MULTI-AXIS PID GAIN TUNER FOR EVTOL HOVER FLIGHT MODE

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ABSTRACT

With the promise of Urban Air Mobility (UAM) becoming more of a reality with major and startup companies alike creating their own designs the academic space also follows suit with their own experimental configurations and designs. This paper proposes and evaluates a safe way for novice pilots to tune their experimental aircraft's PID flight controller successfully.

1. Introduction

Urban Air Mobility (UAM) concepts promise to bring clean efficient, low noise, transportation to high density urban areas. Vertical takeoff/landing is a critical mission objective to accommodate for limited access and convenience. With many large and startup companys alike developing their own inhouse Electric Vertical Take-off and Landing (eVTOL) vehicles UAM has become a branch of increased research [1]. As academic institutions develop their own experimental aircraft, a problem arises where the researchers discover that piloting experimental aircraft is dangerous not only for those in the area, but for the aircraft also. These eVTOLs are typically controlled using a controller, specifically a Proportional–Integral-Derivative (PID) controller.

This paper will discuss the design and evaluation of a multi axis gimbal for the purpose of tuning experimental eVTOL aircraft in an academic setting.

2. Design

To begin designing a mechanism that would allow an eVTOL aircraft to be free to move in pitch, roll, and yaw a commercial RC aircraft was selected for use. The E-flite Convergence was selected due to availability. The E-flite convergence is a three motor Y3 tilt-rotor aircraft [2] where the front two motors will tilt forward when entering any forward flight mode. A model was constructed first in OpenVSP and then transported to Fusion360.

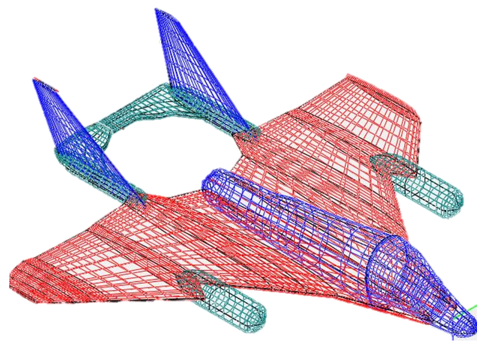

Figure 1. OpenVSP model of E-flite Convergence

Once a model was available in CAD software bearing designs were considered. First a custom yoke design [3] was considered as it was a popular design choice. This however leads to a complex design when allowing movement in a multi axis environment.

Instead, the design chosen makes use of widely available parts, rod end ball bearings, and conventional ball bearings inside a cylindrical aluminum housing. Two-piece adjustable clamps were used to keep the bearing rods in place. Using off the shelf parts allows for a build that will be easily replicated. The cylindrical housing will house one pair of ball bearings, and will allow movement in the yaw axis, and a rod which is attached to the rod end ball bearing which allows movement in two axes, in this use case pitch and roll. Once dimensions are finalized fabrications of the bearing housing was done in house at Old Dominion University.

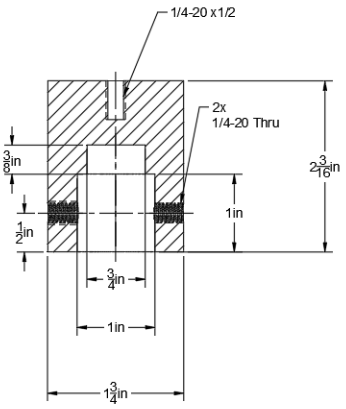

Figure 2. Housing for bearing assembly

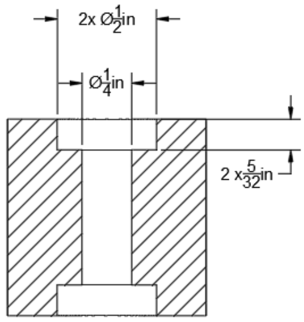

Figure 3. Bearing Assembly

The bearing assembly housing contains a ¼ inch – 20 threaded hole which interfaces with a commercially sold telescoping monopod. This allows for the adjustability of height to make sure that the vehicle is able to exit ground effect, or enter it, whatever is the desired tuning scenario. The monopod is then placed into a wooden block which is interfaced with a metal plate to firmly anchor the assembly down during tuning.

Figure 4. Fully constructed design in Fusion360

A Pixhawk flight controller was used in lieu of the stock flight controller so that PID gains could be adjusted as the main flight controller alongside ArduPilot's QuadPlane firmware which allowed for the correct configuration to match the chosen motor combination.

3. Tests

Procedure for testing and evaluating the aircraft's performance falls under the response probing method for a PID controller [4]. This procedure begins with selecting the derivative gain (Kd) for a specific axis, roll, pitch, or yaw, and then increasing that gain in steps of 50% until oscillations appear in the response, for Kd smaller higher frequency oscillations are observed [5]. Proceed to decrease that parameter in steps of 10% until the oscillations disappear, then further reduce Kd by 25%. For the proportional gain (Kp) a similar procedure is followed, however, instead of small higher frequency oscillations, larger lower frequency oscillations are observed. Each time Kp is adjusted, the integral gain (Ki) should be set equal to Kp [6].

4. Results

Results from Table 1 were obtained from the procedure outlined above. Each axis was tuned individually to eliminate any noise during the tuning process.

	Roll	Pitch	Yaw
Kp	0.378	0.241	0.151
Ki	0.378	0.241	0.151
Kd	0.015	0.17	0.01

Table 1. Table of Gains for each axis

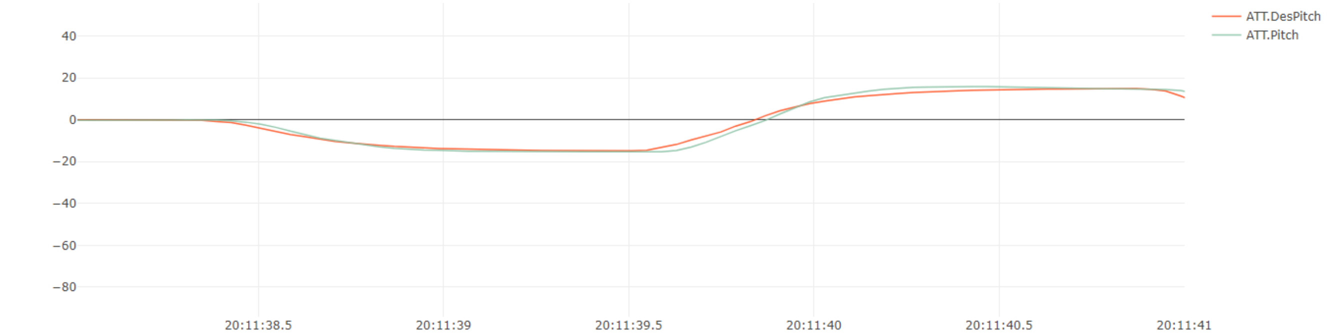

Figure 5. Pitch vs time.

Tests were conducted by giving the aircraft a 15-degree input and evaluating how long it takes for the command to be reached, and whether there is significant overshoot and steady state error. If the steady state error, percentage overshoot, and rise time were within acceptable ranges then the aircraft was considered tuned in that axis. Acceptable ranges were below 5% for steady state error and percentage overshoot. Rise time should be within the range of 0.400 ± 0.2 seconds [1].

Figure 5 shows the actual pitch attitude and the desired, or input, pitch attitude overlayed on top of one another versus time. This leads to the determination of the rise time (Tr). For pitch the rise time was evaluated to be 0.436 seconds, which is acceptable [1]. Steady state error is approximately zero, and the percentage overshoot is also negligible.

Figure 6. shows roll vs time as figure 5 did, however the response lags much more than pitch does. The time response is measured at 0.632 seconds which is just outside the acceptable range. This is likely due to the added weight from the modifications to accommodate for the gain tuner, unbalancing the aircraft in the roll axis. Or this configuration, 3 motors in a Y configuration, could have roll vulnerabilities. With minimal overshoot and steady state error this is still an acceptable result [5].

5. Conclusions and future work

A practical multiple axis PID gain tuner is an extremely useful tool to those studying aerospace, specifically those who are interested in experimental aircraft designs which utilize eVTOL configurations [2]. The results here prove that an acceptable gain can be reached by securing an aircraft safely and ensuring everyone involved can conduct research in a risk-free environment. The results proved tuning works in a constrained environment, but future work should be done in free air flight.

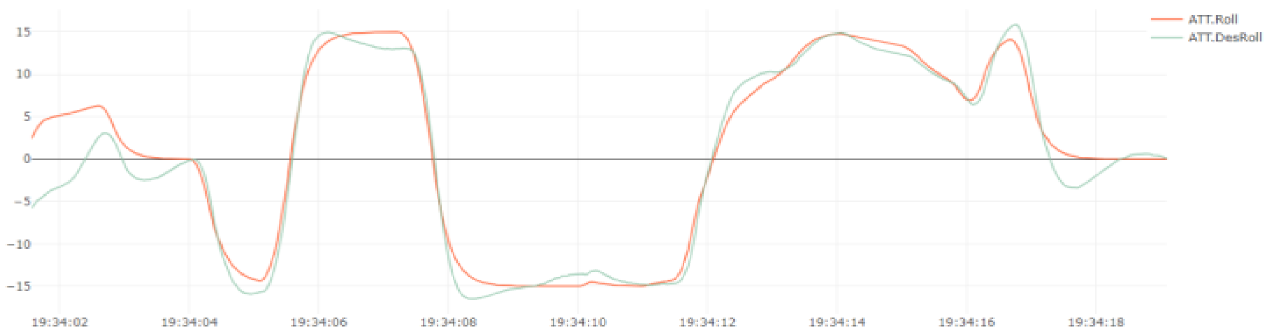

Figure 6. Roll vs Time.

6. Acknowledgements

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References

[1] S. K. Armah and S. Yi, "Analysis of Time Delays in Quadrotor Systems and Design of Control," in *Time Delay Systems: Theory, Numerics, Applications, and Experiments*, T. Insperger, T. Ersal, and G. Orosz, Eds. Cham: Springer International Publishing, 2017, pp. 299-313.

[2] A. Bacchini and E. Cestino, "Electric VTOL Configurations Comparison," *Aerospace,* vol. 6, no. 3, p. 26 (19 pp.), 03/ 2019.

[3] F. J. Capone, D. B. Owens, and R. M. Hall, "Development of a free-to-roll transonic test capability," in *41st Aerospace Sciences Meeting and Exhibit 2003, January 6, 2003 - January 9, 2003*, Reno, NV, United states, 2003: American Institute of Aeronautics and Astronautics Inc.

[4] G. Vasarhelyi *et al.*, "Outdoor flocking and formation flight with autonomous aerial robots," in *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), 14-18 Sept. 2014*, Piscataway, NJ, USA, 2014, pp. 3866-73: IEEE.

[5] C. Toapanta, J. Villafuerte, and P. J. Cruz, "3DoF Multi-Rotor Experimental Testbed for Teaching Control Systems," in *2018 IEEE Third Ecuador Technical Chapters Meeting (ETCM), 15-19 Oct. 2018*, Piscataway, NJ, USA, 2018, p. 6 pp.: IEEE.

[6] P. Sanchez-Cuevas, G. Heredia, and A. Ollero, "Characterization of the Aerodynamic Ground Effect and Its Influence in Multirotor Control," *International Journal of Aerospace Engineering,* vol. 2017, p. 1823056 (17 pp.), / 2017.