Preliminary Design Review

Baffling Buffs: Deployable Star Tracker Baffle

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Project Overview

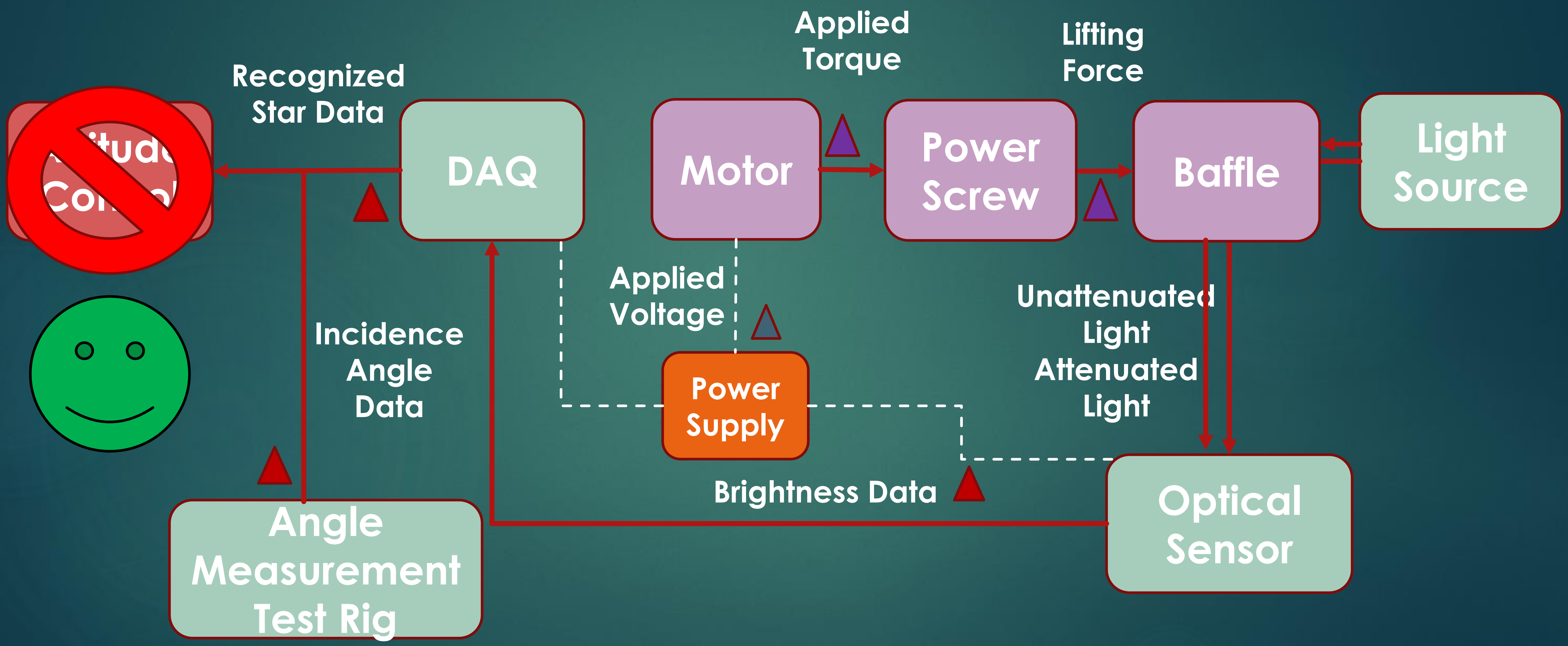
Star Tracker Baffles

- Star trackers need to **see dim light** from distant stars
- They **compare** what they see with on board star catalog to make spacecraft attitude adjustments
- Nearby bodies emit/reflect stray light which **hinders** star trackers ability to see dim light
- Baffles **attenuate and eliminate** stray light from nearby bodies

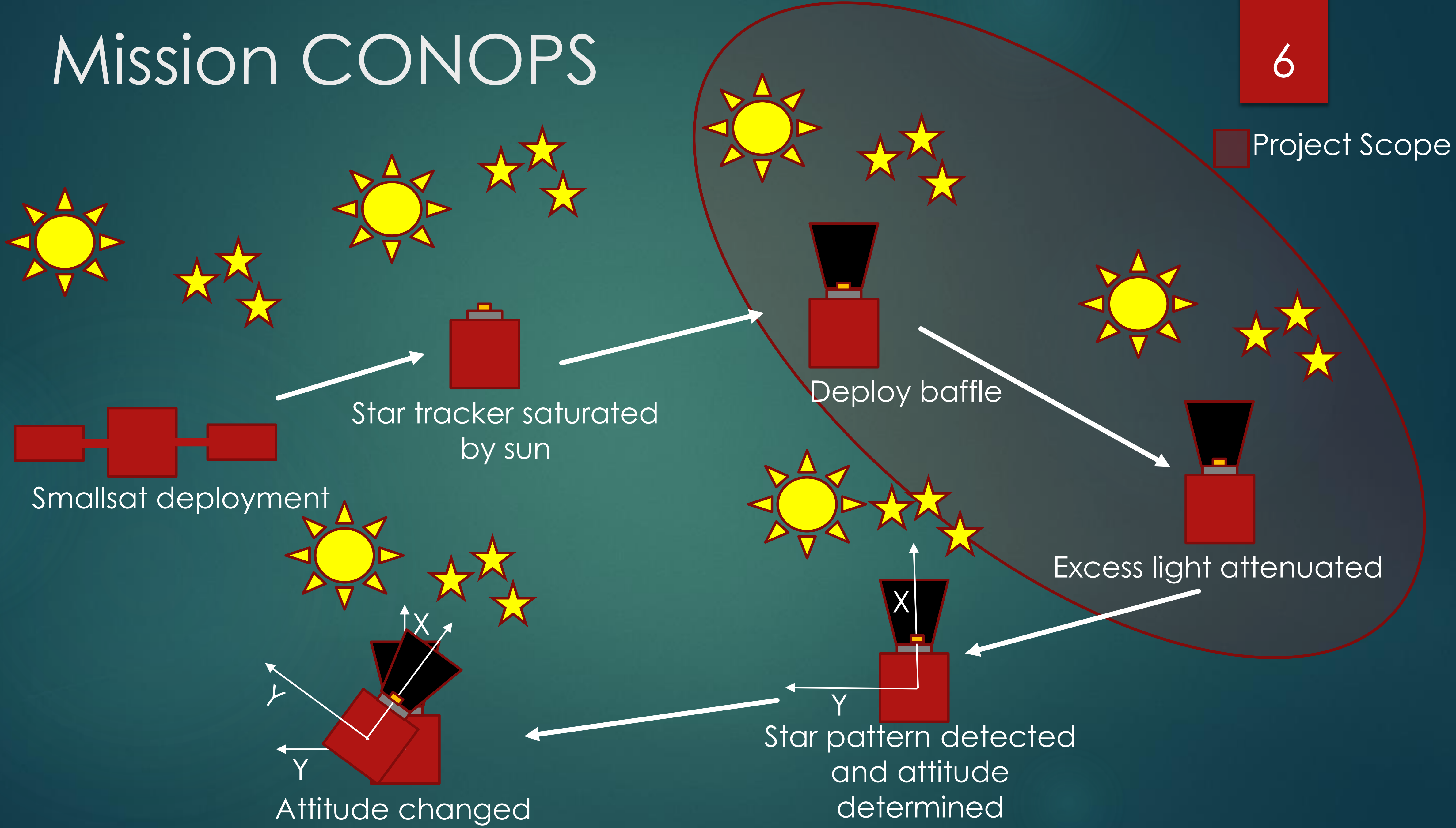
Project Goals

- **Develop a prototype** deployable baffle for a star tracker to be used on a small satellite platform
- **Design and manufacture** a deployable baffle to limit stray light into an optical sensor
- **Develop a test methodology** and instrumentation suite to measure performance of the baffle for stray light elimination
- **Perform the tests** for the deployment and stray light elimination of the baffle

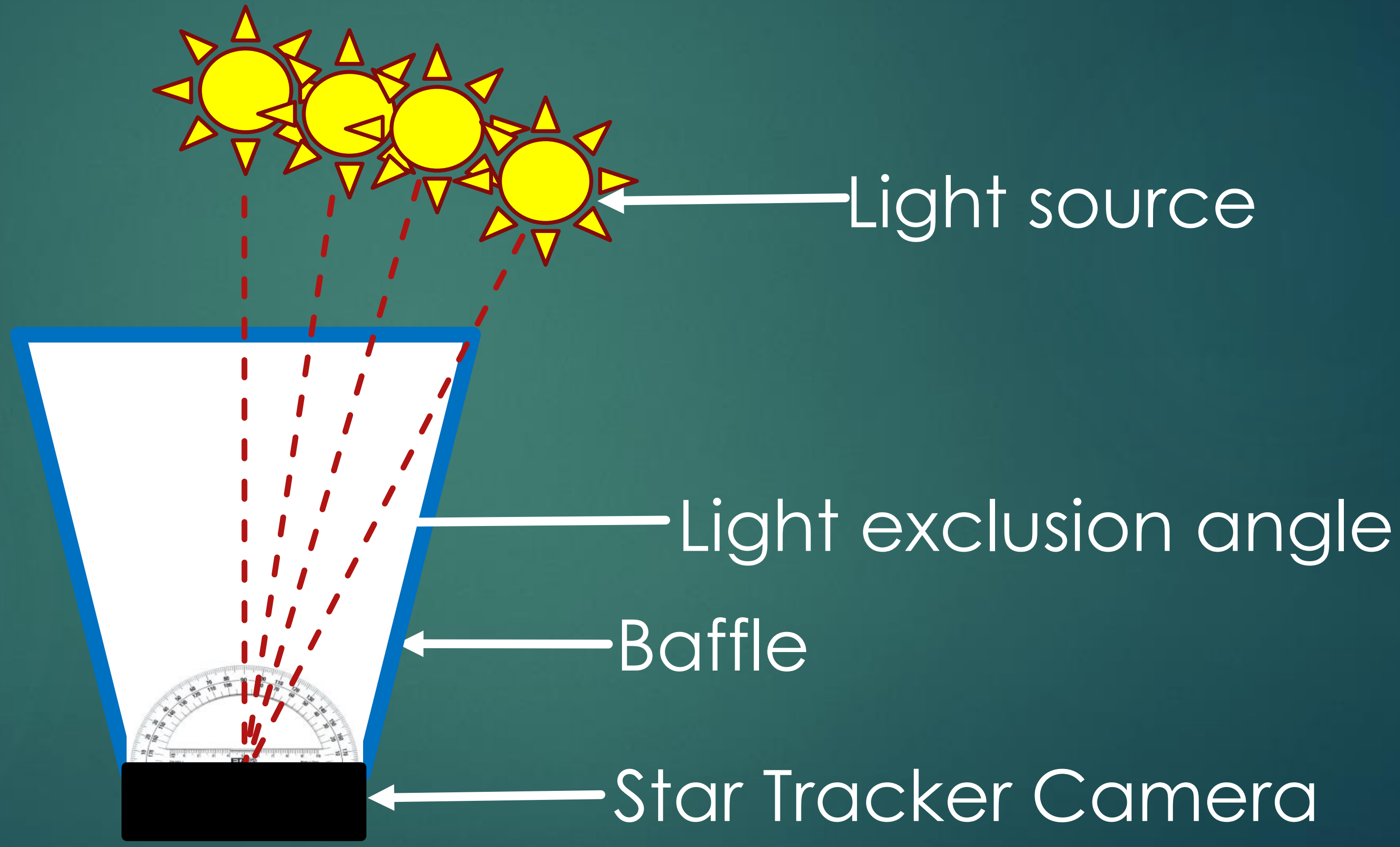
Functional Block Diagram



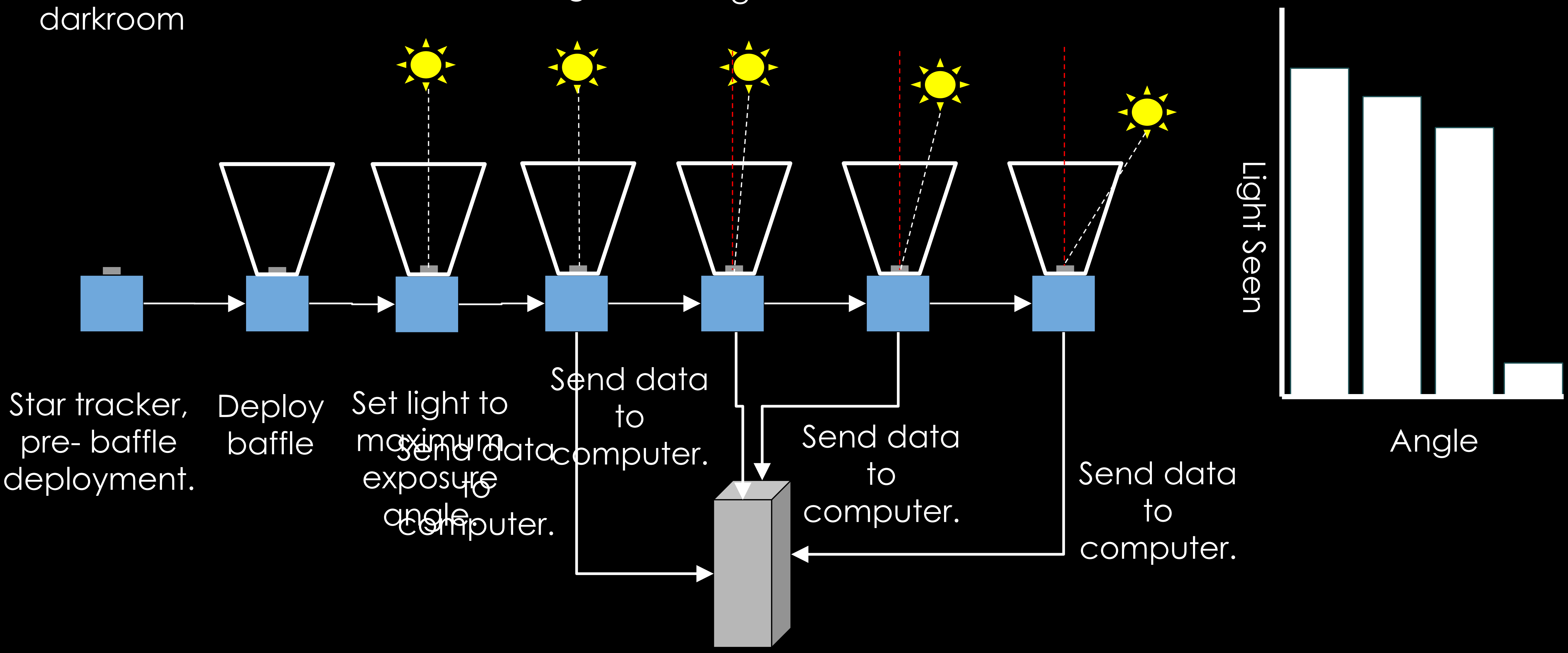
Mission CONOPS



Light Exclusion



Testing CONOPS



Project Assumptions

- Design is proof of concept
  - Need not be space grade
- Focus on attenuating light from Sun and Earth
- Spacecraft will be in L.E.O.

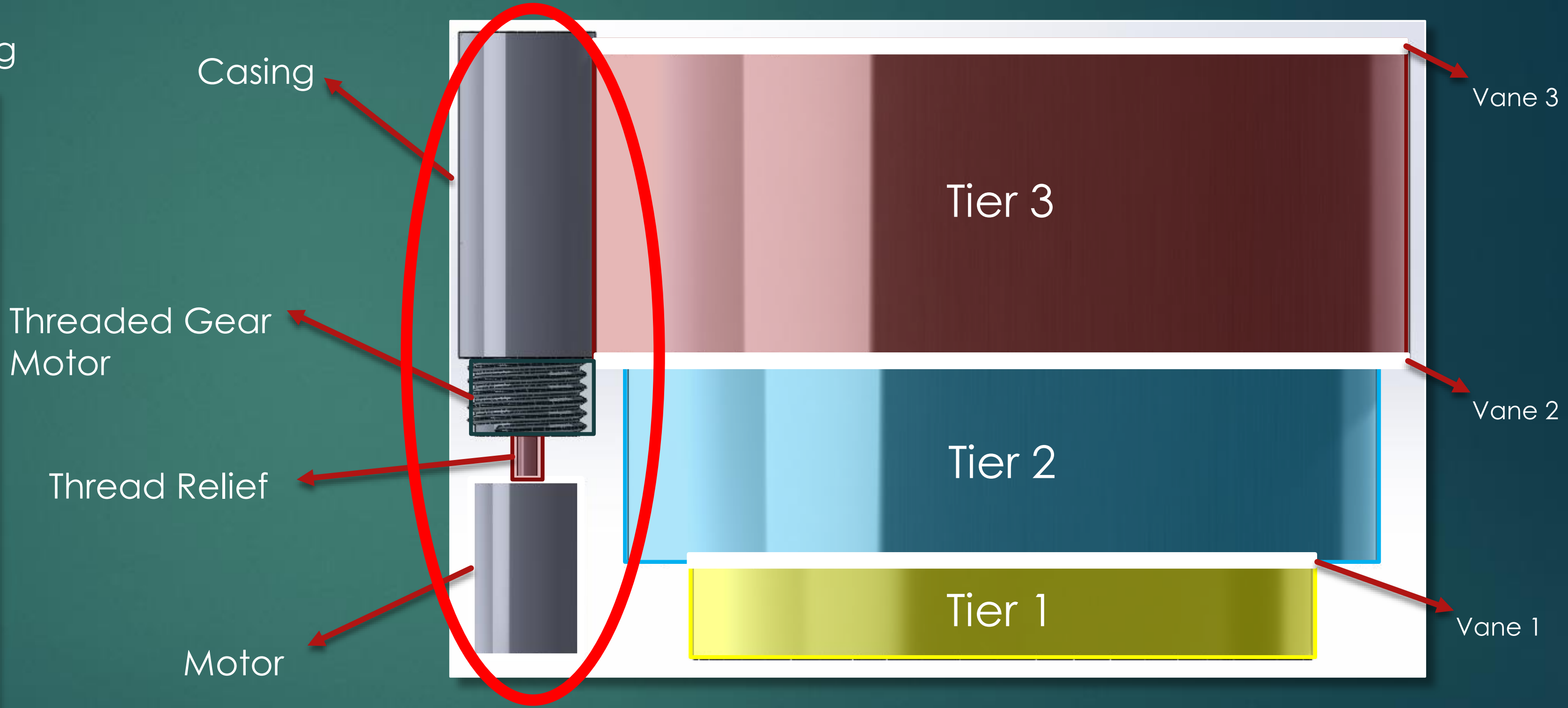
- From spacecraft bus:
  - Voltage available: 28 V
  - Current available: 2.5 Amps
  - Power available: 70 Watts

Functional Requirements

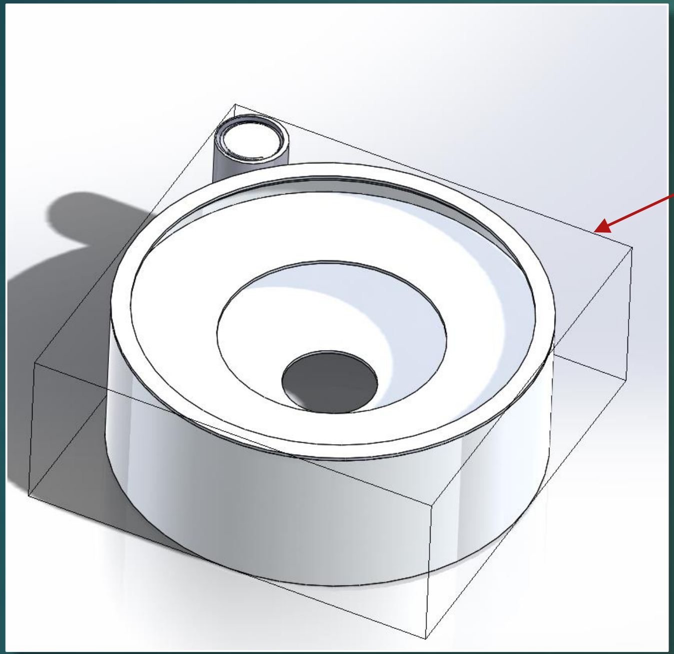
FR1:	Baffle shall be deployable	Electronic deployment with wired connection
FR2:	Baffle shall fit within given stowed volume constraints	125 mm length 125 mm width 50 mm height
FR3:	Baffle shall adhere to given mass constraints	≤ 300 grams
FR4:	Testing shall be done to determine baffle performance at given light exclusion angle.	30° light exclusion angle

Baseline Baffle Design

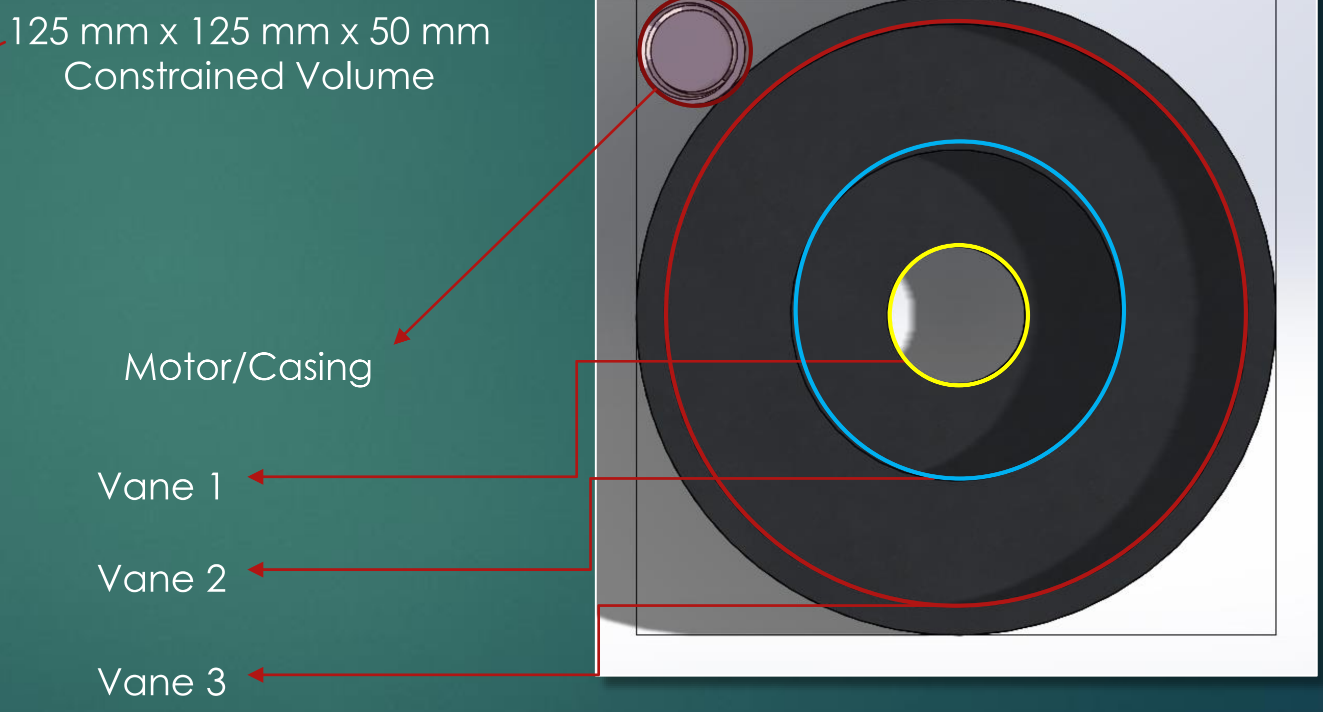
Deployed



Baseline Baffle Design



Stowed



- **FR2:** Stowed Volume Requirement:
  - 125mm x 125mm x 50mm
  - **FEASIBLE**

Baseline Baffle Design

- Deployment Mechanism
  - A screw driven by an electric motor will be used to lift a threaded casing fixed to the top tier of the baffle
  - When fully deployed, baffle height will be 96 mm
  - Lubricant will most likely be required to prevent binding
  - Spring mechanism was ruled out early on due to force to weight ratios not being feasible

Baseline Feasibility Analysis

Critical Project Feasibility Elements

1) Feasibility of Deployment

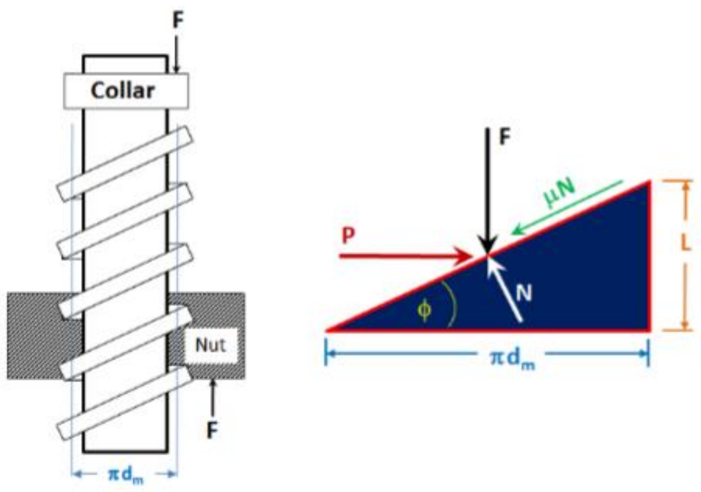
- Motor selection
- Deployment mechanism
- Material
- Manufacturing
- Software
- Testing

2) Feasibility of Light Attenuation

- Background light
- Baffle geometry
- Needed improvements
- Coating
- Stray light testing

Feasibility of Deployment

Feasibility of Deployment Mechanism



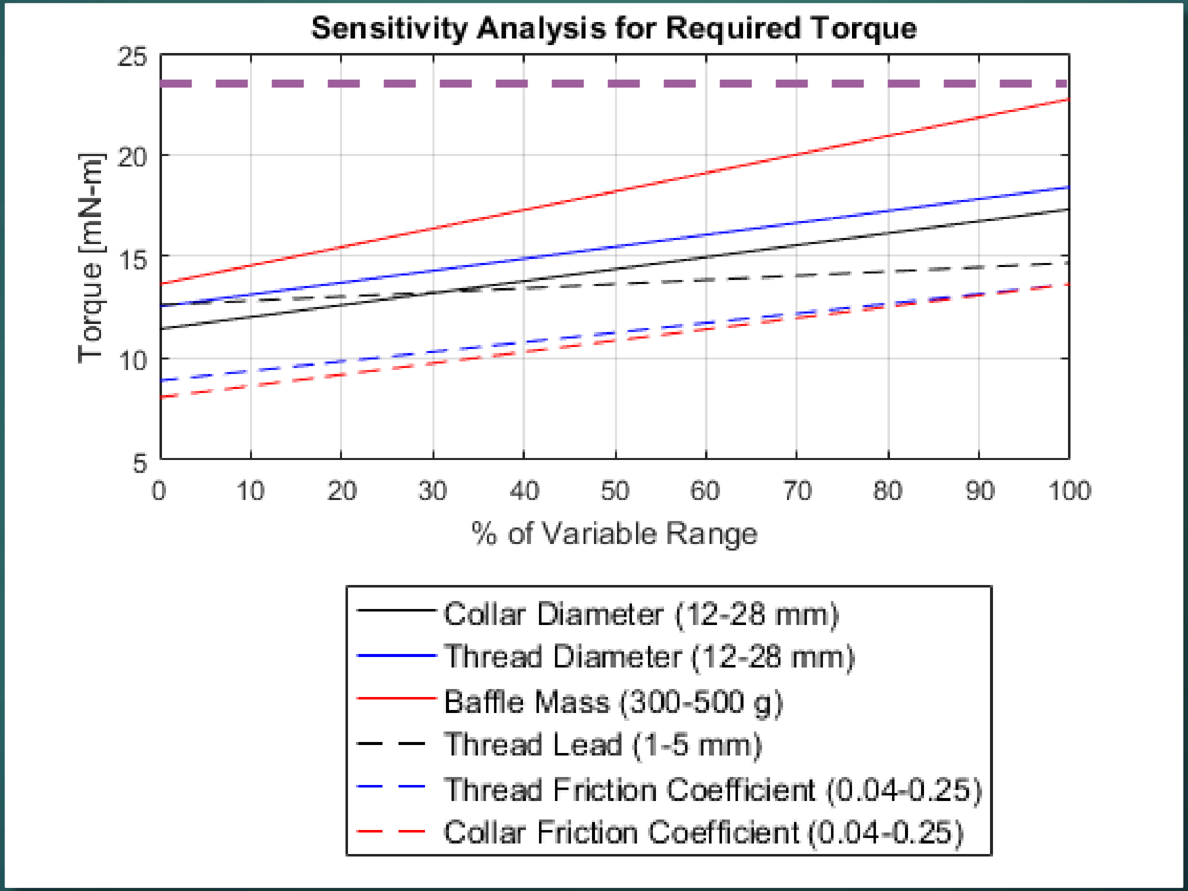
- d_m = mean thread diameter
- L = lead
- F = load
- μ = coefficient of friction for thread
- μ_c = coefficient of friction for collar

- Desired torque from lifting force:

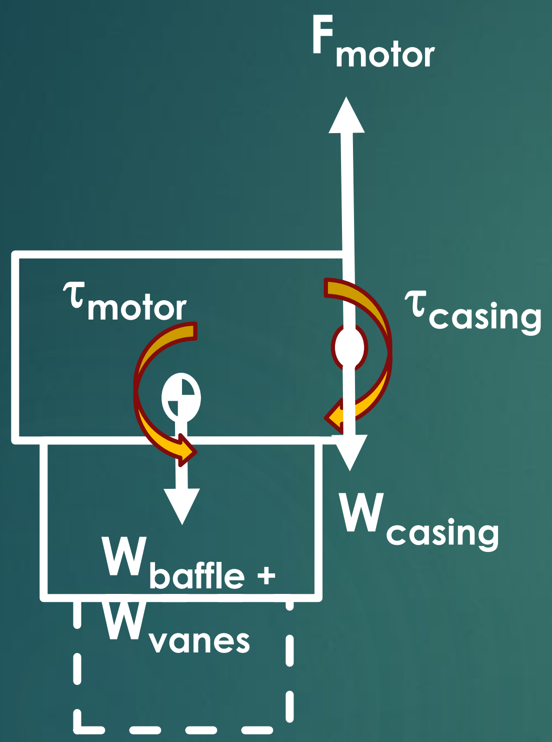
$$T_R = F \cdot \frac{d_m}{2}\left(\frac{L + \pi \cdot \mu \cdot d_m}{\pi \cdot d_m - \mu \cdot L}\right)$$

- Performed sensitivity analysis on variables to determine upper limit of torque: 23 mN*m
  - Plots on next slide

Feasibility of Deployment Mechanism



Motor Selection



Ideal case :

- $\tau_{casing} = \tau_{motor}$
- $W_{total} = W_{baffles} + W_{vanes} + W_{casing}$
- $\tau_{motor} > \tau_{weight}$

- Weight force of top 2 tiers: $W_{baffles}$ = 1.37 N
- Weight force of top 2 vanes: W_{vanes} = 0.284 N
- Weight force of motor casing attached to top tier: W_{casing} = 0.031 N
- Required upward force of motor:

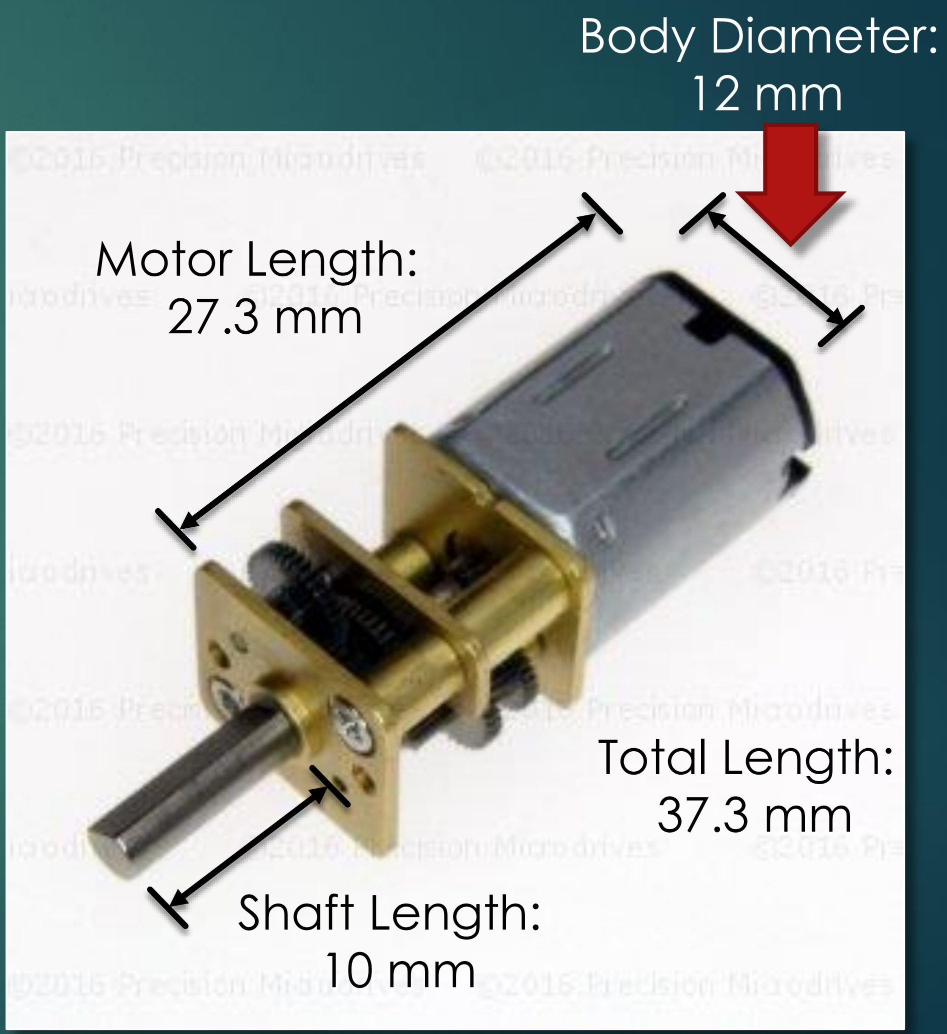
  W_{total} = 1.68 N

  τ_{weight} = 5.93 mNm
- Selected motor torque must be greater than τ_{weight}

FEASIBLE

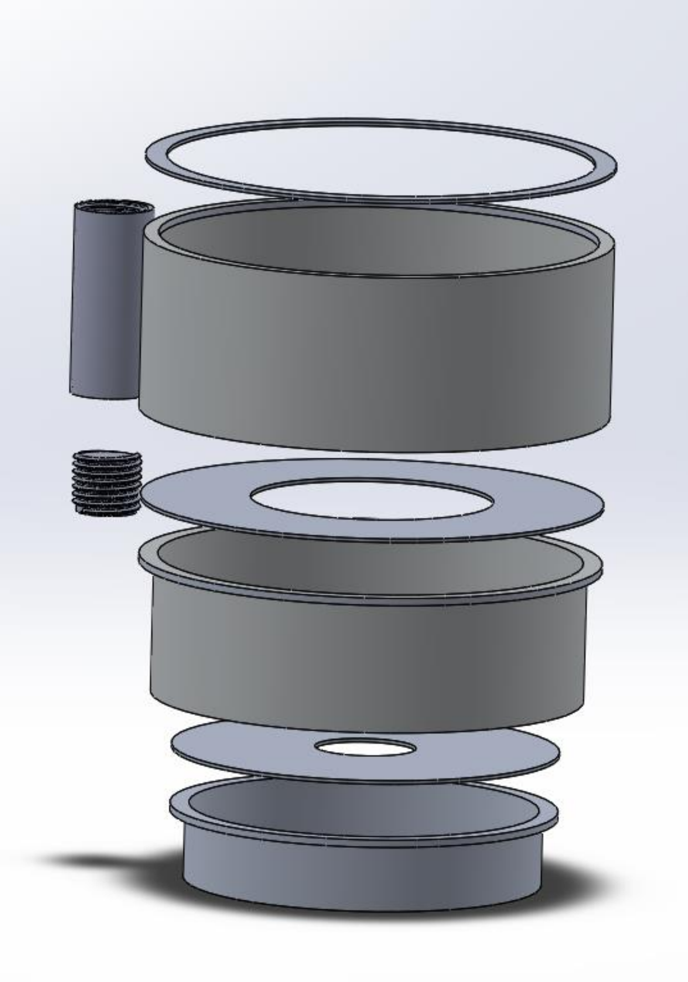
Motor Selection

- Precision Microdrives 212-117
  - Mass: 10.3 grams
  - Cost: $21 plus shipping
  - Operating Voltage: 3.3 V
  - Typical Operating Power: 345 mW @ 35mA
  - Loaded Speed: 8 rpm at 100 mN*m loaded torque



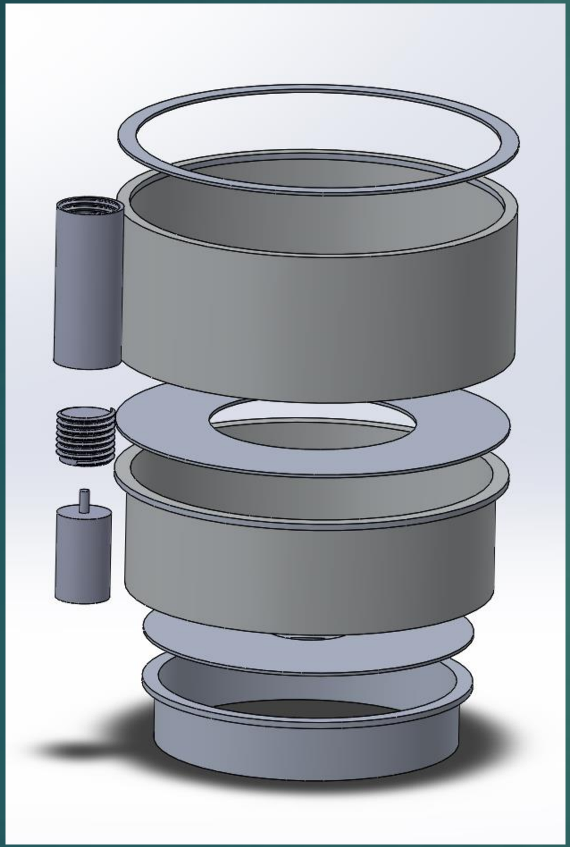
Feasibility of Chosen Material

- Aluminum 2024
  - Density: 2.78 g/cc
    - 1mm thick for shells and vanes
  - Available in:
    - 145mm of 145 mm round
      - Enough material for baffle and vanes
      - Cost: $304.42
    - 145mm of 44.45 mm round
      - Enough material for 2 motor sleeves and deployment gear
      - Cost: $17

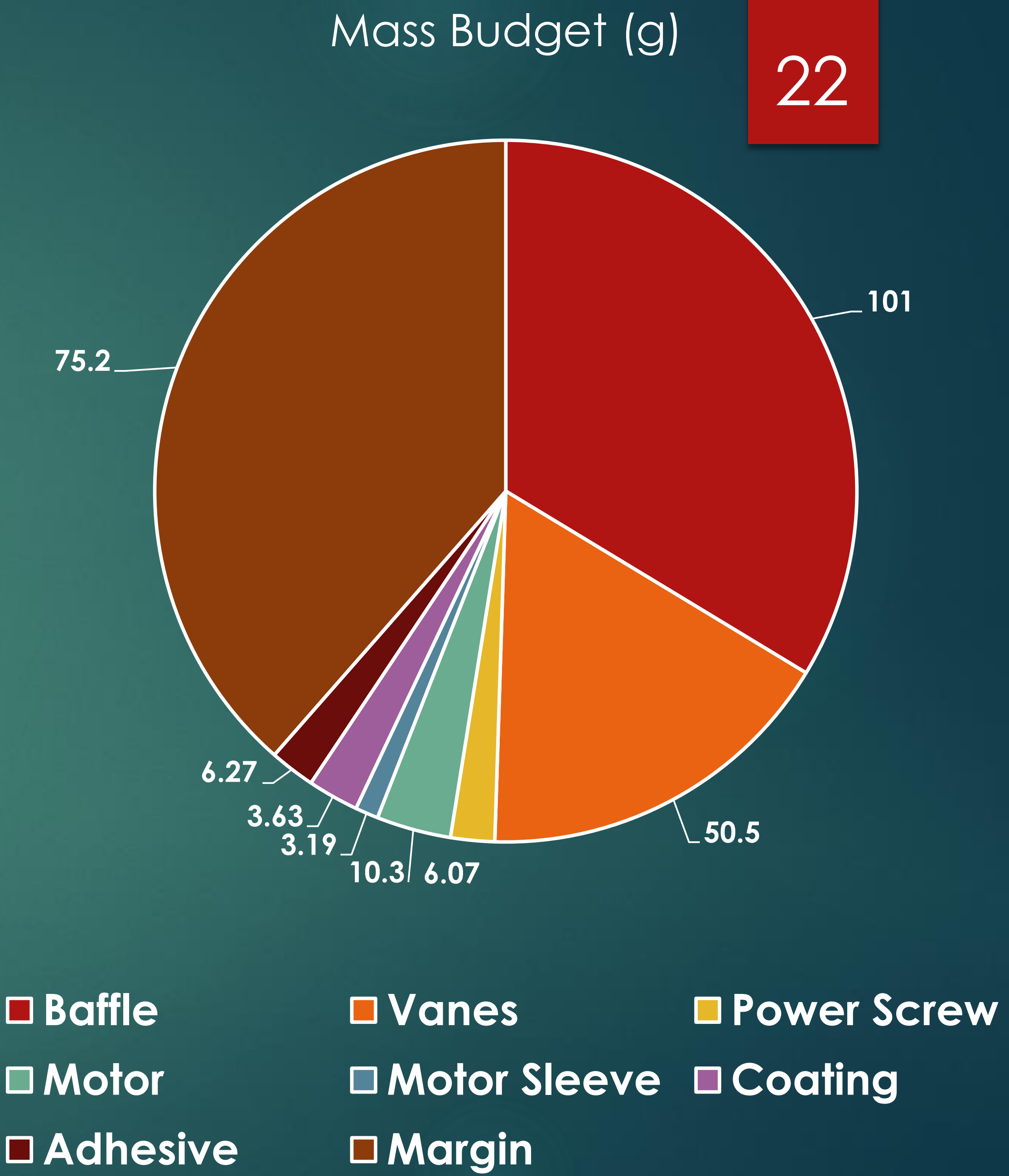


Mass Budget

- Budget: 300 g



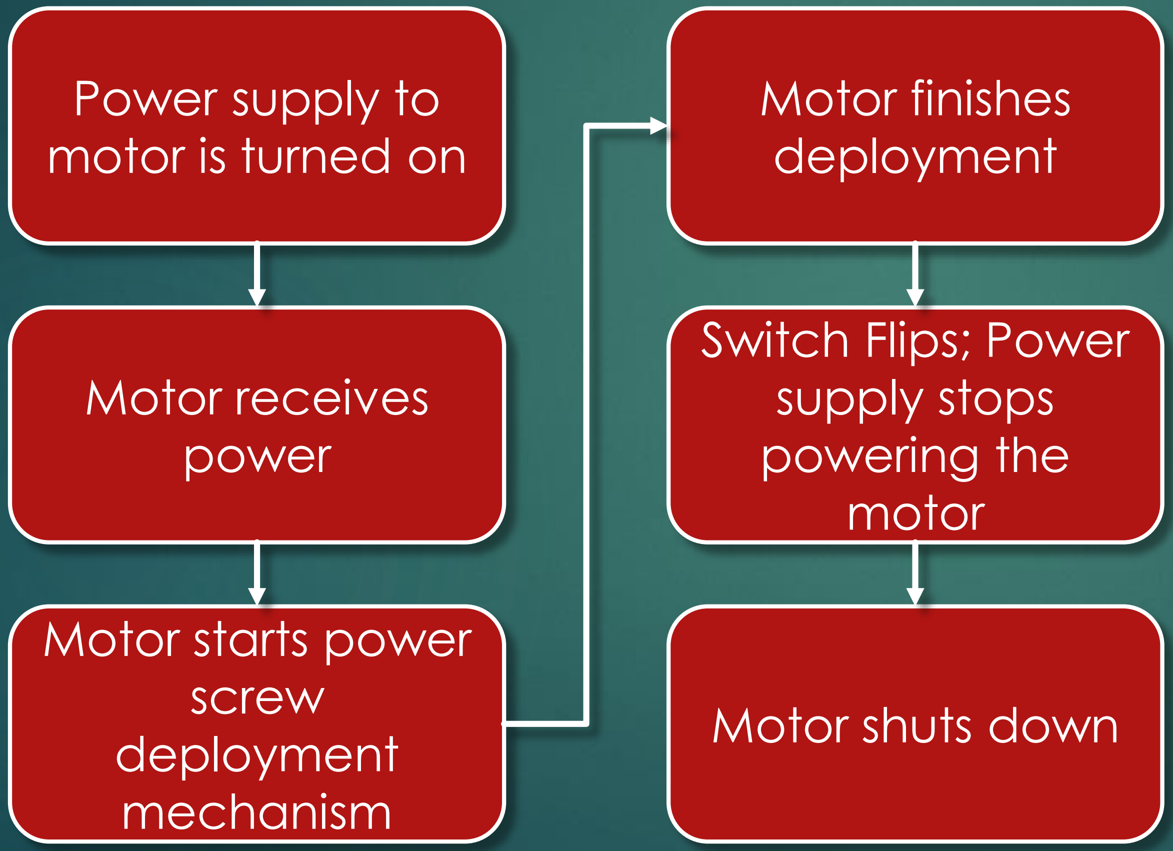
- **Total Mass:** 225 g **FEASIBLE**
- **Margin:** 75.2 g



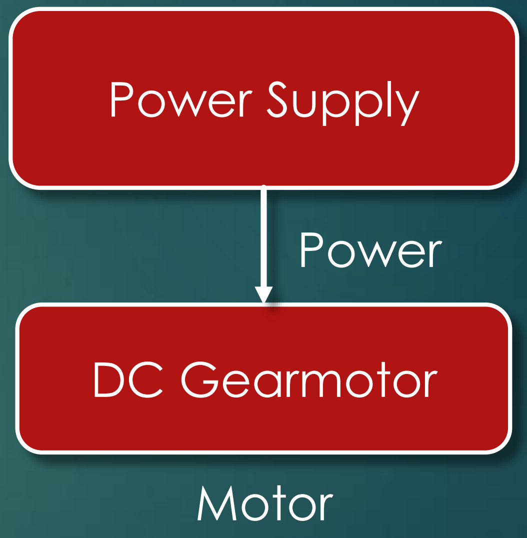
Deployment Testing

Deployment

Algorithm Flowchart



Hardware Components

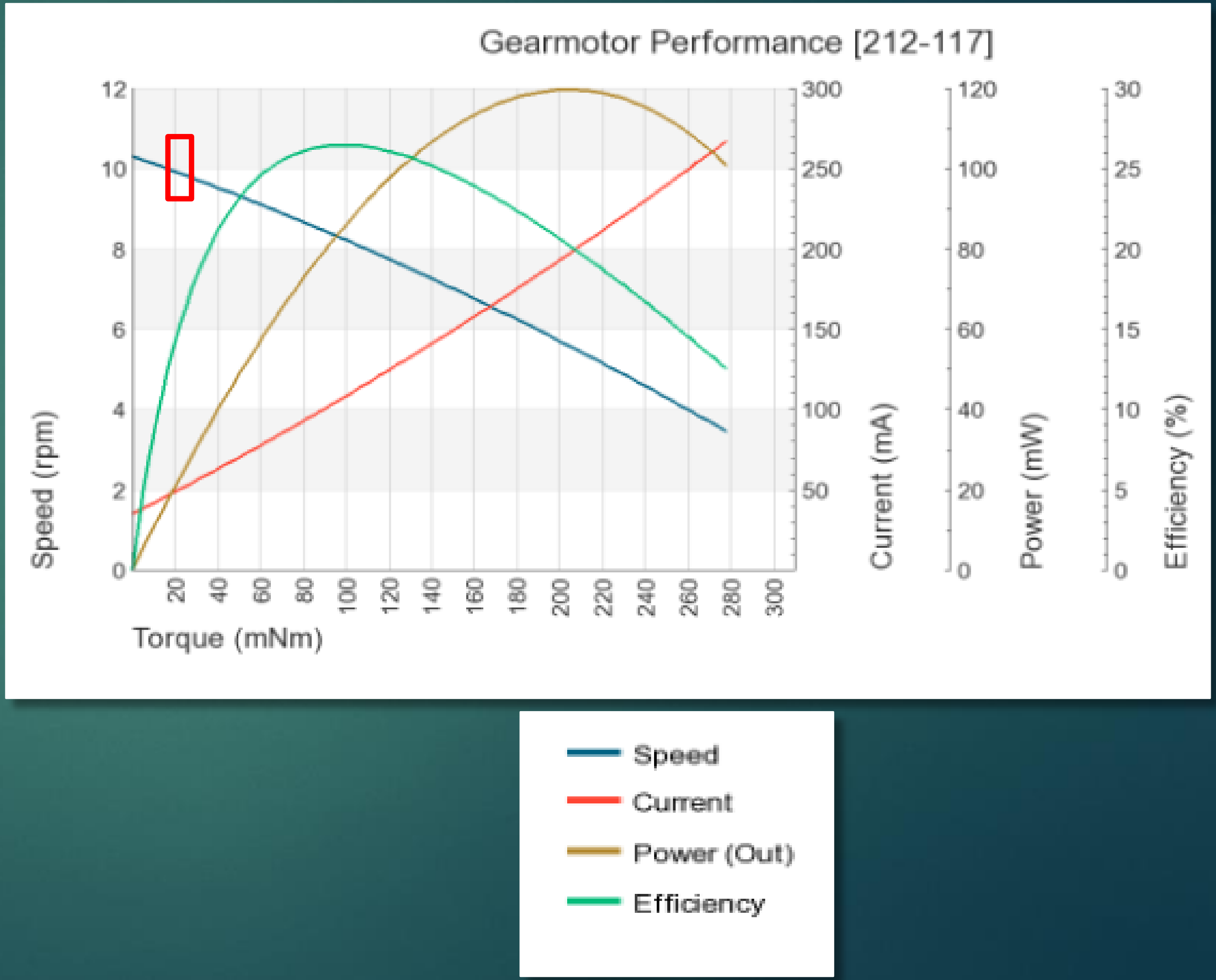


FR1: Electronic Deployment with Wired Connection

FEASIBLE

Stopping Deployment

- Software Timing of the Motor
  - From performance specs and design parameter, 10 rpm * 24 rotations = 2 minutes 24 seconds
  - Official time value for deployment will be determined in deployment testing
- Future Research – Kill Switch



Deployment Testing

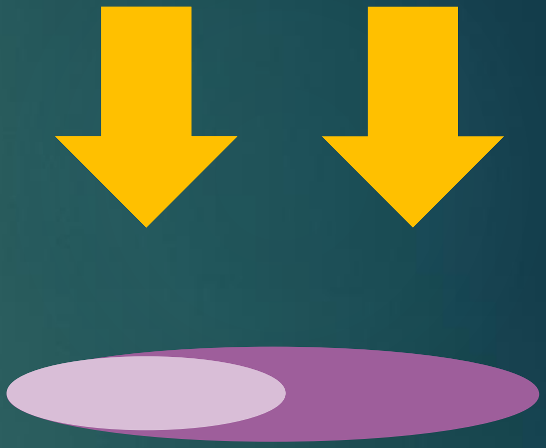
- Will know exact height of baffle when fully deployed after manufacturing
- During test, baffle will deploy and a measuring device will be placed alongside baffle
- Timer will start when baffle begins deployment
- When baffle is fully deployed timer will stop
- Observed deployment time will be compared to calculated deployment time to calculate error

Feasibility of Light Attenuation

Background on Light Attenuation

- Light attenuation = $\frac{Current\ Amount\ of\ Noise\ light}{Initial\ Amount\ of\ Noise\ light}$

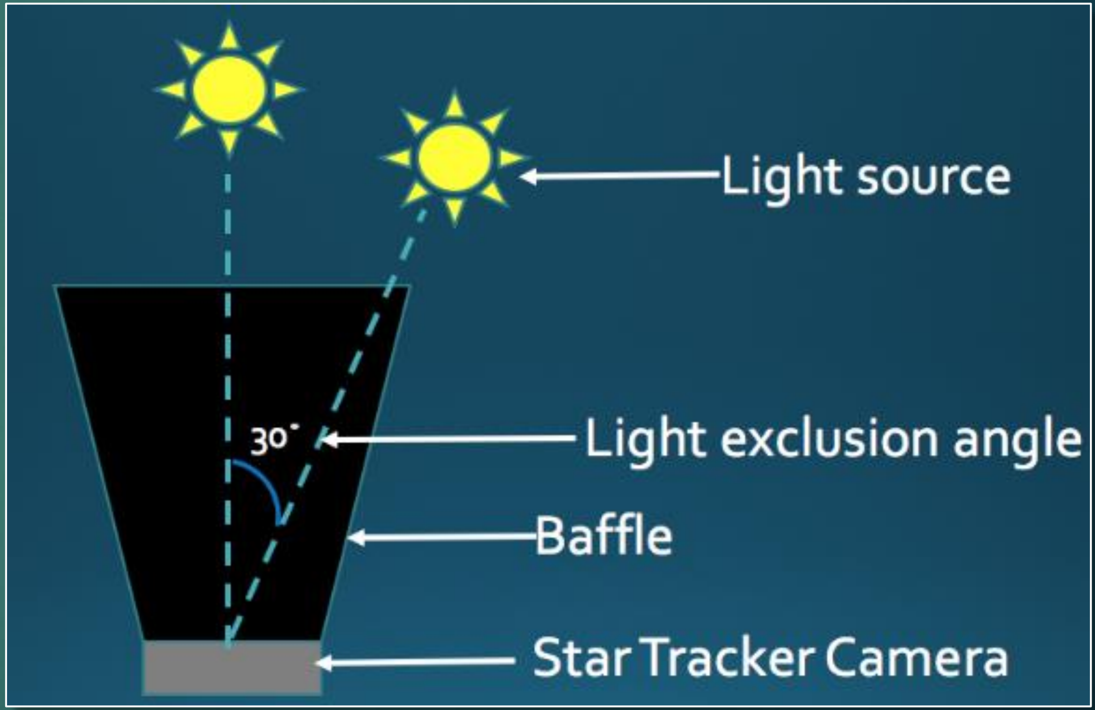
- Chosen sensor measures “lux”
  - Lux = Luminous flux/unit area = $\frac{W}{m^2}$
  - Light attenuation = $\frac{\frac{W_{current}}{m^2{}_{seen}}}{\frac{W_{initial}}{m^2{}_{initial}}} = \frac{flux_{current}}{flux_{initial}}$



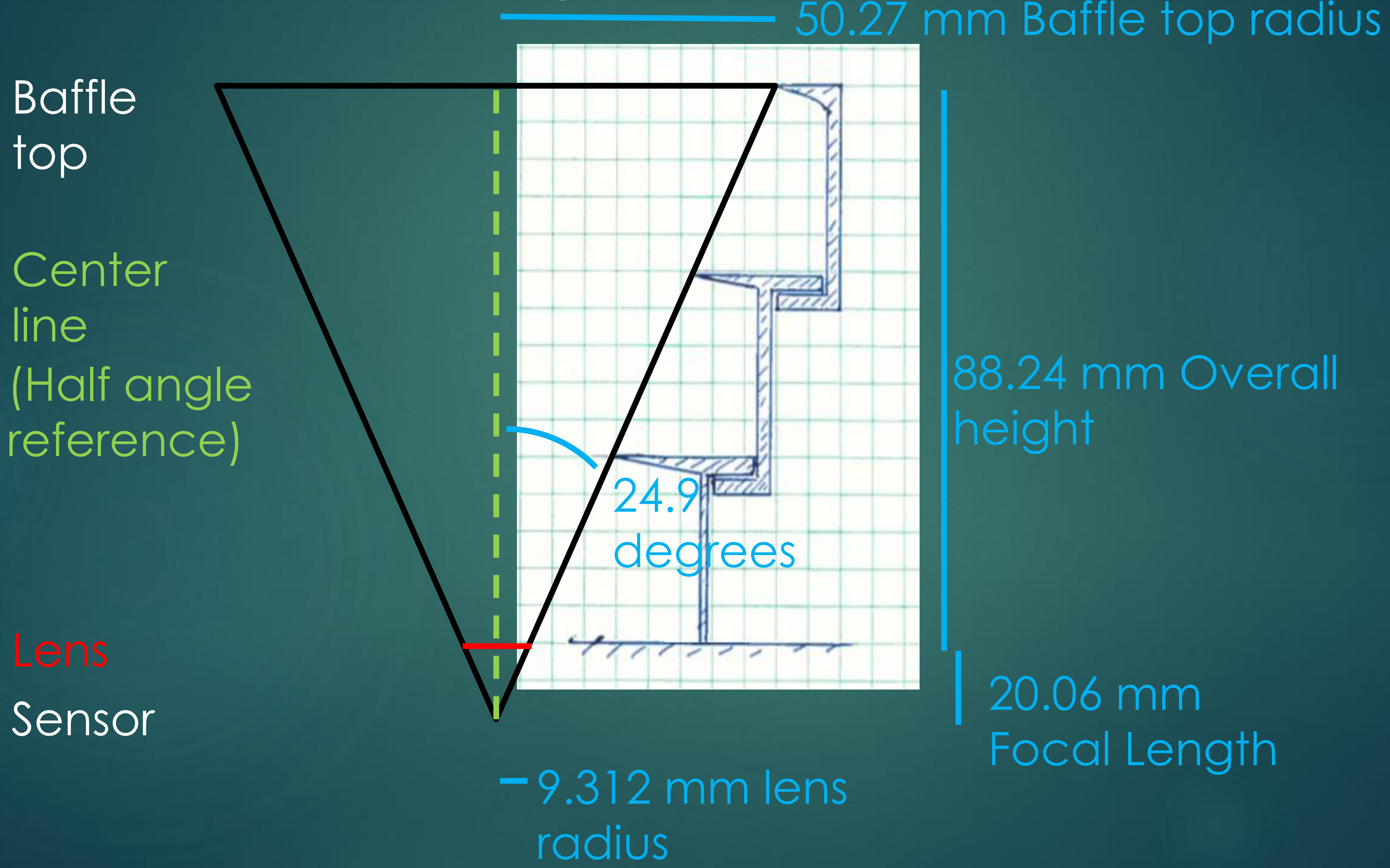
Baffle Performance Requirements

- Attenuation of baffles at max. light exclusion angle is typically 99%-99.9%
- Attenuation of 99.9% not accurately possible with B.O.T.E. calculation
- Meet attenuation of 99% with model

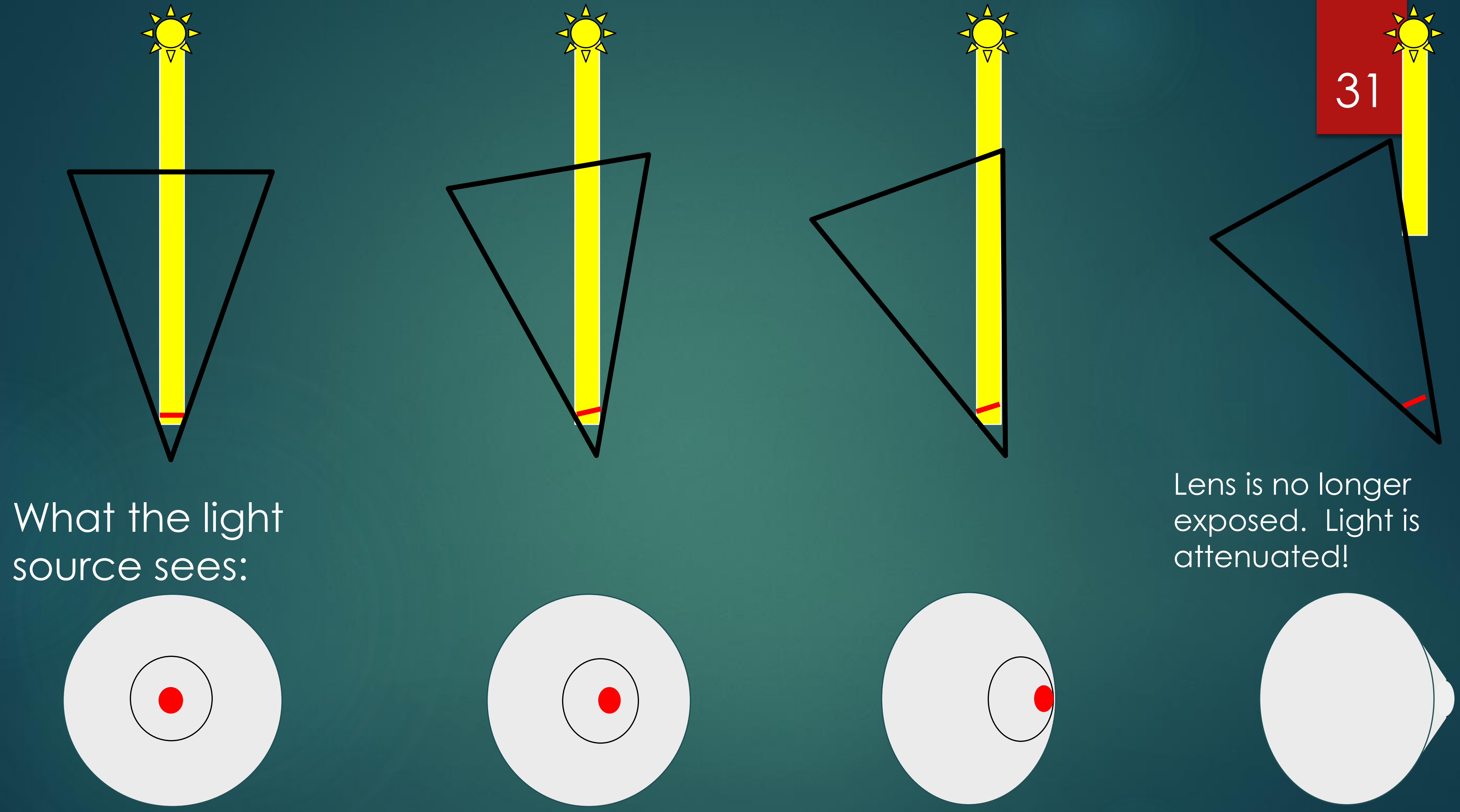
- **Customer Requirement:**
  - Stray light shall be attenuated to 99% at a half angle of 30° or greater.



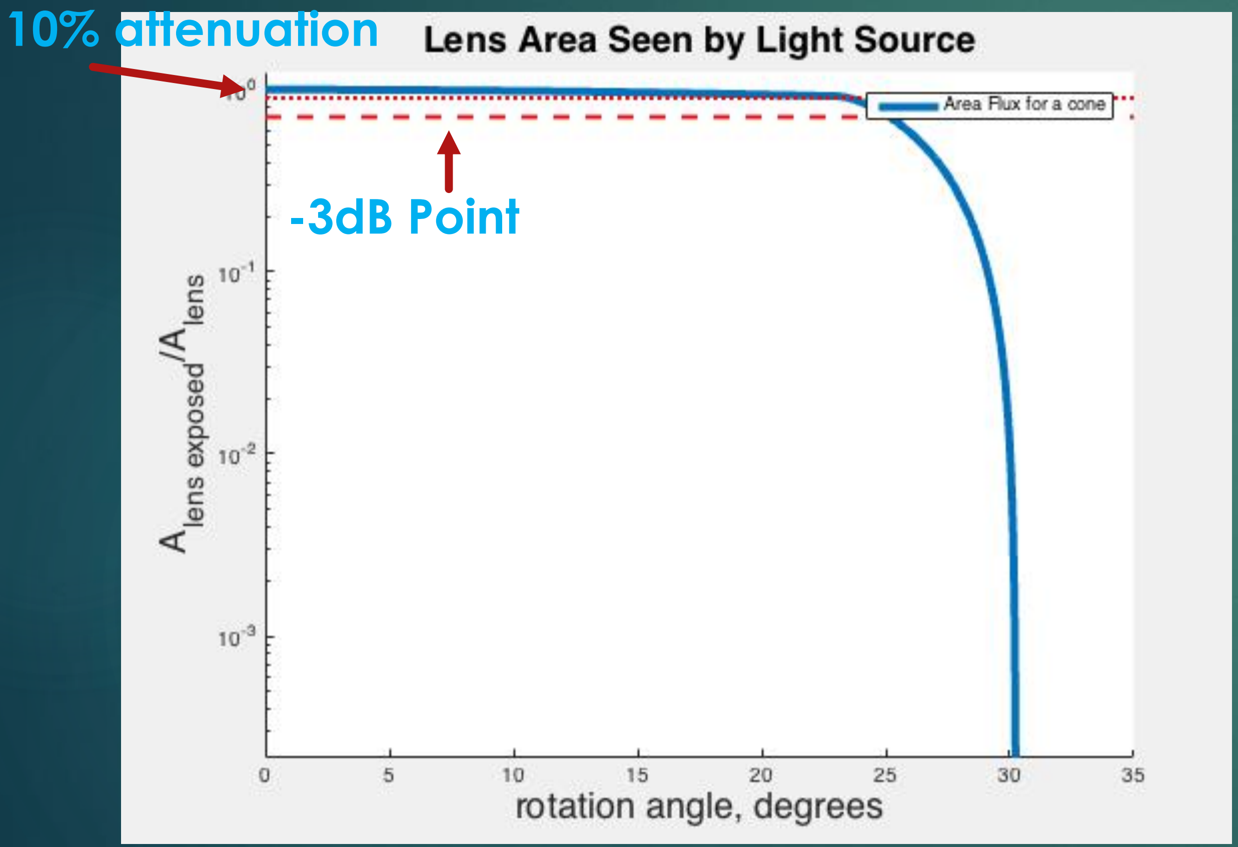
Baffle Geometry



This reflects the geometry of the baffle, not its final shape!


What the light
source sees:
Lens is no longer
exposed. Light is
attenuated!

Baffle Geometry – Attenuation Model



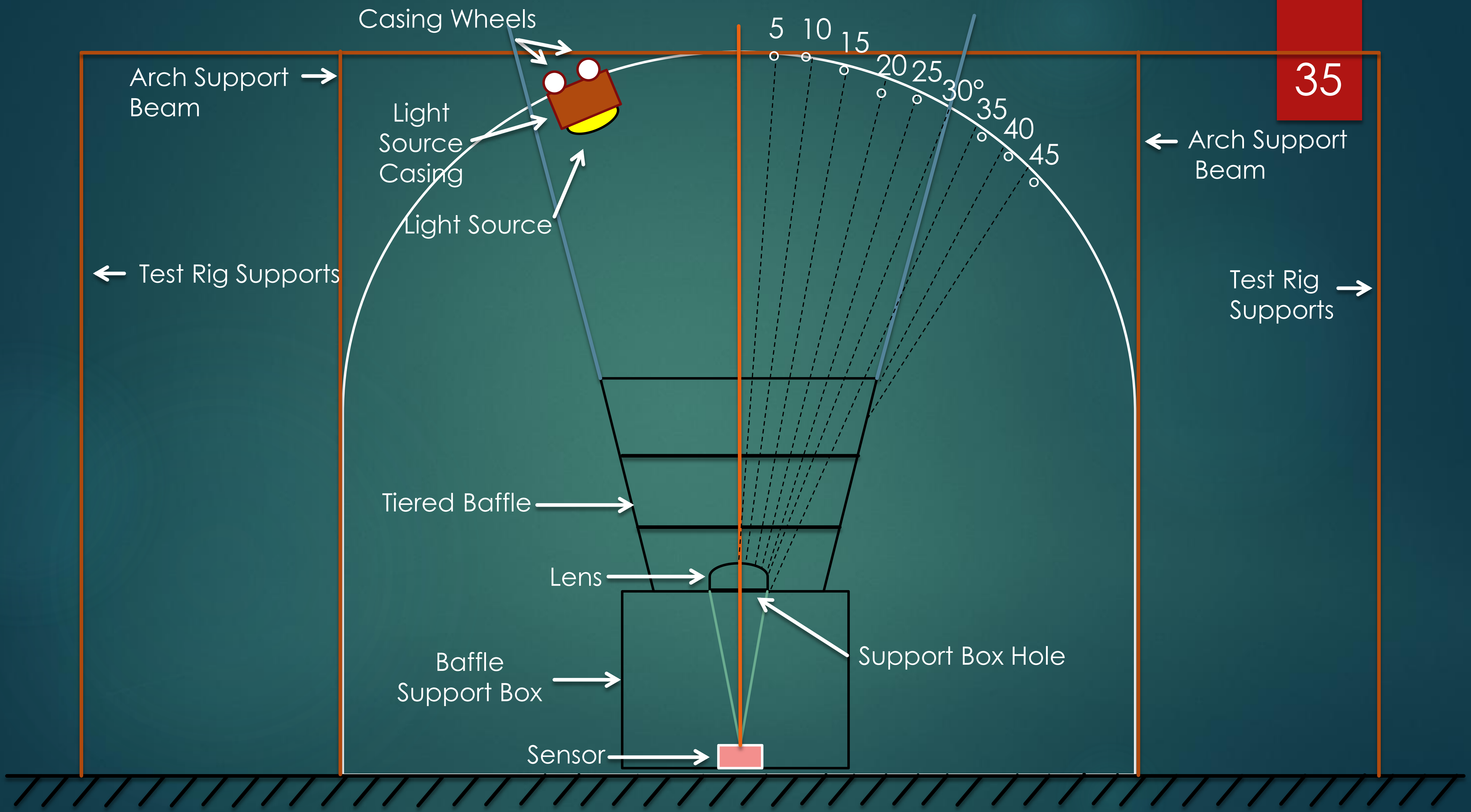
B.O.T.E. Model

- Model assumptions:
  - If lens can "see" light source, then light is directed to the sensor
  - No light is reflected from inner baffle walls
    - i.e. Inner baffle absorptivity is perfect (α = 1)
- Resulting attenuation
  - 99% at 30.03°
  - Geometric half angle of 26°
    - Note: 10% attenuation.
- **FEASIBLE**

Light Attenuating Coating

- Aeroglaze® Z360 Polyurethane Coating
  - Cures to flat black finish
  - Properties:
    - **Solar absorptivity: ≥0.95**
    - **Emissivity: 0.90**
    - Density of coating: 0.97 kg/L
  - Geometry:
    - Two coats recommended (thickness per coat = 0.0254 mm)
      - Max total thickness = 0.1 mm (possible non-uniform coating equivalent to four coats)
    - Surface area to be coated: 72,575 mm^2
    - Total volume of coating: 7.3 mL
    - Total mass added to baffle: 7.04 g
  - Cost:
    - $354/quart + $20 hazardous material fee + professional application cost

Stray Light Testing

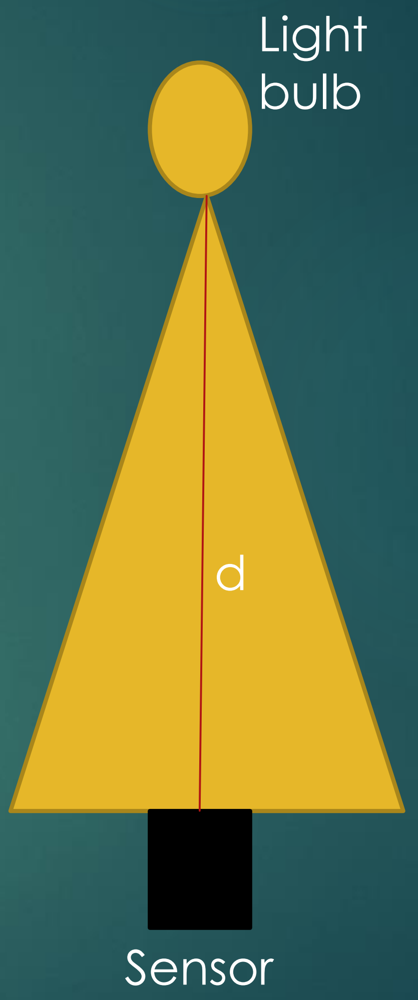

Casing Wheels
Arch Support Beam
Light Source Casing
Light Source
Test Rig Supports
5
10
15
20
25
30°
35
40
45
Arch Support Beam
Test Rig Supports
Tiered Baffle
Lens
Support Box Hole
Baffle Support Box
Sensor

Apparent brightness of Sun

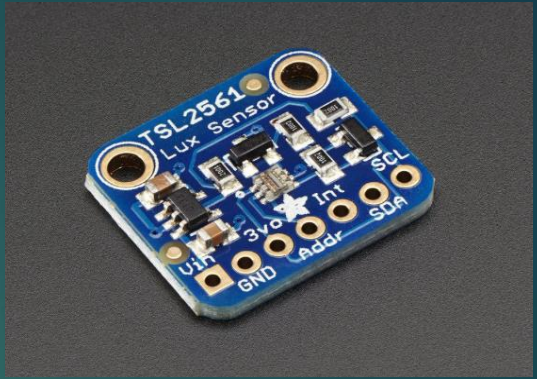
- Function of luminosity and distance
- $Brightness = \frac{L}{4\pi d^2}$
- For sun: L = 3.846 x 10^{26} W
- Closest distance to sun from LEO: d = 1.47 x 10^{11} m
- Thus, brightness = 1416.33W/m^2

Darkroom Testing

- 500W light bulb will be used to simulate light of the sun
- Darkroom located in Engineering Center
- To reproduce brightness of sun (1416 W/m^2)
- $d = \sqrt{\frac{L}{4\pi b}}$
- Thus, d = 0.028m assuming a 500 watt light bulb



Stray Light Testing



- Sensor
  - Adafruit TSL2561 Digital Luminosity/Lux/Light Sensor Breakout
    - Measures Lux
      - 0.1 to 40,000 Lux
      - Measures infrared, full-spectrum or human-visible light spectrum
    - Technical Specs.:
      - 0.5 mA current draw when sensing
      - Operating Voltage: 2.7–3.6 V
      - 3.3 V regulator and level shifting circuitry so it can be used with any 3-5 V microcontroller
      - Digital (i2c) interface
    - Cost: $5.95 plus $8.59 shipping

Sensor Responsivity

Light wavelengths sensor can detect

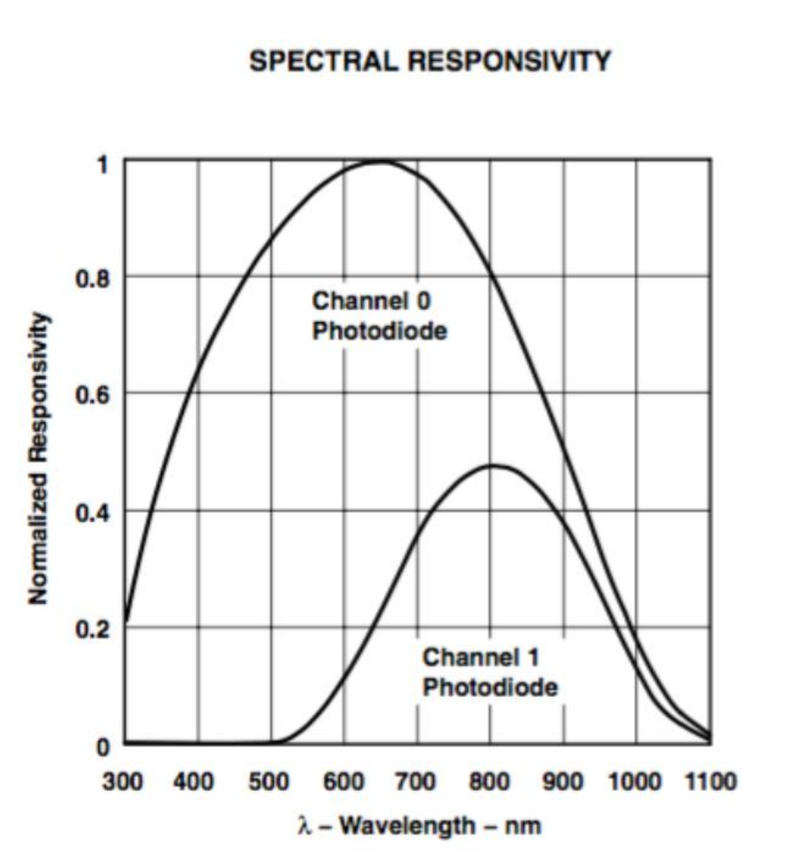
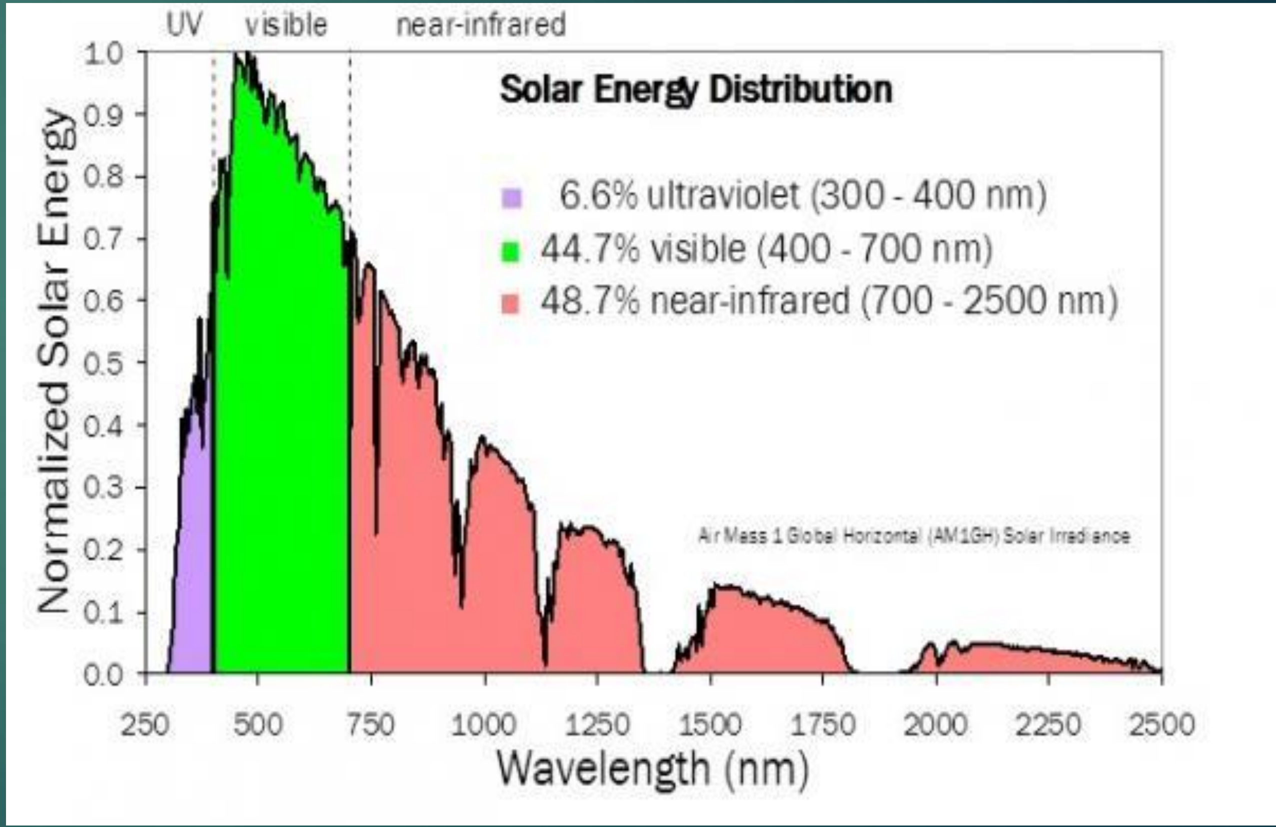


Figure 4

Light wavelengths from Sun

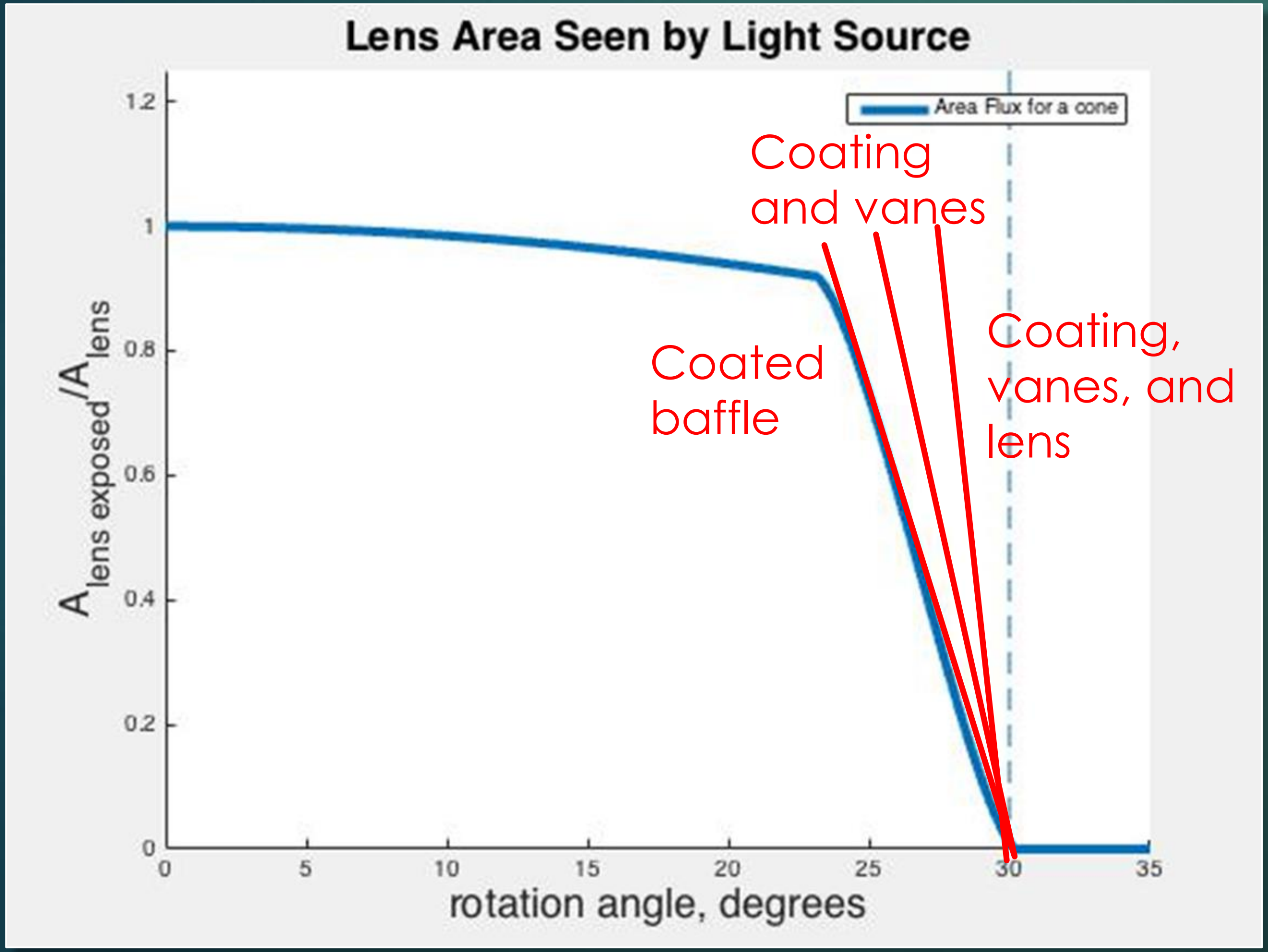


Further Studies

Feasibility

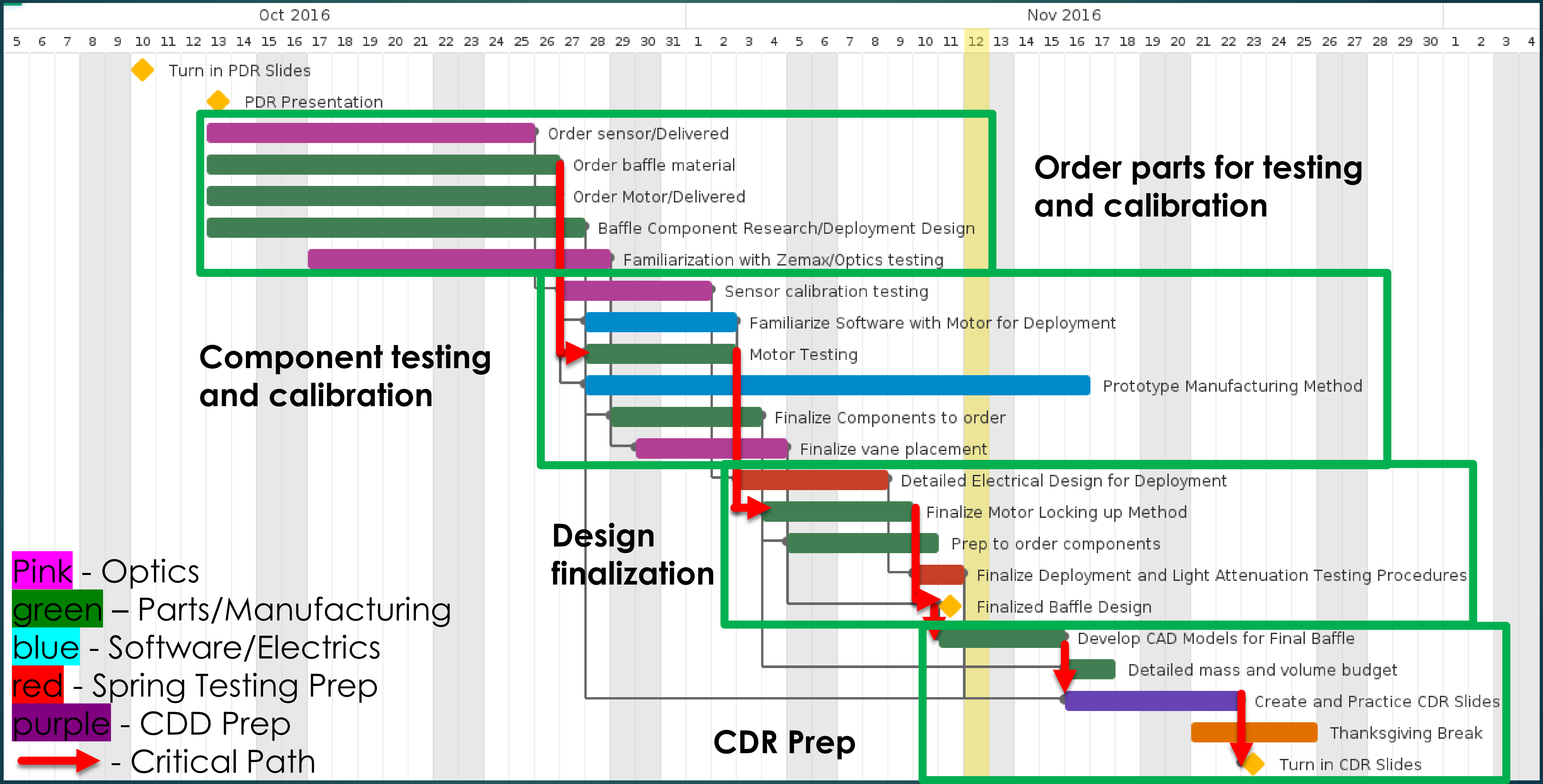
	Functional Requirement	Feasibility Shown	Level of Risk
FR1	Electronic deployment with wired connection	Deployment Software ✓ Deployment Testing ✓	Low
FR2	125 mm length 125 mm width 50 mm height	Baffle and Motor Casing Geometry✓	Medium
FR3	≤ 300 grams	Mass Budget ✓	Medium
FR4	30° light exclusion angle	Baffle Dimensions ✓ Vanes ✓ Light Attenuating Coating ✓	High

Attenuation Model Improvements



- Overall attenuation goal:
  - Increase the geometric half-angle and attenuation magnitude without increasing the FOV half-angle of 30 degrees
    - This will increase the roll off angle causing sharper attenuation later
  - Analysis Method:
    - Use the CAD model and ray-tracing software to place internal structure.
    - Explore the effects of vanes (knife-edge collimators), absorbent coating, and lens geometry to increase the fall off angle **and** the magnitude of attenuation (10^{-2} +)

Time Budget



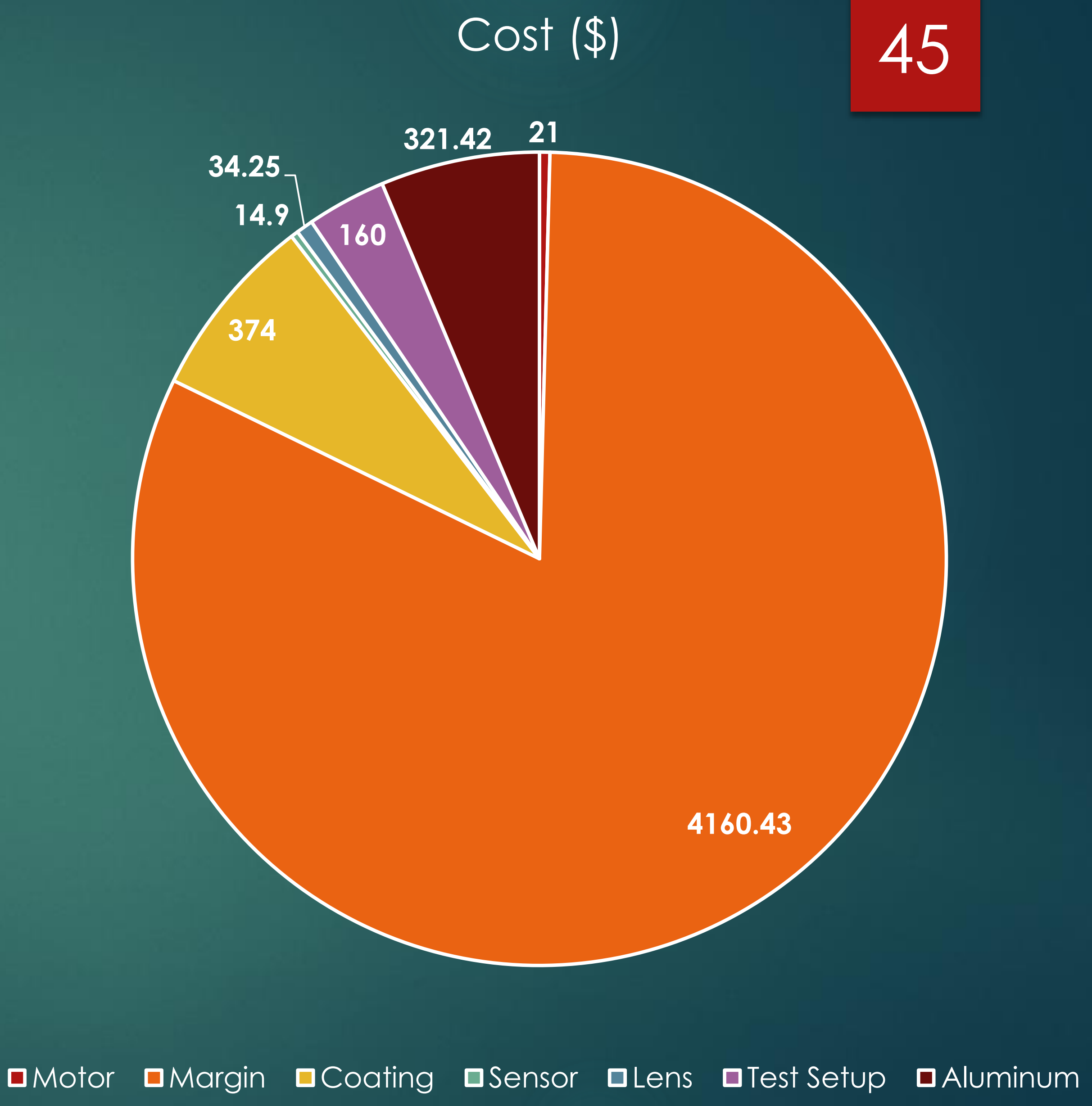
Pink - Optics
green – Parts/Manufacturing
blue - Software/Electrics
red - Spring Testing Prep
purple - CDD Prep
→ - Critical Path

Status Summary

Project Overview | Feasibility Analysis | Further Studies | Status Summary | References | Backup Slides

Cost Budget

- $5000 budget
- **Total Costs:** $839.57 **FEASIBLE**
  - Coating: $374
  - Aluminum $321.42
- **Margin:** $4160.43



Questions?

References

References

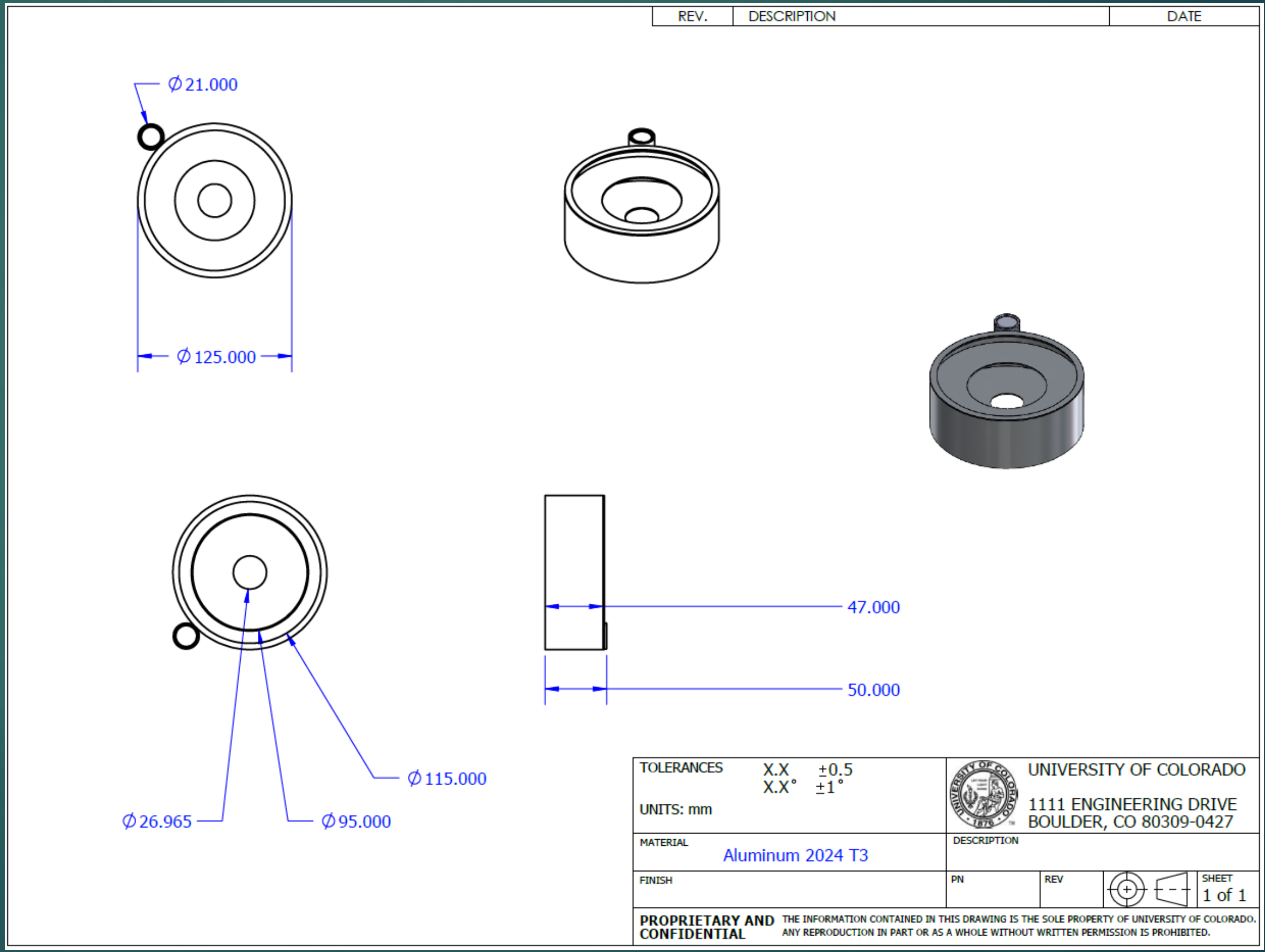
- "Aeroglaze® Z306 Polyurethane Coating Where To Buy." *Aeroglaze® Z306 Polyurethane Coating*. N.p., n.d. Web. 10 Oct. 2016.
- "Angular Diameter." *Wikipedia*. Wikimedia Foundation, n.d. Web. 10 Oct. 2016.
- "Baffle Attenuation Performance." Message to Scott Taylor. 7 Oct. 2016. E-mail.
- " Gantt Charts for Asana." *Instagantt*. N.p., n.d. Web. 09 Oct. 2016.
- "Luminosity and Apparent Brightness.“Palma, Christopher*Welcome!* N.p., 2015. Web. 10 Oct. 2016.
- *MATLAB & SIMULINK: Student Version*. Natick, MA: Mathworks, 2013. Computer software.
- "MatWeb - The Online Materials Information Resource." *MatWeb - The Online Materials Information Resource*. N.p., n.d. Web. 09 Oct. 2016.
- "Protractor." *Johnny Allen 6th Grade Campus*. West Corporation, n.d.Web. 09 Oct. 2016.
- "Rigel-L Star Tracker." Subsystems. Surrey Satellite Ltd, n.d. Web. 09 Oct. 2016.
- *SolidWorks 2007 Education Edition*. Concord, MA: SolidWorks Corp., 2007. Computer software.
- Type, By. "AEROGLAZE Z306 (170811)." *Buy AEROGLAZE Z306*. N.p., n.d.Web. 10 Oct. 2016.
- "XU4 Shifter Shield." *ODROID*. Hardkernel Co., Ltd, n.d. Web. 09 Oct. 2016.
- "12mm DC Gearmotor - 27mm Type." *Precision Microdrives*. N.p., n.d.Web. 01 Oct. 2016.
- "2024-T3T3511 Extruded Round Bar." *2024-T3T3511 Extruded*. N.p., n.d.Web. 09 Oct. 2016.
- 20, Taos059N March. TSL2560, TSL2561 LIGHT-TO-DIGITAL CONVERTER (n.d.): n. pag. Web. 26 Sept. 2016.
- "Cool Roofs." *Berkeley Lab*. Heat Island Group, n.d. Web. 10 Oct. 2016.

Backup Slides

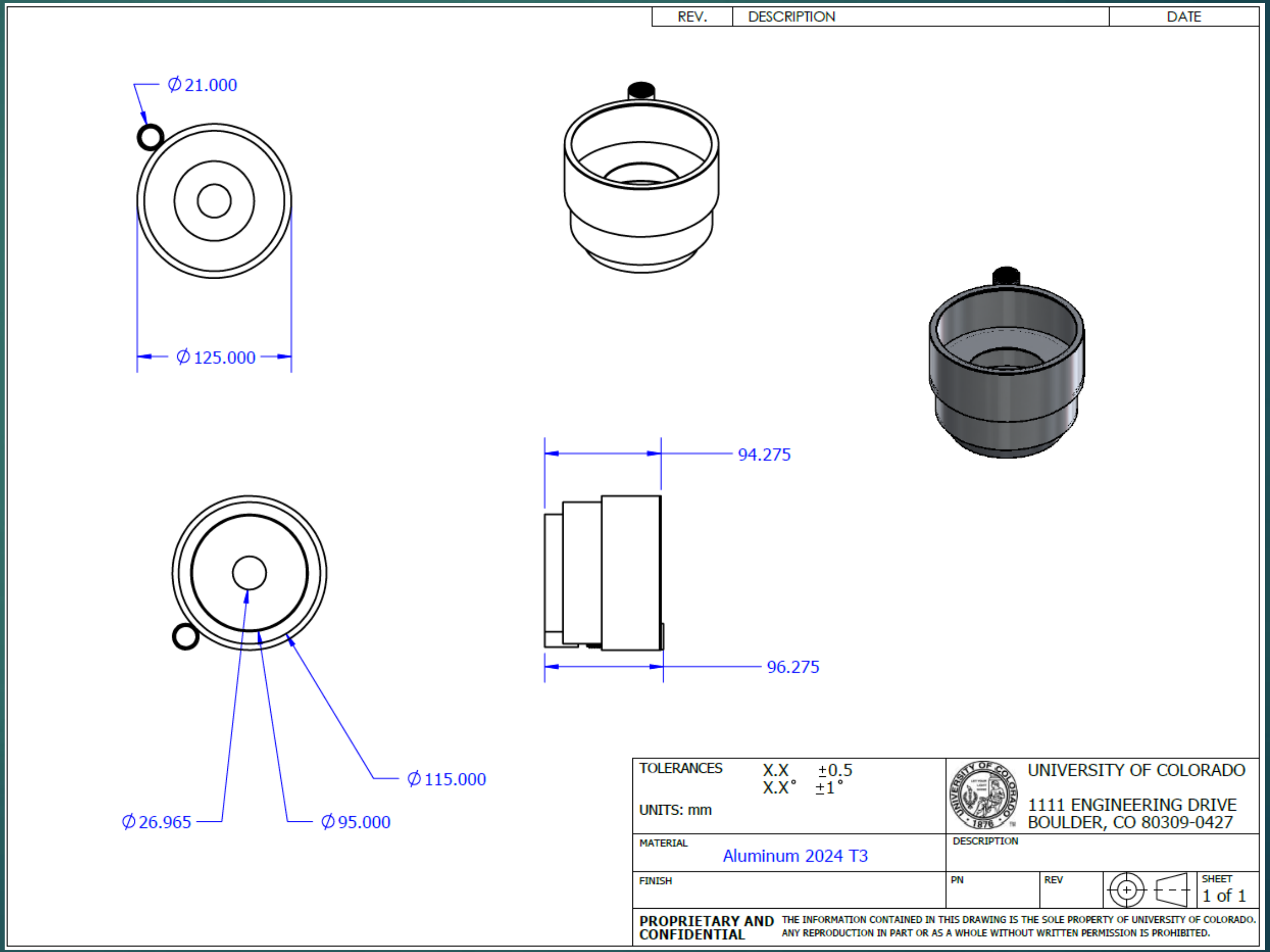
Change of Baseline Baffle Design

- Baseline design from CDD had spring as best deployment mechanism
- Design has completely changed since then
  - Spring deployment was not feasible
  - Diameter of baffle (and therefore spring) and the spring constant needed, yielded spring that wasn't within mass budget
- Alternate deployment mechanism chosen
  - Feasibility proven, analysis shown later

Baseline Baffle Design

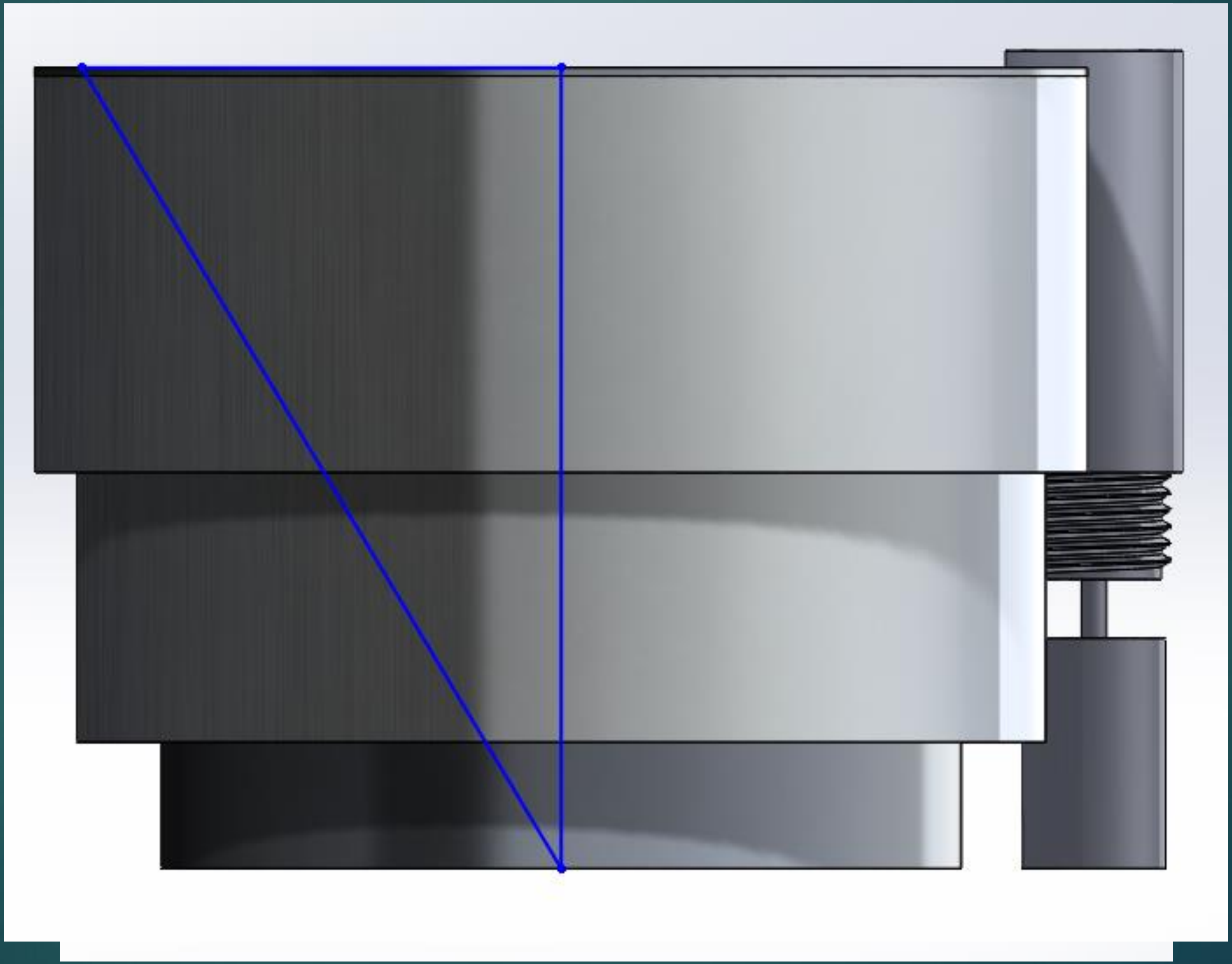


Baseline Baffle Design



Baseline Baffle Design

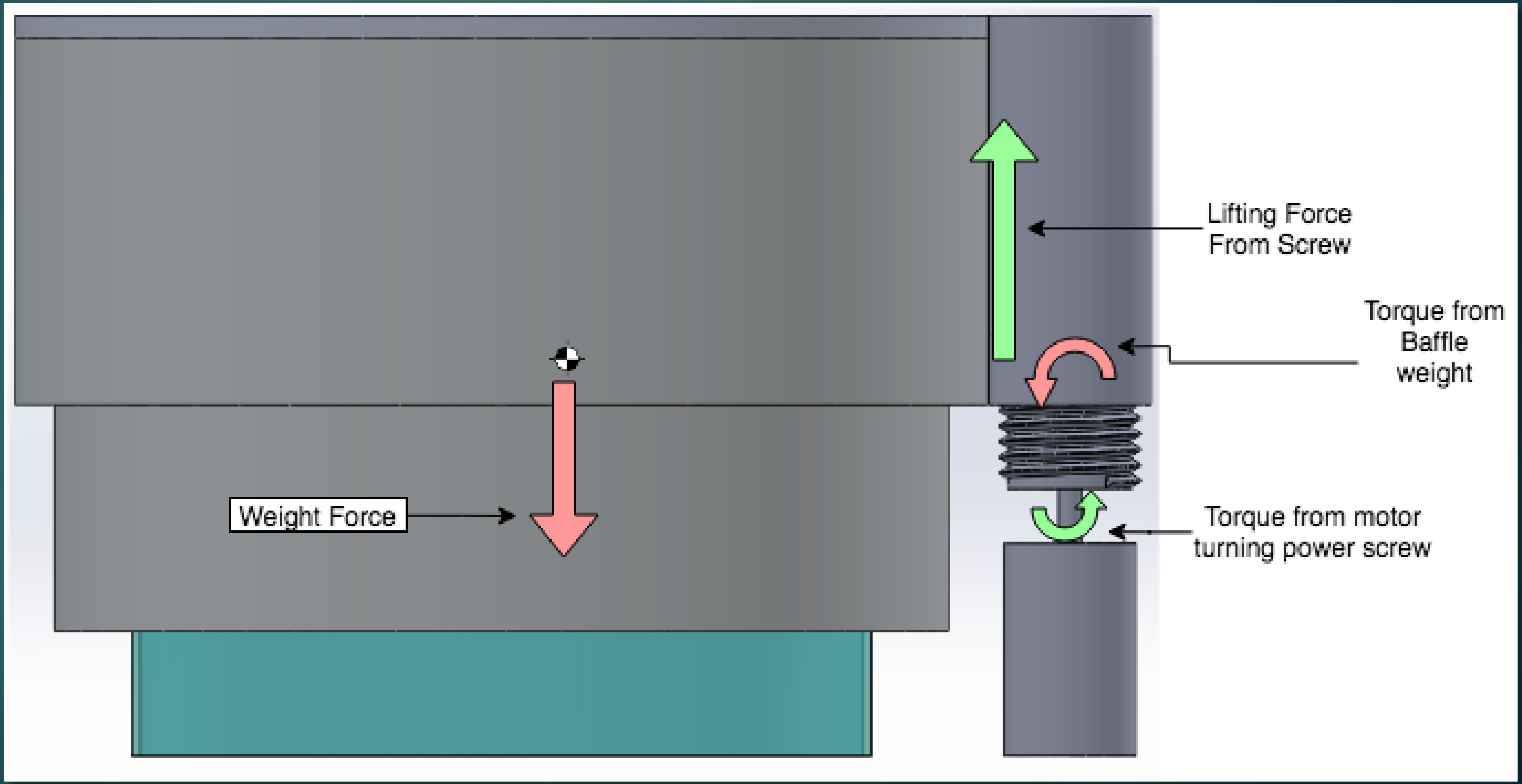
Baffle Geometry



Baffle Binding Concerns

- Concern:
  - Deployment mechanism will be halted by the telescope layers moving out unevenly due moment created by weight of baffle
- Can be solved by having a second motor on the other side, but would bring with it more complications and added mass
- Isn't estimated to be a problem with free body diagram estimation of the moment and the estimated support of the screw system (next slide)

Baffle Binding Concerns



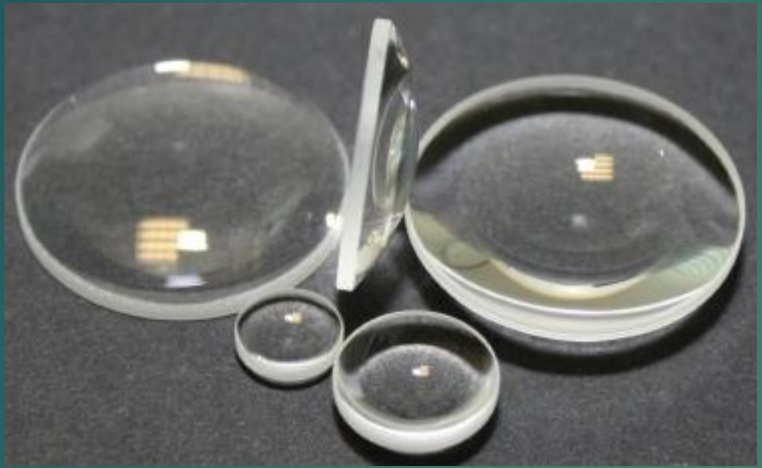
Free Body
Diagram of
Baffle with
Motor Force

Feasibility of Required Manufacturing

- Baffle
  - 1 mm thick shells for each tier
  - Use lathe in Aerospace Machine Shop

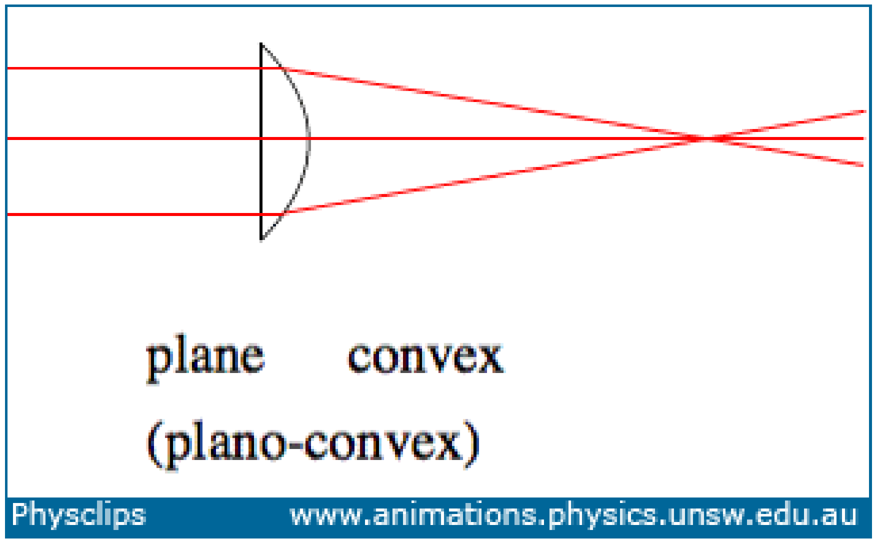
- Vanes
  - 1 mm thick
  - Use lathe and mill in Aerospace Machine Shop
  - Vanes will be attached to baffle tiers with glue
    - Vanes will experience no force

Lens Approximation

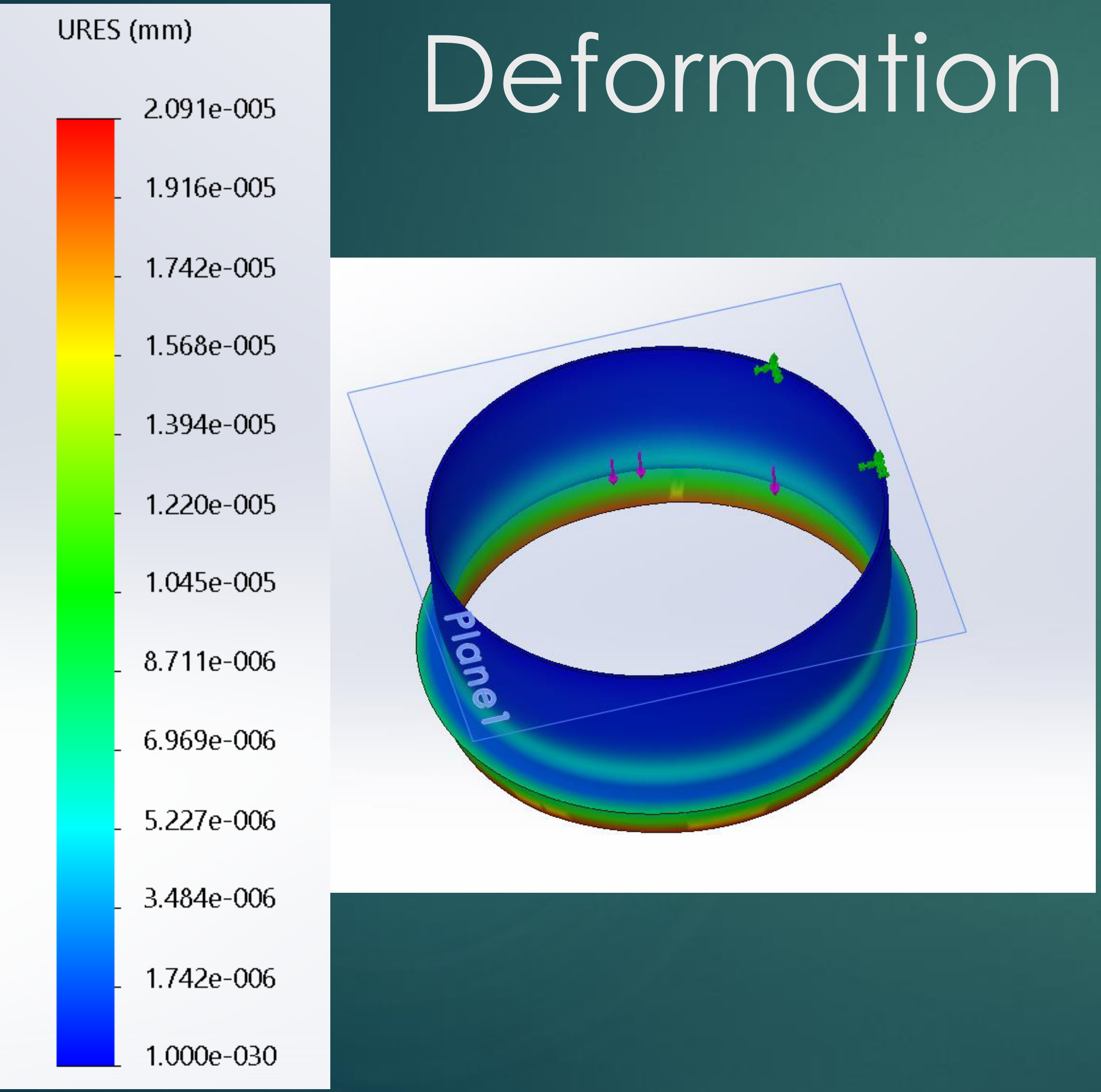


Stock Optics Plano Convex Lens
- 15 mm diameter
- 20 mm focal length
- $34.25

- Will like have to order custom lens
- As of PDR, lens manufacturer has not responded to quote request



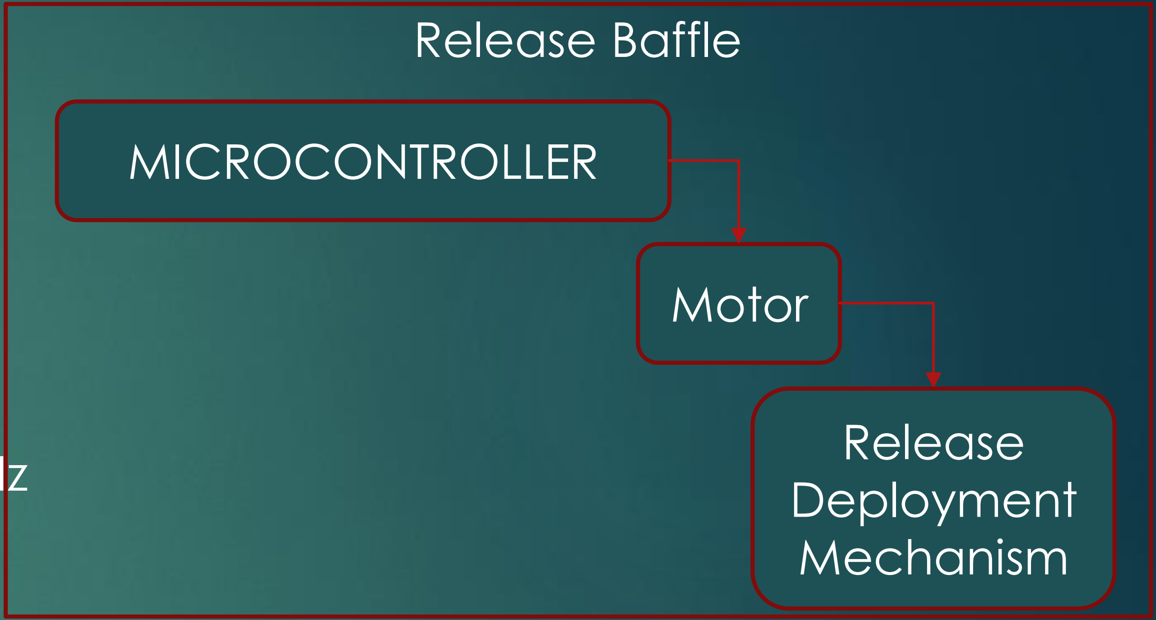
SolidWorks: Single Baffle Tier Deformation

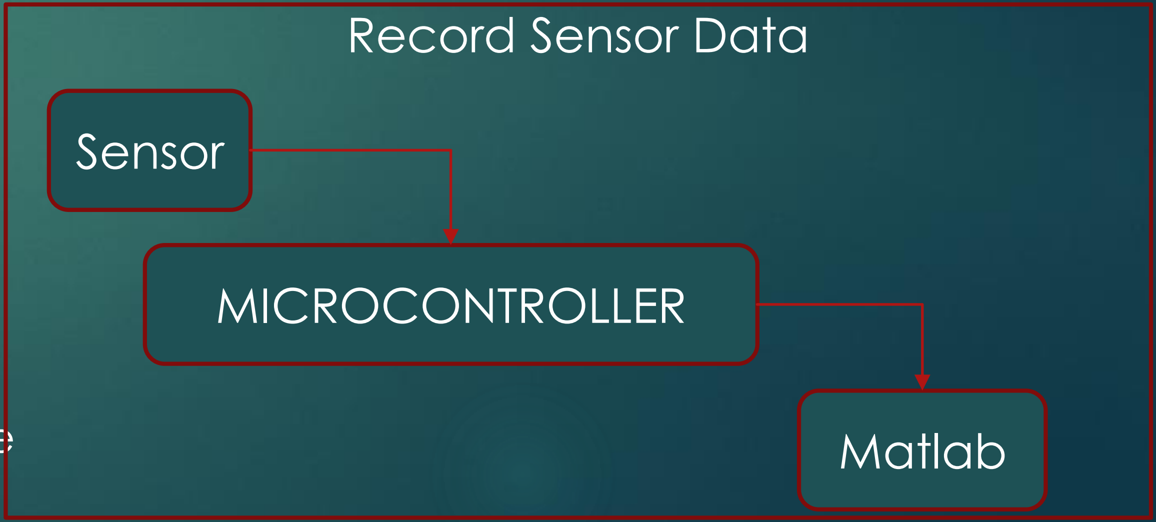


- SolidWorks Force Analysis
  - Using 1N of force
    - Just over total mass of baffle
    - Extra force accounts for force from motor
  - Maximum displacement of top section
    - 2.09×10^{-5} mm
  - Minimal deformation proves baffle pieces withstand applied forces required for deployment

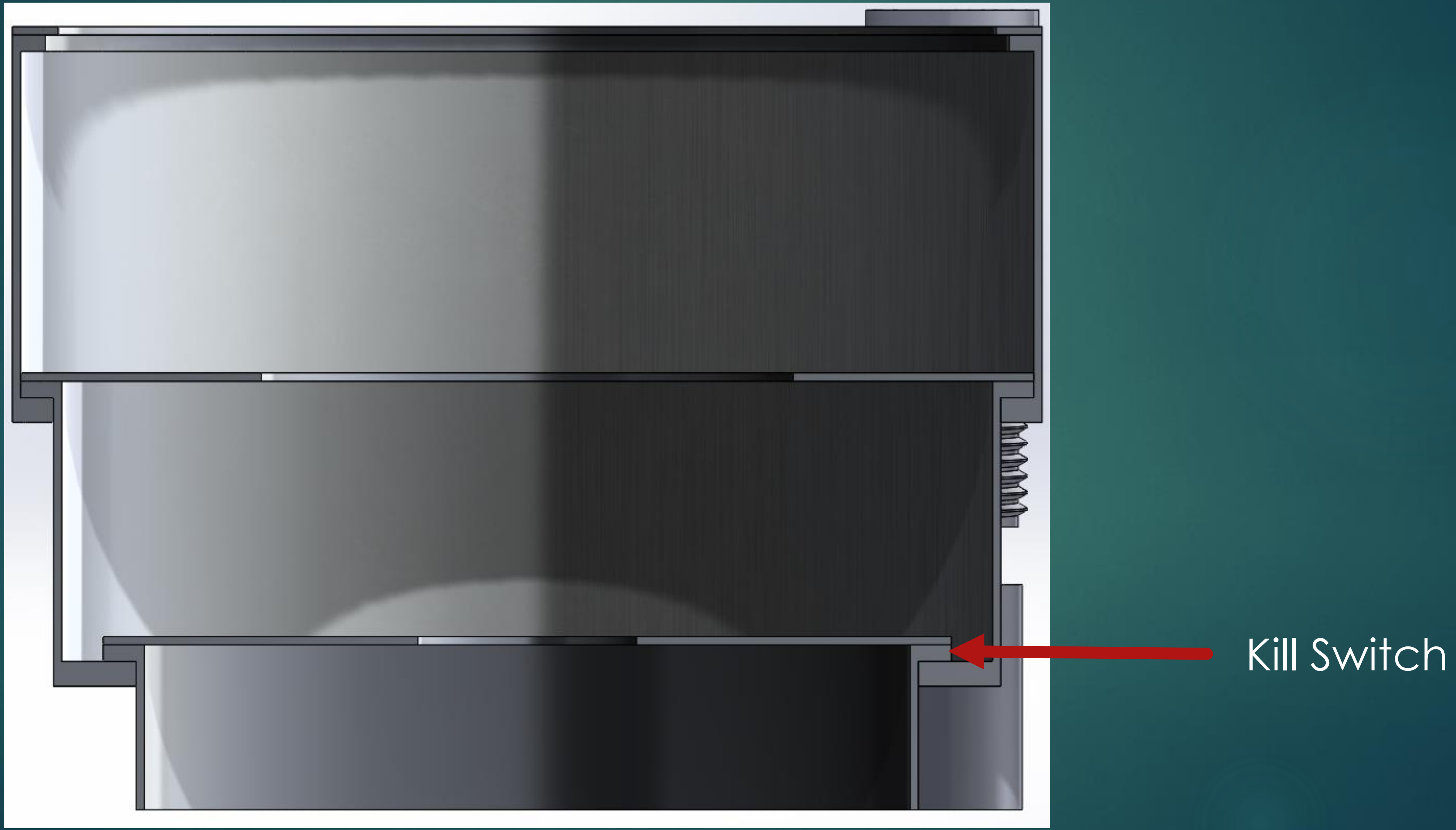
Microcontroller

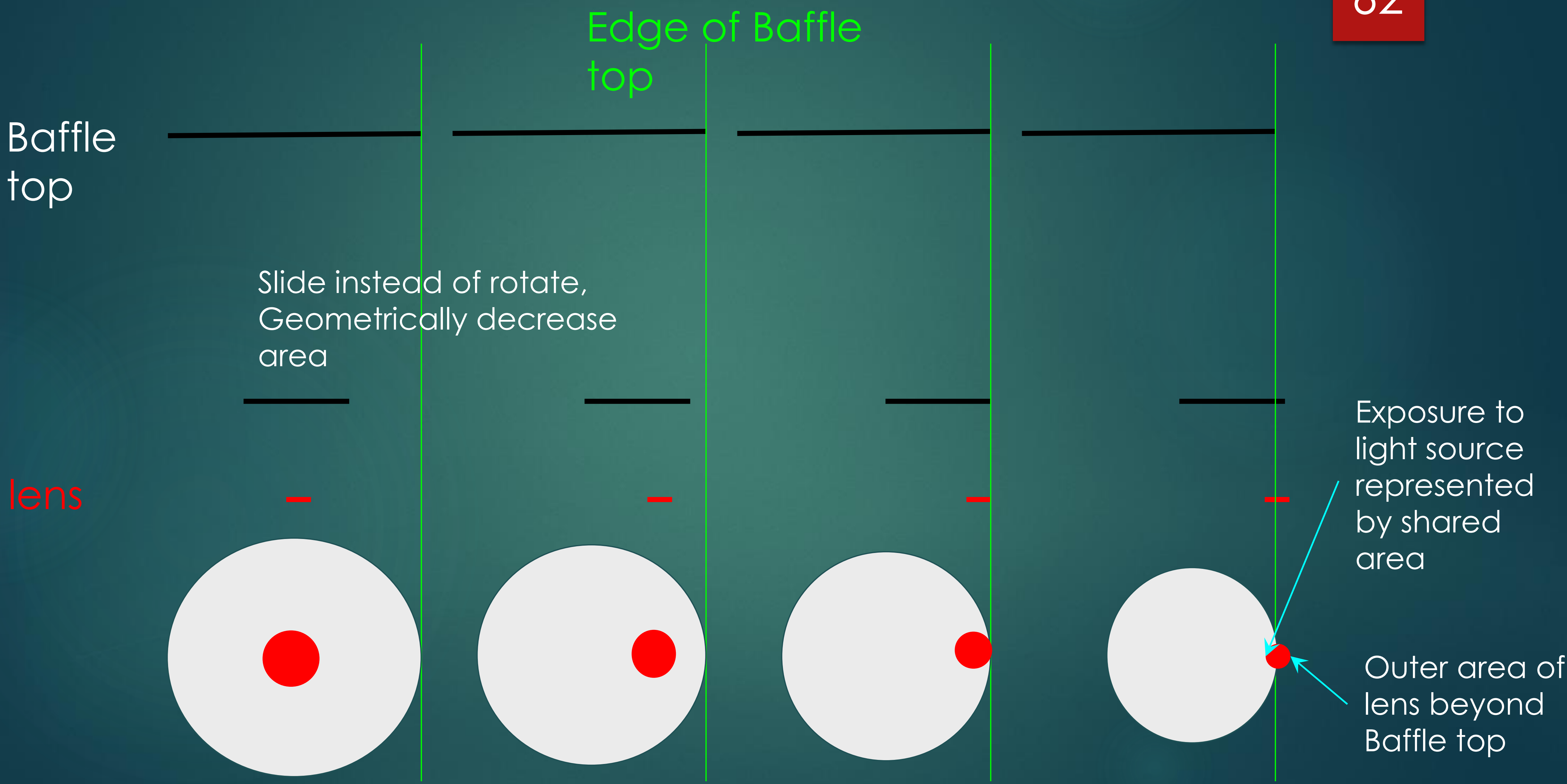
- ODroid-XU4
  - Cost: $74
  - USB 3.0 Connection
  - Processor: Quad Core – 2 GHz
  - RAM: 2 Gbytes
  - Required Voltage: 5 V
- Other Considerations:
  - Raspberry pi 3
  - Arduino Zero
    - These have less performance

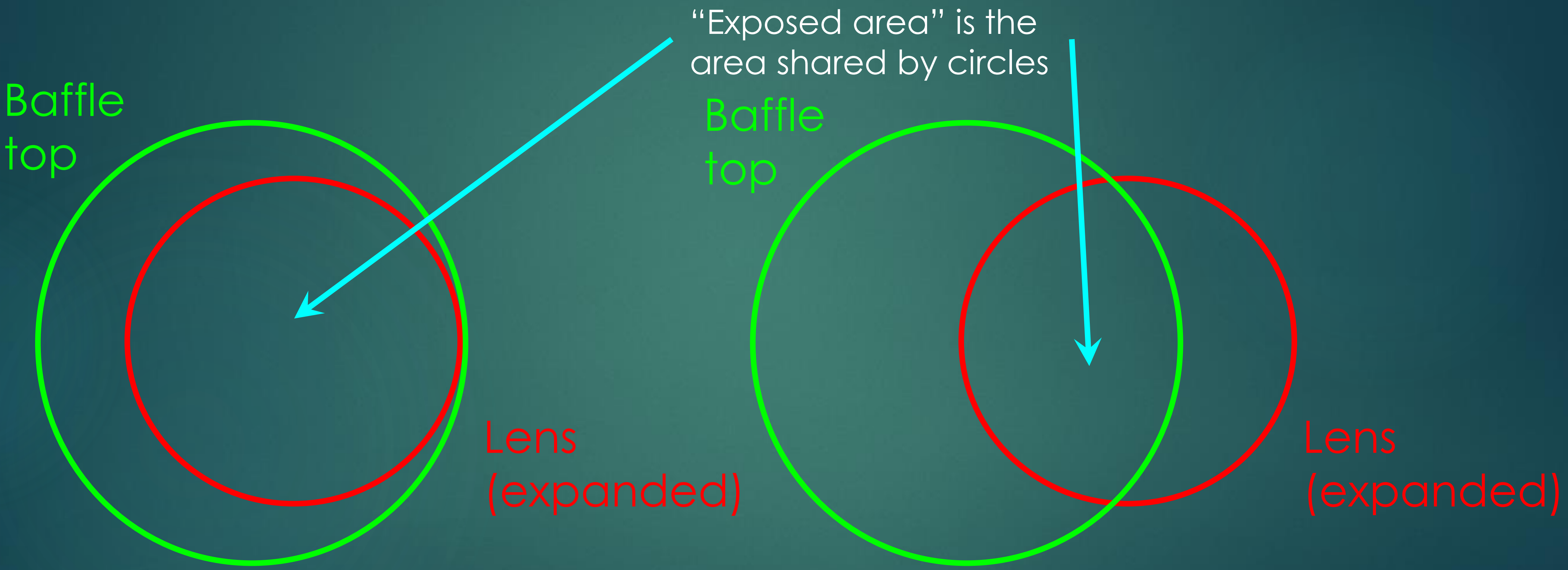




Kill Switch Placement

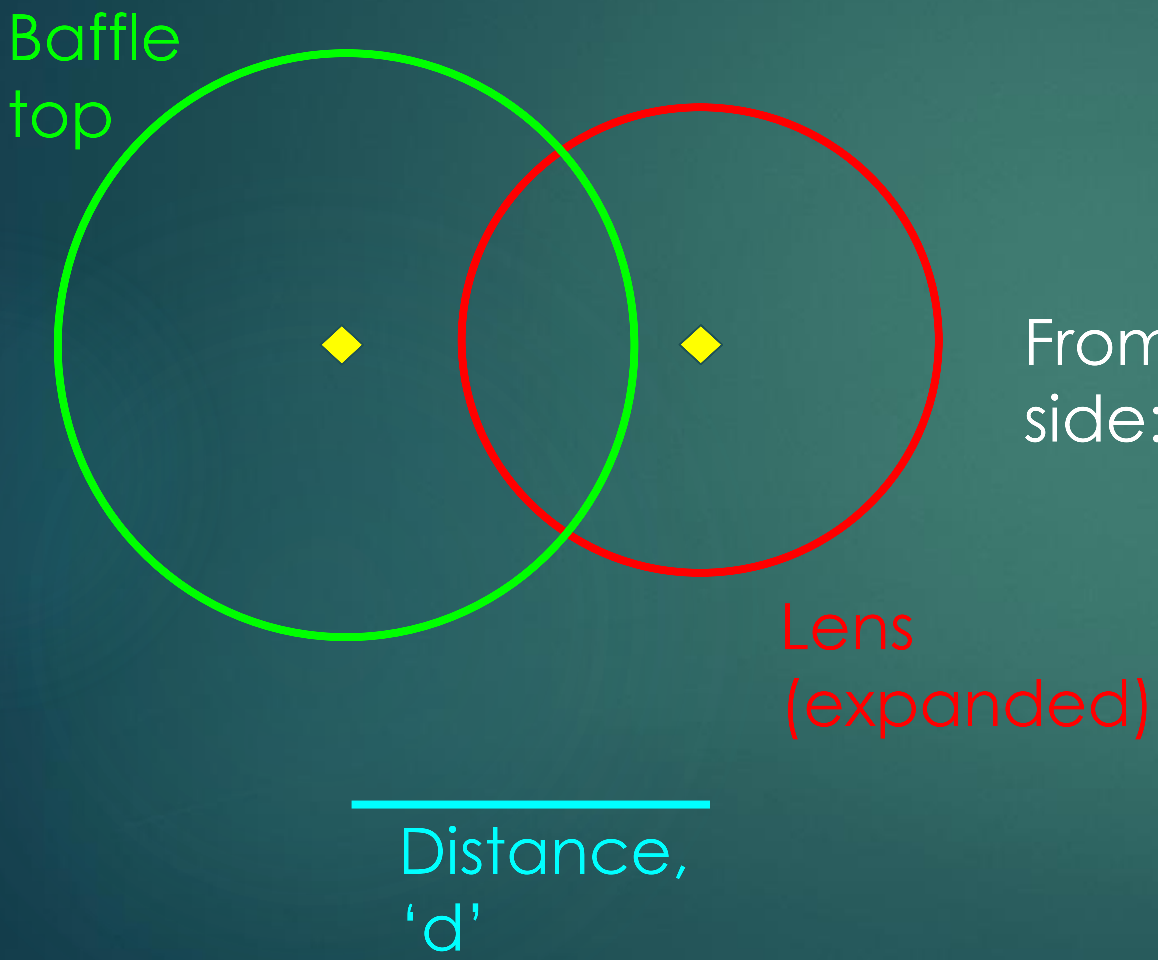



Edge of Baffle top
Baffle top
Slide instead of rotate, Geometrically decrease area
lens
Exposure to light source represented by shared area
Outer area of lens beyond Baffle top

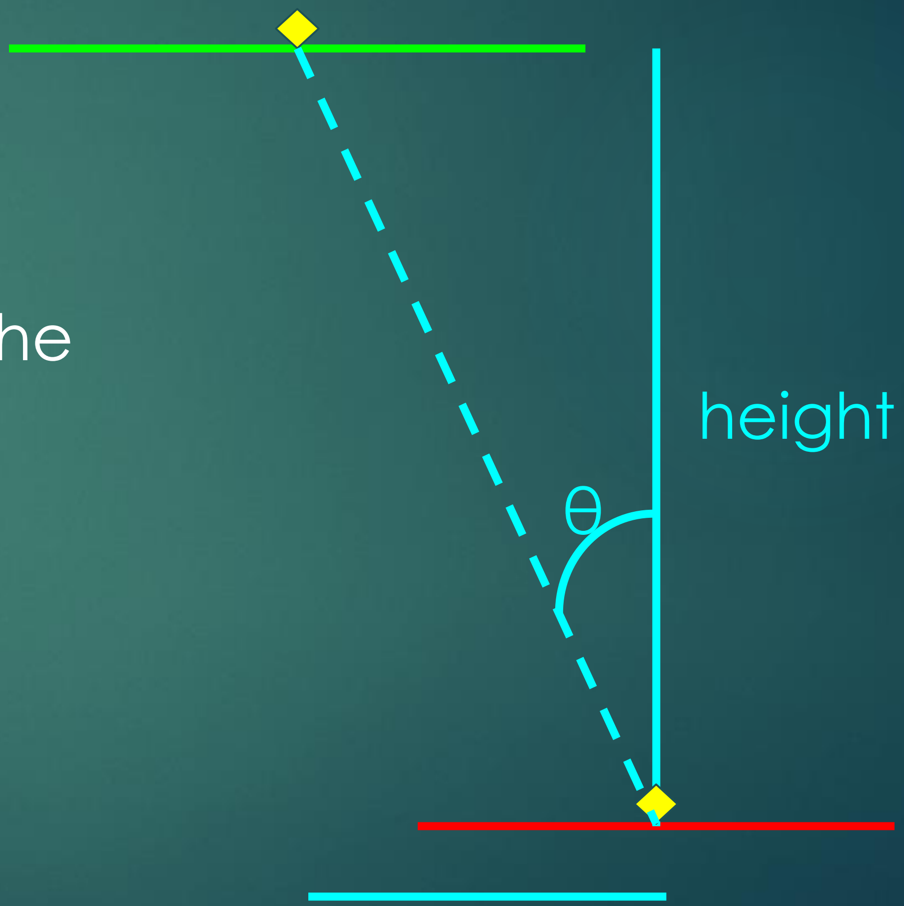


Shared area = small circle area

Shared area = overlap



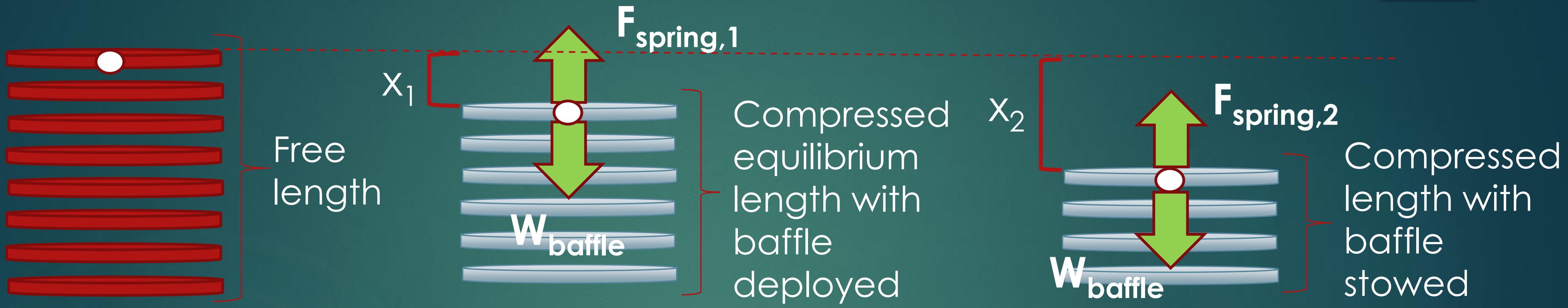
From the side:



Distance, 'd'

$d = (\text{height})(\cos\theta)$

Spring Feasibility



<u>Equilibrium (deployed)</u>

$$F_{spring,1} = -W_{baffle} = kx_1$$

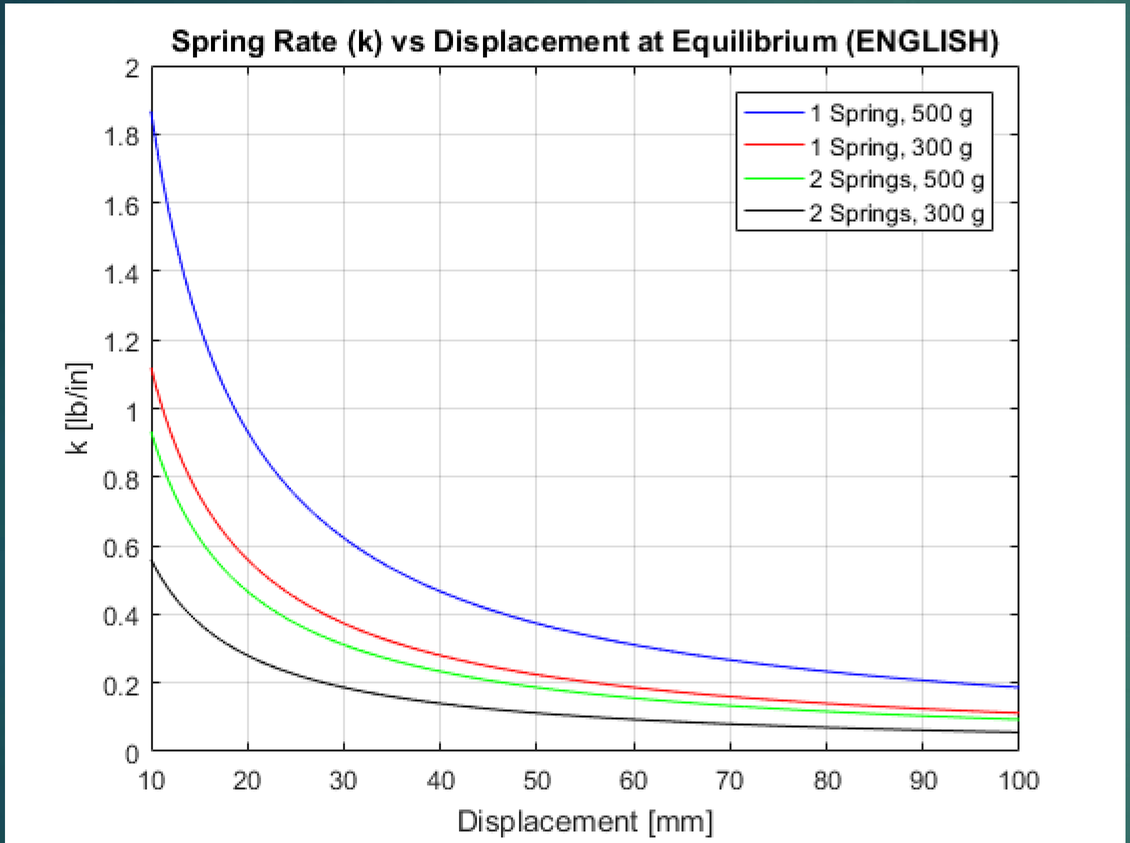
<u>Forced Compression (stowed)</u>

$$F_{spring,2} = kx_2$$

Choose k such that this condition is satisfied

$x_2 > x_1$ therefore $F_{spring,2} > F_{spring,1}$ therefore spring returns to equilibrium length once lock-down mechanism removed

Spring Feasibility



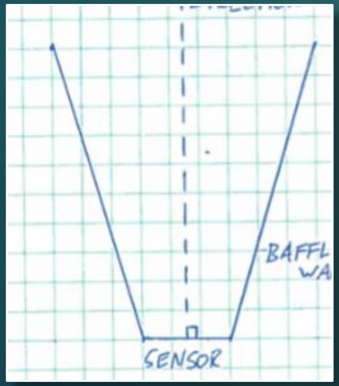
- k < 1 for most configurations of displacement at equilibrium
- Received custom spring manufacturers quote for single spring concept
  - Spring of appropriate diameter and k: 270 g
  - $250 + parts + labor
- Inherent stability issues with 2-spring design
  - Even deployment unlikely
- Ultimately decided spring deployment is not feasible

Trade Studies

Shape Trade Study

	Weight	Cone	Cylinder	Parabolic
Simplicity of Design	0.2	5	4	2
Technology Readiness Level	0.5	5	5	1
Affordability	0.2	5	1	3
Total	1	5	3.9	1.7

Manufacturing Method Trade Study



	Weight	Telescoping	Veggie Steamer	Hinged Close	Straight Side
Simplicity	0.3	4	1	2	5
Affordability	0.1	4	2	3	5
Small Stored Volume	0.3	5	4	2	5
Reliability	0.1	4	3	3	2
Heritage	0.2	5	1	1	4
Total	1	4.5	2.2	2	4.5

Stray Light Attenuation Trade Study

	Weight	Vanes	Lense	Coating
Mass	0.1	3	2	4
Stored Volume	0.1	3	2	5
Ease of Manufacturing	0.15	3	3	5
Receiving Time	0.1	3	2	5
Attenuation	0.2	4	2	4
Technology Readiness Level	0.2	5	3	4
Availability	0.15	5	2	4
Total	1	3.9	2.05	4.35

Deployment Method Trade Study

	Weight	Spring	Balloon	Motor	Magnets	Electrostatic
Technology Readiness Level	0.1	5	3	5	2	3
Ease of Manufacturing	0.3	4	3	4	3	3
Affordability	0.1	5	3	3	4	2
Impulse Powered	0.3	5	5	5	5	0
Mass	0.2	2	4	2	3	5
Total	1	4.1	3.8	3.9	3.6	2.4

Sensor Selection Trade Study

	Weight	Camera	Photoresistor	Luminosity Sensor
Data Handling	0.1	5	2	4
Affordability	0.25	2	5	3
Sensitivity of Intensity	0.45	3	2	4
Receiving Time	0.2	5	5	5
Total	1	3.35	3.35	3.95