Go With the Flow:

Micro Aerial Vehicles as Lagrangian Particles in the Atmospheric Boundary Layer

Nate Simon, Skywalker Li, Nick Conlin, Nathan Wei, Girguis Sedky,
Anirudha Majumdar, Marcus Hultmark

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APS DFD

IRoM Lab
Intelligent Robot Motion Lab

Fast Lab

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California fires, Sep. 2020
NOAA GOES-West GeoColor
Youtube: canvrno

Methods for measuring atmospheric wind:

Eulerian:

- Towers
- Kites
- Aircraft / sondes
- LIDARs

Lagrangian:

- Balloons / Tetroons

We want to track

small scales (~10 cm)

over *long distances* (~10 km)

at *multiple points*

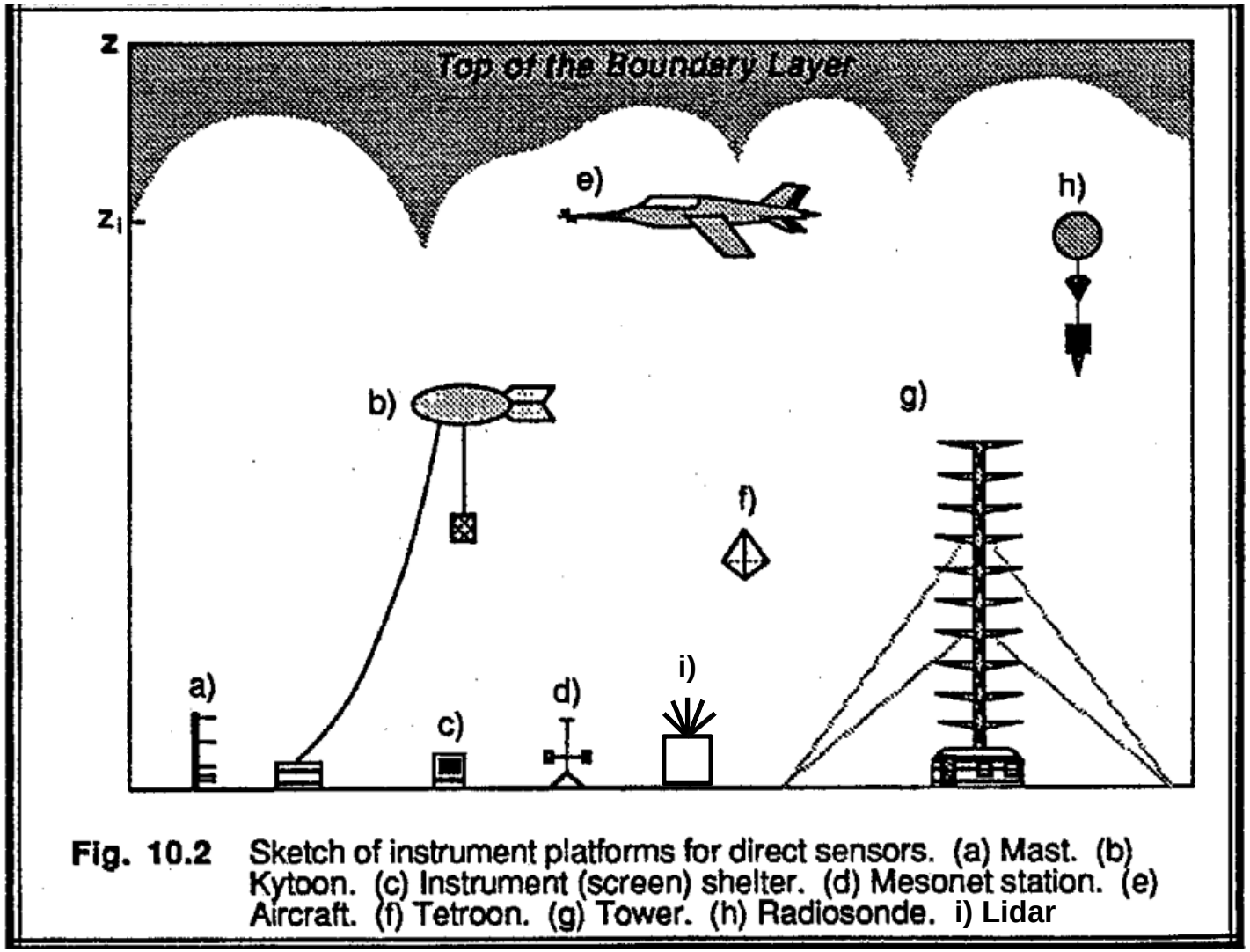

Fig. 10.2 Sketch of instrument platforms for direct sensors. (a) Mast. (b) Kytoon. (c) Instrument (screen) shelter. (d) Mesonet station. (e) Aircraft. (f) Tetroon. (g) Tower. (h) Radiosonde. i) Lidar

(Stull, 1988)

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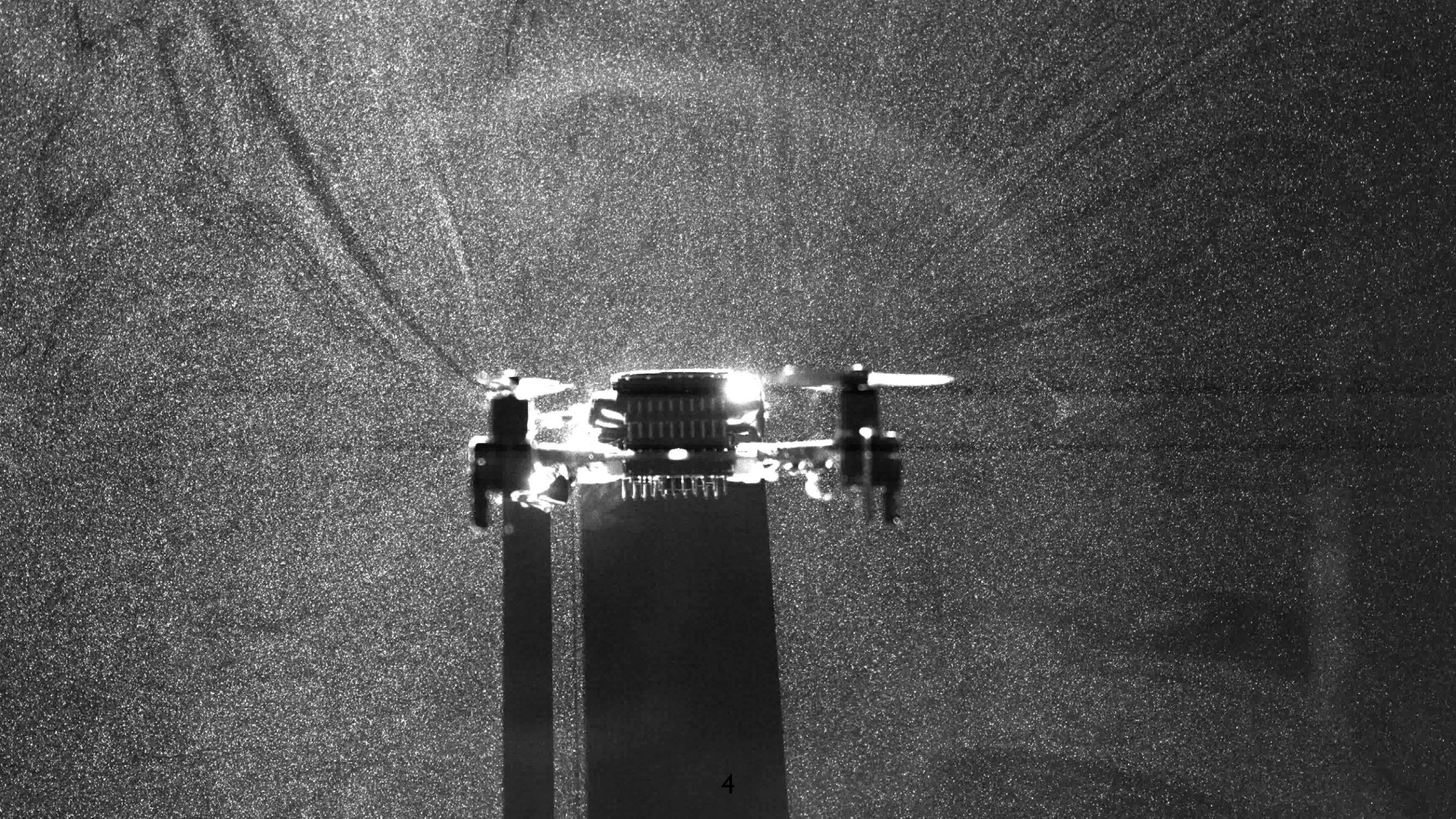
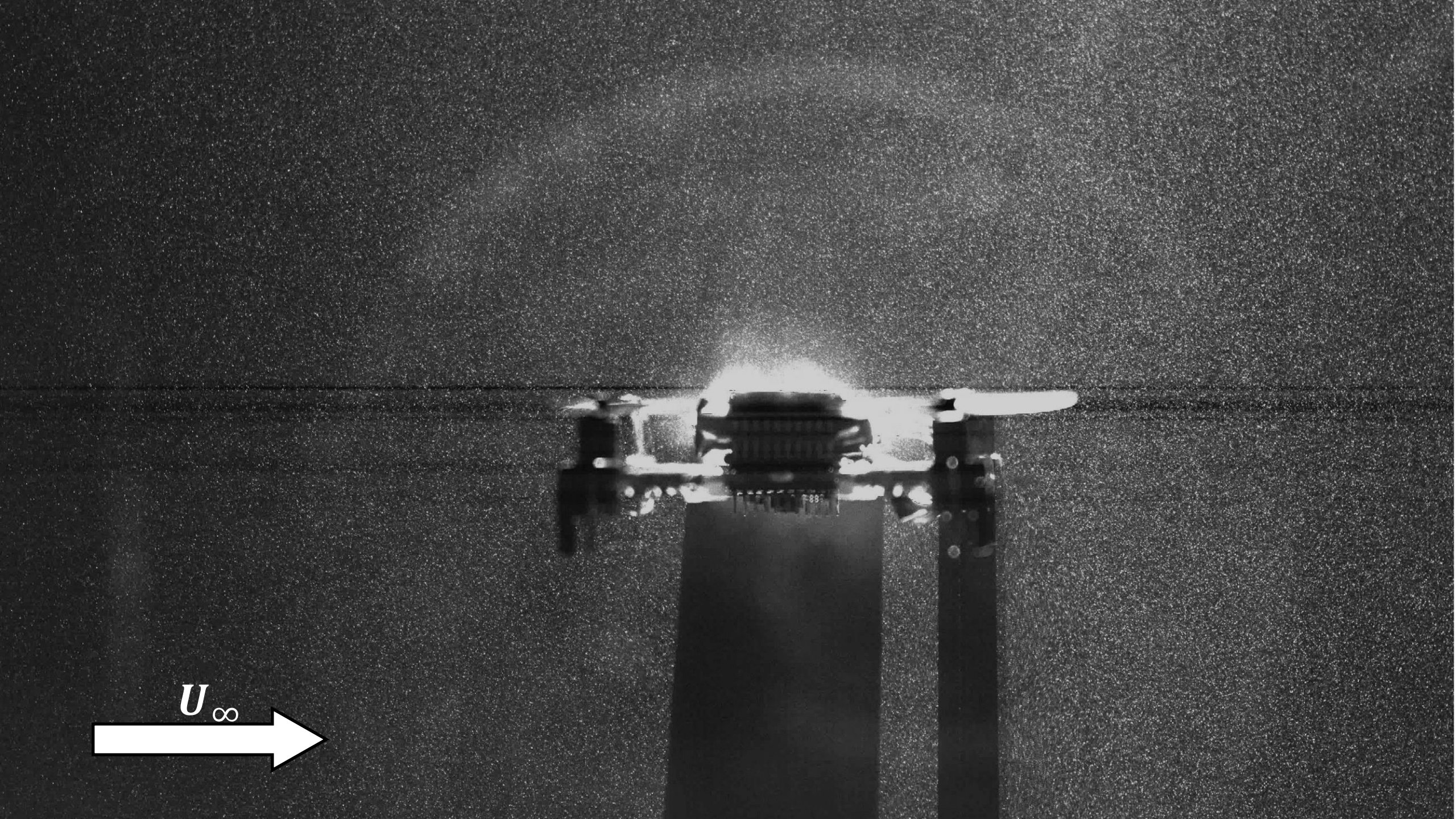
We need a "smart particle" that:

- Starts from a specified initial position $(x_0\ y_0, z_0)$,
- Moves with the flow,
- Tracks itself precisely,
- Flies long trajectories (~ 10 km),
- Is scalable (i.e., swarm of particles),
- Is inexpensive, reusable, and requires minimal infrastructure.

Could a small drone accomplish this?

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Lagrangian Drone

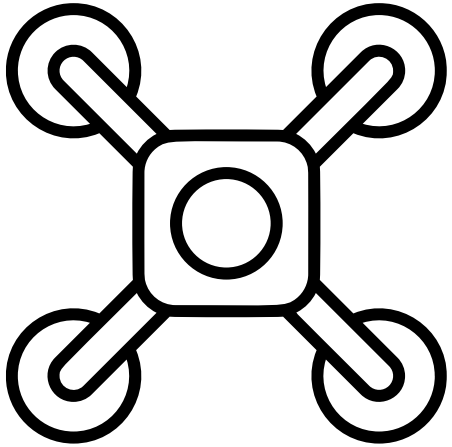
La Drone

LaDrone

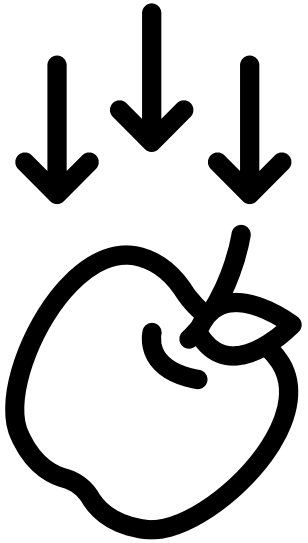
Towards LaDrone

Core aspects of LaDrone:

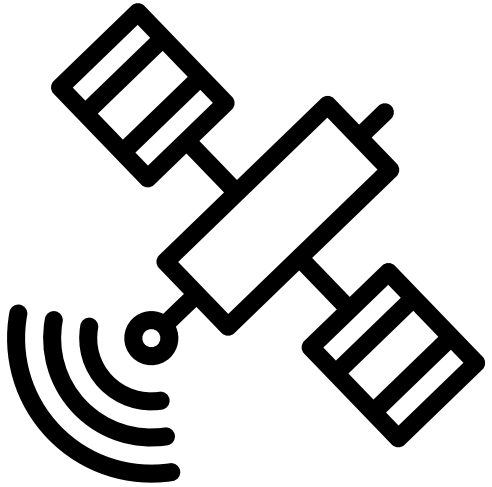
micro aerial vehicle
(~40 grams)



gravity compensation
(neutral buoyancy)



sub-cm trajectory
tracking

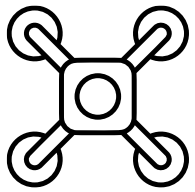


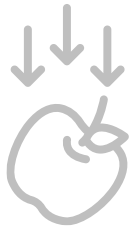
Core aspects of LaDrone:

Crazyflie 2.1

gravity compensation (neutral buoyancy)

sub-cm trajectory tracking



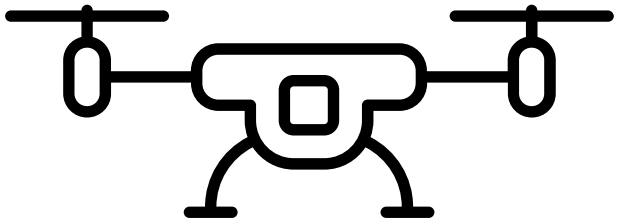


Core aspects of LaDrone:

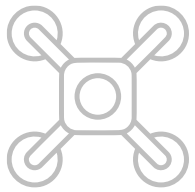
Crazyflie 2.1

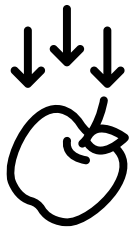
roll, pitch = 0°

thrust = weight



sub-cm trajectory tracking





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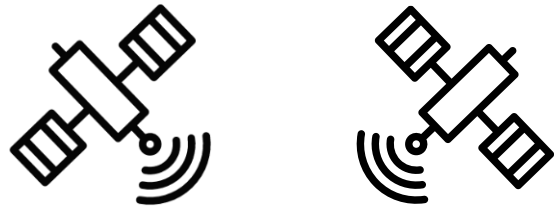
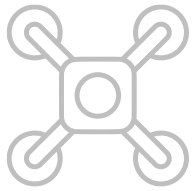
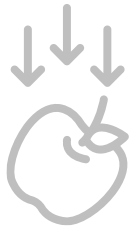
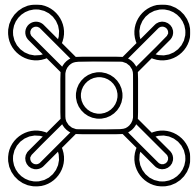






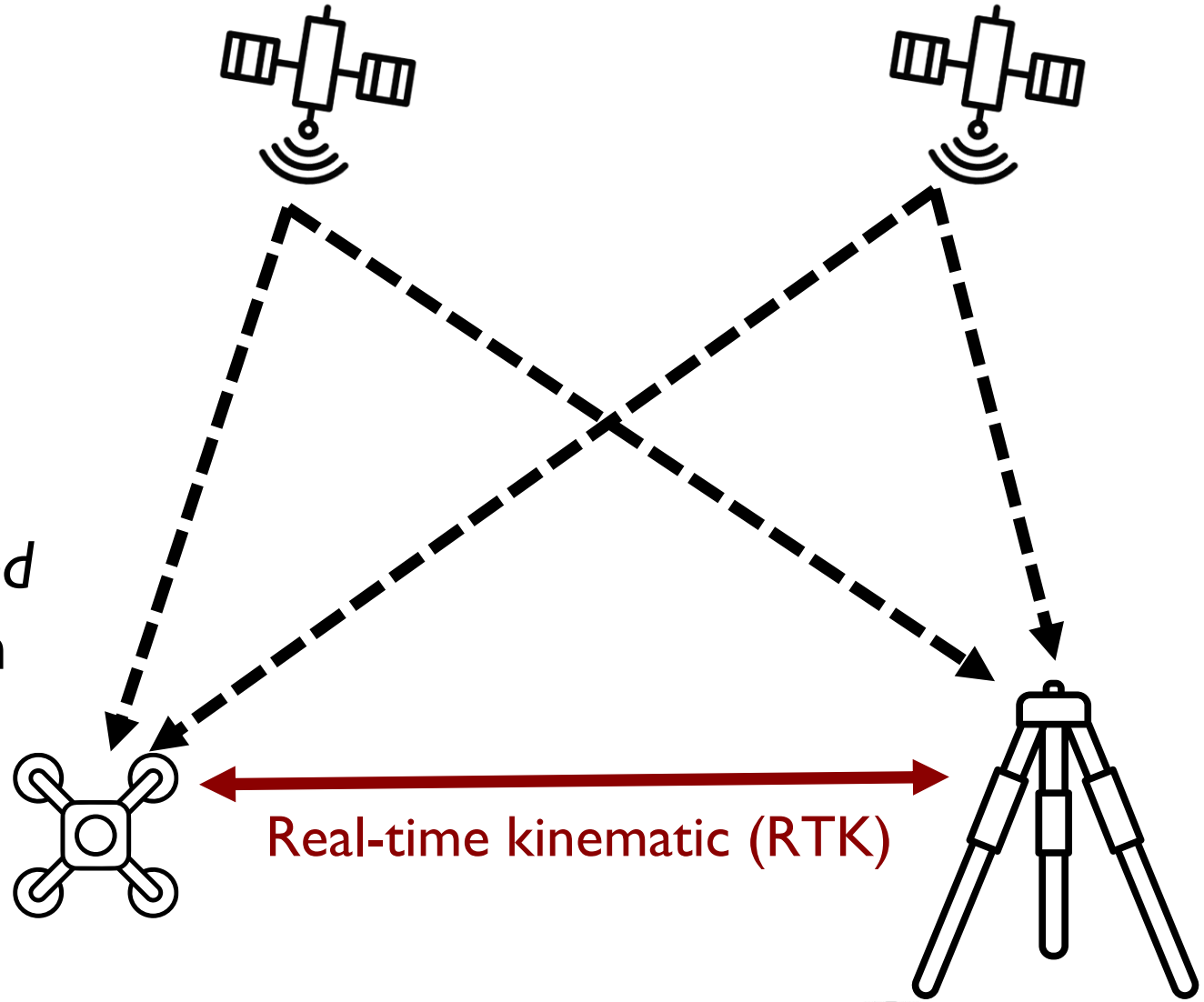


Global GNSS error (~2 m) is due to:

- Limits in timing estimation,
- Ionosphere effects,
- Errors in satellite ephemeris,
- …

However, position *relative to a fixed base* can be determined to sub-cm precision!

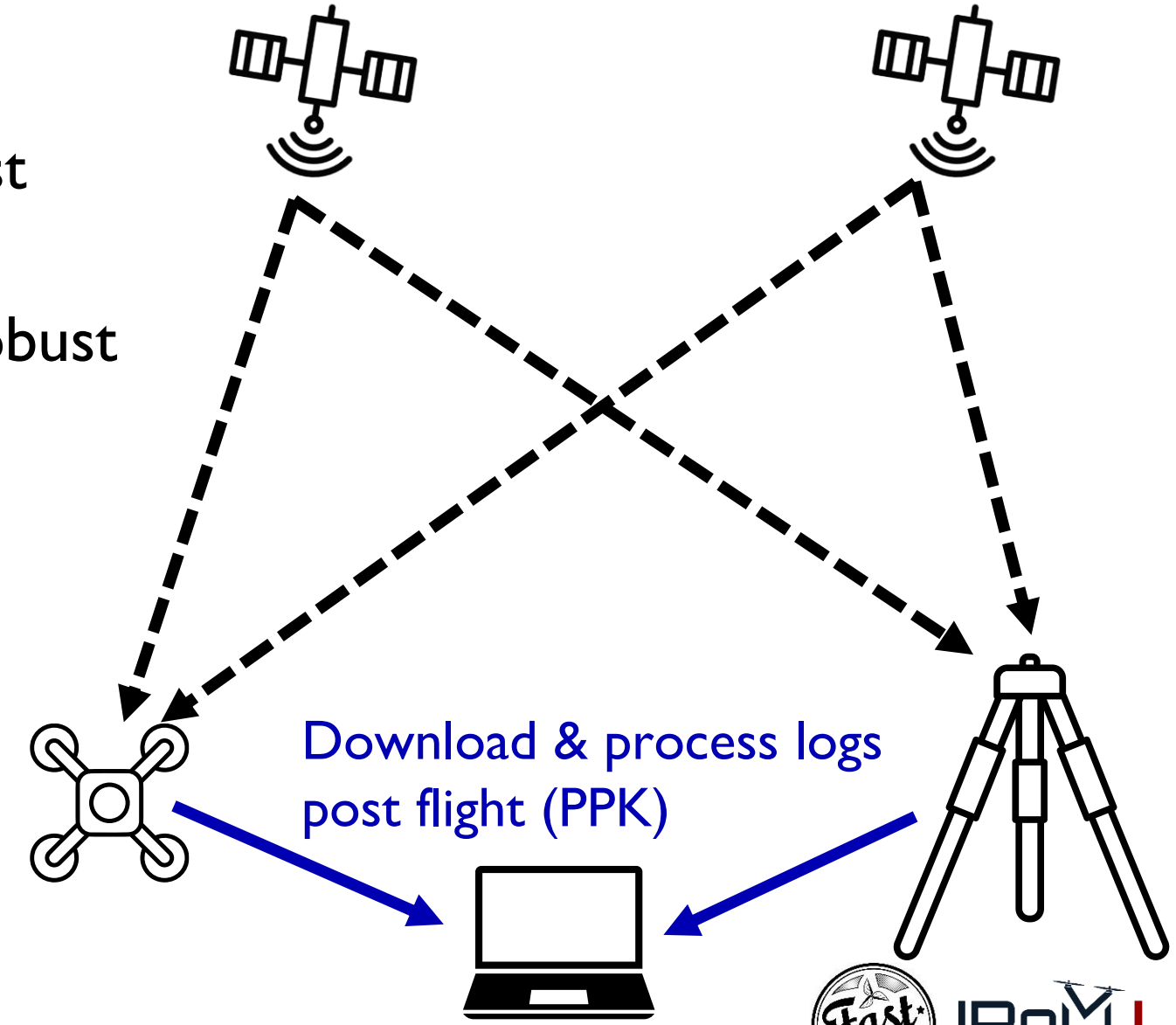
(Requires a real-time link)



If *real-time* precision is not needed:

Post-processing kinematic (PPK)

- Log separately and process post flight!
- Simpler to implement, more robust



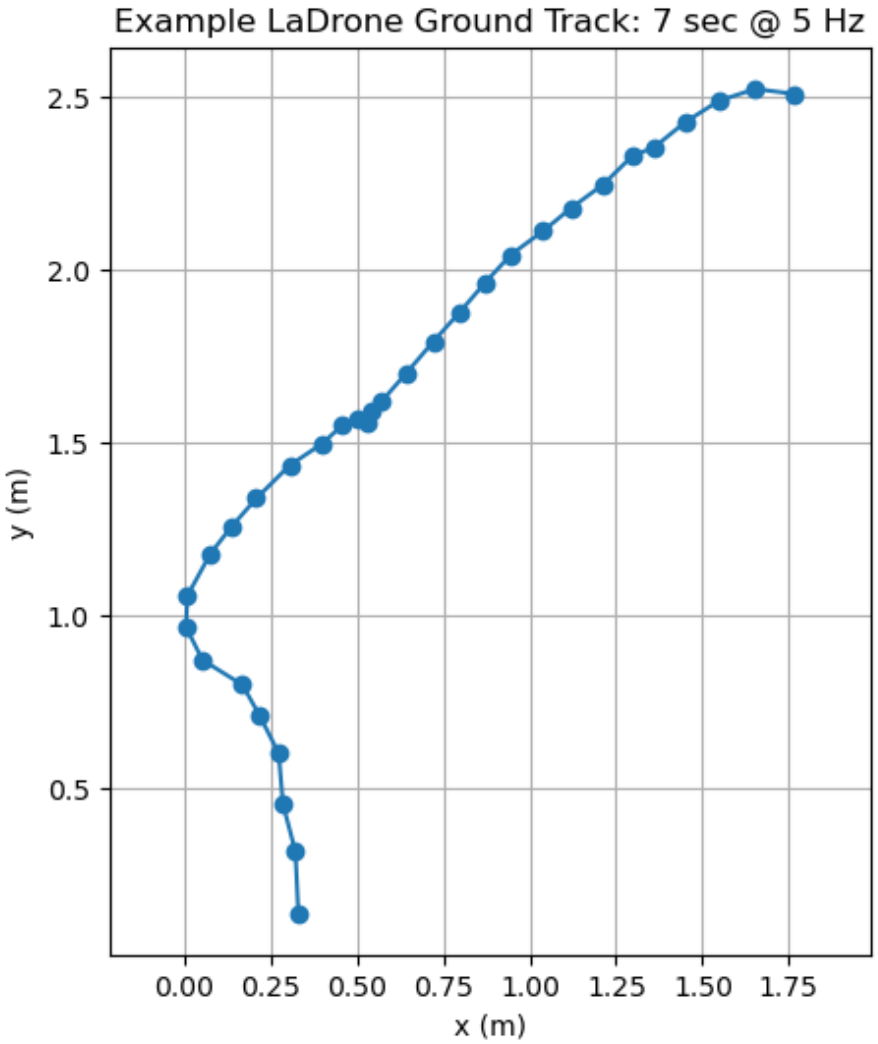
LaDrone implementation:

- Off the shelf components
  - Inexpensive and scalable!
- Onboard logging
- Ceramic GNSS antenna

Questions:

- Can we accurately track LaDrone?
- Does LaDrone follow wind velocity?

A taste of GNSS data



Google Earth Overlay

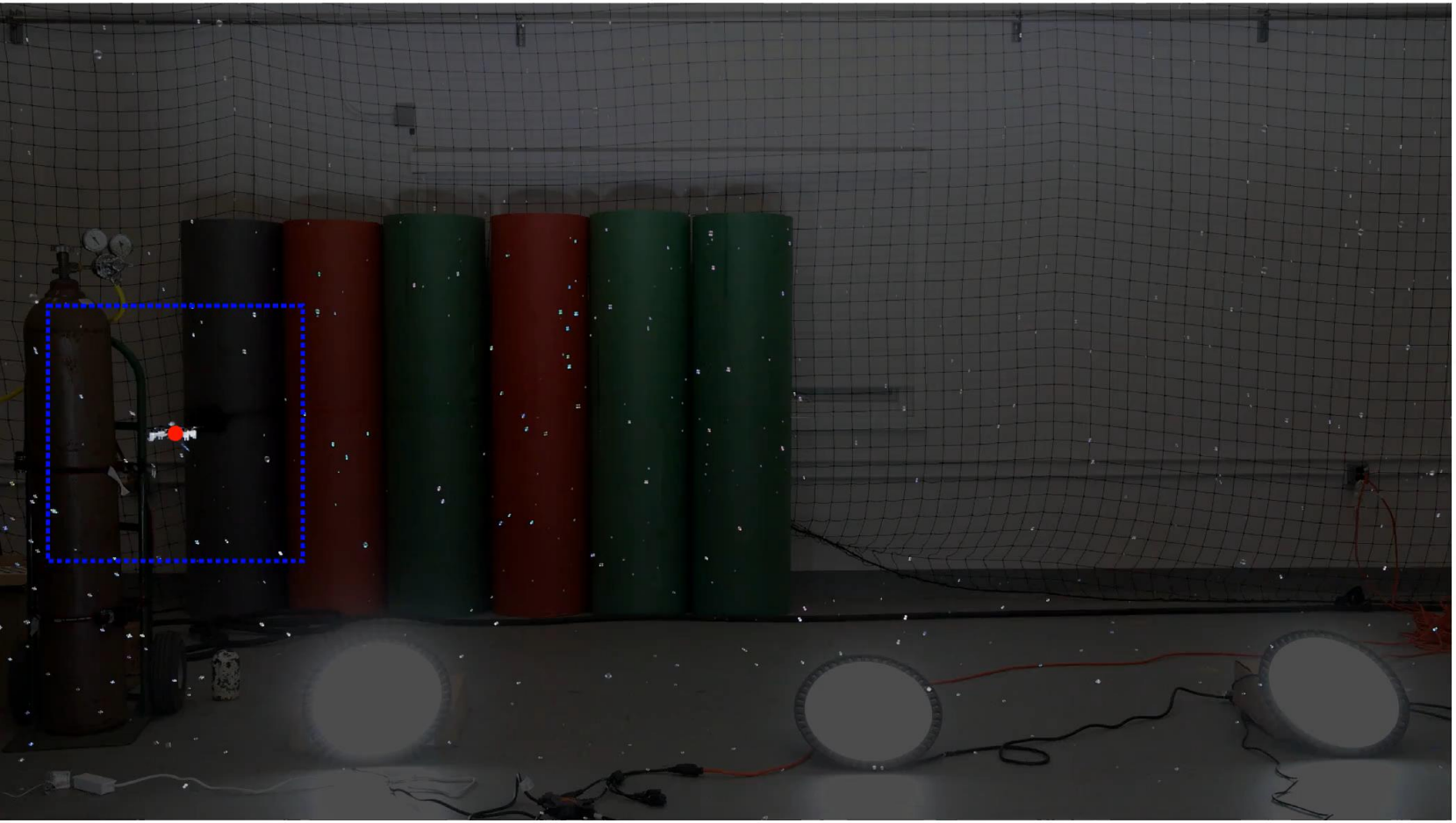
- Tracking at 5 Hz
- Precise (~10 cm) relative to base station
- Need to enable tracking over longer distances

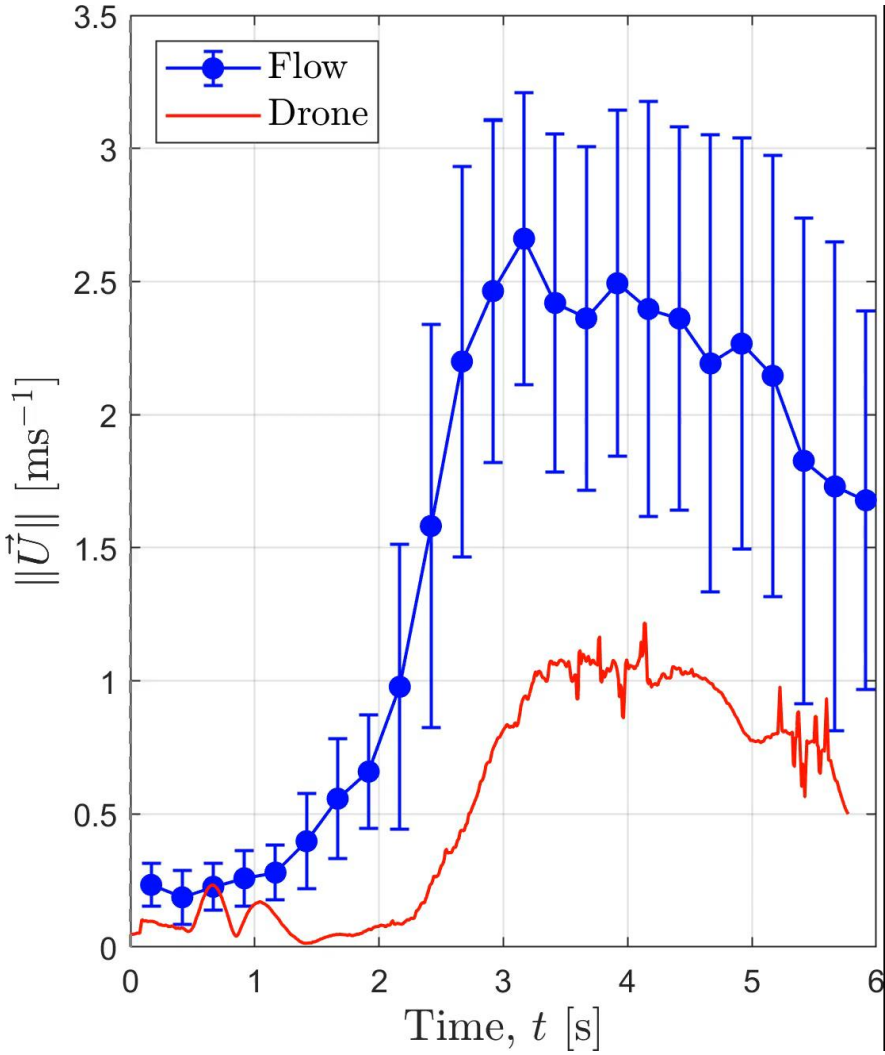
Does LaDrone move like a particle?

Experiment:

- Windshape fan array: gust $0 \rightarrow 4\ \mathrm{m/s}$
- Seed room with helium-filled soap bubbles
- Track the drone and bubble positions with computer vision

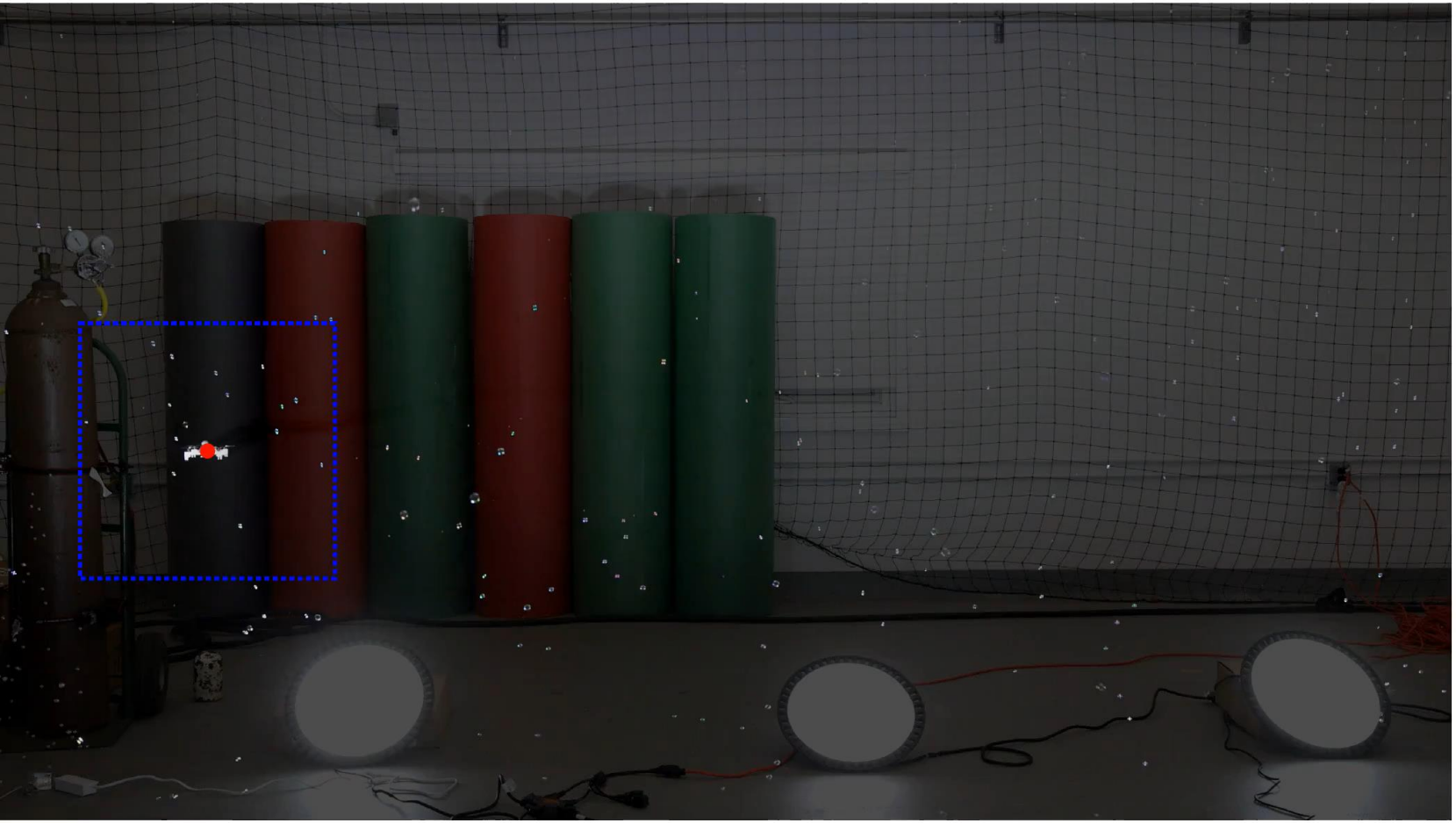
Does LaDrone move like a particle? (low speed)

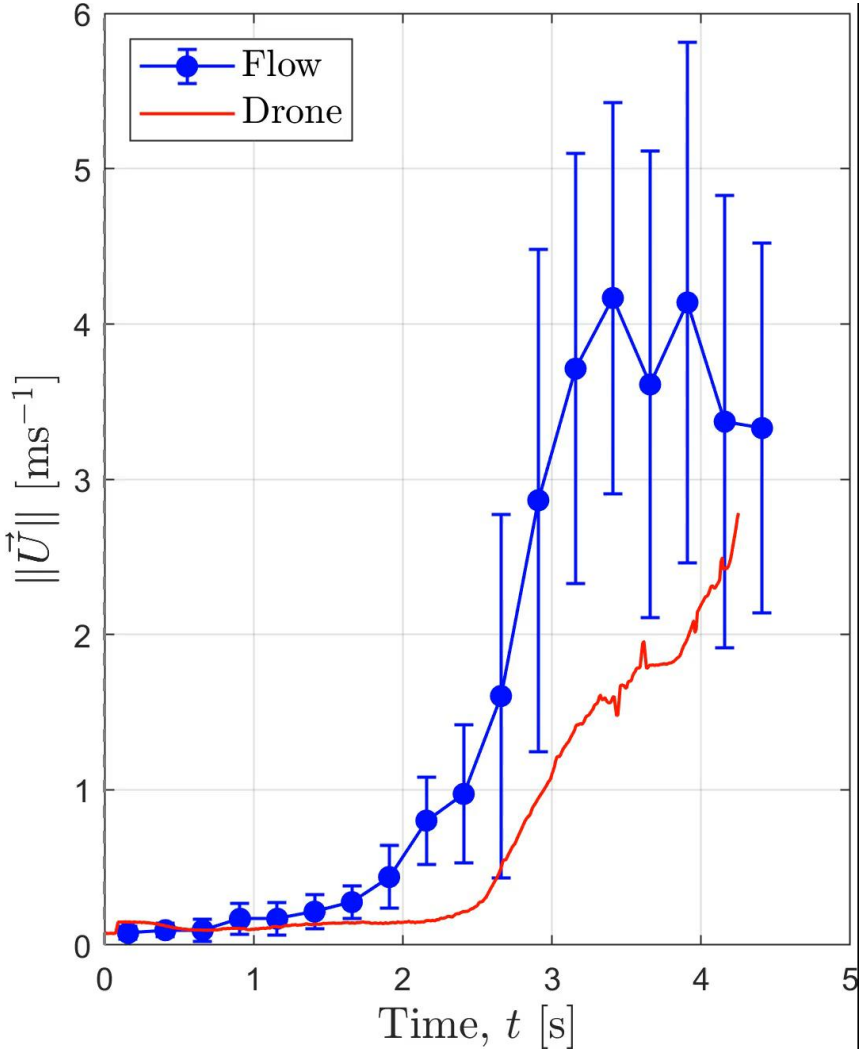




For flow speed, we average the bubble velocities within the blue box.

Does LaDrone move like a particle? (high speed)

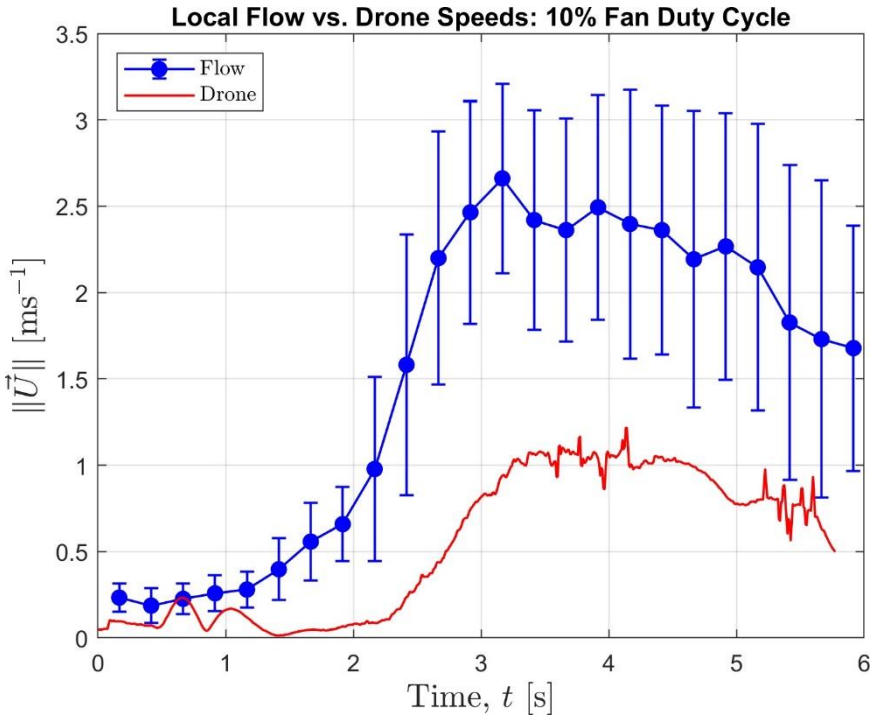




For flow speed, we average the bubble velocities within the blue box.

Does LaDrone move like a particle?

- LaDrone is quick to react, but tracks $\approx 0.5\left\|\vec{U}\right\|$
- Hypothesis: nonzero pitch results in horizontal components of thrust



For two excellent talks on bubble velocimetry:

From the Field to the Wind Tunnel: Methods for Studying Insect Olfactory Search

R21.00007

Hannah Even

Field Measurements of Lagrangian Statistics in the Atmospheric Surface Layer

T43.00006

Nick Conlin

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Future work:

- Improve post-processing pipeline for long distance tracking
- Improve “anti-gravity” control for faster time response
- Customize parts for significant weight savings

Helical antenna
(dual-band)

Field + Swarm experiments!

Related talks @ APS:

R21.00007
Hannah Even

T43.00006
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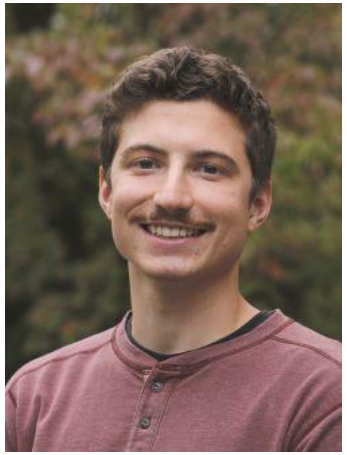
Acknowledgements

Our Team

Ani Majumdar

Marcus Hultmark

Skywalker Li



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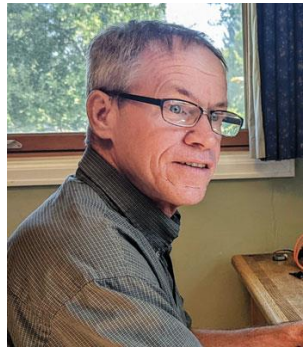
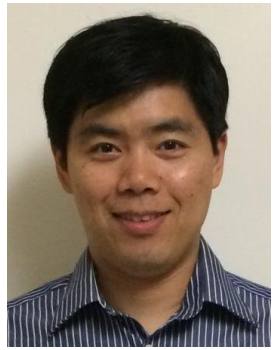
Funding Sources

GNSS Community



Tim Everett
rtklibexplorer



Sherman Lo
Stanford PNT

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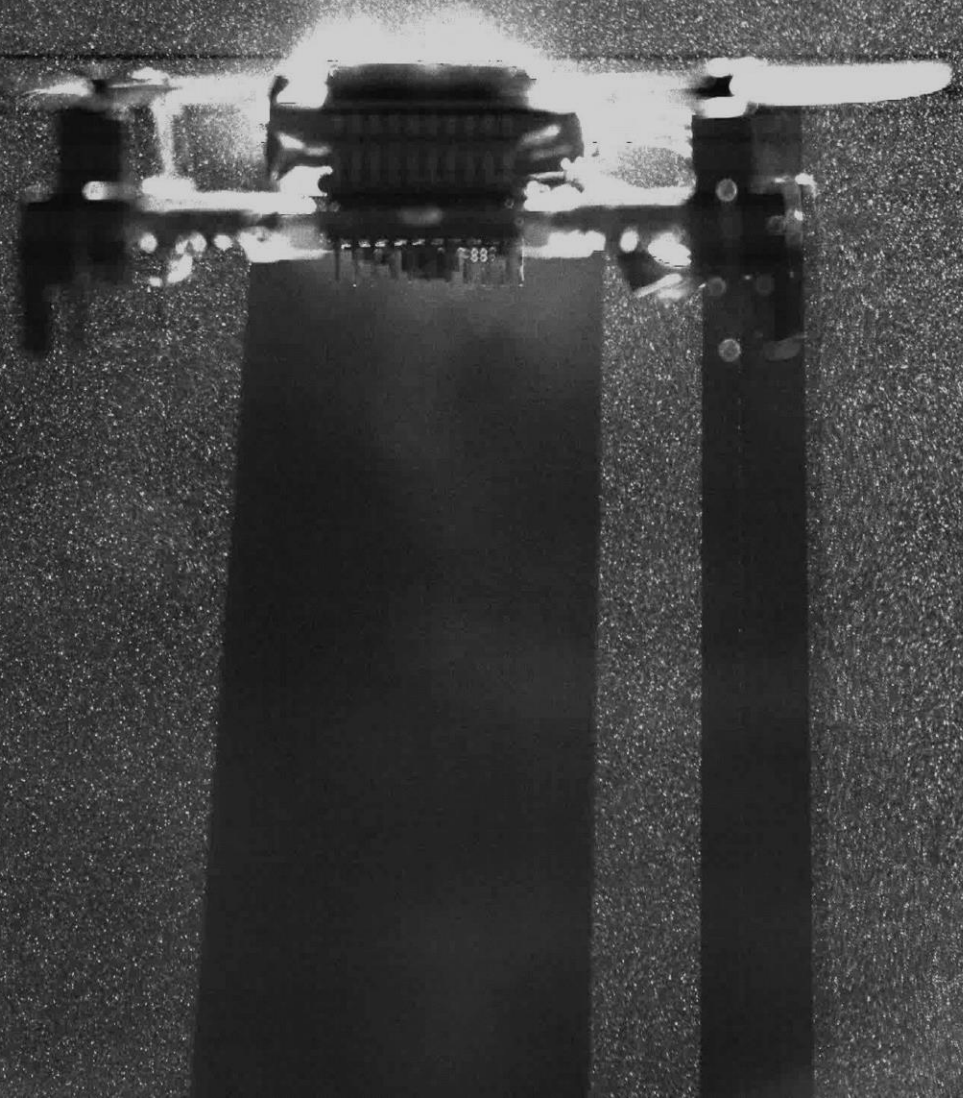
LaDrone: Demo!

Thank you!
Questions?

Stay tuned!



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