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Department: Mechanical Engineering

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Project: Thrust Vector Control (TVC) Rocket & Testing Design

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Abstract:

Since the beginning of space flight rockets have relied on stabilization by either aerodynamics, inertial control, of thrust directive control[[1]](#footnote-0). The goal of our project is to use thrust directive control of the rocket motor with a two-axis gimbal to simulate a space flight system. NASA uses TVC technology in their rocket systems[[2]](#footnote-1) and companies like SpaceRyde[[3]](#footnote-2) are working to make these systems smaller and more efficient for space travel. As part of our honors research project through the CMU Mechanical Engineering Department we are researching to develop the test method development of the rocket along with minimizing the mass of our system for a fixed propellant. Since there is a lack of test methodology in the TVC model rocket realm, we will address this gap and use our testing technology to develop a safer method for tuning TVC systems. With a reliable testing system we will be able to compare the reaction performance of different gimbals to determine the most weight efficient gimbal design without sacrificing stabilization performance. From this research, we hope to suggest ways to make low orbit rocket systems more efficient and the test method more reliable to make space more accessible to humanity.

Proposal:

1. **Objectives and Contributions of Research**

We have two main goals that we intend to reach for our research project. Firstly, we want to minimize the weight of a two-axis gimbal for a thrust vector rocket. Currently, the smallest orbital rocket is the SS-520-5[[4]](#footnote-3) which weighs in at 2.6 tons. This rocket used aerodynamic stabilization along with solid propulsion but we believe that a more efficient method may be a single stage TVC style system since it would reduce the aerodynamic drag. As the density of the atmosphere diminishes, aerodynamic control becomes less dependable[[5]](#footnote-4) and a guiding system other than aerodynamics is necessary to control the rocket’s path into orbit. By researching how we can minimize the mass for a fixed thrust in our system, we believe we can extrapolate these findings to higher powered systems with reasonable accuracy.

Secondly, we would like to develop an open-source and safe testing environment for TVC rocketry, expandable to a higher powered system. Currently, there aren't reliable testing methods for this style of model rocketry, especially equipped with sensors to help with optimizing our feedback system. The testing environment would allow for reliable static-fire tests that would allow us to adjust the proportional, integral, and derivative (PID) constants of our controller based on the discrepancy between our input and output data.

1. **Background**

Students Ian Turner and Elijah Sech are Mechanical Engineering Bachelors candidates expected to graduate in the Spring of 2023. Research Advisor Dr. Mark Bedillion is a Teaching Professor within the Department of Mechanical Engineering, has advised the Carnegie Mellon Rocket Command Team, and has had a career in control systems engineering.

1. **Methodology**

We plan to develop a Simulink model allowing us to input an initial arbitrary angle (to represent disturbance) and simulate the behavior of the rocket and the time it takes to reach an angle of zero, which means it is pointed exactly upward. We will run optimization to find the best theoretical PID values for our feedback control system. To test this, we will design and build a testing environment containing encoders, which will be used to compare the output of our system to our controller input. We will determine the transfer function of the rocket, based on the response recorded by our encoders from the known input of disturbance of an impulse hammer. We will then improve our simulation by adding this transfer function to our model, making the simulation more closely resemble our physical system. With this improved model we will be able to generate new, more accurate PID controller values.

In order to successfully minimize the mass of our gimbal, we will complete a trade study of different designs to minimize mass and evaluate their performance output based on reliability. We will integrate these designs into our previous rocket, and conduct both static-fire testing and field testing to compare their performance. We will make use of multiple trials to record statistically significant data comparing each gimbal design based on consistency of the flight path. We hope our redesigns will help the rocket converge to a vertical position at the same rate or faster than the previous gimbal design.

The projected outcomes of our research are:

1. To design a safe, open source testing environment that will successfully simulate the dynamics of a real life test so that we can tune our PID optimization constants and be able to launch a rocket without any issues the first time around.
2. Develop a gimbal with minimized mass that will allow the rocket to correct itself as well as or better than previously. We hope that this model will be representative of potential technology that could be scaled up in size and applied to a real-life space system.

* Budget - **$1005.57**

The bill of materials for the items for which the grant money will be used for is as follows:

| **Name** | **Vendor** | **Type** | **Part No.** | **Price** | **Quantity** | **Total** | **Link** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Load Cell - 50kg, Disc (TAS606) | SparkFun | Load cell | SEN-13331 ROHS | 64.5 | 2 | 129 | [here](https://www.sparkfun.com/products/13331) |
| Alloy Steel Shoulder Screw,1/4" Shoulder Diameter, 3" Shoulder Length, 10-24 Thread | Mcmaster-  Carr | Shaft | 91259A106 | 2.72 | 4 | 10.88 | [here](https://www.mcmaster.com/91259A106/) |
| Fire Retardant Spray | Amazon | Fireproofing | B07JBLHGQ8 | 34.95 | 1 | 34.95 | [here](https://www.amazon.com/Retardant-Curtains-Eco-Safe-DRI-ONE-Institute/dp/B07JBLHGQ8/ref=sr_1_15?keywords=fire+retardant+paint&qid=1663862634&sr=8-15) |
| AMT112Q-V-4096 | Digi Key | Encoder | AMT112Q-V-4096 | 37.4 | 2 | 74.8 | [here](https://www.digikey.com/en/products/detail/cui-devices/AMT112Q-V-4096/5034549) |
| 2x4 | Home Depot | lumber | N/A | 5 | 10 | 50 | N/A |
| Amazon Basics ABS 3D Printer Filament, 1.75mm, Red, 1 kg Spool | Amazon | 3d printing material | ABS175PACK5 | 20 | 5 | 100 | [here](https://www.amazon.com/AmazonBasics-Printer-Filament-1-75mm-Spool/dp/B07Y3PHD2C) |
| AEROTECH 29MM HP SU DMS MOTOR - G12ST-P | Apogee Rockets | Rocket Motor | 81275 | 41.72 | 14 | 584.08 | [here](https://www.apogeerockets.com/Rocket-Motors/AeroTech-Motors/29mm-Motors-Single-Use/Aerotech-29mm-HP-SU-DMS-Motor-G12ST-P) |
| 13 x 46 Feet Anti Bird Netting, Green Garden Netting Protect Fruit and Vegetables from Birds and Animals, Bonus 20 PCS Cable Ties - 0.56 in Mesh | Amazon | Netting for test rig | B08PDGWNPN | 8.99 | 1 | 8.99 | [here](https://www.amazon.com/Netting-Garden-Protect-Vegetables-Animals/dp/B08PDGWNPN/ref=sr_1_49?crid=2F89ISJU63DTI&keywords=netting&qid=1665684767&qu=eyJxc2MiOiI2Ljg2IiwicXNhIjoiNi41MSIsInFzcCI6IjYuMjQifQ%3D%3D&sprefix=nettin%2Caps%2C91&sr=8-49&th=1) |
| SparkFun Load Cell Amplifier - HX711 | SparkFun | Amplifier Board for Load cells | SEN-13879 ROHS | 10.95 | 1 | 10.95 | [here](https://www.sparkfun.com/products/13879) |
| SparkFun Load Sensor Combinator | SparkFun | Combinator board | BOB-13878 ROHS | 2.1 | 1 | 2.1 | [here](https://www.sparkfun.com/products/13878) |

1. https://engineering.purdue.edu/~mjgrant/aiaa-guidance-navigation.pdf [↑](#footnote-ref-0)
2. https://www.youtube.com/watch?v=i2gU4CVDV6Y [↑](#footnote-ref-1)
3. https://payloadspace.com/spaceryde-tests-gimbaling-rocket-engine/ [↑](#footnote-ref-2)
4. https://global.jaxa.jp/press/2018/04/20180427\_guinness.html [↑](#footnote-ref-3)
5. https://www.masterclass.com/articles/how-rockets-work-with-chris-hadfield [↑](#footnote-ref-4)