Automatic Balancing of an Air-Bearing Three-Axis Small Satellite Test Platform

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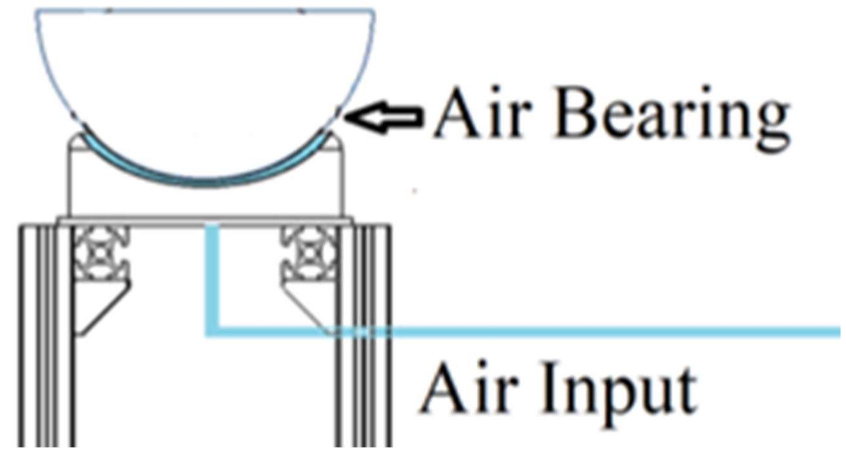
OCTOBER 30TH, 2019

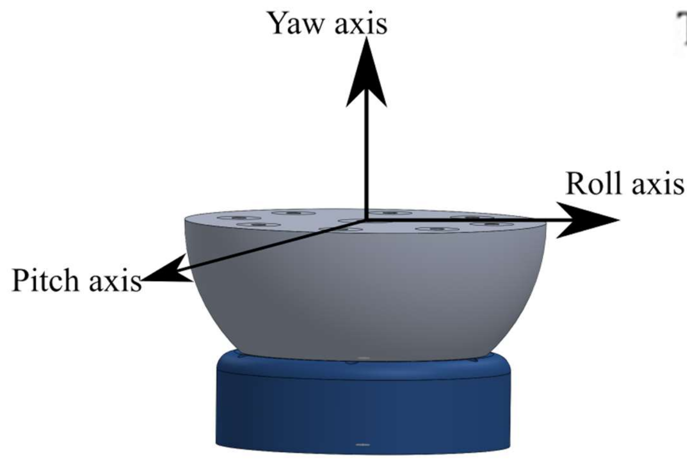
Overview

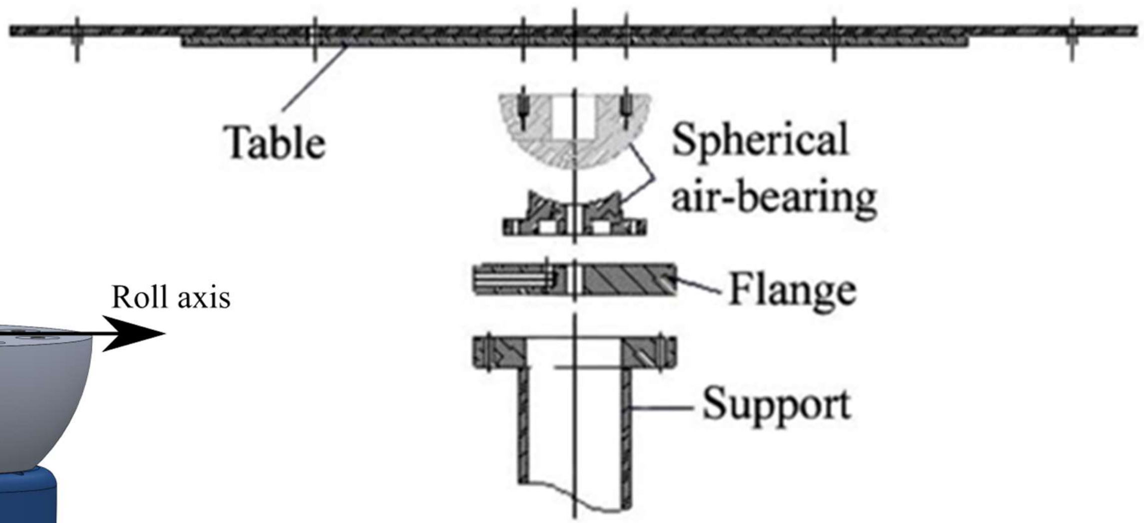
- Background
- Project Goals
- Literature Review
- Trades
- Design
- Next Steps
- California

Testing ADCS Components

- Small torque devices: reaction wheels, magnetorquers, micro-thrusters
  - Need a frictionless environment to test
- Air tables are commonly used
  - Provides a nearly frictionless platform with rotational freedom using an air bearing
  - Able to test in vacuum to further remove effects of the atmosphere



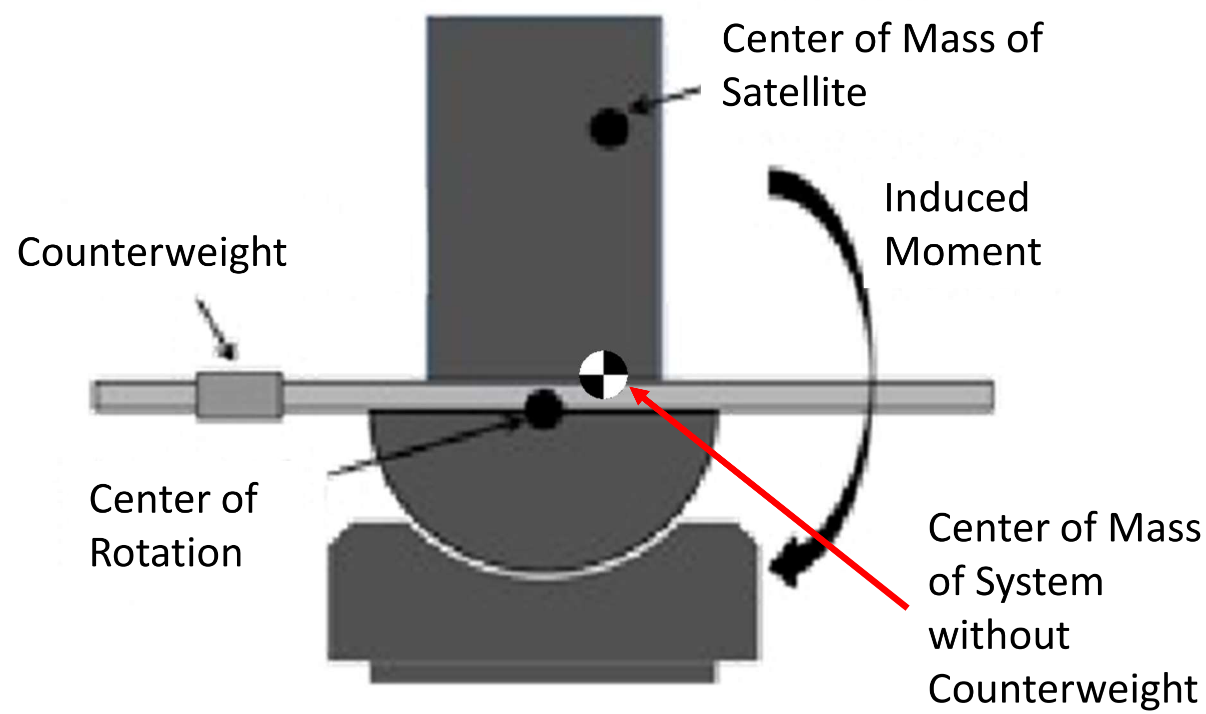




Top: M. Hernandez Herrera, Kyushu Institute of Technology
Bottom left: H. Hisatsugu, Kyushu Institute of Technology
Bottom right: J. Prado et al., National Autonomous University of Mexico

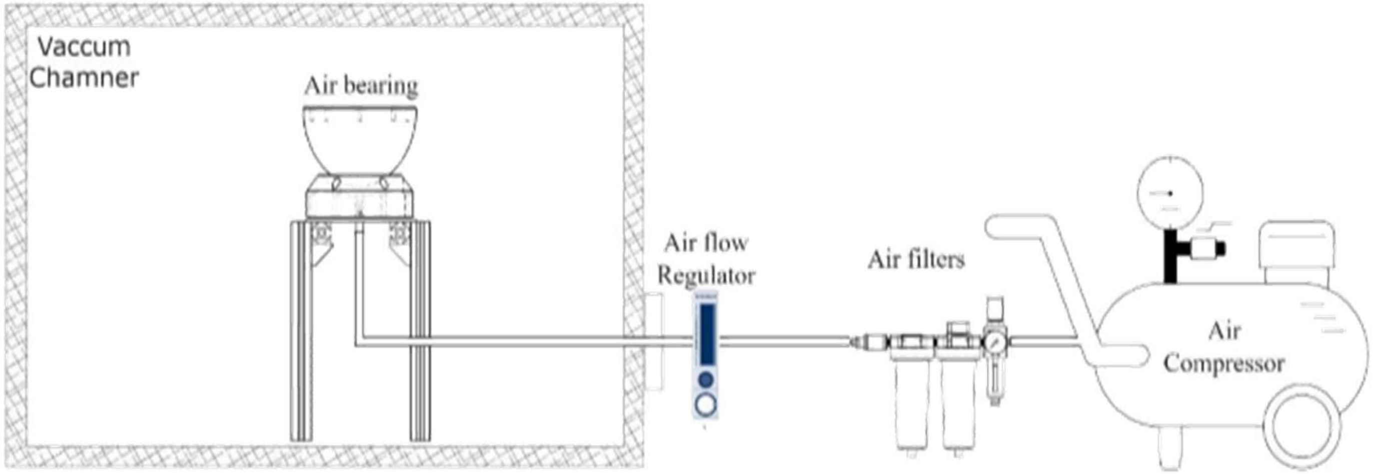
The Balance Problem

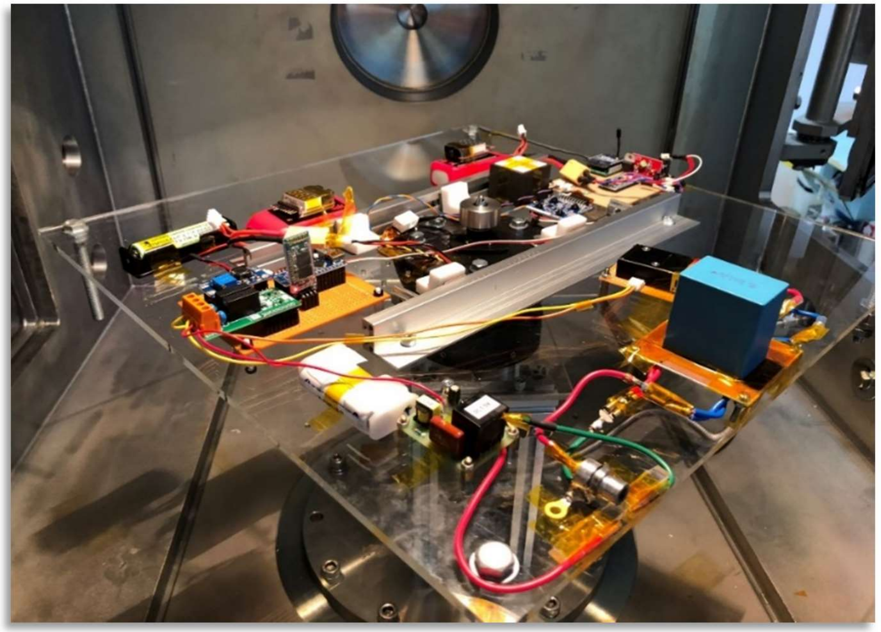
- Imbalance exists when the Center of Mass of the system is not aligned with the Center of Rotation
  - Gravity torque causes a pendulum motion of the system, which takes time to settle
- In order to remove the gravity torque, the Center of Mass of the system needs to be at the Center of Rotation
  - Done by having adjustable counterweights to move the Center of Mass
  - More difficult when there is geometric complexity
    - Sensors, wires, actuators, etc.
  - Have to determine the Center of Mass



Kyutech's Air Table

- Developed and verified by Marcos Hernandez Herrera in 2018
- Features:
  - Free rotation in yaw and ±45° in pitch and roll
  - Can be used in and outside of the vacuum chamber
  - Can support up to ~68 kg
- Uses:
  - Testing magnetorquers, reaction wheels, and thrusters in the same vacuum environment
- Currently manually balanced in the yaw axis using nuts and threaded bolts, and roll and pitch by adding nuts to the tabletop
  - ***Problem: time consuming, requires user experience, takes time to settle before testing (up to a day)***



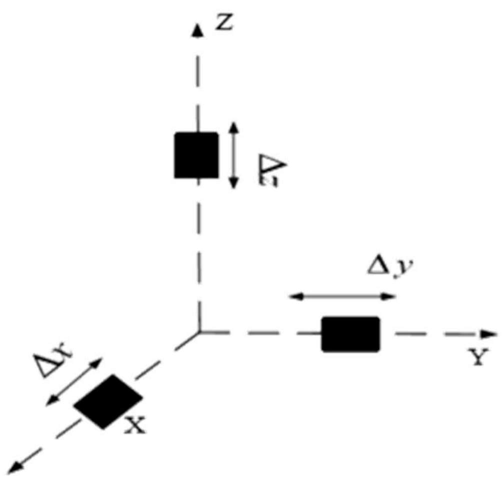


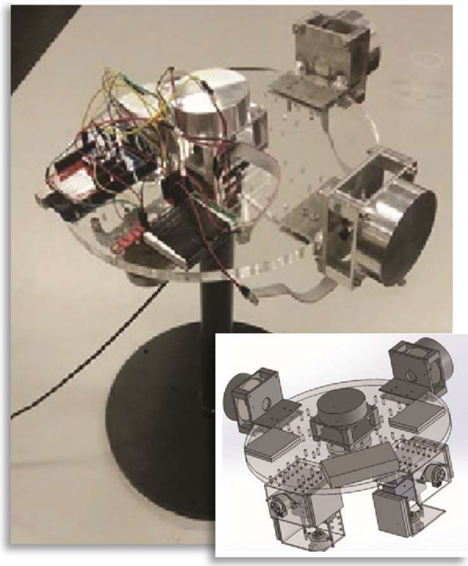
Top: M. Hernandez Herrera, Kyushu Institute of Technology
Bottom: H. Hisatsugu, Kyushu Institute of Technology

Project Goals

- Design an automatic balancing system
  - Reduced inertia to decrease the amount of mass needed to balance
  - Be able to fit inside vacuum chamber/Helmholtz cage
  - Be balanceable with or without a CubeSat
- Deliver:
  - Block diagram
  - Sensor and actuator choices to purchase
  - CAD model
  - If time, a control algorithm for the balancing procedure

Literature Review



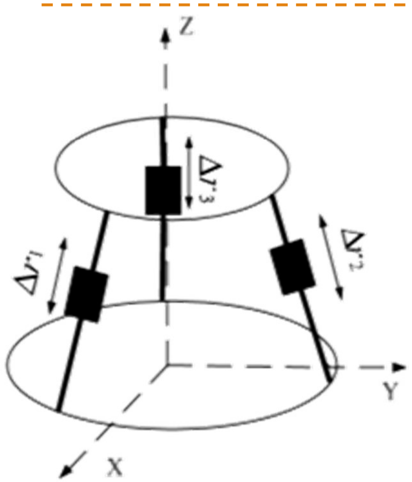


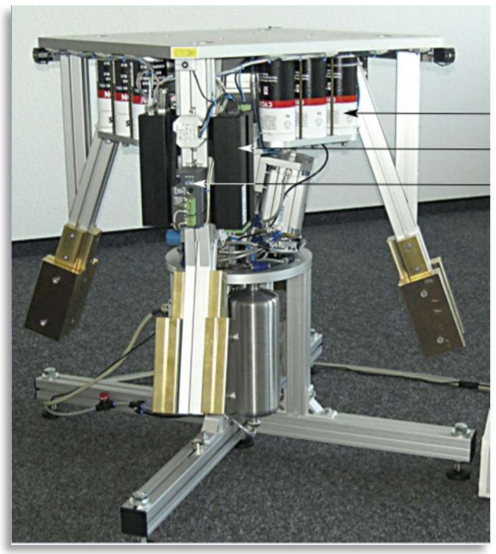
University of Sydney

- Currently manually adjusted by sliding a mass with a screw, one in pitch and roll axes
- Automatic system developed with 4 moving masses
- Used CAD model to determine CM and size masses/sliders

National Autonomous University of Mexico

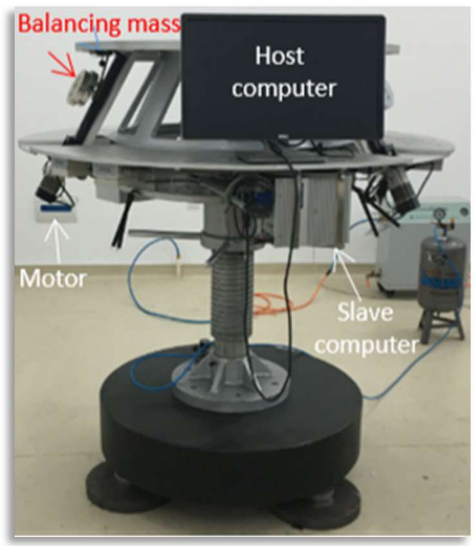
- 3 moving masses; 2 using high resolution stepper motors
- Manual yaw axis balancing
- Use inclinometers for autobalancing for pitch and roll
- Command torque profile, use an IMU to determine system CM and inertia





Astrofein, Germany

- 7 moving masses: 4 non-orthogonal for course adjustment, 3 orthogonal for fine adjustment
- Commercial product
- No information on balancing procedure



Harbin Institute of Technology, China

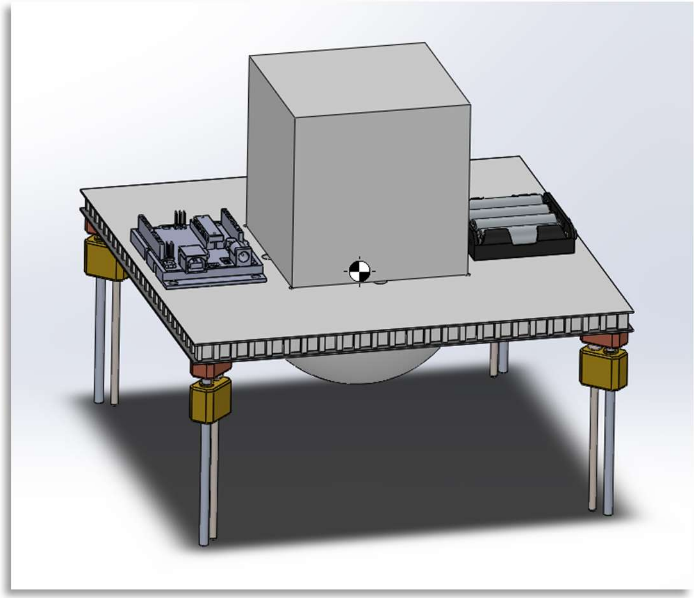
- 3 moving masses
- Inclinometer and gyro are used to estimate CM for automatic balancing

Top left: T. Kwan et al., University of Sydney, Top right: J. Prado et al., National Autonomous University of Mexico
Bottom left: Astro-und Feinwerktechnik Adlershof GmbH, Bottom right: Y. Liu et al. , Harbin Institute of Technology

Vertical vs. Diagonal Sliders Trade

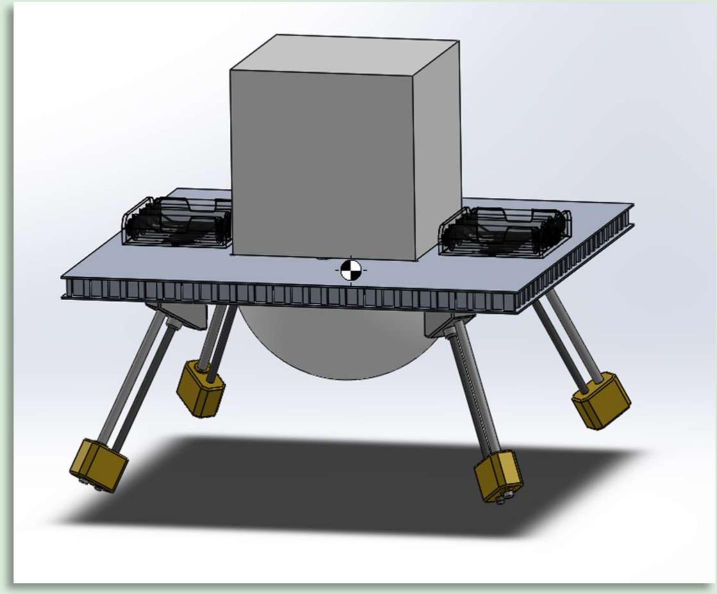
Vertical (Current Table)

- No pitch and roll axis CM control
  - Would still need to manually balance by adding mass on tabletop
  - Impractical, especially in vacuum
- ~7.5 mm control in the yaw axis



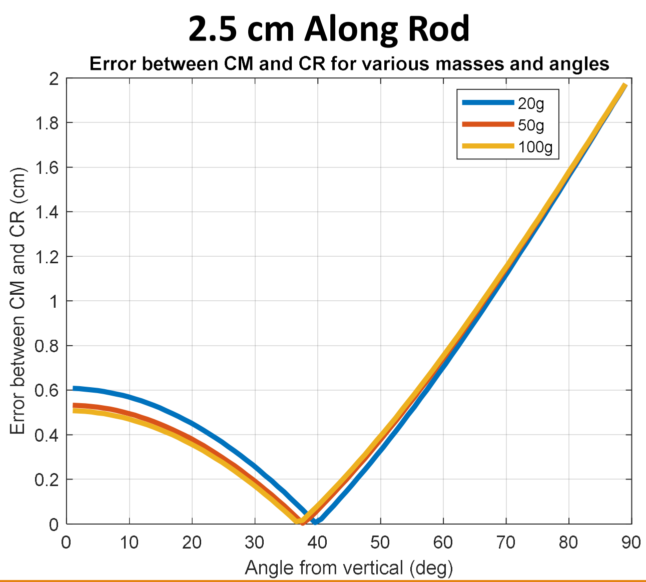
Diagonal

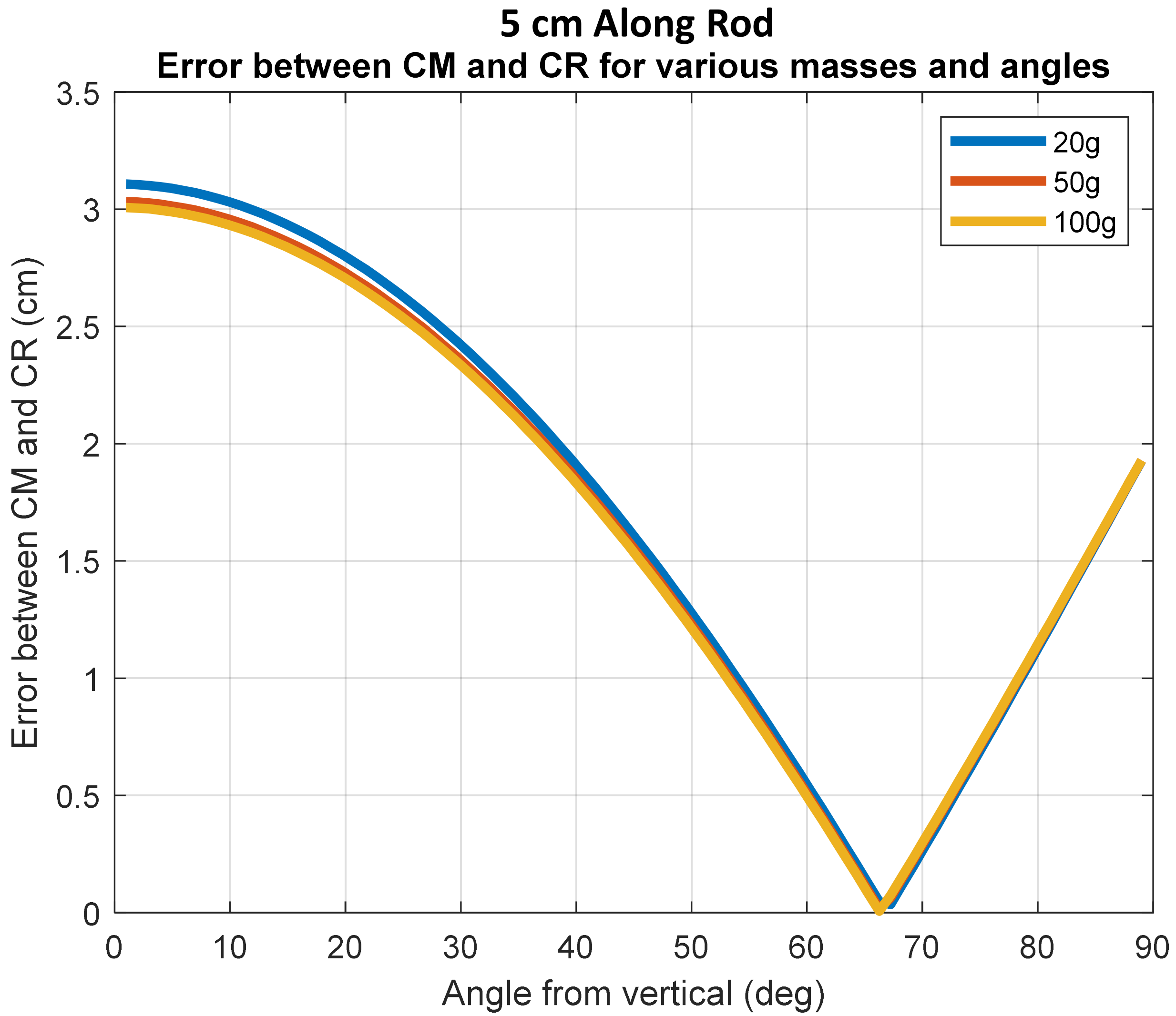
- Requires longer legs to get same yaw effect as vertical but has control over roll and pitch axes
  - ~7 mm control in the yaw axis
- Moving one mass changes CM in all axes



Optimal Diagonal Design

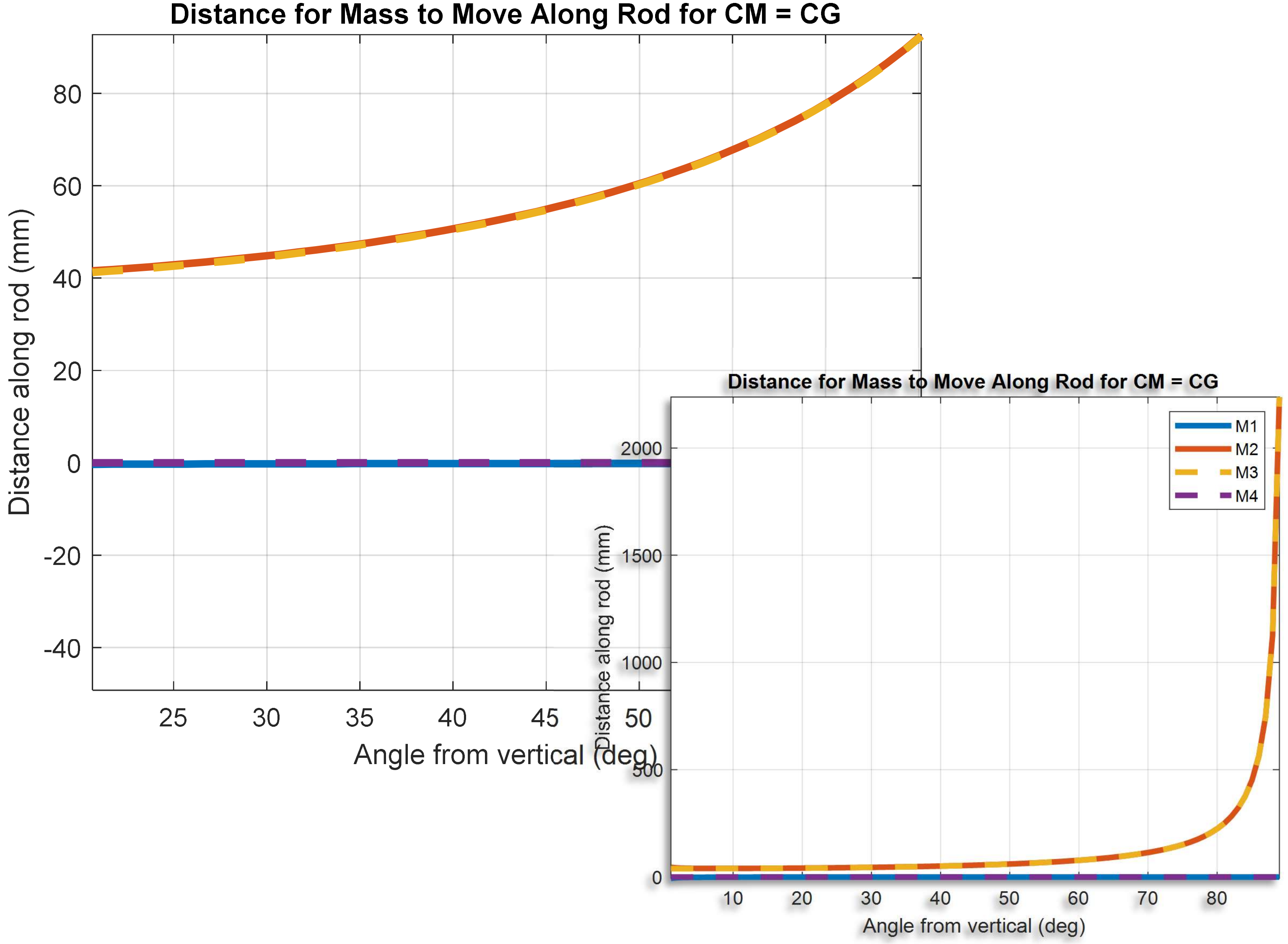
- Using representative CM, compared magnitudes of distance error
  - 0-90deg from vertical
  - 20, 50, 100 kg masses
- Optimal angle is the chosen case is ~67deg but this is Center of Mass specific
- For current design, mass of counterweights does not affect the error





Control Algorithm

- Developed a script that determines how much each weight must move to correct the CR/CM offset
- Accounts for the mass of each counterweight if they vary
- Can help determine lengths of rods needed for chosen configuration
- Could be used for the automatic balancing procedure



Next Steps

- Determine the possible center of mass of other setups that may be put on the table to find the best angle
- Choose actuators and sensors for CM determination and correction
- Order parts
- Test control algorithm

Inclinometer

Threaded Shaft Motor

Right: Walfront
Left: Muratta

A Brief Introduction to My California

Cal Poly and San Luis Obispo

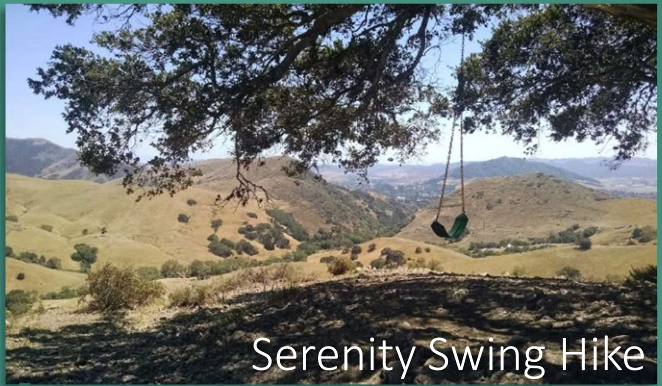
Central Coast

Mojave Desert

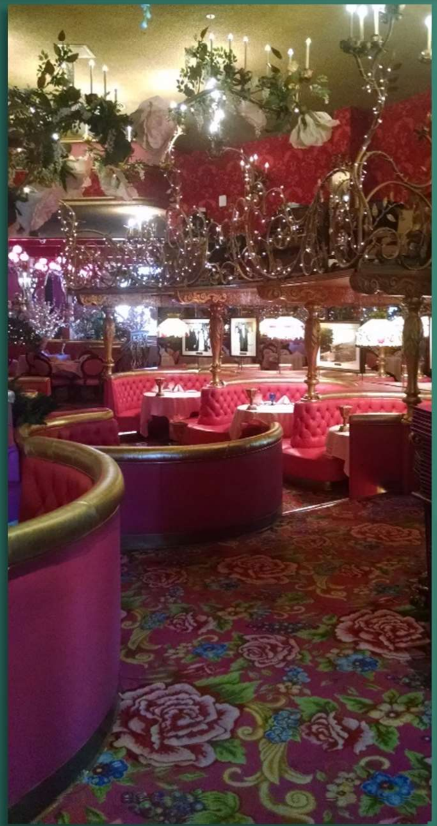
Cal Poly and San Luis Obispo

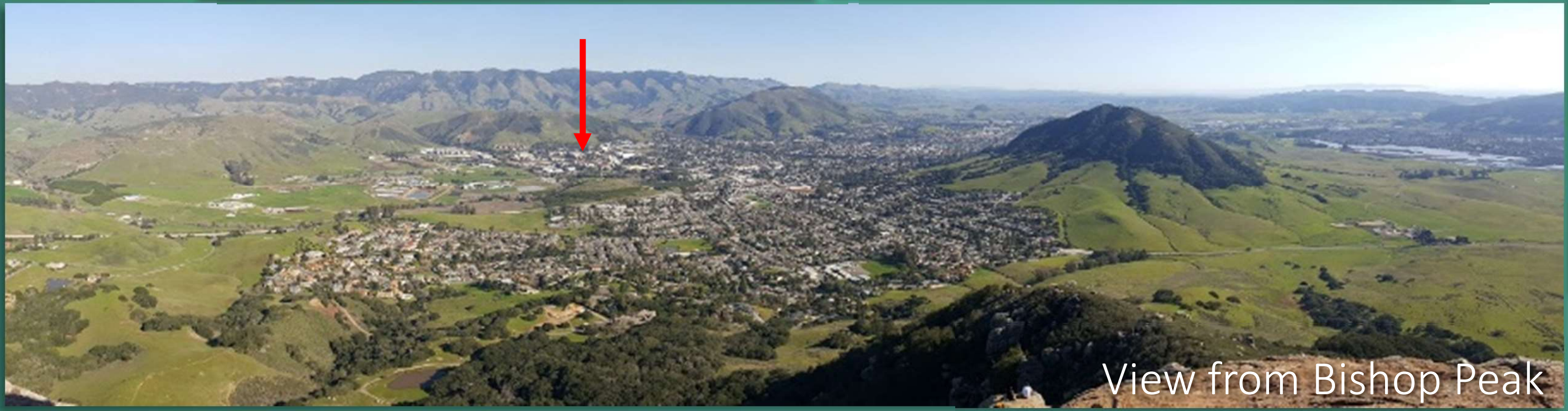

Architecture Graveyard


Arboretum

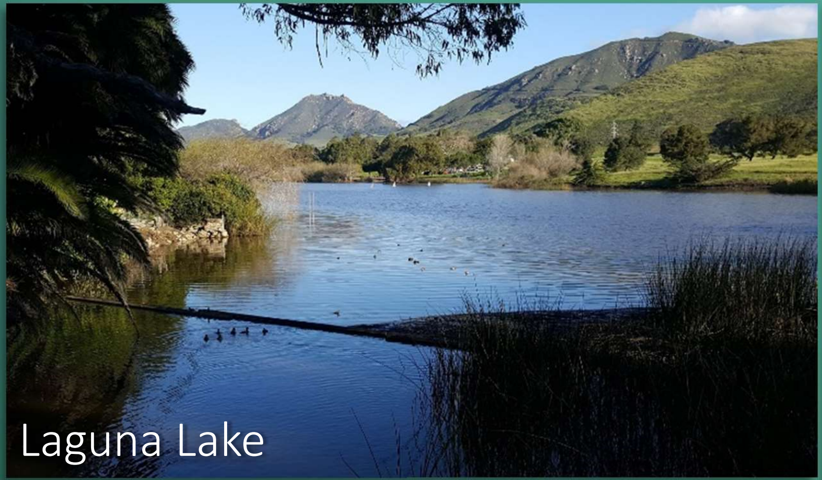

Serenity Swing Hike

College of Engineering


Madonna Inn and Restaurant


View from Bishop Peak

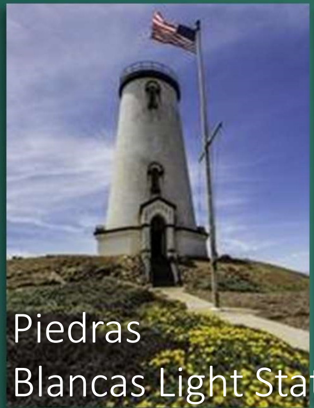
BooBoo Records

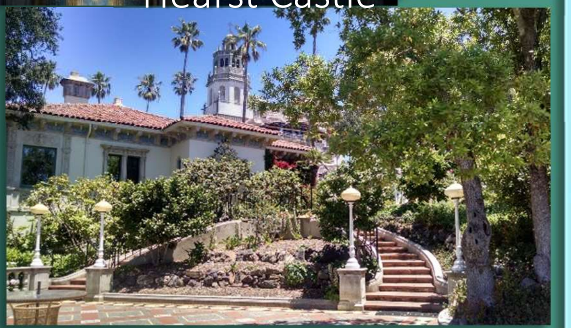

Laguna Lake


Bubblegum Alley

Fremont Theater

Central Coast of California





SLO Donut Company (SloDoCo)

Tacos de Acapulco

In-N-Out Burger

Must Have Foods Around SLO

High Street Deli

Santa Maria Style Tri-tip BBQ at Old SLO BBQ Company


Mojave Air and Space Port


Apple Valley


Elmer's Bottle Tree Ranch


Bonnie
Springs Ranch, NV


Kangaroo Rat

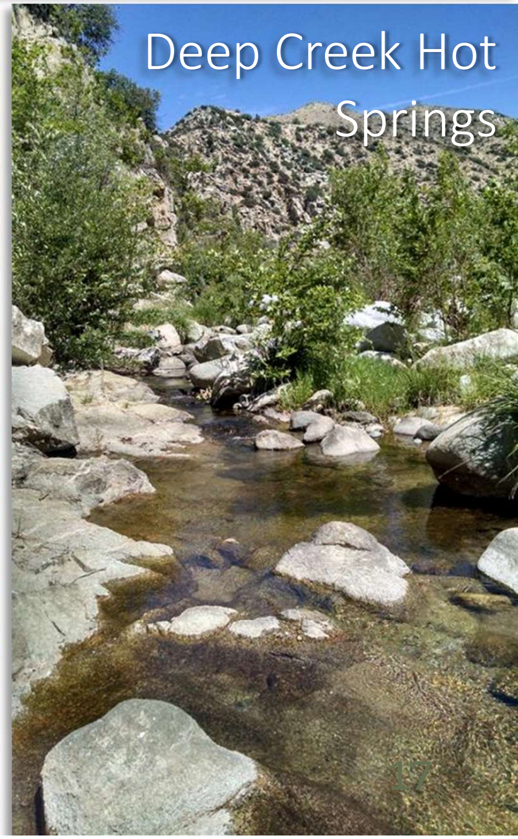

Phelan


Cabazon Dinosaurs


Red Rock, NV


Calico Ghost Town


??? Lizard


Deep Creek Hot
Springs


Lancaster

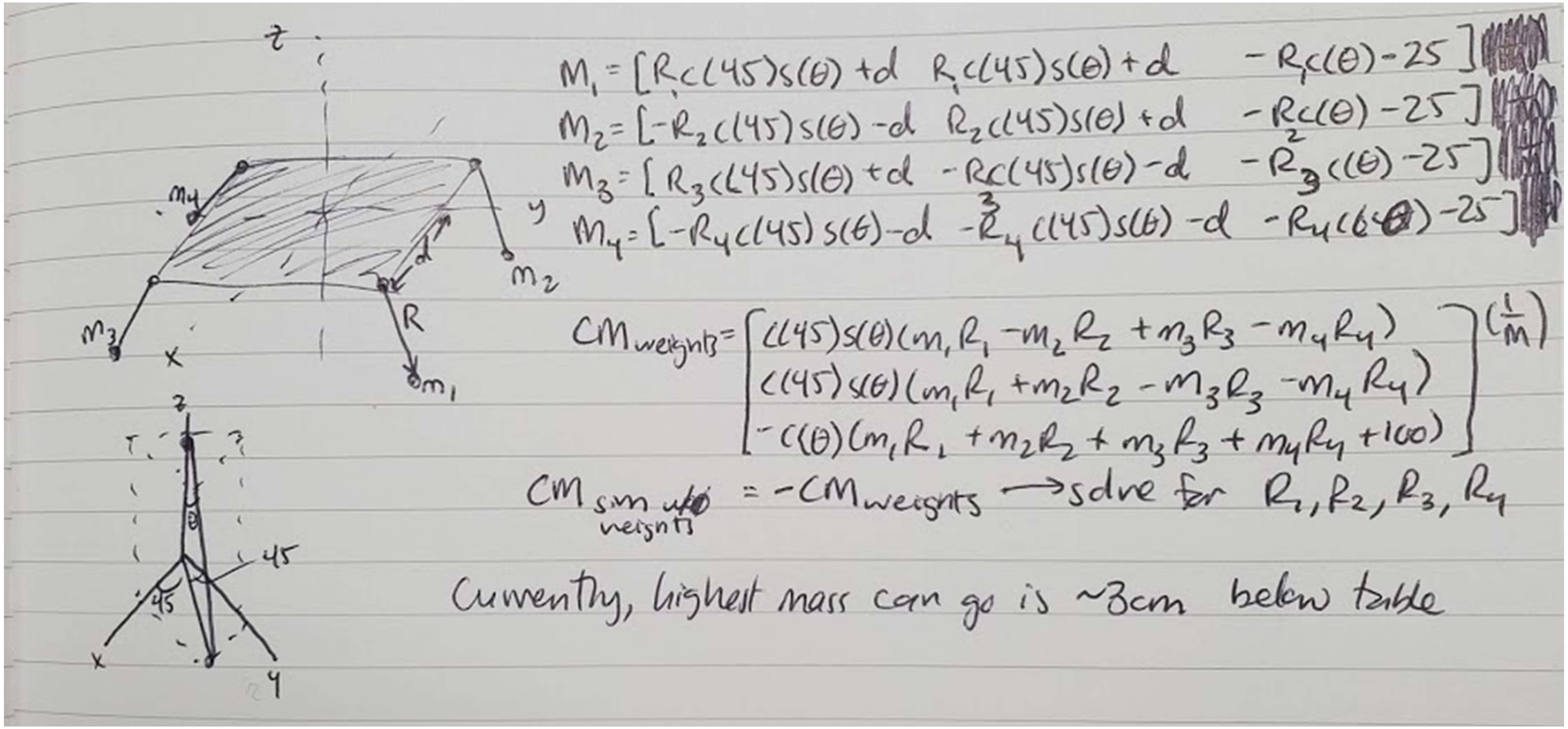
Thank you!

Manual vs. Automatic Trade

	Manual	Automatic
Pros	• Already used at Kyutech • Less time to implement up front • Cost-effective (fewer additional parts)	• Quick (minutes)[2] • New state-of-the-art[1,4] • Does not require experience
Cons	• Time consuming (hours) [1,2,4/5] • Trial and error[2] • Limited accuracy[1,2,4/5] • Changes to system require repeat process[2] • Requires experience[3]	• More time to implement up front • Requires control algorithm development • Requires procurement of actuators

1 - Yang Liu et al.: Automatic Mass Balancing of a Spacecraft Simulator Based on Non-orthogonal Structure
2 - Simone Chesi et al.: Automatic Mass Balancing of a Spacecraft Three-Axis Simulator: Analysis and Experimentation
3 - Shuai Wang et al.: Balancing Methods on the Three-Axis Air-Bearing Platform
4 – Jae-Jun Kim et al.: Automatic Mass Balancing of Air-Bearing-Based Three-Axis Rotational Spacecraft Simulator
5 - Jae-Jun Kim et al.: System Identification and Automatic Mass Balancing of Ground-Based Three-Axis Spacecraft Simulator
6 - Trevor Kwan et al.: An Air Bearing Table for Satellite Attitude Control Simulation

Center of Mass Calculation



Other Credits

- Slide 13:
  - Seals: https://i.pinimg.com/originals/f9/d9/64/f9d964c7e13906dd8fc6d60b1f56d771.jpg
  - Lighthouse: https://www.blm.gov/visit/piedras-blancas
- Slide 15:
  - SloDoCo: Yelp
  - High Street Deli: Yelp and High Street Deli Facebook Page
  - Tri-tip: Yelp
  - Tacos de Acapulco: Yelp
  - In-N-Out outside: http://www.thesungazette.com/article/news/2019/07/31/visalia-site-plan-review-points-to-a-second-in-n-out-location/
  - In-N-Out hat: https://www.ebay.com/itm/IN-N-OUT-BURGER-Paper-hats-LOT-OF-9-hats-Southern-California-NEW-/223565581991
- Slide 16:
  - Stratolaunch: https://www.popularmechanics.com/flight/a26715/stratolaunch-rolls-out-of-hangar/