Modeling Hose Dynamics for Unmanned Aerial Vehicles

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INTRODUCTION

Bridges and other large pieces of infrastructure accumulate massive amounts of dirt, dust, and other particulates that can obscure the structure when scanning to discern structural integrity. Traditionally, these particulates have been removed by humans operating handheld compressed-air hoses, often while mounting ladders -- a risky and inefficient task. To improve infrastructure scanning, unmanned aerial vehicles (UAV) equipped with hoses could be used to clean the structure in place of the current method.

The challenge in equipping a UAV with a hose is compensating for the reaction forces and torques produced by fluids expelled by the hose. In order to counteract these reaction forces and torques, the process should be carefully modeled and incorporated in the controller architecture.

Fig. 1. Hose mounting is modeled with some: horizontal and vertical offset from CoG, angle from UAV's roll and pitch origin, and force magnitude as function of tank PSI.

Vehicle	Quad	Octo	Array
Mass (kg)	5	15	60
Rotors (n)	4	8	24
Arm Length Mean (m)	.15	.25	.5

Fig. 2. Hose dynamics will have very different effects depending on the vehicle inertia and thrust, so 3 different UAV are modeled according to the characteristics above.

METHODS

- Model force and torque from hose as in Fig. 1. and visualized in Fig. 3.
- Add hose contributions to full UAV dynamic models using characteristics from Fig. 2.
- Solve for zero translational and rotational acceleration to find allowable PSI, hose angle, and offset combinations, visualize as in Fig.4.

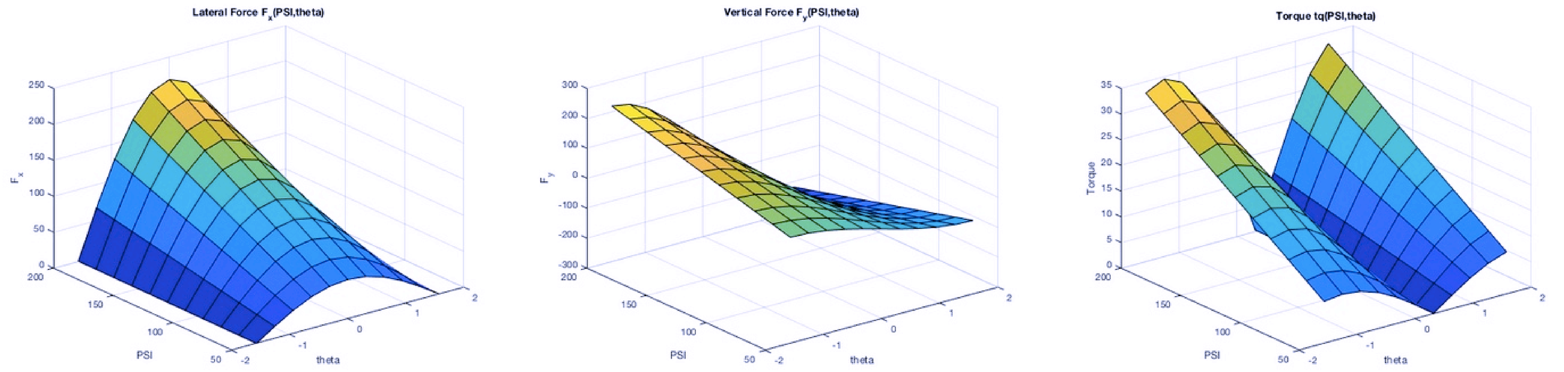

Fig. 3. Left: lateral force contribution grows with PSI and decreases with magnitude of angle; Center: force of hose can increase or decrease load on motors depending on direction of hose; Right: torque increases with PSI and angle magnitude.

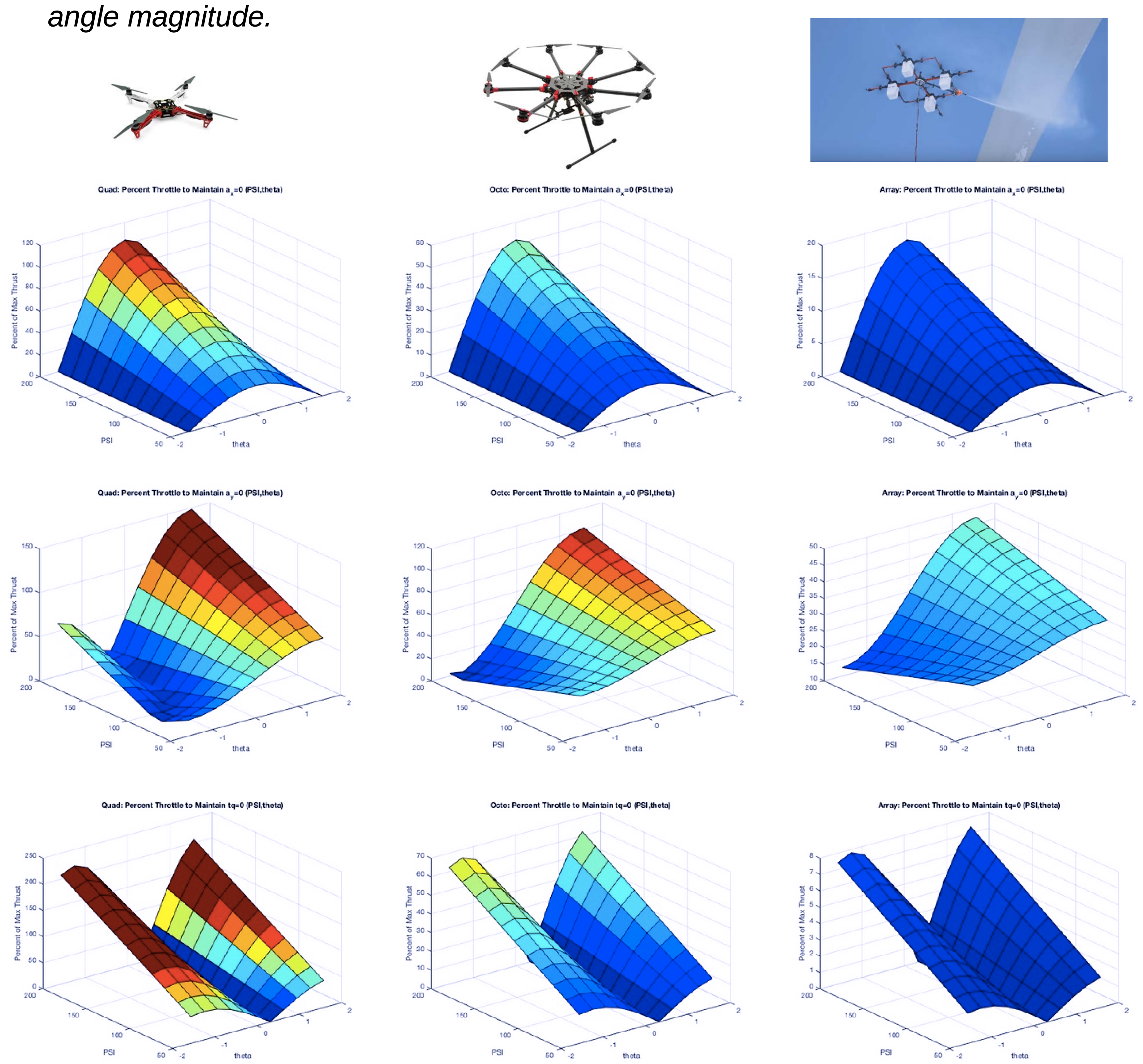

Fig. 4. Each column represents simulated tool-space for respective UAV. Yellow represents the edge of safe operating throttle %, with red greater than or equal to 100% throttle.

RESULTS

Initial results explore stability with permutations of flow from 50 to 200 PSI and hose angle between –pi/2 to pi/2 radians. The generalized force components and torques from the hose are visualized in Fig. 3.

The generalized forces and torques from Fig. 3 are applied to vehicle-specific MATLAB simulations representing three common types of UAV shown in Fig. 2: quadcopter, octocopter, and multi-rotor array. For each vehicle, the percent throttle required to maintain 0 translational and angular acceleration is calculated. The 3D charts in Fig. 4 represent the robot tool-space. Points in the ground plane represent combinations of PSI and hose angles. For each combination, some percent throttle is required to hold the vehicle stable during hose operation. This percent throttle required for stability is plotted on the vertical axis. Between 80% and less than 100% throttle is considered the "warning" zone and is represented by yellow and orange shading. 100% throttle or greater is shaded red. Safe tool-space configurations are shaded blue, with darker blue corresponding to a lower percent throttle required for stability.

CONCLUSIONS

The modeling presented suggests vehicle-specific limits on hose PSI and angle to maintain safety and stability. Hose dynamics are largely negligible for vehicles with more inertia and thrust. However, even light, low-power UAV can safely use surprisingly high PSI with careful hose angle selection. Results also imply that design of hose mounting offset from CoG determines center of angle bandwidth for safe tool-space. If designing for known hose angle within vehicle tool-space's allowable angle bandwidth, it should be possible to choose hose mount position producing zero torque.

REFERENCE

B. Hament, P. Oh, "Modeling Hose Dynamics for Unmanned Aerial Vehicles," INSPIRE UTC Annual Meeting Poster Session, August 2018.

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