Pulse Density Modulation (PDM) of Propulsion System

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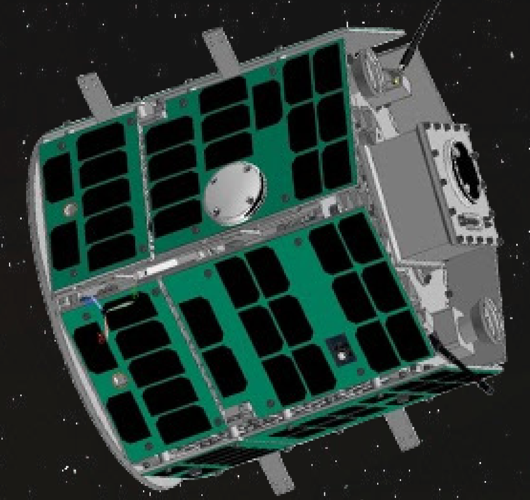

INTRODUCTION

- Space advancement is becoming increasingly important as the space industry races to commericialize space travel and research distant planets.
- Characterizing and calculating thrust produced from low-thrust space vehicles is a challenge. Small satellites require modular testing and new approaches to calculating thrust.
- Pulse Density Modulation (PDM) is a technique often used to convert a complex multi-bit signal into a simpler binary signal. PDM testing of cold gas propulsion systems may be a potential solution to characterizing and calculating thrust in millinewton space applications.

OBJECTIVES

- Calculate the thrust produced by the Missouri Rolla Satellite and Missouri Rolla Second Satellite (MR & MRS satellite) using PDM.
- Demonstrate the viablility of the ballistic pendulem approach and PDM to precisely calculate thrust produced from a propulsion system.
- Using the calculated thrust, provide values to help control the thrust, propellant consumption, and duration of burns by adjusting the duration and frequency of pulses.

PENDULUM THEORY APPROACH

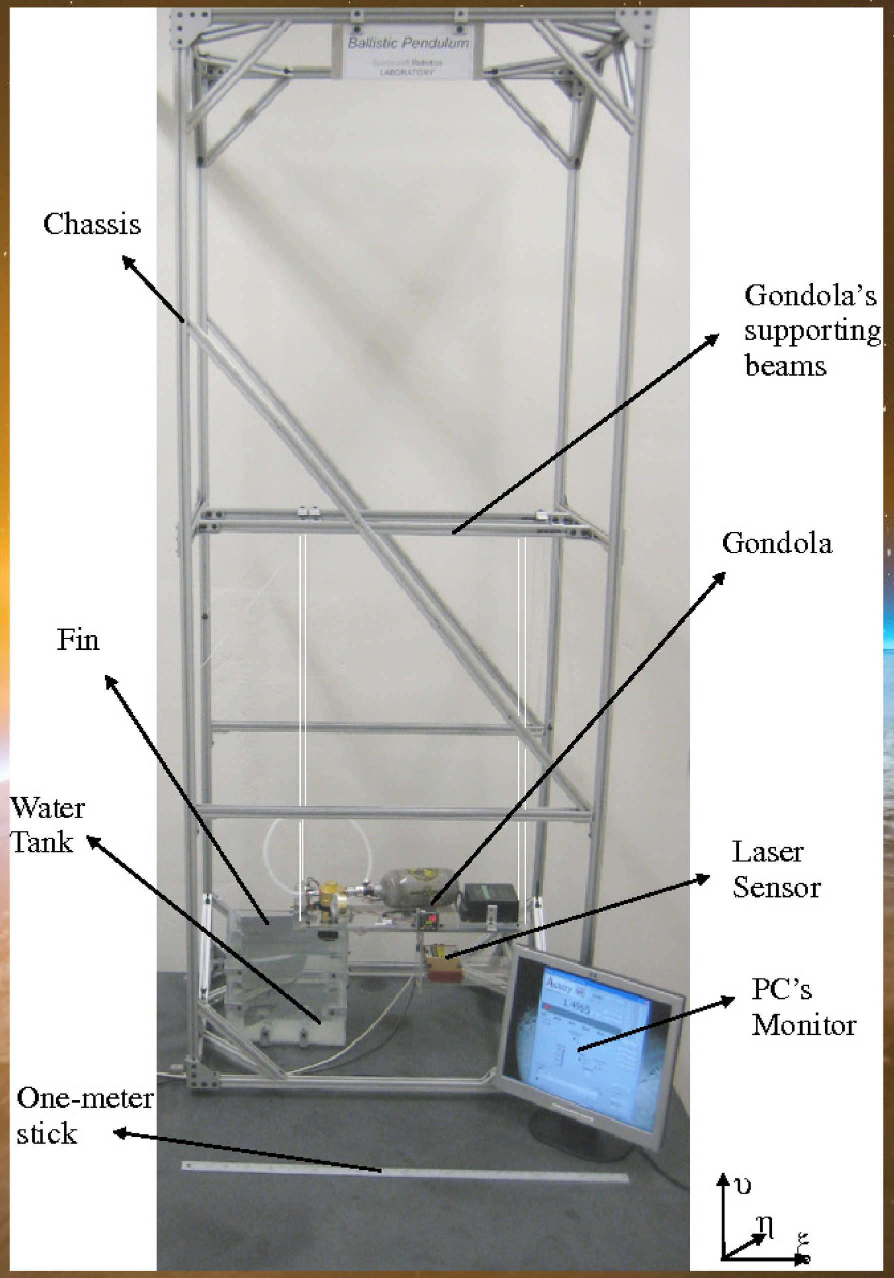

Figure 1 - C. &. R. M. Lugini Ballistic-Pendulum Test Stand

- The model in Figure 1 served as the model for MR & MRS ballistic pendulum apparatus in Figure 2.
- The ballistic pendulum test theory attempts to measure the displacement of a simple pendulum and convert recorded measurements to thrust calculations.

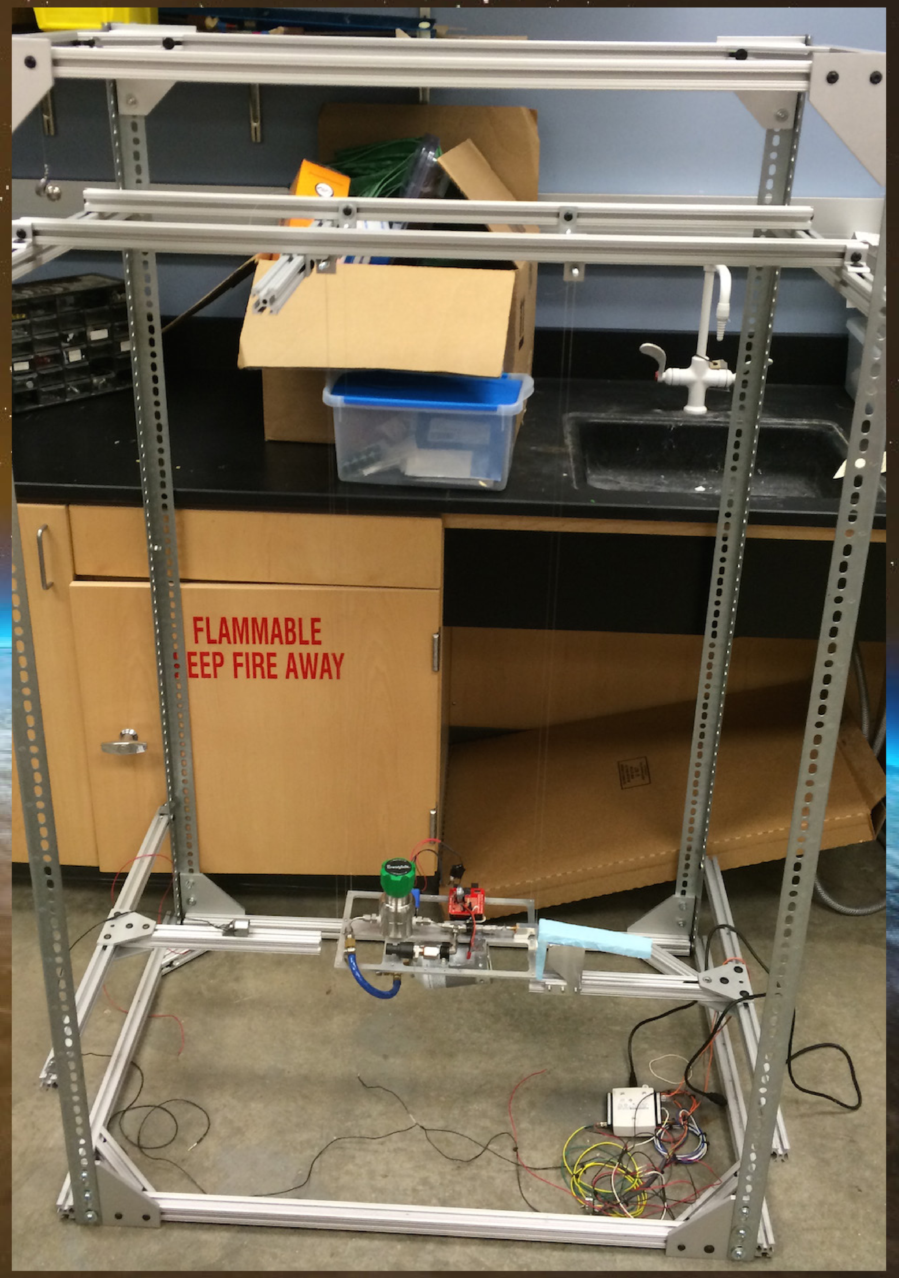

Figure 2 - Ballistic Pendulum Thrust Test Stand (PDM apparatus)

- MR & MRS PDM apparatus consists of a free-dampening pendulum system which contains a canister of propellent R-134a, the thruster board housing the solenoid, the battery, the Arduino, and the relay switch (Figure 3).

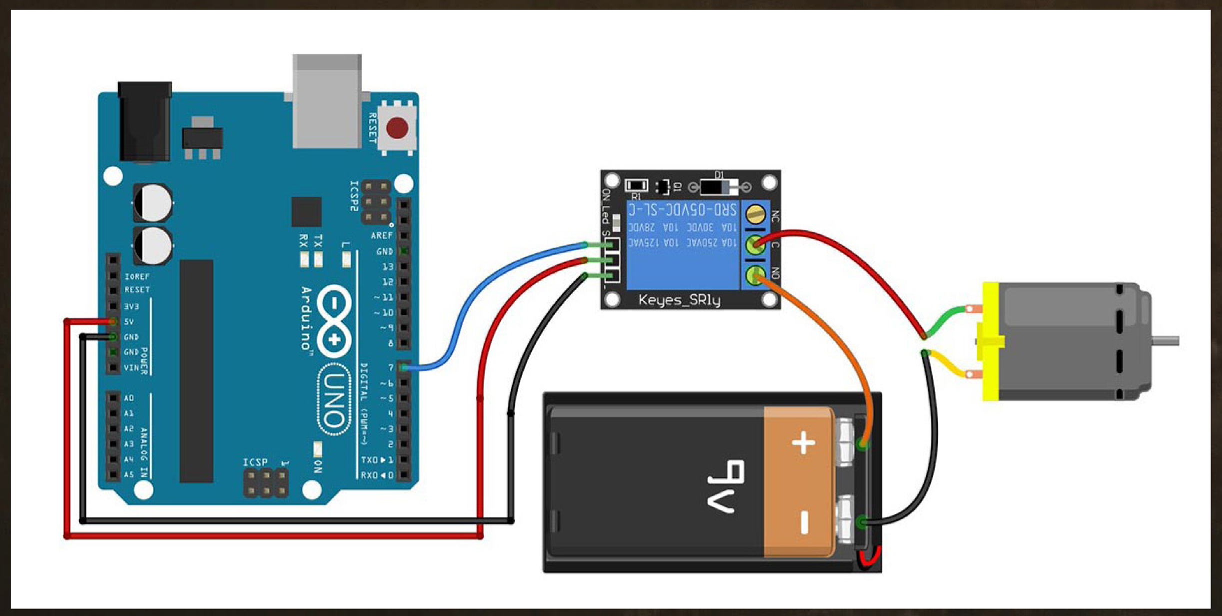

Figure 3 - Battery, Arduino Board, Relay Switch, and Solenoid Configuration

- The thruster board is controlled by a programmed Arduino that activates the relay switch. The relay switch regulates the battery voltage supply to fully power the solenoid and related components. The Arduino also controls the duration and frequency of pulses.

ANALYSIS

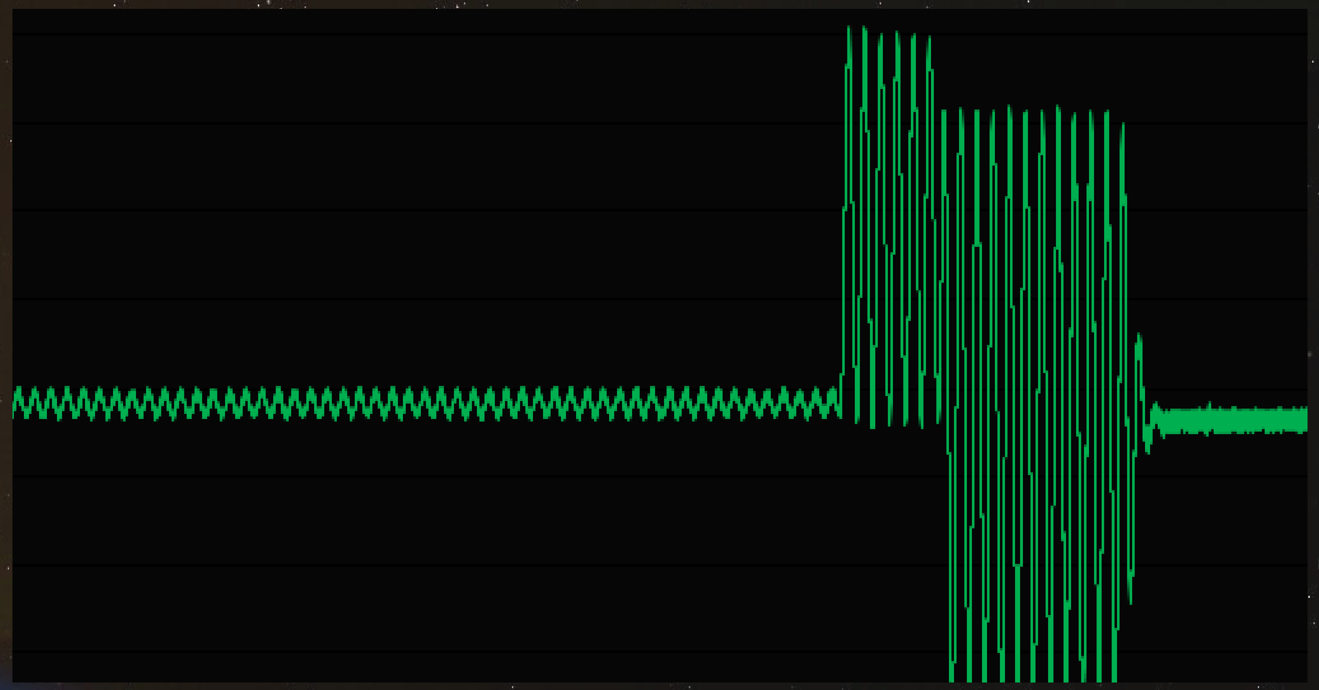

Figure 4 - PDM Displacement Data for 100% Thrust

- The PDM test was conducted in atmospheric and vacuum conditions in multiple trials. Displacement of the PDM thruster board was measured using LabView and a highly sensitive laser. A view of the displacement data can be seen in Figure 4.
- To calculate thrust, a Newtonian equation of motion was derived with the assumption that the thruster board was a point mass on the frame, the pendulum string was rigid and weightless, and the mass flow rate was negligible.

$$F_{produced} = \gamma m g \left(\frac{deq - do}{L} \right)$$

Figure 5 - Derived Newtonian Equation of Motion for a Pendulum

CONCLUSIONS

- Through the calculated mean value of the displacement data, the thrust produced was 18.42 millinewtons at 100% thrust.
- The pendulum theory approach provided a precise method to calculate thrust produced from a small-scale propulsion system.