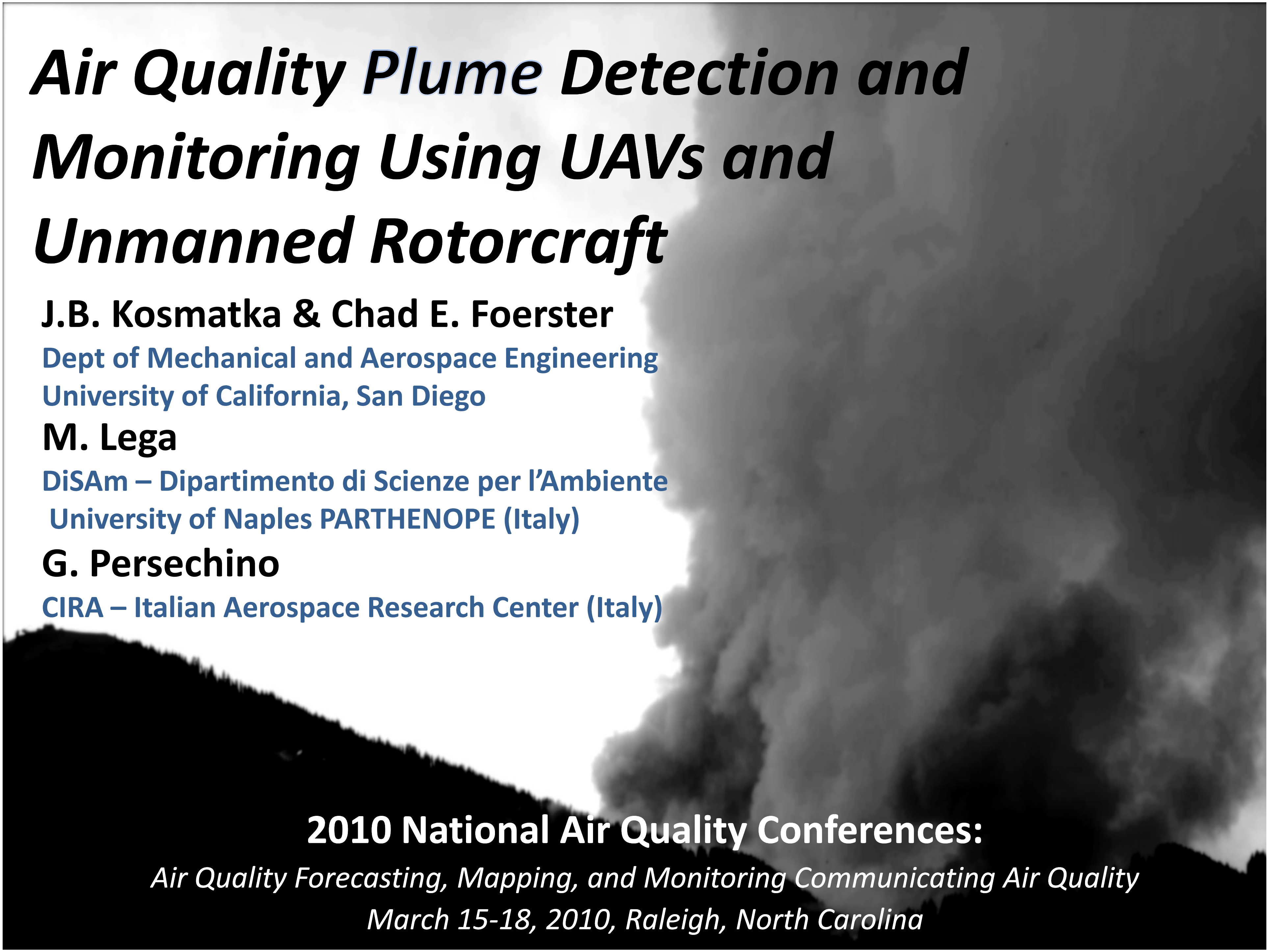

Air Quality Plume Detection and Monitoring Using UAVs and Unmanned Rotorcraft

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Air Quality Forecasting, Mapping, and Monitoring Communicating Air Quality

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Outline

- Introduction
- System Details
- Test Plan
- Results
- Conclusions

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Airborne Plumes

- **Plumes** are point source releases of pollutants that may include radioactive material, biological or chemical agents, and particulate matter

- Possible massive **evacuations** to avoid contamination and health issues

- A **fielded system** is needed that can **identify, monitor and predict plume evolution**
  - Multi-scale for different plume types
  - Monitoring non-emergency activities

"UW Power plant malfunction sends black plume over Seattle" KOMO News, December 2nd 2009

"Oblique View of the Arnica Fire, Yellowstone National Park, Wyoming" NASA Earth Observatory, September 24th 2009

Roving Host Methodology

- **Stationary Sensor Network**
  - High cost of Installation
  - Best for dense urban environments
  - Suburban / wilderness require towers

- **Mobile UAV platform**
  - Low cost
  - Best for suburban / wilderness
  - FAA restrictions for populated areas

"Unmanned Aerial Vehicles (UAV) for Border Security "

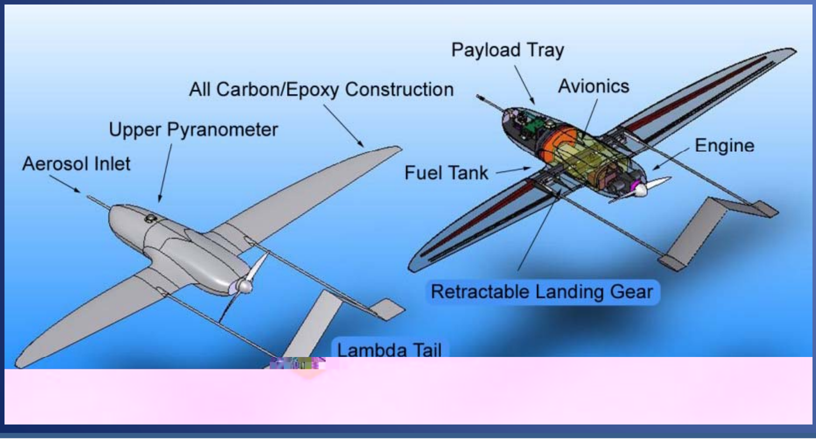
- **Proposed System**
  - Multiple autonomous vehicles with onboard path planning
  - Central command station to monitor the aircraft and relay information from the plume forecasting algorithm
  - A turn-key tailored system for first responders

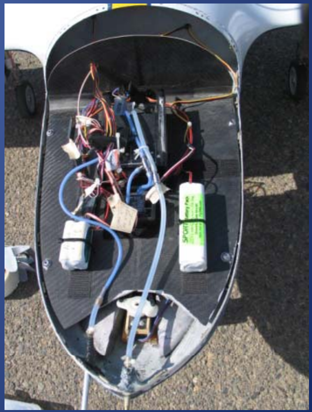
UAV Selection

- Based upon probable threat scenarios, natural disasters or contaminant releases:
  - Plume growth, evolution, and duration
  - Sensor size/weight, onboard data reduction
  - Time/length scale of plume, sensor, aircraft
- Novel designs for dual purpose operations
  - Dart to plume, then slow loiter in plume

NextGen's shape-changing UAV morphs in flight

UCSD is a leader in novel UAV development

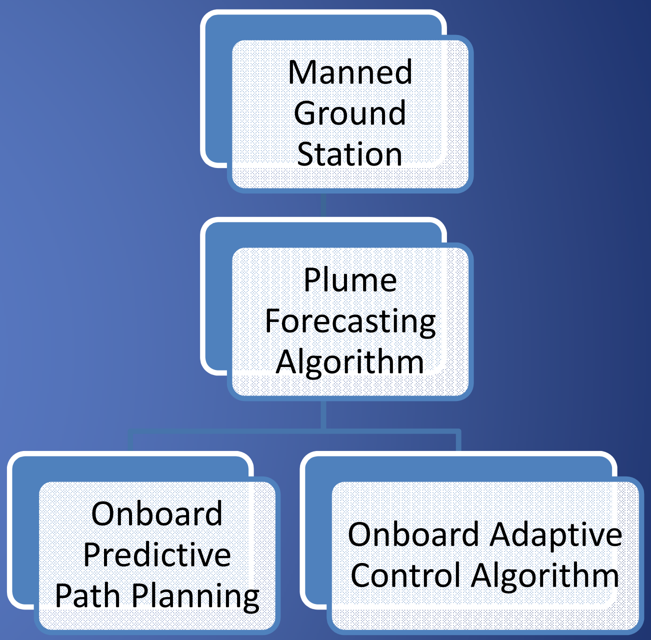




Desired Platform Capabilities

- Determine loiter/cruise/dash speed, endurance, altitude, payloads
- Autopilot with failsafe modes that interacts with onboard microcomputer and a manned ground station
- Integrated sensors that provide input to onboard path planning algorithms
- Ground station that coordinates autonomous UAVs and relays navigation commands generated by the plume forecasting algorithm

Control Hierarchy



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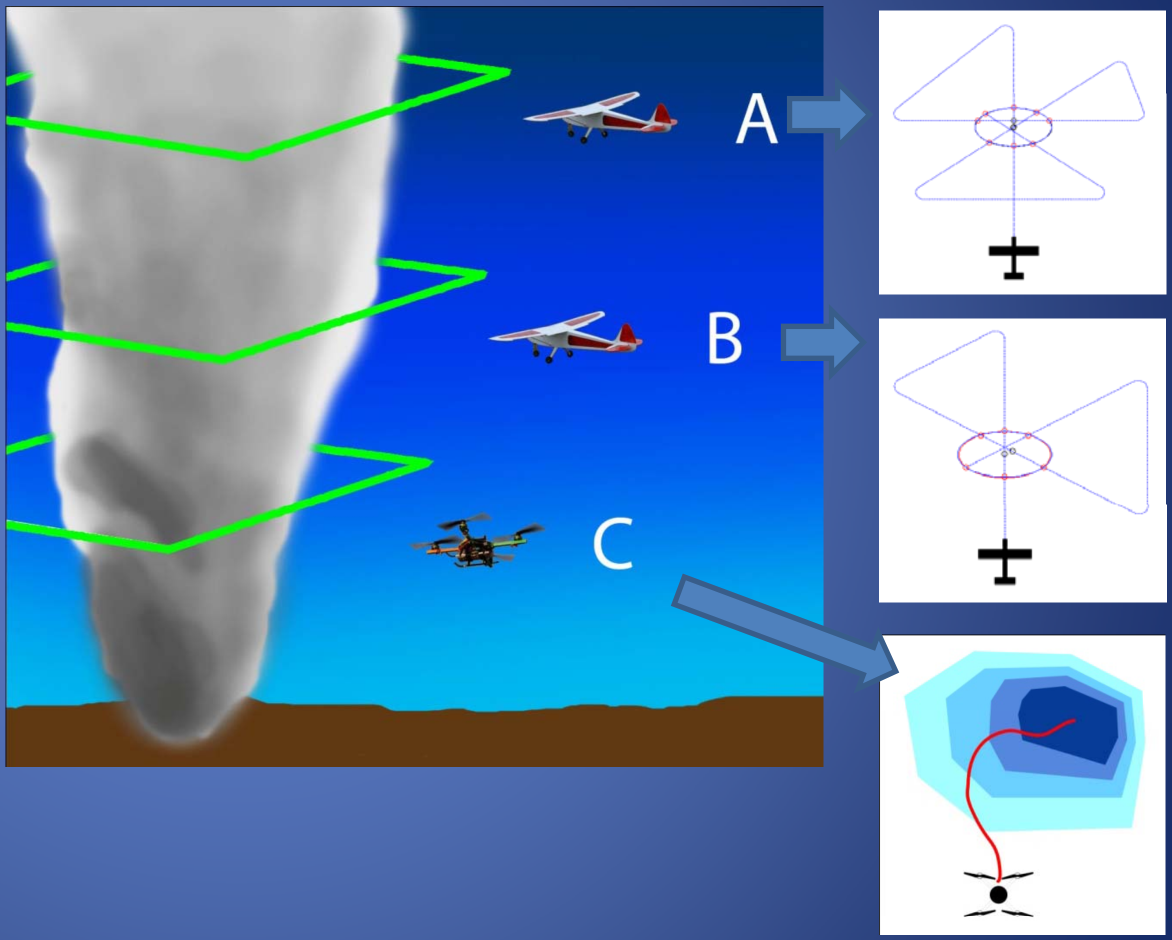
Plume Tracking Approach

- **Multi-UAV** tracking at different altitudes. Two different algorithms to determine plume shape, center, and motion
- **Quad-rotor** for low altitude source location. Sensitivity mapping to find plume source



UCSD/LANL UAV Platform

Empty Weight	5.97 kg
Flight Battery Weight	1.6 kg
Autopilot Weight	0.584 kg
Maximum Payload Weight	3.2 kg
Wing Surface Area	98.19 sq. dm
Wing Span	2.794 m
Cruise Speed	16-19 m/s
Maximum Speed	35 m/s
Stall Speed	9 m/s
Endurance	30-45 min at Sea Level

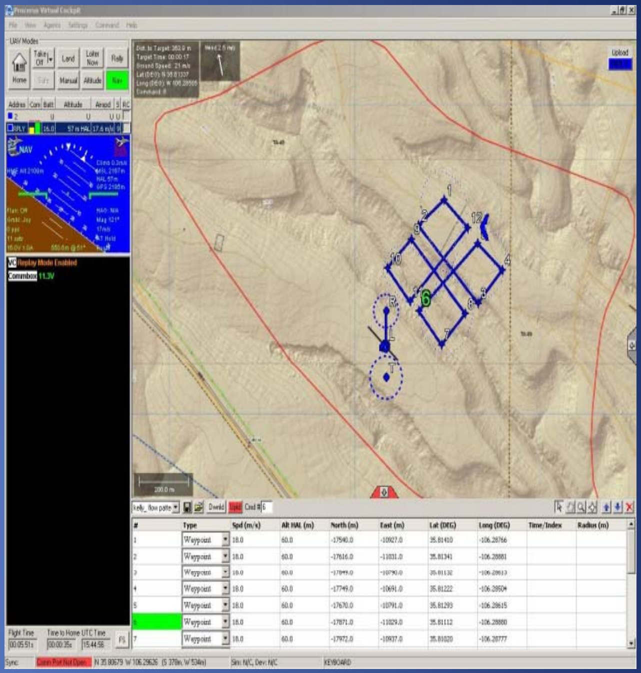
UCSD/LANL Quadcopter Platform

- **Specifications**
  - Max Endurance: 30 minutes
  - Max Payload Weight: 500 grams

- **Capabilities**
  - Fully integrated and tested autonomous and semi-autonomous modes including takeoff, landing, hover now, and waypoint navigation
  - Ability to interface with an auxiliary microprocessor board and modify path based on either source tracking or envelope mapping algorithms

Ground Station Software

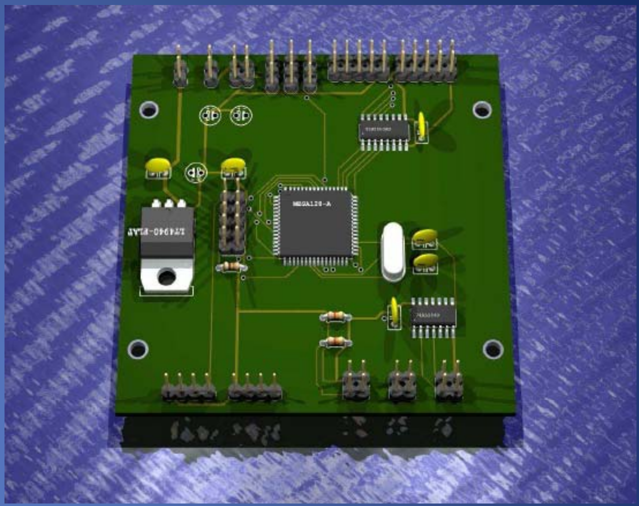
- Provide interface between the autopilot and the operator, telemetry and sensor information
- Specialized GUI developed to log the position and sensor information for each aircraft
- A separate wireless network shares basic information between each UAV and relays commands to other out of range aircraft
- Adaptive control methods for source tracking and path planning using an onboard microcomputer. Provide navigation commands to the aircraft's autopilot



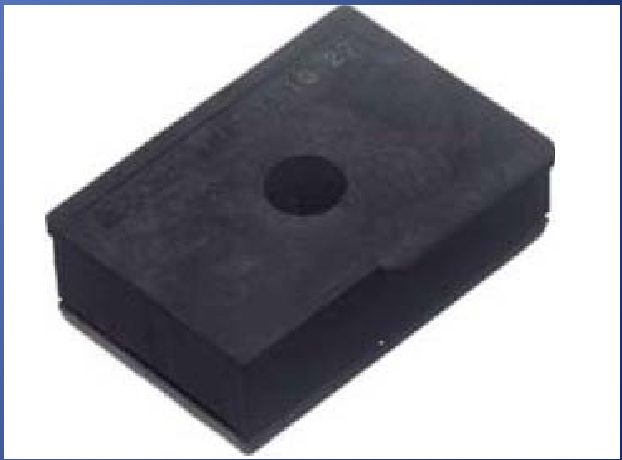
Ground station software

Sensors

- CO_2 , particulate, and chemical detection
- Final selection based LANL field restrictions
- Compact optical dust sensor was chosen which gave particulate density in mg/m^3
- Custom microprocessor board designed to accommodate future analog or digital sensors and interface with the autopilot
- Sensor location on the aircraft
  - minimize the response time
  - Evacuate any residual particulate matter in the sensor housing upon exiting the plume



Sensor Interface Board



Flight Operations at LANL Kelly Field

- Restricted airspace allowing for autonomous flight operations

- **Dedicated runway** for aircraft with landing gear and net capture setup for additional retrieval options

Plume Generation

- Off the shelf smoke grenades were used which emitted either Saf-Smoke or hexachloroethane (HC) smoke

- Single plume source could be moved around the flying field based on the weather conditions

Smoke grenade and plume release

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Wind Sensor Setup

- Three sensor locations:
  - One on flight-line at 1.5 m AGL
  - North and south of the runway at 9 m AGL
- Wind Sensor Specifications:

Measurement	Units	Resolution	Accuracy
Wind Speed	m/s	0.1	Larger of 3% of reading or least significant digit
Wind Direction	º	1º	5º

- Test Flights: 25 to 75 m AGL collecting data
- Paths centered around wind sensor poles
- Data was collected using RC flights and autonomous UAV flights

Wind Sensor Setup: Pole and tripod mounted configurations

Plume Release Studies

- Conducted in various weather conditions to ascertain the general progression of the plume at the flying field

- Plume source locations and grenade initiation timing were tailored for each flight to maximize the availability of the plume for sampling by the UAVs

Plume Releases with UAVs

- Multiple UAVs flown around the plume releases in a coordinated fashion to demonstrate the ability of the aircraft to identify and locate the plume with its onboard sensors
- **Low altitude passes** conducted to capture the highest concentration measurements
- Autonomous flights at higher altitudes performed at the aircraft's cruise speed

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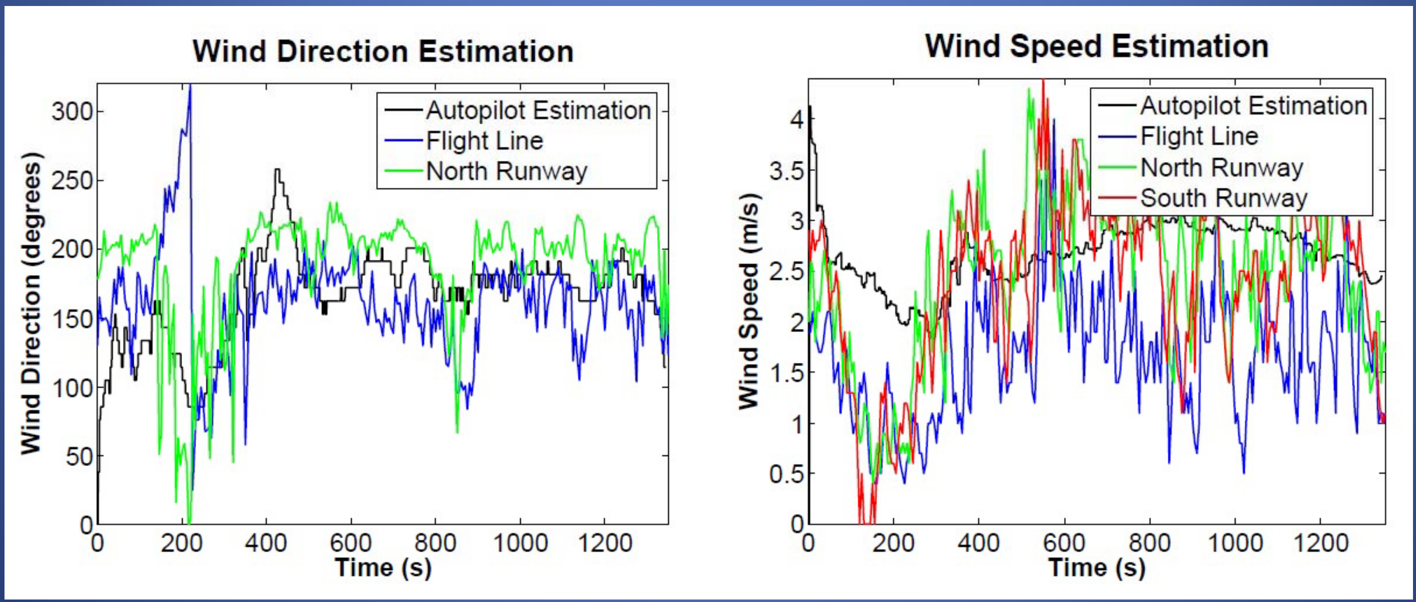
Wind Estimation Performance

- **Noticeable lag** in wind estimation generated by the autopilot
- **Inability** to capture detailed wind changes close to the ground
- More robust methods are **needed** for estimating wind speeds



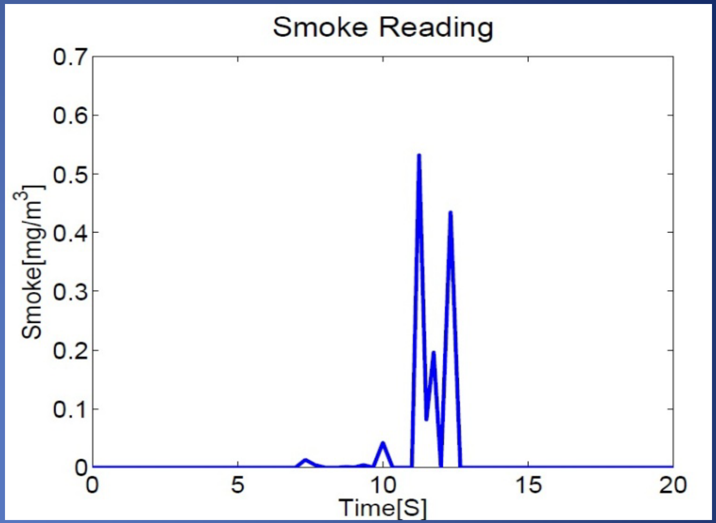
Estimation Results: First 500 seconds are in RC mode at altitudes below 50 m, from 500 to 1100 seconds it is in autonomous mode at 100 m altitude, transition back to RC mode after 1100 seconds

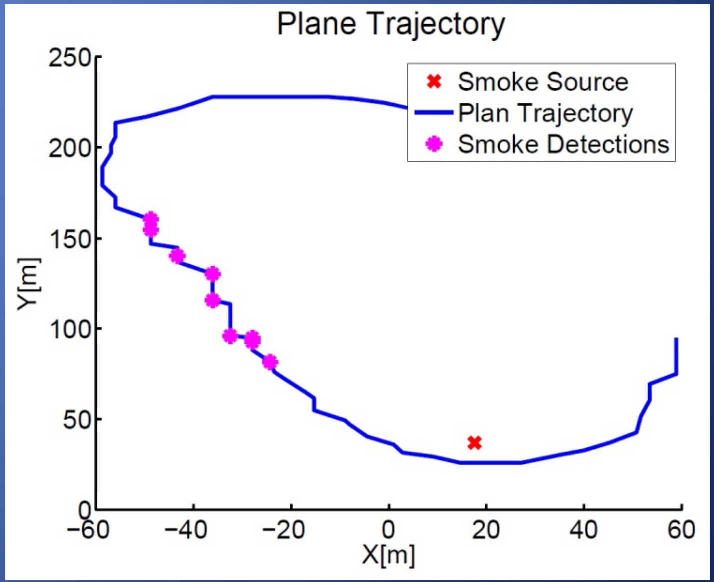
Particulate Sensor Readings

- Sensor saturation on almost every low altitude pass through the plume

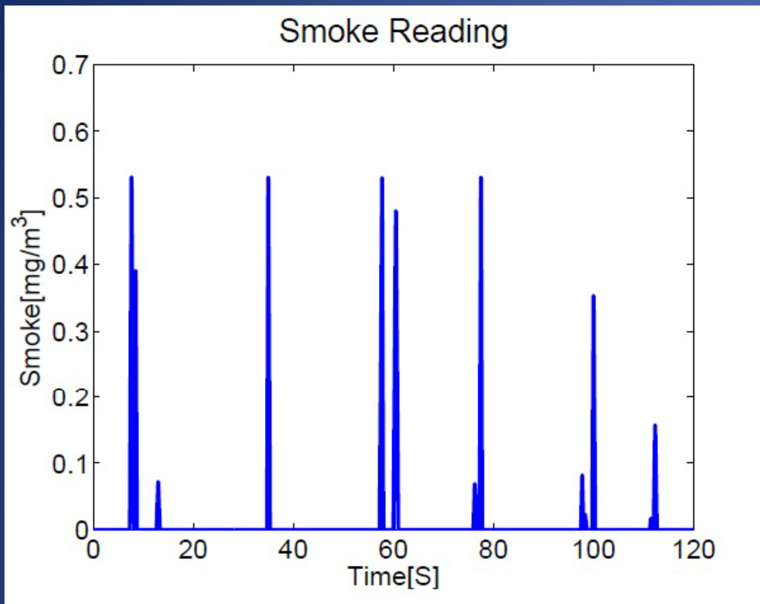
- For each pass through the smoke the system logged three to four samples a second, a pass usually lasted one to two seconds

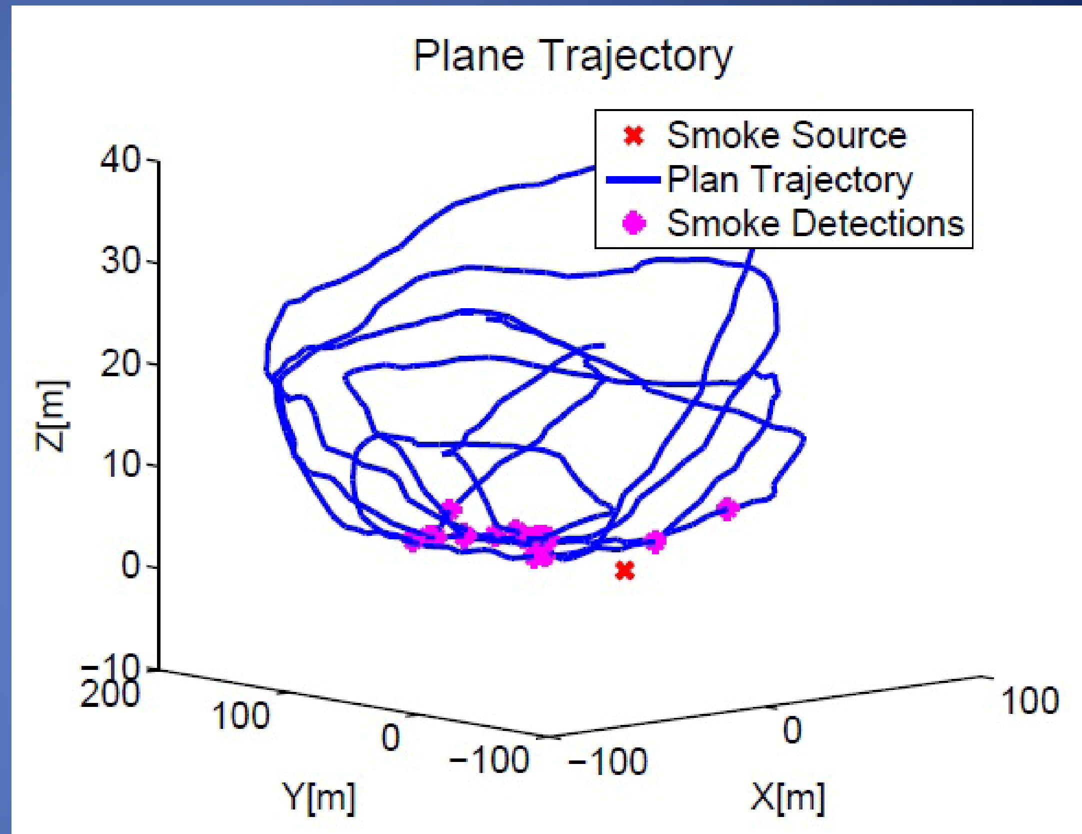
- Currently investigating slower vehicles and faster sensors to get more data within the plume.





3D graphs of plume passes





Successfully mapping plume definition

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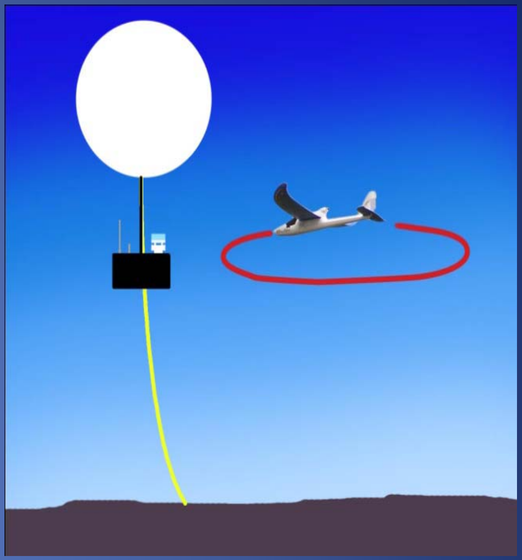
Demonstrated Capabilities

- Autonomous aircraft operation with multiple onboard sensors and computer systems for adaptive plume identification.
- Coordinated multi-UAV flights for plume identification and tracking

Current Studies: Wind Estimation

- **Wireless ultrasonic sensors** tethered to weather balloons at 25 m intervals from 0 to 150 m to get a wind profile map
- Multi-aircraft flights with individual aircraft tackling the wind estimation in certain altitude bands provide a wind profile estimate that can be compared to the wind sensors
- Investigate preferred aircraft closed path definition for wind speed and direction



Current Studies: Improve Mapping

- **Increase the sampling frequency** of the onboard sensors to provide a more precise mapping of the variations in particulate concentration
- Use a **slower fixed wing UAV** platform to better match the release capabilities of the LANL flying field
- **Validate** sensitivity search algorithm for locating plum source using the quad-rotor.

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