Aerodynamics of a Payload Suspended from a Multirotor Vehicle

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Purpose

Interest in applying multirotor copters to perform payload carrying tasks such as parcel delivery and weather sensing has increased exponentially in recent years. Several of these applications require a drone to carry a free-swinging payload beneath it. These experiments explore the response of a payload suspended beneath a drone subjected to crossflow conditions to simulate either a drone in motion or a hovering drone in wind. This research explored the ability of drone downwash to either dampen a free-swinging payload or conduct sensing from a payload.

Experimental Design

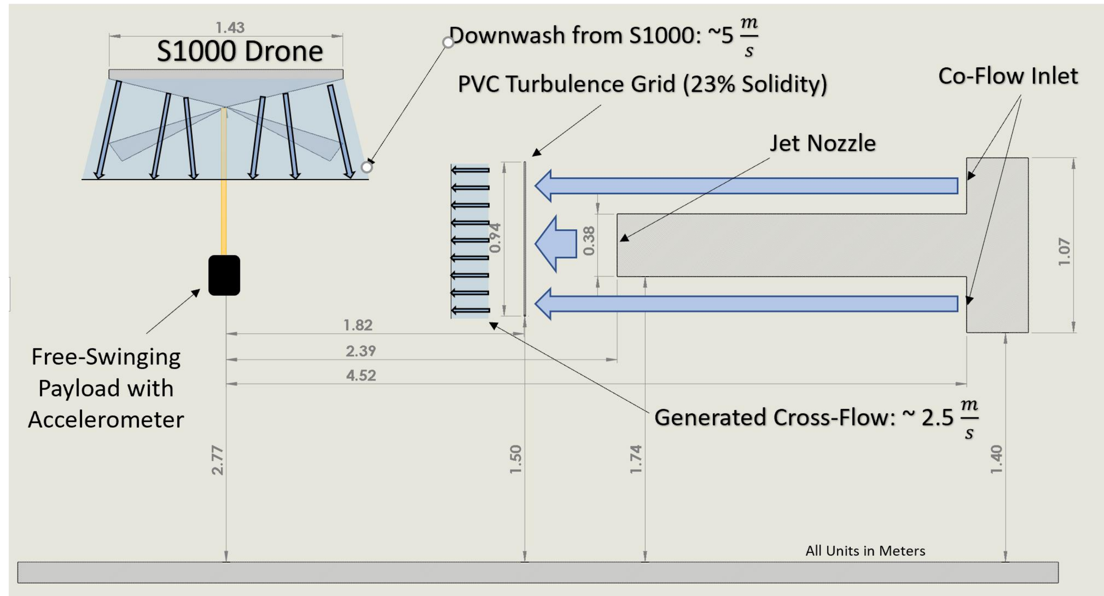

Figure 1: Experimental design of DJI S1000 octocopter suspended downstream of a turbulence grid. A free-swinging payload is suspended from the S1000 into the crossflow from the jet nozzle and exhaust fan (Co-Flow).

Figure 2: Experimental set-up within an anechoic chamber.

Figure 3: Traversing hotwire positioned beneath S1000 to acquire profile of freestream velocity of the crossflow that is interacting with the drone's downwash.

Methods

- Accelerometer Measurements
  - An accelerometer is incorporated into the payload to measure forces from oscillations in the x and z directions.
- Hotwire Profile Measurements
  - Hotwire anemometry is used to investigate and determine the profile of both mean-velocity and turbulence intensity in the test section directly beneath the drone.

Payload Accelerometer Data

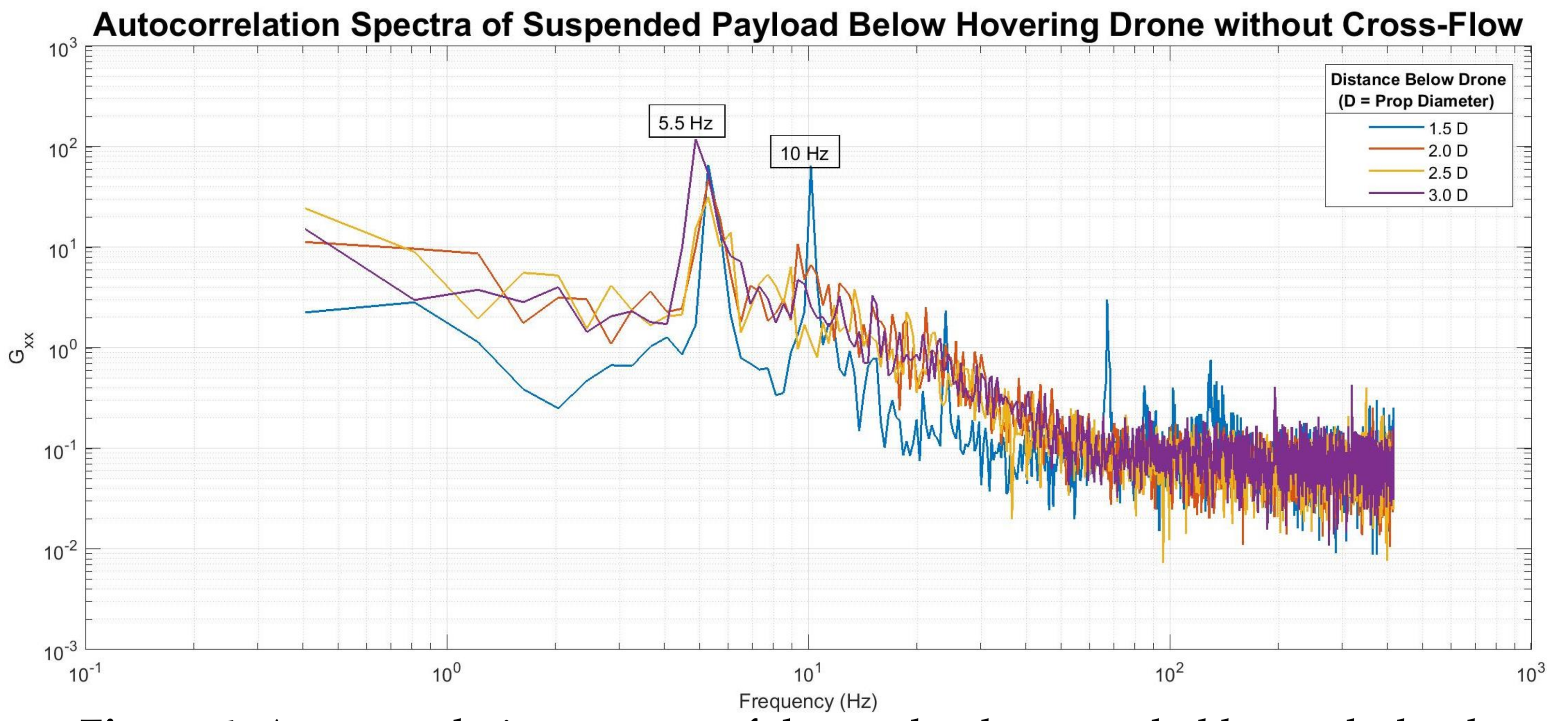

Figure 4: Autocorrelation spectra of the payload suspended beneath the drone without crossflow. Data acquired in increments below drone based on the diameter of the S1000's propellers (D = 0.38m).

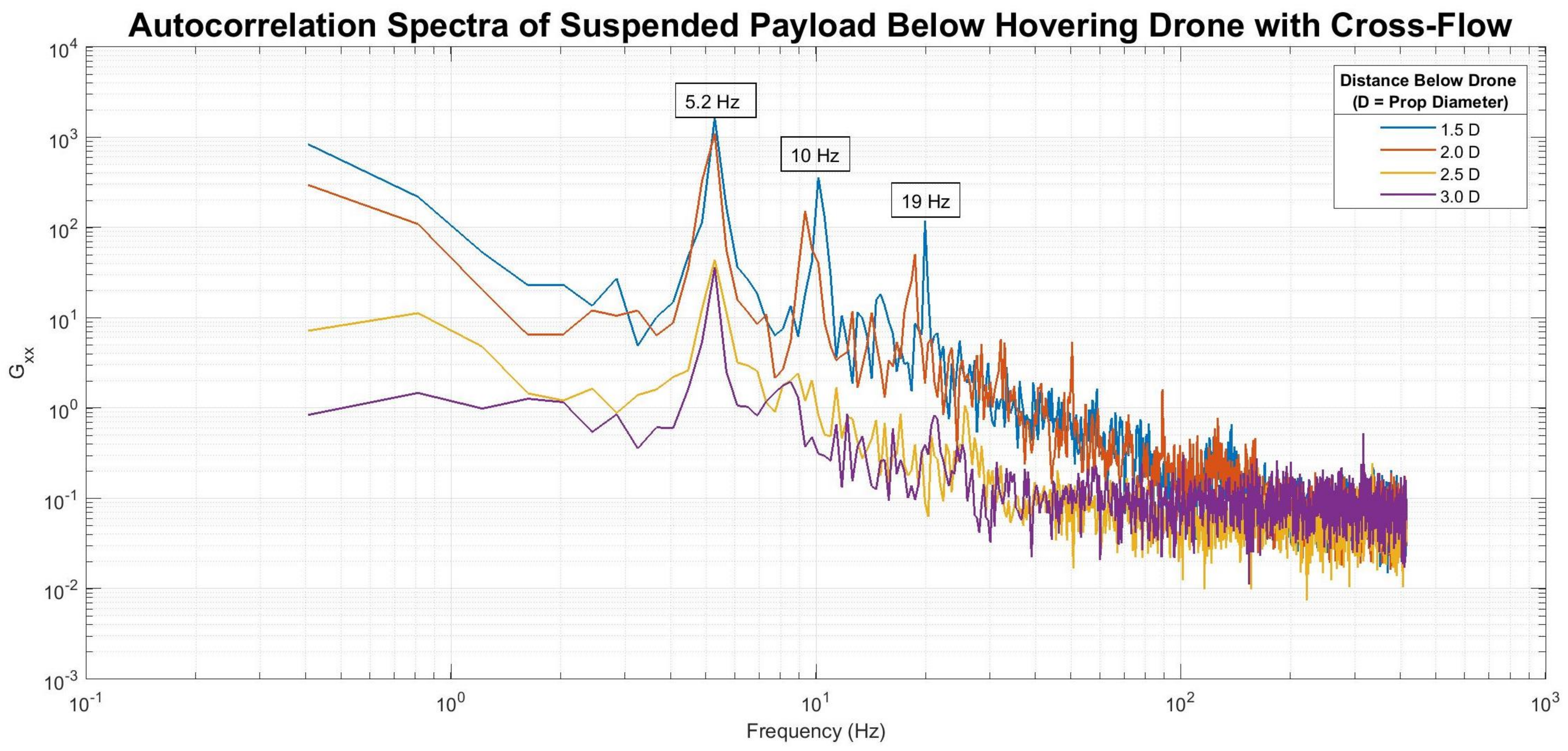

Figure 5: Autocorrelation spectra of payload subjected to both downwash and cross-stream turbulence.

Cross-Flow Profile Data

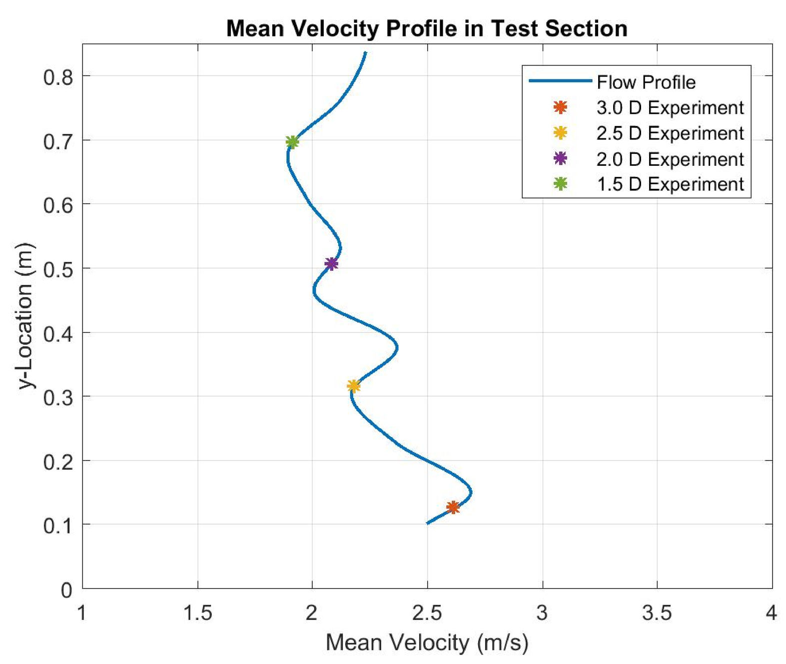

Figure 6 : Velocity profile of cross flow and corresponding test locations below drone.

Free-Swinging Payload Model

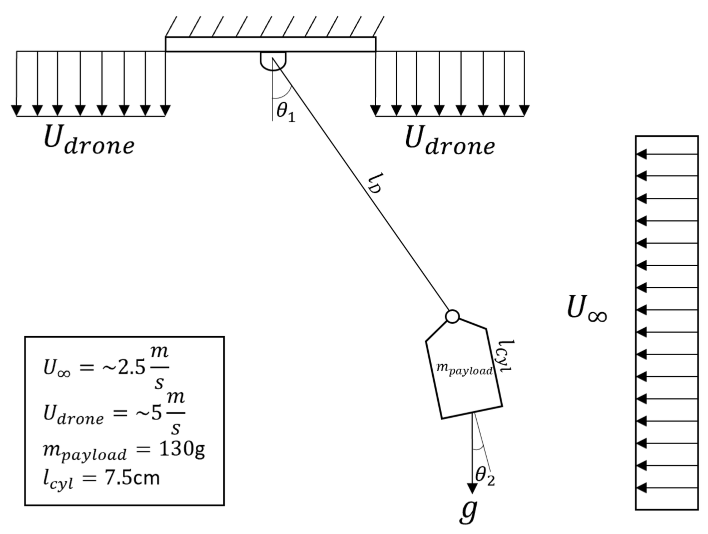

Figure 7: Model of free-swinging payload's interaction with downwash and cross-flow.

Facilities and Equipment

- Experiments take place in Skytop Turbulence Laboratory's Anechoic Chamber.
- Multirotor Vehicle:
  - DJI S1000 Octocopter (Prop Diameter = 0.38m)
- A.A. Labs Constant Temperature Anemometry System
- Midé Slam-Stick X (Accelerometer)
- Cylindric payload to house accelerometer (2.5cm Diameter)
- 1x1 meter turbulence grid with 23% solidity

Results and Conclusions

- Free-swinging payload behaved similarly to a two degree-of-freedom pendulum when subjected to drone downwash emanating low-frequency oscillation responses at ~5Hz and ~10Hz. Distance below propeller wake showed minimal effect to dampen this oscillation.
- At a nondimensionalized distance between 1.5-2 propeller diameters below the drone, it is shown in Figure 5 that a dominant peak is observed at 19 Hz.
- This frequency is consistent with the expected shedding frequency from the cylindrical payload ($Re_D = 4.10 * 10^3, St = 0.197$) indicating it may be possible to determine atmospheric wind conditions from within the wake of a multirotor vehicle.

Future Work

The next steps in this project include:

- Flow visualization about a tether or payload suspended beneath a drone.
- Full-scale outdoor experiments to explore true atmospheric weather conditions interacting with a tether or payload.
- Explore ability of onboard flight controller algorithms to identify and dampen a free-swinging payload by adjusting stability.

Figure 8: DJI S1000 Octocopter used in experiment. (*Courtesy: DJI*)

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