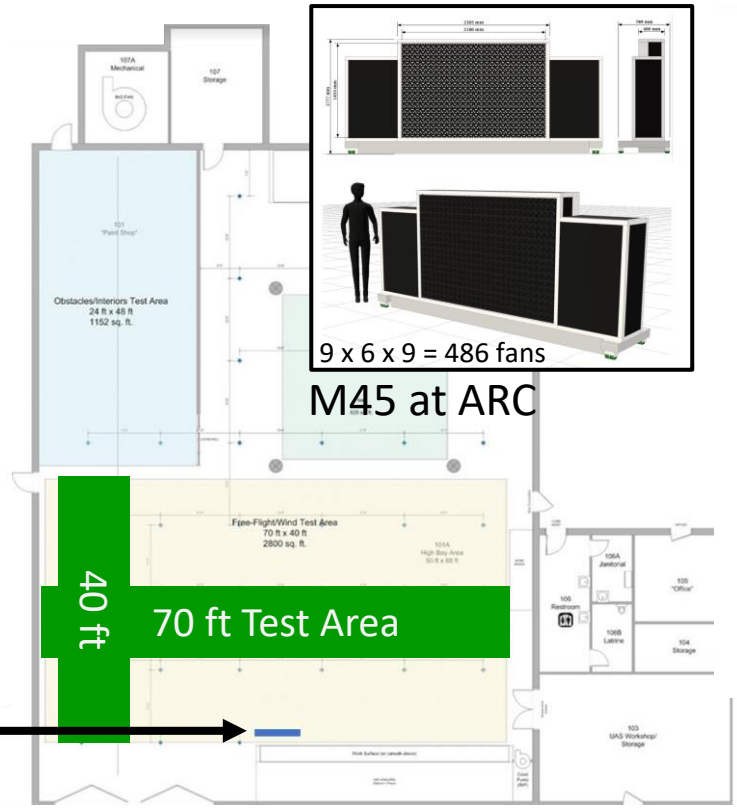
- Key Barrier:
  - Wind tunnel tests are expensive, difficult to schedule, and require well-defined test plan for efficient usage
  - Outdoor flight testing requires safety reviews, appropriate weather, difficult to know PRECISE attitude, positioning, and winds
  - Replicating dynamic atmospheric wind turbulence at vehicle scale is a challenge for ‘single-fan’ wind tunnels
- Problem Space: Enable medium-scale indoor research on vehicle-as-sensor and control algorithms
- Activities: Procurement of WindShape for ARC M45 moving forward (indoor UAS testing with OptiTrack motion-capture system



(a) (b)

Fig. 1 Free-flight testing in a multifan, real-wind facility (windshaper) of (a) Matternet multirotor delivery drone, and (b) senseFly *eBee X* fixed-wing mapping drone.

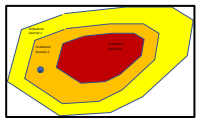
(from AIAA 2023-0812 by Walpen, Catry, and Noca)





ARC Status: Wind & Turbulence Display

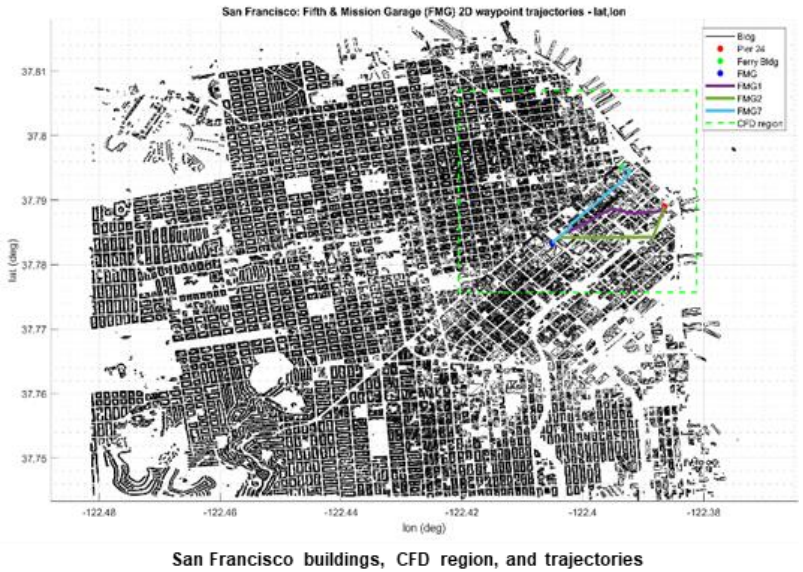
Data from existing projects: CFD/wind database, flight simulated dynamics, trajectories, etc.
*(**DRF**, **TTT**, VMS (John M., ARC), & **RVLT**)*



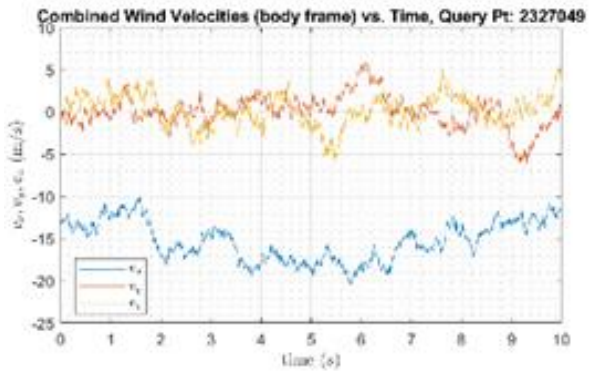
Example: Real-Time Turbulence ATC Display Interface

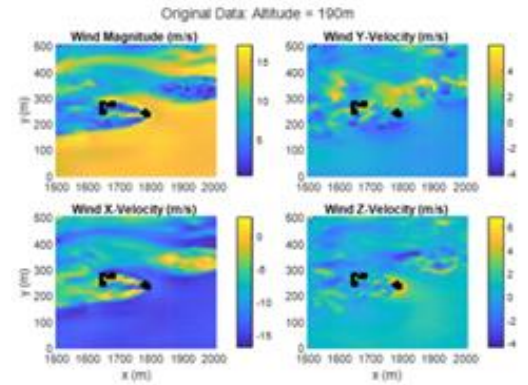
1. Key barrier: Wind and turbulence display
2. Problem space
   a. Create W&T display in Reflection (C/C++ software from **TTT**)
   b. Use **DRF** multivehicle simulation as starting point (top left figure)
   c. Use standard **RVLT** model
3. FY23 activities
   a. Created waypoint-based trajectories in San Francisco to simulate vertiport taking off and landing (MATLAB, bottom left figure)
   b. Combine Von Karman turbulence model with wind field database from San Francisco CFD simulation (MATLAB, top right figure)
   c. Neural network wind predictions based on CFD wind field data (bottom right figures): top – original data, bottom – NN-generated

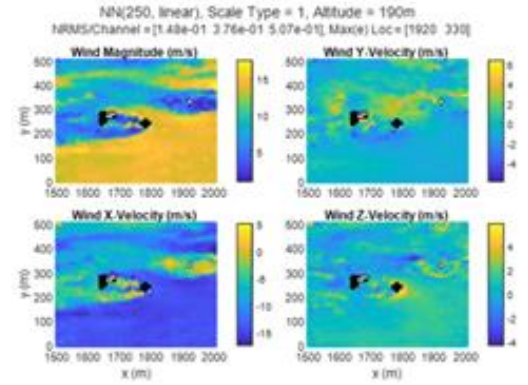




San Francisco buildings, CFD region, and trajectories





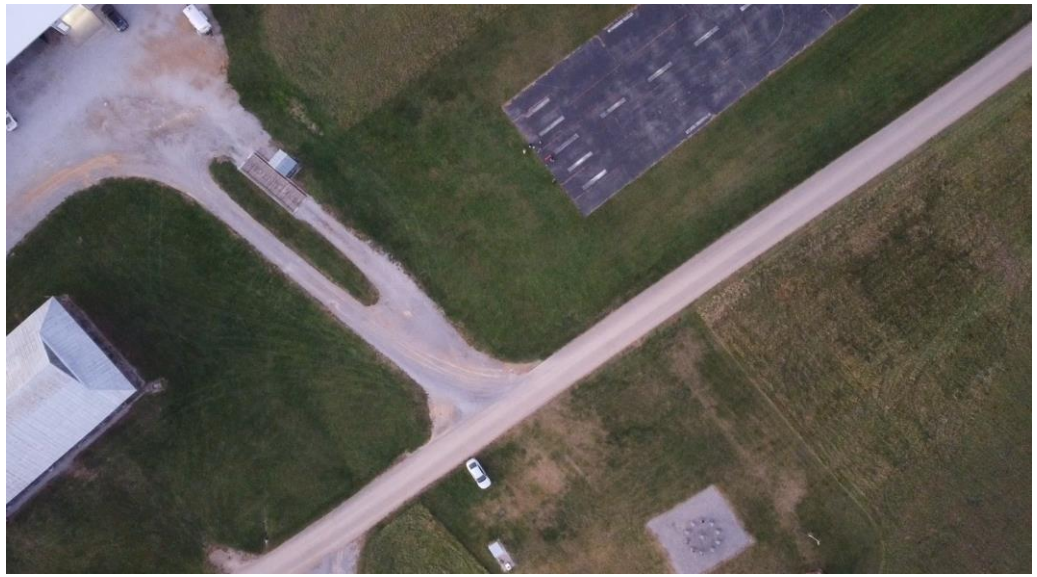


Flight Campaigns

- Key Barriers
  - Large gaps in weather data, especially wind, exist in the atmospheric boundary layer and within the built environment
  - Best practices for validating simulated urban wind flows to the real atmosphere are not established
  - Impacts of hyperlocal urban weather conditions on eVTOL aircraft and passenger comfort are mostly unknown
- Problem Space
  - Collect a comprehensive set of high-density, real-world weather measurements around an isolated large building
    - Coordinate a plethora of ground-based and airborne assets
- Activities
  - Fall 2022 flight test at Virginia Tech, Kentland Experimental Aerial Systems Laboratory
    - Fixed-wind and rotorcraft-based measurements compared to wind lidar
  - Spring 2023 flight test at LaRC CERTAIN
    - Anemometer payload on Alta-X compared to wind ldiar
  - Summer 2023 flight campaign at AFRC (see following slide)



AFRC Shuttle Hangar test site



Smoke visualization of wind flow during lidar, anemometer, and vehicle-based comparison

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