



University of Idaho

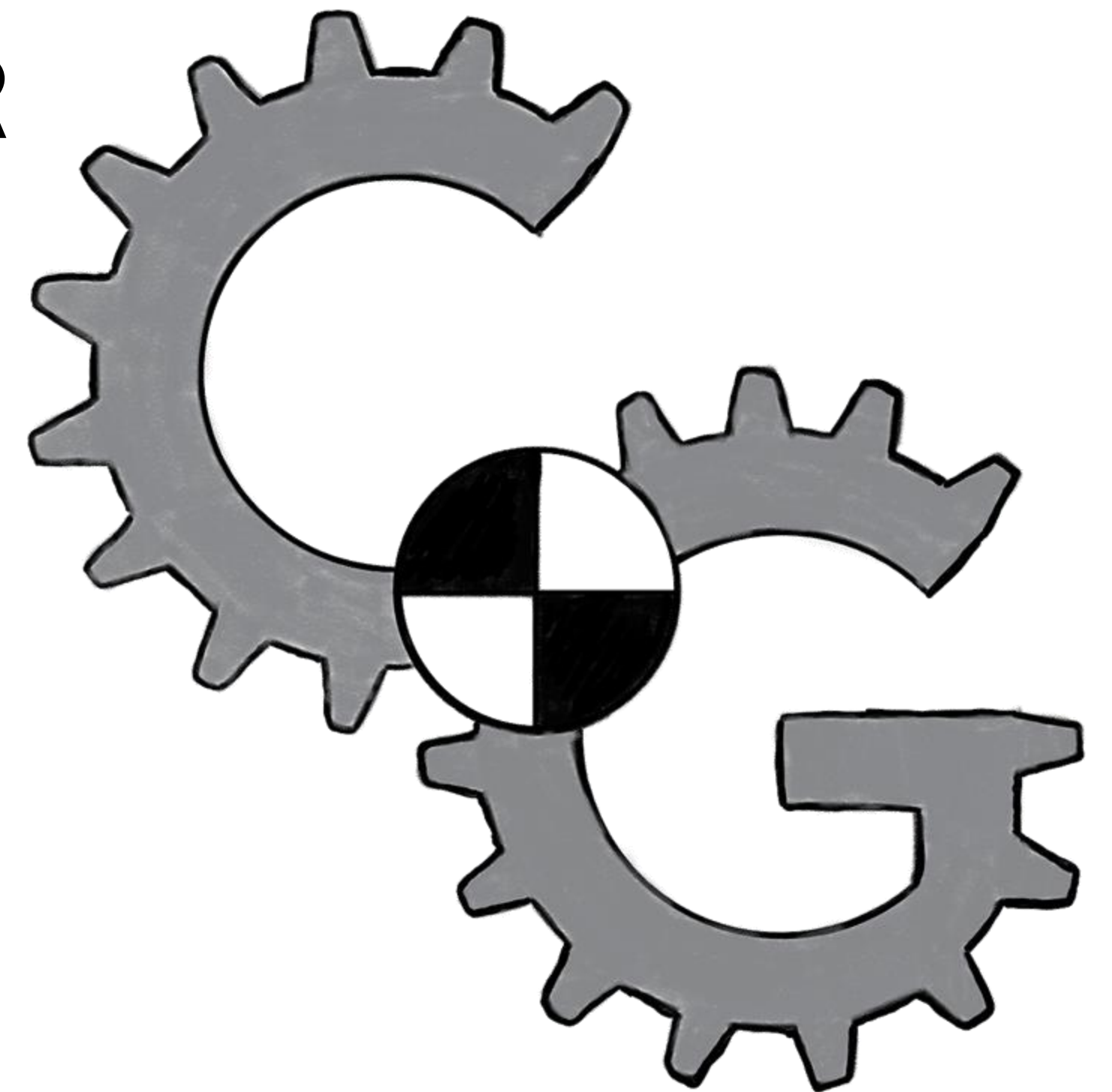
College of Engineering

3-AXIS CENTER OF GRAVITY INSTRUMENT

KALEB CARTIER

KENDALL GRAY

ERIC SMEAD



INTRODUCTION



General Center of Gravity Equation

$$CG = \frac{W_1 d_1 + W_2 d_2 + W_3 d_3 + \cdots + W_i d_i}{W}$$

USEFULNESS

- I Natural Frequency of Entire Device
- I Strain on Server Rack Mount Ears



PROJECT REQUIREMENTS

MECHANICAL

- I Automatic
- I Vibration Test
- I 50 lbs.
- I 24" x 12" x 20"
- I Rack Mount Capabilities
- I Re-creatable
- I 1.0% Accuracy

ENVIRONMENTAL

- I 60 to 85 °F

ELECTRICAL

- I 120 VAC
- I Low power consumption

SOFTWARE

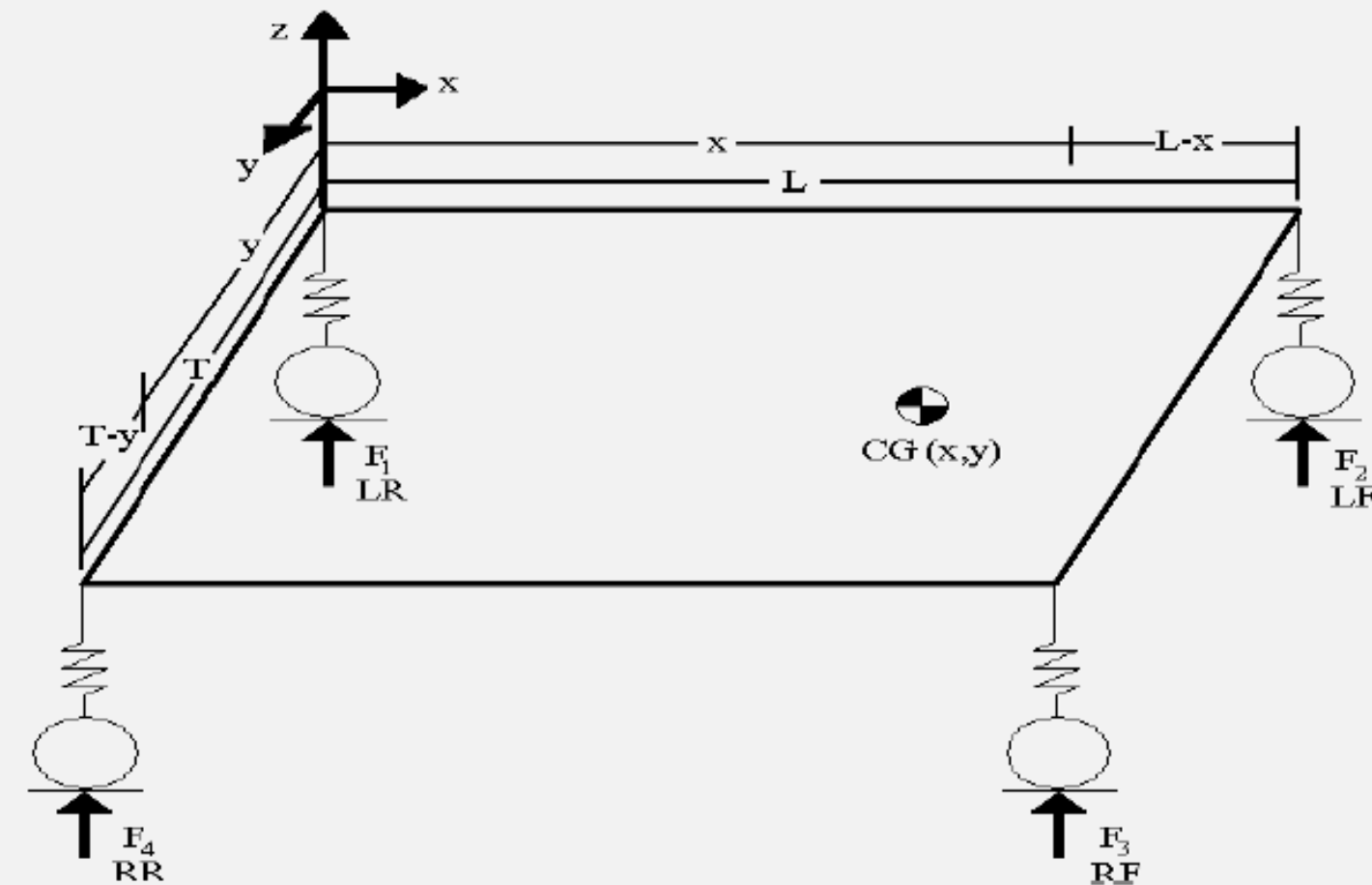
- I Average Cartesian CG

BUDGET

- I \$1661

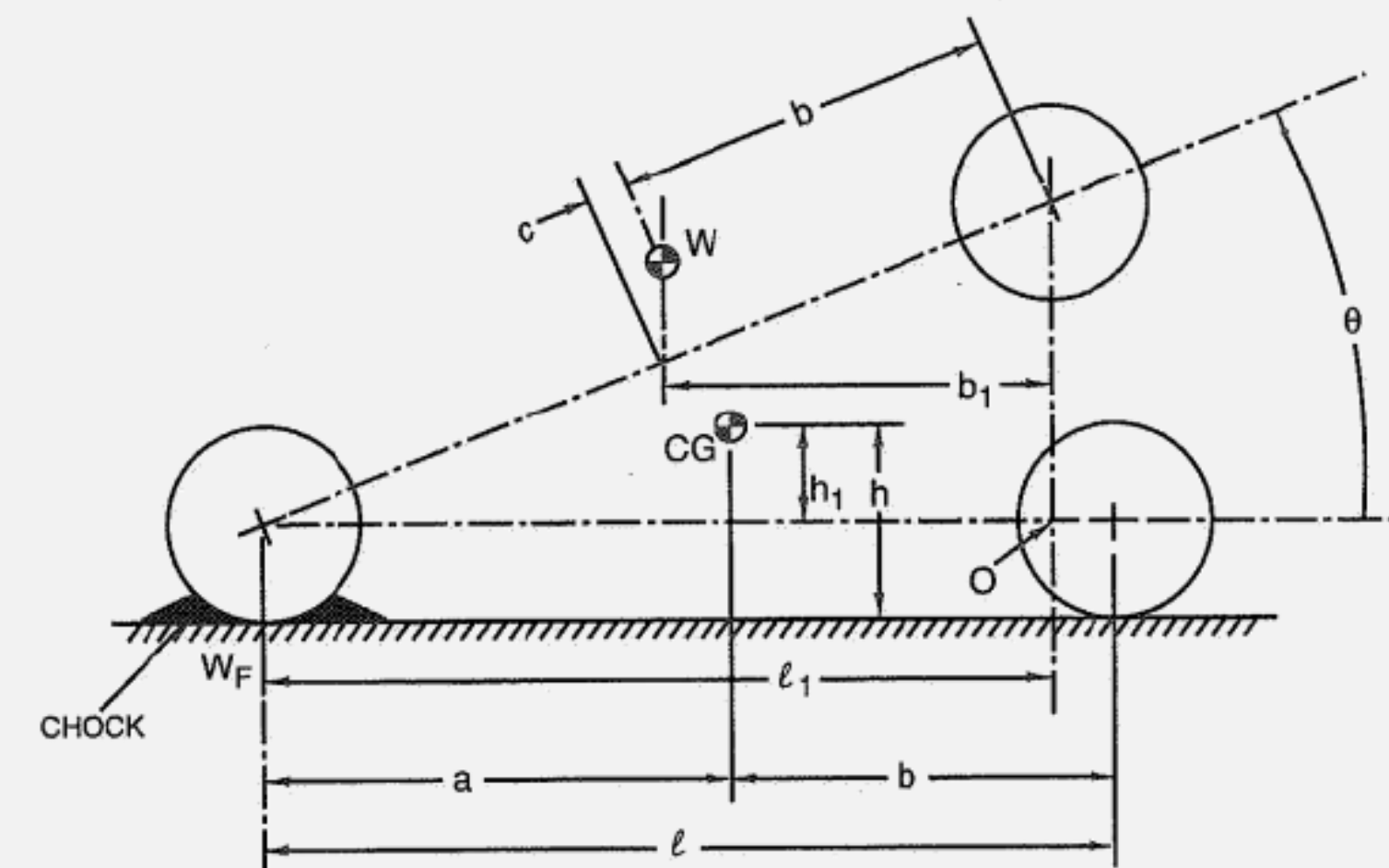
RESEARCHED SOLUTIONS

MEASURING CG USING 4 LOAD TRANSDUCERS - SANDIP G. PATEL, JAINISH J. TOPIWALA



$$x = \frac{(F_2 + F_3) \cdot L}{(F_1 + F_2 + F_3 + F_4)}$$

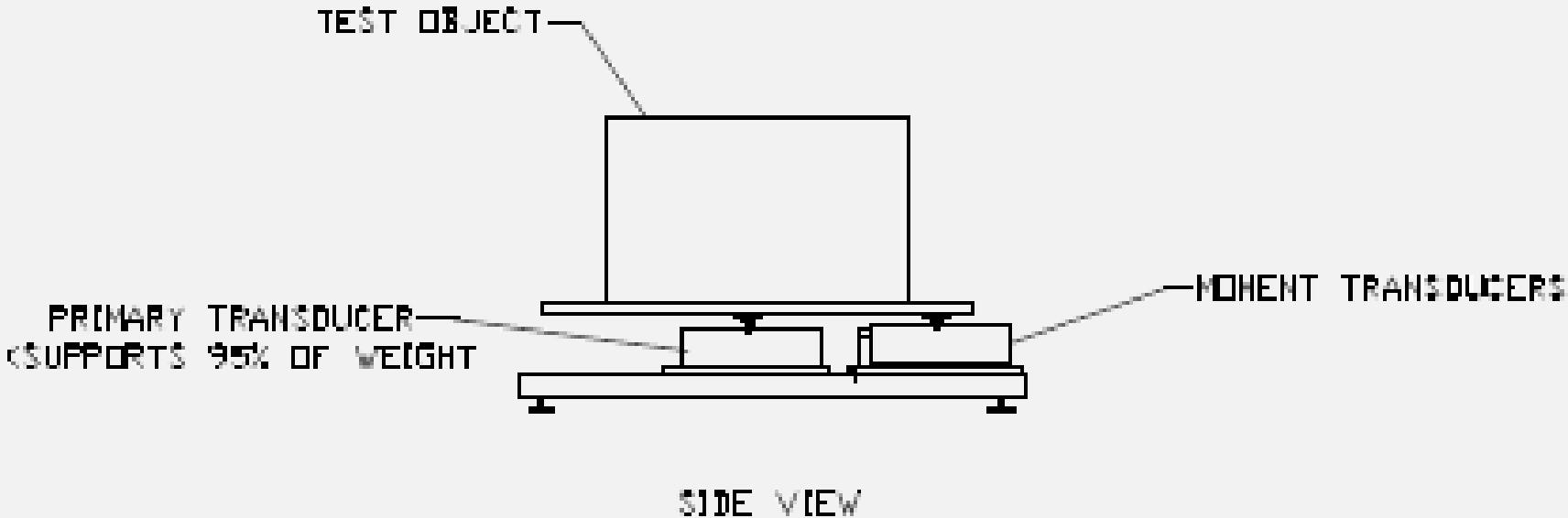
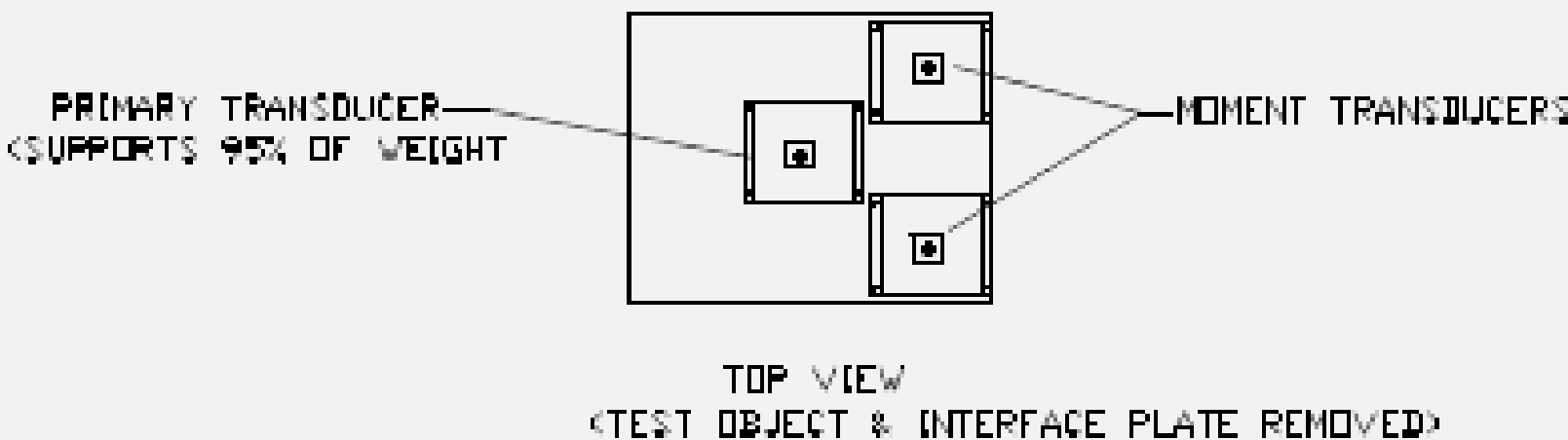
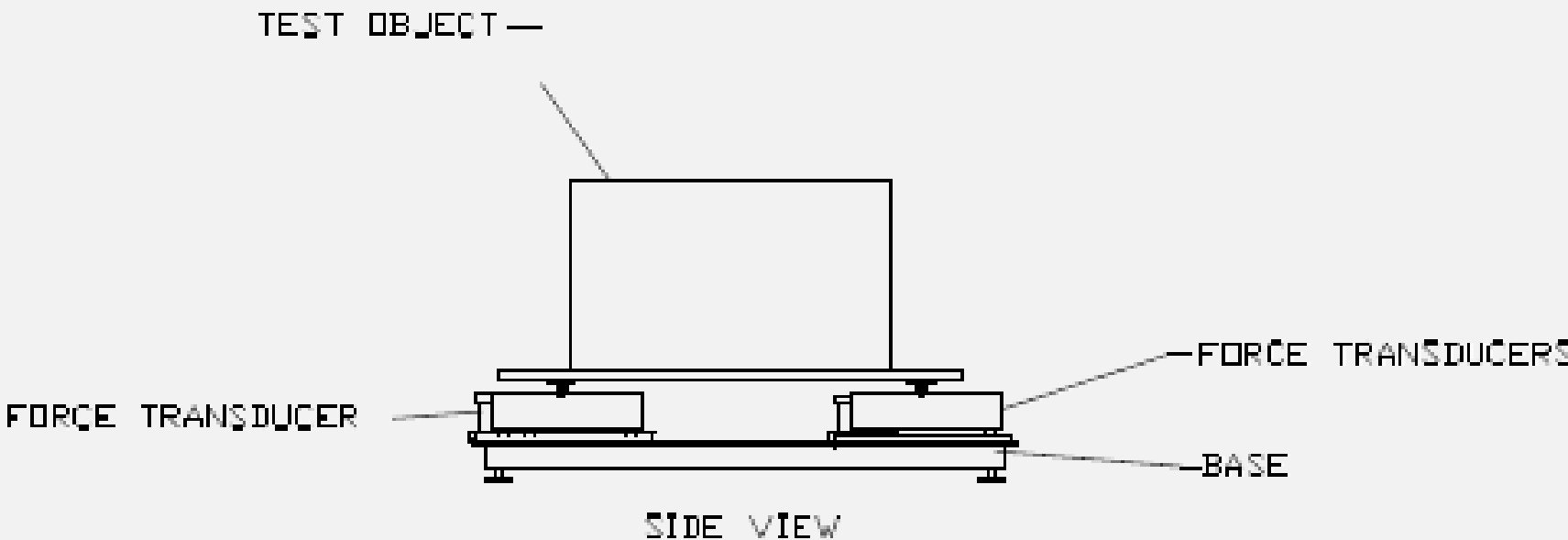
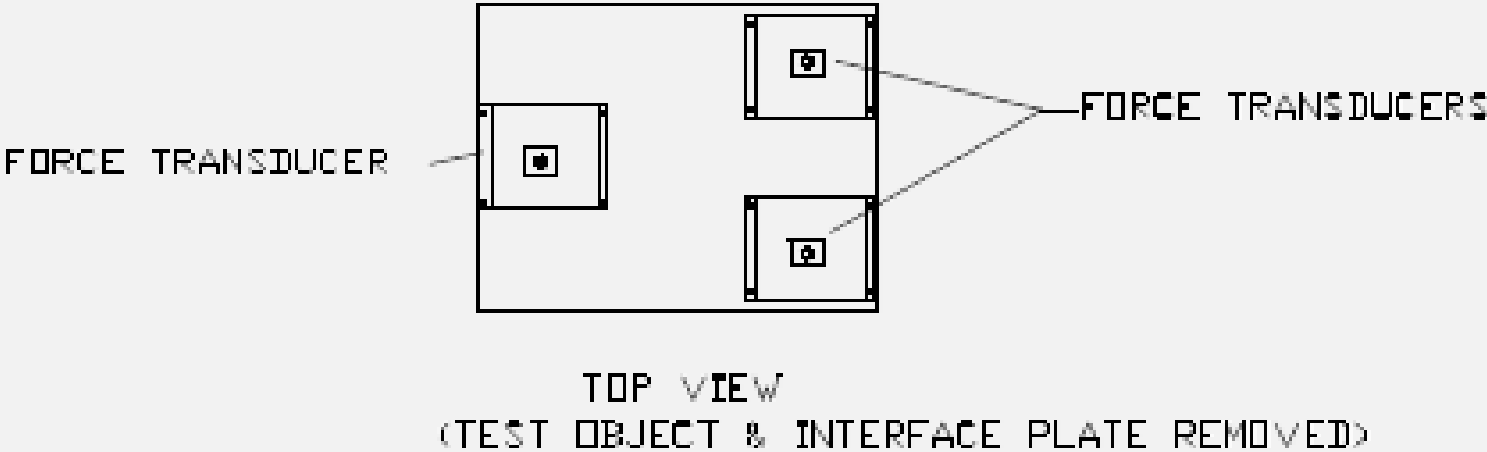
$$y = \frac{(F_3 + F_4) \cdot T}{(F_1 + F_2 + F_3 + F_4)}$$



$$z = R_L + \left(\frac{W_F \cdot l - W_b}{W \cdot \tan \theta} \right)$$

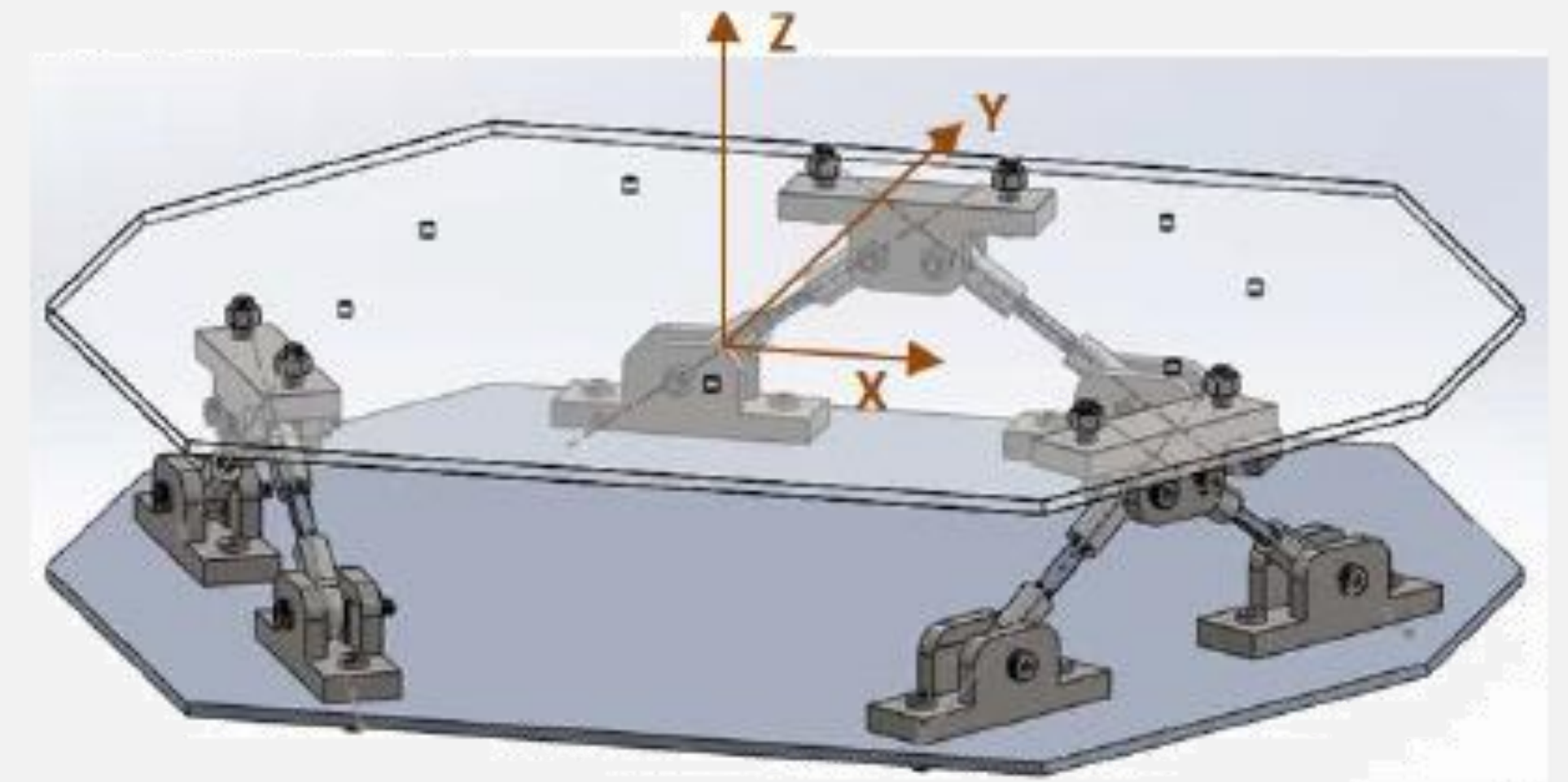
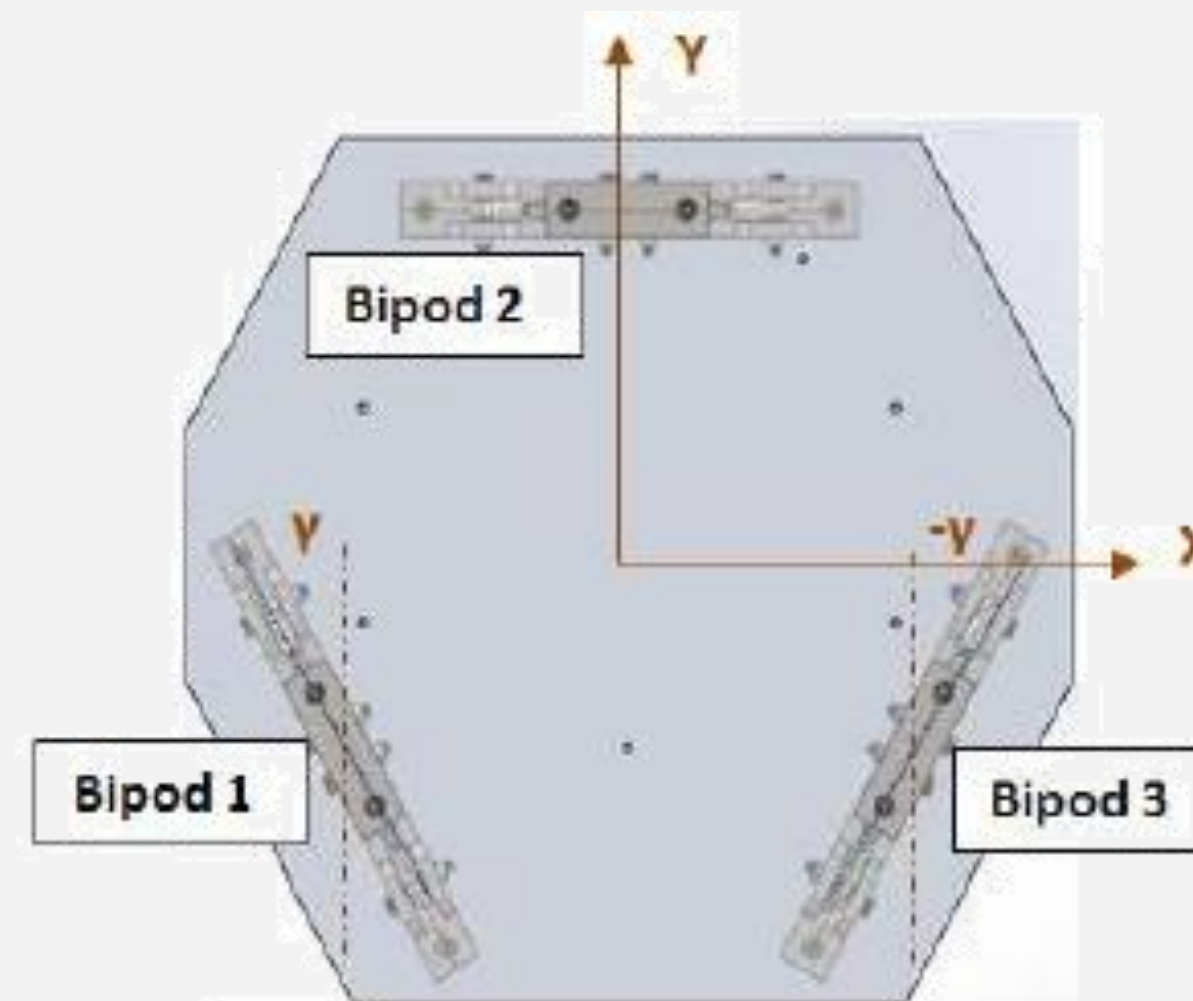
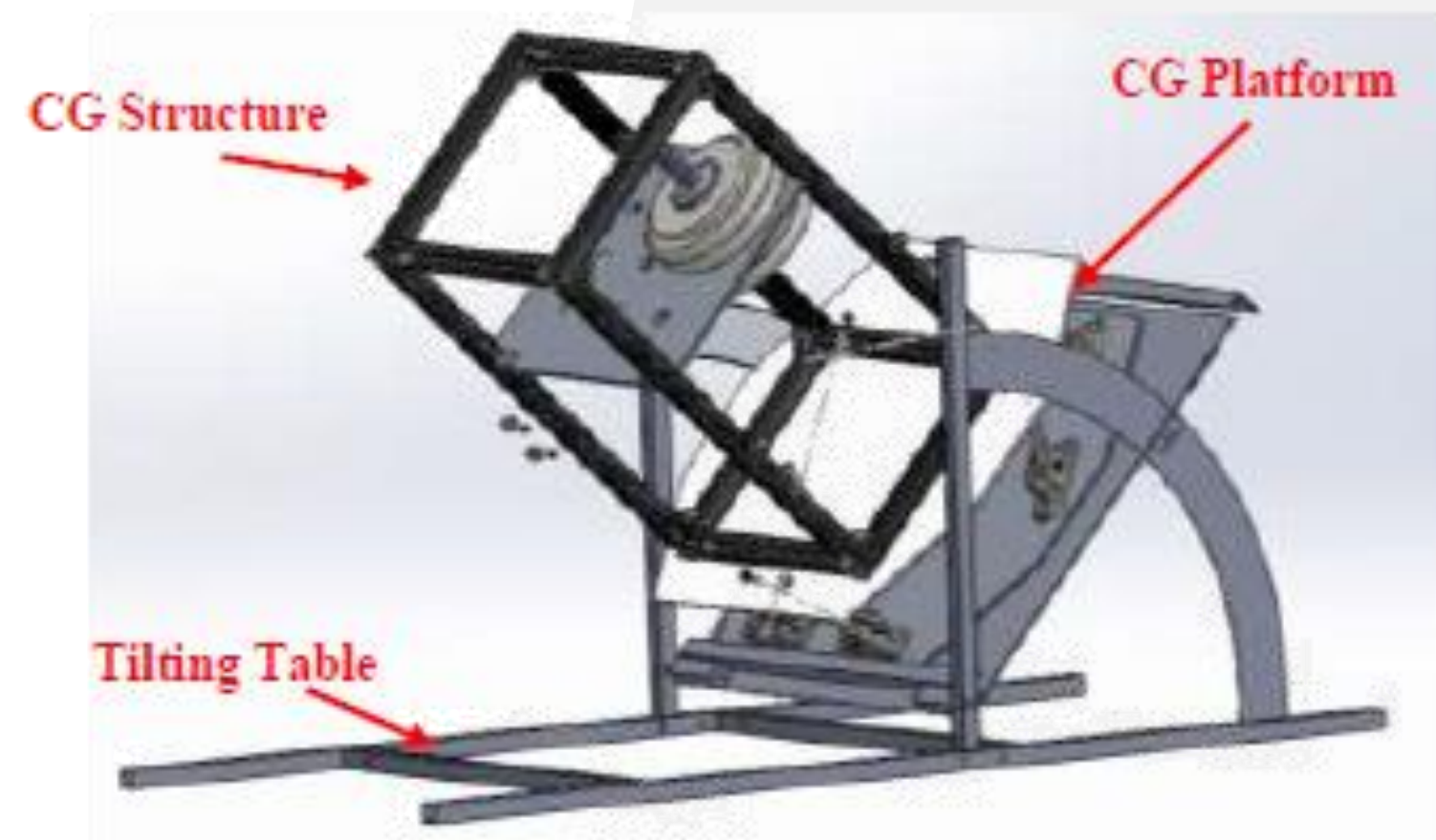
RESEARCHED SOLUTIONS

MEASURING CG OF A ROCKET MOTOR - RICHARD BOYNTON



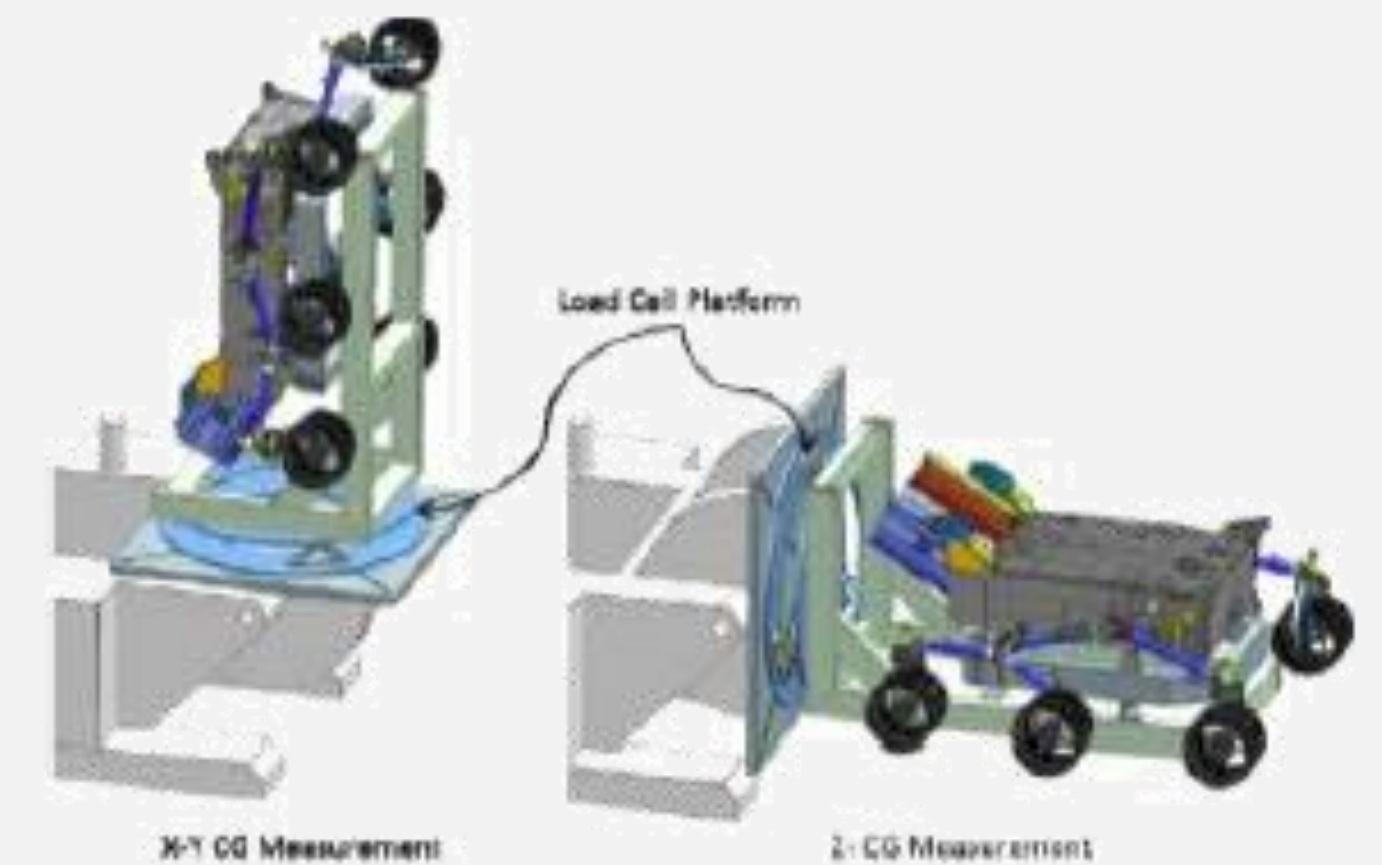
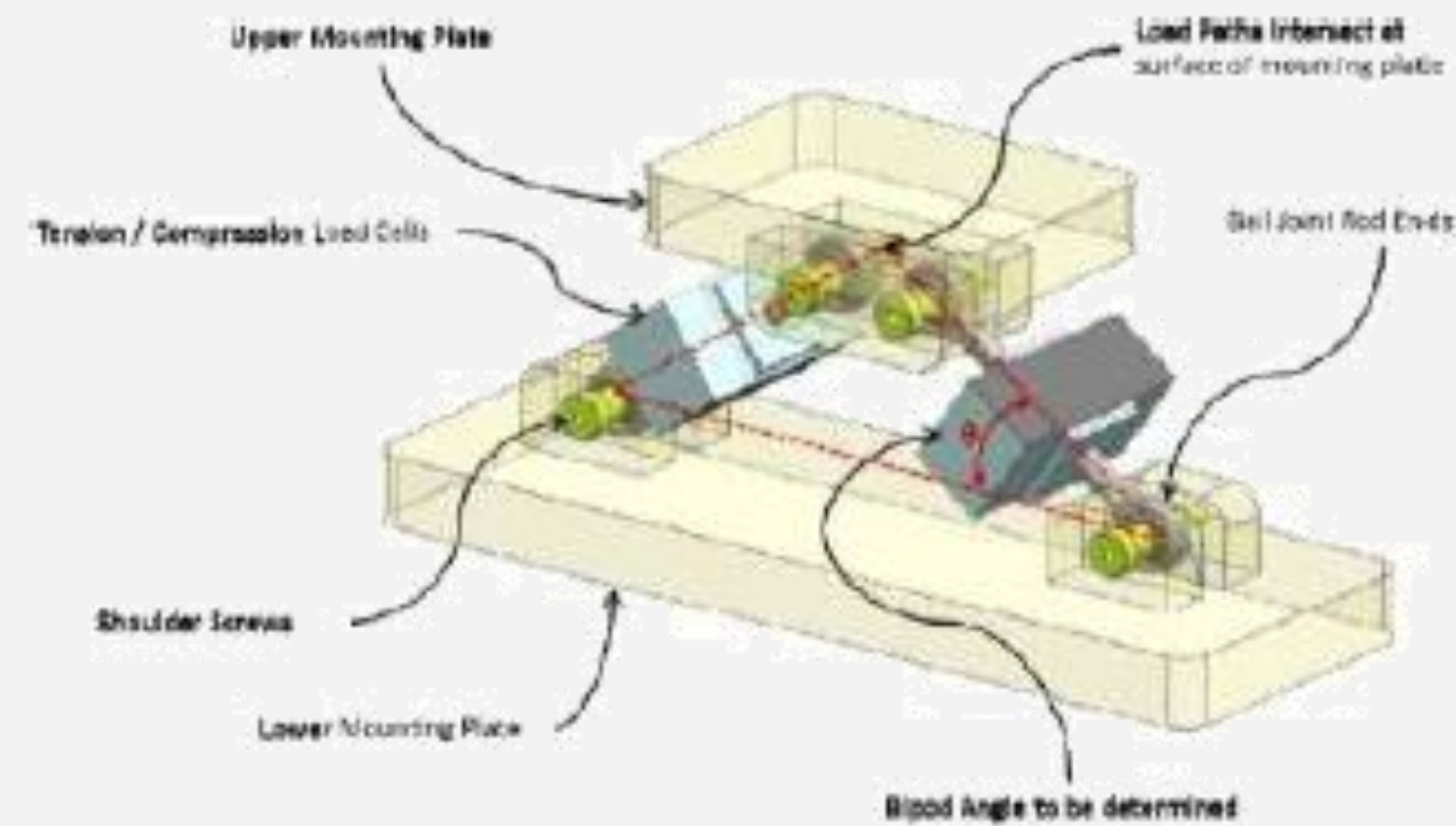
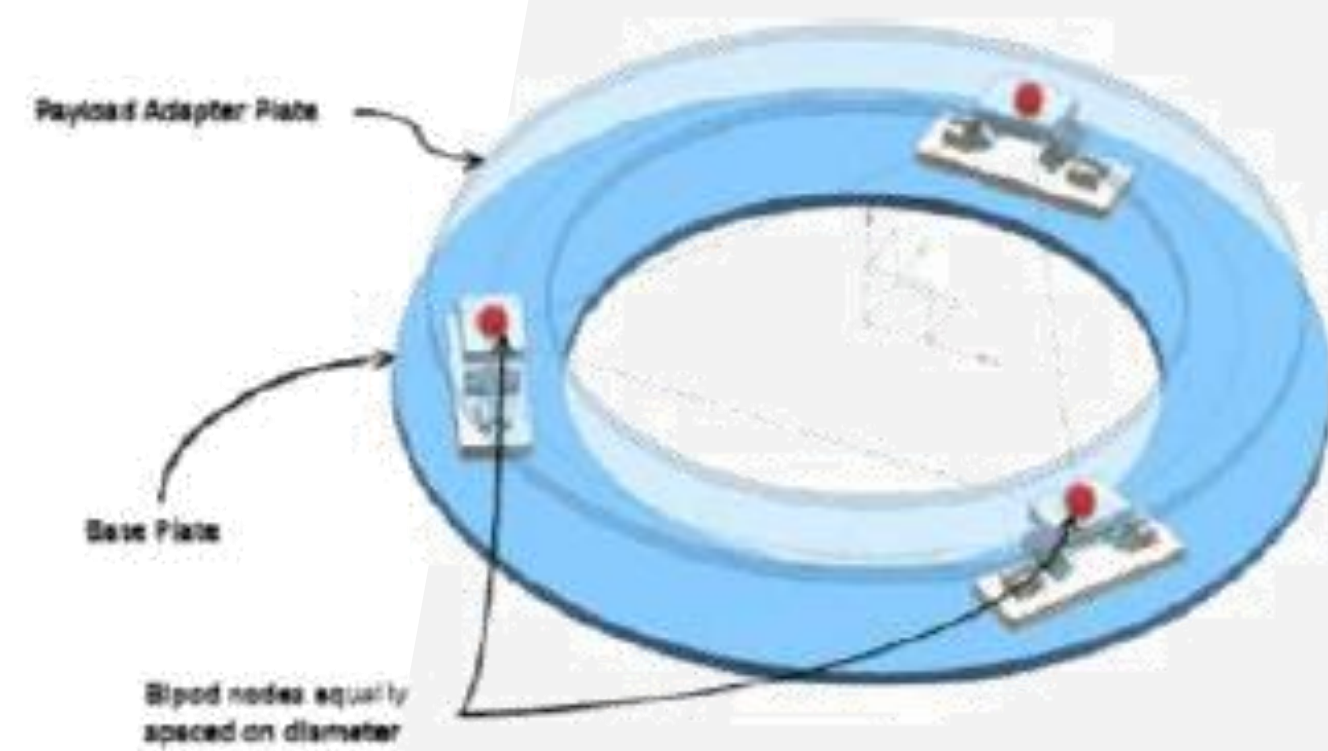
RESEARCHED SOLUTIONS

VALIDATION OF A CG MEASURING PLATFORM USING EXPERIMENTAL TESTS -MICHAEL LASHORE

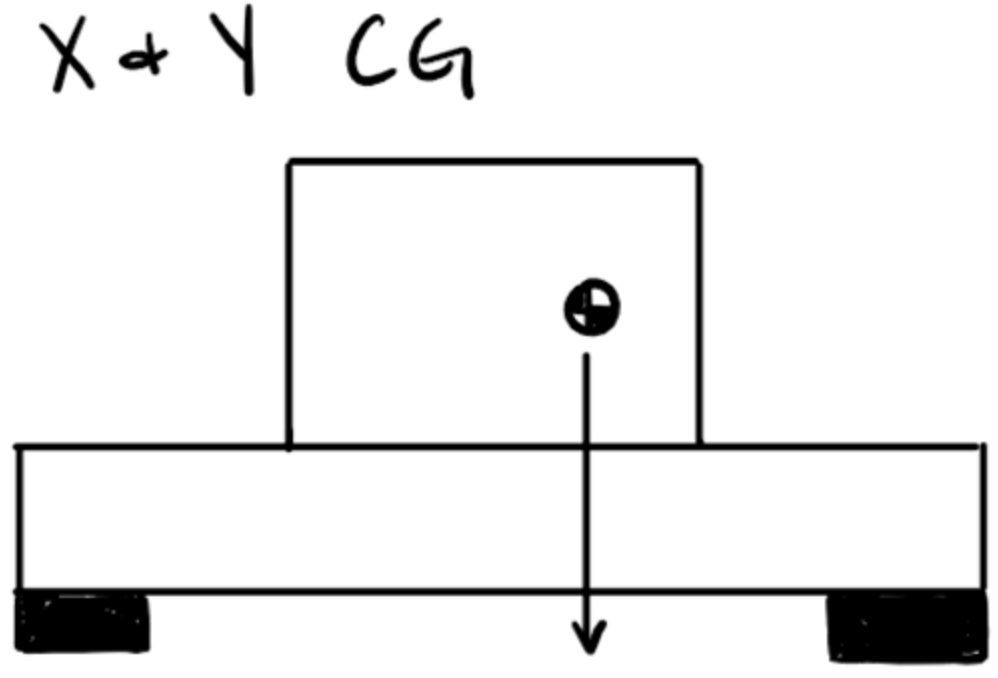


RESEARCHED SOLUTIONS

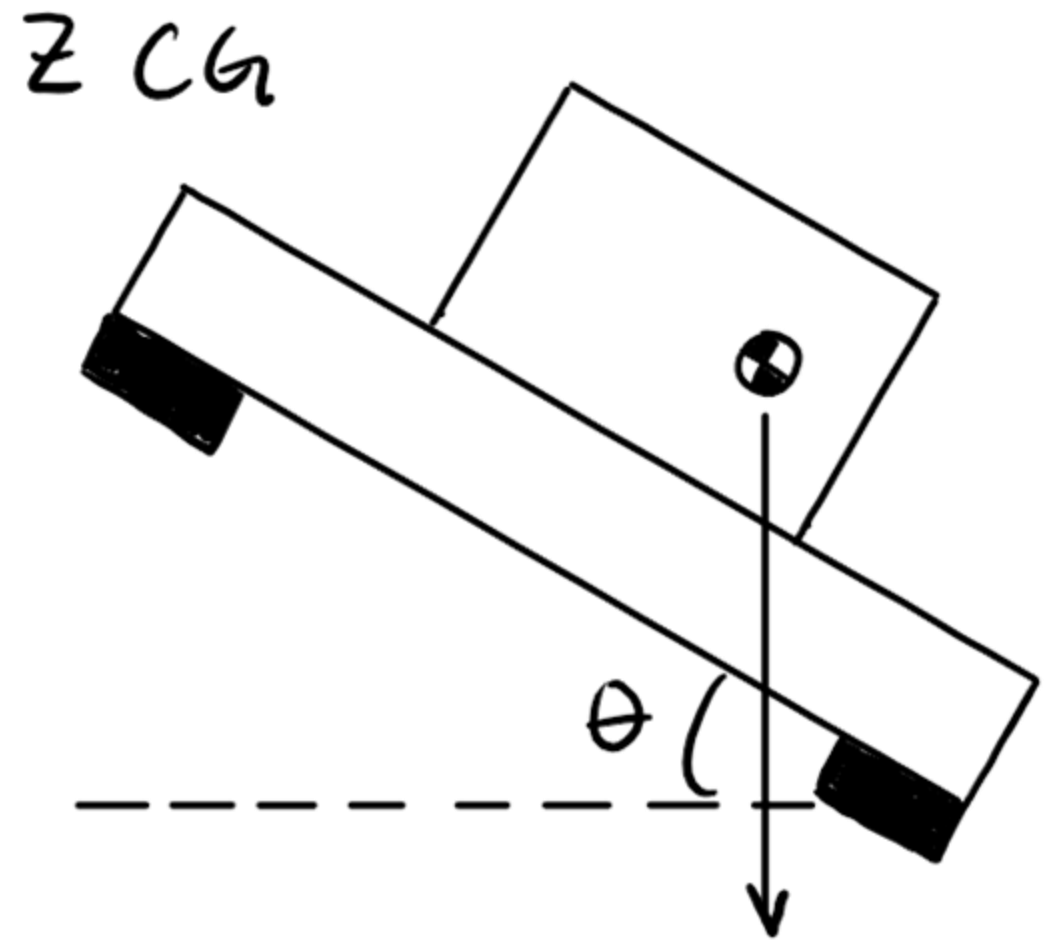
VALIDATION OF A CG MEASURING PLATFORM USING EXPERIMENTAL TESTS -MICHAEL LASHORE



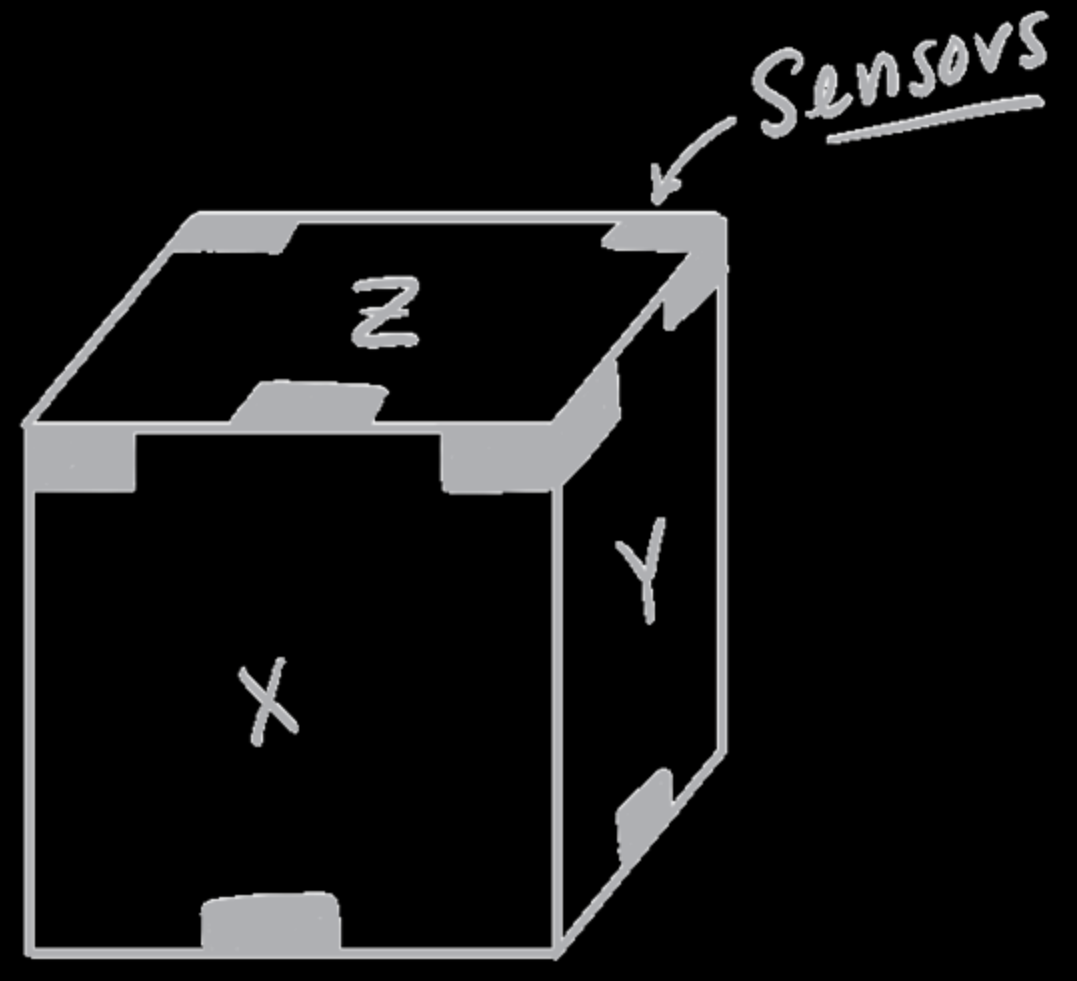
PRELIMINARY DESIGNS



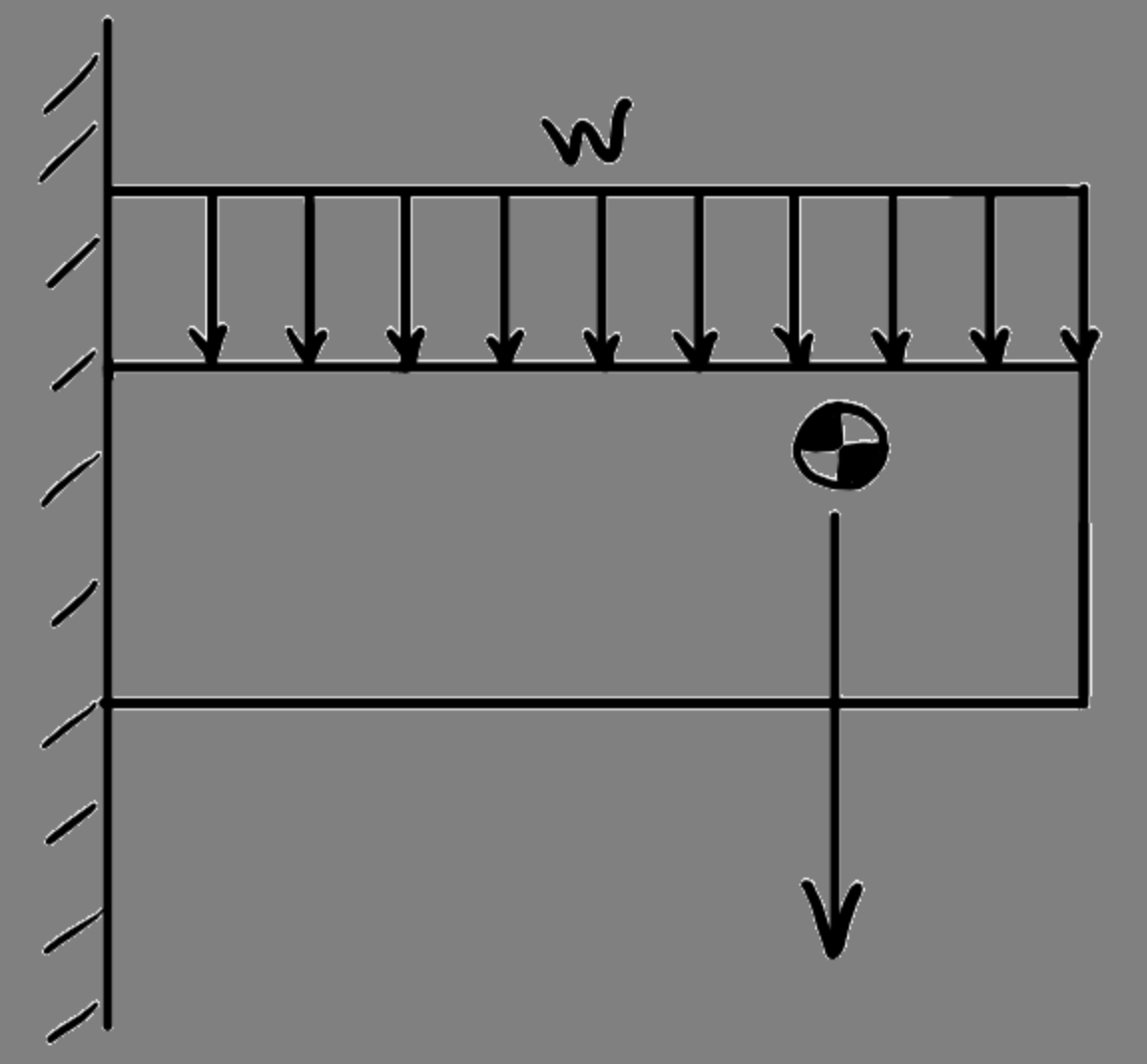
TILTED TABLE



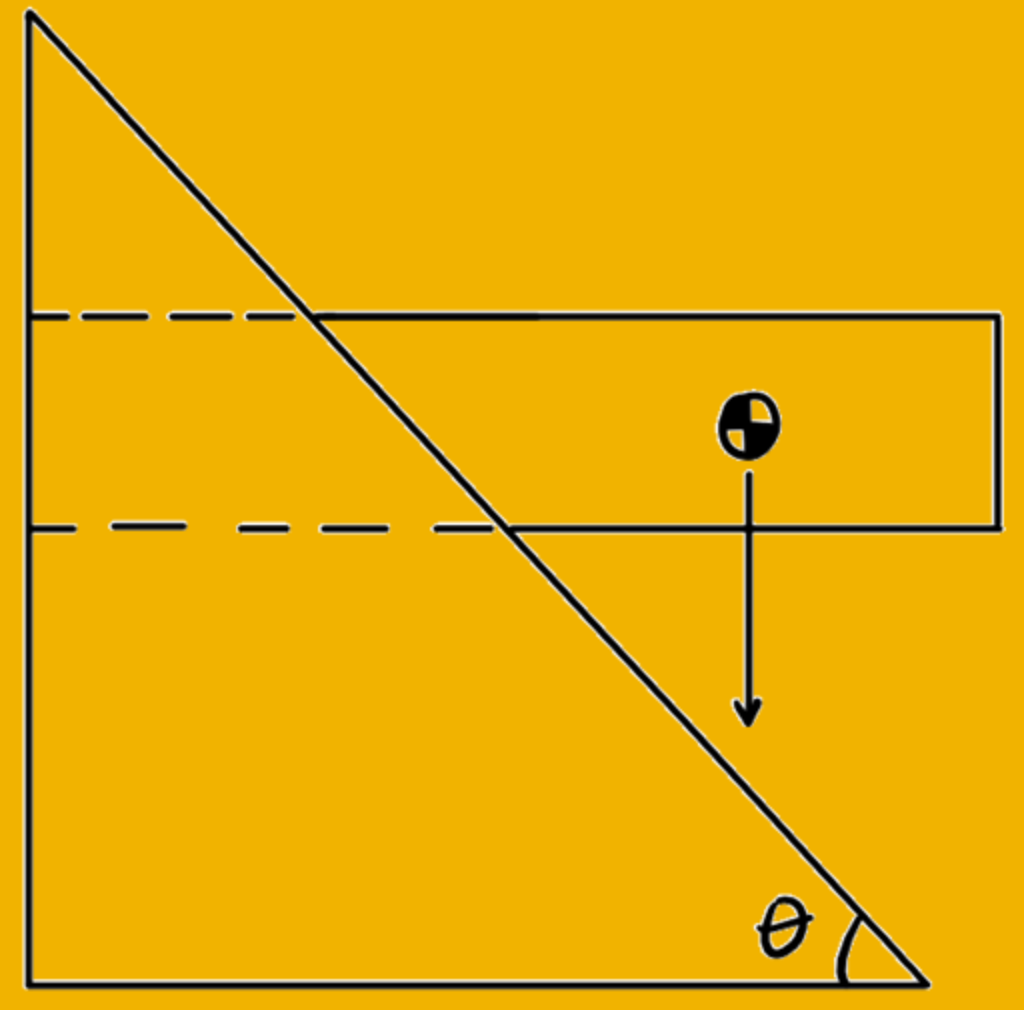
TILTED TABLE



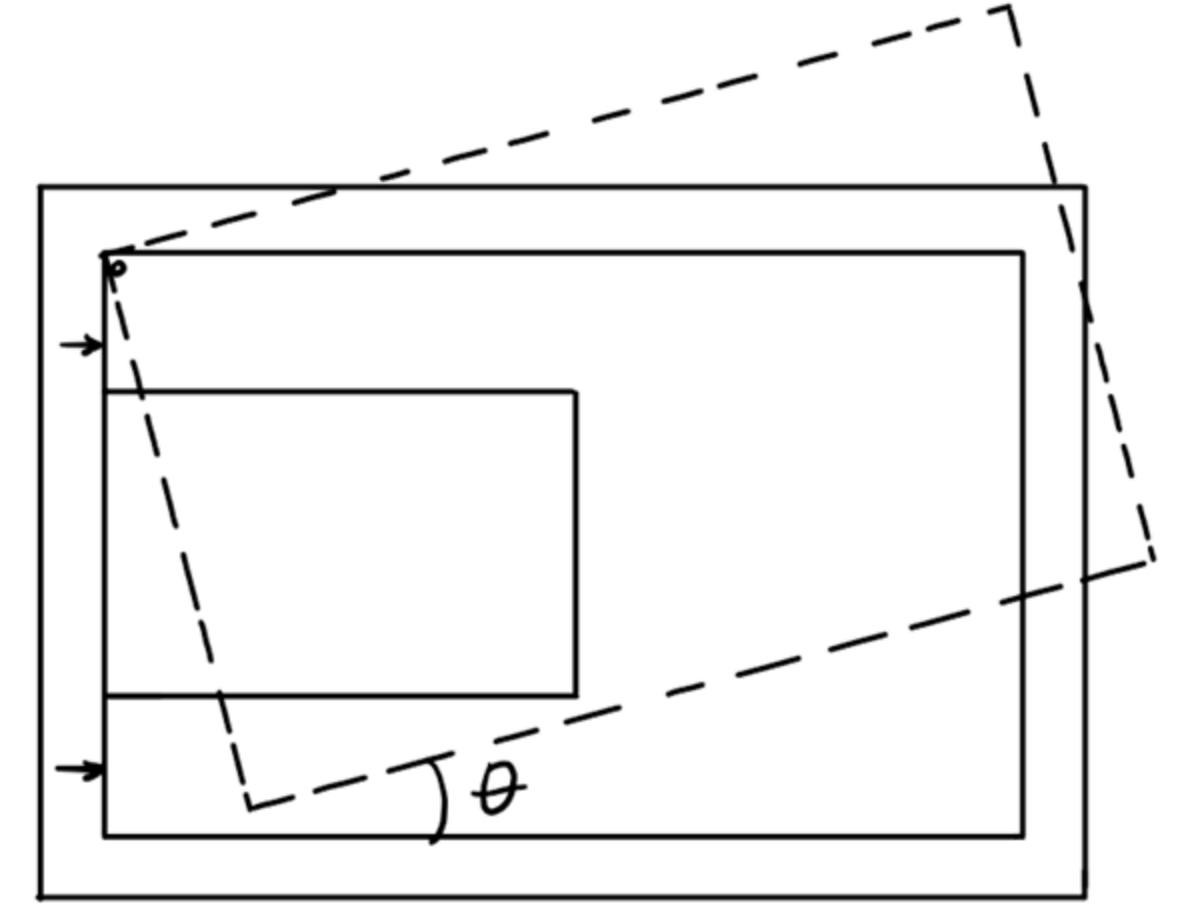
AUTOMATIC ROTATION



CANTILEVER BEAM



RACK MOUNTED

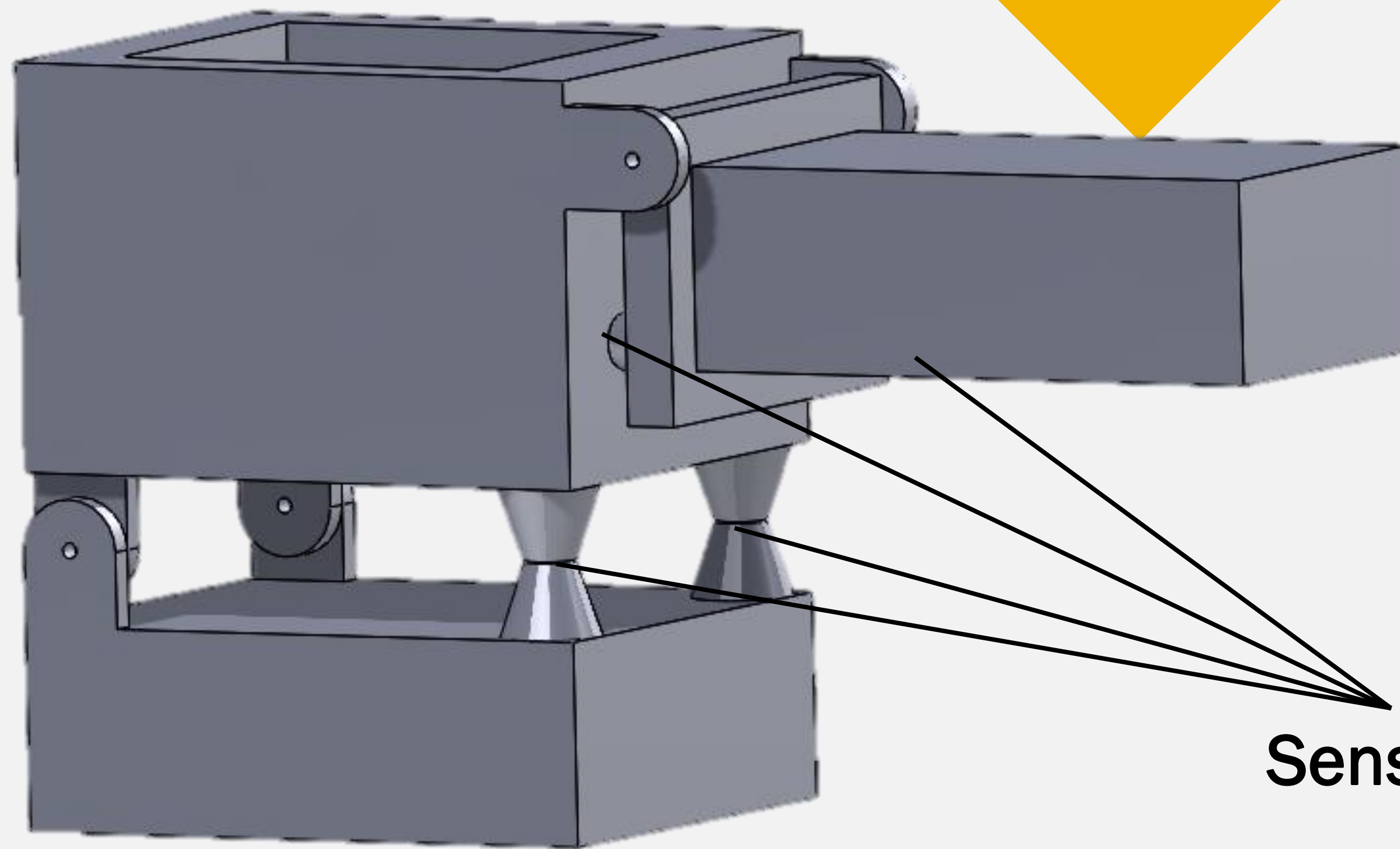


CANTILEVER BEAM WITH BOX

LEARNING THE HARD WAY



Place
Object
Here



Sensors



DECISION MATRIX

		Criteria (0-100)									
		X and Y Axis	Z Axis	Size	Accuracy (X-Y)	Accuracy (Z)	Ease of Use	Time	Rack Mount Capable		
	Importance Rating (0-100)	100	95	50	95	95	85	10	100		
Design Idea	Comment									Totals	Percentage
Design 1	Cantilever Beam	100	100	100	92	50	90	100	100	56640	89.90%
Design 2	Automatic Rotation	100	100	100	100	100	90	80	10	52950	84.05%
Design 3	4 Transducer tilt table	100	100	100	100	100	100	100	50	58000	92.06%
Design 4	JPL tilt table	100	100	100	100	100	100	100	50	58000	92.06%
Design 5	Rack Mounted	100	0	100	92	0	90	0	100	41390	65.70%
Design 6	Cantilevered Beam with Box	100	100	90	92	100	90	100	100	60890	96.65%
Design 7	Prototype 1 - AT-AT	0	0	100	0	0	90	100	50	18650	29.60%
Design 8	Prototype 2 - Triangle	100	100	100	100	100	100	100	100	63000	100.00%

WHICH DESIGN SHOULD WE USE?



84

AUTOMATIC ROTATION



97

CANTILEVER BEAM
WITH BOX



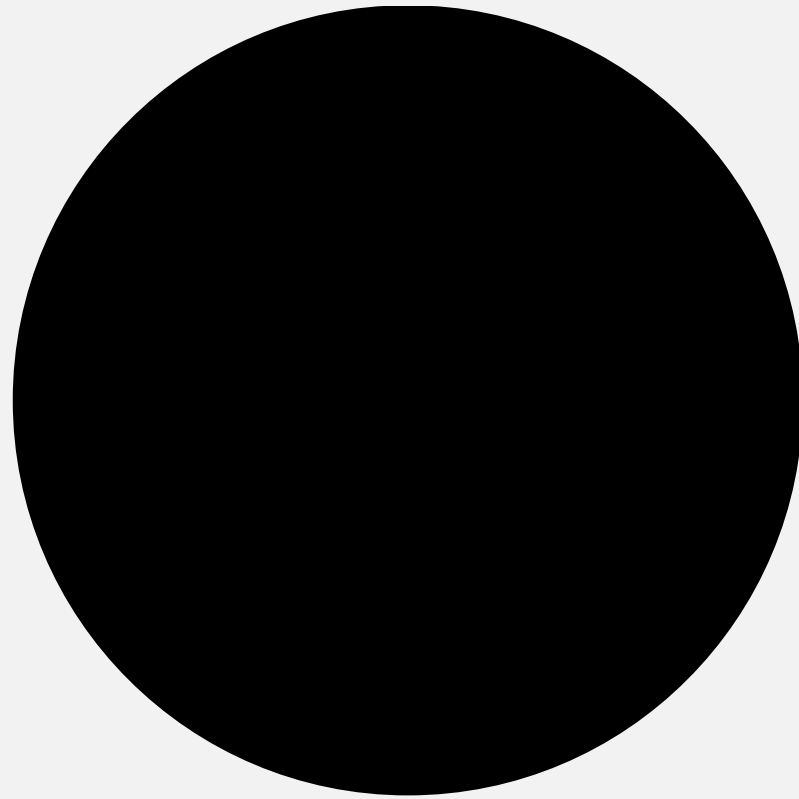
66

RACK MOUNTED



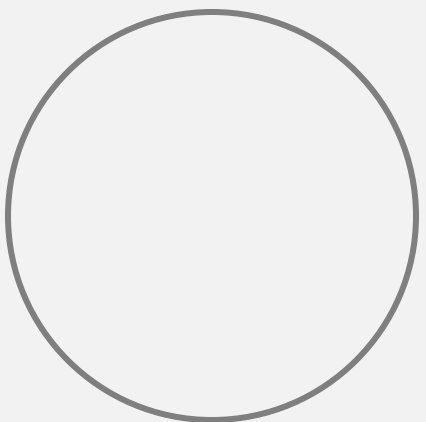
92

TILTED TABLE



100

TRIANGULAR TABLE
PROTOTYPE



0

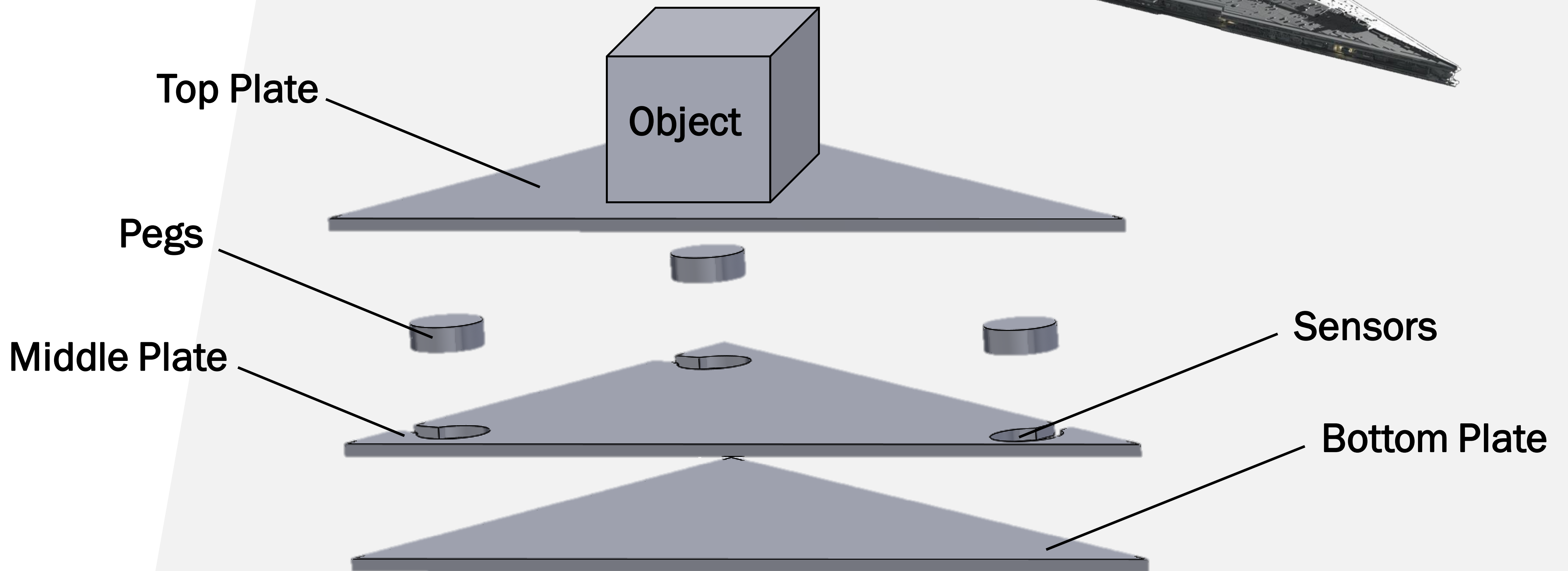
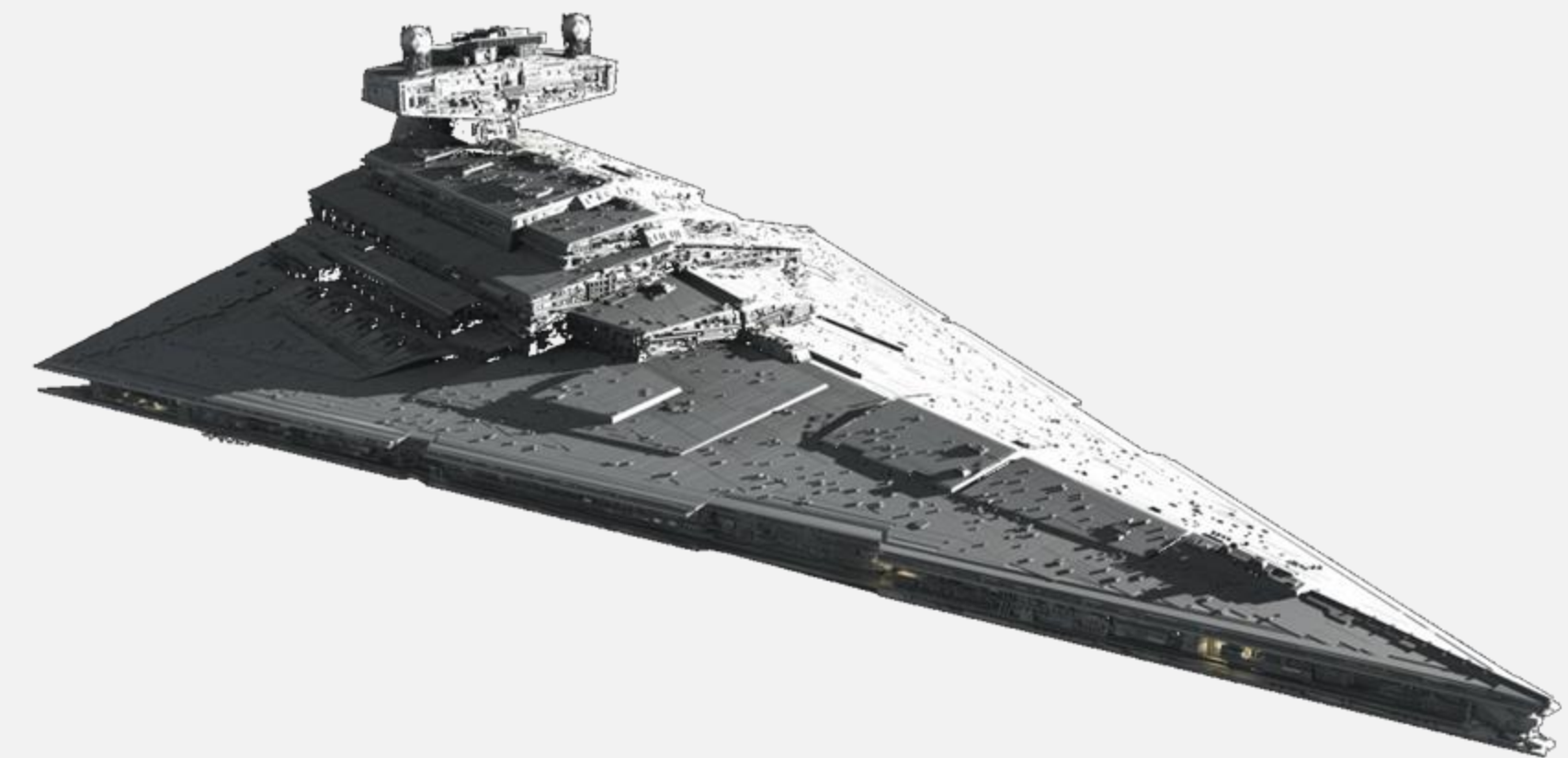
AT-AT PROTOTYPE

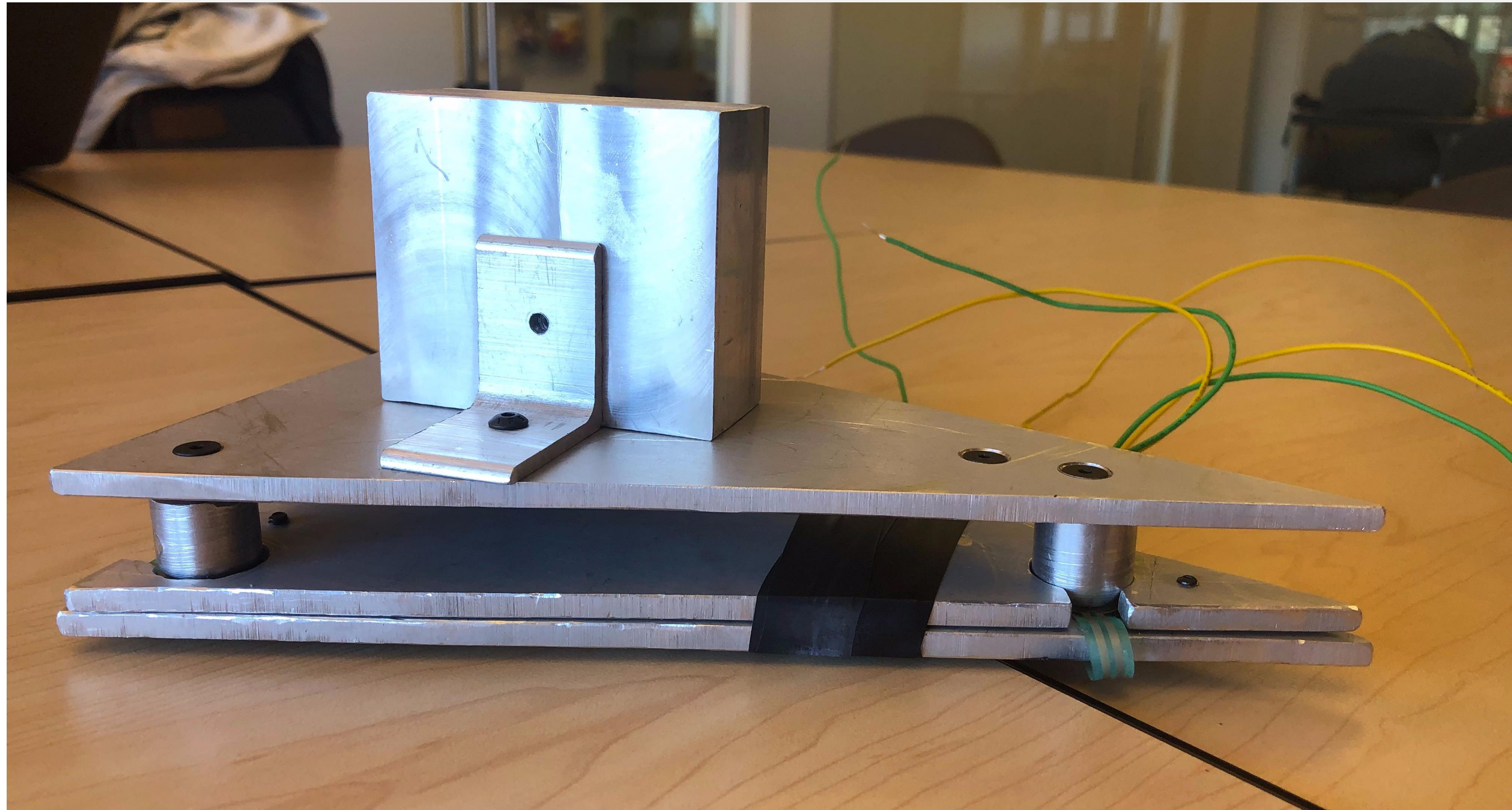


89

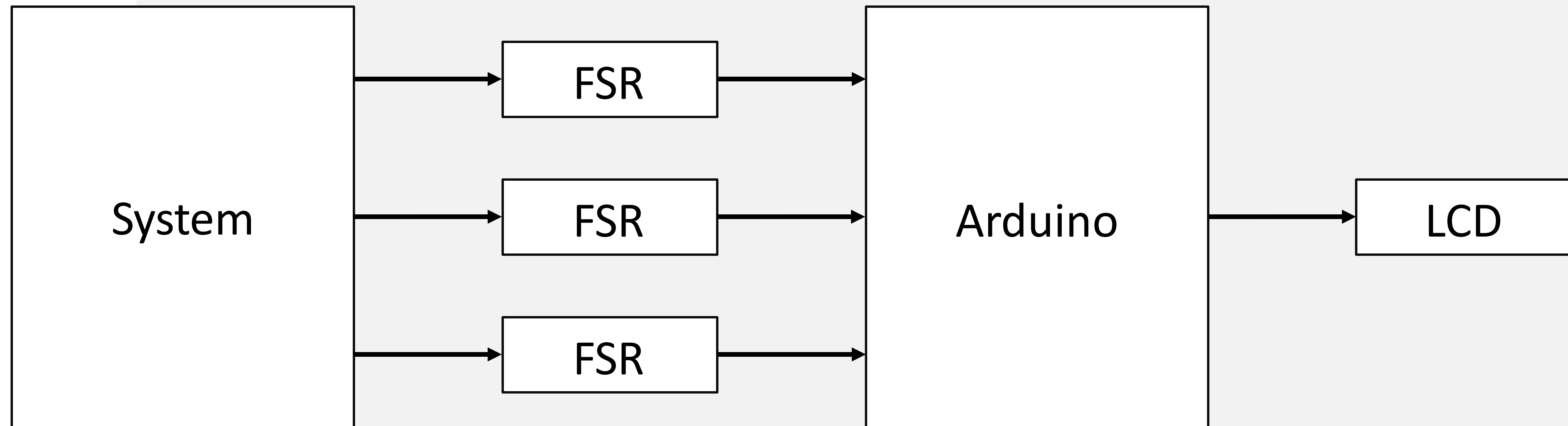
CANTILEVER BEAM

A NEW HOPE

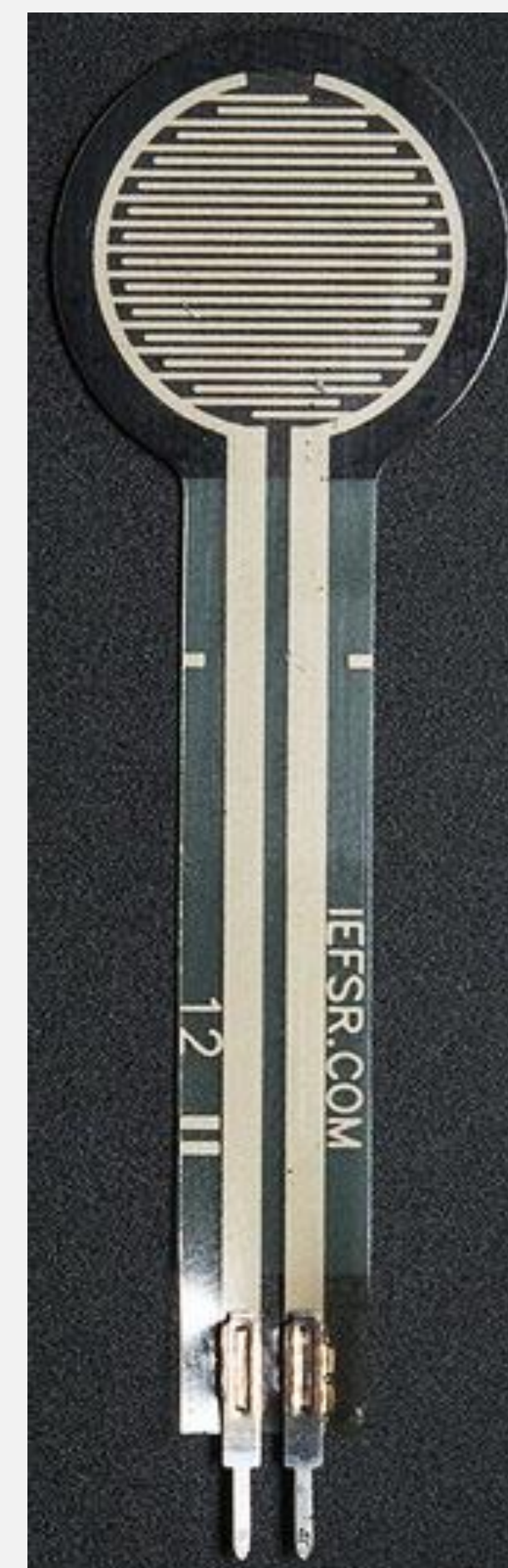
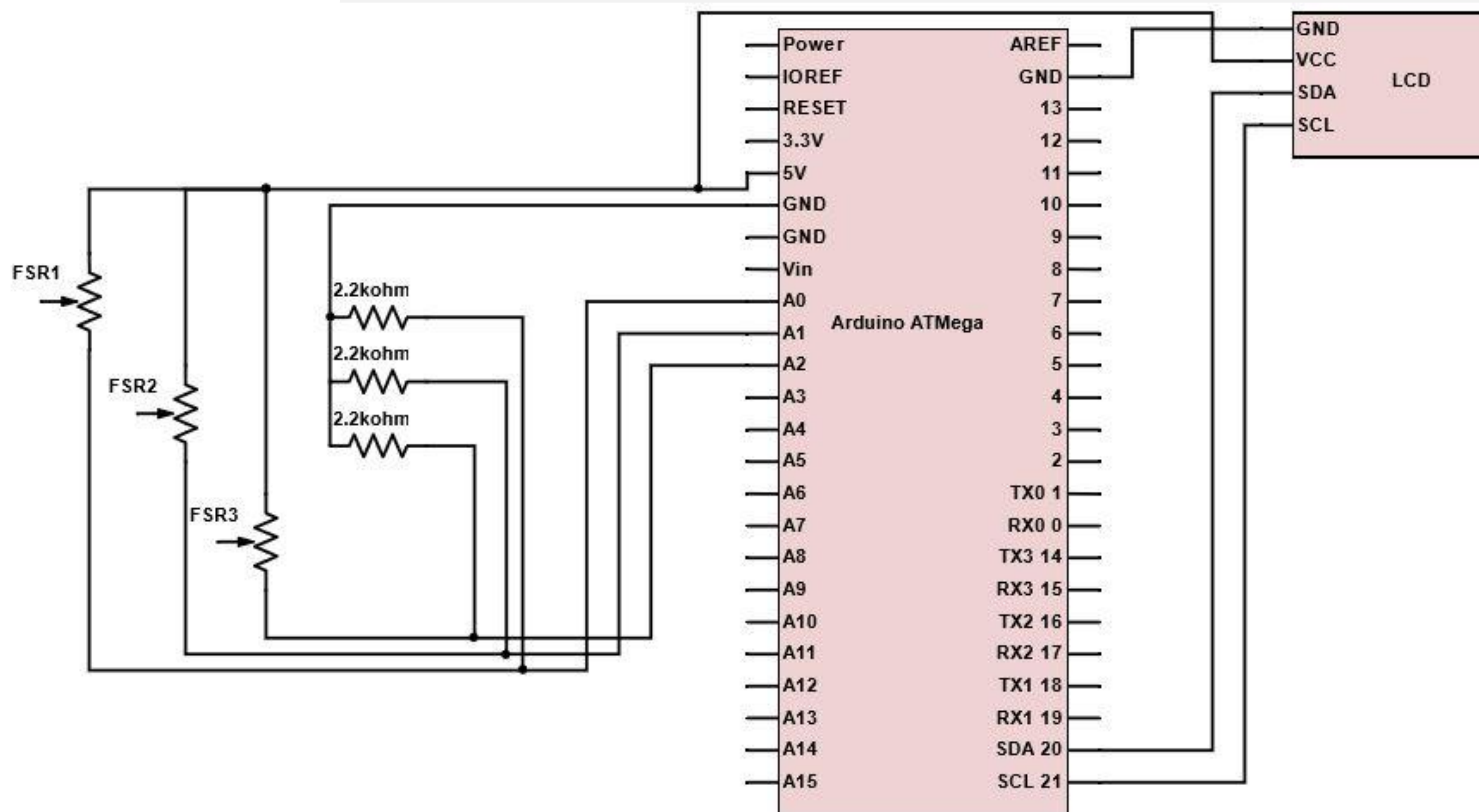




SYSTEM DIAGRAM



ELECTRICAL DESIGN



UNCERTAINTY ANALYSIS

$$U_{total} = \sqrt{U_{v1}^2 + U_{v2}^2 + U_{v3}^2 + \dots + U_{vi}^2}$$

$$U_{vi} = \frac{\partial}{\partial(vi)} \times \Delta vi$$

PREDICTED ACCURACY

10% Accuracy Sensors

$$X_{CG} \quad 3\% \quad \longrightarrow \quad X_{CG} = 3.3 \pm 0.112 \text{ in}$$

$$Y_{CG} \quad 5\% \quad \longrightarrow \quad Y_{CG} = 4.8 \pm 0.240 \text{ in}$$

$$Z_{CG} \quad 19\% \quad \longrightarrow \quad Z_{CG} = 10.07 \pm 1.912 \text{ in}$$

WILL NEW SENSORS IMPROVE ACCURACY?

1% Accuracy Sensors

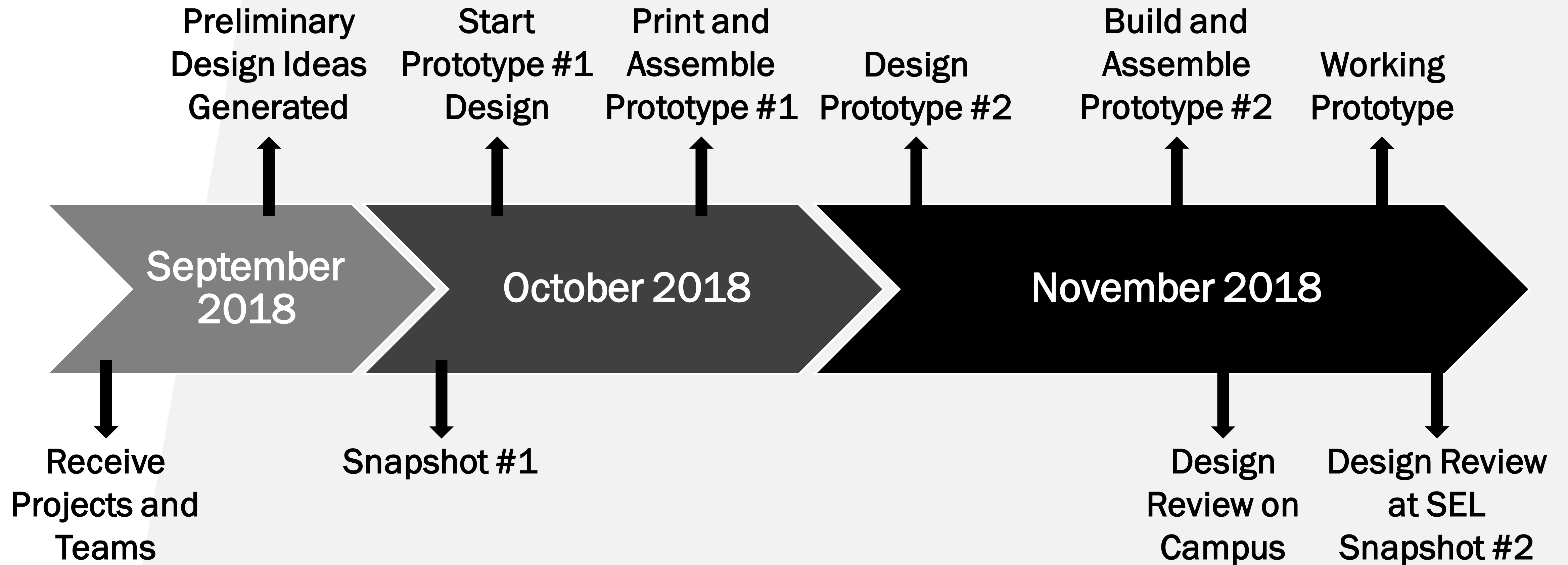
$$X_{CG} \quad 0.4\% \quad \longrightarrow \quad X_{CG} = 3.3 \pm 0.011 \text{ in}$$

$$Y_{CG} \quad 0.5\% \quad \longrightarrow \quad Y_{CG} = 4.8 \pm 0.024 \text{ in}$$

$$Z_{CG} \quad 18\% \quad \longrightarrow \quad Z_{CG} = 10.07 \pm 1.818 \text{ in}$$



PROGRESS SO FAR



LESSONS LEARNED

- I 3D Printing
- I Math Validation
- I Manufacturing
- I Short Circuit
- I Melted Sensor



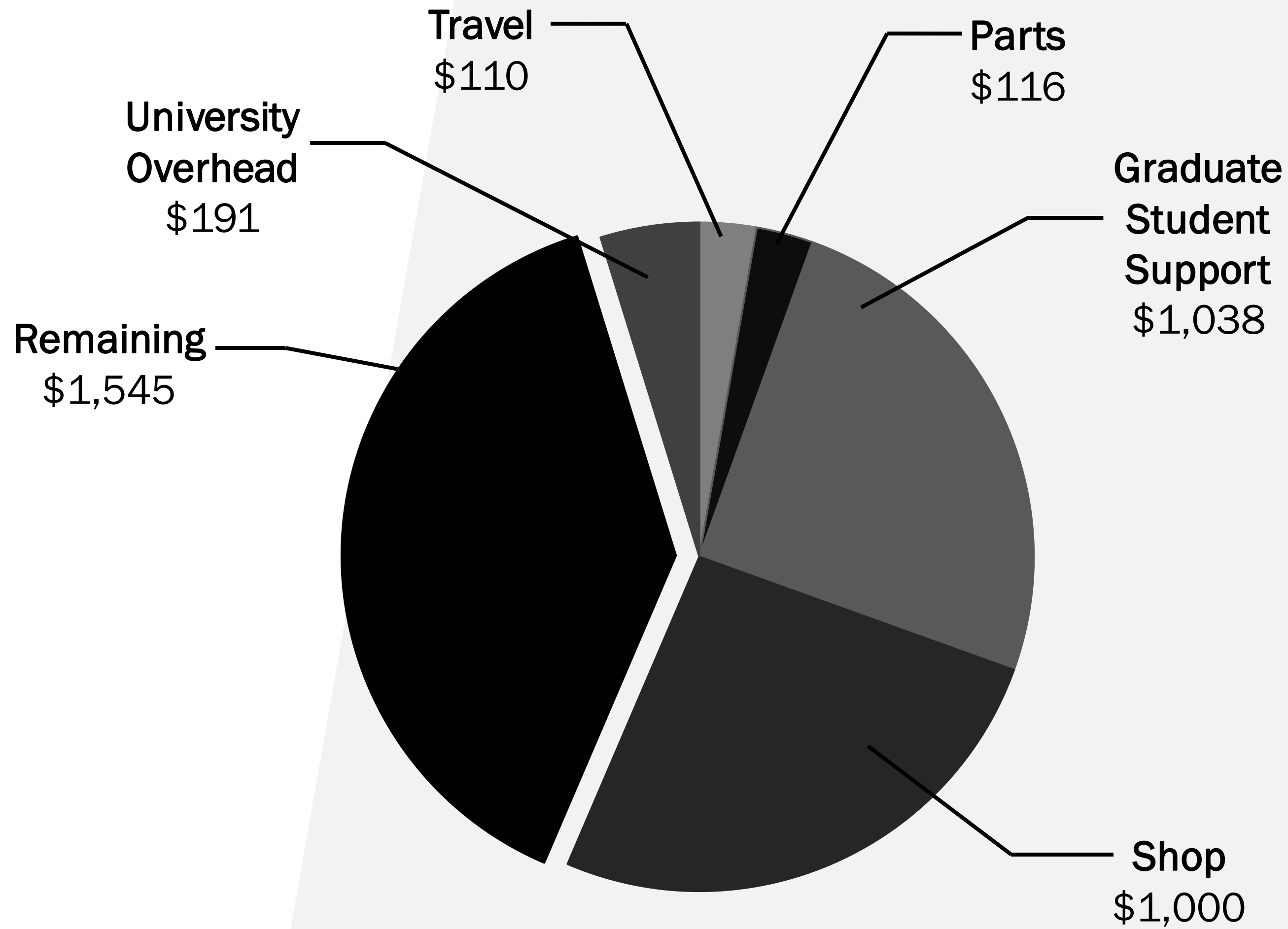
FUTURE SPENDING SENSORS

I Lord Sensing: $\$915.00/\text{sensor} * 4 \text{ sensors} = \3660.00

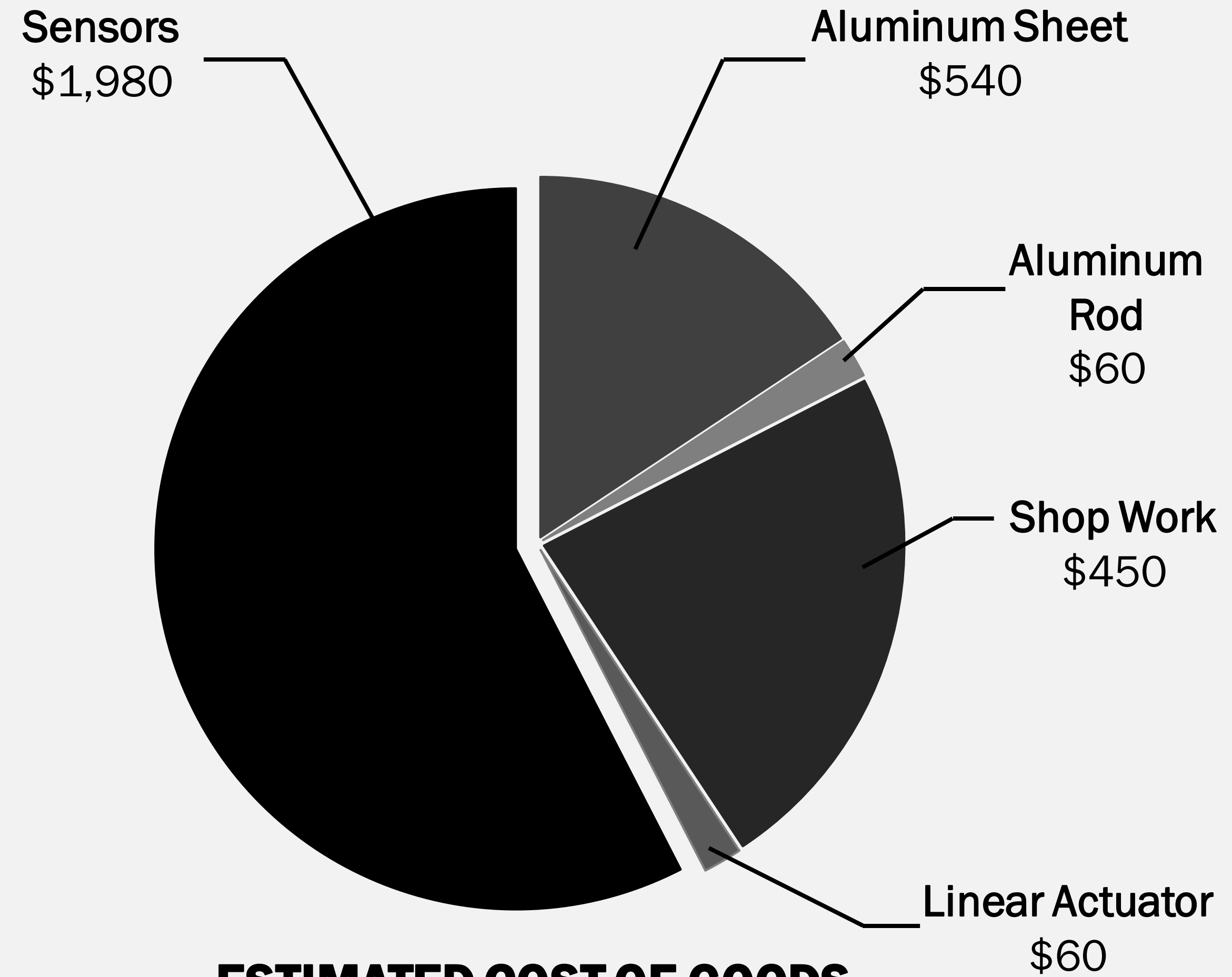
I Flintec: $\$495.00/\text{sensor} * 4 \text{ sensors} = \1980.00



LET'S TALK MONEY

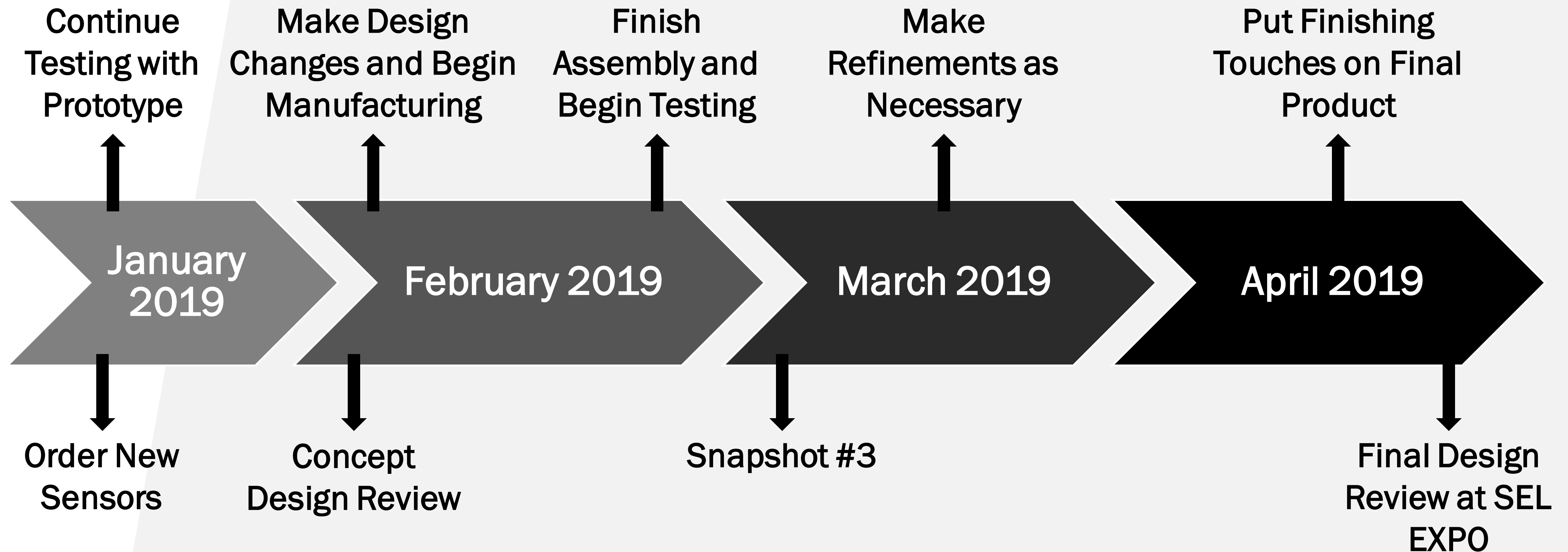


CURRENT BREAKDOWN
TOTAL: \$4,000



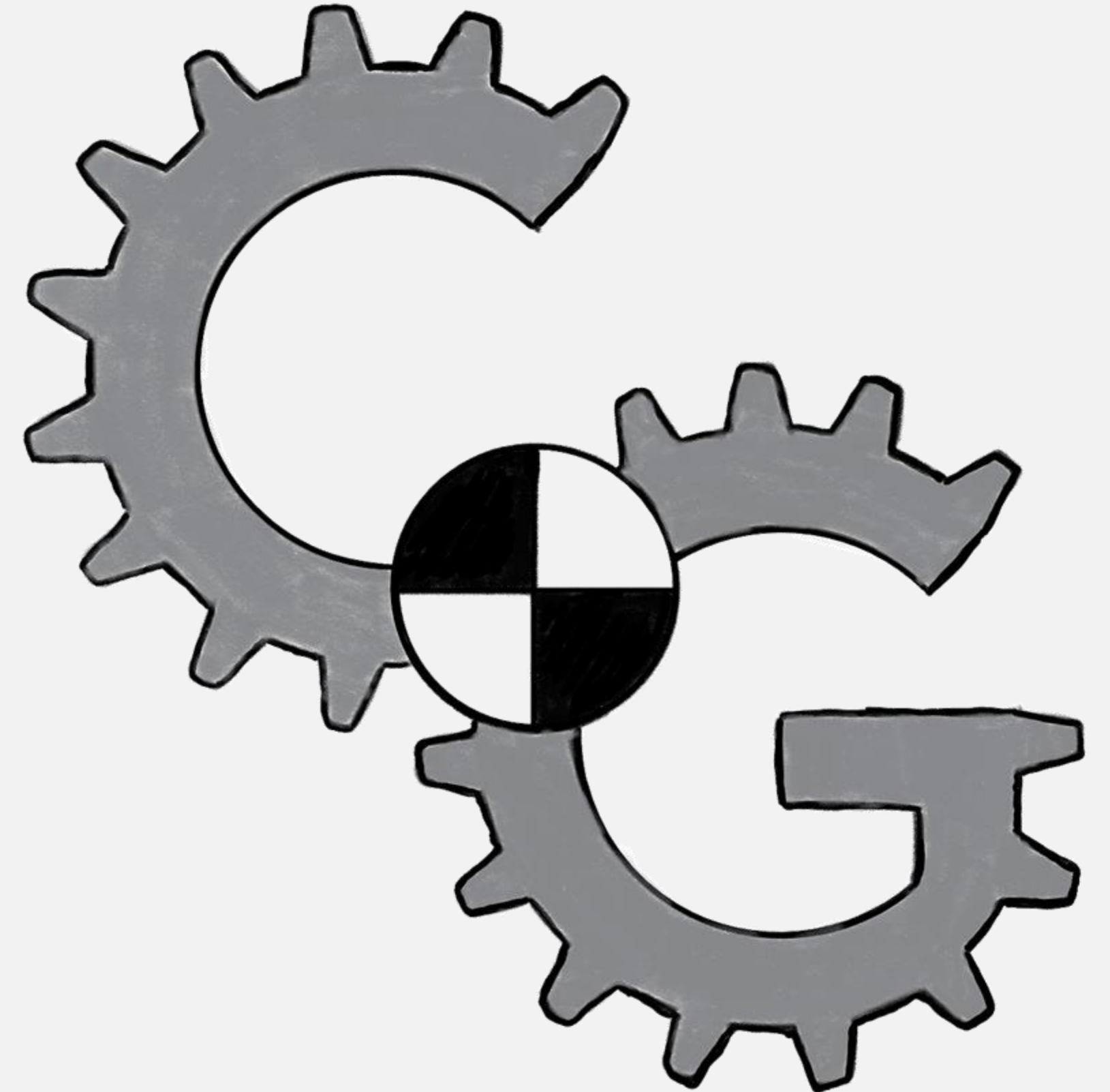
ESTIMATED COST OF GOODS
TOTAL: \$3,090

WHAT WE PLAN TO ACCOMPLISH



WORKING TOWARDS THE FINAL PRODUCT

- I Fully automated
- I Scale Up Size
- I Accurate Sensors
- I Stronger Materials

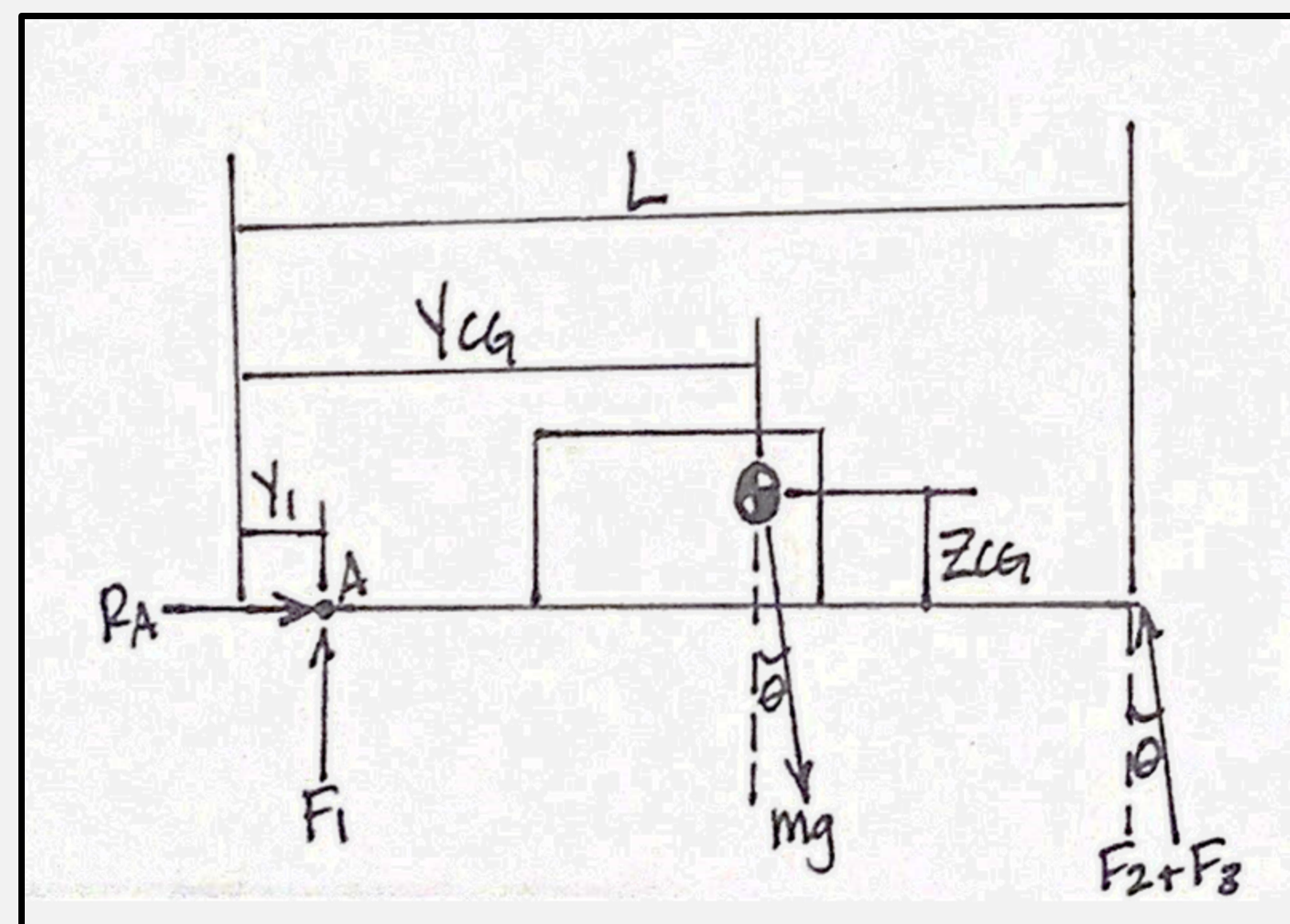
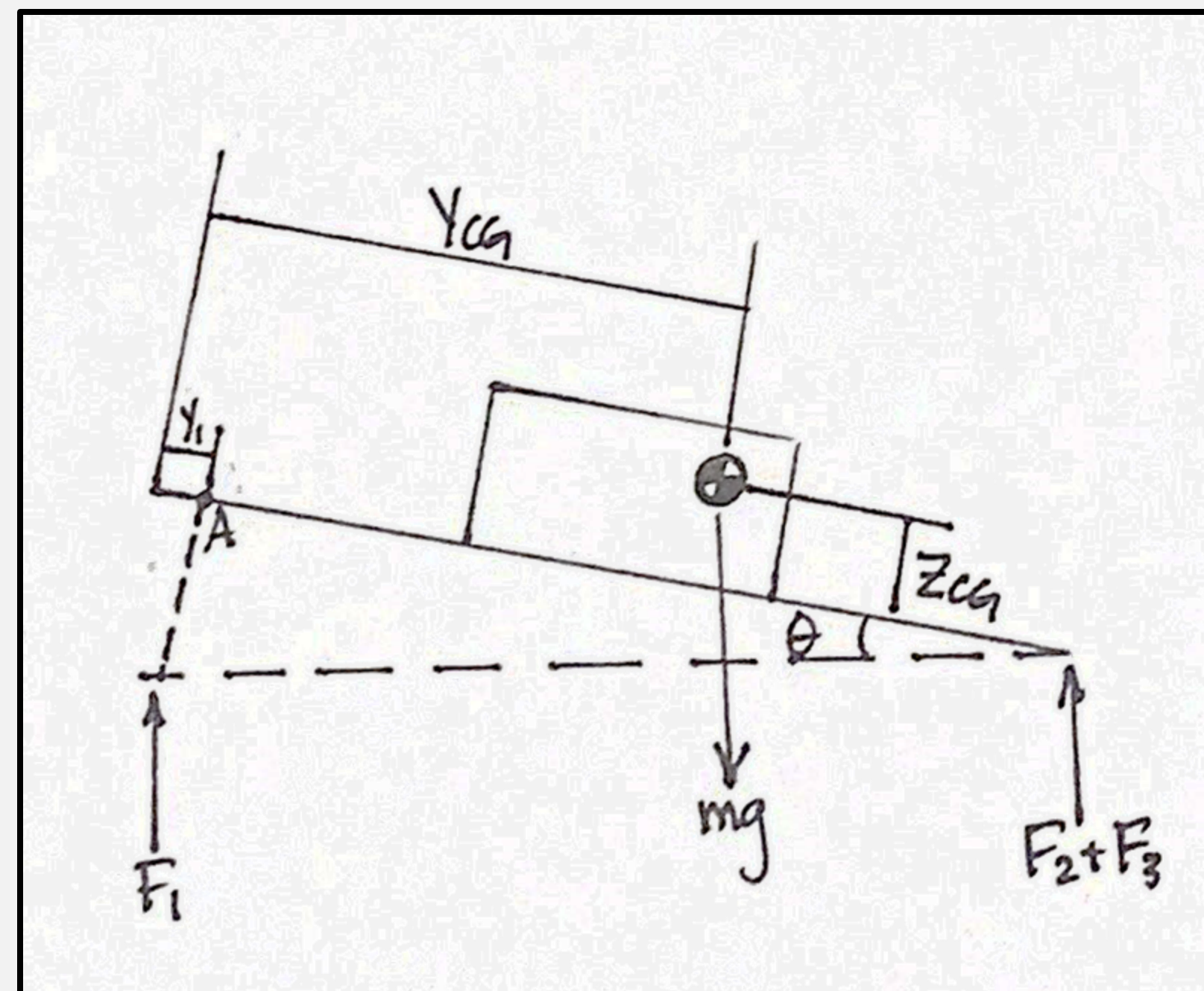
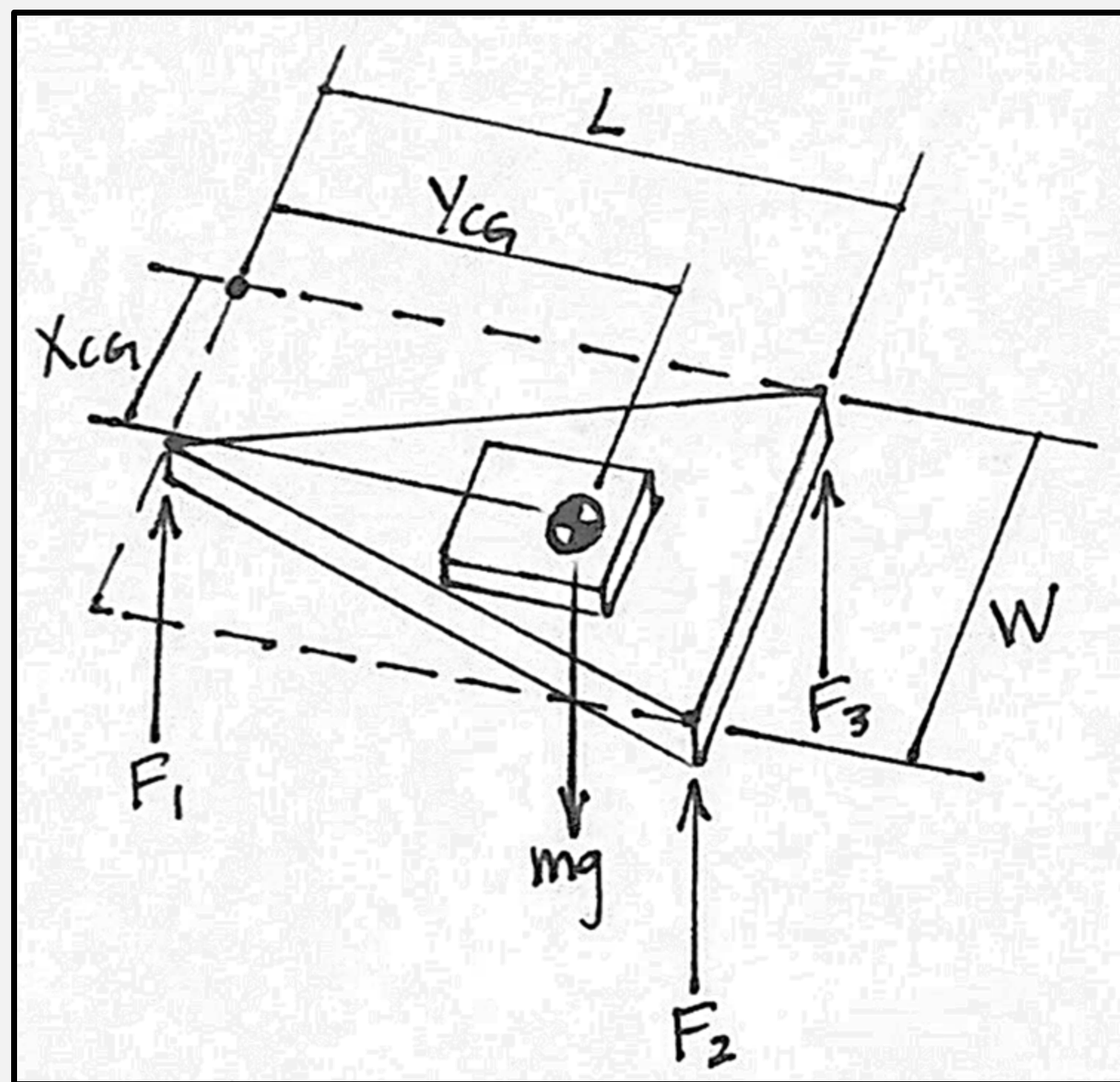




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College of Engineering

FREE BODY DIAGRAMS



THEORETICAL EQUATIONS

$$mg = F_1 + F_2 + F_3$$

$$x_{cg} = \frac{F_1(W/2) + F_2(W)}{mg}$$

$$y_{cg} = \frac{F_2(L) + F_3(L)}{mg}$$

$$z_{cg} = \frac{(mg \cos \theta)(L_{edge \rightarrow B} - y_{cg}) - F_1(L_{A \rightarrow B}) - (F_2 + F_3)y_1}{(mg \sin \theta)} - L_{2,3}$$

ARBITRARY VALUES CURRENT PROTOTYPE

Variables

$$F_1 = 0.4 \text{ [lbf]}$$

$$F_2 = 0.4 \text{ [lbf]}$$

$$F_3 = 0.2 \text{ [lbf]}$$

$$W = 5.5 \text{ [in]}$$

$$L = 8 \text{ [in]}$$

$$L_{\text{edge}} = 3 \text{ [in]}$$

$$L_{\text{ab}} = 7.5 \text{ [in]}$$

$$y_1 = 0.375 \text{ [in]}$$

$$L_{23} = 0.5 \text{ [in]}$$

$$\theta = \frac{\pi}{6} \text{ [rad]}$$



LARGE SCALE ACCURACY

1% Accuracy Sensors

$$X_{CG} \quad 0.3\% \quad \longrightarrow \quad X_{CG} = 10.73 \pm 0.034 \text{ in}$$

$$Y_{CG} \quad 0.6\% \quad \longrightarrow \quad Y_{CG} = 12 \pm 0.074 \text{ in}$$

$$Z_{CG} \quad 6.3\% \quad \longrightarrow \quad Z_{CG} = 32.46 \pm 2.051 \text{ in}$$

ARBITRARY VALUES LARGE SCALE

Variables

$$F_1 = 25 \text{ [lbf]}$$

$$F_2 = 15 \text{ [lbf]}$$

$$F_3 = 10 \text{ [lbf]}$$

$$W = 19.5 \text{ [in]}$$

$$L = 24 \text{ [in]}$$

$$L_{\text{edge}} = 10 \text{ [in]}$$

$$L_{\text{ab}} = 20 \text{ [in]}$$

$$y_1 = 2 \text{ [in]}$$

$$L_{23} = 7 \text{ [in]}$$

$$\theta = \frac{\pi}{6} \text{ [rad]}$$

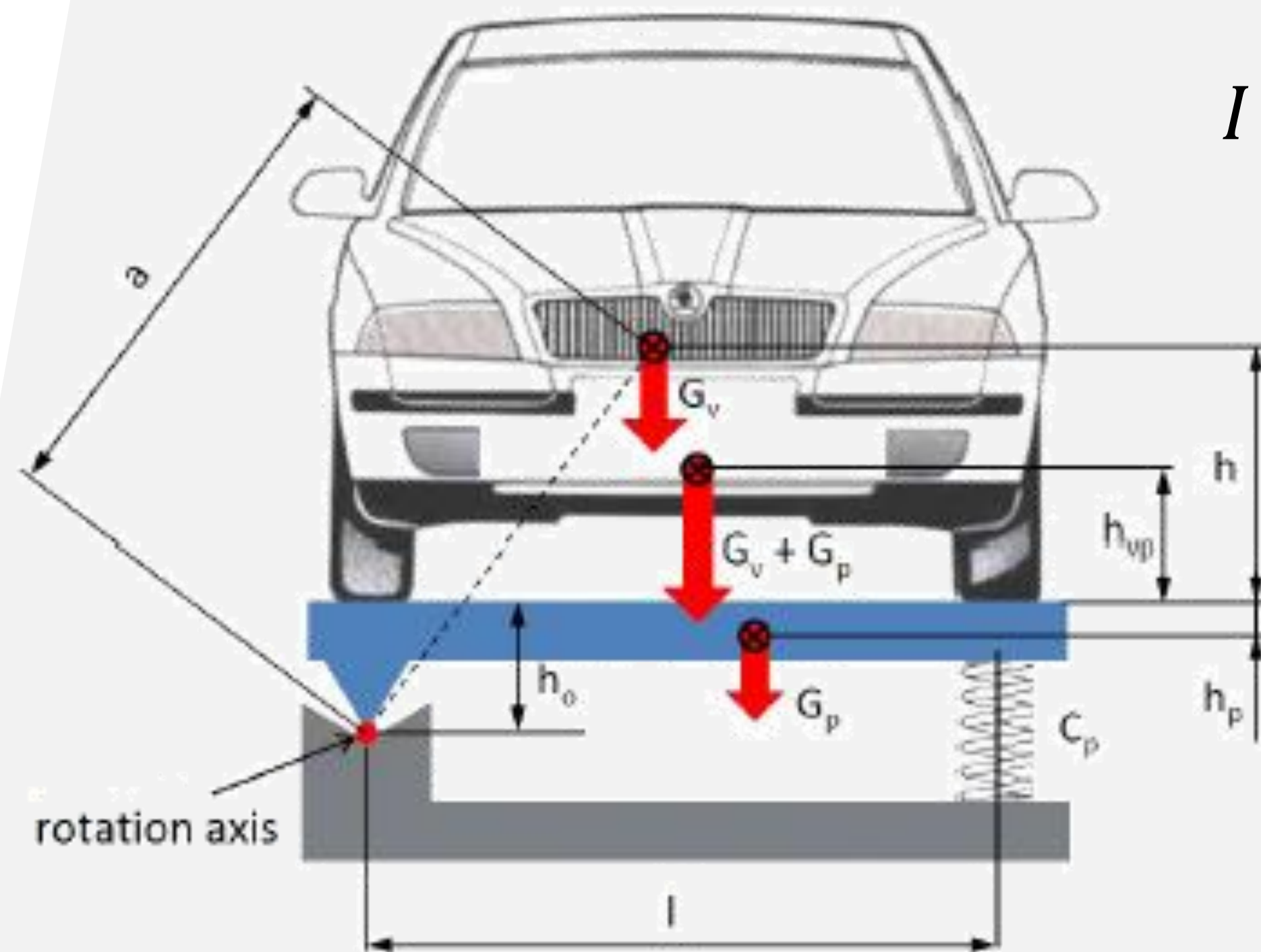


ESTIMATED COST OF GOODS

Item	Aluminum Sheet Metal	Aluminum Rods	Hours of Shop Work	Linear Actuator	Sensors
Cost per unit	\$180.00	\$20.00	\$75.00	\$60.00	\$495.00
Quantity	3	3	6	1	4
Total each	\$540.00	\$60.00	\$450.00	\$60.00	\$1,980.00
				Sum total	\$3,090.00

PROJECT LEARNING

NEW APPROACH TO MEASURE THE CG OF A VEHICLE



$$I = \frac{C_p \cdot l^2 - G_v \cdot (h_o + h) - G_p \cdot (h_o - h_p)}{4 \cdot \pi^2} \cdot T^2$$

C_p Coil spring stiffness

G_v Vehicle weight

G_p Pendulum weight

I Moment of inertia of vehicle and pendulum

l Distance from spring to rotation axis

h Vehicle center of gravity height

h_o Distance from rotation axis to pendulum floor

h_p Distance from pendulum center of gravity to pendulum floor