GA Presentation 2

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Project Description

- Design a test fixture that attaches a 12U CubeSat to a 250 mm diameter hemispherical air bearing
- Fixture must align the center of gravity with the center of rotation of the bearing to allow it to remain upright
- The intention is to design a test stand for GA to use when testing their satellite

- The Black Box Model is based on the setup that GA will be using during their testing.
- The Functional Decompositional Model was done for the relocation of the center of gravity

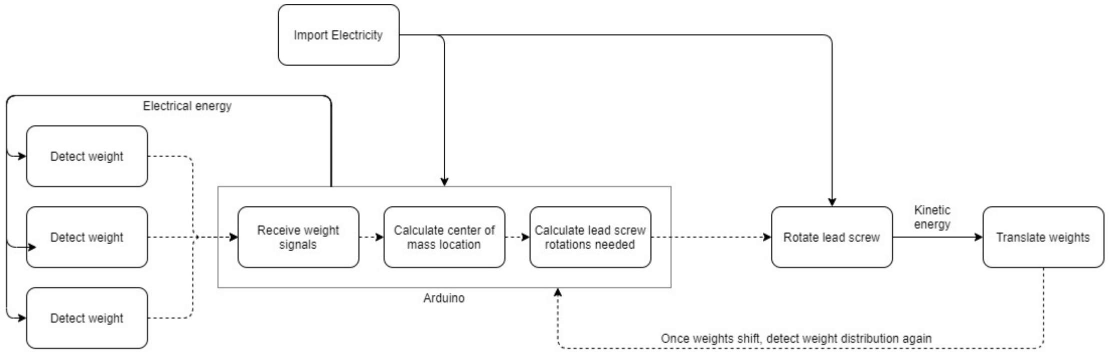

Figure 1: Functional Decompositional Model

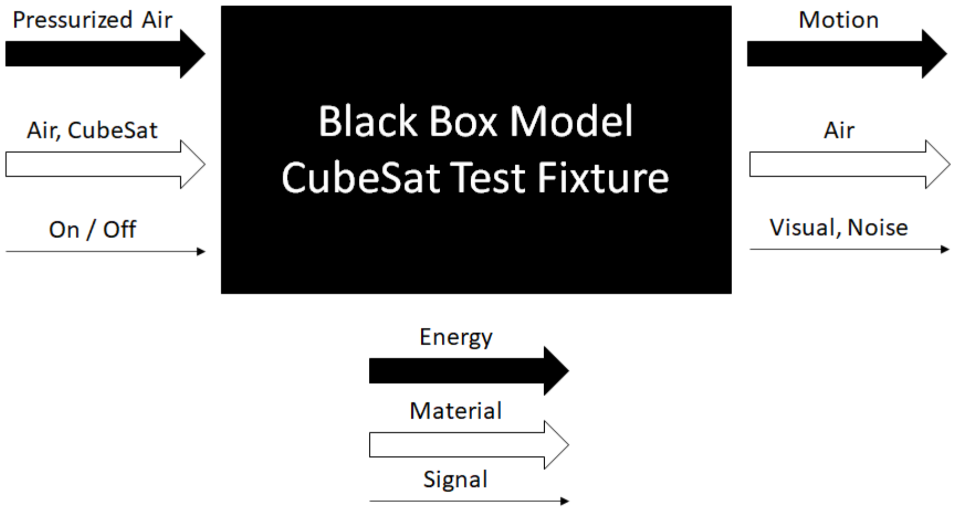

Figure 2: Black Box Model

Concept Generation

- Concept generation broken down into 3 sections
  - Move Mass
    - How we will relocate the Center of Gravity to collocate it with the Center of Rotation of the bearing
  - Test Stand
    - What we will use as a Testing Apparatus to simulate spherical air bearing
  - Safety System
    - What safety systems the design will incorporate to prevent damage to the satellite in the event of catastrophic failure
      - **Note:** GA has quoted the value of the satellite they intend to test on our design at over $1,000,000
- Multiple concepts generated per student per section
- Pugh Chart created for each section to rank concepts
- Highest rated concepts considered as best option

Moving Mass

- The customer needs were:
  - Ability to adjust the center of mass in all three dimensions
  - Ease of integration
  - Precision
  - Minimize weight of mount assembly
  - Reduce time needed for balancing
  - Price
- The top designs
  - Satellite Moving and Axial Relocation Terminals
  - The Previous Teams Designs
  - Spherical Weight Distributor

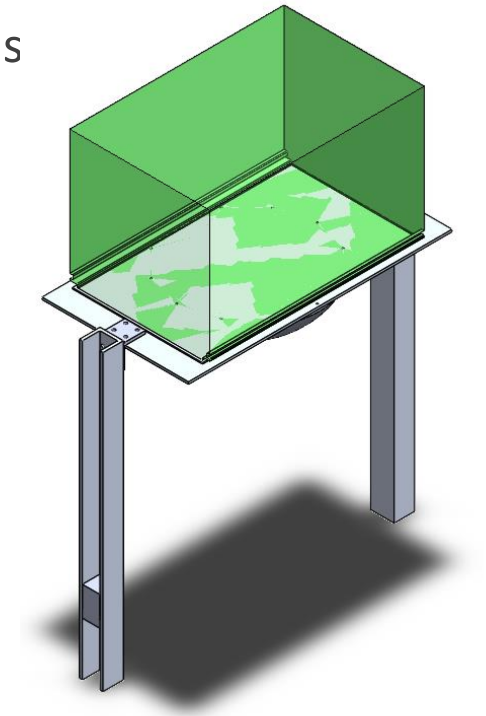

Figure 3: CAD Model of S.M.A.A.R.T. Fixture

Table 1: Pugh Chart Analysis of Ways to Adjust Center of Gravity

		How to Adjust Center of Gravity					
Criteria	Weight	Previous group's design	Cartesian coordinate weight movement	cylindrical / spherical coordinate weight distribution	fluid redistribution to relocate CoG	satellite relocation for x, z dir control, separate y dir weight control	Automatic
Ease of integration	4		1	-1	-2	1	0
CG location adjustable in 3 axes	5		-2	0	0	0	0
Minimize weight of mount assembly (↓)	2		0	1	2	2	0
Reduce time needed for balancing	2		-1	-2	-2	-1	0
Precision	3		-1	0	-2	-1	0
Price ($)	2		-2	1	-2	0	-1
Technical difficulty (1=high, 2=low)			2	1.2	1	1.6	1.2
Total		DATUM	-30	-4.8	-18	4.8	-2.4

Moving Mass - Evaluation

Test Stand - Introduction

- GA is using a PIglide HB A-656 hemispherical air bearing for testing purposes.
  - This would be the best option for us to test as it would be the most accurate results that GA could expect when using our design
    - Unfortunately, it would cost at least $12,210 to acquire one of our own and PI is not able to donate one for educational purposes.
- For our own testing stand, we considered the following criteria:
  - Reliability during typical wear
  - Similar Function to the actual bearing GA is using
  - Ease of setup, teardown
  - Ease of testing procedure
  - Manufacturability
  - Ability to minimize external forces
  - Stability
  - Price
  - Ease of Repair
  - Professional Factor

Figure 4 PIglide HB 250 A-656 Hemispherical Air Bearing
Source: [1]

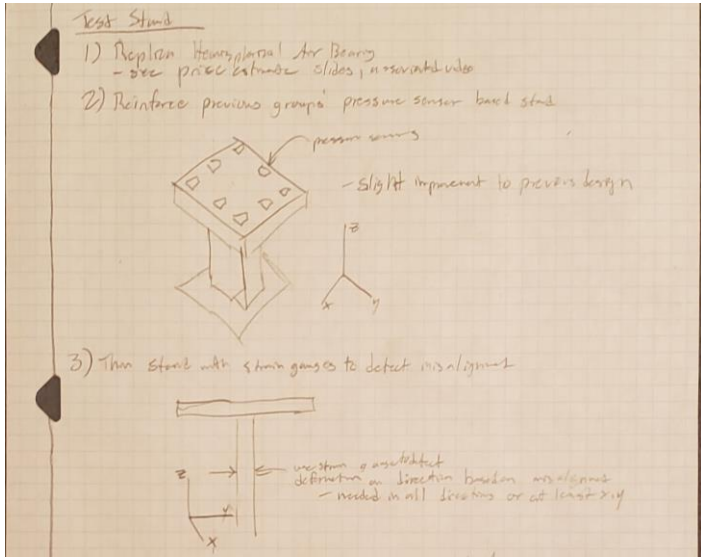

Figure 5: Sketches of Concepts

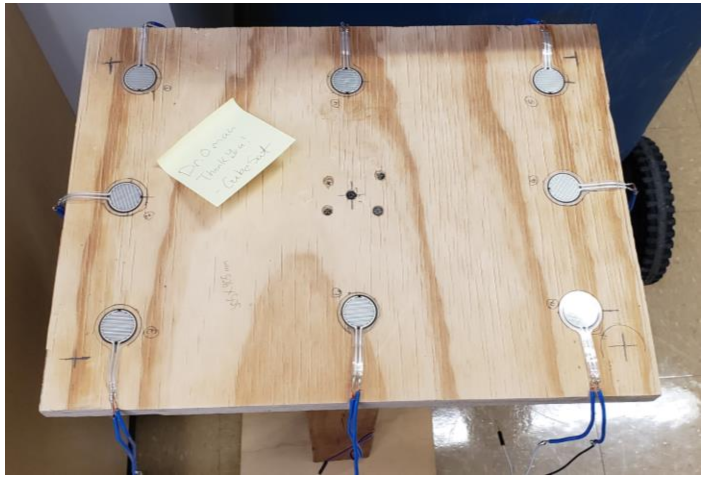

Figure 6: Previous Group's Test Stand

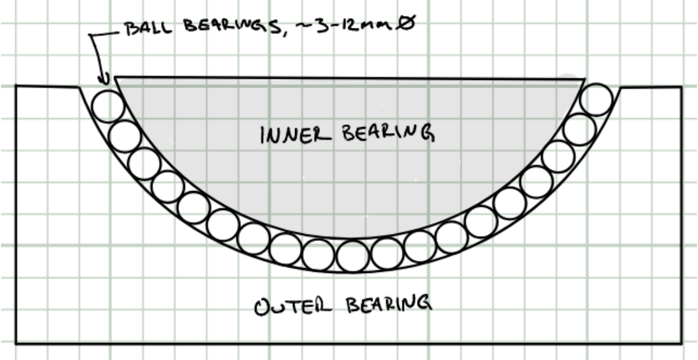

Figure 7: Sketch of Ball Bearing System

Test Stand - Concepts

Table 2: Cost Estimate for Graphite Based Replica Spherical Air Bearing

	Spherical Air Bearing Replica Cost Estimate to Manufacture											
	Graphite Sheet	Hemispherical Steel Ball x2 or 1 Full Sphere	Vacuum Pump	Hose Fittings	Housing (3d printed)**		Total	Tax, shipping if applicable	Total with tax, shipping			
Price*	$ 25.99	$ 21.43	$ 56.99	$ 0.70	$ 3.45		$ 108.56	$ 16.28	$ **124.84**			
Source/ Notes	1	2	3	4	5							
Notes									3D printer filament 1 kg spool (Hatchbox PLA)			
1	100mmx100mm130mm size should be more than sufficient but it may be worth getting a slightly larger one								$ 22.99			
2	roughly 300 mm diameter, stainless steel, will require slight adjustments for graphite sheets and housing, will have to be cut in half											
3	Unknown if this will supply sufficient vacuum, also may need filters or dry nitrogen supply											
4	$0.70 each, may require a few additional ones											
5	price may change slightly based on steel ball size and if we need to increase wall size, should stay under $10 regardless of size											

*Note: all prices referenced from Amazon

**Note: 3D printed housing requires 150g of filament

Test Stand – Replica Spherical Air Bearing Additional Information

Table 3: Pugh Chart Analysis of Test Stand Concepts

		Test Stand					
Criteria	Weight	PIglide HB-250 Spherical Air Bearing (250mm)*	Graphite based replica spherical air bearing	Previous group's stand	Deformation based vertical rod	Ball bearings between inner, outer bearing	Suspended from cable, swivel
Endures typ. wear for multiple uses (↑)	5	2	1		0	1	2
Similar function to actual bearing	7	2	2		0	1	0
Ease of setup, teardown	3	-2	1		-2	1	2
Ease of testing procedure	5	2	2		-1	2	-1
Manufacturability	7	2	-1		2	1	2
Minimize external forces	6	2	2		0	2	-2
Stability	6	2	1		1	1	2
Price ($)	10	-2	-1		0	-1	1
Ease of repair	8	-2	-1		0	2	2
Professional Factor	5	2	2		0	1	-2
Technical difficulty (1= high, 2= low)		2	1		1.4	1.8	1.8
Total	62	80	35	DATUM	12.6	109.8	73.8

*Note: PIglide HB 250 Spherical Air Bearing is only shown for reference, it is not possible to purchase with our current budget

Test Stand - Evaluation

Safety System

- The customer needs were:
  - Permit full range of motion
  - Prevent satellite from falling
  - Minimize damage to CubeSat
  - Prevent bearing, stand from falling
  - Minimize weight on CubeSat
  - Ease if Setup
  - Price
  - Minimize additional equipment
- The top designs:
  - Safety Cables Suspension
  - Satellite Latches
  - 3D Printed Legs

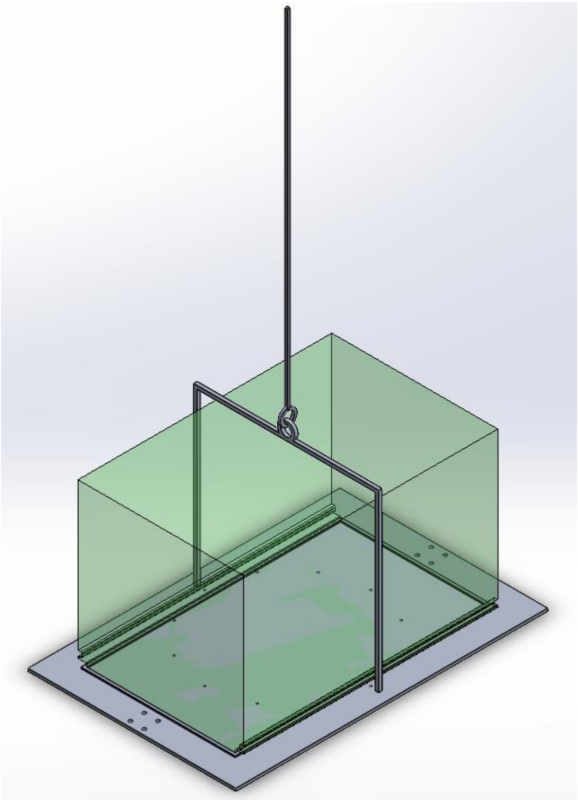

Figure 8: Safety System concept

Table 4: Pugh Chart Analysis of Safety Systems

		Safety System						
Criteria	Weight	Latches to hold satellite in place	Wires that hook onto satellite	Wires to constrict movement along the top	Pneumatic extendable legs	Safety cables suspending system	Vacuum preload on bearing (only if graphite-based replica sab used)	3D printed / plastic legs
Permits full range of motion	5	0	0		0	0	0	0
Prevents satellite from falling	5	2	1		2	2	2	1
Prevents bearing, stand from falling	4	0	0		2	0	0	0
Minimize additional equipment, setup	2	0	0		-2	-1	1	-1
Minimize weight on CubeSat	3	1	1		-1	1	1	0
Ease of setup	3	0	0		-1	-1	1	-1
Minimize damage to CubeSat	5	0	0		2	2	2	2
Price ($)	3	0	0		-2	2	2	1
Technical difficulty (1=high, 2=low)		1.8	1.6		1	2	1.5	1.8
Total		23.4	12.8	DATUM	12	48	51	23.4

Safety System - Evaluation

Concept Evaluation

- After Pugh Chart analysis the highest rated concepts are chosen as best option
- In Summary, the highest rated designs are:
  - Move Mass: Satellite relocation (move the satellite instead of weights)
  - Test Stand: Ball bearing design
  - Safety System: Cables suspending system

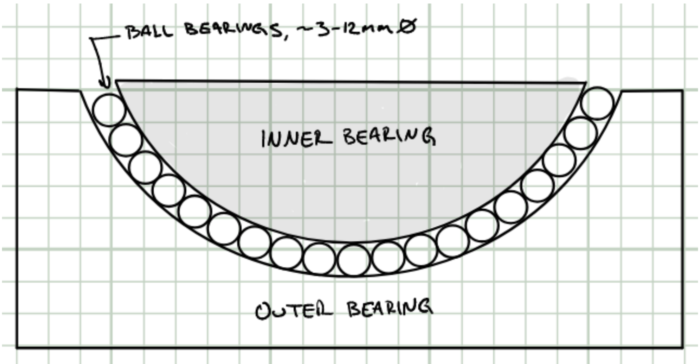

Figure 9: Sketch of Ball Bearing System

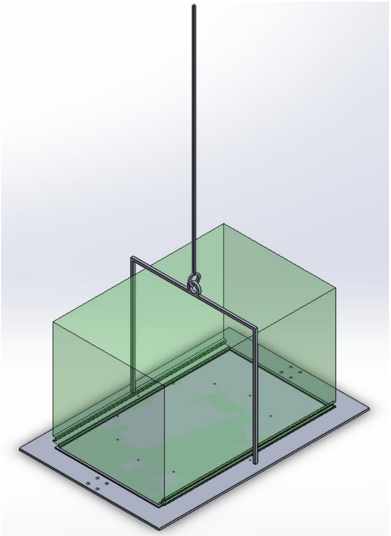

Figure 10: CAD Model of Cable Suspension

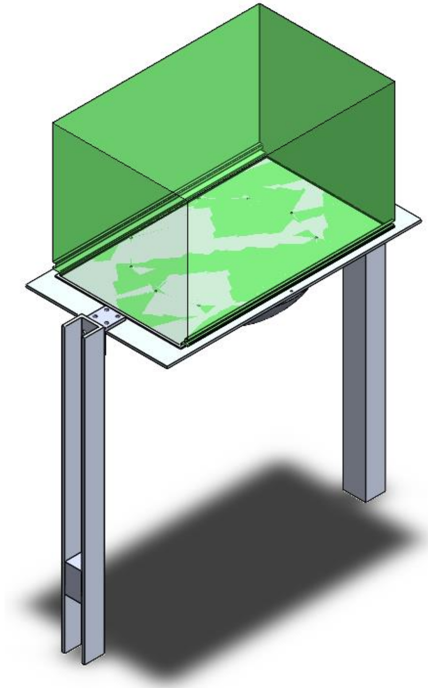

Figure 11: CAD Model of S.M.A.A.R.T. Fixture

Budget Planning: Bill of Materials

Subsystem	Component	Specifications	Qty	Cost /ea.	Cost
Test platform	Outer bearing surface	Aluminum, CNC	1	$300.00	$300.00
	Inner bearing surface	Aluminum, CNC	1	$150.00	$150.00
	Ball bearings	Stainless, 6mm, packs of 50	4	$12.03	$48.12
	Pedestal	Wood	1	$20.00	$20.00
				Subtotal	**$518.12**
Safety system	Cable	Braided steel, 6mm	2	$1.00	$2.00
	Ferrules		10	$0.10	$1.00
	Hooks		2	$5.00	$10.00
	Swivel hook		2	$5.00	$10.00
				Subtotal	**$23.00**
Fixture assembly	Platform	1m x 1m, Aluminum?	1	$50.00	$50.00
	Satellite clamps		6	$20.00	$120.00
	Rails		4	$20.00	$80.00
	Weights		4	$10.00	$40.00
	Lead screws		4	$10.00	$40.00
	Motors		4	$20.00	$80.00
	Motor control system		1	$50.00	$50.00
	Sensors		4	$10.00	$40.00
				Subtotal	**$500.00**
				Total	**$1,041.12**
				Budget	$8,000.00
				Budget remaining	$6,958.88

Budget Planning

- Budget remaining after initial prototype: $6,500-$7,000

- Additional prototypes, repairs: $2,000
- Final design: $1,000
- Travel: $2,000
  - GA University Symposium Day
    - Virtual or in-person unknown

References

1. Physik Instrumente, "A-65x PIglide HB: Hemispherical Air Bearing Module," PI, 2021. [Online]. Available: https://www.pi-usa.us/en/products/air-bearings-ultra-high-precision-stages/a-65x-piglide-hb-hemispherical-air-bearing-900712/#description. [Accessed 21 February 2021].

Questions?