Stabilizing a High-Power Quadcopter

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A small group of hobbyists and I built an ultra-high-powered quadcopter with a thrust-to-weight ratio of 8:1 with the hope of setting a world record. Because the quad was constructed from off-the-shelf parts that were known to work well, we expected it to just fly. But it just crashed immediately. I was responsible for getting the quad to fly. I had to modify the firmware of the flight controller and the electronic speed controls (ESCs) in order to stabilize such a high-powered quadcopter. My first challenge was to figure out a procedure for making forward progress. Normally, flight controller parameters are refined by observing in-flight behavior. But nothing can be learned from immediate crashes. The procedure I devised was to lower the power of the quad (by modifying the ESC firmware) until the quad flew stably. Then in successive flights I gradually increased the power until I could observe and fix poor flight behavior before it was severe enough to cause a crash. This procedure worked great. It allowed me to identify and solve multiple problems in the flight control firmware. One problem required innovation. The flight control firmware used a single set of PID gains for the entire throttle range. But, my flight testing showed that the gains have to change with the throttle. So I modified the firmware to implement a 10-segment piecewise-linear gain curve. I devised a novel procedure for determining the gains at multiple points in the throttle range. Mechanically restraining the quad allowed me to evaluate the stability of any given set of gains and throttle setting without damaging the quad. I used in-flight testing to verify the efficacy of my modifications.