ESTIMATING AERODYNAMIC PROPERTIES OF PLANETARY SURFACES USING DRONE ATTITUDE. B. Jackson (bjackson@boisestate.edu) Physics Dept, Boise State Univ.

Summary: Measuring the wind profile near a planet's surface provides a way to estimate friction velocity u_* and the surface's aerodynamic roughness length z_0, key for understanding and predicting aeolian activity. In this presentation, we describe a proof-of-concept experiment to measure the wind profile using only the attitude of a small drone. Such an approach may be advantageous in planetary exploration where instrument payload, data volume, and power are all limited. Estimates of the martian wind profile are likely already feasible with telemetry from Mars 2020 Ingenuity. Given the enormous influence of wind in energy and sediment redistribution on Mars, such measurements are critical to understanding aeolian processes and constraining parameters used in geologic and climate models. Future work should explore how to improve this approach and whether the already collected telemetry from Ingenuity might be used.

This abstract provides a summary of a study published in RNAAS - tinyurl.com/dronewindprofile [1].

Introduction: The Mars 2020 Ingenuity helicopter has opened the door for aerial exploration of other worlds. Not only do rotorcraft offer unprecedented mobility, they can also uniquely probe interactions within an atmosphere. Profiling volatiles, temperatures, and aerosols will constrain transport mechanisms and dynamics. Wind measurements will elucidate the operation of aeolian processes, which depend on aerodynamic surface interactions. For Mars especially, aeolian processes play crucial roles in shaping the surface and driving meteorology.

Even after decades of studies, the threshold conditions for dust and sand motion on Mars remain poorly constrained. The key parameter for determining motion is the friction velocity u_*, defined as $u_* = \sqrt{\tau/\rho}$, where τ is the wind shear and ρ is the atmospheric density. Although the appropriate thresholds depend on the type of motion considered, the threshold friction velocity remains highly uncertain for Mars [2]. Thus, measurements of friction velocity during a grain movement episode on Mars would be especially informative.

Drones provide a new way to measure wind profiles, and [2] showed a multi-copter's tilt, while in fixed-point hover mode, provides an accurate proxy for wind speed. Assuming a drone's unique aerodynamic response is known, the drone's attitude can constrain wind speed without the need for additional instruments. Instructing a drone to hover at several altitudes consecutively, then, could provide a method for determining wind profiles, analogous to erecting a tower bedight with several anemometers. We conducted a proof-of-concept experiment on Seal Beach in LA to demonstrate this approach.

Methods and Results: Figure 2(a) shows the field set-up. An onshore breeze held steady for the duration of the experiments. Four anemometers, each at a different height (62, 85, 108, and 154 cm) and aerodynamically isolated from one another, collected 2-D wind speed data. Fitting the Law-of-the-Wall wind profile to the average wind speeds, gave $u_* = 26\pm3$ cm/s and $z_0 = 0.01\pm0.01$ cm, consistent with expectations for a calm sea. Next, we flew the drone. By hovering next to one of the anemometers, we determined the tilt-wind speed relationship for the drone (Figure 1). Then, we programmed the drone to hover for 30 seconds at each of four altitudes (2, 4, 8, and 16 m) consecutively. We averaged the drone tilt measurements at each altitude and estimated the wind speed via the tilt-wind speed relationship. Fitting the resulting wind profile returned $u_* = 39\pm4$ cm/s and $z_0 = 0.37\pm0.24$ cm (Figure 2). These values roughly agree (to within 3σ) with the anemometers.

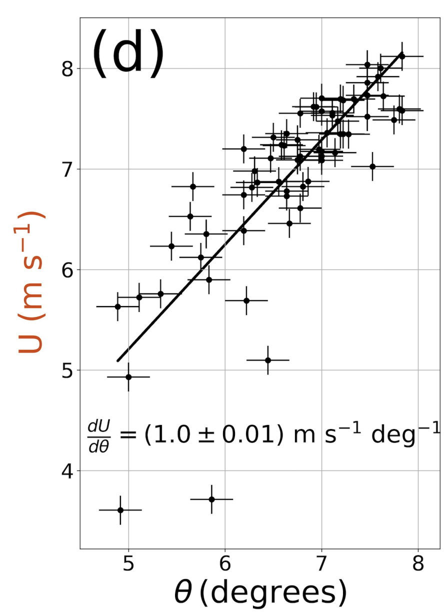

Fig 1. Aircraft tilt vs. wind speed.

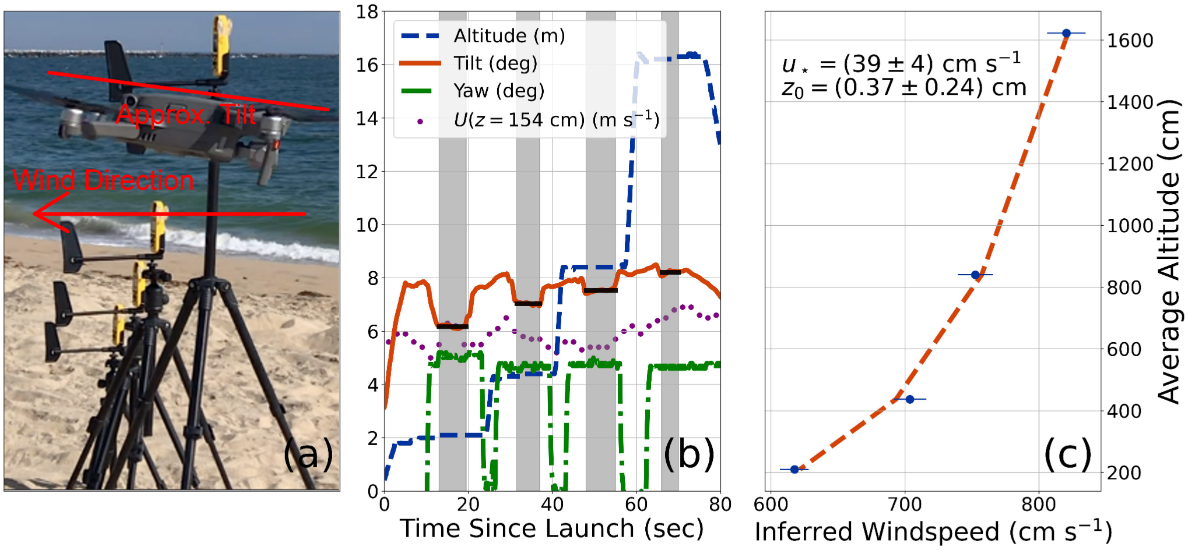

Fig 2. (a) Field set-up. The four anemometers measuring wind speeds at various heights are in the background. The drone is hovering flush with the uppermost anemometer. (b) Drone telemetry (curves) and wind speed (purple dots) collected by the uppermost anemometer (in m/s). The dashed blue curve shows the drone altitude (in m), the solid orange curve shows the tilt (in degrees), and the dash-dot green curve shows the yaw (in degrees azimuth). The grey shaded regions show when the drone settled at a fixed altitude and attitude, allowing determination of an average tilt (shown by the horizontal solid black lines). (c) Inferred wind speeds at each altitude (blue dots), along with uncertainties estimated by combining in quadrature the uncertainties on the drone tilt and on the tilt-wind speed relationship. The dashed, orange line shows the model fit, and wind profile parameters with uncertainties are indicated.

Conclusions: These results support the possibility of inferring a near-surface wind profile using only the attitude of a drone, rather than requiring a dedicated anemometer. This approach, however, has important limitations. For instance, winds exhibit temporal variability, so measuring a wind profile at several points consecutively rather than simultaneously could result in inaccurate values. However, monitoring the wind speed at one specific altitude can reveal the timescale of variability and help mitigate this issue. Figuring out how to thread the needle between hovering long enough to obtain an accurate average tilt and not hovering so long that wind conditions significantly evolve would be useful for future work. Also, time series analysis techniques that incorporate turbulent or non-Gaussian noise would likely make estimates of the average wind speed at a given altitude more robust.

The precision to which the wind profile parameters can be determined depends on the details of the experiment (number of profile points, duration of hover, how many different locales, etc.), but how accurately would the parameters need to be measured to be useful for Mars studies? For u_*, improved estimates are required to predict the onset of aeolian activity. [3] discuss estimates for the friction velocities required for mobilization ranging from 0.5 to about 1.5 m/s for 100 micron grains, for example. The predicted range for the threshold u_* therefore spans a wide range, so significant improvements via drone-based measurements seem readily achievable.

Public reports indicate that the Ingenuity drone has a precision inclinometer, and the drone has hovered alongside the Mars 2020 rover, which itself has several anemometers. Thus, the calibration data required to establish Ingenuity's tilt-wind speed relationship are likely already collected. Moreover, Mars 2020 has observed several dust movement events [4], and so the data required to estimate the relevant friction velocities may also already be collected.

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References: [1] Jackson, B. 2022, RNAAS, 6, 12. [2] Meier, K. et al. 2022, Atmosphere, 13, 551. [3] Newman, C. E. et al. 2022a, in Treatise on Geomorphology (2nd Ed), Oxford: Academic Press, 637-666. [4] Newman, C. E., et al. 2022b, Science Advances, 8, eabn3783.