Development and Application of Unmanned Aerial Emission Sampling

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"This presentation has been reviewed by the U.S. Environmental Protection Agency, Office of Research and Development, and approved for presentation."

Disclaimer

- While this presentation mentions the use of unmanned aerial systems (UASs) or “drones” the EPA Office of Research & Development does not have appropriation authority to buy an UAS or contract for UAS flights.
- All UAS flight operations mentioned in this presentation were under contract with entities of the DoD.

Why does DoD need aerial emission sampling?

- Installation air permits
- Regional air quality attainment requirements
- Warfighter exposure protection
- Determination of range contamination
- Good neighbor policy

What DoD sources have aerial emissions?

- Demilitarization operations
- Land management with prescribed fires
- Burn pits at Forward Operating Bases (FOBs)
- Others (Ranges, Fast Cook Off fires)

Demilitarization Operations

- Open Burning (OB) of propellant
- Open Detonation (OD) of explosives
- Static Firing (SF) of rocket motors

Land Management with Prescribed Fires

- Purpose of prescribed fires:
  - To reduce wildfire risk
  - To maintain ecological balance
  - To maintain the land for training operations

- Smoke issues:
  - Inhalation concerns
  - Road visibility
  - Ozone and PM concentration and non-attainment status

Burn Pits at Forward Operating Bases

- Burn pits at FOBs have been used when incinerators are over capacity or malfunctioning
- The FOB sites are small so inhalation exposure is a concern
- Claims of inhalation effects have led Congress to establish a “Burn pit registry” of exposed soldiers
- These sites are hard to sample, hard to distinguish from other air pollutant sources

Others: Ranges, Fast Cook Off Fires

- Warfighter exposure at firing ranges.
- Fast Cook Offs used to test ignitability of ordnance under war fighting or accidental fire scenarios

The Issues

How do we efficiently and safely sample these plumes?

- Getting into the plume
- Finding the plume
- Fully measuring every pollutant of interest
- Ensuring sample quality:
  - Sufficient sample to avoid non-detects
  - Representative sample
  - Repeatable results
- Frag hazard for people and equipment
- Thermal hazard for equipment

IDEA

A balloon, loaded with sampling equipment, maneuvered into the plume by an army of post-docs.

Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

Researchers on the balloon turn on samplers, collect sample.

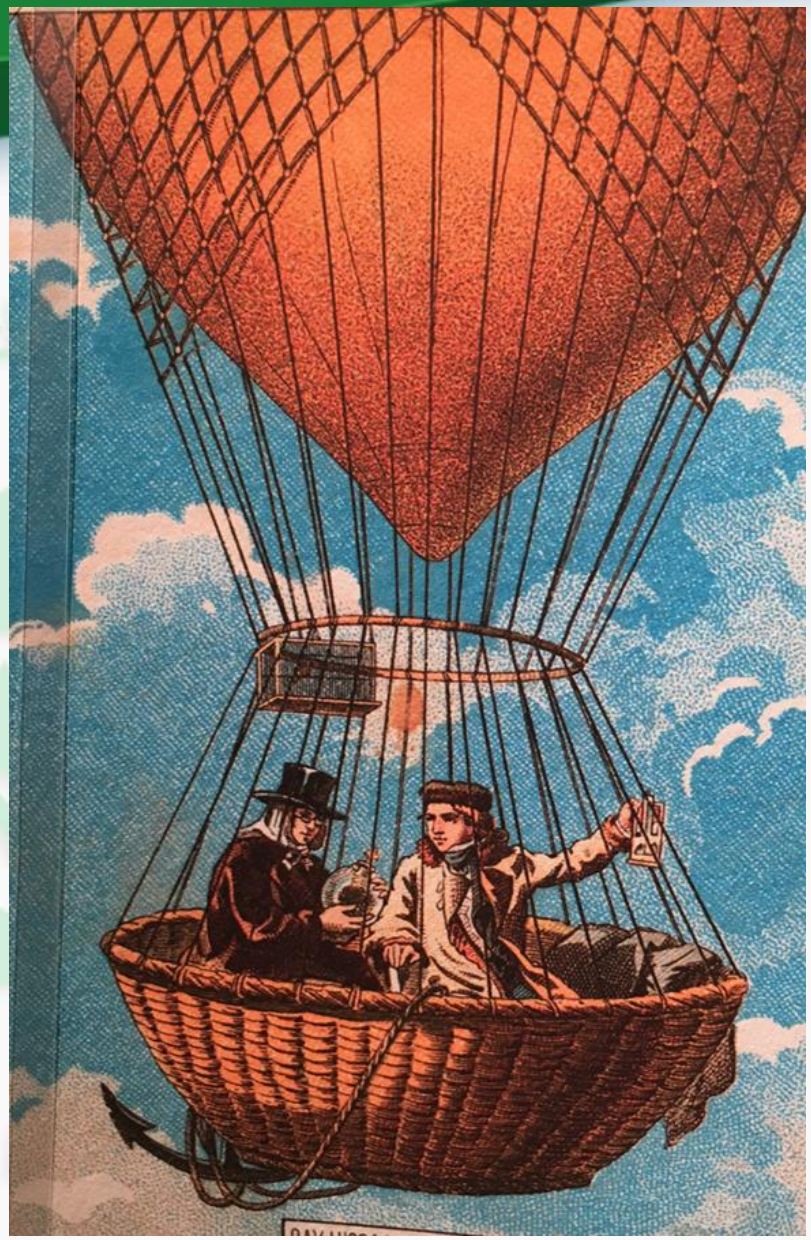


Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

Potential drawbacks.

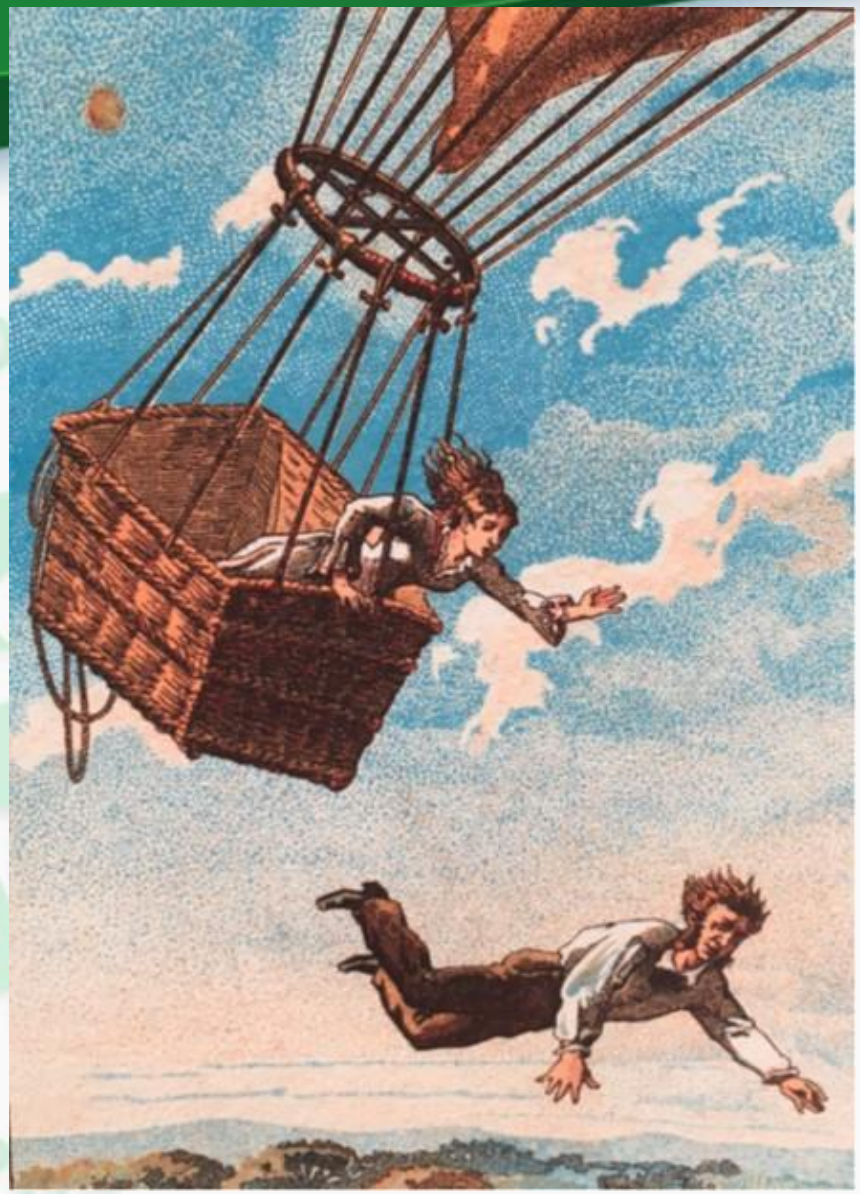


Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

An Unmanned, Aerostat Carrying a Novel Instrumentation System

The EPA “Flyer”: An unmanned, custom-built, telemetry-controlled sampling system.

5 m diameter, helium-filled aerostat, attached to two remotely controlled winches mounted on XUVs.

The Flyer Capabilities

- CO_2 by NDIR
- $PM_{2.5, 10}$ by impactor
- PM DustTrack
- PM metals, ions (XRF or ICP)
- Volatile organics, carbonyls
- Black Carbon, Brown Carbon
- PAHs, PCDDs/PCDFs,
- Energetics, nitroaromatics
- Cl, perchlorate
- Cr(VI)
- Others

Features:

- On-board and remote data acquisition
- Data telemetry
- CO_2 pump triggers
- GPS

The Aerostat/Flyer Applied to OB/OD at Tooele Army Ammunition Depot

Open burning of propellant at Tooele.

Open detonations at Tooele.

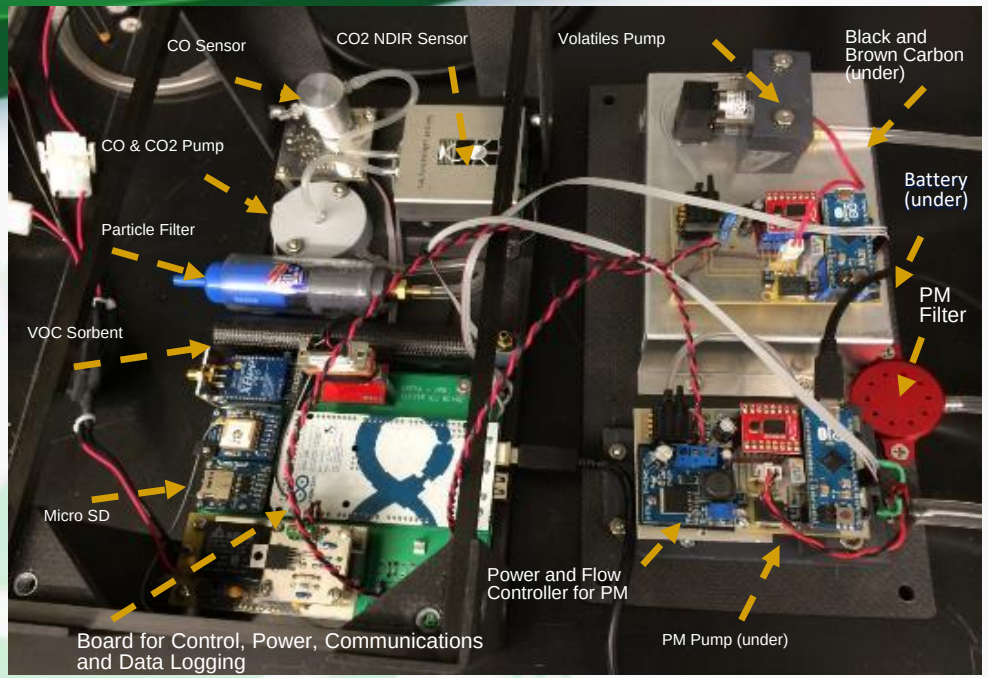
Sampling of an Open Detonation

Limits on Aerostat/Flyer Method

Tethered aerostat/Flyer sampling has worked well in measuring OB/OD/SF emission factors, but has constraints:

- Maneuverability
  - Tethers (trees, power lines)
  - Need 1 or 2 winch-mounted ATVs
  - Limited 3D range (wind shifts, plume drift)
  - Terrain and boundary limits
- Resource requirements
  - Large team: 5-6 people
  - Large equipment (and expensive helium)
  - Cost
- Balloons don't like holes

The “Kolibri”: A Lightweight, Small Sensor/Sampler



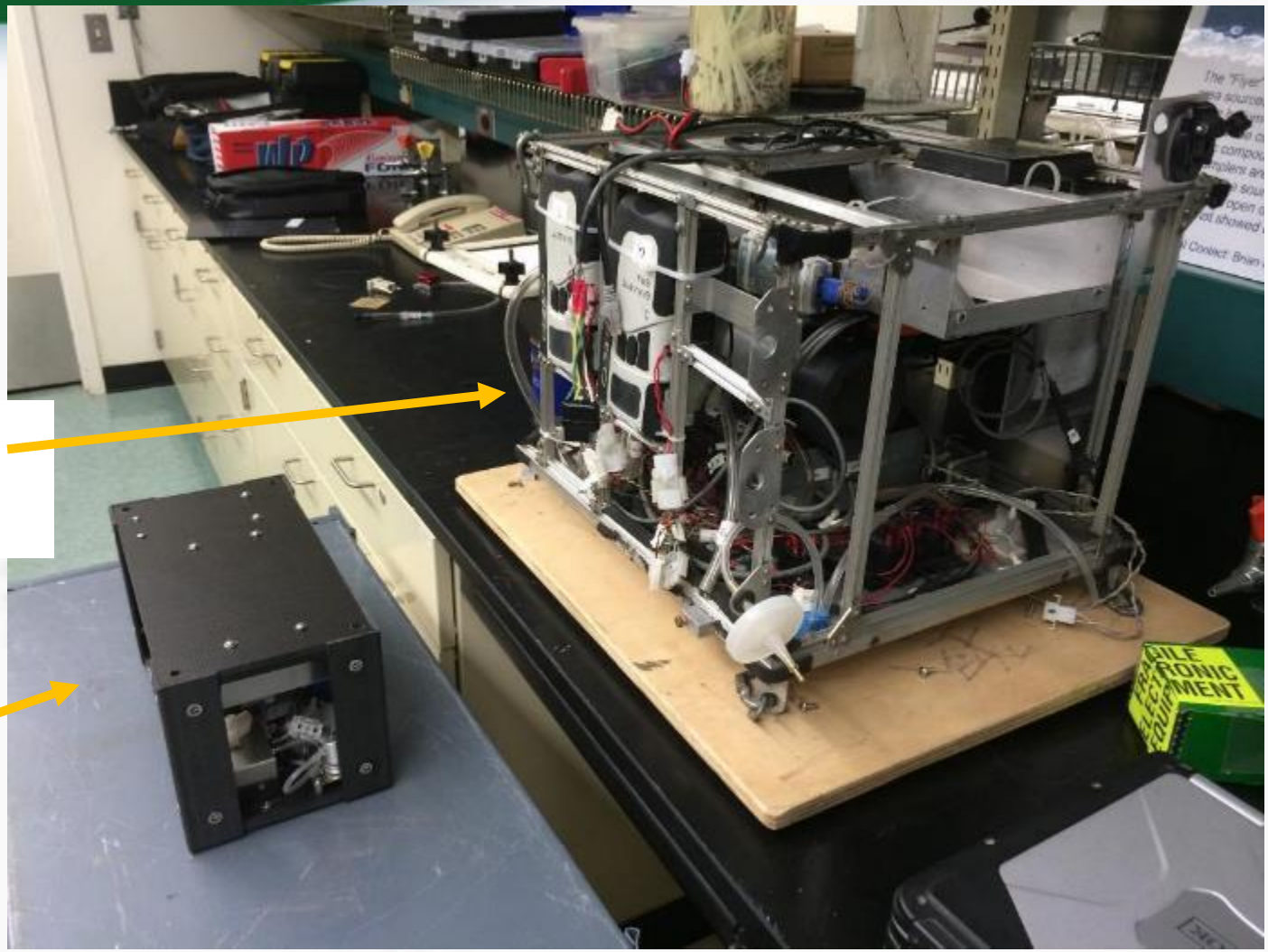
The Kolibri is 3.56 kg and can measure:

- CO_2
- CO
- PM (all sizes)
- Metals, ions
- Volatile organics, carbonyls
- Black Carbon, Brown Carbon
- PAHs, PCDDs/PCDFs
- Energetics, nitroaromatics
- Cl, perchlorate
- Cr(VI)

Features:

- GPS
- Carbon fiber frame
- Teensy microcomputer 3.2 USB-based data acquisition and transmission system running Arduino control code
- 32 V batteries and voltage regulators
- Labview program provides storage, live data, and control using an Xbee radio wireless network

Development of a Smaller, Lighter Sampler



>21kg,
55 x 50 x 45 cm

3.56 kg,
15 x 15 x 30 cm

Utility of Unmanned Aerial Systems (UASs)

- Advances in GPS, carbon fiber, computer, and battery technologies have led to UAS development, particularly for multicopters
- They are operator controlled or fly programmed paths
- They have auto-return, boundary, and auto-land features
- Personnel are safely at a distance
- Recent designs can carry payloads of 5 kg for 15-20 minutes
- They are portable (fold up) and fast to deploy
- They do not have a disturbance footprint
- Require only two people
- Costs for a high capacity multicopter are about $10K

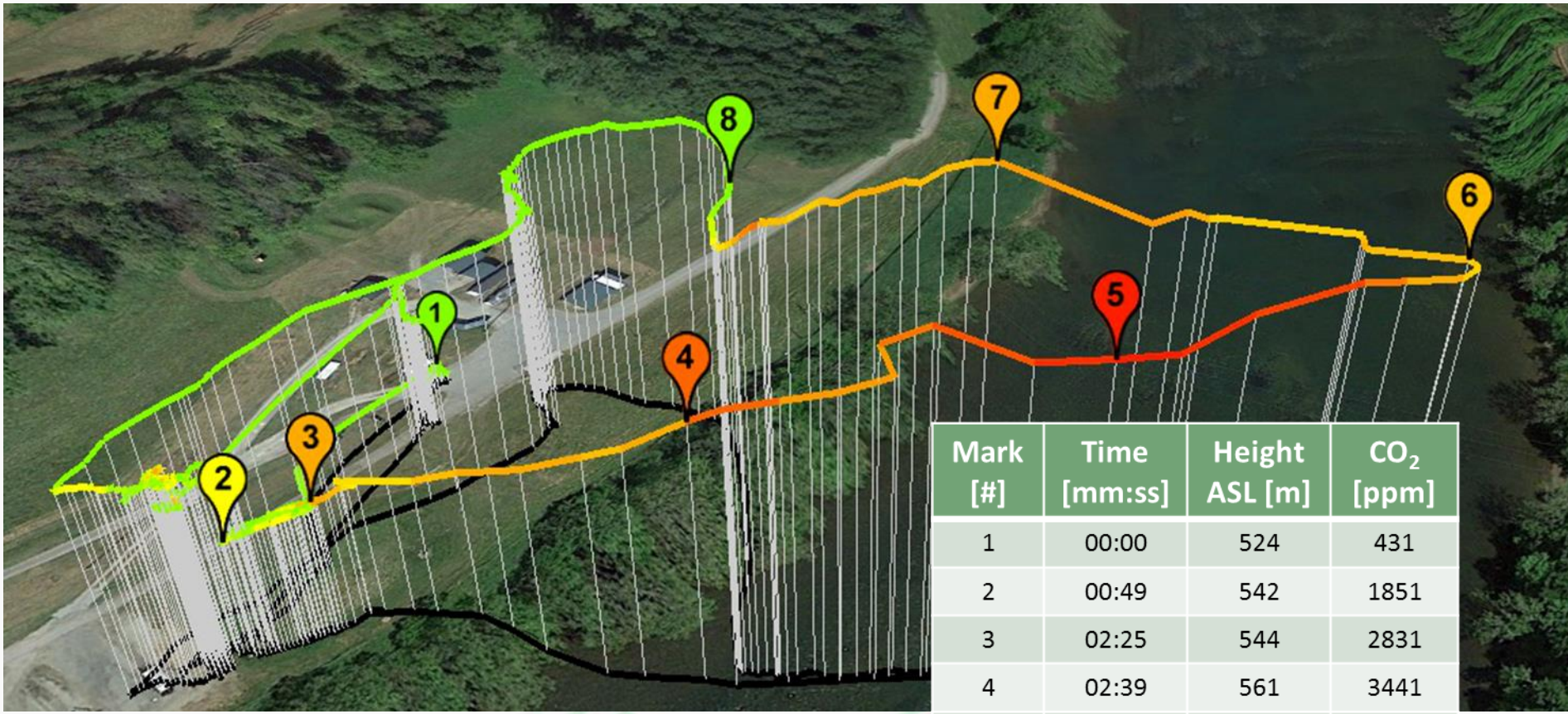
The Kolibri attaches to an Unmanned Aerial System (UAS, aka “drone”)

NASA-owned and flown UAS hexacopter

UAS/Kolibri sampling OB plume at Radford AAP

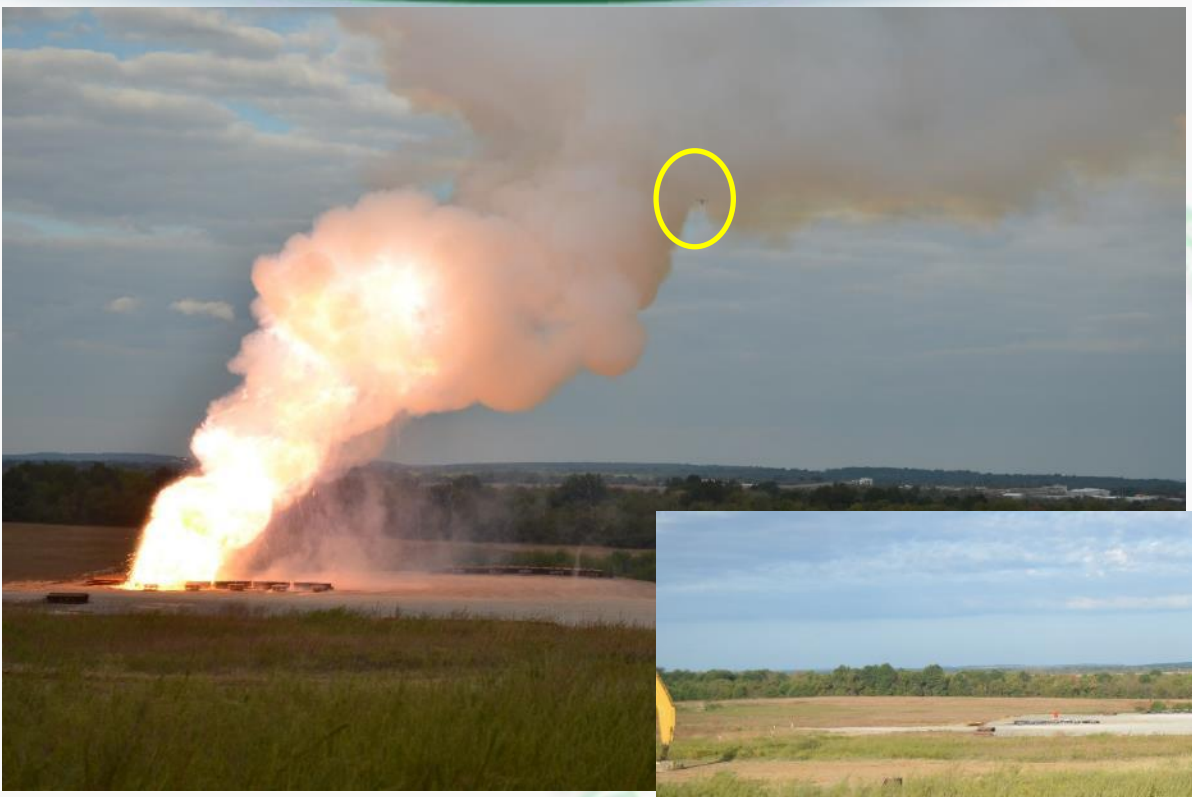
Sampling of an Open Burn

Field Results: UAS Path, OB Sampling



Mark [#]	Time [mm:ss]	Height ASL [m]	CO_2 [ppm]
1	00:00	524	431
2	00:49	542	1851
3	02:25	544	2831
4	02:39	561	3441
5	02:47	572	4085
6	02:54	583	2562
7	03:02	602	2678
8	07:13	586	436

UAS Sampling of Propellant Open Burns



Sampling of an Open Burn

Sampling Aspects

- Pump flow calibrations
  - Daily
  - Compensating and non-compensating pumps
- Sensor calibrations
  - Daily multipoint CO and CO_2 calibration curves
  - Daily drift
  - Sensor interferents
- UAS frequency overlaps with telemetry system
  - 2.4 GHz is Matrice, versus our 900 MHz
- Duration, payload
  - 20 min, 3-4 kg
  - > 1 km on the NASA Ames *DJI Matrice 600*

How are the Measurements Used?

- We are determining time-resolved concentrations and cumulative mass collected
- We want to determine emission factors or the mass of the pollutant per mass of fuel consumption
- This is determined from the ratio of the pollutant mass to the mass of carbon, C, that is co-sampled (CO + CO_2)
- For OB/OD/SF, we know the amount of "fuel" so we know the amount of C
- For biomass, we estimate that the biomass fuel is about 50% C by weight

- $$EF = \frac{mass\ of\ pollutant\ sampled}{mass\ of\ C\ sampled} \text{ x } \frac{mass\ of\ C\ in\ fuel}{mass\ of\ fuel}$$
- Emission factors are used as primary inputs for:
  - dispersion models (concentrations and exposure)
  - deposition models
  - national inventories for source prioritization
  - installation air permits

Summary

- Small, lightweight sensor/sampler systems have been built and demonstrated
- They offer personnel and equipment safety enhancements
- They are positionally flexible and adjustable
- The use of UASs has been demonstrated to sample many pollutants under challenging conditions

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