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Amateur Rocketry Control System

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Project Interest

From our extensive experience with collegiate rocketry it's become clear that implementation of a control system to improve stabilization is essential to achieving faster and higher launches. This inspired our research question:

Can we develop a low-cost, reliable, and lightweight RCS control system leveraging COTS and easily accessible hardware for amateur rocketry teams?

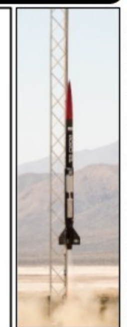


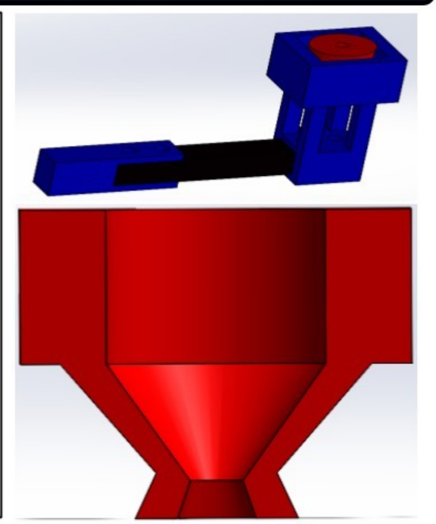
Figure 1: SDSU RP Aetherios Launch

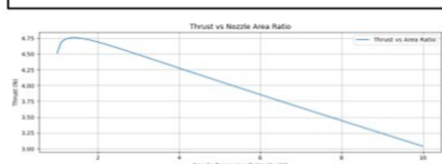
Propulsion

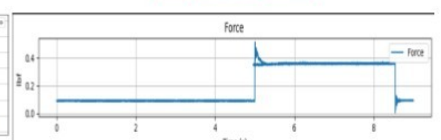
Requirements:
- Design and test nozzles to be implemented on psst stand
- Maximize thrust output for 185 inlet pressure into solenoid
- Ensure size and weight is minimized

Design:
- 8 converging-diverging nozzles
  - 2 pitch
  - 2 yaw
  - 4 roll
- Circular mount was used to ensure nozzles remained stagnant and in proper positions

Test & Validation:
- Verified nozzle designs through separate nozzle test stand
- Optimized nozzles through isentropic relations
- Ensured proper thrust through full system testing with snappy reaction control





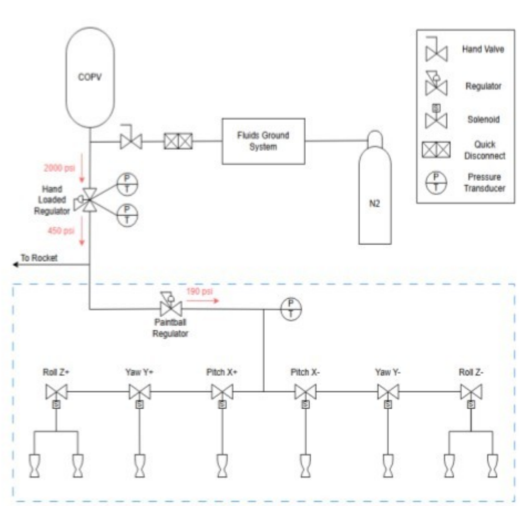


Fluid Systems

Requirements:
- Implement an RCS system onto a pressure fed rocket by tapping off from the pressurant source
- Regulate propellant down to nozzle operating pressures
- Feed propellant to 8 nozzles for control

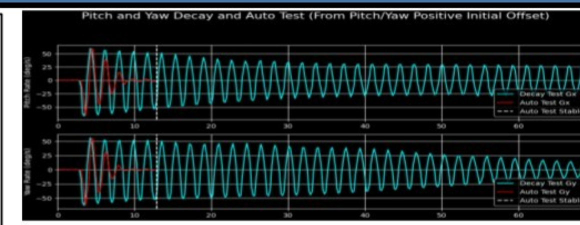
Design:
- Uses a composite overwrapped pressure vessel (COPV) for pressurant storage
- Able to interface with existing fluid ground systems for propellant loading
- 2 regulators to mimic pressure regulation systems on rocket
- 6 Solenoids for propellant control to each nozzle

Test & Validation:
- 4 pressurized test with manual and auto control of solenoids

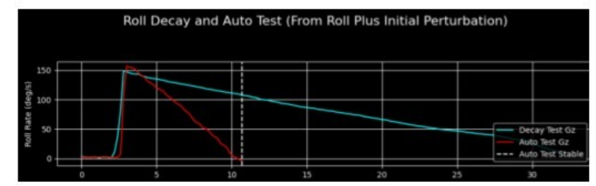


Results

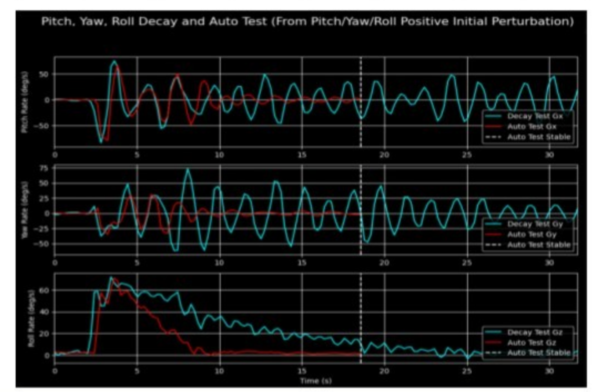
Pitch and Yaw Control (Roll Locked):
- Controller significantly reduces amplitude compared to natural decay
- Note: Tests with negative initial offsets (not shown) revealed different oscillation frequencies, confirming the non-uniform inertial tensor of liquid propellant systems



Roll Control (Pitch and Yaw Locked):
- Controller follows optimal path to stability with minimal overshoot
- Approximately 8× faster response with active control vs. natural decay
- Rates comparable to expected flight rates



Combined Three Axis Control:
- Complex coupled dynamics with cross-axis interactions
- Integrated controller handles asymmetric inertial properties effectively
- Roll stabilizes more quickly than pitch/yaw axes

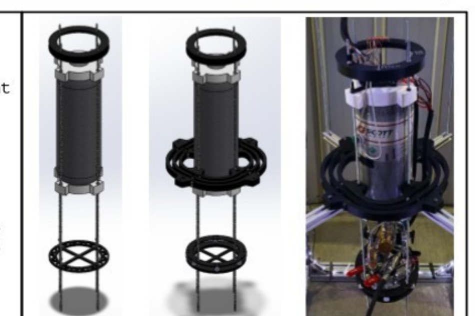


Next steps:
- More robust test stand structure to avoid induced additional DOF's
- Inertia distribution was not entirely representative of a complete rocket
- Inverting test stand to better simulate flight dynamics

Structures

Requirements:
- Create a "moc rocket" to act as the system structure
- Degrees of Motions: Create a main mount that is able to allow motion in roll, pitch & yaw
- Make sure all other sections have proper mounts for equipment

System Structure:
- Held together using four threaded rods which act as spars. This design allows for modularity and iteration.
- COPV is held in place using cradles that have been flown on RP rockets.



Gimbaling System:
- Made entirely from 3D printed parts, 8020 framing, and five ball bearings.
- 8020 framing cage allows for rolling motion
- Three gimbal rings allow for pitch and yawing motion

Other Structures:
- Nozzle Mount: Holds the nozzles in specific directions during testing to allow for pitch yaw and roll movement.
- OBC Mount: Holds the OBC and was built to be easily deintegrated.
- Slip Ring Mount: Mounts the slip ring to allow wiring to turn with the gimbal.

Acknowledgments

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Objectives

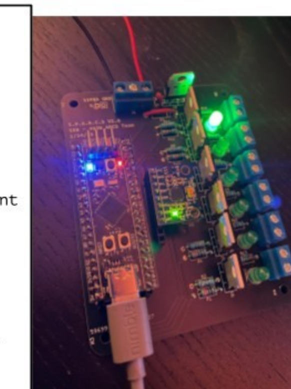
Develop and demonstrate a low-cost, lightweight, and reliable Reaction Control System (RCS) prototype which easily integrates with existing amateur level liquid rocket architectures.

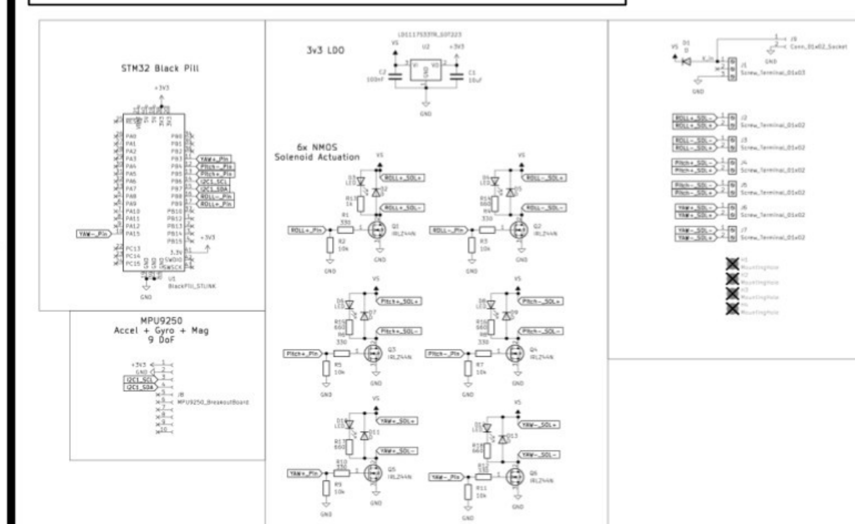
Avionics

Requirements:
- Interface with 6x Solenoid Valves at 12Vdc
- Obtain angular rates on all three axis
- Implement custom control algorithm
- Send data back to be analyzed

Design:
- STM32 Black Pill MCU
- 6x MOSFETs to actuate solenoid valves
- MPU6065 (6-DOF) or MPU9250 (9-DOF) Inertial Measurement Unit (IMU)
- Sends data back through USB-C
- Custom printed circuit board (PCB) to wire everything together

Test & Validation:
- Over 15 pressurized tests to validate electronics and data acquisition
- Sample Rate of 10-60Hz
- Executed manual and auto control of solenoid valves





Control System

Requirements:
- Rocket Stabilization: Implement control systems to reduce pitch, roll, and yaw rates to zero, achieving stable flight orientation

Design:
- Uses custom PD bang bang controller
- Rate-based control algorithm with defined minimum rate thresholds for efficient thruster activation
- Custom solenoid actuation rates to maximize RCS thruster control authority

Test & Validation:
- Verified effective rocket control capability through multiple pressurized and non-pressurized ground tests
- Performed sensor noise analysis with comparative data evaluation between controlled and uncontrolled flight conditions
- Employed multi-modal validation through on-board sensor estimates cross-referenced with external camera-based angle measurements

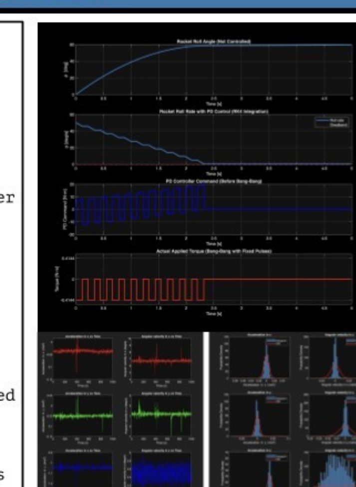


Figure X: Roll Control Sim & Noise