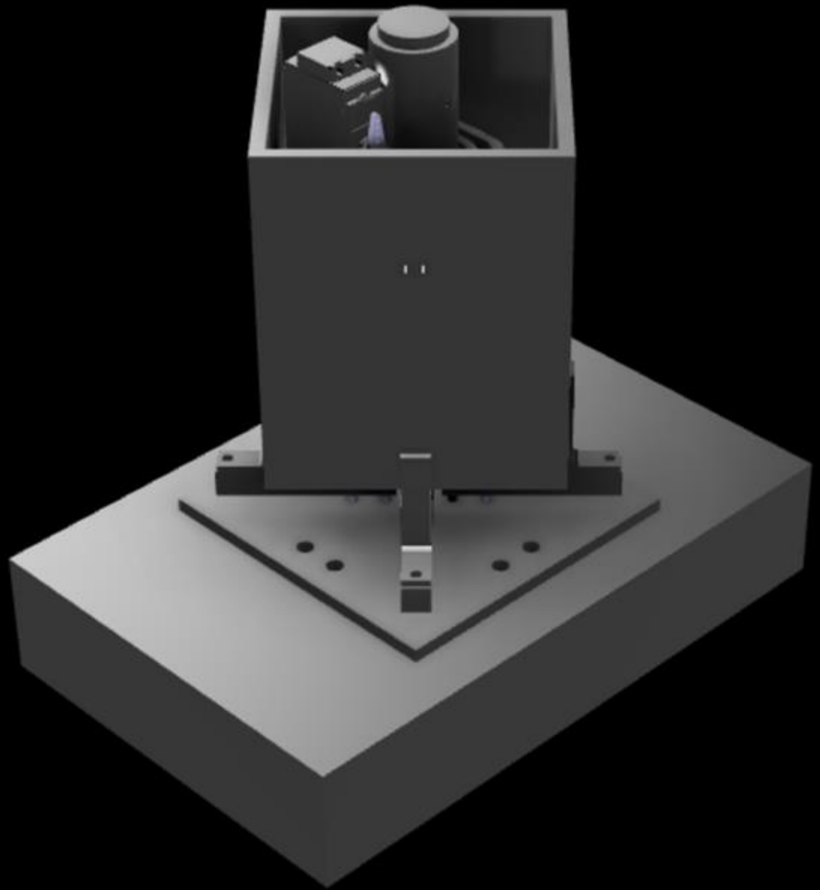
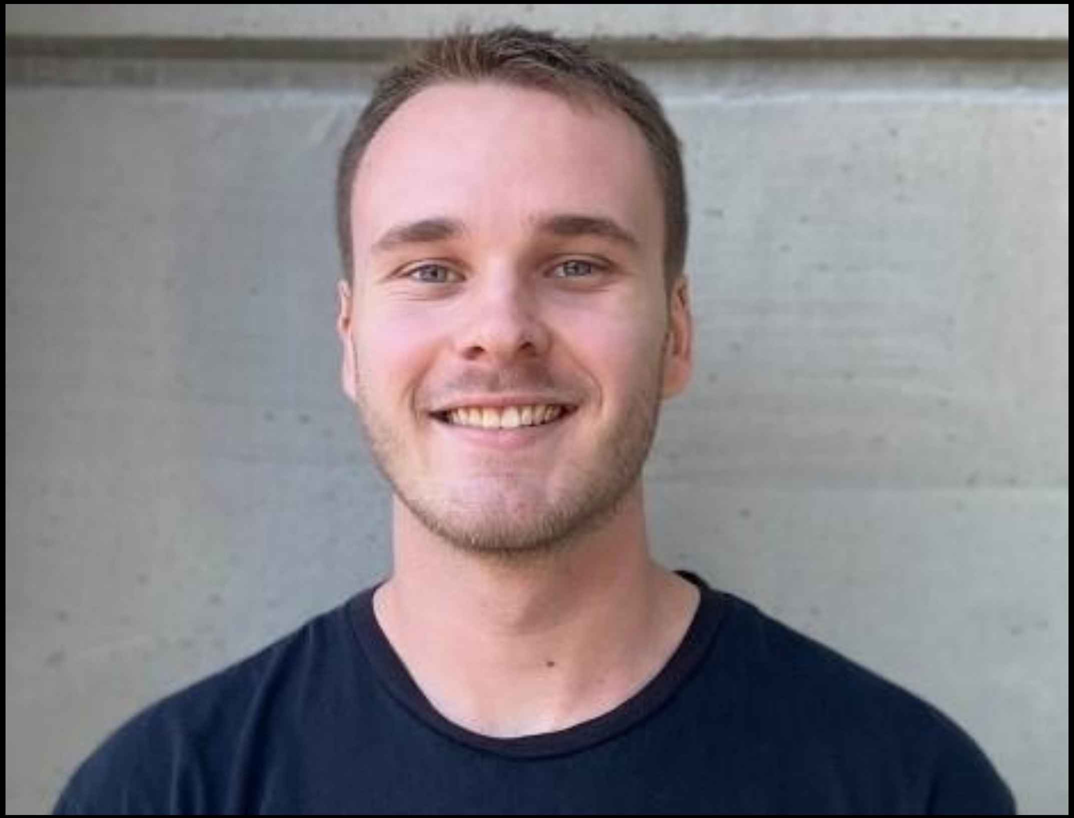
LANDER

Lunar Ascent and Descent Excavation Resource



System Verification Review

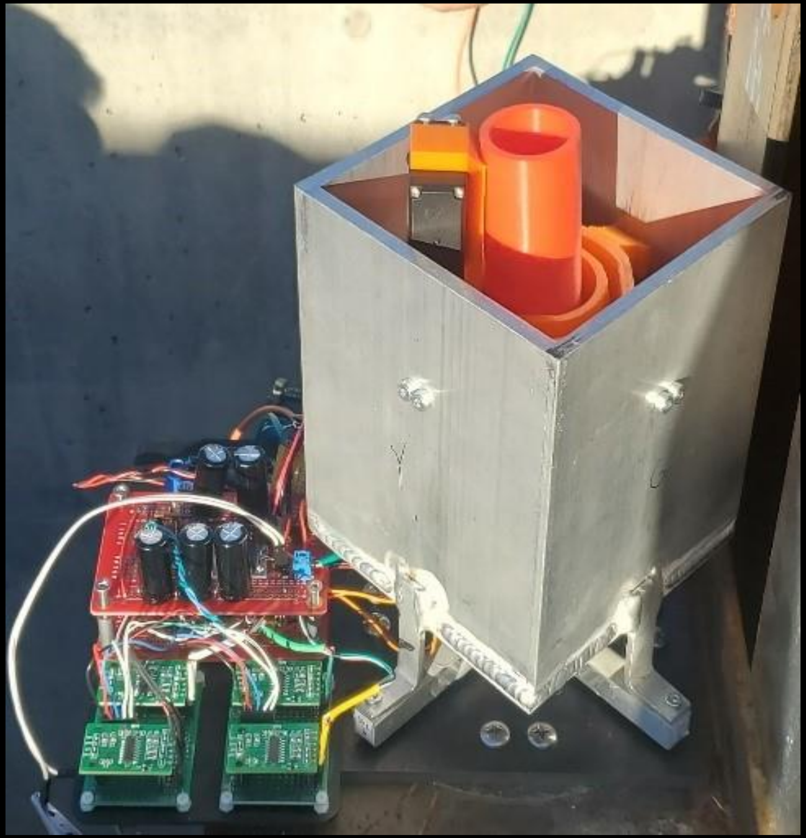
Anson Biggs, Joshua Ku, Brendan McGeeney, Michelle Passmore, Matthew Robinaugh, Maverick Thigpen, Brian Wahlstrom



System-Level Overview

Michelle Passmore & Brendan McGeeney

Project Lander Overview



Vehicle Assembly

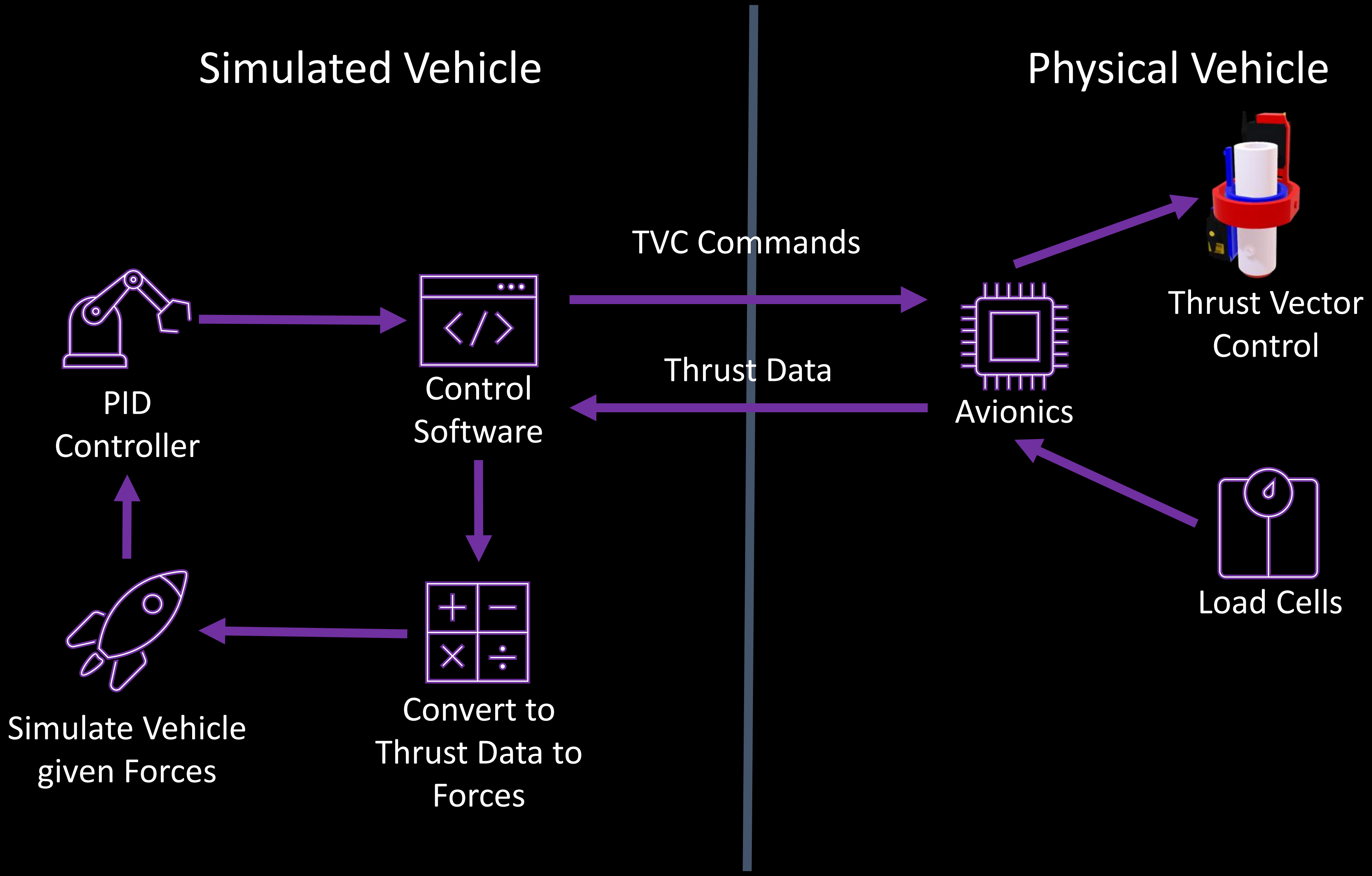
<u>Objective:</u> Perform a hot fire test that demonstrates controlled propulsive landing abilities.

<u>Solution:</u> Design control software that utilizes hardware in the loop feedback to command a thrust vector control (TVC) system and simulate a landing based on given flight conditions.

The system is comprised of a physical vehicle and simulated vehicle.

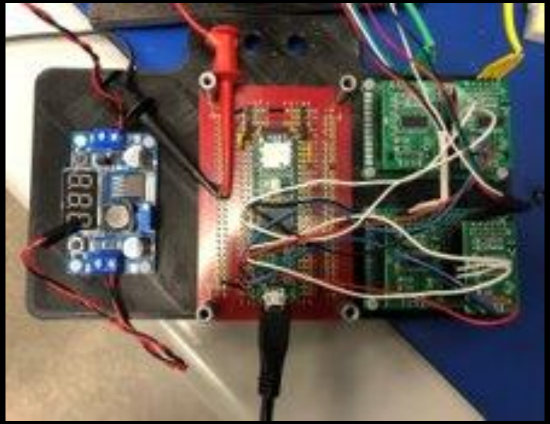
- The simulated vehicle uses control software to send interoperate simulated data to the physical vehicle.
- The physical vehicle's avionics converts simulated flight data into commands for the TVC.
- The experimental outputs angles from the TVC are compared to expected outputs to determine success criteria for the controlled propulsive landing.

Concept of Operations



Overview of Critical Tests

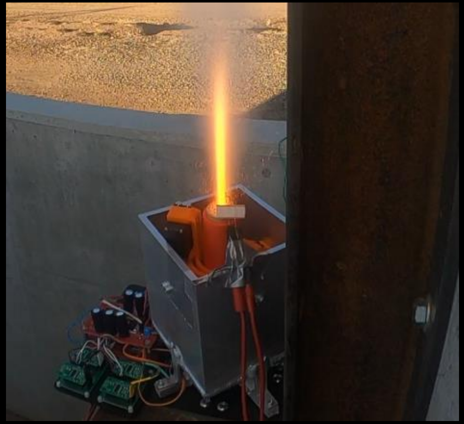
Avionics Integration Test



TVC Test

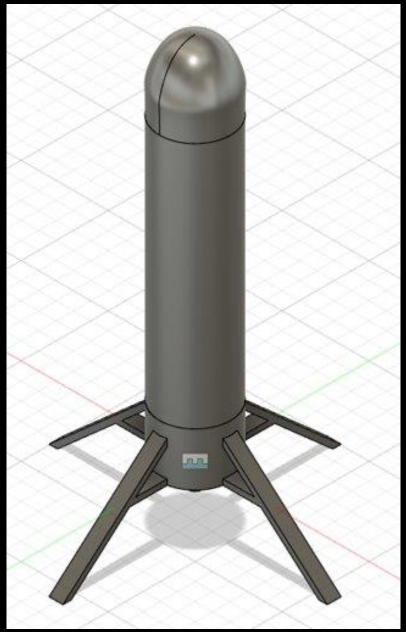
Static Load Test

Operational Demonstration

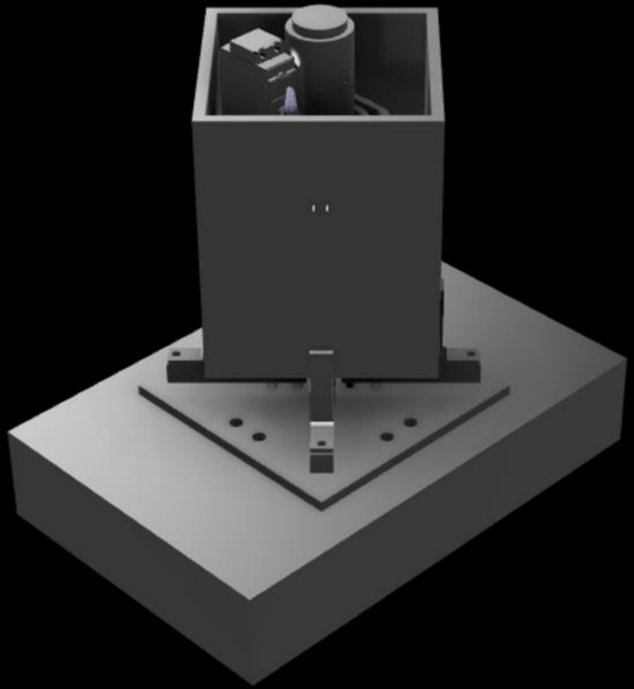


Design History

- Influenced by lunar mining and colonization missions
- Inspired by Space X Falcon 9 functionality
- Descoped from real flight test to stationary test stand demonstration
- Changed entire structural design from preliminary design

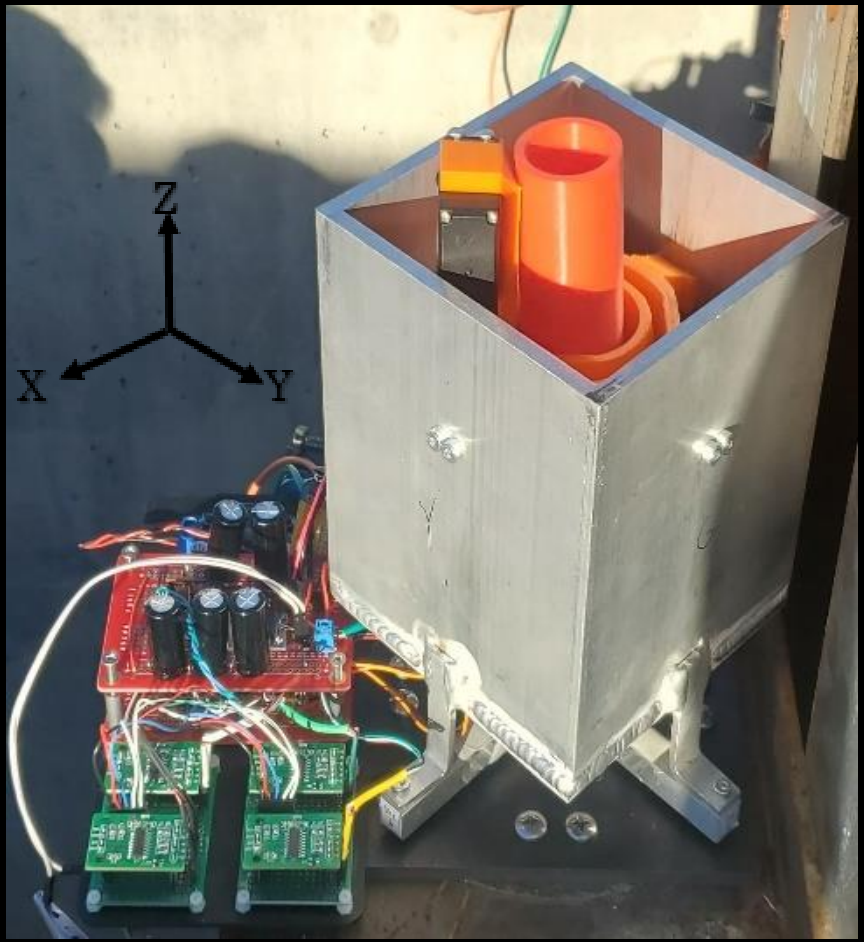


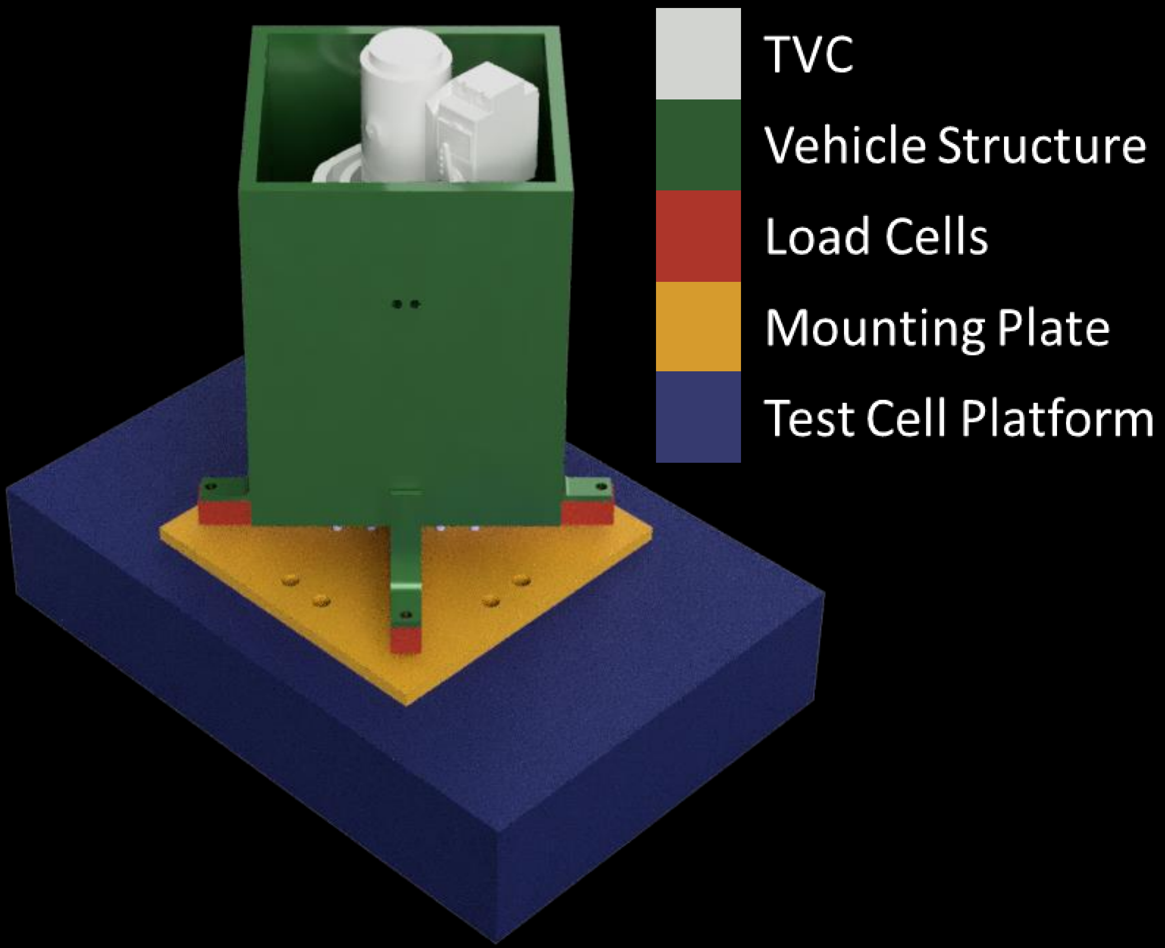
Preliminary Vehicle Design CAD



Final Vehicle Design CAD

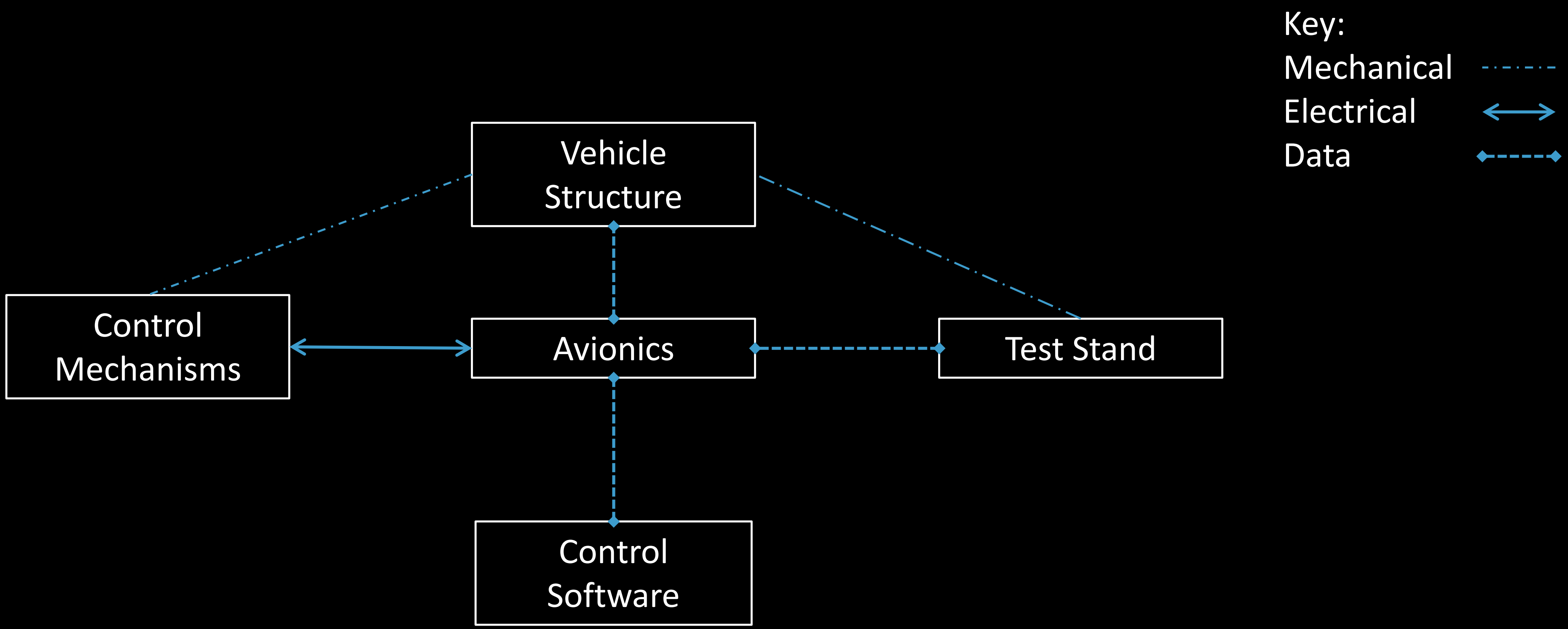
Design History





Final Vehicle Design

Subsystem Breakdown of Lander



Subsystem Integration

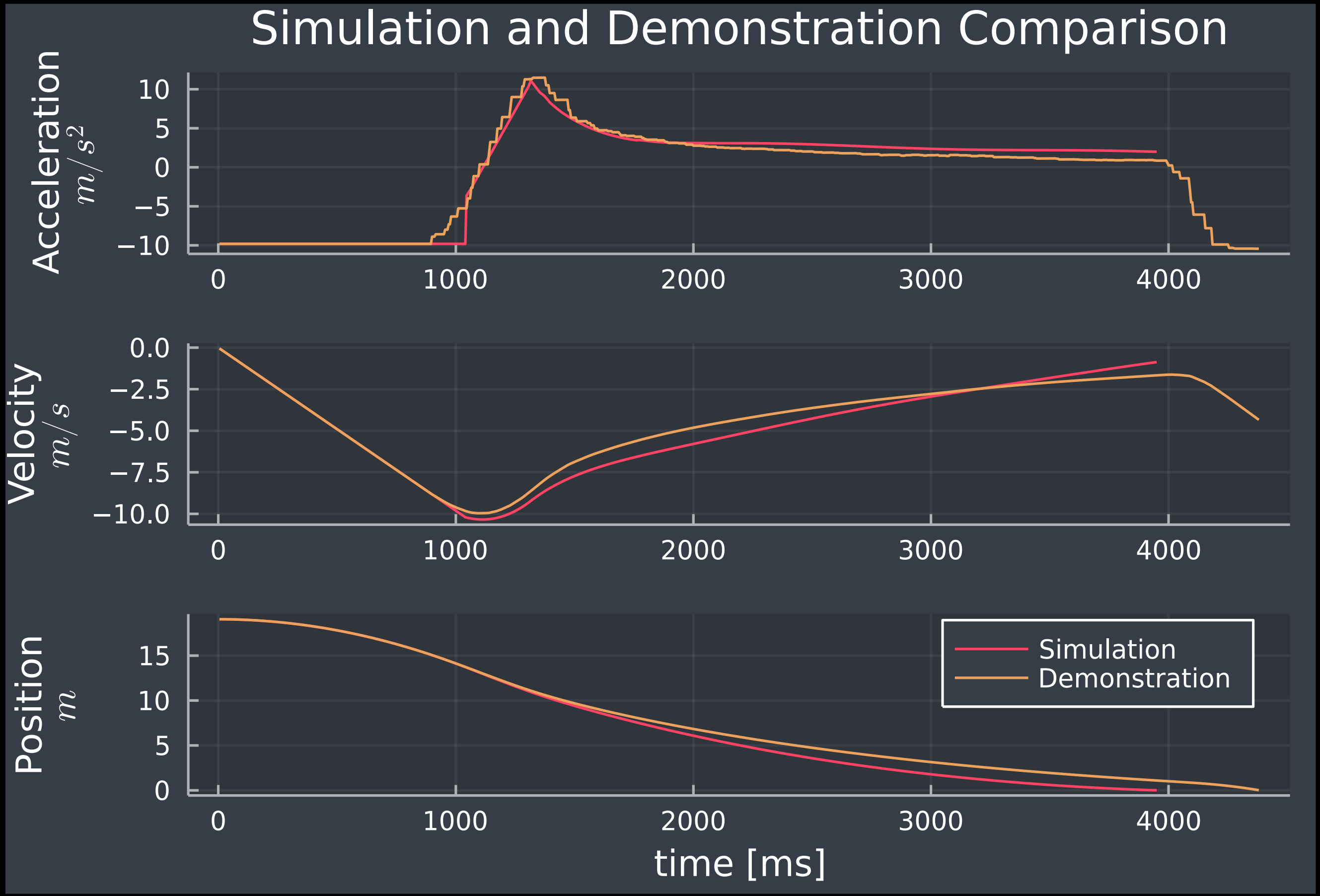
System Level Critical Requirements

SLR ID	Requirement	Performance Metric	Verification Procedure	Pass/Fail Criteria	Pass/Fail Status
SLR_1.2	The simulated vehicle shall control attitude upon completion of operation within ±5°.	Final Attitude Threshold	Operational Demonstration	Final velocity within ±5° orthogonal to the xy plane.	Fail
SLR_1.3	The simulated vehicle shall have a maximum vertical velocity of 1 m/s upon completion of operation.	Final Maximum Velocity	Operational Demonstration	Final maximum velocity of 1 m/s.	Fail
SLR_1.5	The system shall process thrust data during operation.	Data Processing Abilities	Operational Demonstration	Data Processing Abilities	Fail

Analysis of system level critical requirements relies on control software readings, hardware integration, and operation demonstrations.

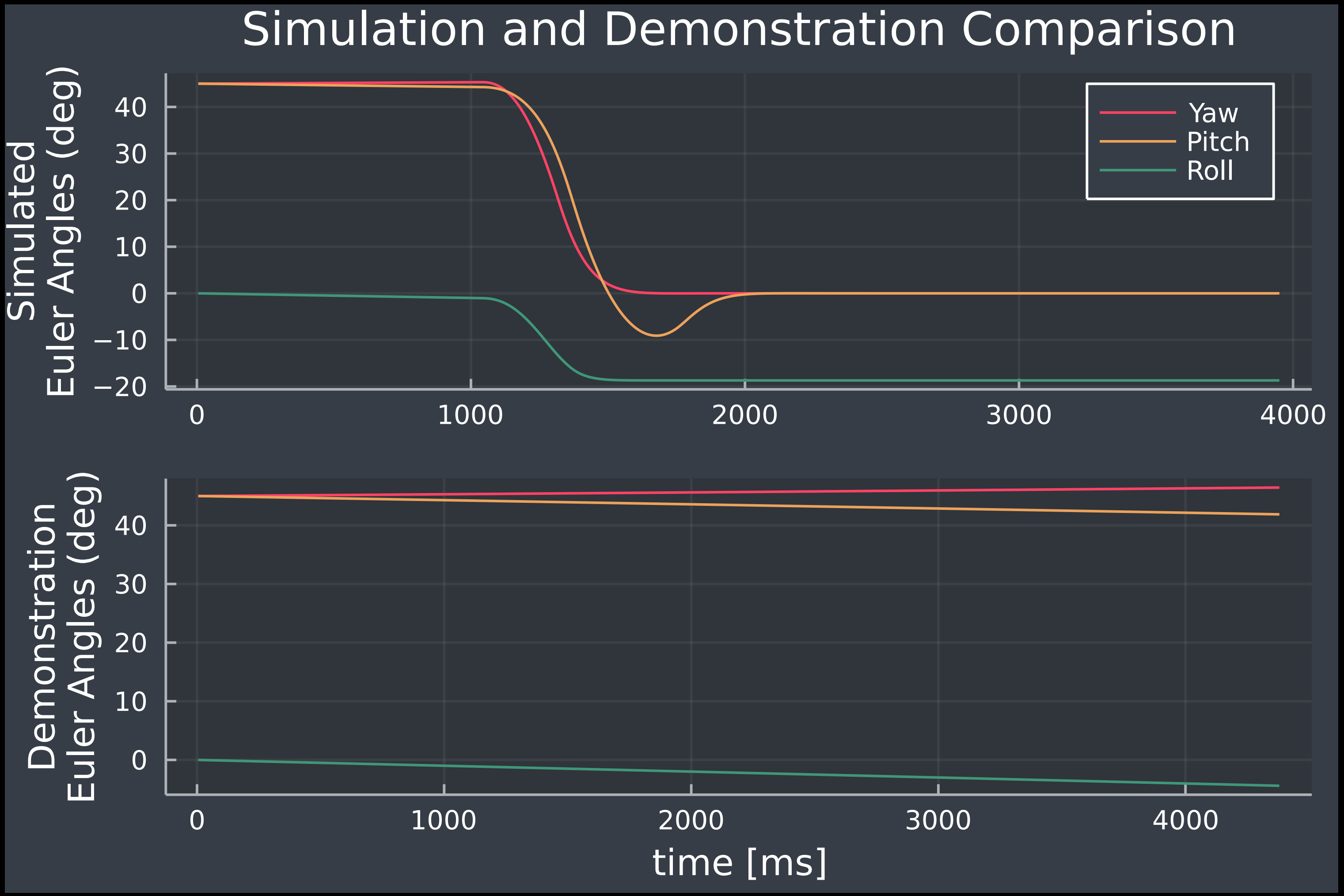
Comparison of Demonstration Results

	Expected Value	Expected Tolerance	Actual Value	Pass/Fail Status
Altitude [m]	0	± 1.0	0.99	Pass
Velocity [m/s]	0	± 1.0	-1.63	Fail
Yaw [°]	0	± 5.0	46.44	Fail
Pitch [°]	0	± 5.0	41.87	Fail
Simulation Response [ms]	< 1	± 0.0	0.014	Pass
Simulation Size [MB]	< 6	± 0.0	0.211	Pass



Future Improvements of the System

- To achieve the expected results:
  - Implement TVC throttling
  - Invest in higher quality load cells
  - Ensure proper fabrication of all critical components



Control Software

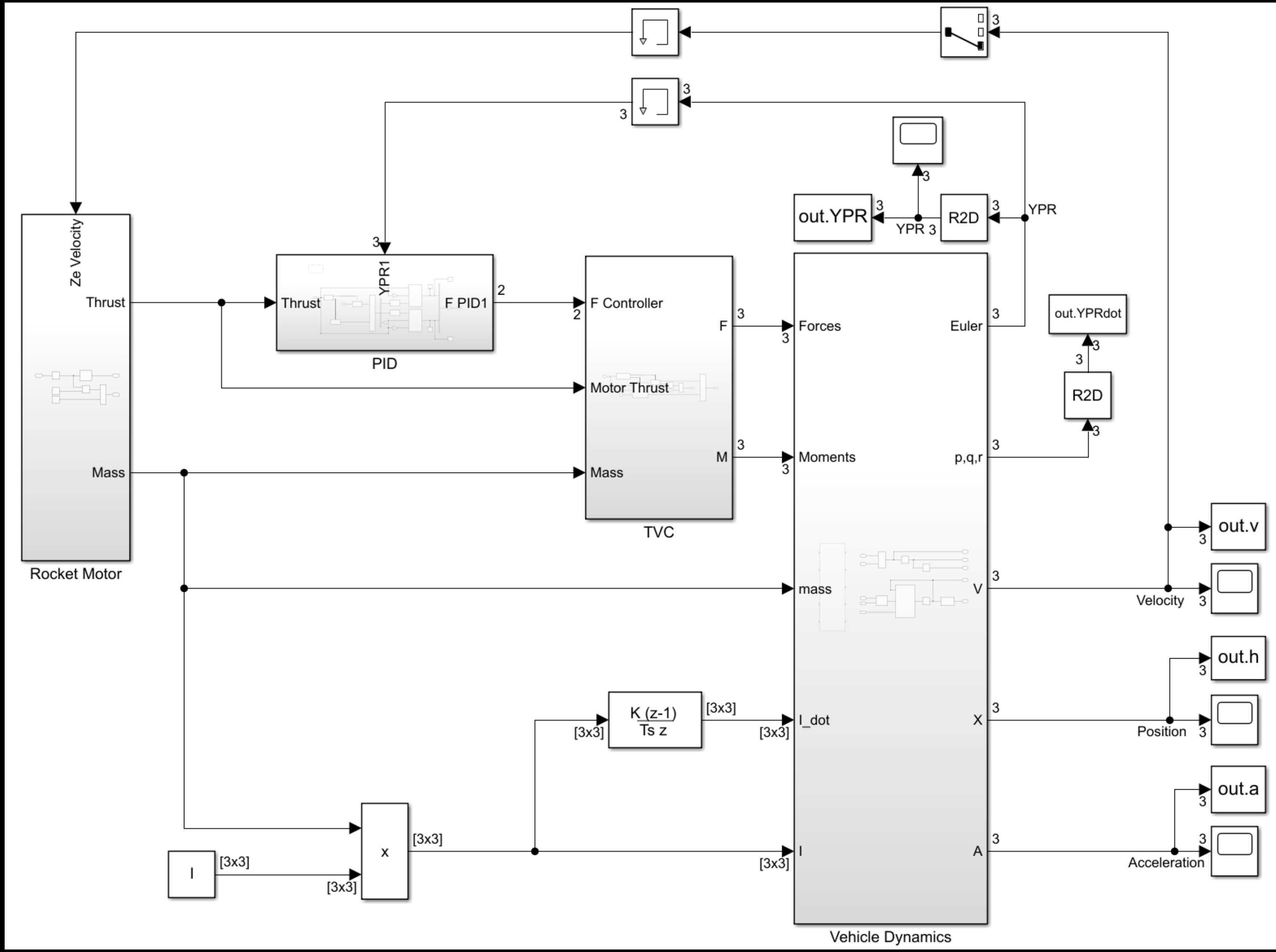
Brendan McGeeney & Matthew Robinaugh

Control Software Critical Requirements

SSLR ID	Requirement	Performance Metric	SLR Uplink	Verification Procedure	Pass/Fail Status
3.1	The size of the control software shall not exceed 6 MB.	Program Size	SLR_1.3 SLR_1.4	Avionics Integration Test	Pass
3.2	The control software shall process sensor inputs from the test stand.	Control Software Inputs	SLR_1.3	Operational Demonstration	Fail
3.3	The control software shall provide outputs to the control mechanisms.	Control Software Outputs	SLR_1.4	Avionics Integration Test	Pass
3.4	Upon receiving a sensor input from the avionics subsystem, the control software shall produce an output to the propulsion subsystem within 1 ms.	Response Time	SLR_1.4	Avionics Integration Test	Pass
3.5	The control software shall receive an input at a minimum rate of 50 Hz.	Input Rate	SLR_1.4	Avionics Integration Test	Pass

Simulink Prototype

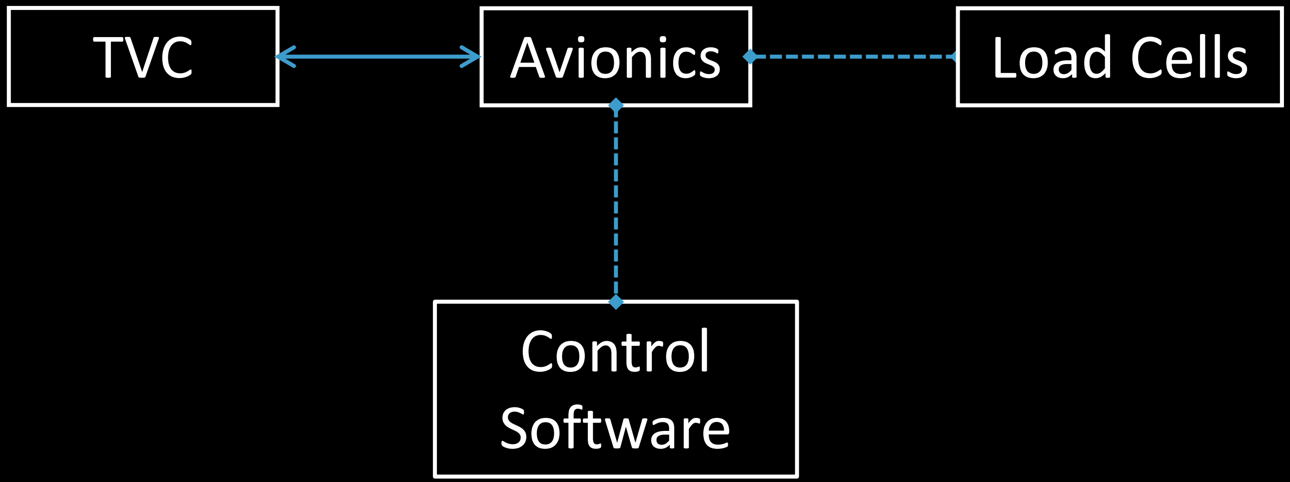
- Enabled understanding of algorithm early on
- Assisted in the choice of rocket motor (Estes F15)
- Enabled quick prototyping during all stages of the project



Final Simulink

Design Metrics and Analysis

- File Sizes
  - Program Size < 6 MB
  - Ruled out exporting code from Simulink
- Inputs/Outputs
  - Four (4) load cell signals
  - Commands to two (2) servos
  - Object oriented languages well equipped for hardware in the loop
- Response Time (< 1 ms)
  - Needed a performant language that compiles to embedded hardware

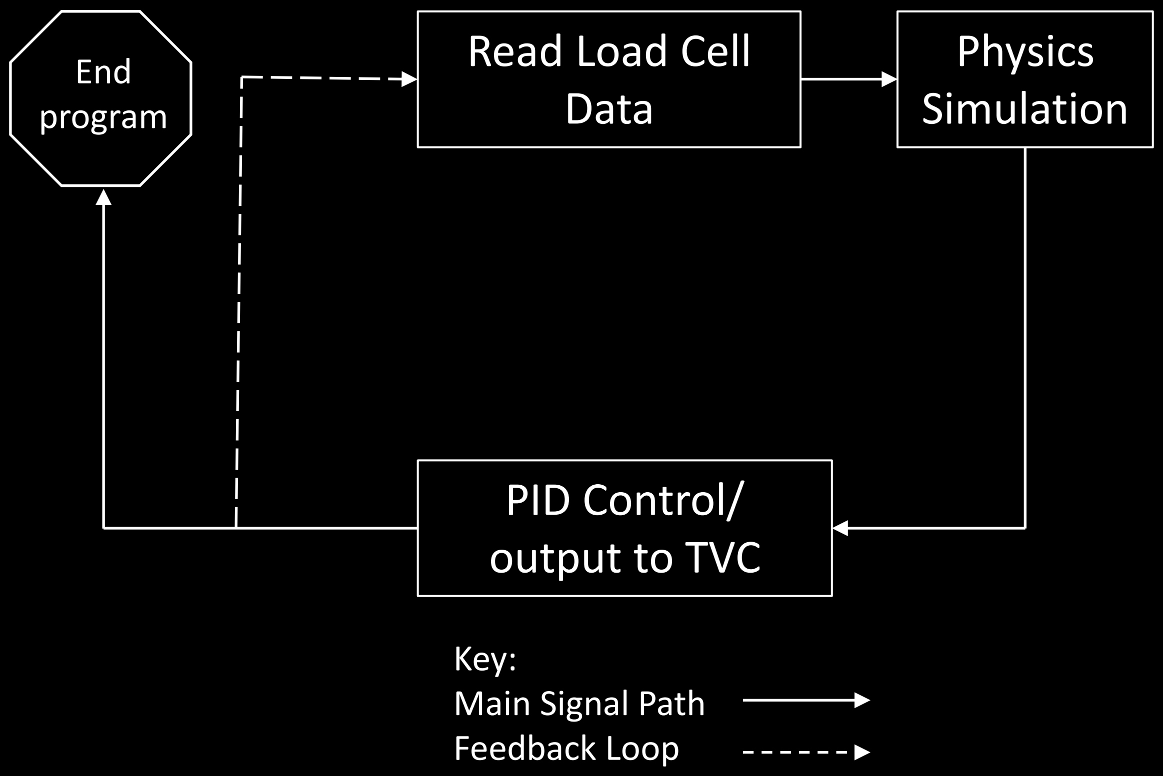


Control Software Integration

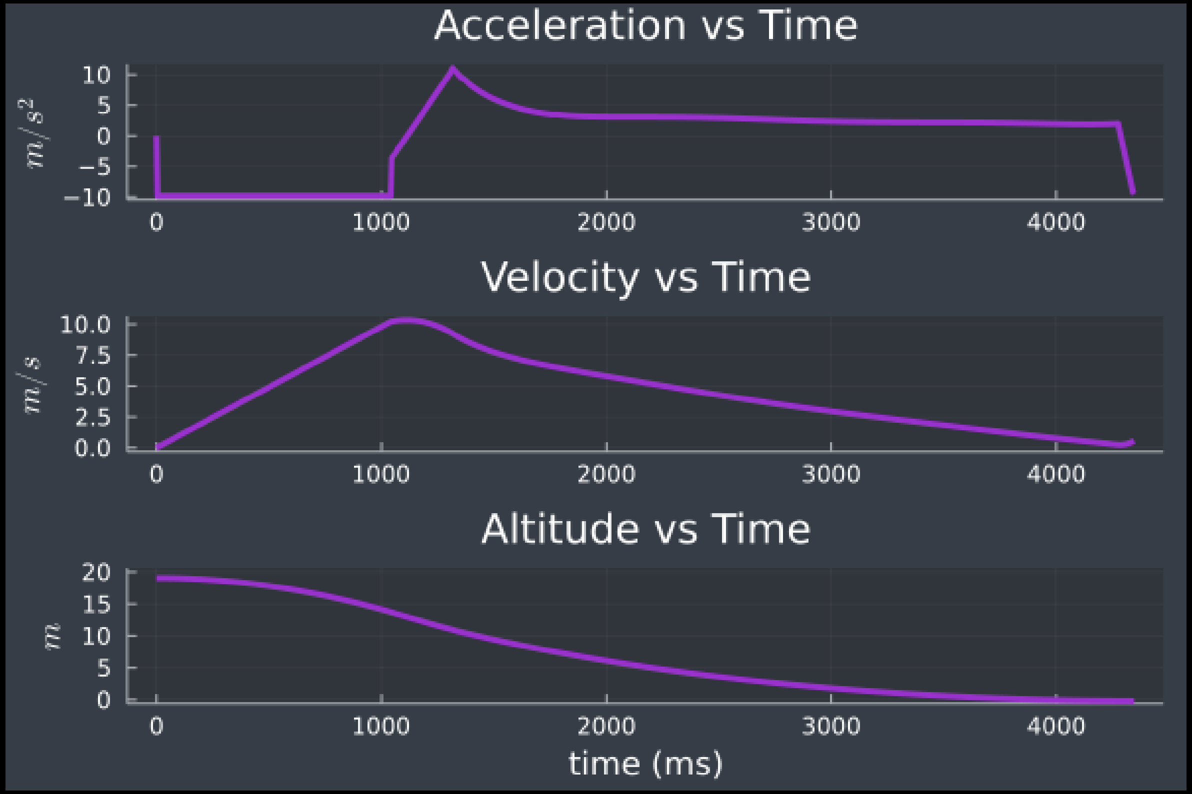
C++ Implementation

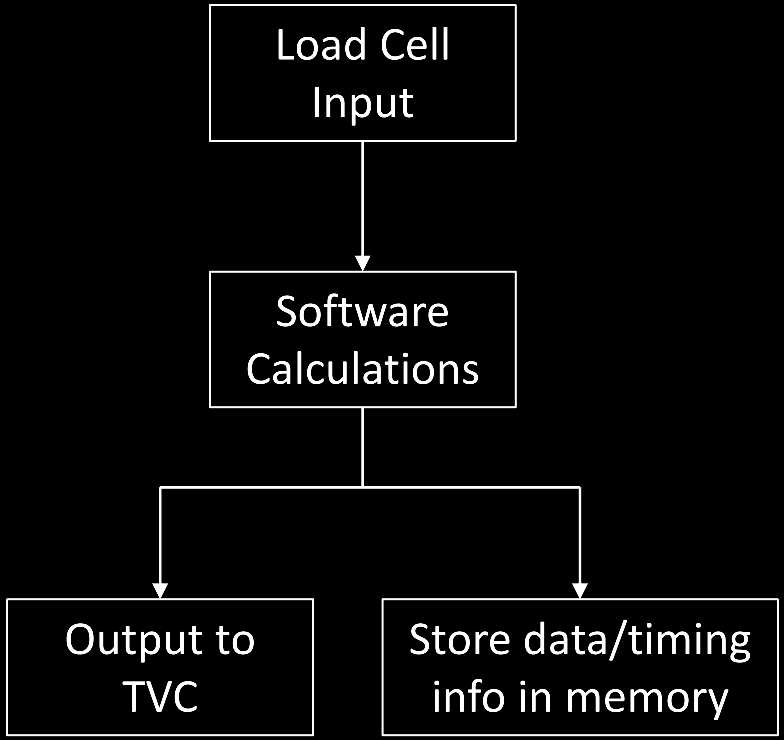
- Burn start predetermined based on drop height and motor type
- Read load cell data
- Initiate burn when simulated vehicle reaches calculated velocity
- Using attitude:
  - Determine maneuvers to correct orientation with a PID controller
  - Output commands to TVC

Control Software Algorithm

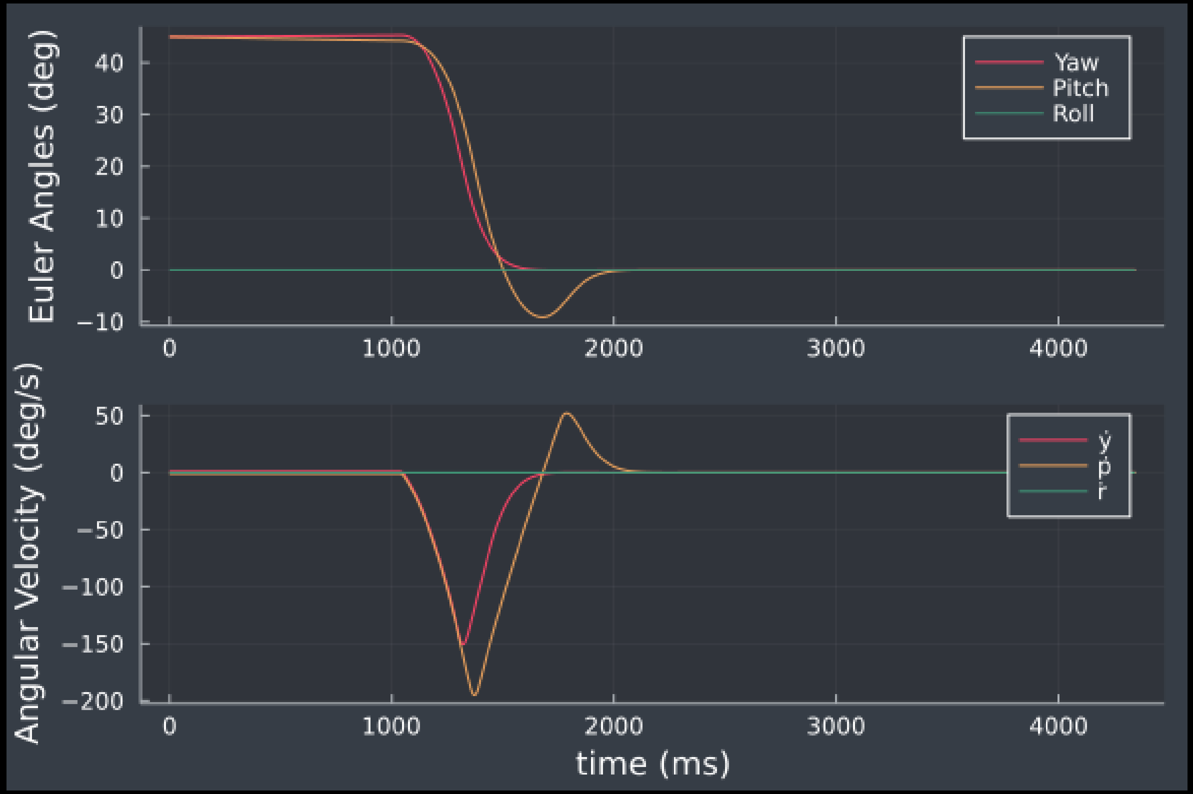


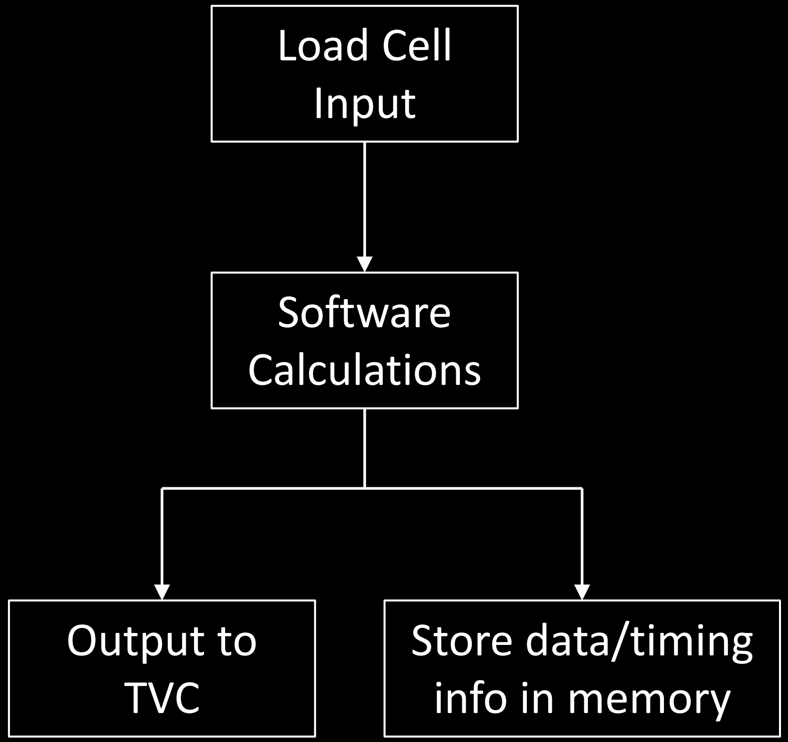
Control Software Testing



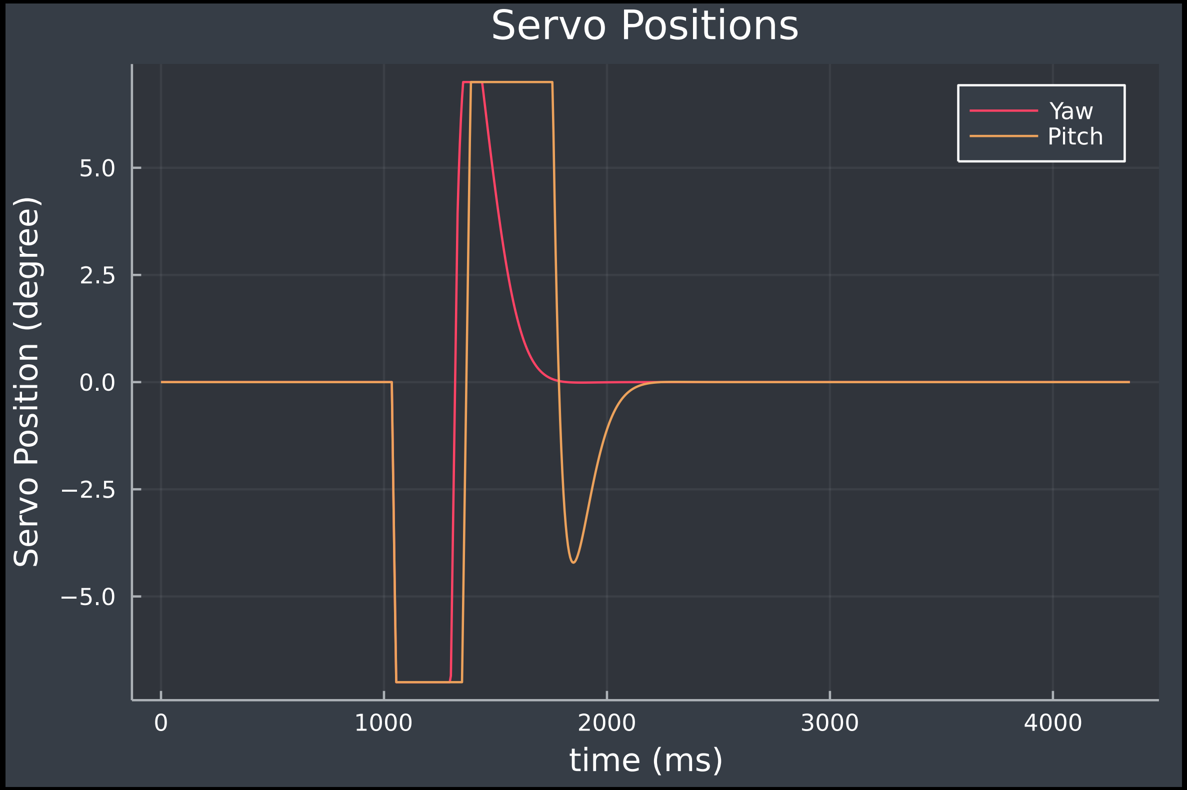


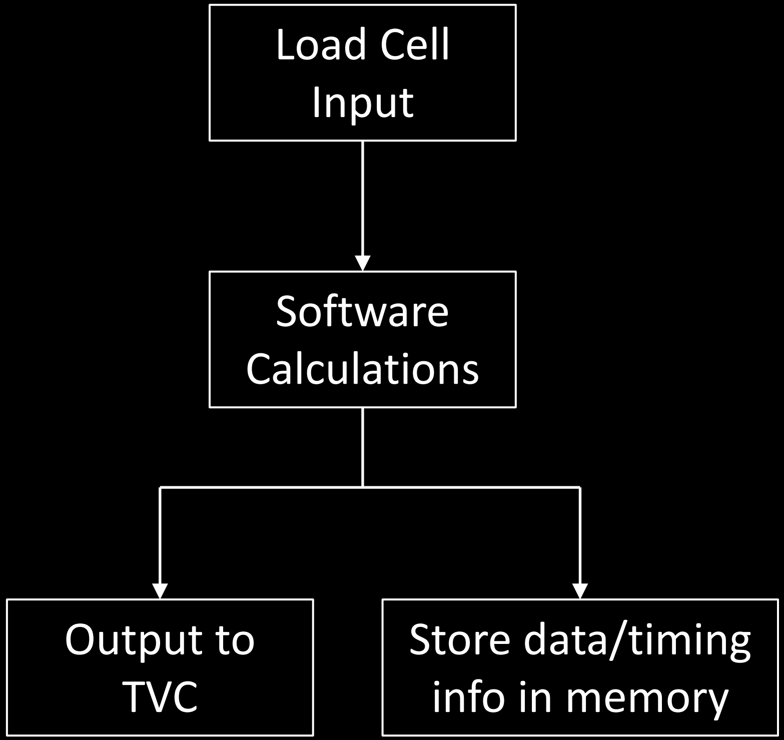
Control Software Testing





Control Software Testing





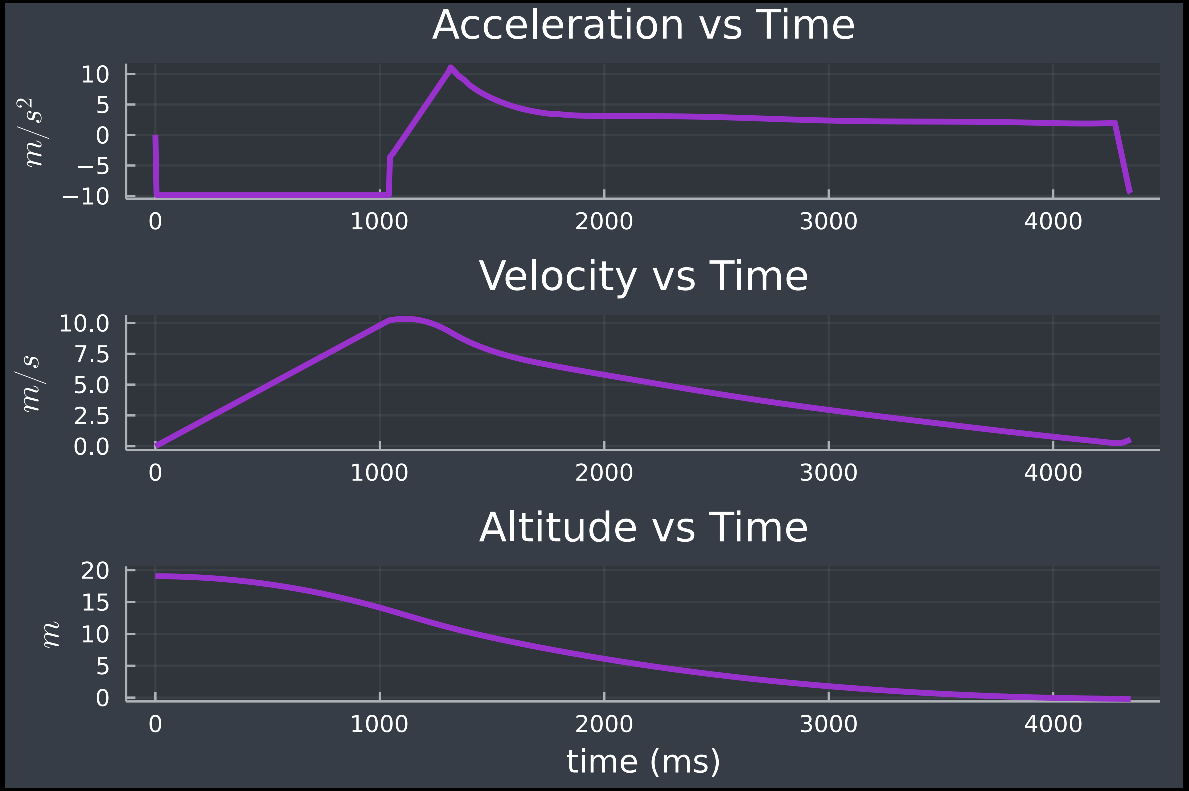
Analytical and Experimental Comparison

- Fall within tolerance, but certainly room for improvement
  - Final height and velocity are very close to being out of tolerance
  - No control over burn time or thrust output of motor

	Expected Value	Expected Tolerance	Actual Value
Altitude [m]	0	± 1.0	-0.980
Velocity [m/s]	0	± 1.0	-0.711
Yaw [°]	0	± 5.0	0.000
Pitch [°]	0	± 5.0	0.000
Simulation Response [ms]	< 1	± 0.0	0.013
Simulation Size [MB]	< 6	± 0.0	0.211

Future Improvements of the Control Software

- Two options to drive the final altitude and velocity closer to 0:
  - TVC Throttling
    - Allows more control of thrust curve
    - Motor still has fixed burn time
  - Liquid propellant motor
    - Allows total control of thrust curve
    - Manual start and stop of the motor



Control Mechanisms

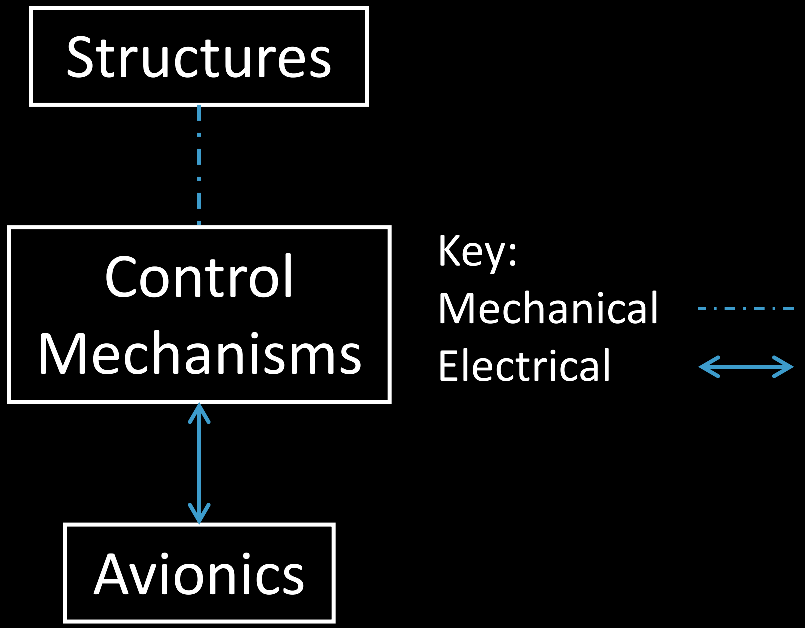
Anson Biggs

Control Mechanism Critical Requirements

SSLR ID	Requirement	Design Metric	SLR Uplink	Verification Method	Pass/Fail Status
4.1	The control mechanisms shall gimbal a minimum of ±5 degrees in the x and y axis.	N/A	SLR_1.2	Inspection	Pass
4.2	The control mechanisms shall communicate with the avionics.	PWM Commands	SLR_1.2	Demonstration	Fail

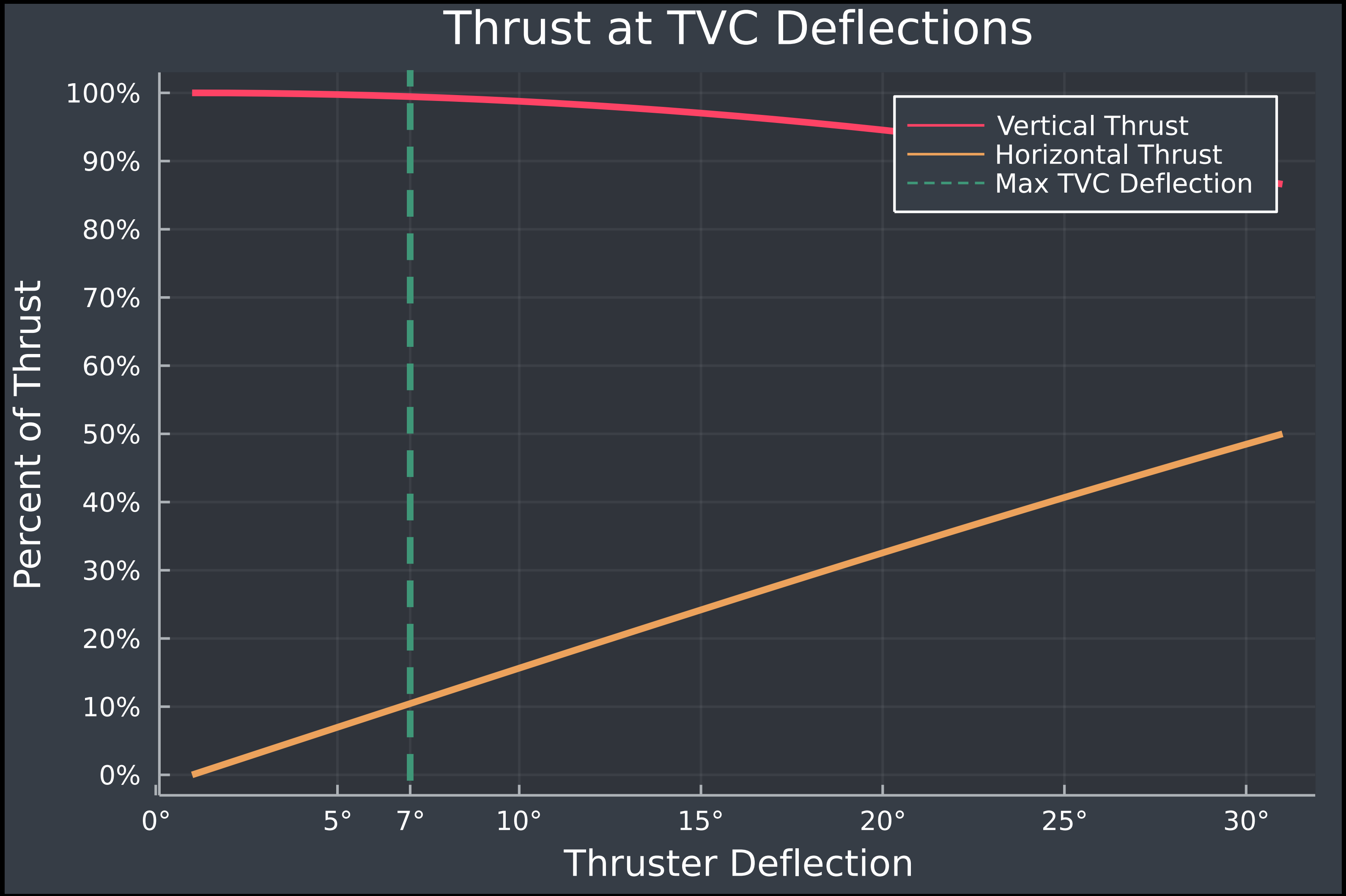
Design Metrics and Analysis

- Gimbal Performance
  - Minimum gimbal rotation in each axis needs to be ± 5°
- Avionics Interoperation
  - Servos need to be able to be commanded by the Avionics
  - Power Requirements need to be met by Avionics

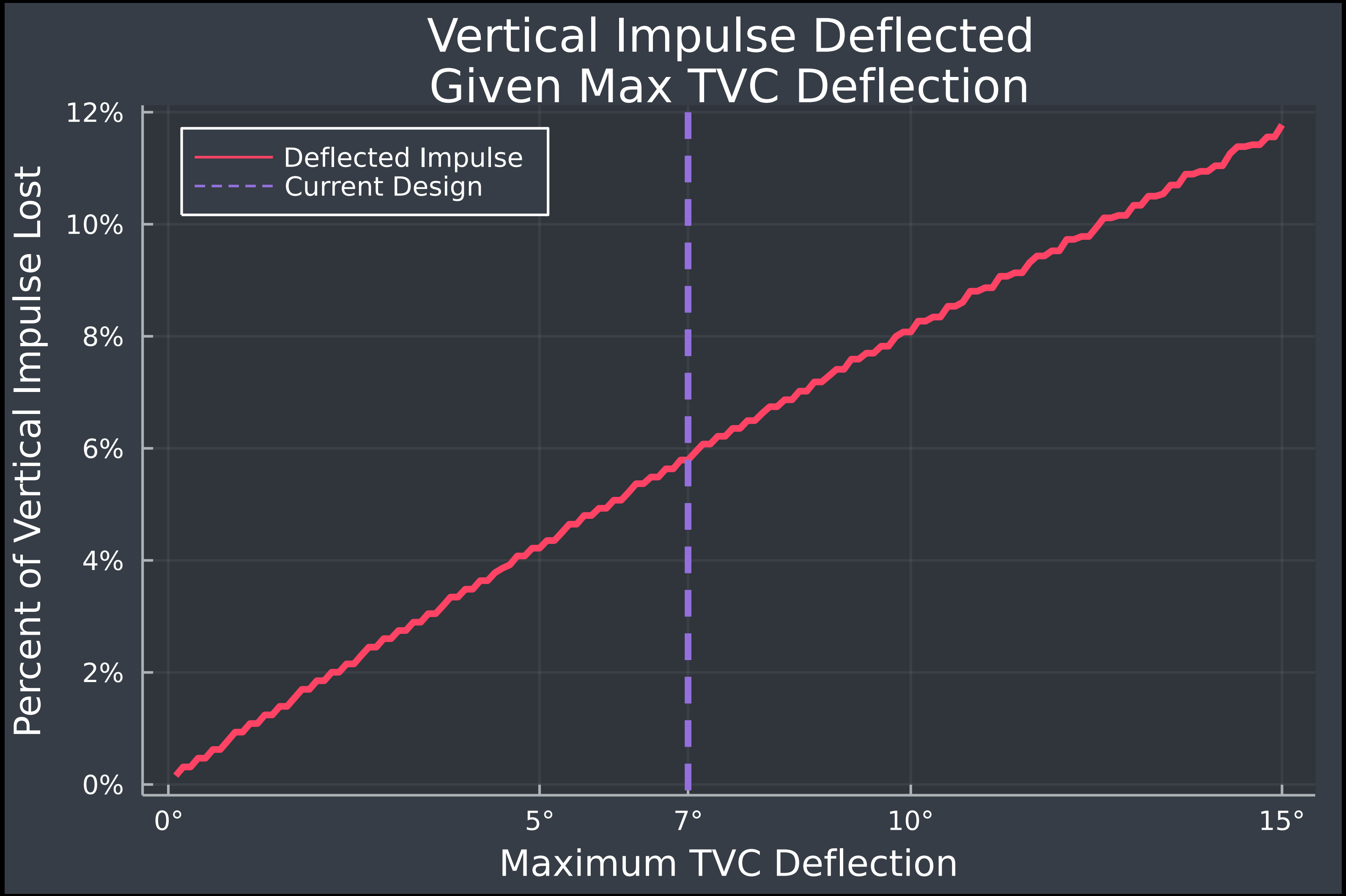


Control Mechanisms Integration

Initial Analysis of TVC Design

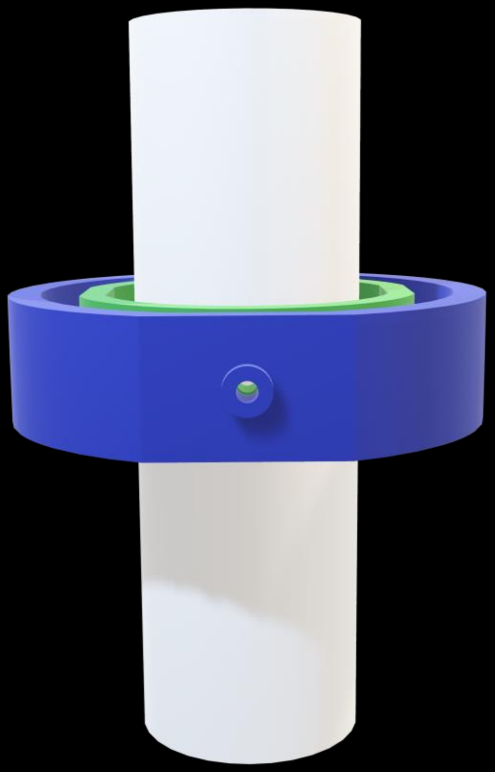


Advanced Analysis of TVC Design

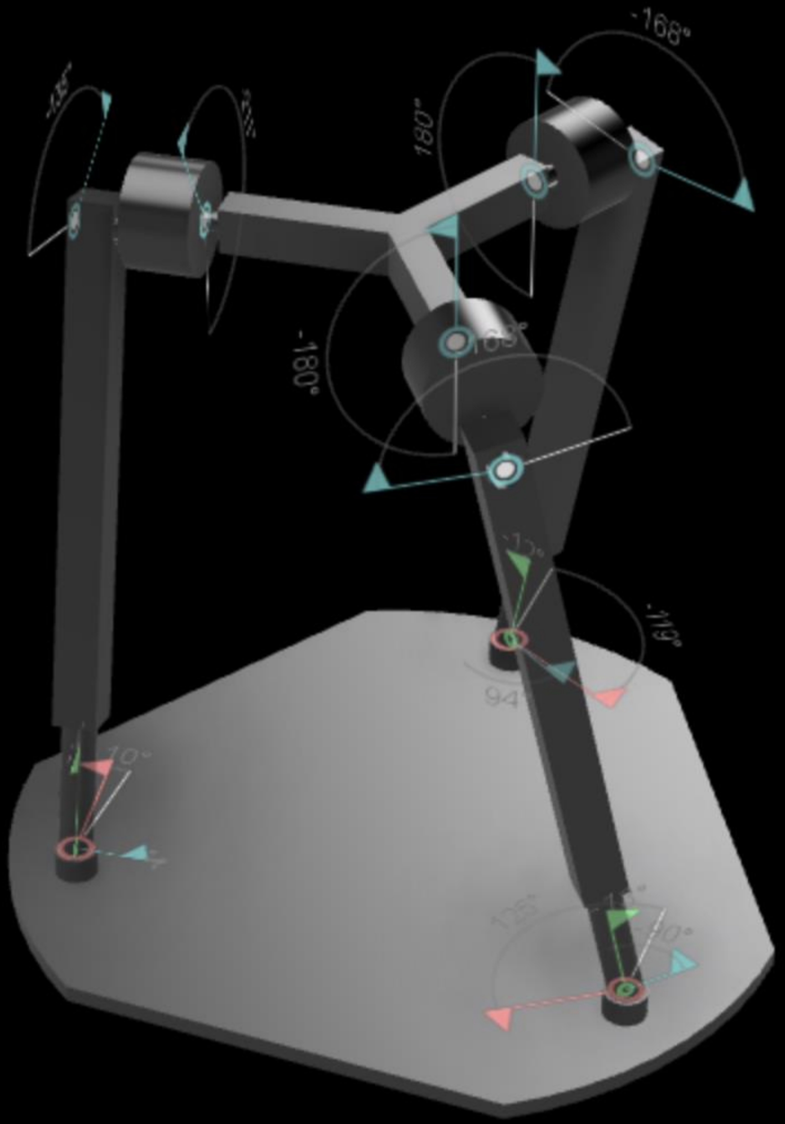


Early TVC Designs

- Early Constraints led to designs that deviated greatly from the final design
  - Desire to have a high gimbal led to very mechanically complex designs
  - Requirement to fit inside of a landing vehicle meant TVC needed a very small footprint

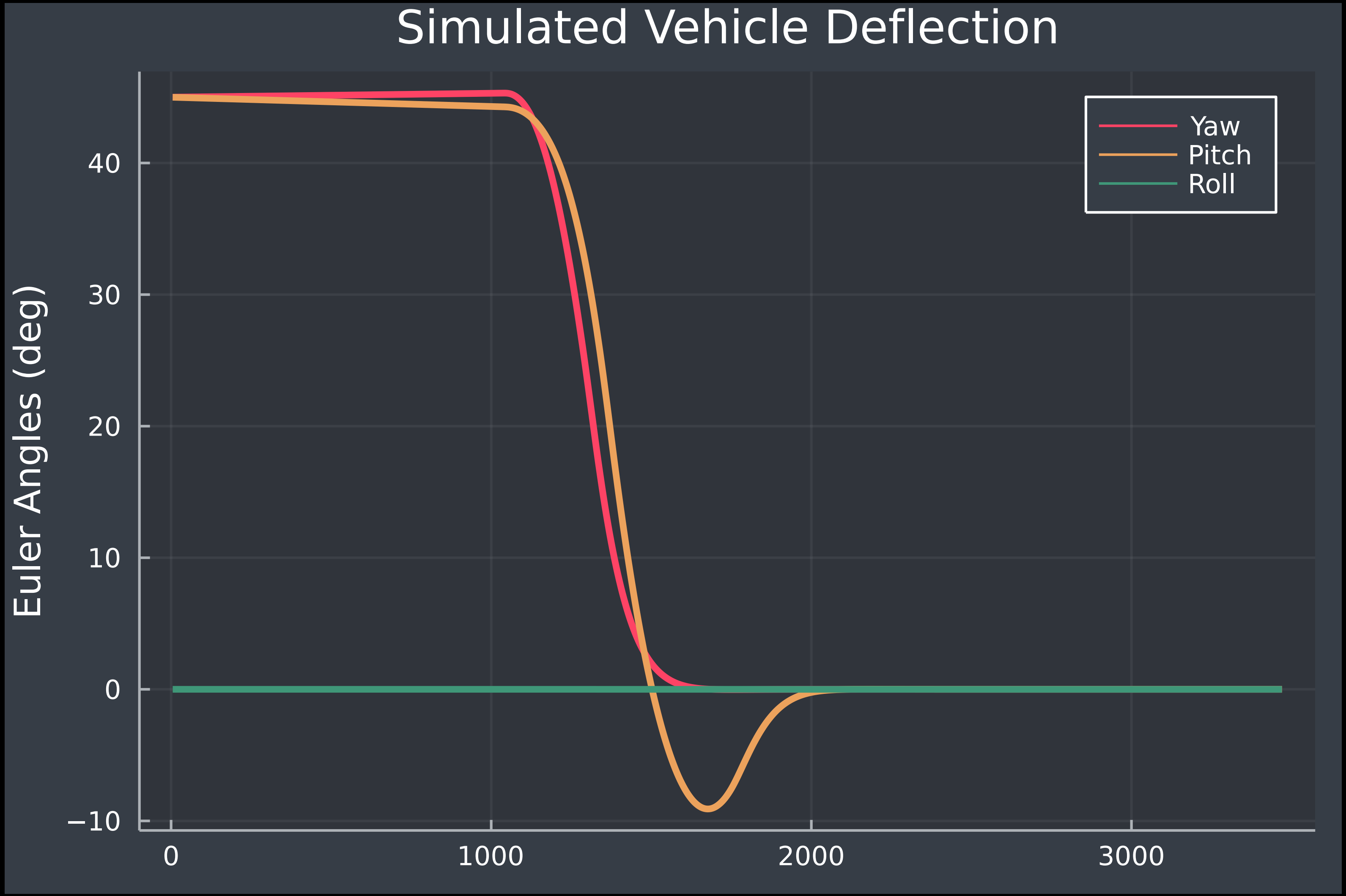


Early version of final design



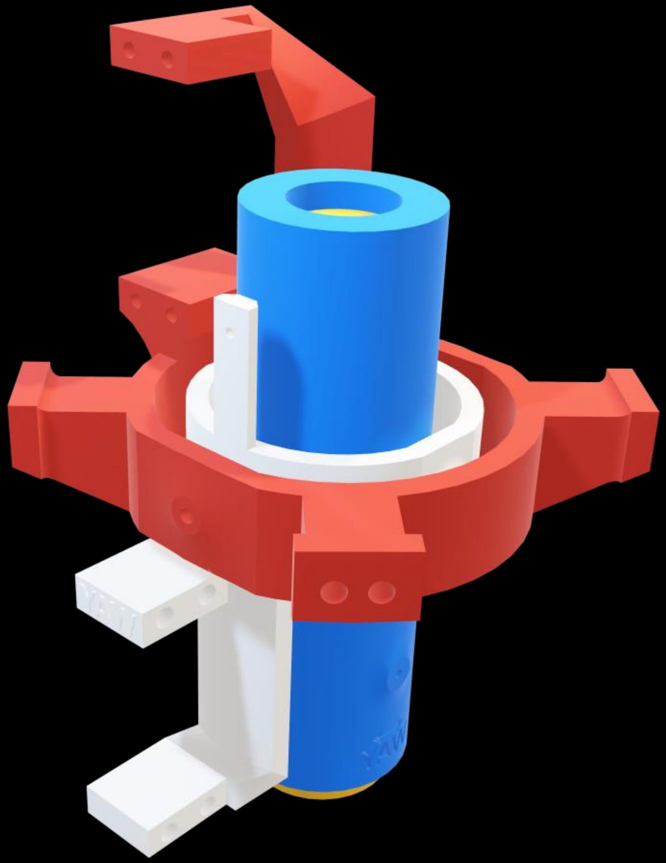
Mechanically complex design

Simulated PID Analysis



Final TVC Design

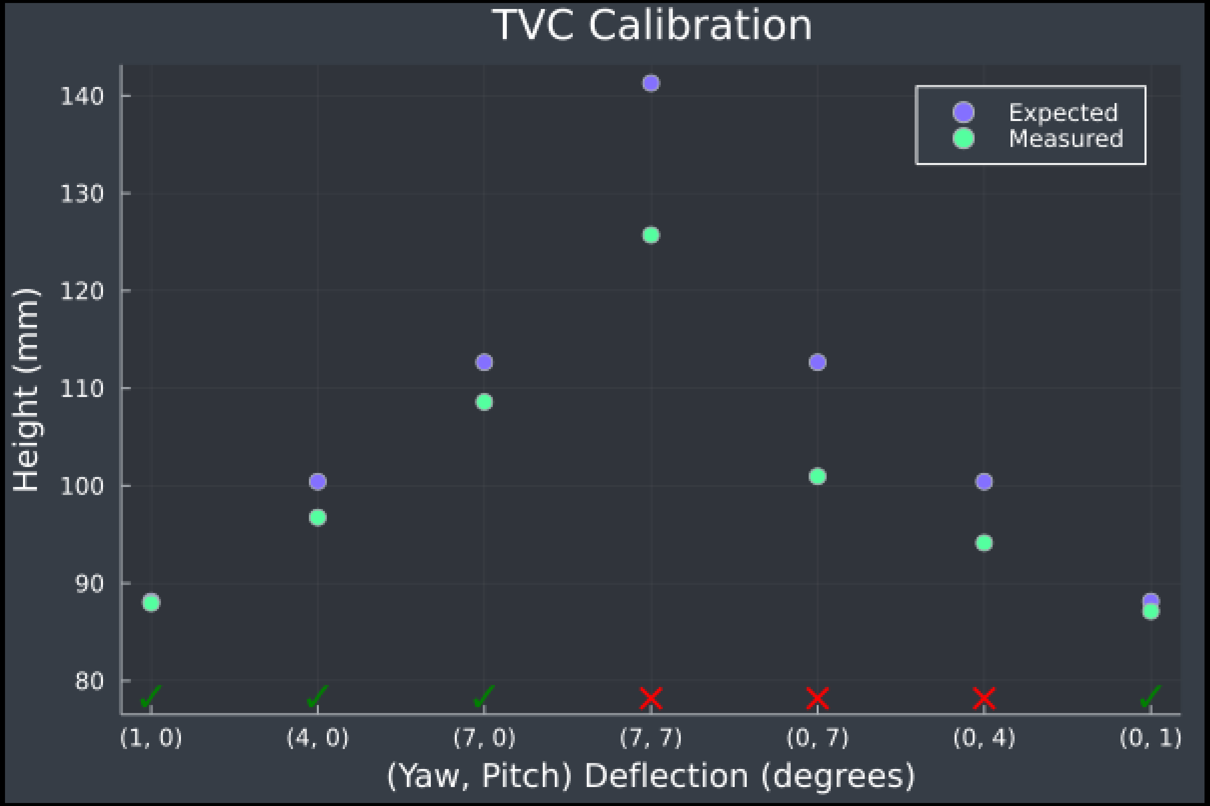
- Devised to be mechanically simple
- Designed with 3D printing in mind
- Integrates with a square structural tube
- Exceeds gimbal critical requirement of 5° gimbal by allowing a maximum of 7° in each axis



Future Improvements of the TVC Subsystem

TVC was difficult to calibrate but could be improved:

- Making the tolerances for the fit between the gimbal rings tighter.
- Designing a better system to verify calibration.
- Selecting servos that weren't overbuilt would relax other constraints.




Vehicle Structure

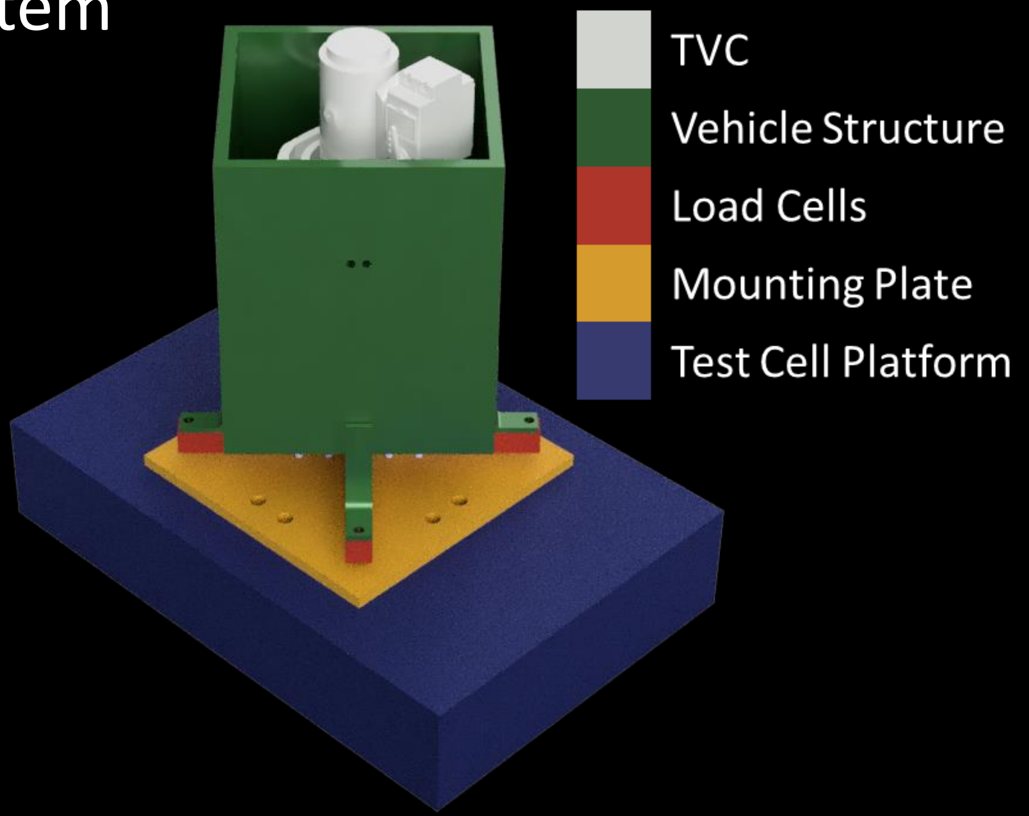
Maverick Thigpen & Matthew Robinaugh

Vehicle Structure Critical Requirements

SSLR ID	Requirement	Performence Metrics	SLR Uplink	Verification Method	Pass/Fail Status
1.1	The vehicle shall not deform more than 1 mm under a static load of 60 N.	Deformation	SLR_1.1	Demonstration	Pass

Structure Overview

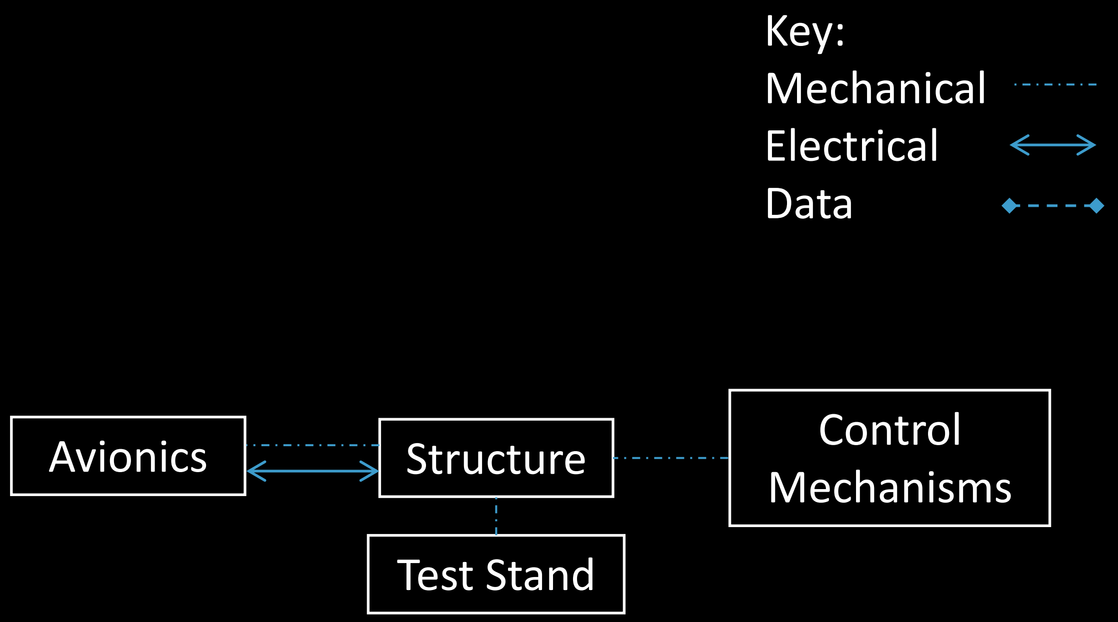
- Green represents the structure subsystem
- Structure is made from aluminum
  - Cheap to acquire
  - Easy to work with
- Square tube chosen
  - Easiest to manufacture
  - Provides base for TVC



Color Coded System Model

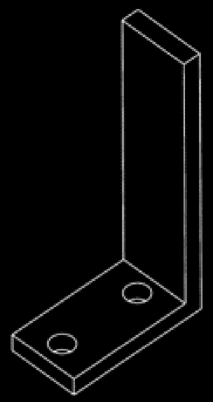
Design Metrics

- Deformation
  - Strong structure material
- Cost Effective
  - Limited budget
  - House relevant subsystems
  - Eliminate expensive materials
- Time Efficient
  - 3-month deadline
  - Simple to manufacture



Structures Analysis

- Main takeaway:
  - Deflection of the aluminum mounting bracket will be in the micrometer range under the current assumptions



Mounting Brackets Design

$$E = Modulus\ of\ Elasticity$$
$$\sigma_{max} = Maximum\ Stress$$
$$F = Force$$
$$F.S. = Factor\ of\ Safety$$
$$A = Cross\ Sectional\ Area$$
$$\Delta L = Change\ in\ Length$$
$$L = Length$$

Mounting Bracket Deflection Calculation

$$E = 69GPa$$

$$\sigma_{max} = \frac{F * F.S.}{A} = \frac{40N * 1.5}{3mm * 12.7mm} = 1.57\frac{N}{mm}$$

$$\Delta L = \frac{\sigma_{max} * L}{E} = \frac{1.57\frac{N}{mm} * 0.05mm}{69000\frac{N}{mm}} = 1.1 * 10^{-6}mm$$

Testing

- Static Load Test
  - System loaded with weight
  - Deformation recorded
- Inspection
  - Top-down view
  - All parts fit

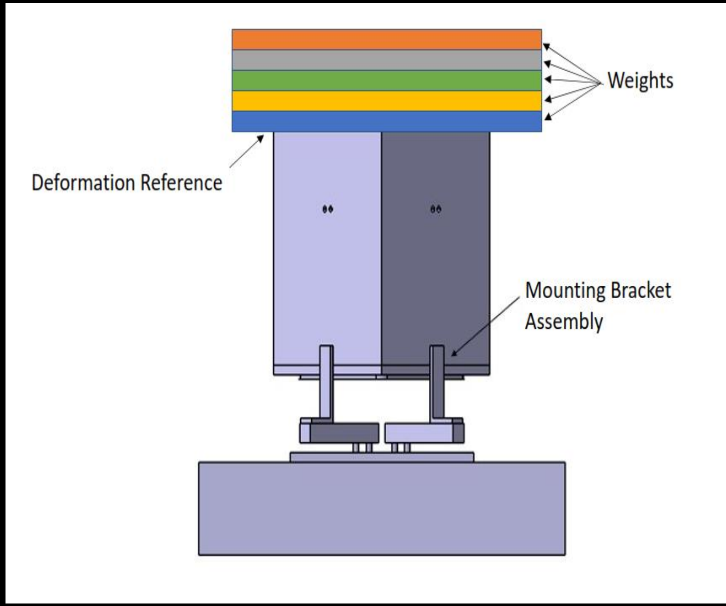
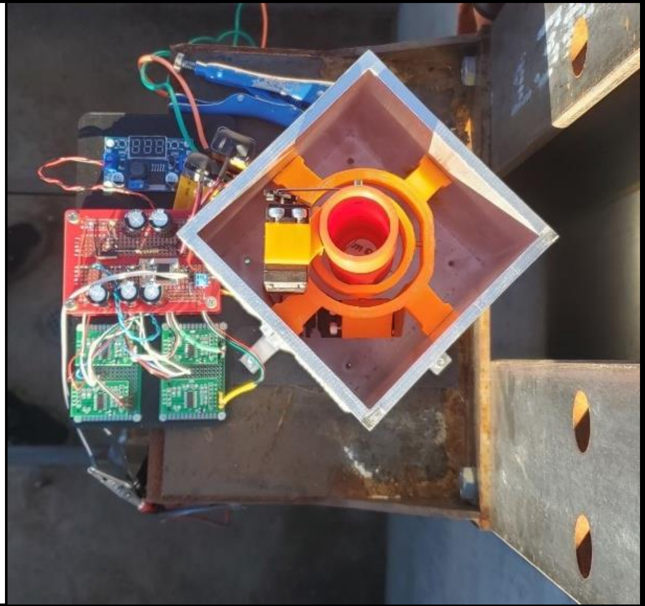


Illustration of static load test



Top-Down View of Full System

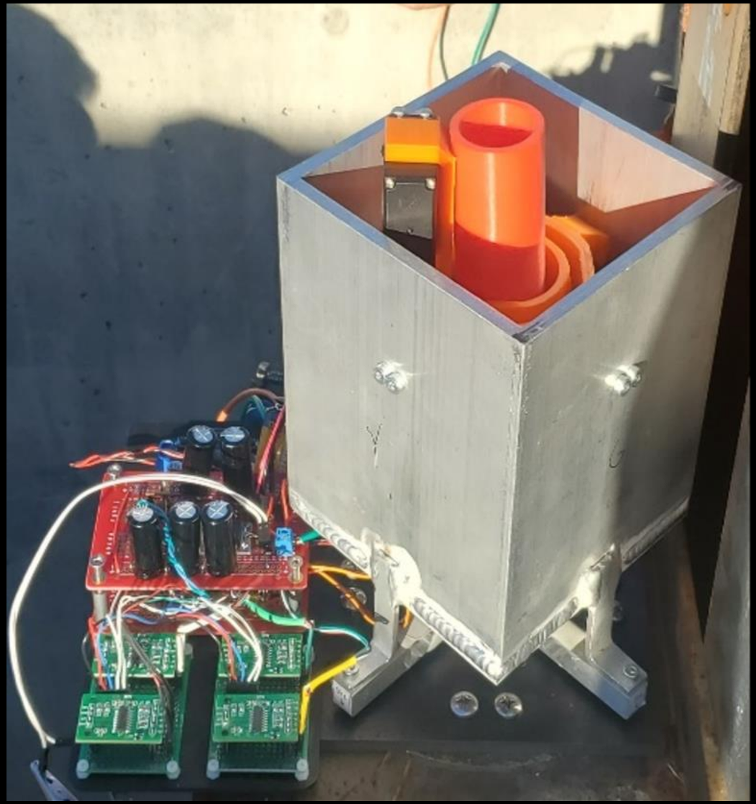
Analytical and Experimental Comparison

- All experiments fell within expected range
  - Deformation was immeasurable after operational demonstration.
  - Relevant subsystems remained in place throughout demonstration.

	Expected Value	Expected Tolerance	Actual Value
Bracket Deformation	1.1 nm	±1 mm	< 1 mm

Future Improvements of the Vehicle Structure

- Manufacturing is not perfect
  - Mounting bracket required post-work
- Avionics did not fit
  - Not enough space between load cells
- Load cells have excessive stress
  - Mounting brackets are positioned poorly
- Budget management
  - Better load cells could've been used after descoping



Full system assembly

Test Stand

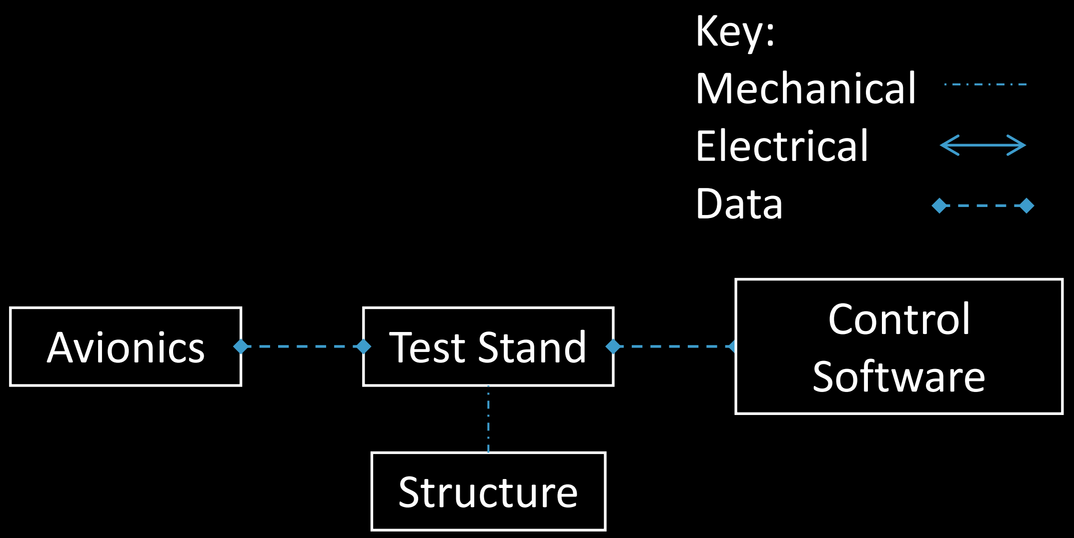
Brian Wahlstrom

Test Stand Critical Requirements

SSLR ID	Requirement	Design Metric	SLR Uplink	Verification Method	Pass/Fail Status
5.1	The test stand shall measure thrust.	Thrust Measurement	SLR_1.4 SLR_1.5	Test	Pass
5.2	The test stand shall send data to the avionics.	Communication Protocol	SLR_1.4 SLR_1.5	Test	Pass
5.3	The vehicle shall be oriented orthogonal to the xy-plane within ±5 degrees at the start of testing.	Vehicle Orientation	SLR_1.6	Demonstration	Pass

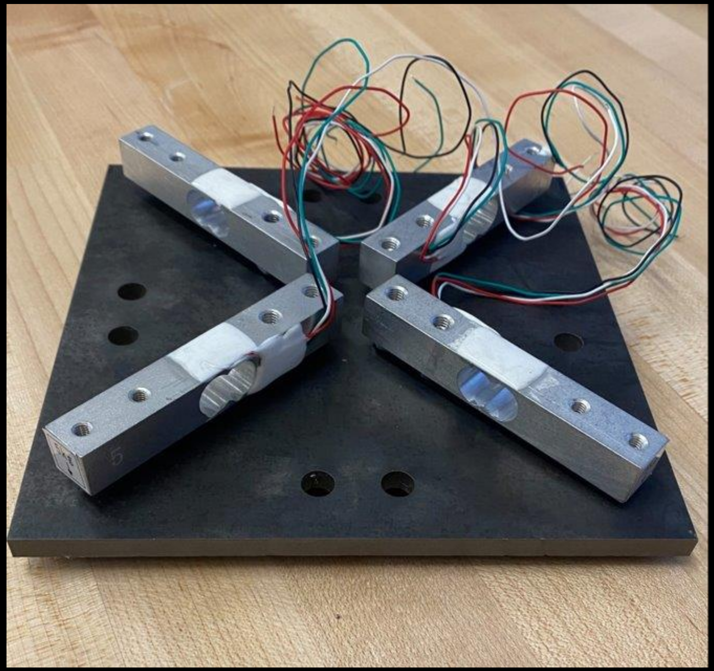
Design Metrics

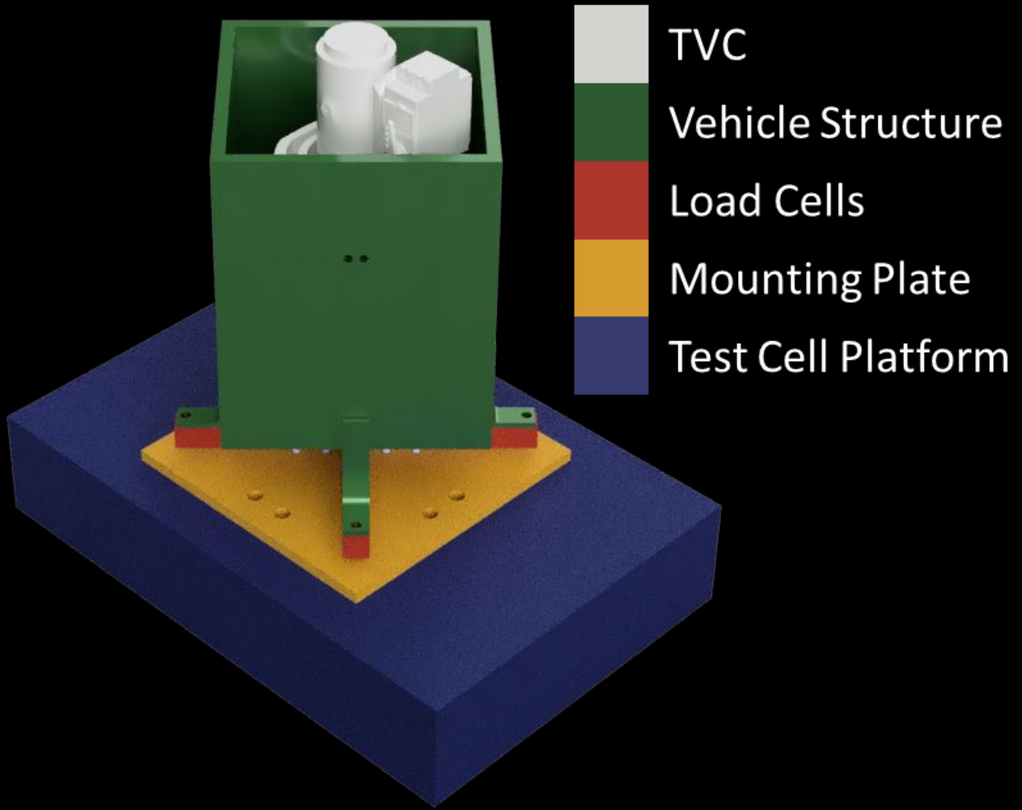
- Capable of measuring thrust
- Support the vehicle
  - Needs to be able to support the vehicle during operation.
- Cost Effective
  - Used steel due to low cost



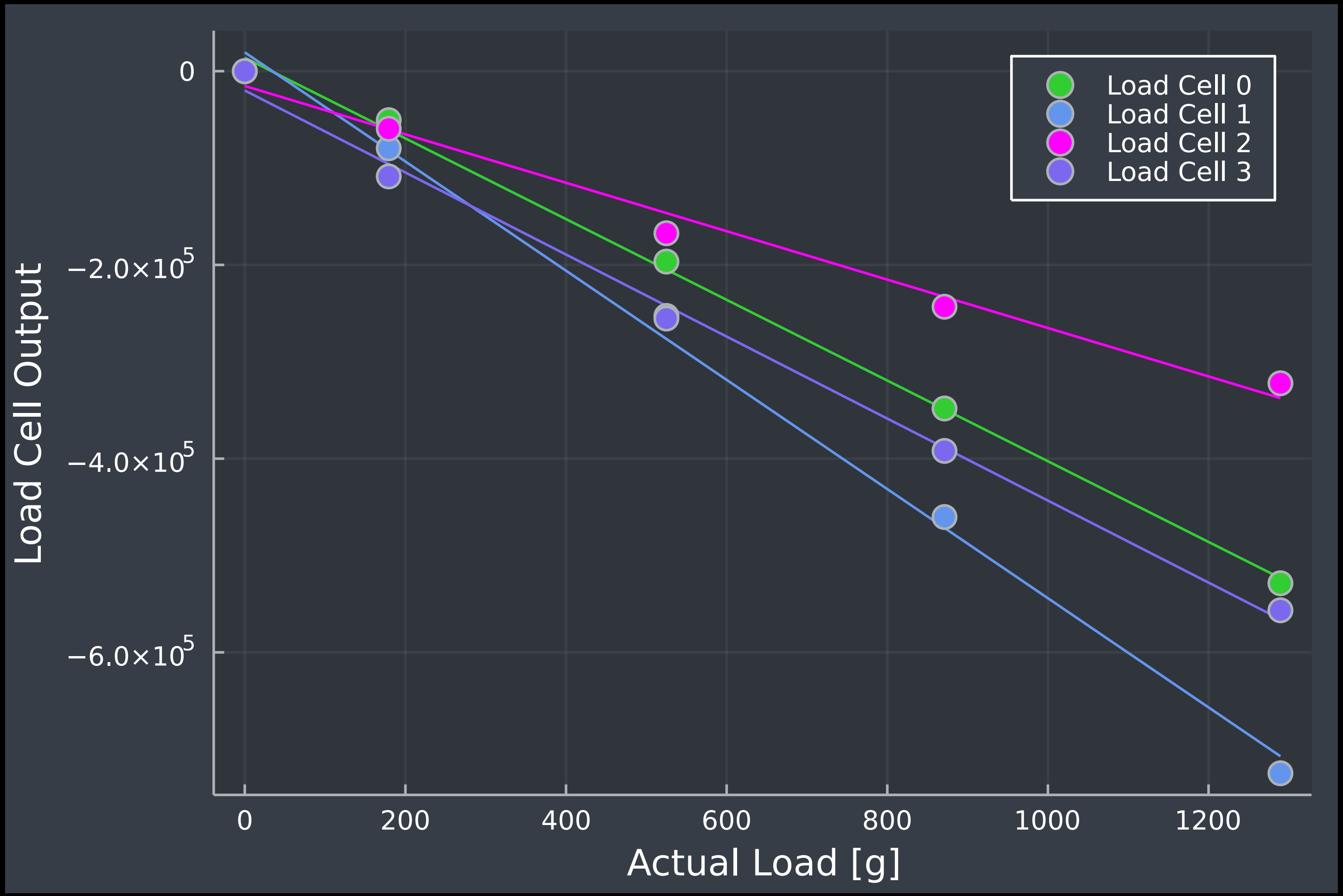
Test Stand Overview

- The Test Stand subsystem is represented by yellow and red.
- The mounting plate (yellow) was manufactured from steel.
    - Readily available
    - Easy to water jet
- The load cells (red) are aluminum 5 kg load cells.

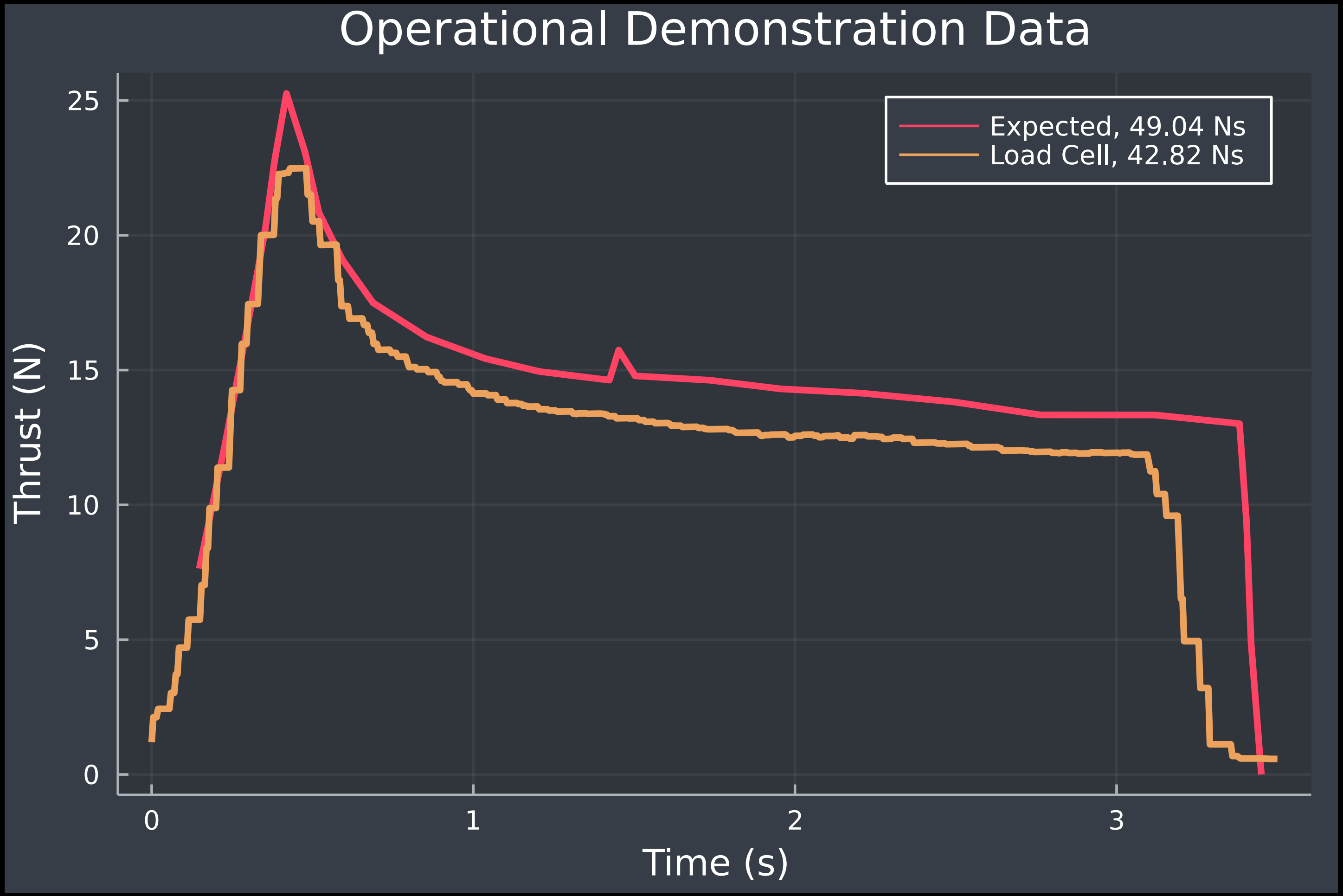




Design Metrics and Analysis

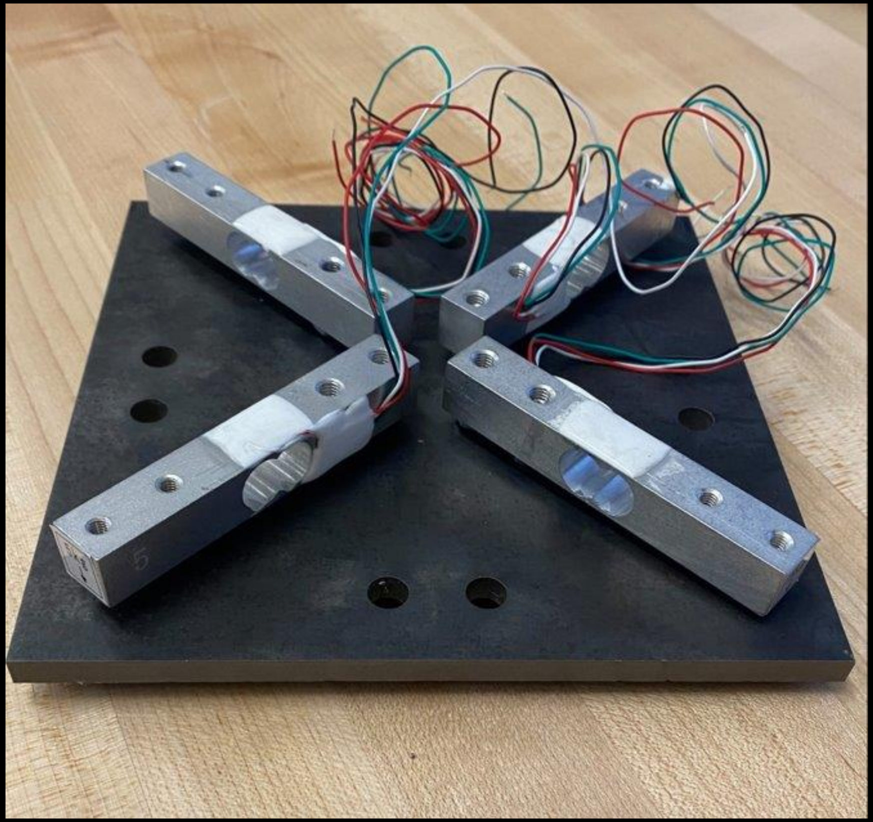


Design Metrics and Analysis



Future Improvements of the Test Stand

- Budget allocation from former avionics suite to load cells after descoping from a full flight demonstration.
- Higher quality load cells.
- Improve mounting to load cells.



Avionics

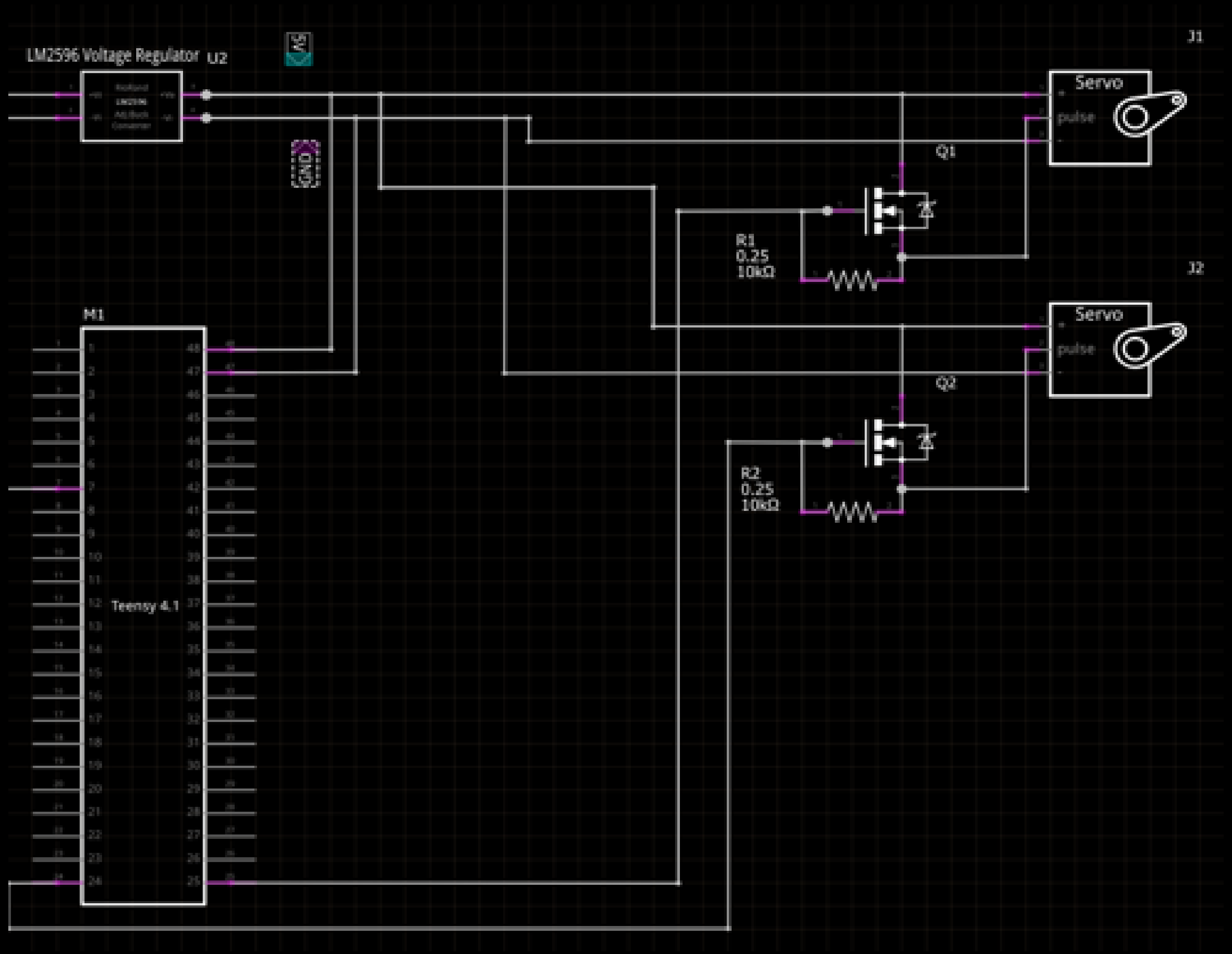
Joshua Ku

Avionics Critical Requirements

SSLR ID	Requirement	Performance Metric	SLR Uplink	Verification Procedure	Pass/Fail Status
2.1	The avionics shall receive thrust data from the test stand.	Test Stand Integration	SLR_1.2 SLR_1.4	Static Load Test	Pass
2.2	The avionics shall output commands to the control mechanisms.	Control Mechanisms Integration	SLR_1.2	Avionics Integration Test	Pass
2.3	The microcontroller shall run the control software.	Control Software Integration	SLR_1.2 SLR_1.4 SLR_1.5	Avionics Integration Test TVC Test	Pass

Avionics Design Overview

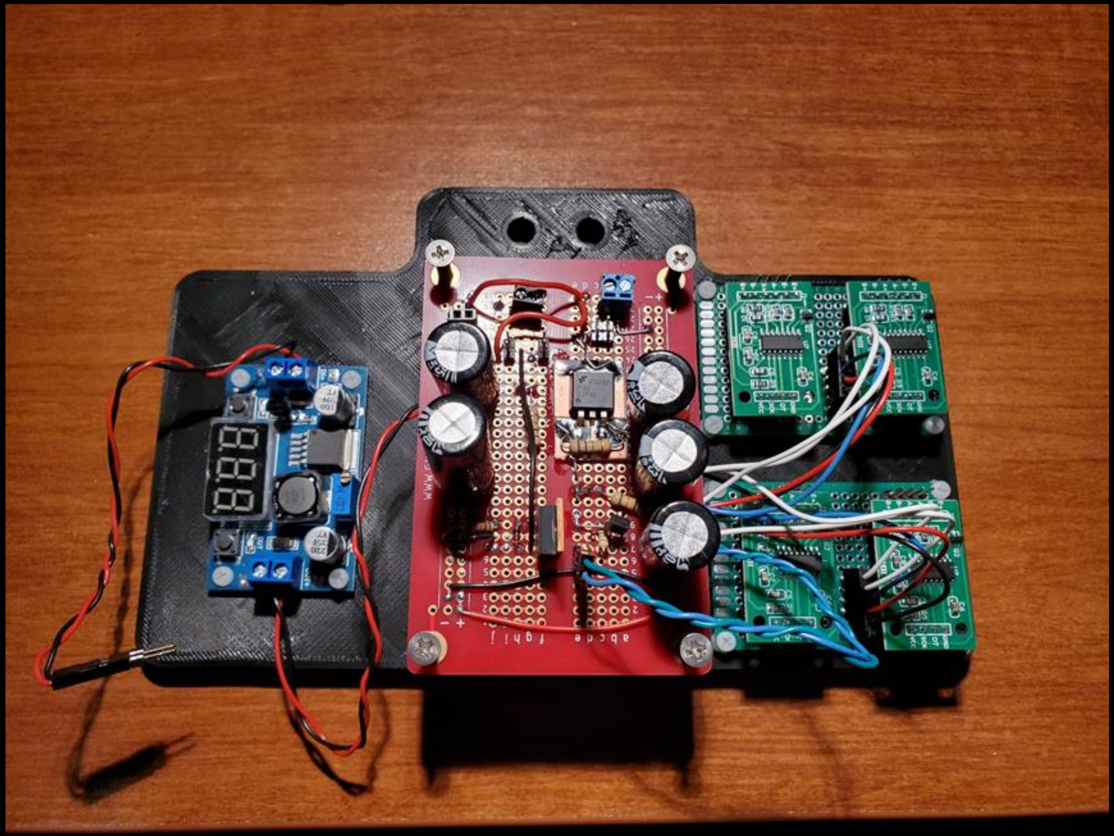
- Power Subsystem
  - Uses 2x 9V batteries controlled by a remote switch to provide power to overall system
- Control Mechanisms Interface
  - Controls 2x TVC servos via PWM signals from microcontroller



Avionics Integration Test Block Diagram

Avionics Design Overview

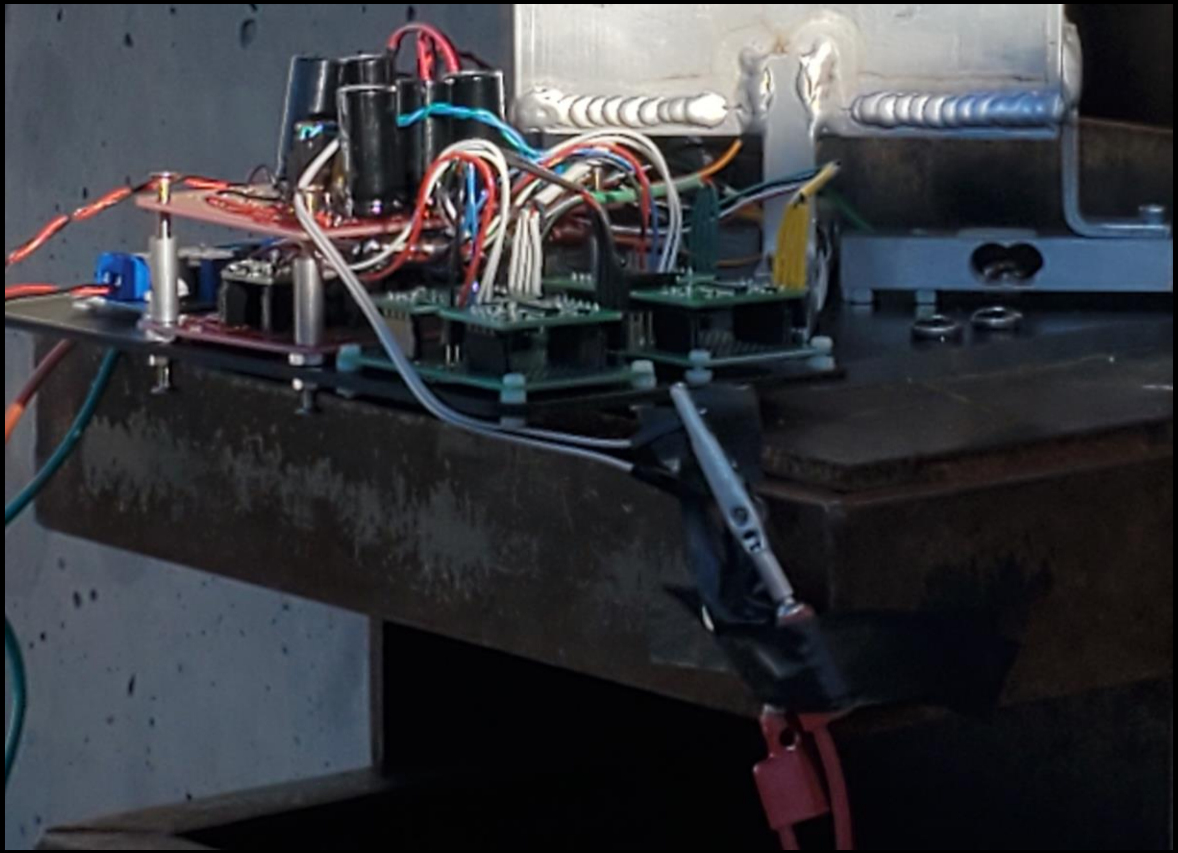
- Ignition Subsystem
  - Fires Estes rocket motor igniter via microcontroller-initiated capacitor bank
- Test Stand Interface
  - Allows microcontroller to read data from 4x load cells



Avionics Tray

Future Improvements of Avionics Subsystem

- Translate design from prototyping boards to custom PCB
- Upgrade remote switch to control box/board



Operational Demonstration Avionics Configuration

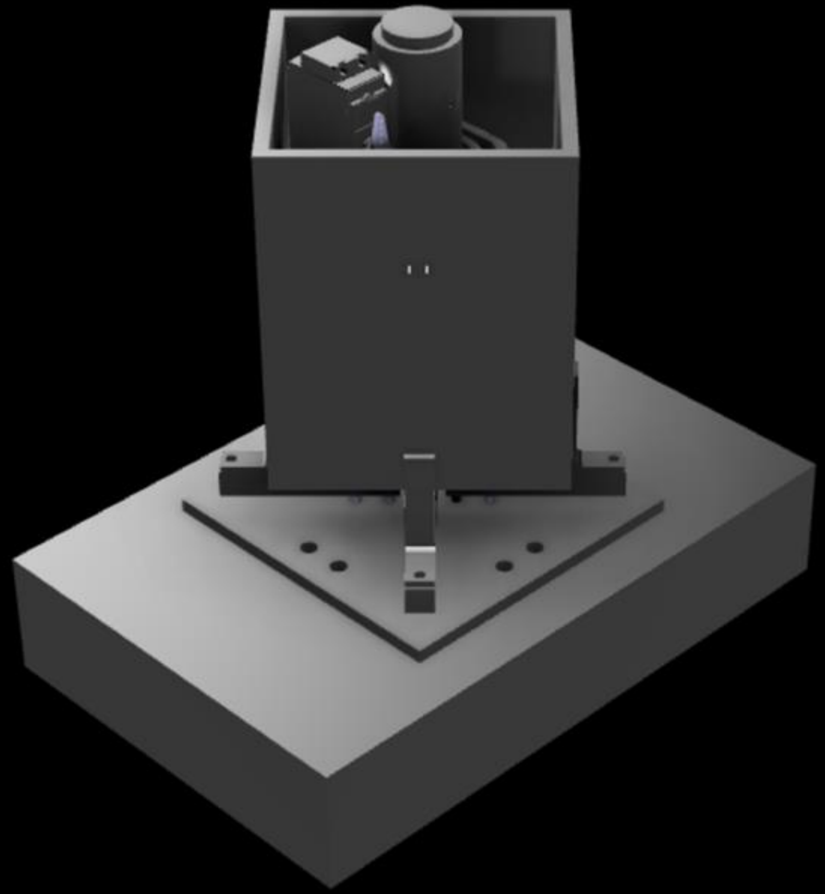
LANDER

Lunar Ascent and Descent Excavation Resource

Conclusion

Summary of Design Status

- Design did not satisfy objective, most requirements satisfied
- Design could be continued by new design team
  - Next steps are to design a vehicle for a real flight test



Summary of Design Status

Test Name	Test Pass/Fail Status	Requirement Description	Requirement Pass/Fail Status
Operational Demonstration	Fail	Attitude Control	Fail
		Maximum Velocity	Fail
		Data Storage	Pass
		Data Processing	Fail
		Vehicle Orientation	Pass
		Equipment Containment	Pass
Static Load Test	Pass	System Yielding	Pass
		Bracket Deformation	Pass
		Test Stand Integration	Pass
		Thrust Measurement	Pass
		Avionics Communication	Pass
Avionics Integration Test	Pass	Control Mech Integration	Pass
		Software Integration	Pass
		Program Size	Pass
		Software Processing	Pass
		Software Outputs	Pass
		Response Time	Pass
		Input Rate	Pass
		Servo Commands	Pass
TVC Test	Fail	Control Mech Integration	Pass
		Control Software Integration	Pass
		Software Inputs	Pass
		Deflection Accuracy	Fail
		Servo Commands	Pass

Lessons Learned

- Start early with integration testing
- Re-evaluate hardware needs as project scope changes
- Fabricate critical components early to allow for rework if necessary

Video of Operational Demonstration

Acknowledgements

Dr. Martin
Dr. Wood
Dr. Twal
Dr. Bryner
Daniel Flynn
Machinists at ERAU

Questions?