Active Stabilization Using Proportional Control

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ABSTRACT

Model rockets suffer from a wide variance of flight patterns due to imperfections in construction, launch equipment, and weather. This reality can make the recovery of rockets or their payloads more difficult when launching within the vicinity of buildings and trees. A functioning stabilization system would be useful in increasing the predictability of a rocket's flight. A canard-based stabilization system using proportional control will allow for its manufacture by groups or individuals who lack resources beyond a high-school education. To demonstrate that such a capability is within reach of high-school students, a model in which to control a small rocket is conceptualized and developed into a proportional control system. A rocket dubbed "Freefall" is designed and built to accommodate the stabilization system and a science payload. Extensive ground testing of the system is completed to validate the concepts of the system, and a live flight test is performed to demonstrate it. Visual evidence and the data from the flight data recorder indicated that the system successfully corrected the pitch and yaw axes but failed to control roll, seemingly a result of overcorrection. The partial success of the control system indicates that a proportional control system is a feasible concept and can be refined further to create a fully functioning system. Above all, the project demonstrates that active stabilization projects are accessible to groups without university instruction or professional help.

INTRODUCTION

- Active stabilization on amateur rocketry has been largely confined to high power rocketry and is considered out of reach for the general rocketeer.
- Historically, aircraft stabilization has been accomplished using simple mechanisms, demonstrating that actively keeping a moving body in a certain orientation can be accomplished without groundbreaking control systems.
- To minimize system complexity and to demonstrate that a stabilization system can be built by someone without a higher education, a simple proportional control setup can be devised.
- This system can be designed, modelled, built, and flown using resources within reach of a hobby rocketeer.

Freefall taking off on its test flight.

CONTROL SYSTEM AND VEHICLE DESIGN

The stabilization system was first developed mathematically. A model was devised where correction responses were generated linearly proportionally to error. Variable limits were imposed on the minimum and maximum permissible corrections in response to any given errors.

Stabilization System Components:

- Arduino Nano- flight computer
- SD card- data recorder
- BNO055 IMU- orientation
- Bluetooth module- wireless launch protocol control
- 9-gram servo motors- canard actuation

"Freefall" Vehicle Design:

- Airframe design was a scaled down R-60 missile, omitting the front destabilizers
- Flight computer housing and servo mounts were designed to be almost entirely 3D printed
- All 3D printed parts were attached to the airframe using screws
- Accommodated a 29mm Aerotech G-79 motor
- Center of Gravity was intentionally skewed to make the rocket astable; the rocket could only fly straight if the stabilization system was working properly
- The rocket's nose was heavy, and the aft section was made as light as possible using a truss fin design

Top Left: Model of Freefall's upper section. Top Right: Launch of "Nosedive" scale model of Freefall. Bottom Left: Lattice Fin shortly before assembly. Bottom Right: Completed Freefall rocket with stabilization system installed.

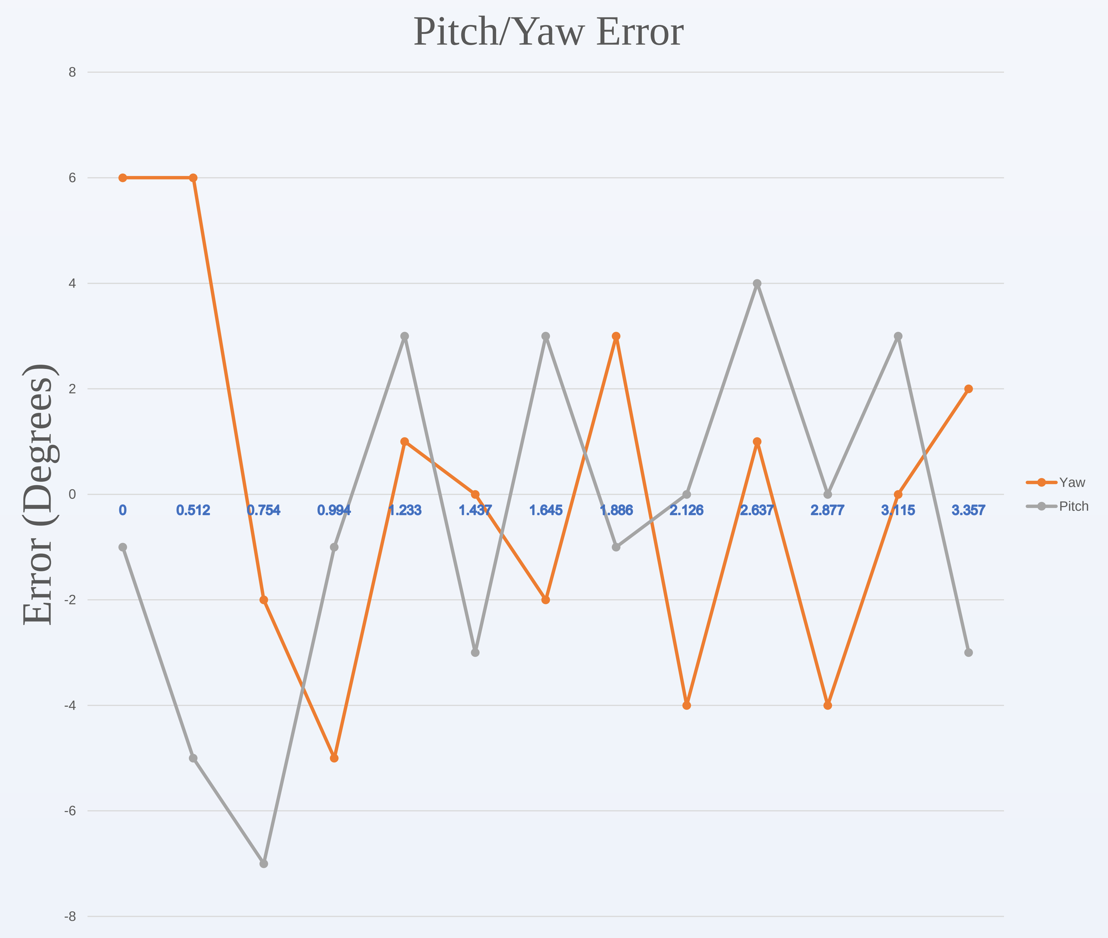
RESULTS

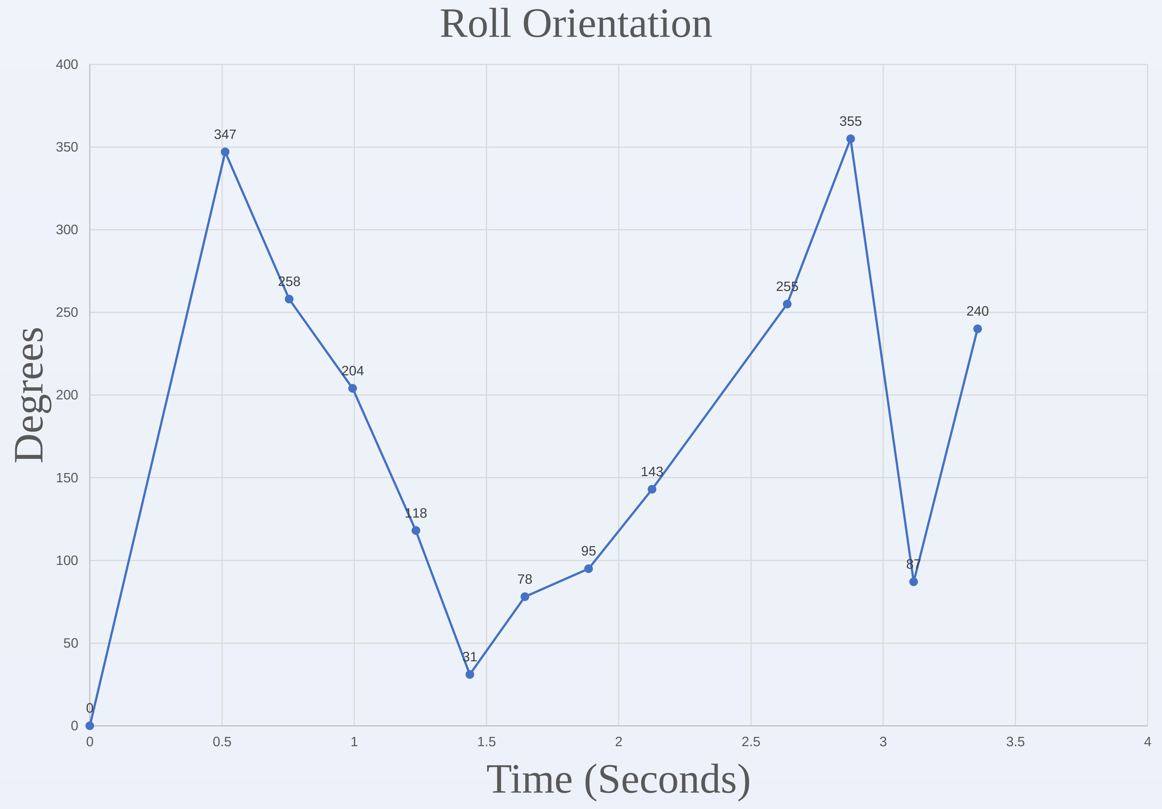
Test Flight:

- Freefall reached a recorded altitude of 322 meters
- The upper and lower sections slid apart prematurely at T+ 3.357 seconds after an internal component in the upper section failed
- Battery was ejected, no data was recorded after T+ 3.357

Post Flight:

- Flight data was preserved by data recorder
- Pitch and yaw were **successfully** stabilized, experiencing minor oscillations and mean errors of -0.61 and .15 degrees, respectively
- Roll was **unsuccessfully** stabilized. Roll direction was reversed mid-flight, but appeared to have overcorrected





Top: Graph showing the errors of pitch (gray) and yaw (orange) with respect to time

Bottom: Graph showing the 360-degree orientation of the rocket with respect to time

CONCLUSIONS

Active stabilization using proportional control was demonstrated to have merit, even if it was not shown to function fully during a test flight. The roll issue shows that further progress can be made on the idea, but the success in the other two axes shows the system has potential. It is entirely plausible that the roll orientation can be developed so that a proportional control system works in all three orientations. Importantly, system and rocket were built with widely available components, remained within an acceptably small budget, avoided the use of advanced concepts beyond a high-school education, and did not need a motor requiring N.A.R. certification. This work shows that it is entirely possible for an active stabilization system to be developed by a hobby rocketeer.

Freefall just before breakup at T+ 3.357 seconds.

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CONTACT

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