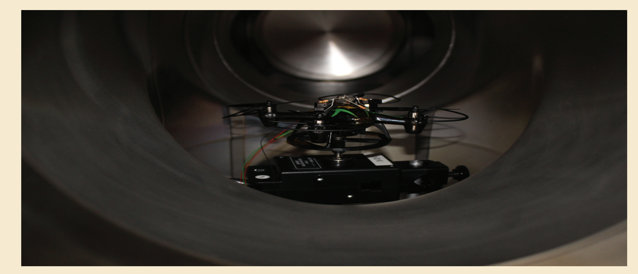
Quadcopter Yaw Control: Conservation of Angular Momentum or Atmospheric Drag?

Kirk Williams, Tori Goff, and Eric Ayars
California State University, Chico
eayars@csuchico.edu



Quadcopters (also known as “Drones”) control yaw (rotation around the vertical axis) by differential propeller rotation; two props rotate clockwise, two rotate counterclockwise. To turn in the clockwise direction, the quadcopter increases the speed of the counterclockwise props and decreases the speed of the clockwise props.

Conservation of angular momentum is the “standard” explanation of how this works, but atmospheric drag torque is an alternate explanation. Both mechanisms may play a part; by placing a quadcopter in a vacuum chamber and removing the air, we can test the relative strength of these two mechanisms.

Challenges

1 Quadcopters do not fly in vacuum. (This should surprise exactly nobody...) Instead of flying it, we mounted it on a PASCO Rotary Motion Sensor. This provided a platform to hold the quadcopter in place, and also allowed precise measurement of the angular position of the quadcopter.

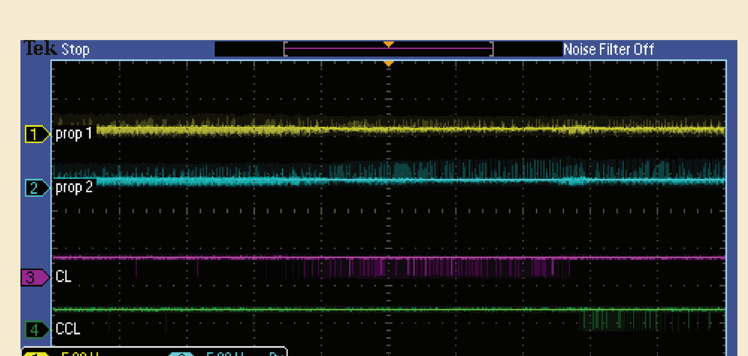
2 One can not place a lithium battery in vacuum more than once. (They explode.) So we had to power the quadcopter from outside the chamber. We didn’t want the wires to restrict the motion of the quadcopter, so we had to use very fine wires... but very fine wires have significant resistance. When the motors would increase their speed, the increased current would result in an increased voltage on the supply wires, which would drop the voltage at the quadcopter, which would shut down because it thought the battery was low. We built a separate circuit to regulate the external voltage and maintain the operating voltage at the quadcopter.

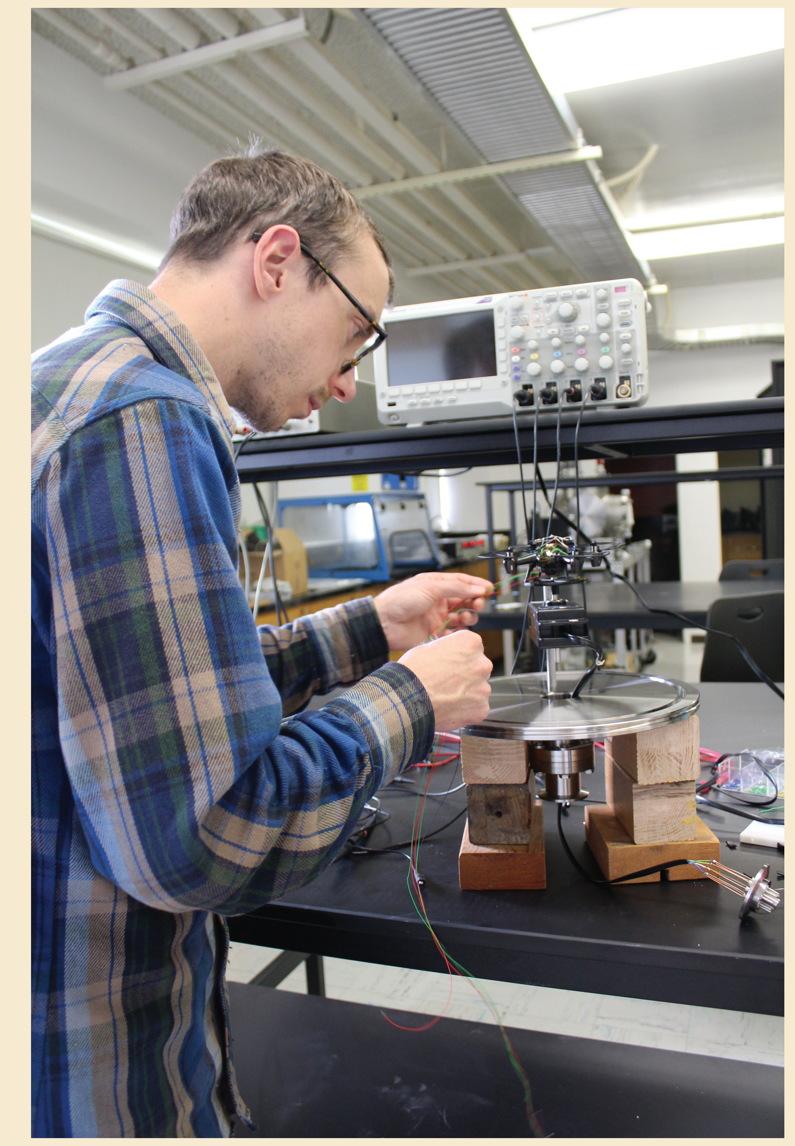
3 The quadcopter requires nearly 3A of current at full throttle. This generates a lot of heat. Normally the quadcopter keeps itself cool by air convection —it has 4 fans right there, after all— but there’s no air in the vacuum chamber and everything gets dangerously hot. We had to run it for short bursts only.

4 We needed to measure the speed of the propellers. We used small photogates for this, which we mounted on a 3D-printed “saddle” attached to the quadcopter. And no, one should never put 3D-printed parts in a vacuum chamber.

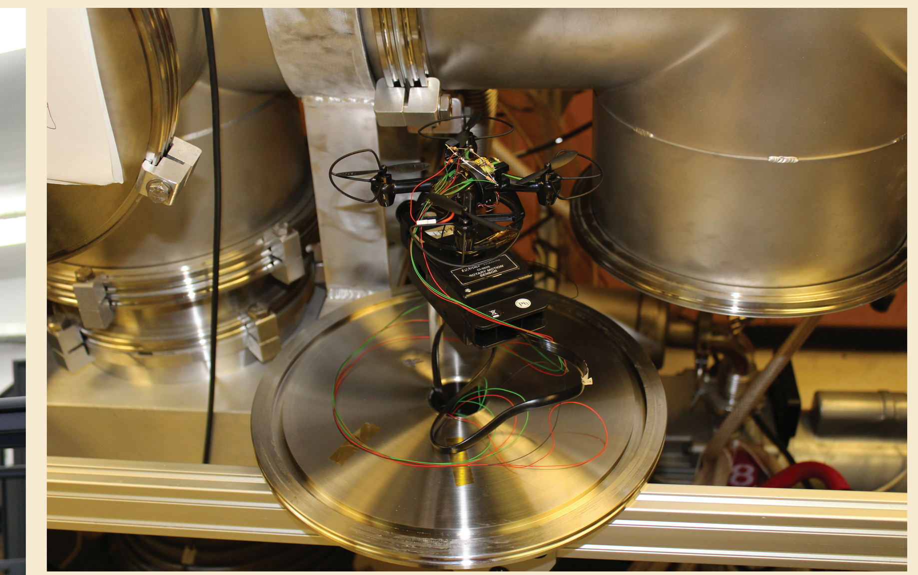
5 We had lots of wires to deal with! 5V for the rotary motion sensor, 3.7V for the quadcopter and propeller sensors, two signals (clockwise, counterclockwise steps) for measuring angular position, photogate signals for two of the props, a ‘sense’ wire to make sure the quadcopter was getting 3.7V, and ground. All of these had to get into the vacuum chamber. Five of those wires had to be attached to the quadcopter itself, so we gently wound them around the axis of rotation to form a torsion spring, which gave us an indication of the torque on the quadcopter.

6 Once we actually got everything working and took data, our data looked like this: just a bunch of high-speed pulses on four different signal lines. We wrote a python program to find the pulses and convert the pulse times into propeller velocity and quadcopter angular position.



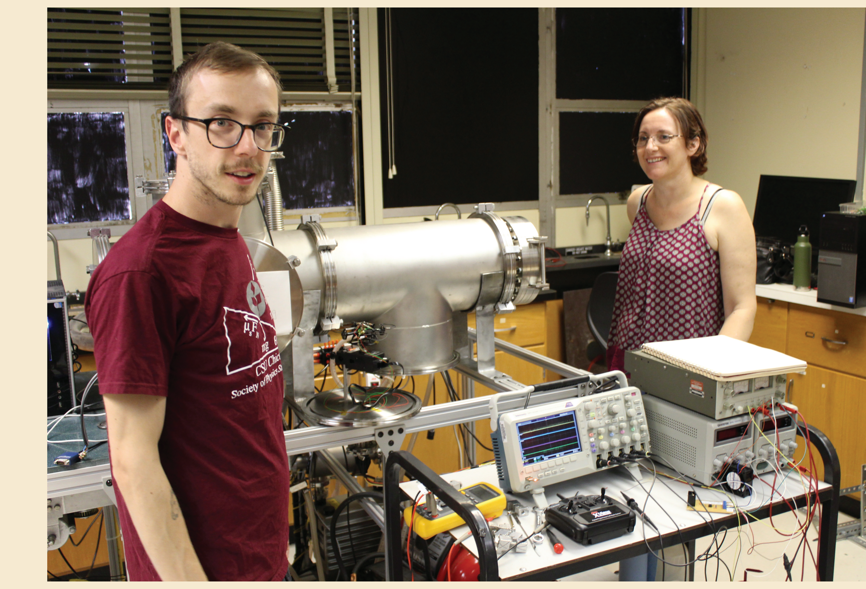


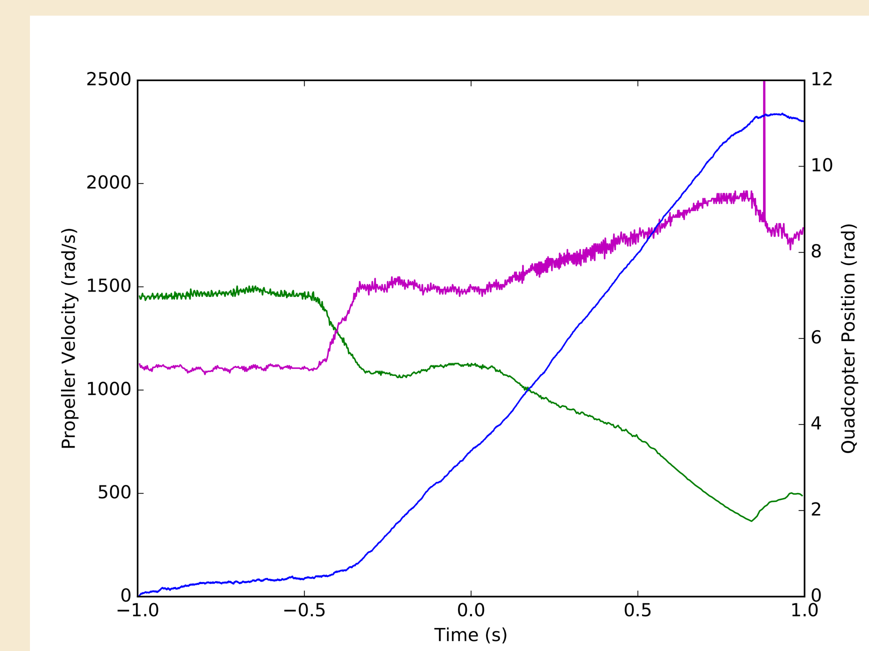
Kirk works on getting wires routed through the baseplate.



The entire contraption was mounted on a baseplate that could then be attached to the vacuum chamber. Here you can see the “torsion-spring” spiral of wiring attached to the quadcopter, as well as the “saddle” holding photogates near two of the propellers.

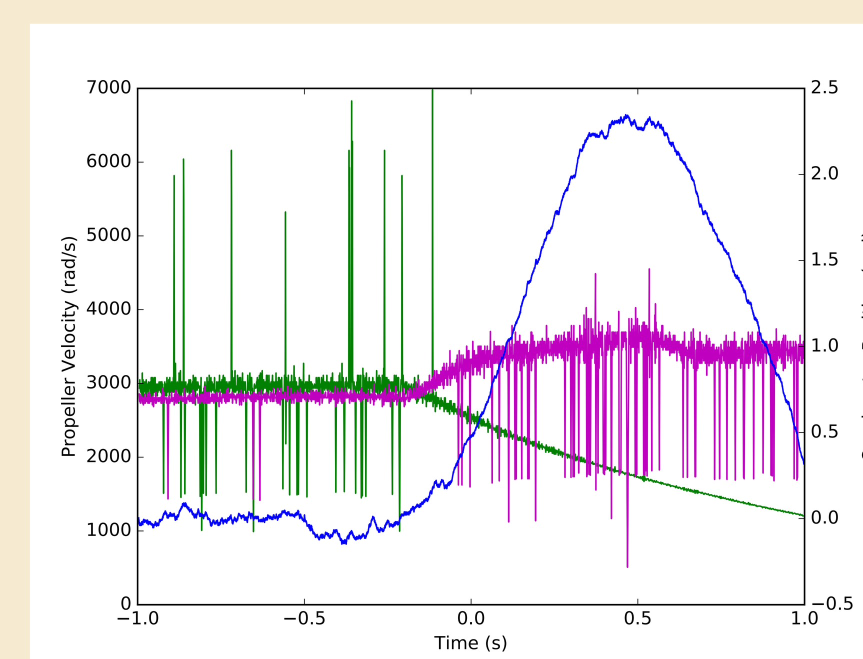
The final setup took four power supplies, an external regulator circuit, a cooling fan for the external regulator circuit so it didn’t catch fire (again) and a high-speed 4-channel oscilloscope. And, of course, a large vacuum chamber.



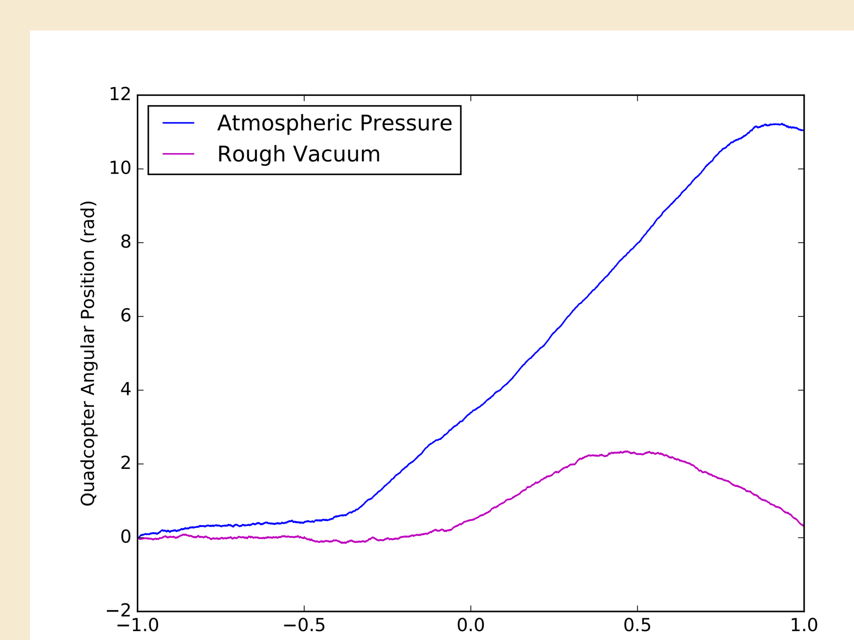


Here’s a typical data run. At approximate time t = -0.5 seconds, we signalled the quadcopter to turn clockwise. The clockwise prop (green) slowed down, the counterclockwise prop (maroon) speed up, and the quadcopter turned through an angle of approximately 11 radians.

This is at atmospheric pressure, so both mechanisms —conservation of angular momentum and atmospheric drag— are in effect.



At rough vacuum (several milli-Torr) the prop data is much noisier (we are not sure why, possibly the higher speed) but one can note several interesting things: The speed of the props is much higher (no air slowing them down) so angular momentum conservation should have *more* of an effect. Instead, the motion of the quadcopter —approximately 2 radians— is considerably *less*. In addition, the quadcopter is immediately kicked back to center by the torsion spring: it’s not able to hold position. Atmospheric drag is eliminated here; the only mechanism in effect is conservation of angular momentum.



Direct comparison of the position graphs indicates that atmospheric drag, not conservation of angular momentum, is the primary mechanism for quadcopter yaw. Conservation of angular mometum causes at most 20% of the effect and possibly much less considering that the higher speed of the props in vacuum actually enhances the normally smaller angular momentum effect.

Special thanks to Sean Murphy at the Kurt J. Lesker company for providing us with a QF40 electrical feedthrough, to Jaydie Lee for 3D-printing a custom connector to that feedthrough, and the Chico chapter of the Society of Physics Students for funding the quadcopter purchase. Without their contributions this project would not have been possible.