Emission Measurements of Open Area Combustion Sources with an Unmanned Aerial System

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Open Area Sampling

- Open area sampling is becoming relatively more important as
  - Industrial point source emissions are generally well-characterized
- Open area sources are recognized for their importance to air shed pollution and air quality attainment
  - Wildfires
  - Prescribed forest and agricultural fires
  - Oil and gas field emissions
  - Chemical industry emissions
  - Landfill fires
  - Accidents (e.g., train car derailments)

60% of the PM2.5 emissions in the USA are attributed to wildland fires.

Examples of Open Sources

Characterizing Emissions

How do we efficiently and safely sample these plumes?

Challenges:

- Getting into the plume
- Measuring every pollutant of interest
- Ensuring sample quality:
  - Concentration accuracy
  - Sufficient sample to avoid non-detects,
  - Representative sample
  - Repeatable results
- Proximity hazard for people (especially fires)
- Proximity hazard for equipment (especially fires)

IDEA

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

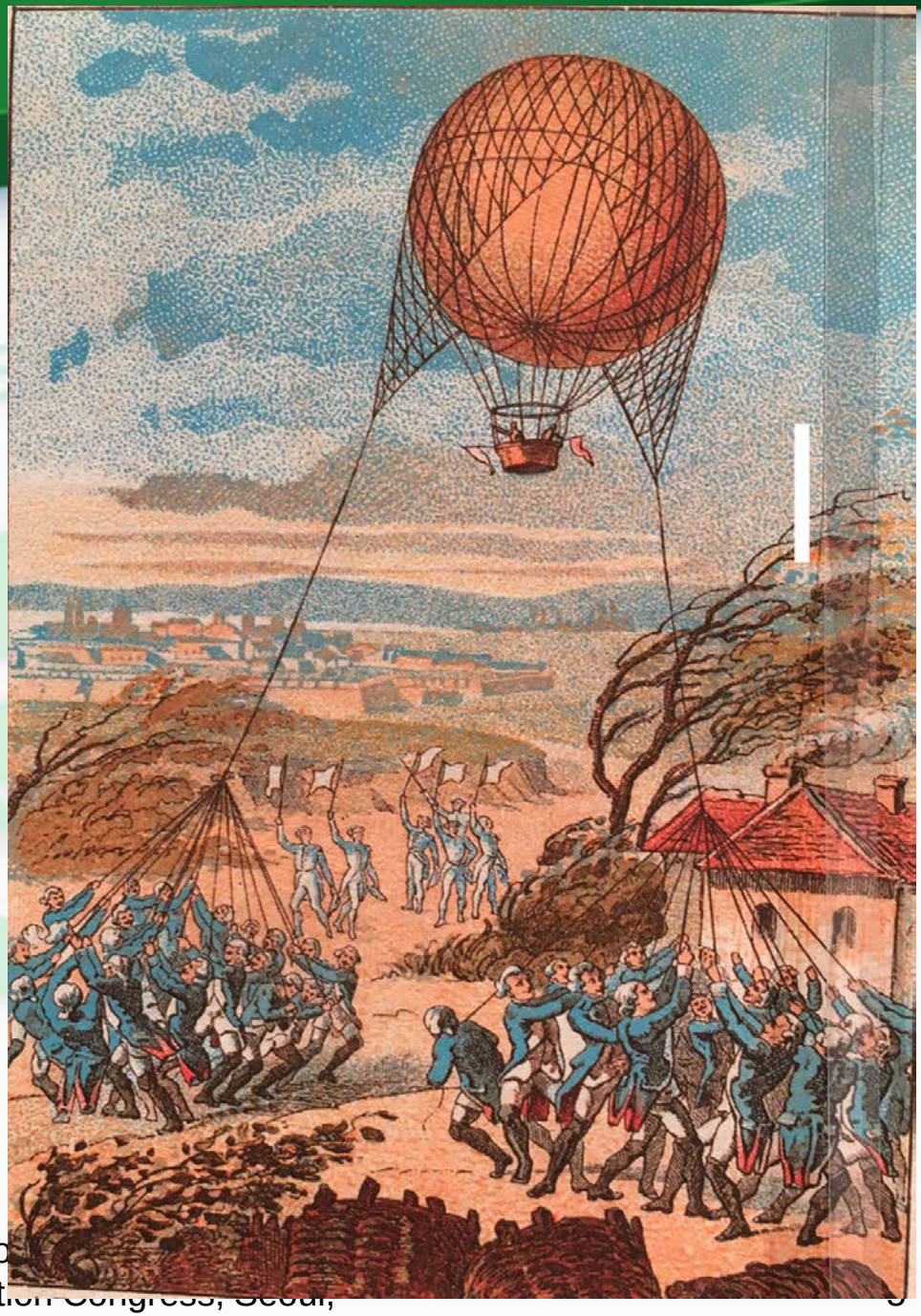


Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

Researchers on balloon turn on samplers, collect sample.

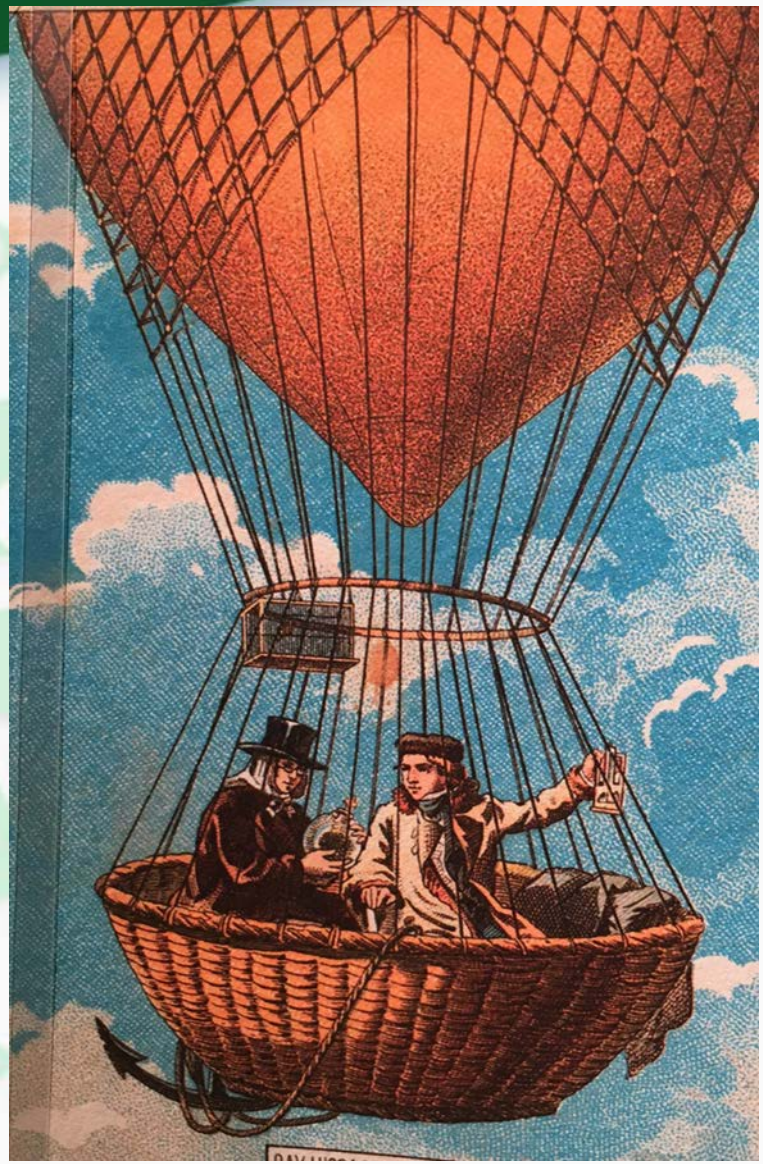


Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

Potential hazards.

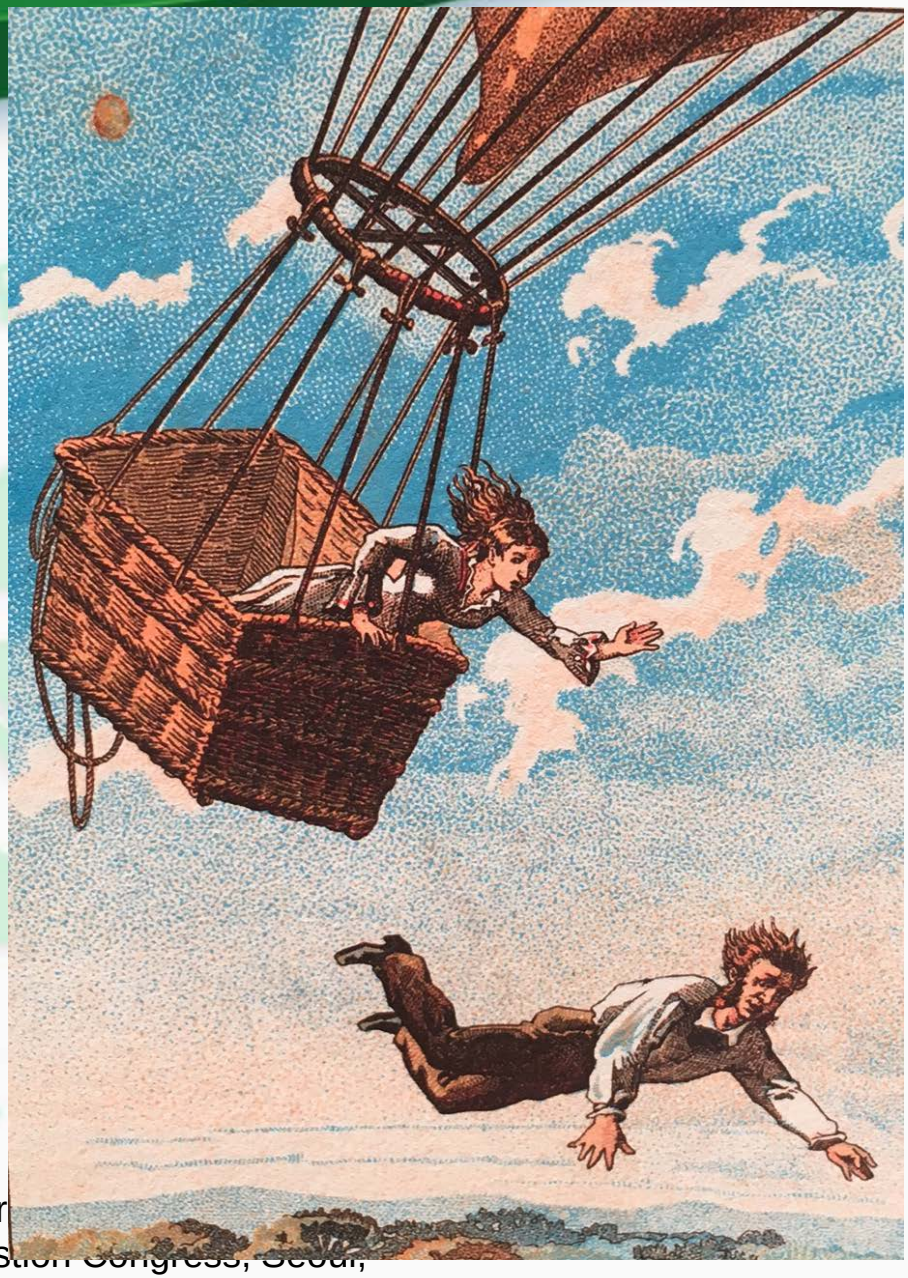
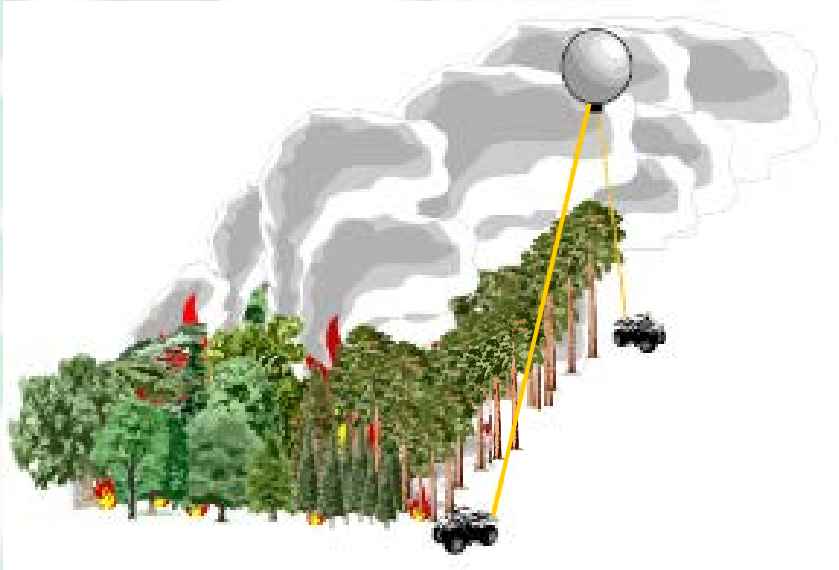


Image from
http://www.loc.gov/pictures/resource/ppmsca.02561/

An Unmanned, Aerostat Carrying a Novel Instrumentation System

The EPA "Flyer": An unmanned, telemetry-controlled sampling system.



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

Open burning of propellant at Tooele.

Open Detonations at Tooele.

Limits on Aerostat/Flyer Method

Tethered aerostat/Flyer sampling has worked well in measuring open fire 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
  - Large equipment (and helium)
  - Cost

“Drones” – An Alternative Solution

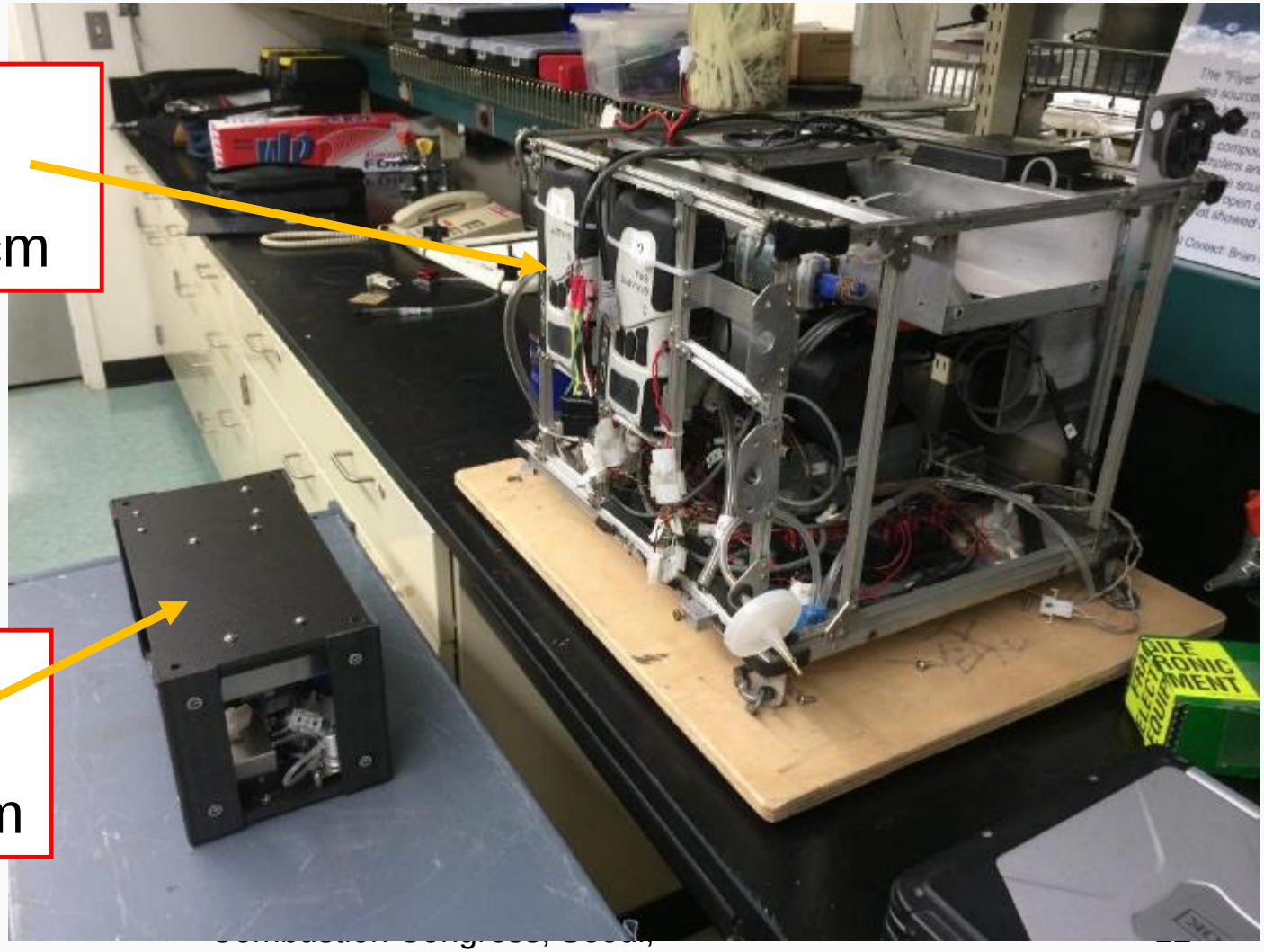
- Advances in GPS, carbon fiber, computer, and battery technologies have led to drone development, particularly for multicopters.
- They are operator controlled or fly programmed paths
- They have auto-return, boundary, and auto-land features
- Personnel are safely at a distance
- Recent designs can 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
- Typical costs range from $1,000 - $10,000

Drone
UAS: Unmanned Aerial System
UAV: Unmanned Aerial
RPAS: Remotely Piloted Aerial System

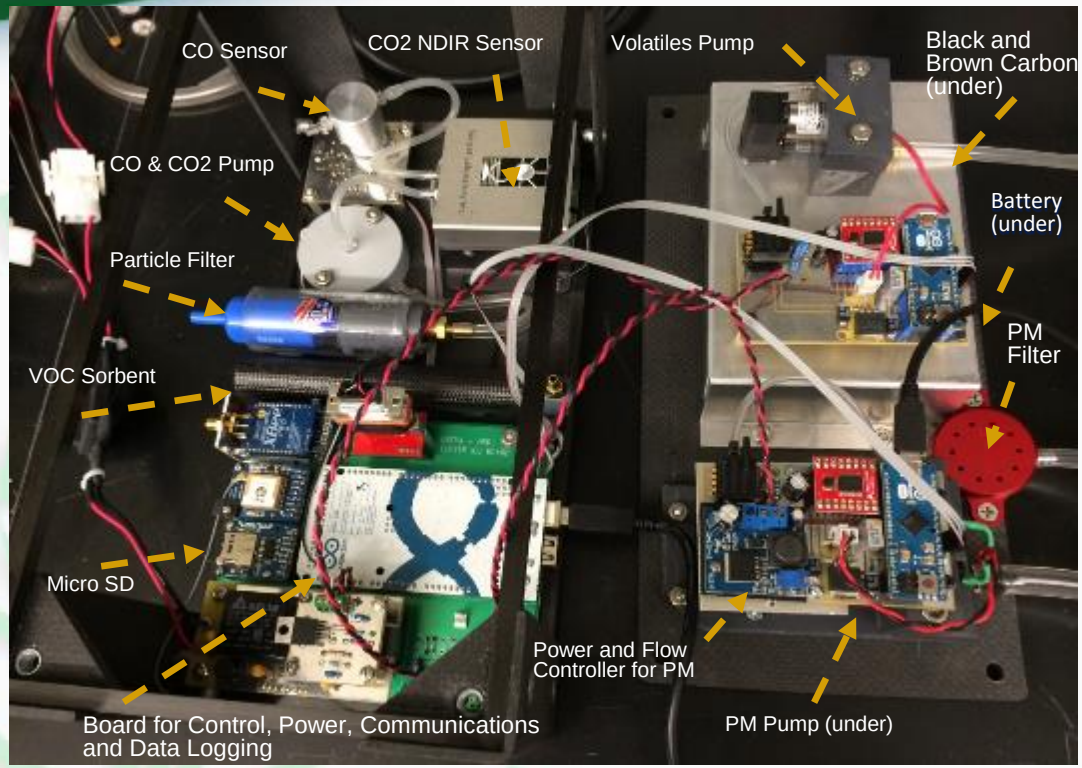
Development of a Smaller, Lighter Sampler

The Flyer:
>21kg,
55 x 50 x 45 cm

The Kolibri:
3.56 kg,
15 x 15 x 30 cm



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



- CO_2
- CO
- PM (all sizes)
- metals, ions
- Volatile organics, carbonyls
- Black carbon, Brown carbon

- PAHs, PCDDs/PCDFs,
- Energetics, nitroaromatics
- Cl, perchlorate
- Cr(VI)

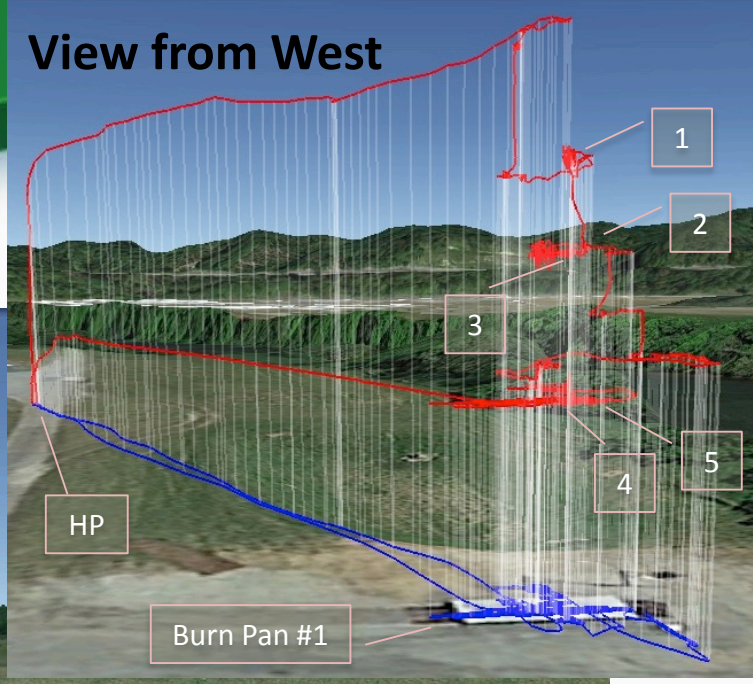
The Kolibri Attached to a UAV/drone. Sampling Demilitarization Propellant Open Burn

NASA-owned and flown UAV hexacopter

UAV/Kolibri sampling OB plume at Radford AAP

UAV Flight Path for Open Burn Sampling

Mark [#]	Time [mm:ss]	Distance [m]	Height [m]	Battery [%]
1	02:00	73.4	13.6	89
2	04:00	71.4	11.2	81
3	06:00	71.2	11.4	72
4	08:00	72.6	7.6	63
5	10:00	73.3	6.5	55

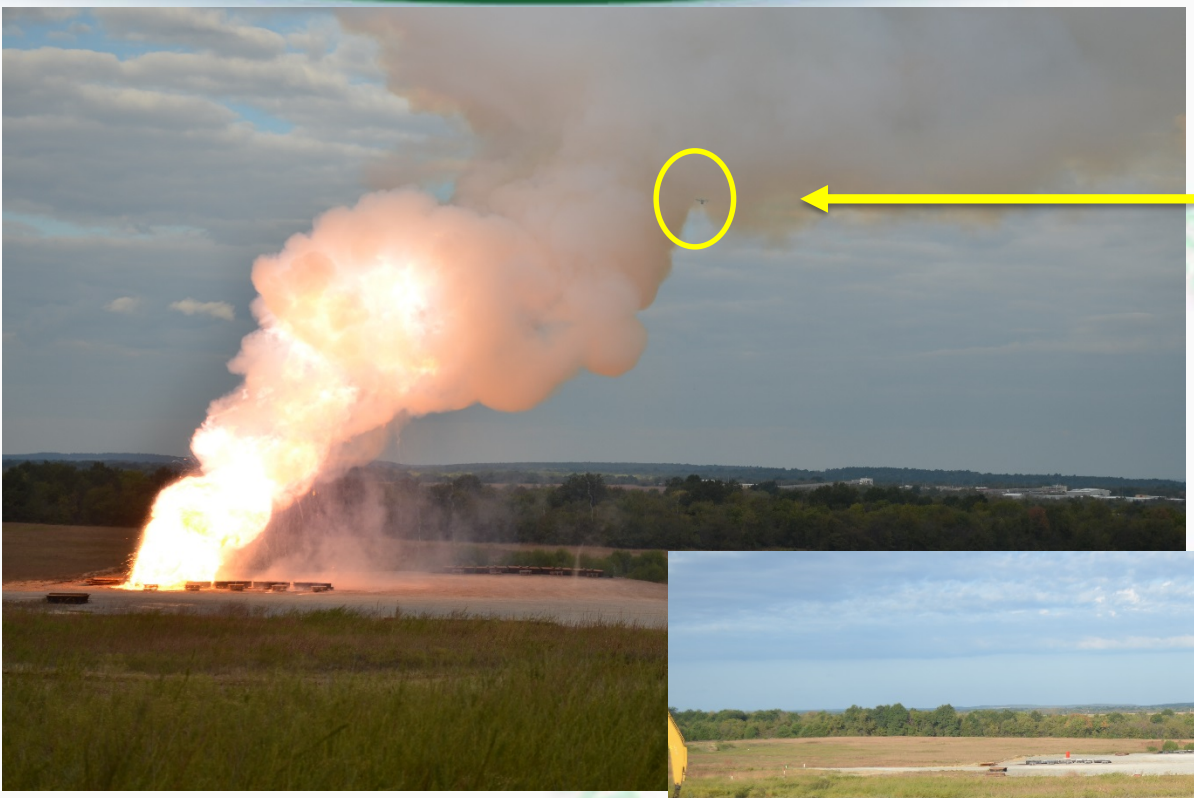


View from South East

SAMPLING AN OPEN BURN FROM A UAV

- Ved's video or my video of flights. His is 1:30 m:s

Sampling Propellant Demilitarization



Truck for perspective on plume height

Mark [#]	Time [mm:ss]	Height [m]	CO2 [ppm]
1	00:00	254	416
2	00:20	259	408
3	01:23	289	2427
4	01:26	290	3778
5	01:31	297	4599
6	01:34	304	3075
7	02:07	331	408
8	02:37	302	410

SAMPLING AN OB WITH A UAS

Future Efforts

- Rocket motor demilitarization (August 2017)
- Prescribed agricultural fires (Sept 2017)
- Open detonation demilitarization (April 2018)
- Gimbal-mounted, high density camera for plume tracking/sampling
- Emergency response hazard detection
- IR, hyperspectral measurements
- Dispersion model verification with spatially- and temporally-resolved concentration data

Related Publications

- Zhou, X.; Aurell, J.; Mitchell, W.; Tabor, D.; Gullett, B., A Small, Lightweight Multipollutant Sensor System for Ground-Mobile and Aerial Emission Sampling from Open Area Sources, Atmos. Environ. 154, 31-41, 2017, http://dx.doi.org/10.1016/j.atmosenv.2017.01.029.
- Aurell, J.; Gullett, B.K.; Tabor, D.; Williams, R.K.; Mitchell, W.; Kemme, M.R.; Aerostat-based sampling of emissions from open burning and open detonation of military ordnance, J. Haz Mat 284: 108-120, 2015.
- Aurell, J., Gullett, B., Pressley, C., Tabor, D., Gribble, R. Aerostat-lofted instrument and sampling method for determination of emissions from open area sources, Chemosphere 85(5), October, 2011, 806-811.
- Aurell, J.; Mitchell, W.; Chirayath, V.; Jonsson, J.; Tabor, D.; Gullett, B. Field Determination of Multipollutant, Open Area Combustion Source Emission Factors with a Hexacopter Unmanned Aerial Vehicle, submitted, 2017.

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