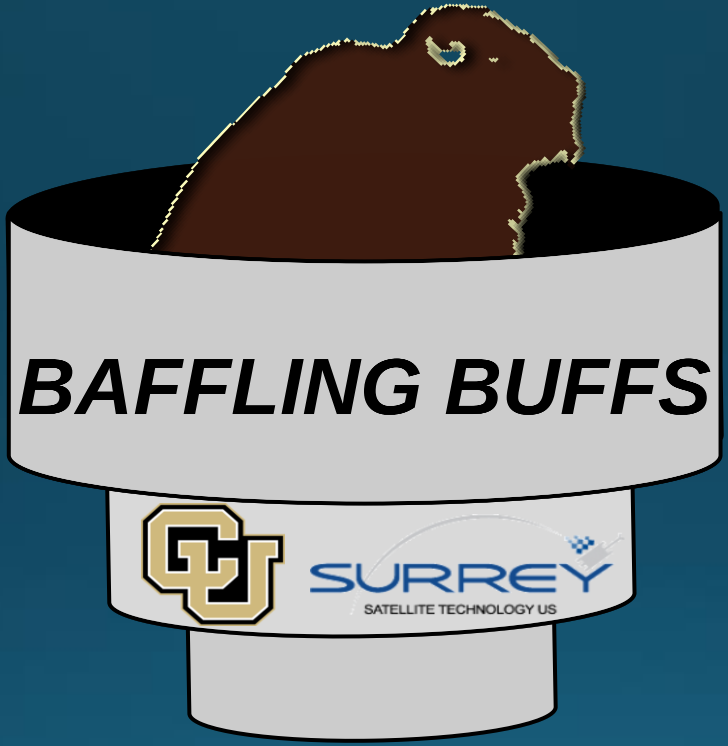
Critical Design Review



Customer:
Scott Taylor,
Surrey Satellite Technology
U.S.

PAB Advisor:
Josh Stamps,
Sierra Nevada Corporation

Presenting: Aspen Coates, Lindsay Goldworm, Elizabeth Luke, Nicholaus Monahan, Sierra Williams

Other Team Members: Anthony Anglin, Emmett Bailey, Steven Hays, Zach McConnel, Mary Scites

Project Overview

Motivation – 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
- **Lightweight deployable** baffle for smallsats

Project Goals

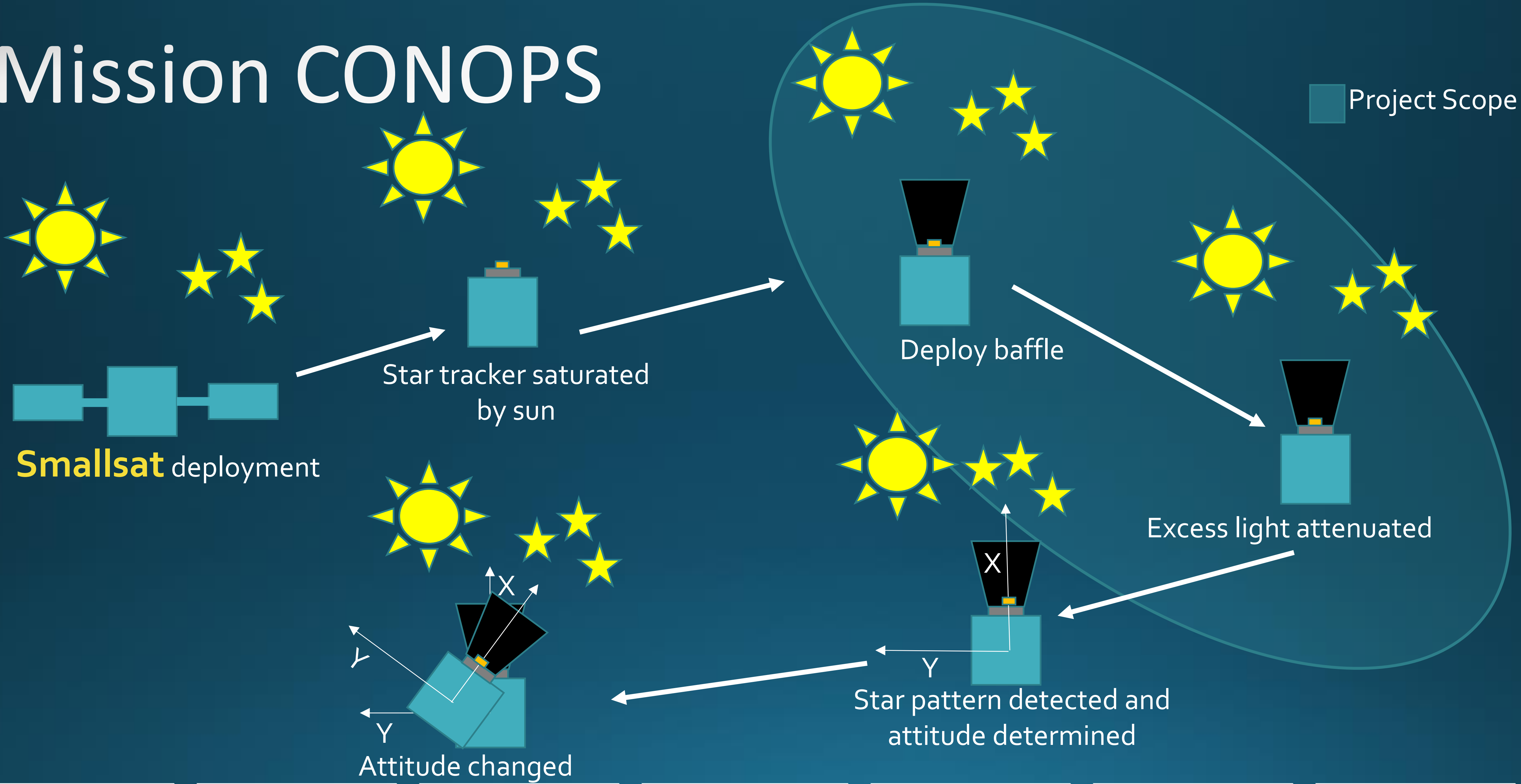
- **Develop a prototype** deployable baffle for a star tracker to be used on a small satellite platform

- **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

Mission CONOPS



Smallsat deployment

Star tracker saturated by sun

Deploy baffle

Excess light attenuated

Star pattern detected and attitude determined

Attitude changed

Requirements

- **FR1: Baffle shall be deployable**
    - DR1.1: Deployable using 28V
    - DR1.2: Full deployment ground testing shall be conducted
- **FR2: Baffle shall fit within volume constraints**
    - DR 2.1: Fit within 125x125x50mm box
- **FR3: Baffle shall adhere to mass constraints**
    - DR 3.1: Weight less than 300g
- **FR4: Baffle shall attenuate light**
    - DR 4.1: Ground testing shall be done to determine light obscuration
    - DR 4.2: 99.9% light attenuation at 30 degrees
    - DR 4.3: Baffle shall have a Pre-Obscuration angle of $\geq 10^{o}$

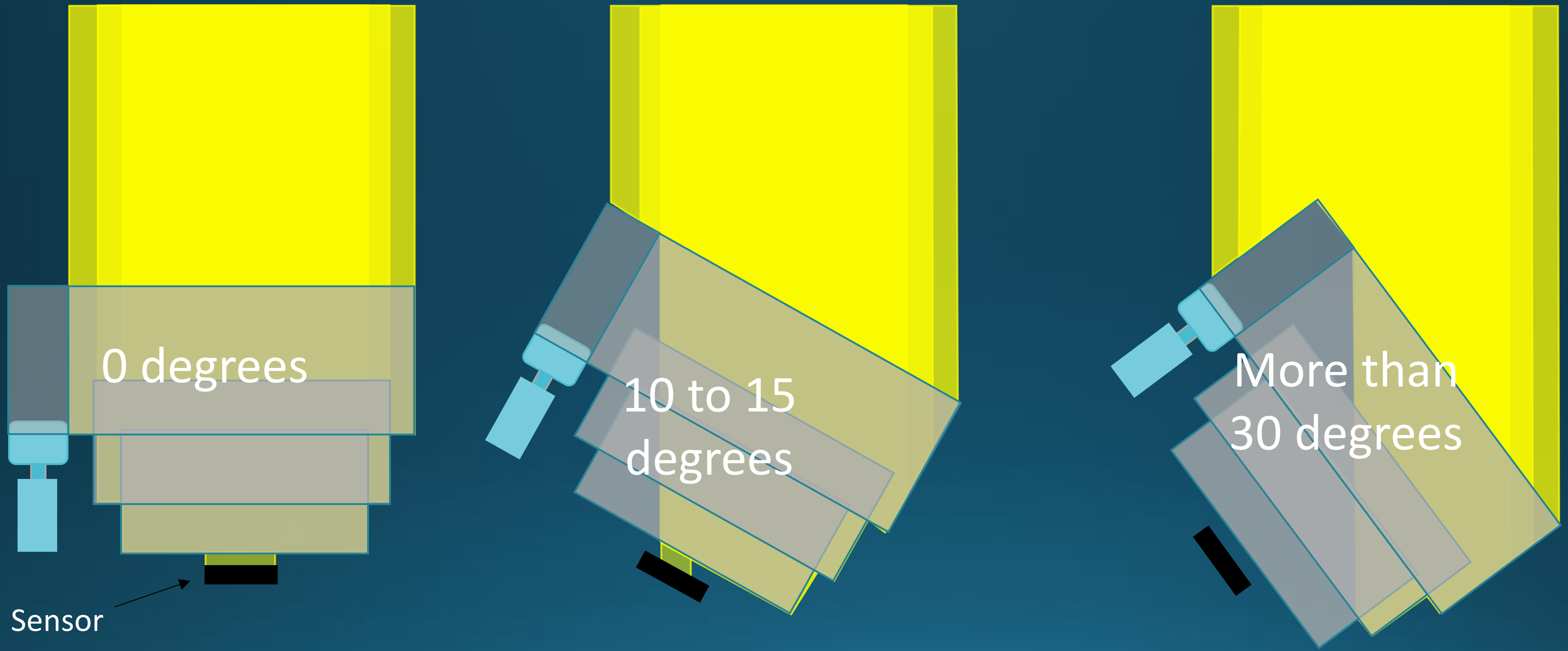
Project CONOPS - Deployment

Power sent to motor

Power Screw Rotates

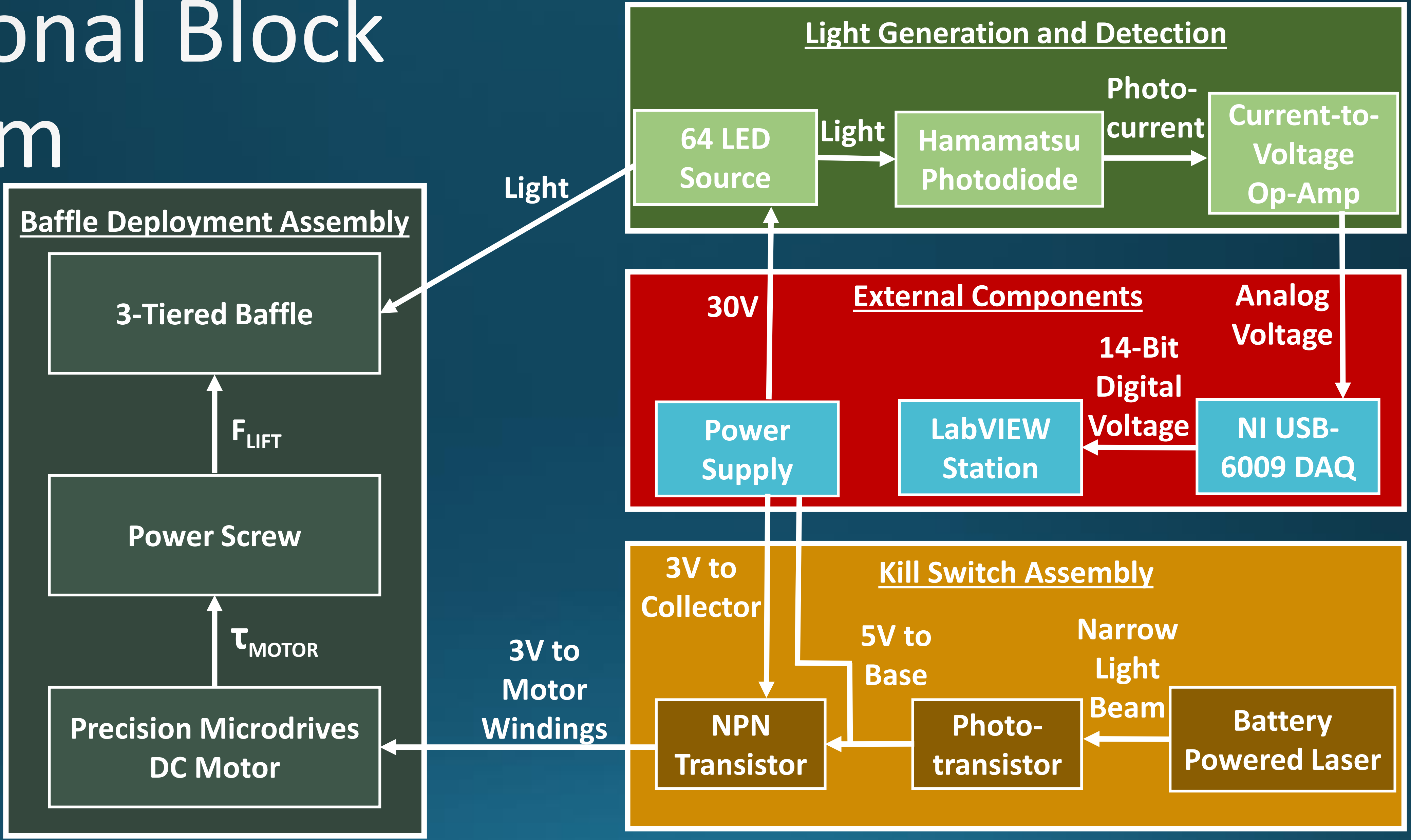
Baffle Deploys

Project CONOPS – Light Attenuation



* In testing the sensor will not be displaced from the baffle

Functional Block Diagram



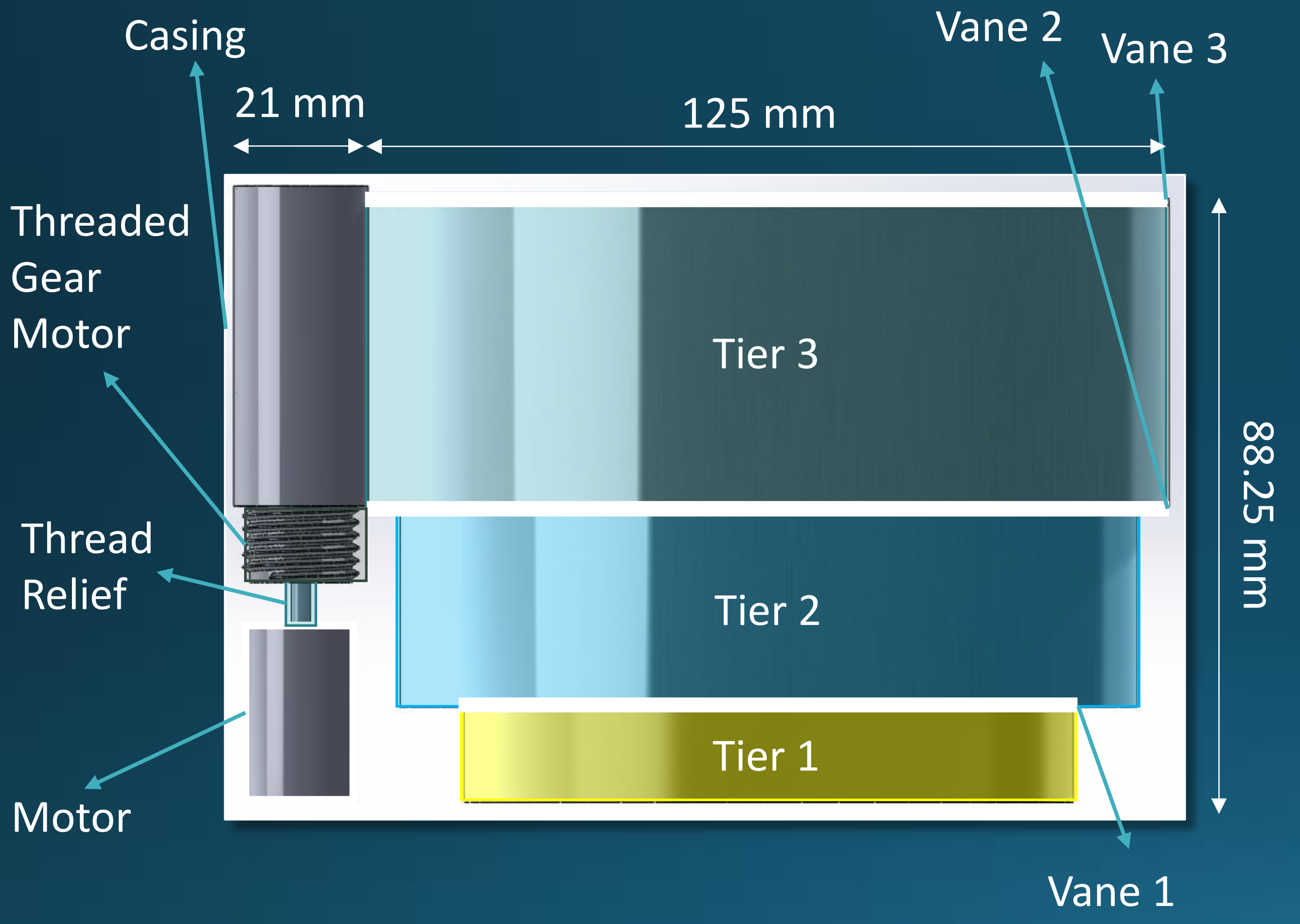
Project Assumptions & Levels of Success

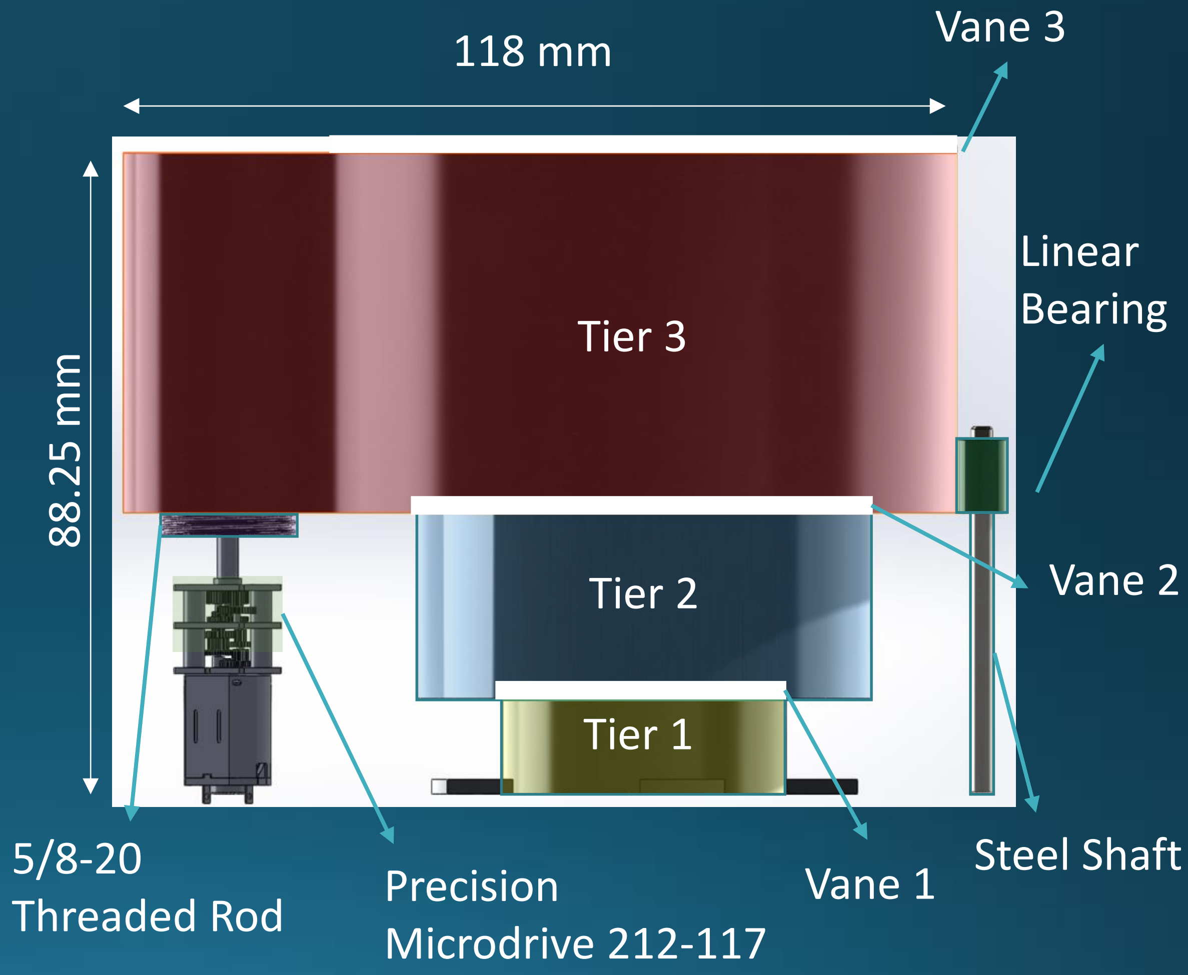
- Design is proof of concept
  - Need not be space grade
- Focus on attenuating light from Sun
- Spacecraft will be in L.E.O.
- From spacecraft bus:
  - Voltage available: 28 V
  - Current available: 2.5 Amps
  - Power available: 70 Watts

	TIER 1	TIER 2
DEPLOY BAFFLE (FR1)	Manual Deployment	Electronic deployment with a wired connection
STOWED BAFFLE VOLUME (FR2)	Constrained by: 175 mm width 175 mm length 50 mm height	Constrained by: 125 mm width 125 mm length 50 mm height
BAFFLE MASS (FR3)	<500 grams	<300 grams
BAFFLE LIGHT EXCLUSION (FR4)	40 degree light exclusion angle	30 degree light exclusion angle

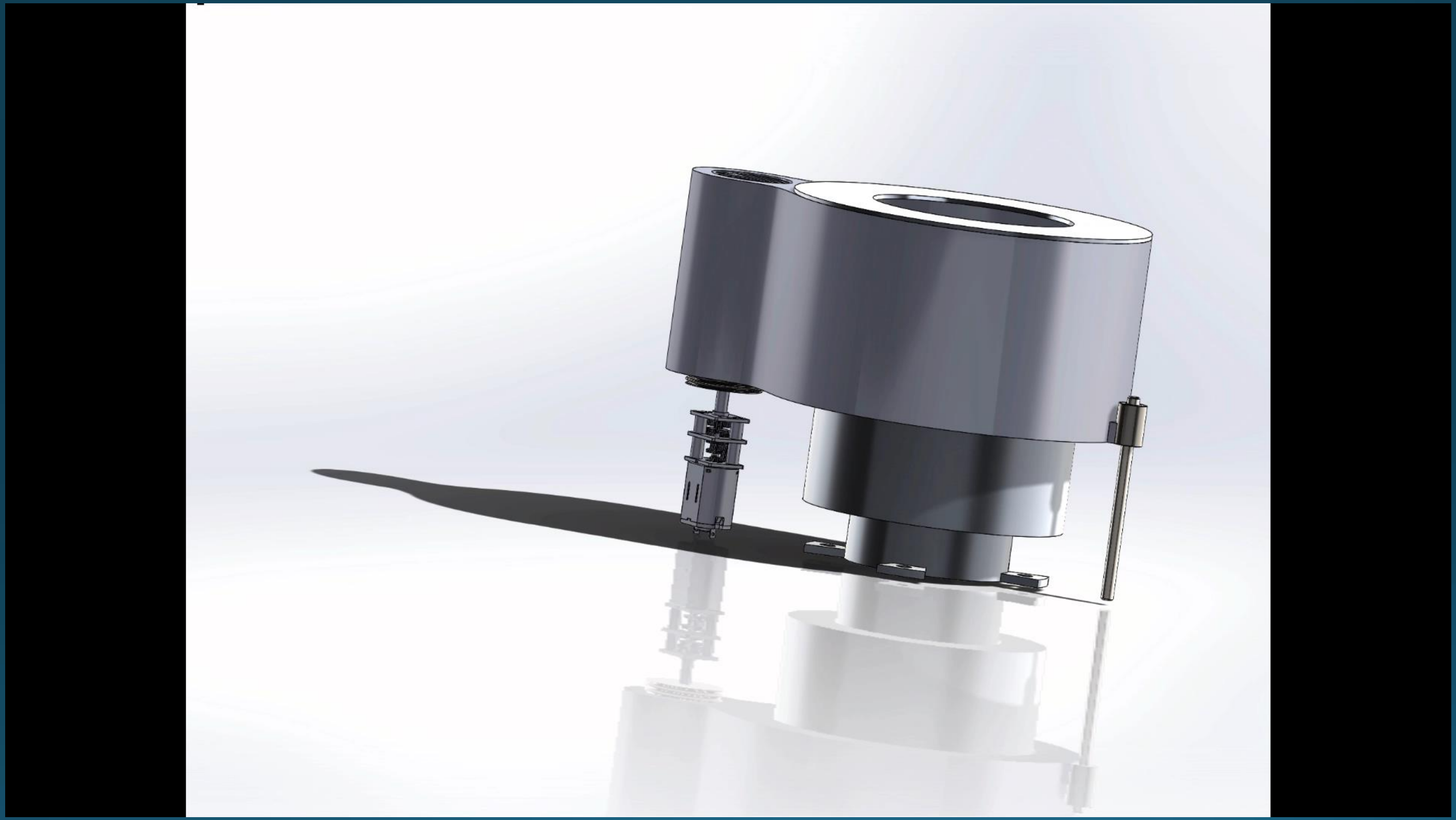
Design Solution

Baffle – Old vs New



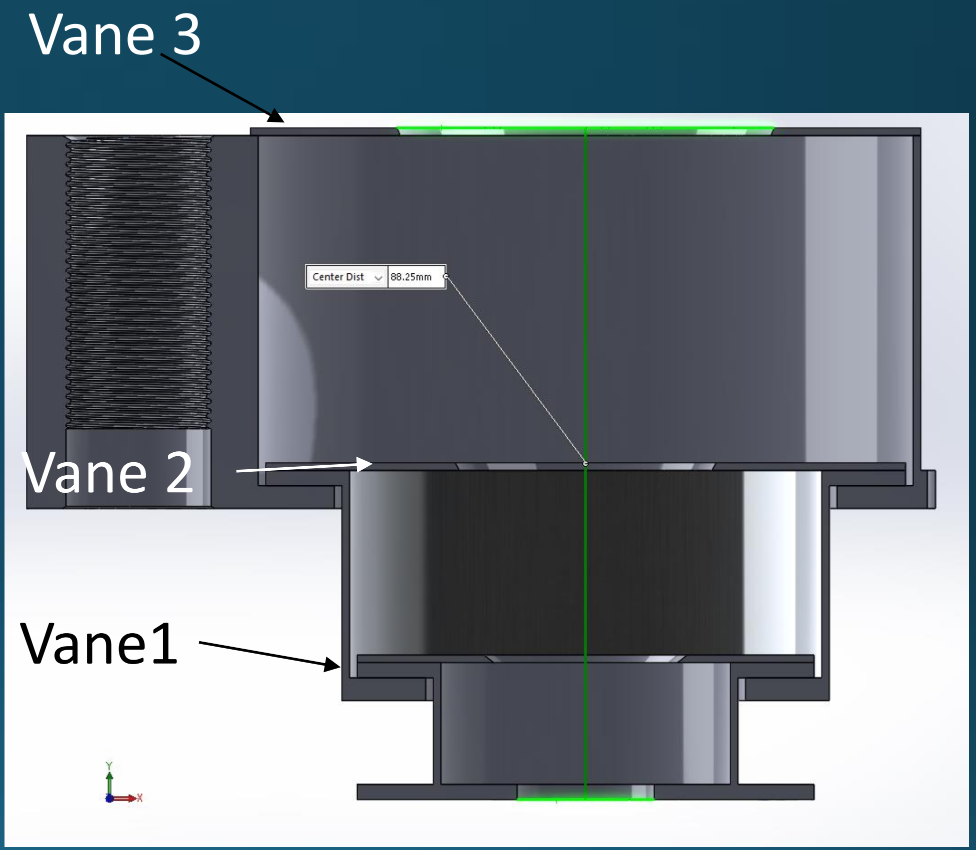


Expanded Baffle

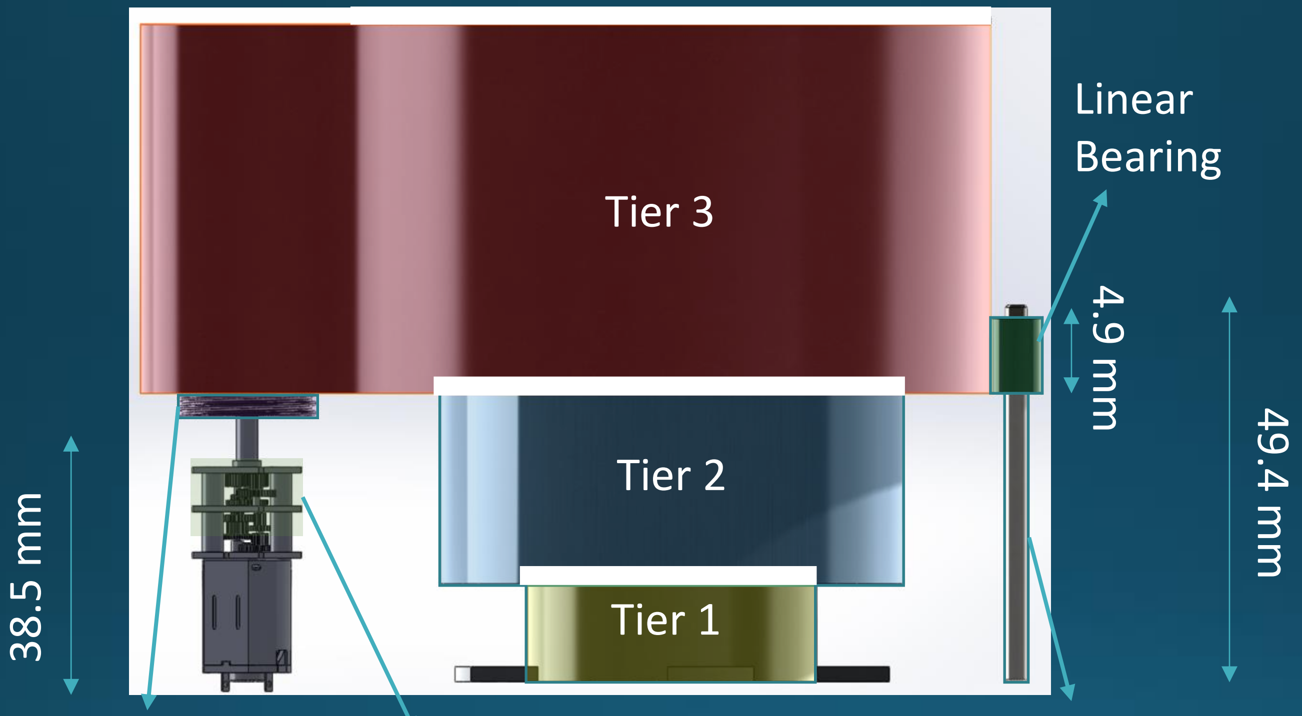


Light Attenuation Design (FR4)

- Vanes
  - On top of each tier
  - Create surface for light to reflect off
- Coating – Aeroglaze
  - 95% absorptivity
  - Applied to the entire inside of the baffle
  - Absorbs incoming light on incident surfaces



Deployment Design (FR1)



Linear Bearing

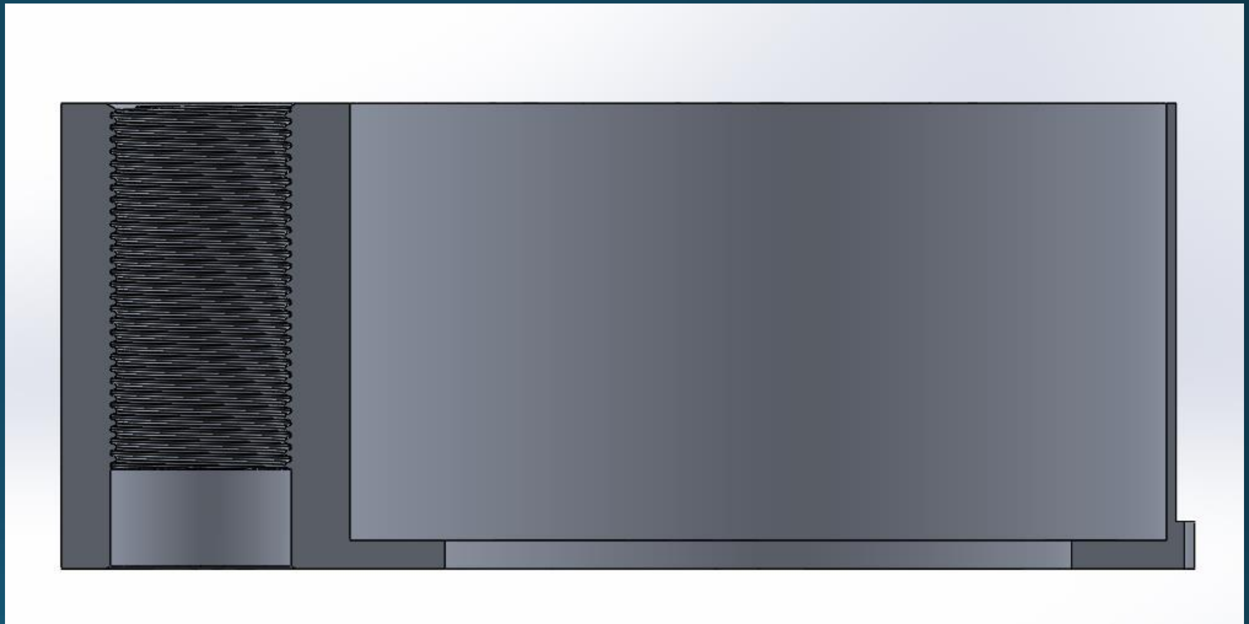
5/8” 20 Threaded Rod

Precision Microdrive 212-117

Steel Shaft

Deployment Stop

- Mechanical
    - Threads stop at full deployment
- Timing
    - Stop motor after specified time when baffle is fully deployed



Critical Project Elements

Critical Project Elements

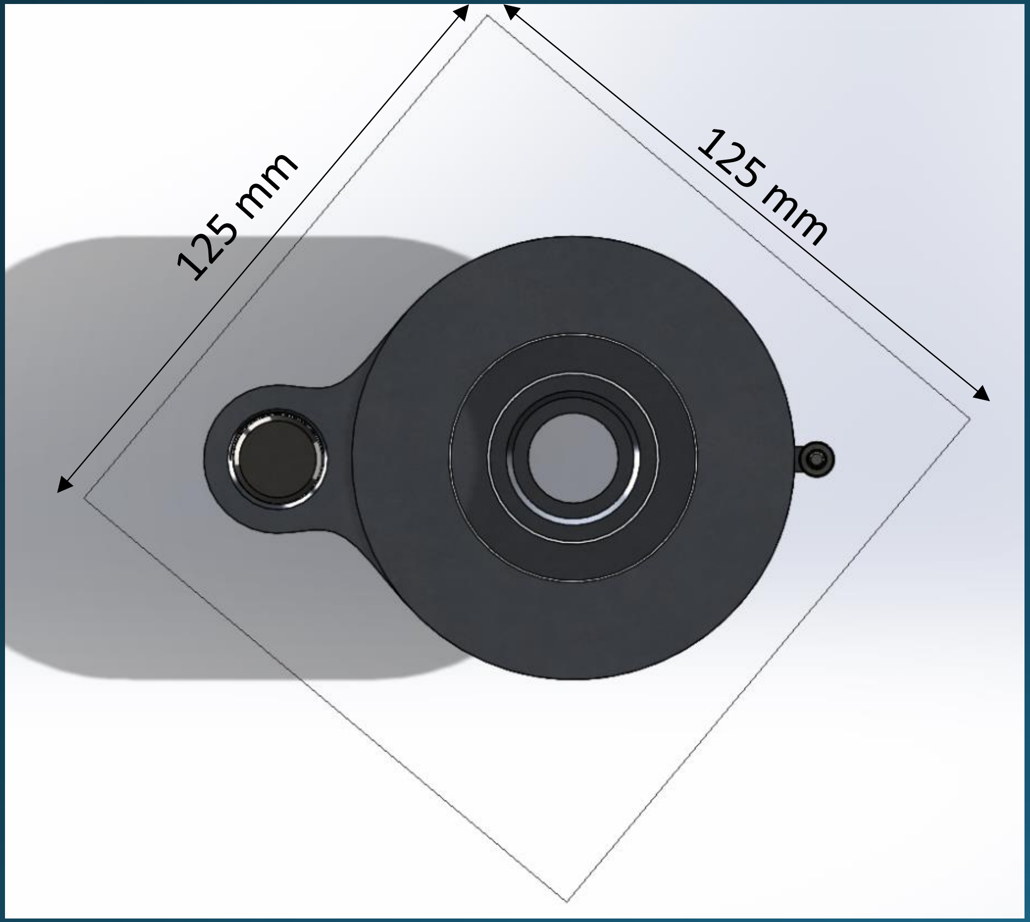
CPE	Project Integration
Deployment (FR1-3)	• Electrical Interface • Mechanical Integration • Manufacturing Baffle Challenges & Tolerances • Mass & Volume Budget
Light Attenuation (FR4)	• Manufacturing Vane Tolerances • Simulation Accuracy
Testing (FR1&4)	• Electrical Interface • Mechanical Integration • Manufacturing Testing Parts • Simulation Accuracy and Precision

Mass Budget (FR3)

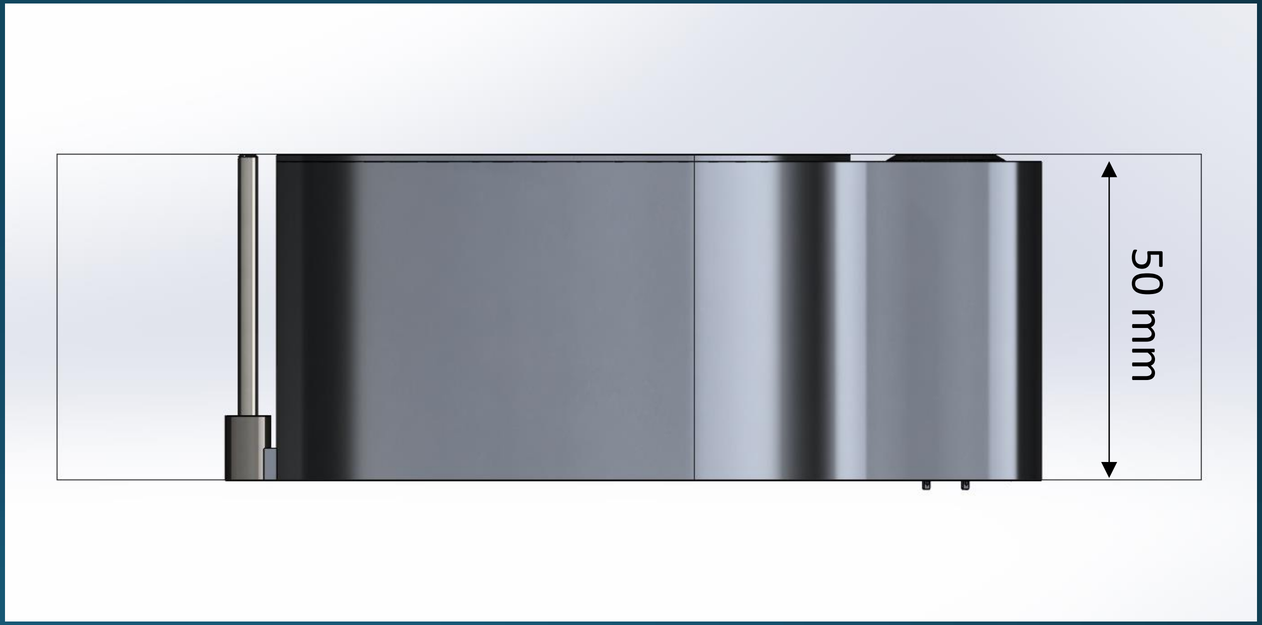
Design Requirement 3.1 MET!

Component	Mass [g]	Component Type	Percent Mass Growth Allowance (AIAA Standard)	Mass Including Allowance [g]
Baffle Tiers	186.16	Structure	15%	214.08
Vanes	31.00	Structure	15%	35.08
Steel Screw	21.05	Structure	3%	21.68
Motor	10.3	Existing Hardware	3%	10.61
Adhesive	5.67	Applied material	50%	8.50
Linear Bearing	5.19	Existing Hardware	3%	5.35
Coating	2.20	Applied material	50%	3.31
Bearing Attachment	0.9	Structure	15%	1.04
Set screw	0.28	Existing Hardware	3%	0.29
Total	263.86			299.94

Volume Budget for Stowed Baffle (FR2)



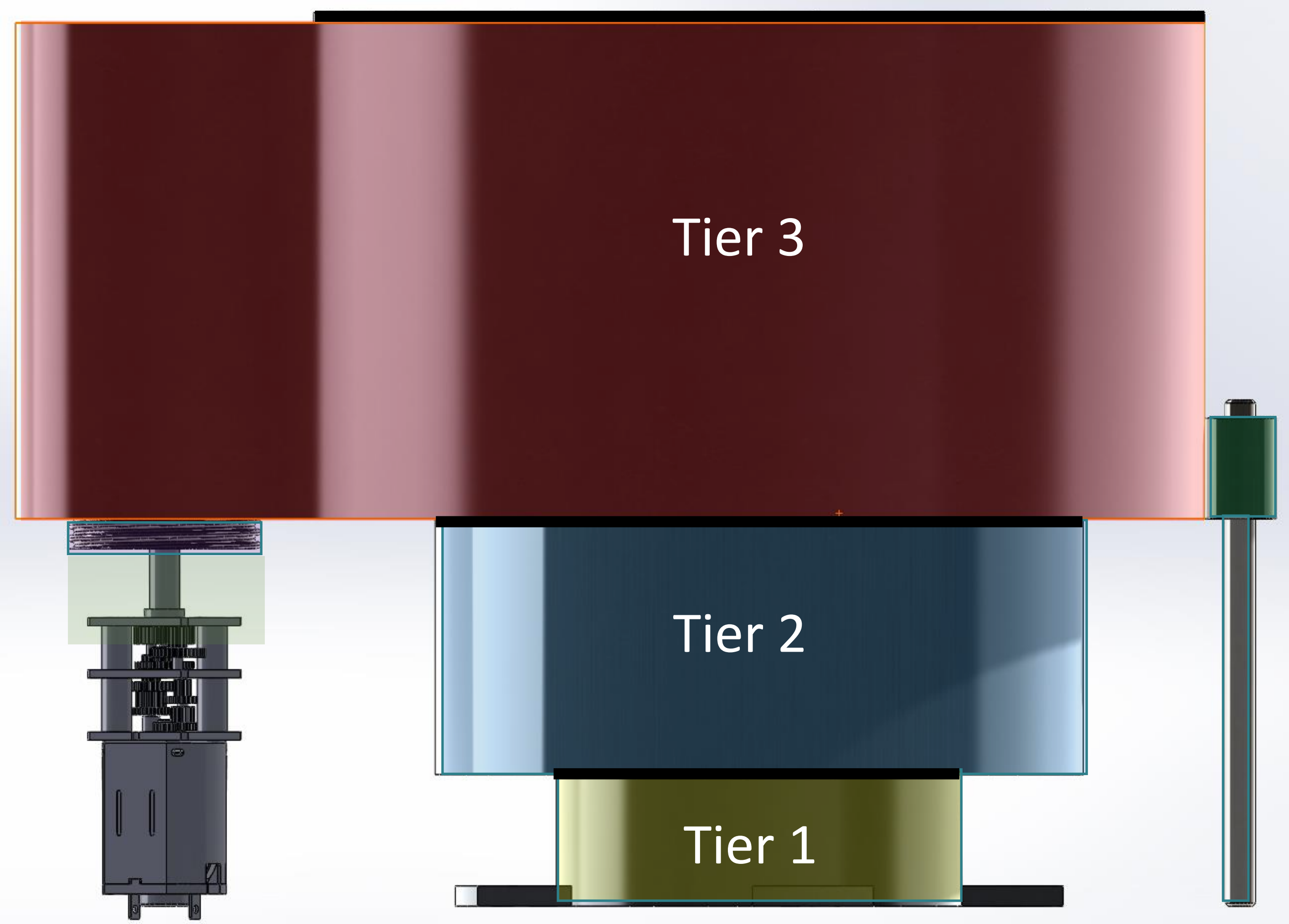
Design Requirement 2.1 MET!



Design Requirements

Baffle Must be Deployable (FR1)

Baffle Design (FR1&4)



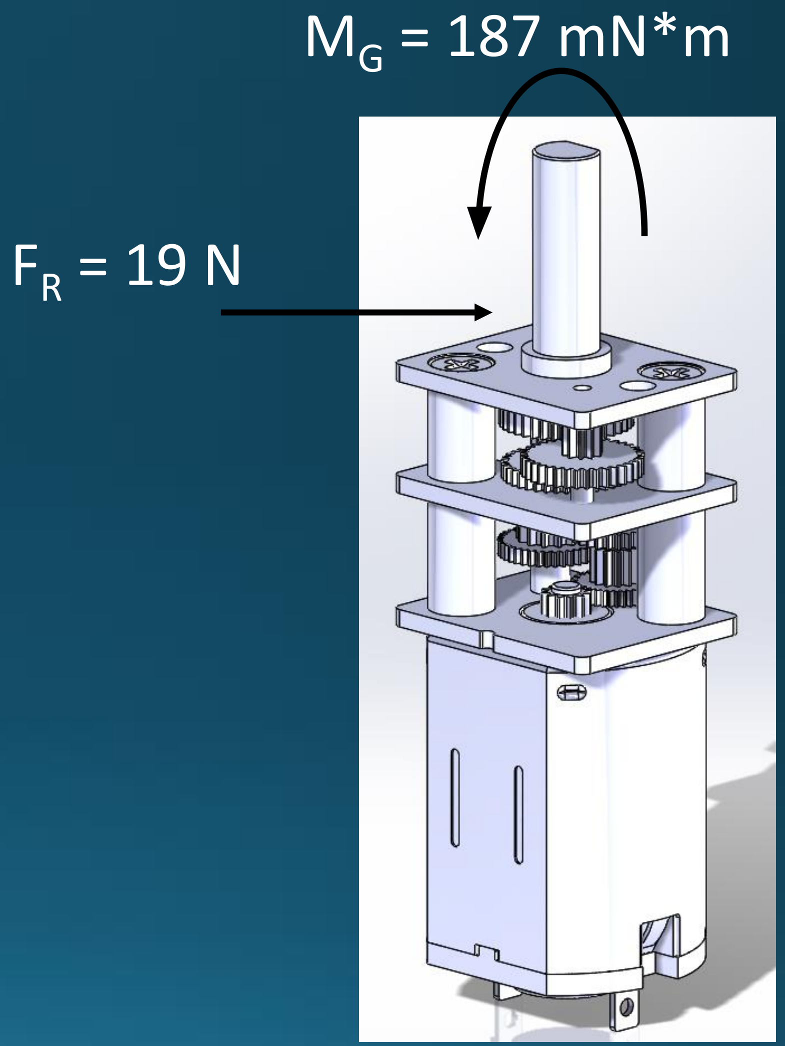
- Three tiered design
- Collapsible
  - Screw deployment mechanism
- Must be deployed to achieve desired optical performance

DC Motor Holding Torque Test

- Ensure motor can support baffle after deployment
- Test was conducted
  - ***Method:***
    - Hang weights in increments until breakaway torque is achieved
  - ***Results:***
    - Largest mass 500g (98 mN*m)
    - Breakaway torque >18 mN*m required

Radial Force on Motor Axle

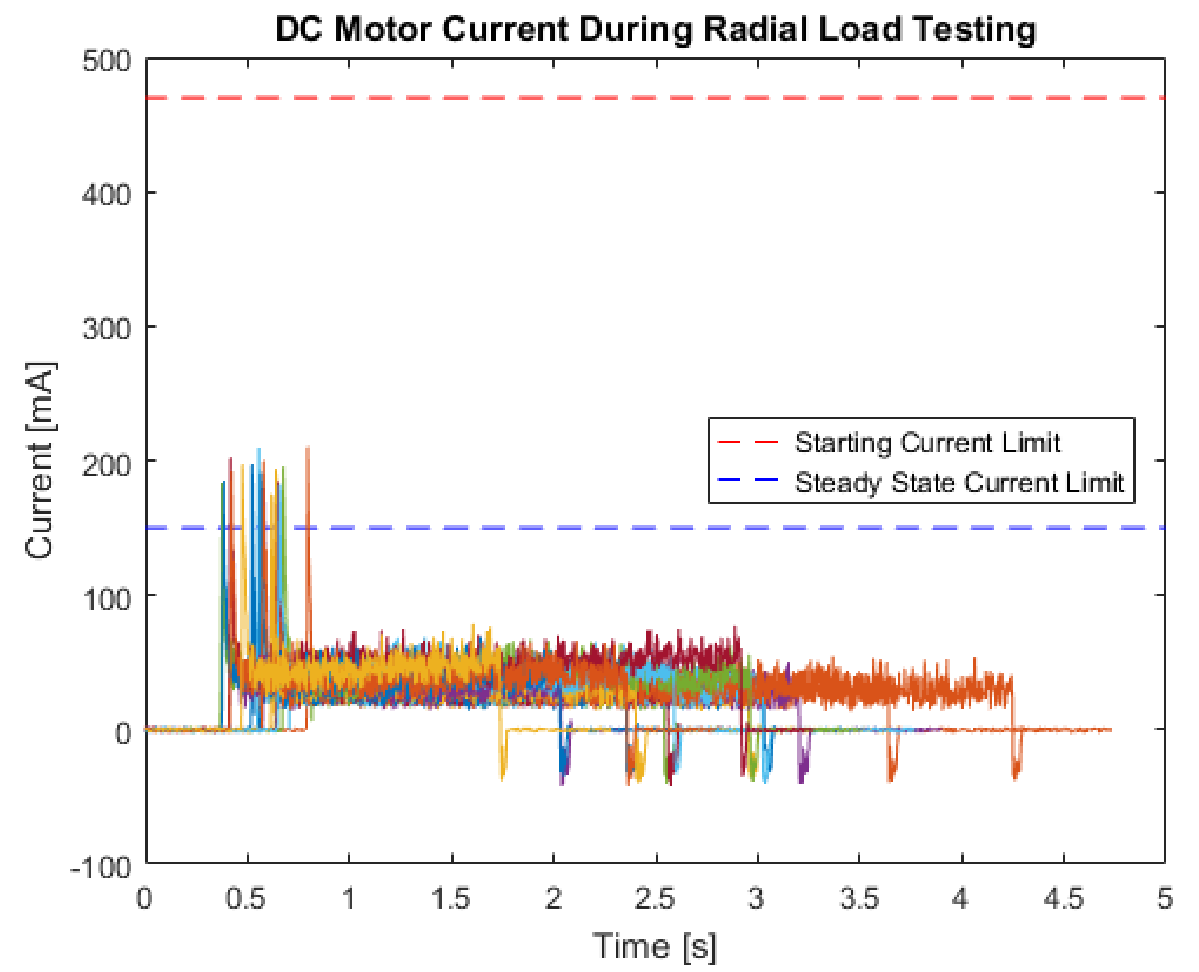
- Motor Data Sheet
  - Maximum allowable radial force: 4 N
- Assuming simplified beam (upper limit values)
  - $M_G = d * F_G$
  - $F_R = \frac{M_G}{d_A}$
- Expected radial force:
  - 19 N



DC Motor Radial Load Test

- Ensure motor can handle expected radial load
- Test was conducted:
  - ***Method:***
    - Hang weights from shaft in increments until shaft stalls

      OR
    - Motor current limit is reached
  - ***Results:***
    - Largest mass: 2500 g (24 N)
    - Did not stall



Friction Moment and Resultant Force on Baffle

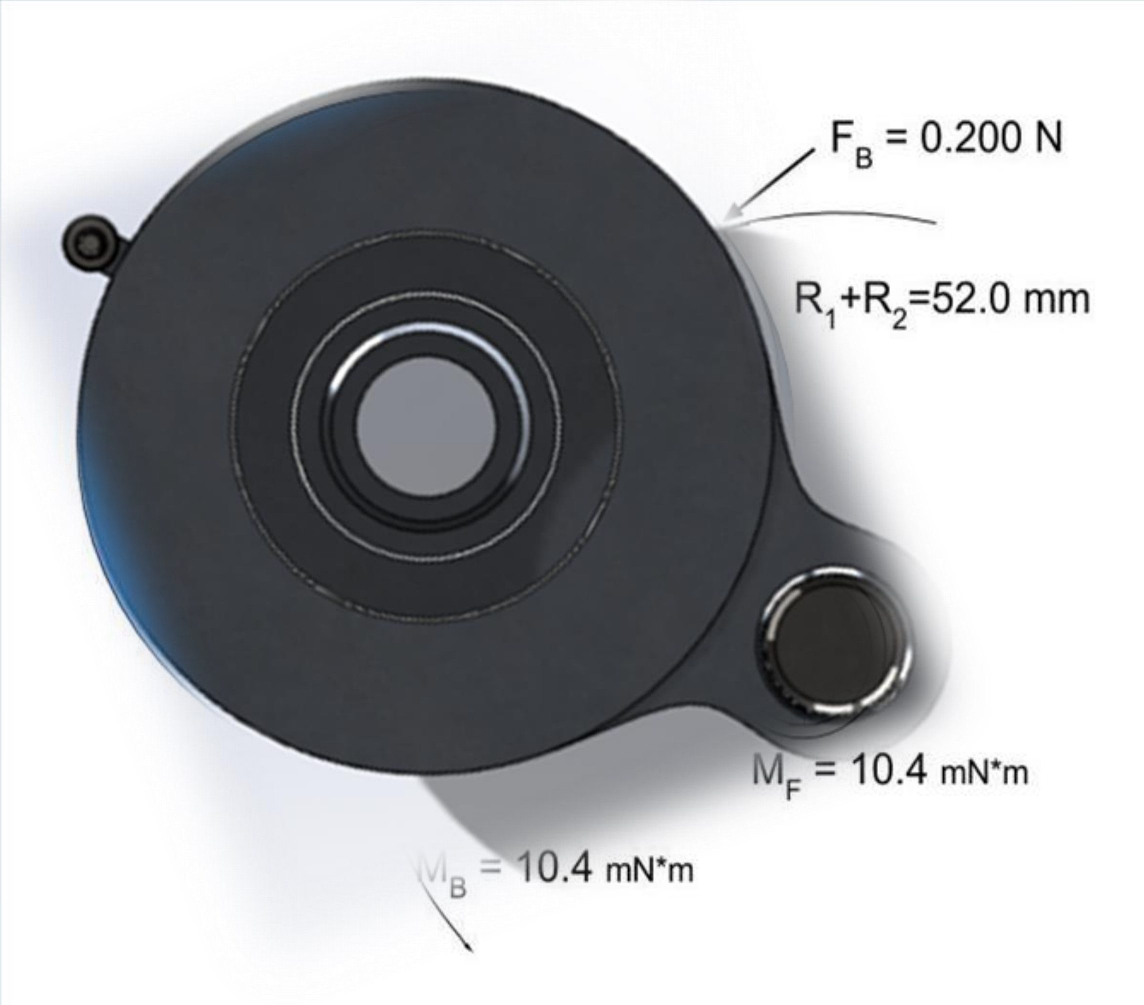
Assumptions:

- Friction of screw on casing

-Coefficient of friction of aluminum on steel

-Full Friction moment is transferred to fixed baffle

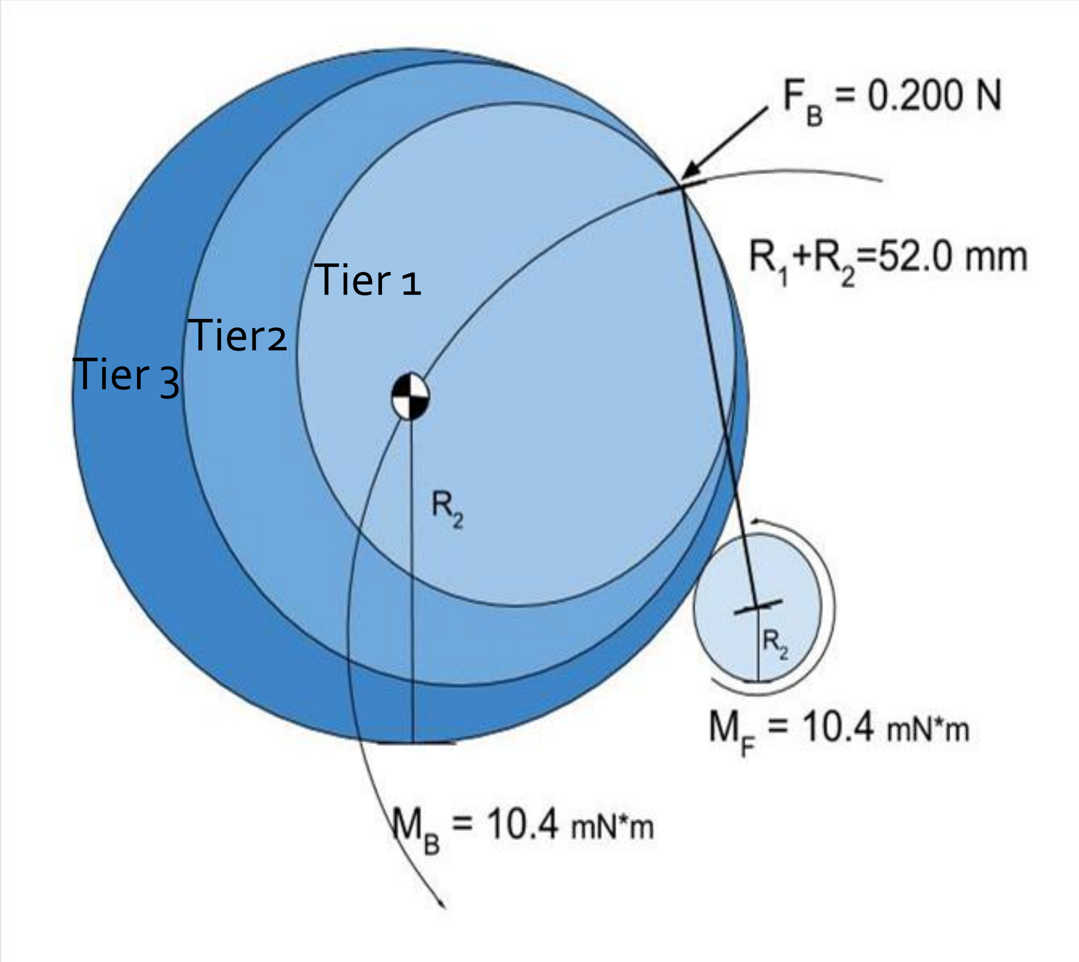
-Moment causes force F_B to be placed on interior baffle sides, also causes off center optics

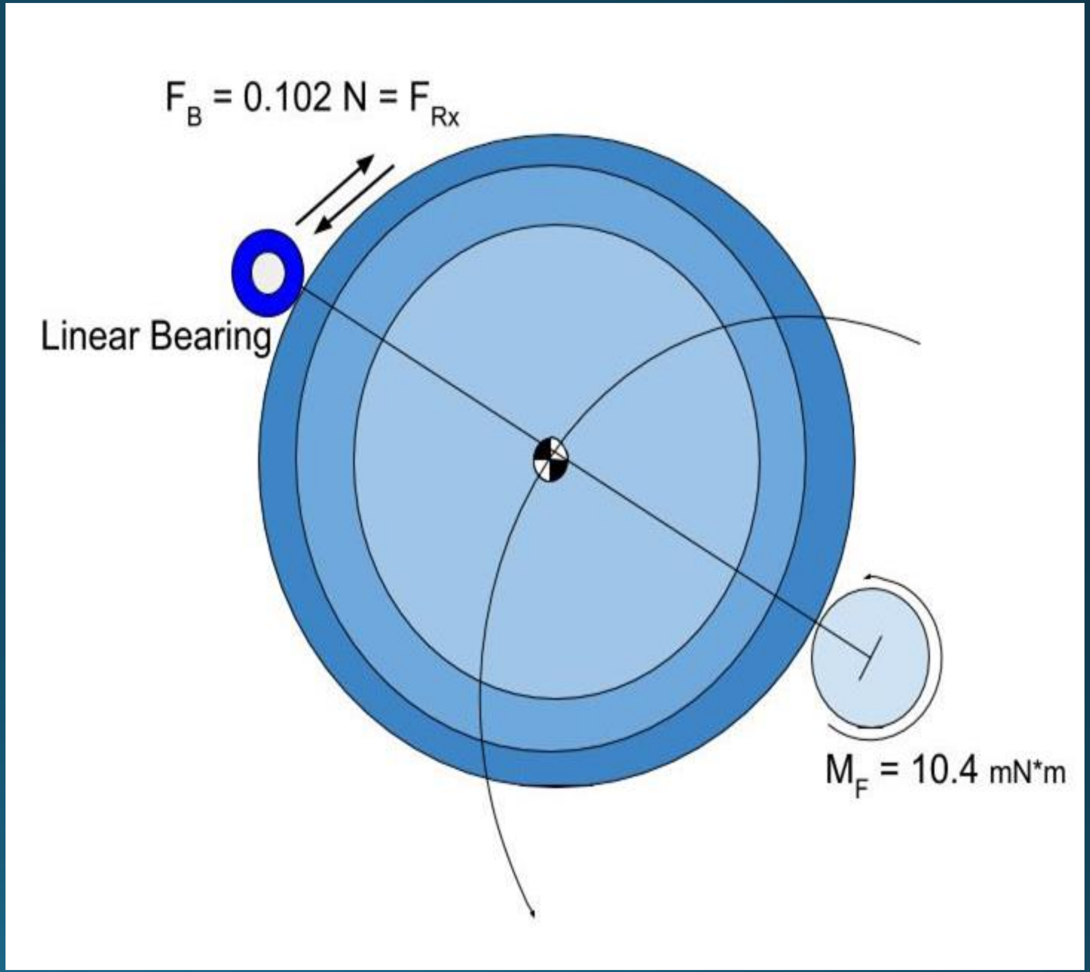


Solution to Moment Concerns: Linear Bearing

- Only allows motion along z-axis
- Moves with top baffle tier
- Counteracts moment generated by motor

Effect of Linear Bearing





Adhesive – Loctite Epoxy Weld

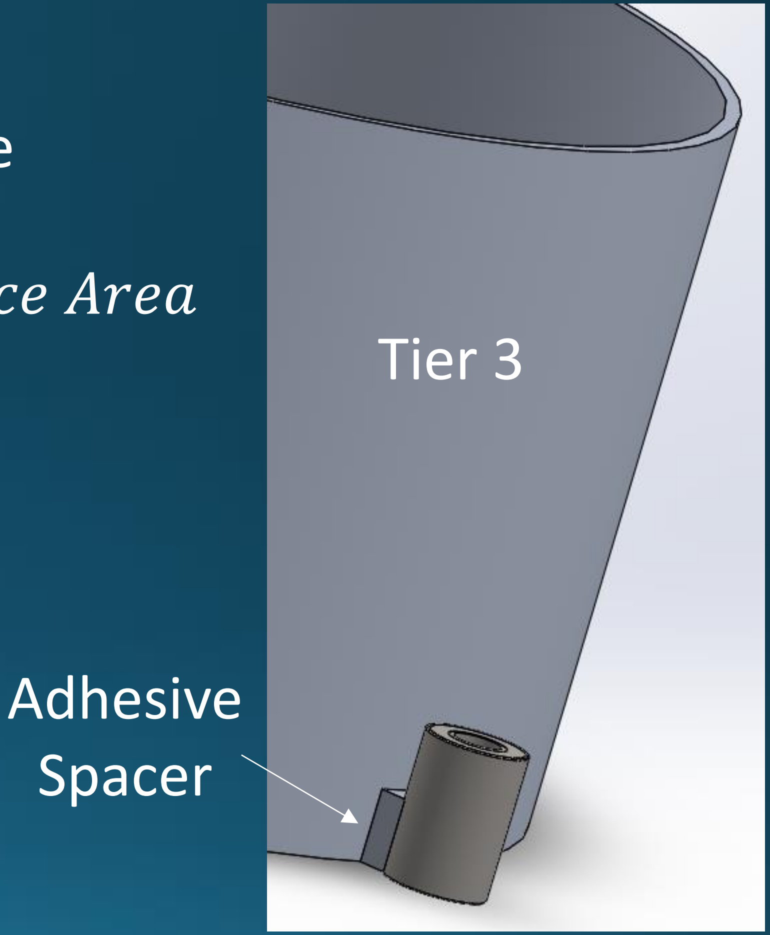
- Will be used to attach vanes & linear bearing
  - No force on vanes, but linear bearing will experience force

$$Bond\ Strength = Adhesive\ Shear\ Strength * Contact\ Surface\ Area$$

$$Bond\ Strength = 1947.33\frac{g}{mm^2} * 45mm^2$$

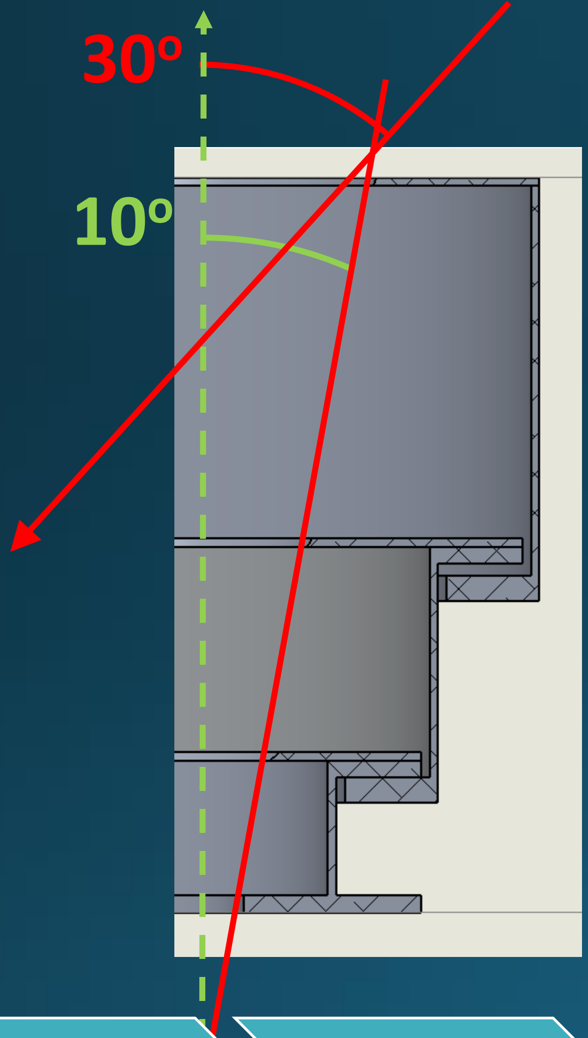
$$\boxed{\boldsymbol{Bond\ Strength = 4870.2\ g}}$$

- Expected mass on linear bearing < 250 g
- **FOS: 19.48**



Baffle Must Attenuate Light (FR4)

Pass- and Stop-Bands



Design the baffle for a star tracker with a 10º FOV half angle:

Pass-band requirement:

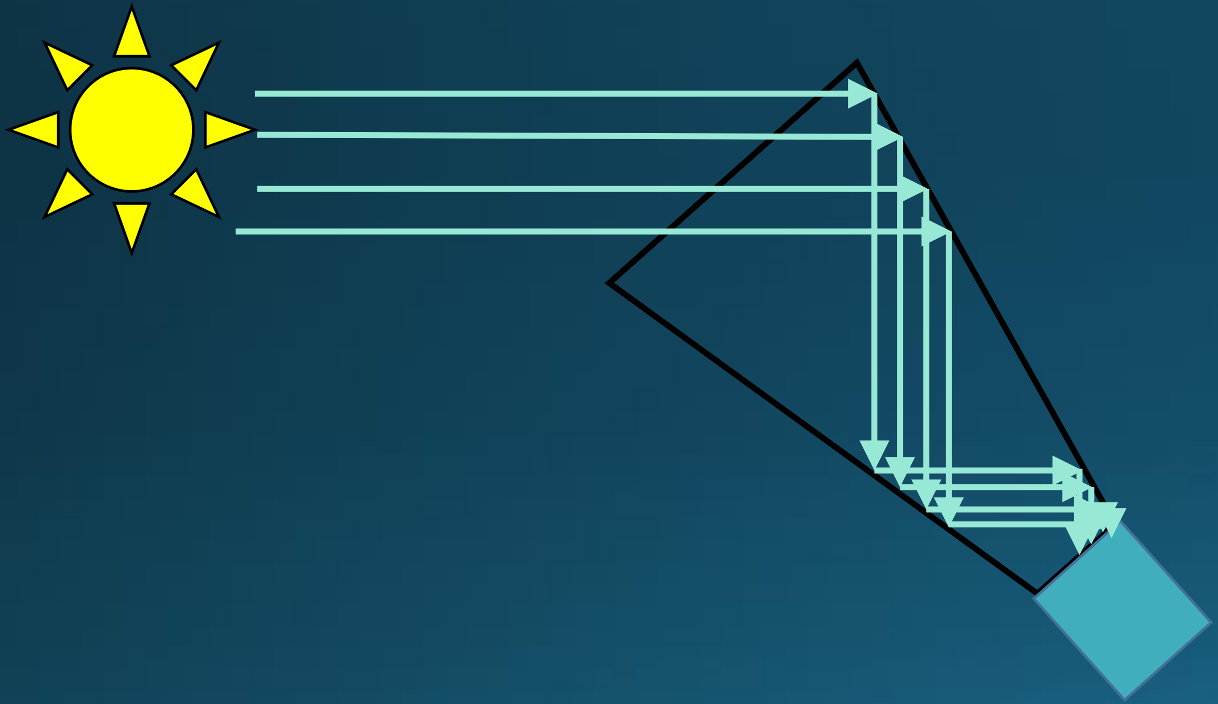
- Stray light attenuated no more than 5% at an incident half-angle of 10º

Stop-band requirement:

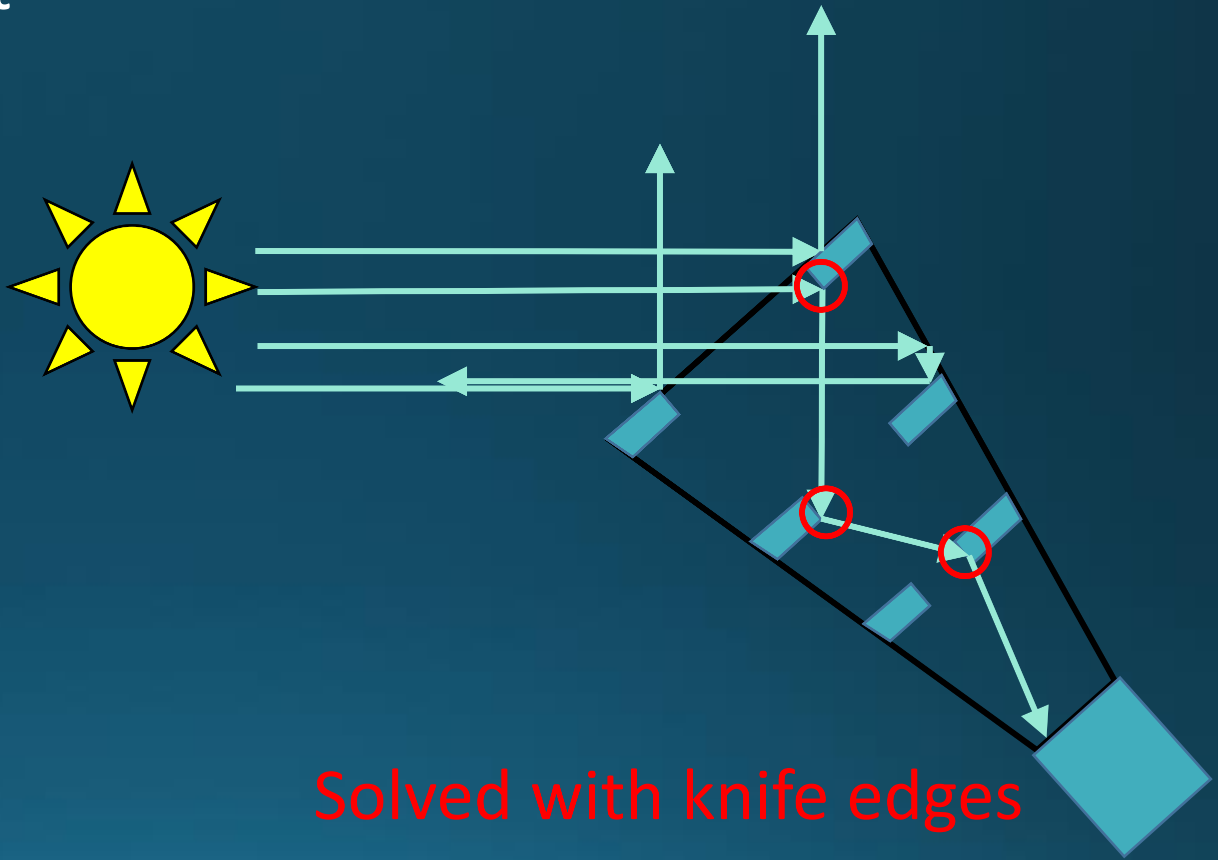
- Stray light attenuated no less than 99.9% at an incidence half-angle of 30º

Vanes

Vanes are used to redirect stray light



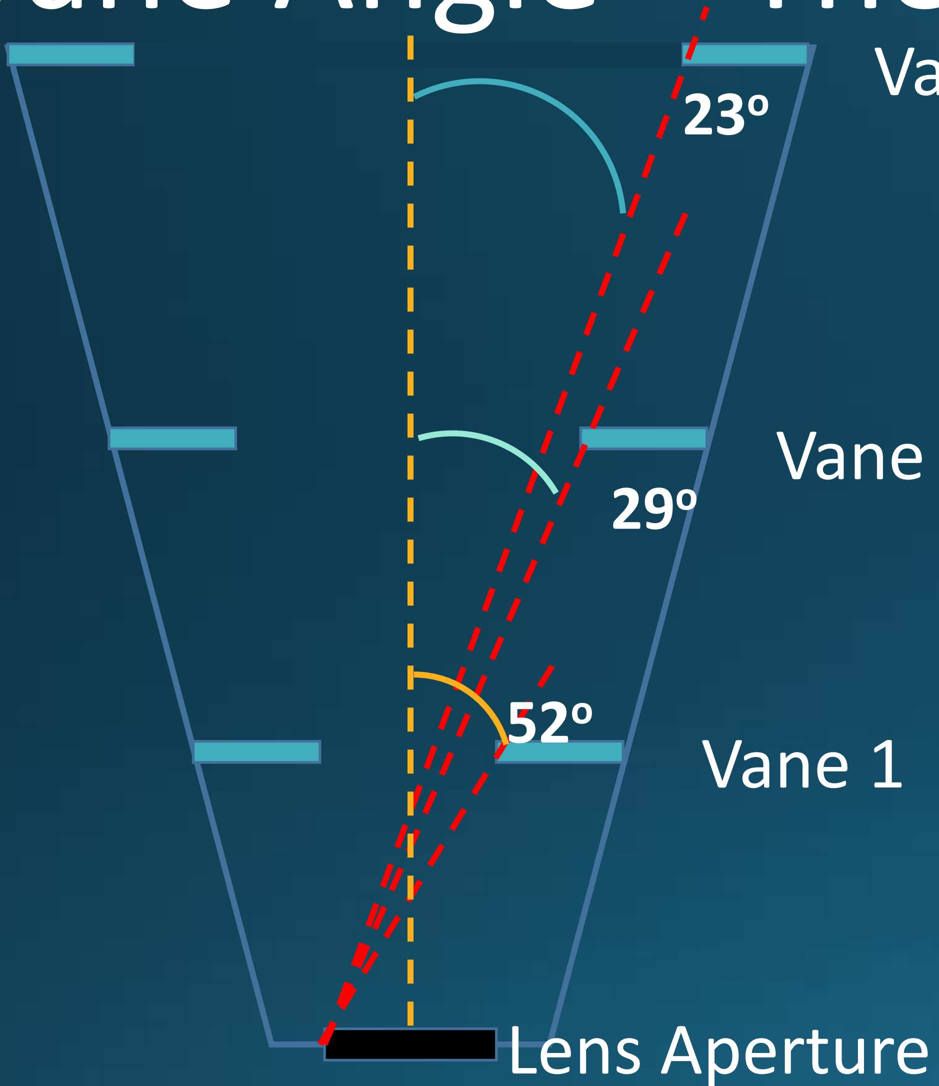
The problem



Solved with knife edges

The solution – vanes!

Vane Angle – The ‘Knife Edge’

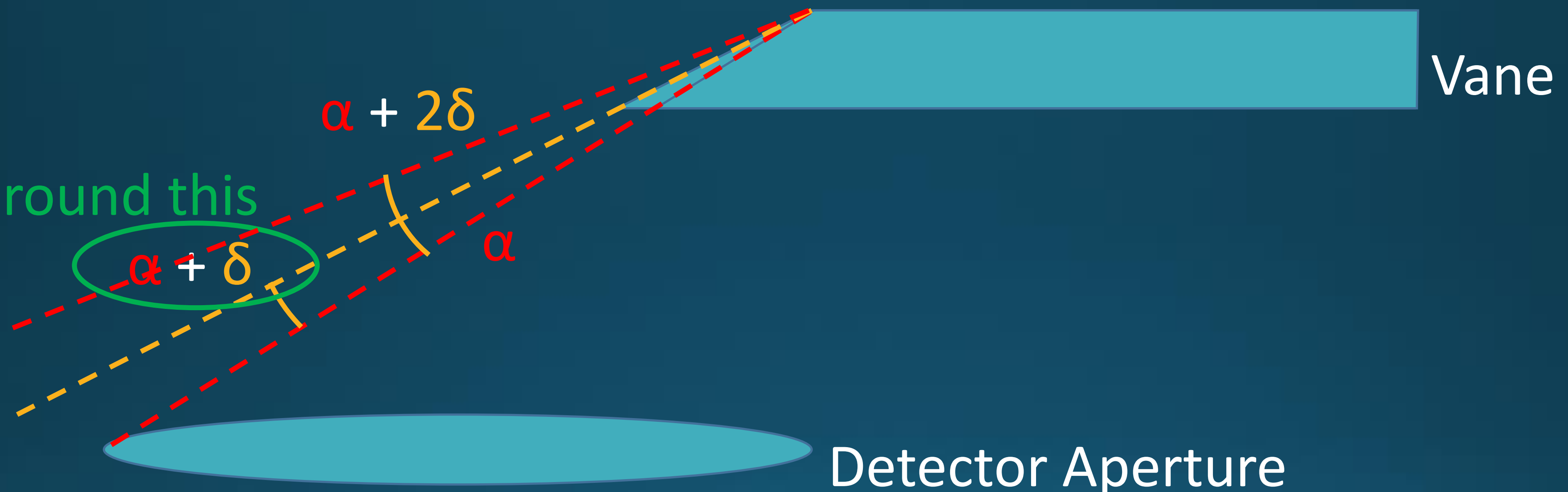


How is vane angle computed?

Vane	Angle	Tolerance
1	52o	+/- 2 o
2	29 o	+/- 2 o
3	23 o	+/- 2 o

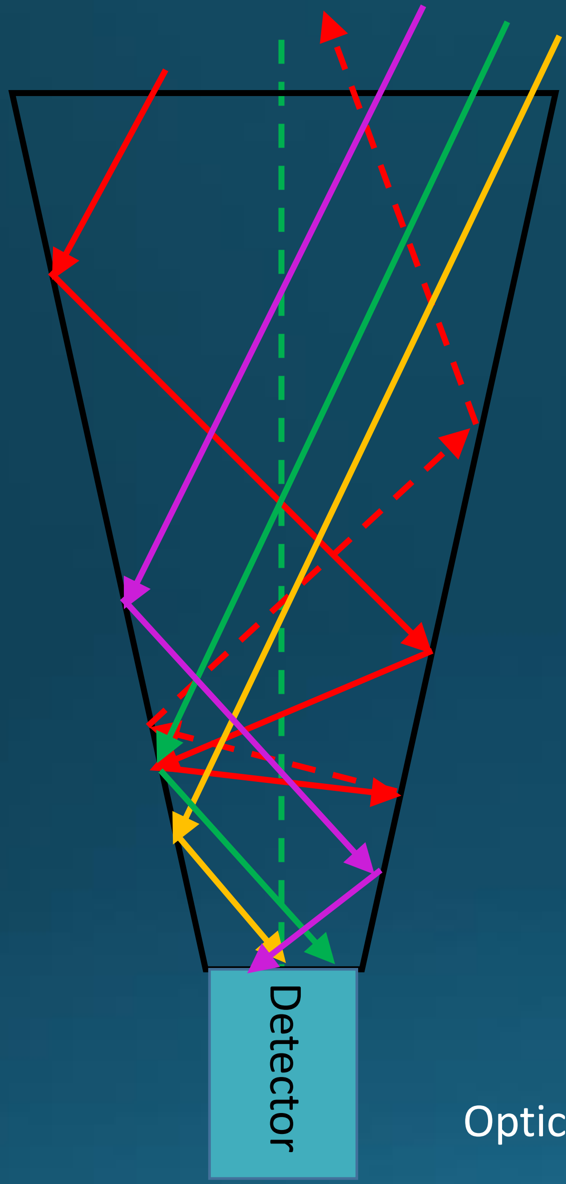
Vane Angle Tolerance

Vane angles are known to +/- 2º



Attenuation effects of making a shallower vane angle are negligible

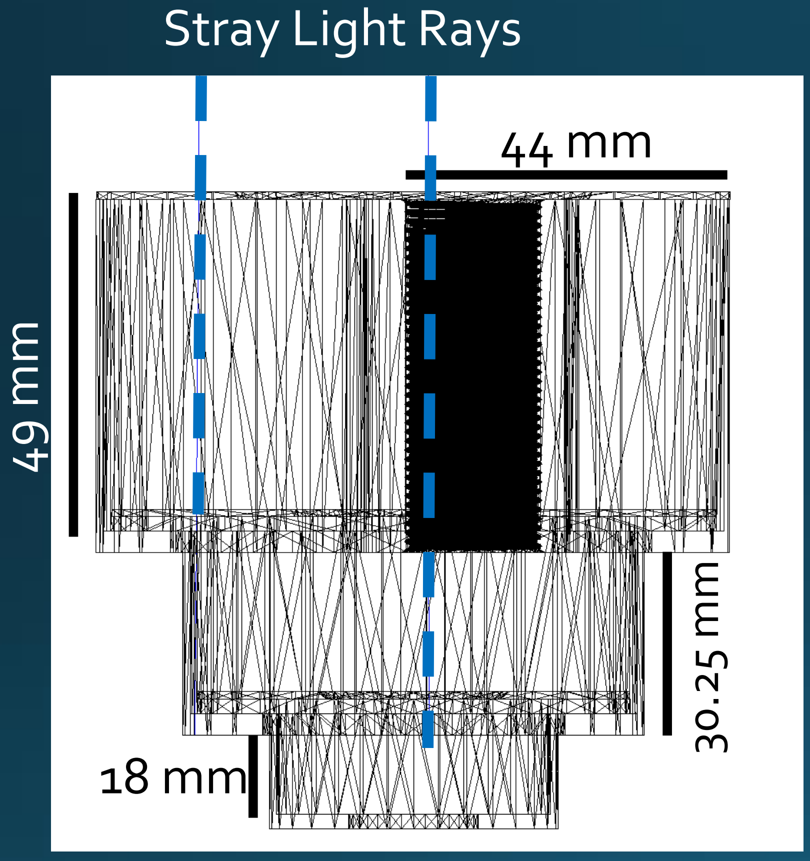
Ray Tracing



First Ray-trace!	Light is not detected
Second ray-trace!	Light is detected
Third ray-trace!	Light is detected
Fourth ray-trace!	Light is detected

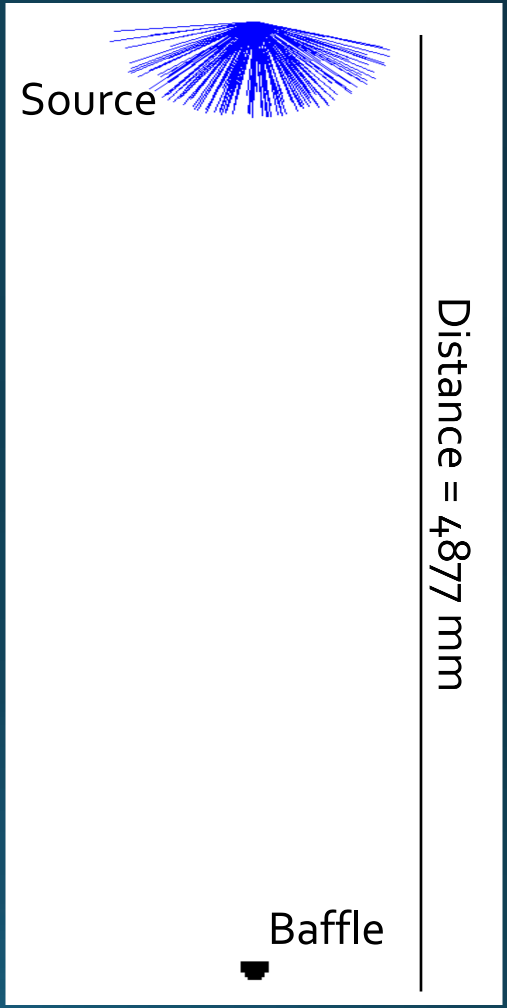
Optical Software: Zemax can simulate 10,000,000 rays in seconds

Zemax Software – Stray Light Analysis



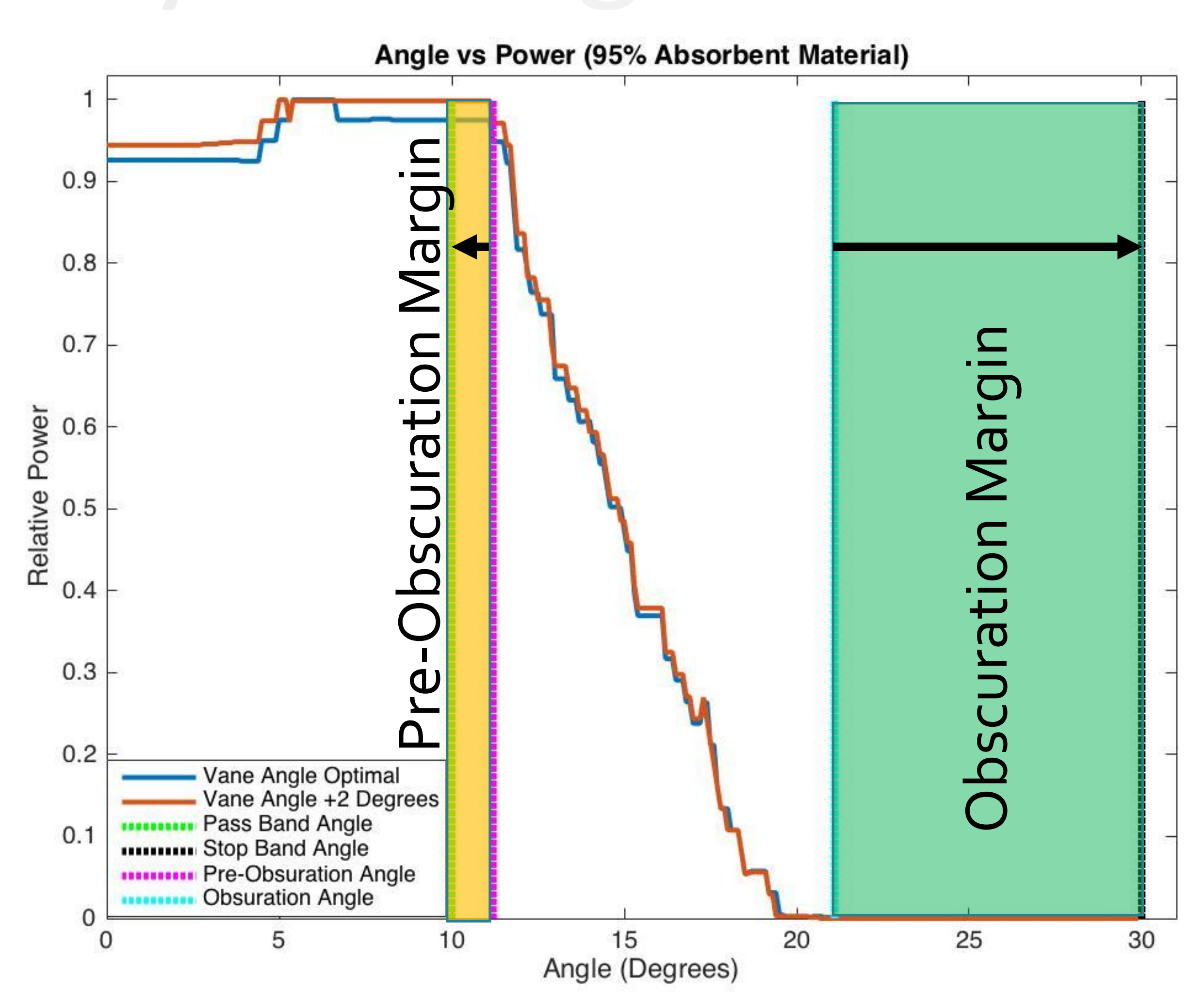
Ray Tracing layout LED

- Surface (Baffle)
  - Cad Model with vanes and coating
  - Absorptivity: 95%
  - Diffuse Reflection: 1.6%
  - Specular Reflection: 3.4%
- Source – (LED’s)
  - Size: 30mm by 30mm – Sun size approximation
- Detector (Sensor)
  - Size: 18mm by 18mm - Same size as sensor
  - Position: Directly under bottom baffle tier
- Analysis
  - Wavelength: 440-645 nm
  - Number of Rays: 10,000,000
  - Step Size: 0.1°



Ray Tracing layout LED

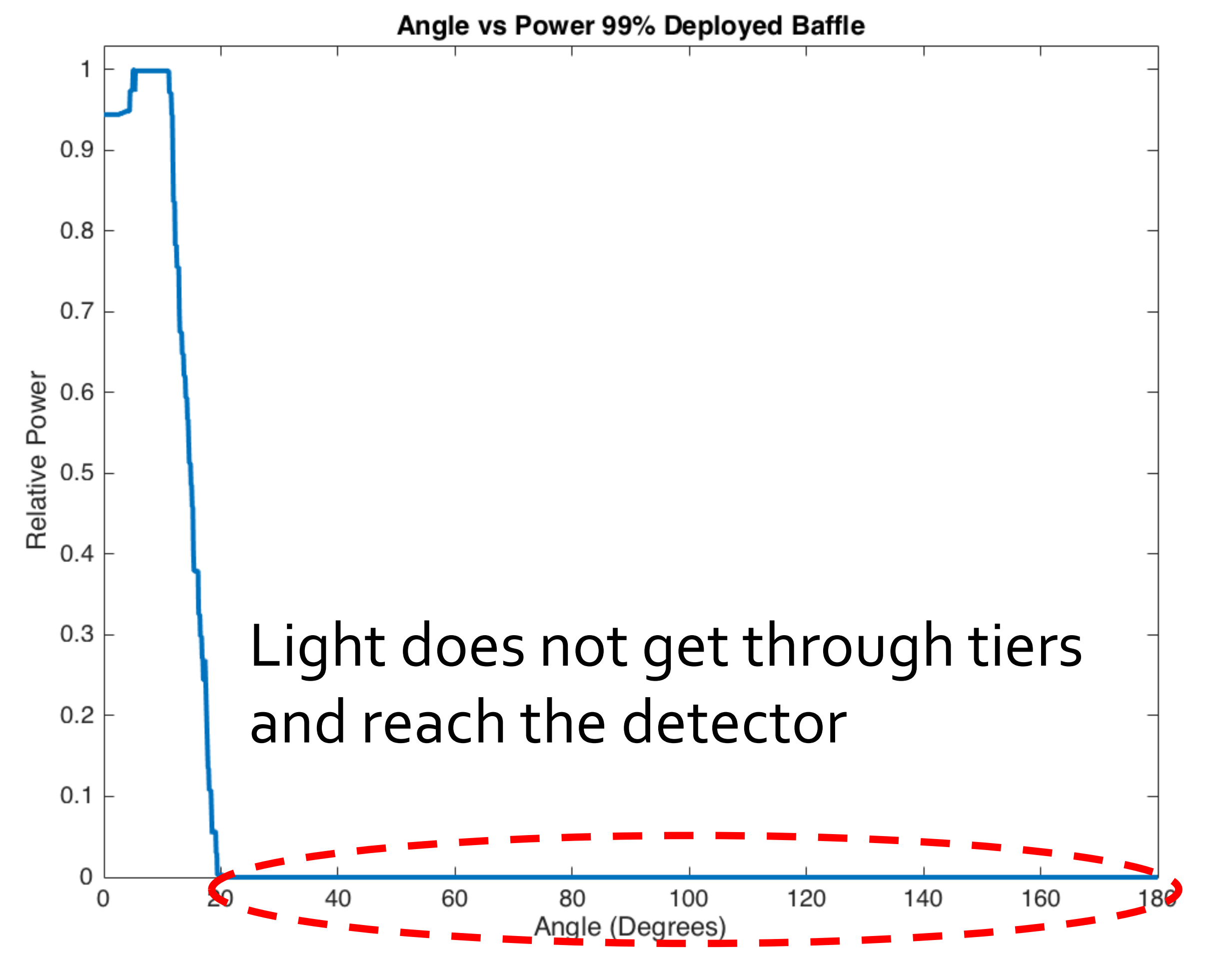
Ray Tracing Simulation Results (FR4)



- Optimal Vane Angle
  - Pass-band requirement (Pre-Obscuration > 10°)
    - Pre-Obscuration Angle = 11.5° ★
  - Stop-band requirement (Obscuration < 30°)
    - Obscuration Angle = 20.6° ★
- Vane Angle $+2^o$
  - Pass-band requirement (Pre-Obscuration > 10°)
    - Pre-Obscuration Angle = 11.5° ★
  - Stop-band requirement (Obscuration < 30°)
    - Obscuration Angle = 21.1° ★

Design Requirement 4.3 MET!

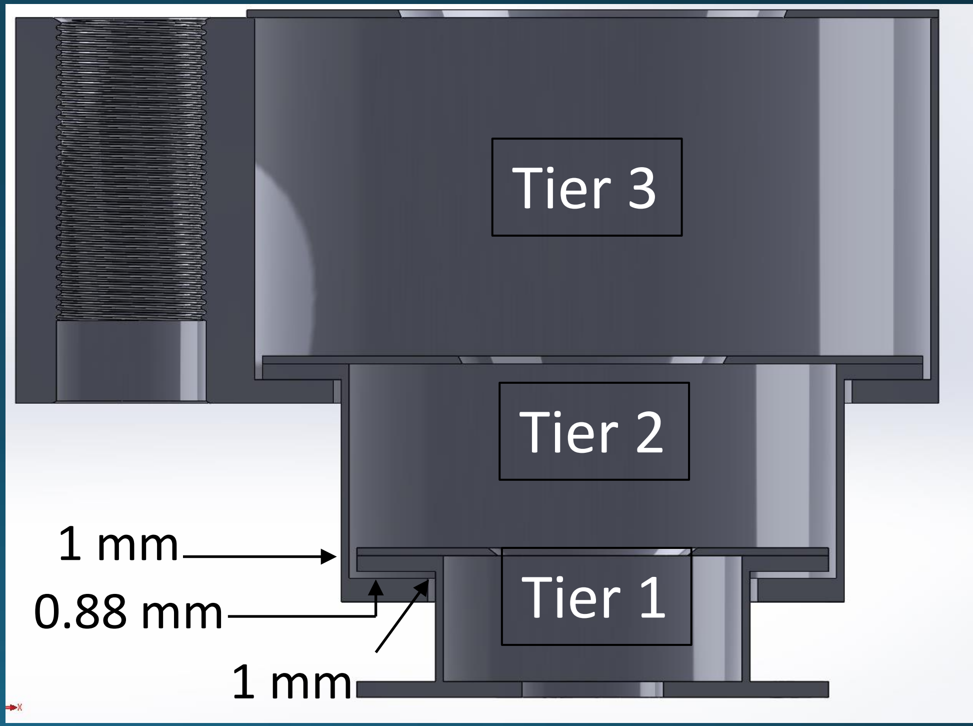
Tier Displacement Check



Light does not get through tiers and reach the detector

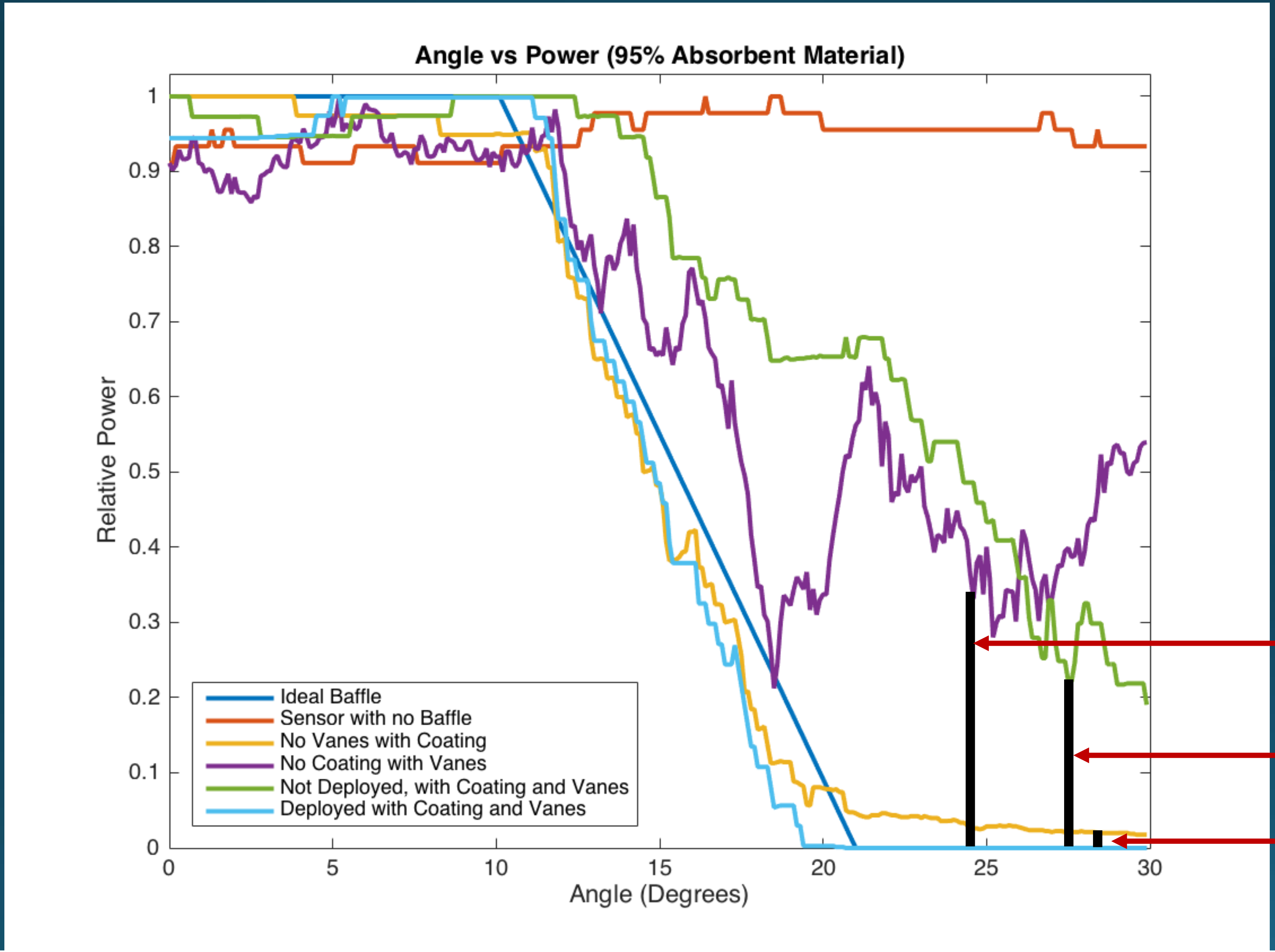
99% Deployed Baffle

- 0.88 mm between baffle tier 1 and tier 2



Design Decision Validation

Design Requirement 4.2 MET!



Coating

Deployment

Vanes

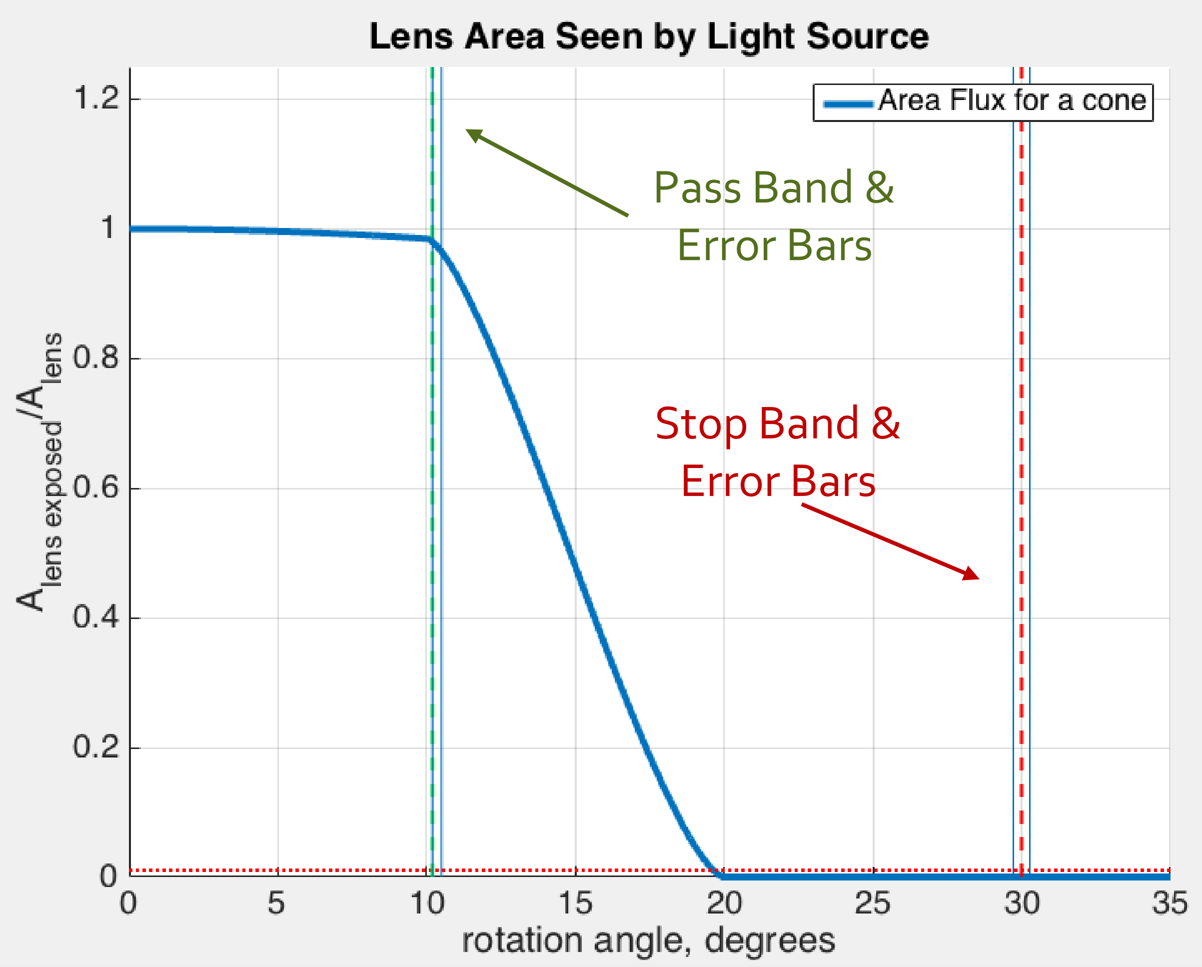
Verification and Validation

Deployment Testing (FR1)

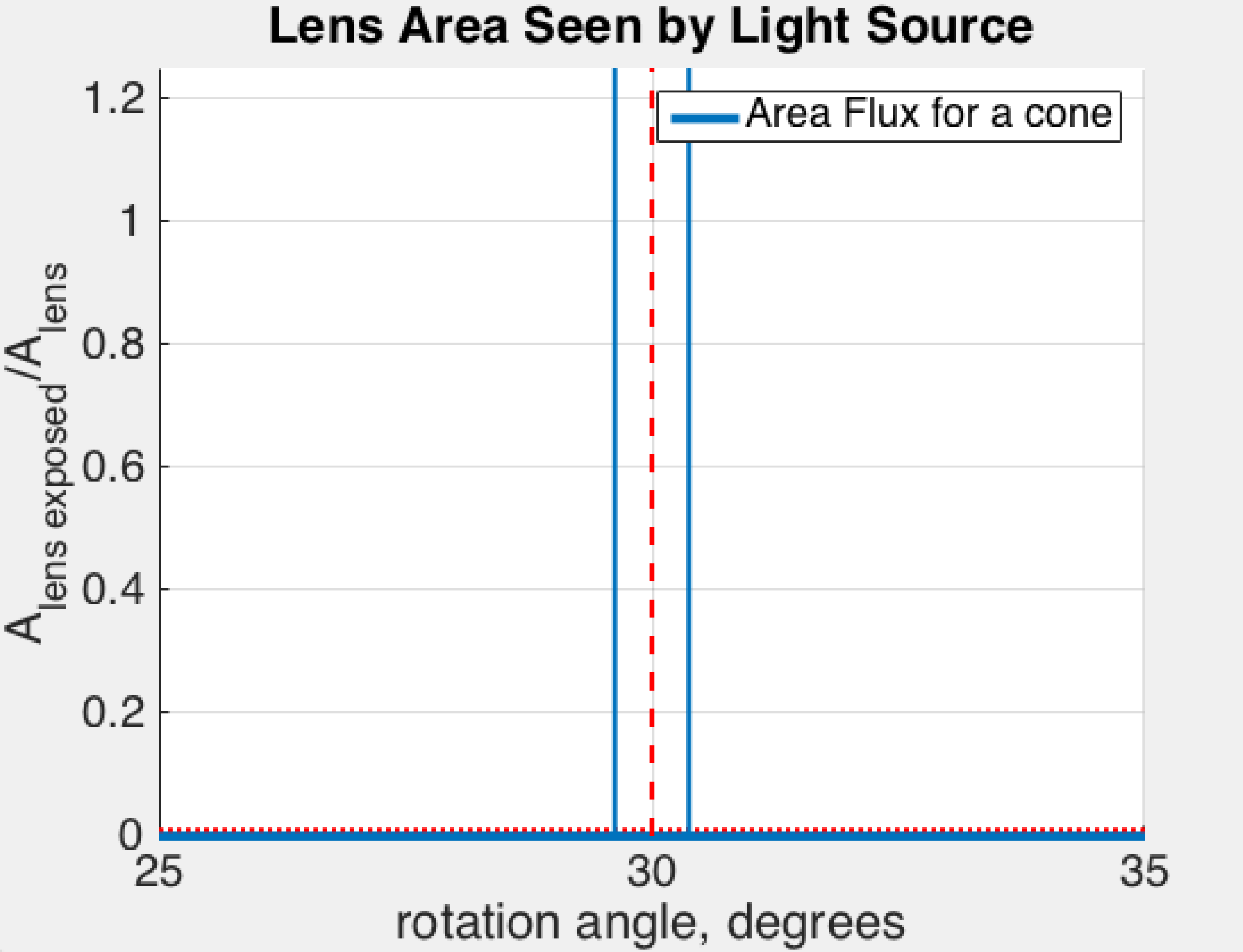
Deployment Testing Motivation

- Need to ensure baffle deploys within a certain height range
- Optical performance will not satisfy light attenuation requirements outside of this range
- Deployment height: 87 mm ± 1 mm
- Deployment range: 84.7 mm – 88.3 mm but can only measure to nearest mm
- **Test Location:** Steam tunnels under ECE wing to ensure phototransistor is not saturated by stray light

Deployment Testing Motivation



Pass-Band & Stop-Band Tolerances

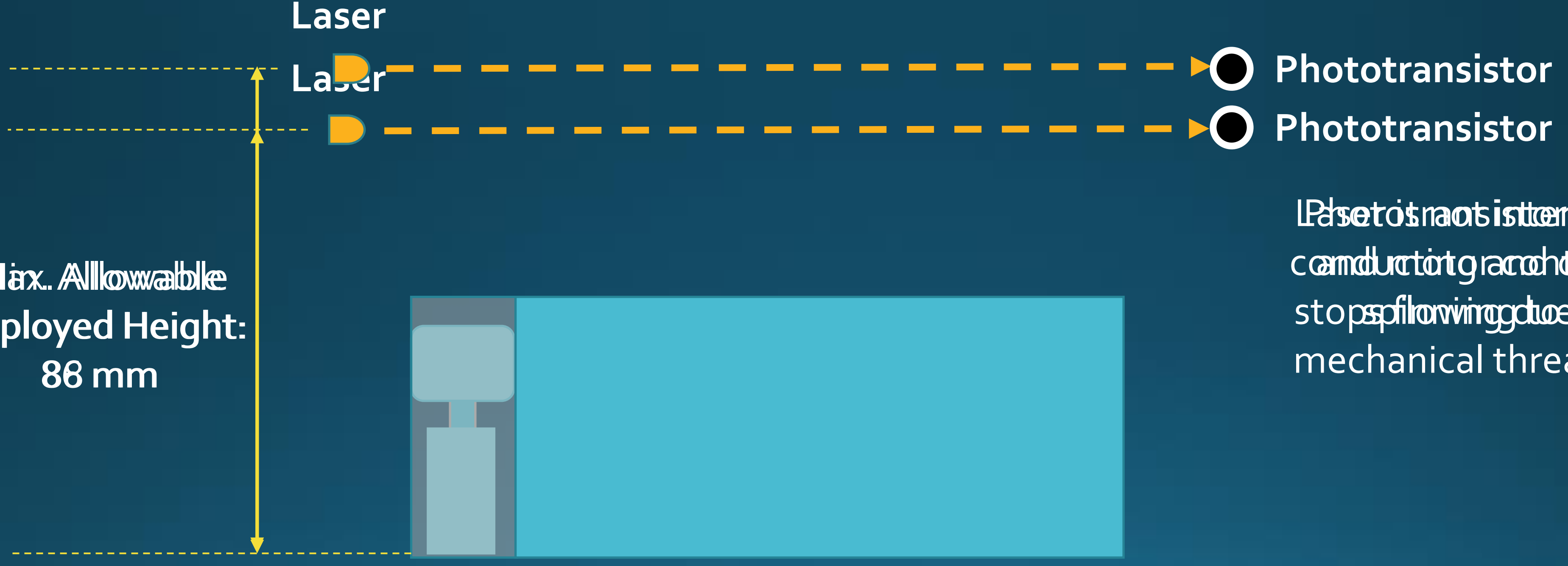


Zoomed Error Bars (Stop-Band)

Deployment Tolerances

Maximum-Deployment

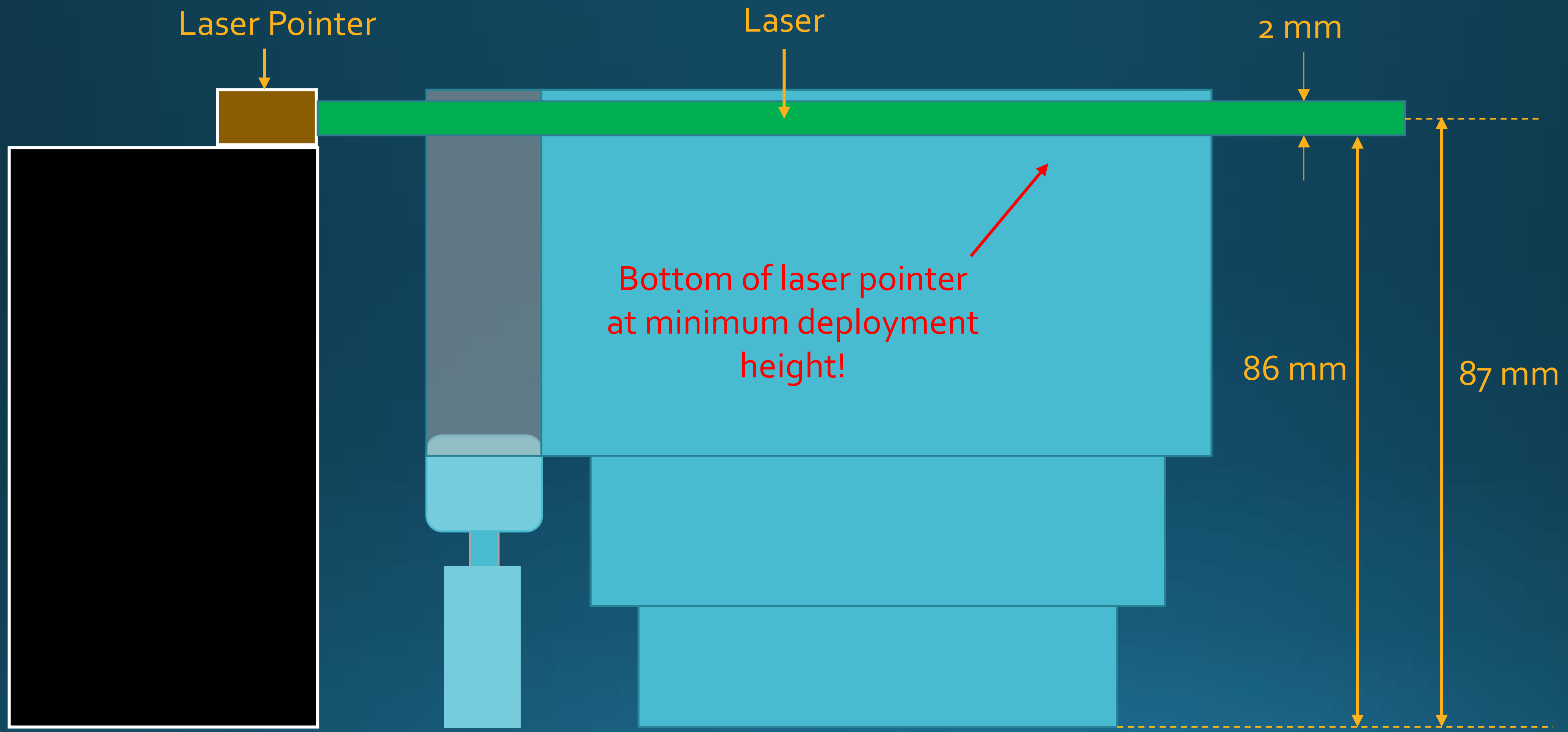
Max



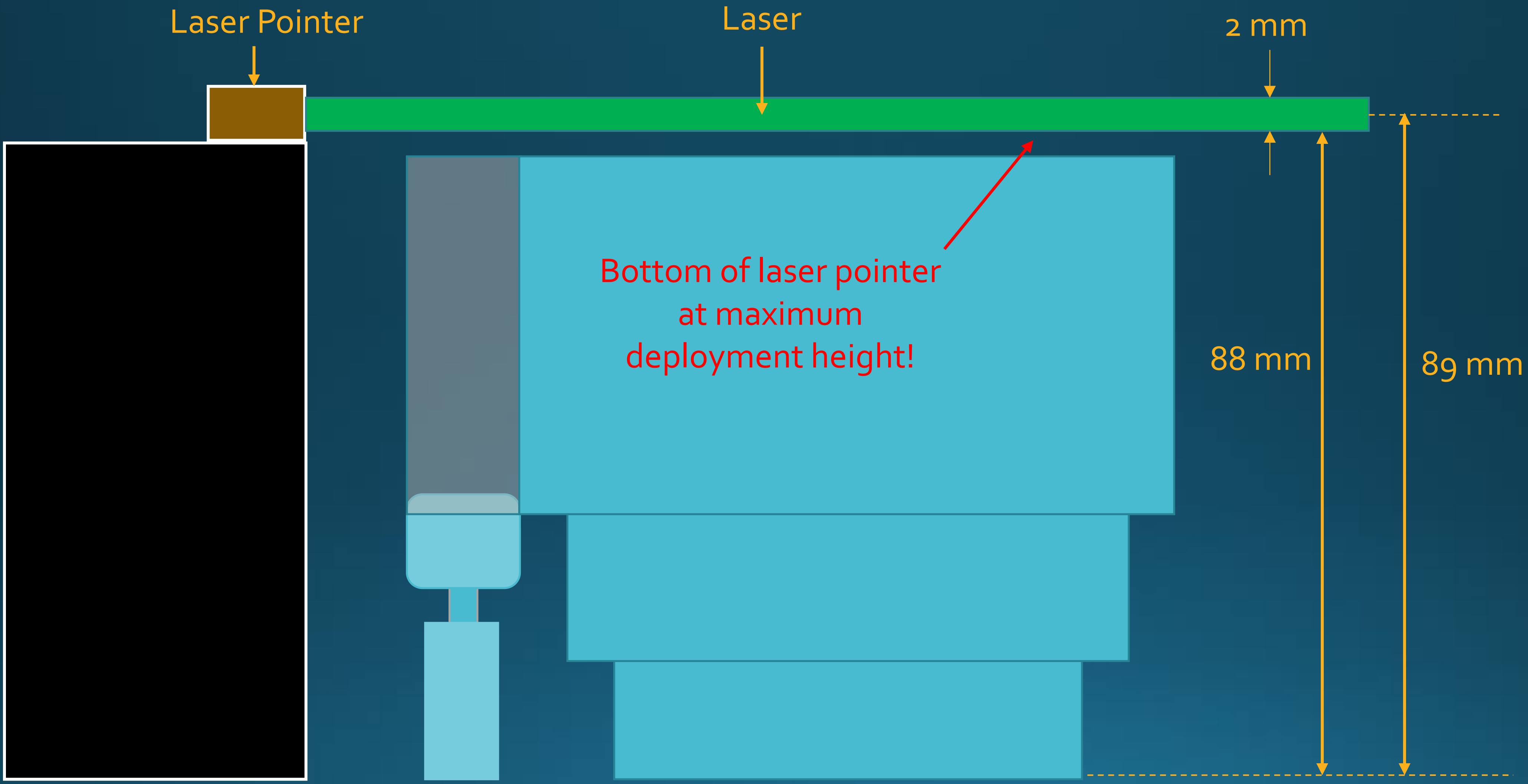
Laser is not interrupted and motor continues spinning due to mechanical thread stop

Phototransistor stops conducting and current stops flowing to motor

Minimum Deployment



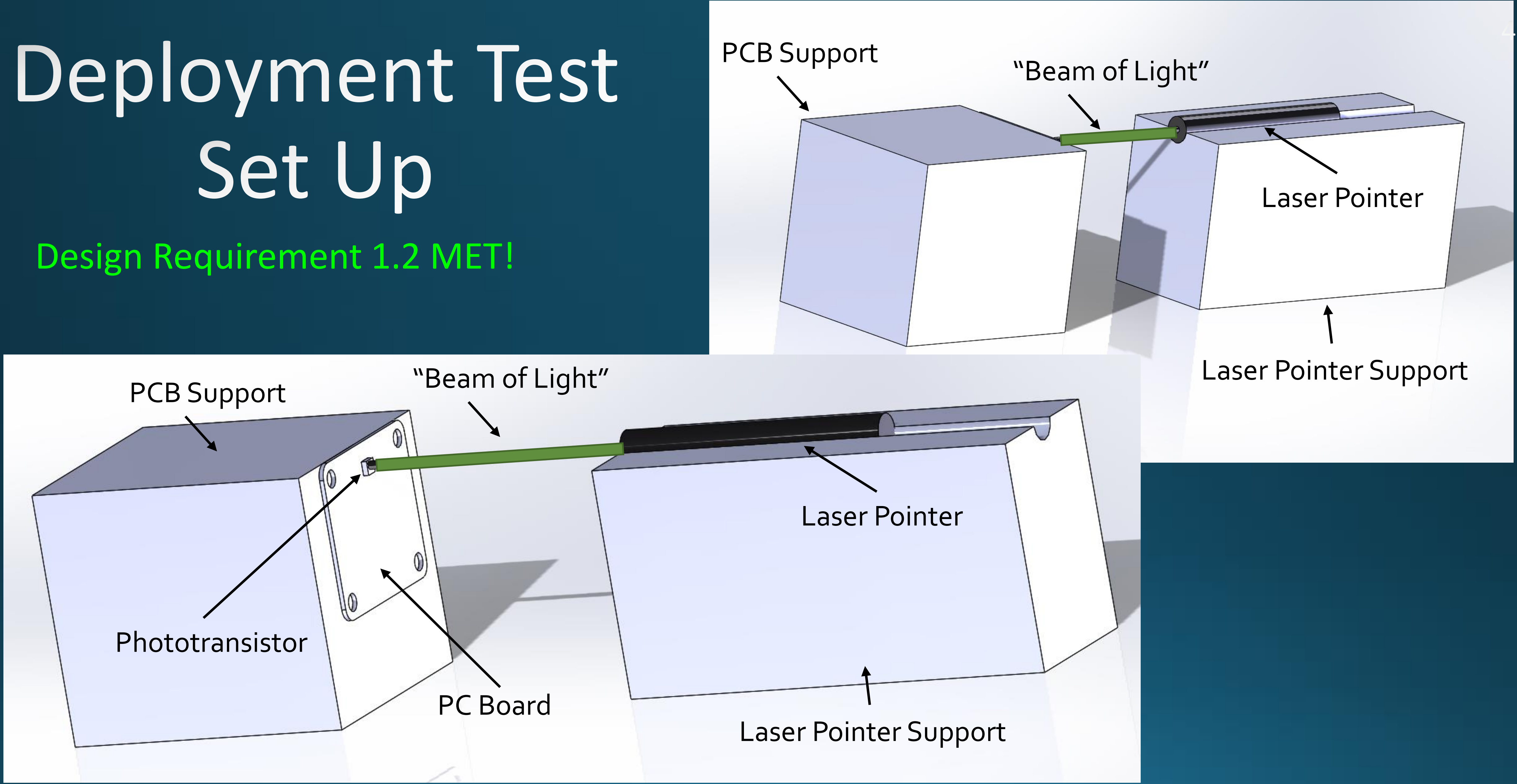
Maximum Deployment



Bottom of laser pointer at maximum deployment height!

Deployment Test Set Up

Design Requirement 1.2 MET!



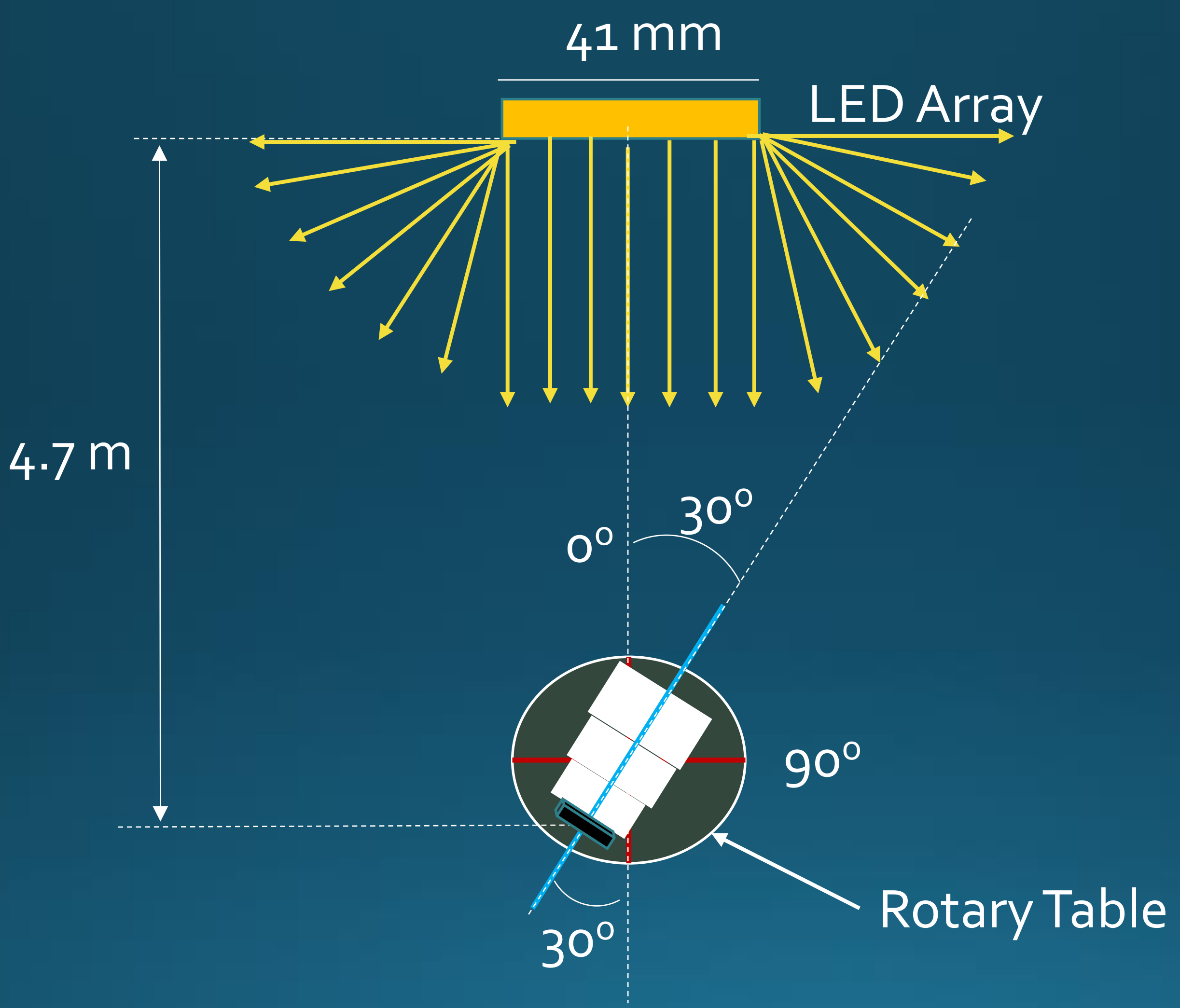
Light Attenuation Testing (FR4)

Stray Light Testing Motivation

- Main Objective:
  - Ensure baffle meets pass-band and stop-band requirements
- Location:
  - Steam tunnels under ECE wing in Engineering Center
- General Procedure:
  - Take measurements in 5 ° increments
  - Resolution will be increased to 0.1 ° near pass-band and stop-band incidence angles

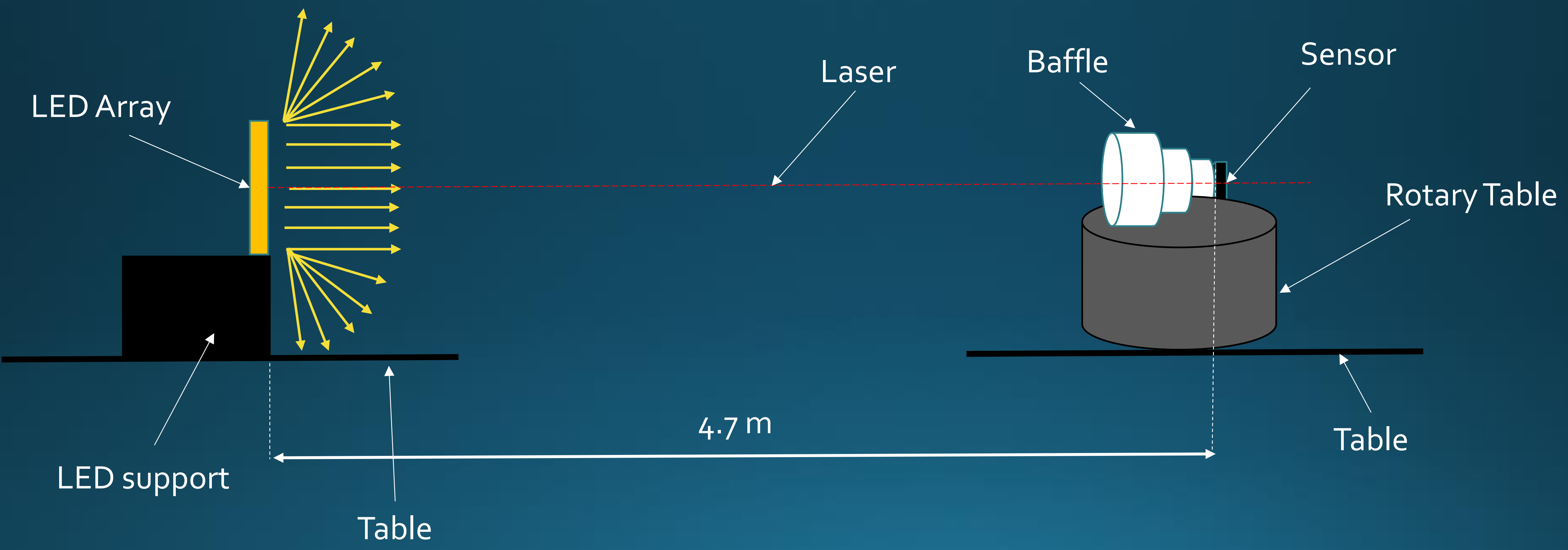
Stray Light Test Setup

Top Down View



Stray Light Test Setup

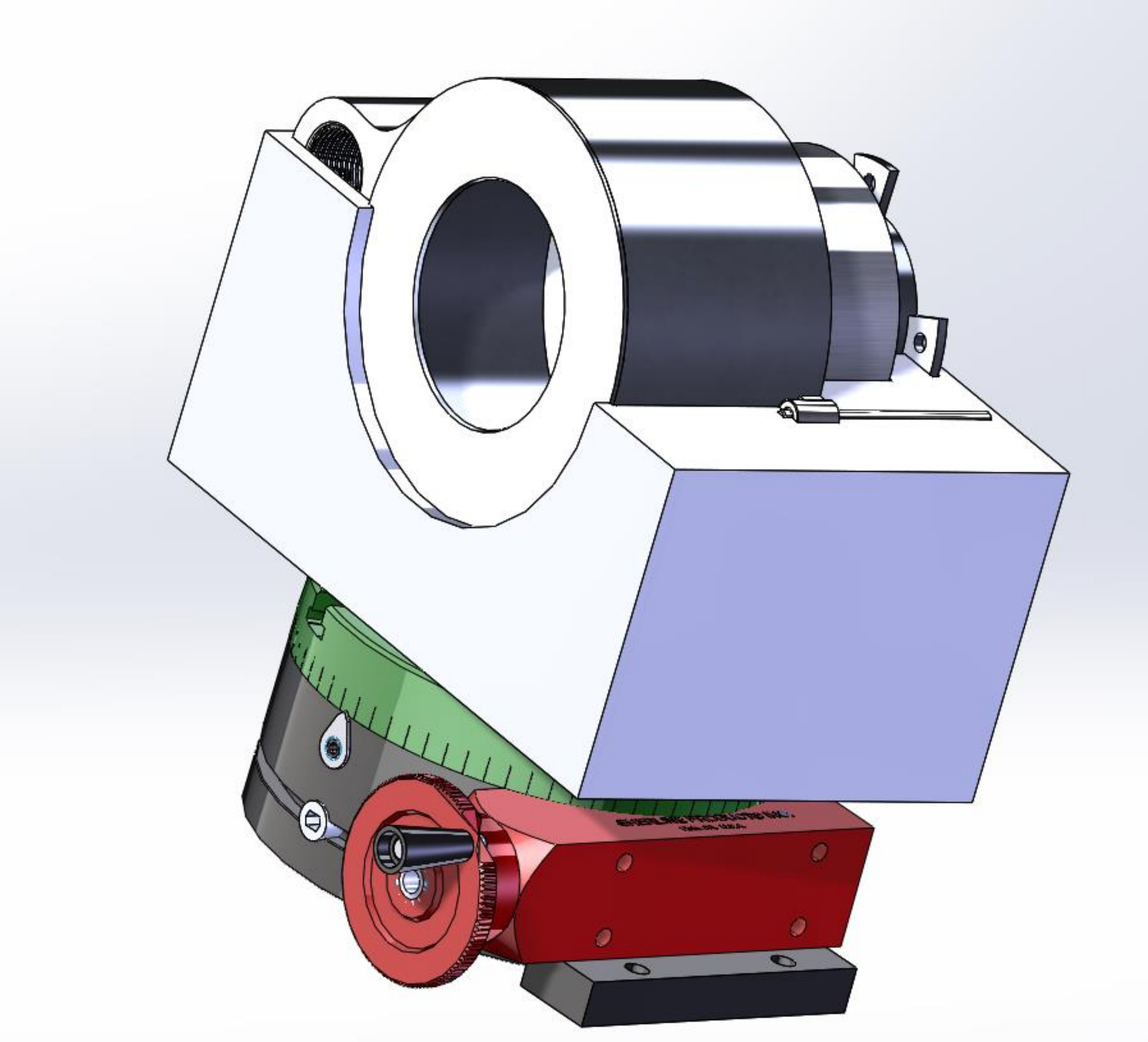
Side View



Stray Light Test Set Up

Design Requirement 4.1 MET!

- 3D Printed Support
  - 0.5 mm tolerance on 3D printer (ITLL)
  - Will shine laser from sensor location to middle of light source to ensure alignment
- Sensor and visible light filter attached to bottom of baffle

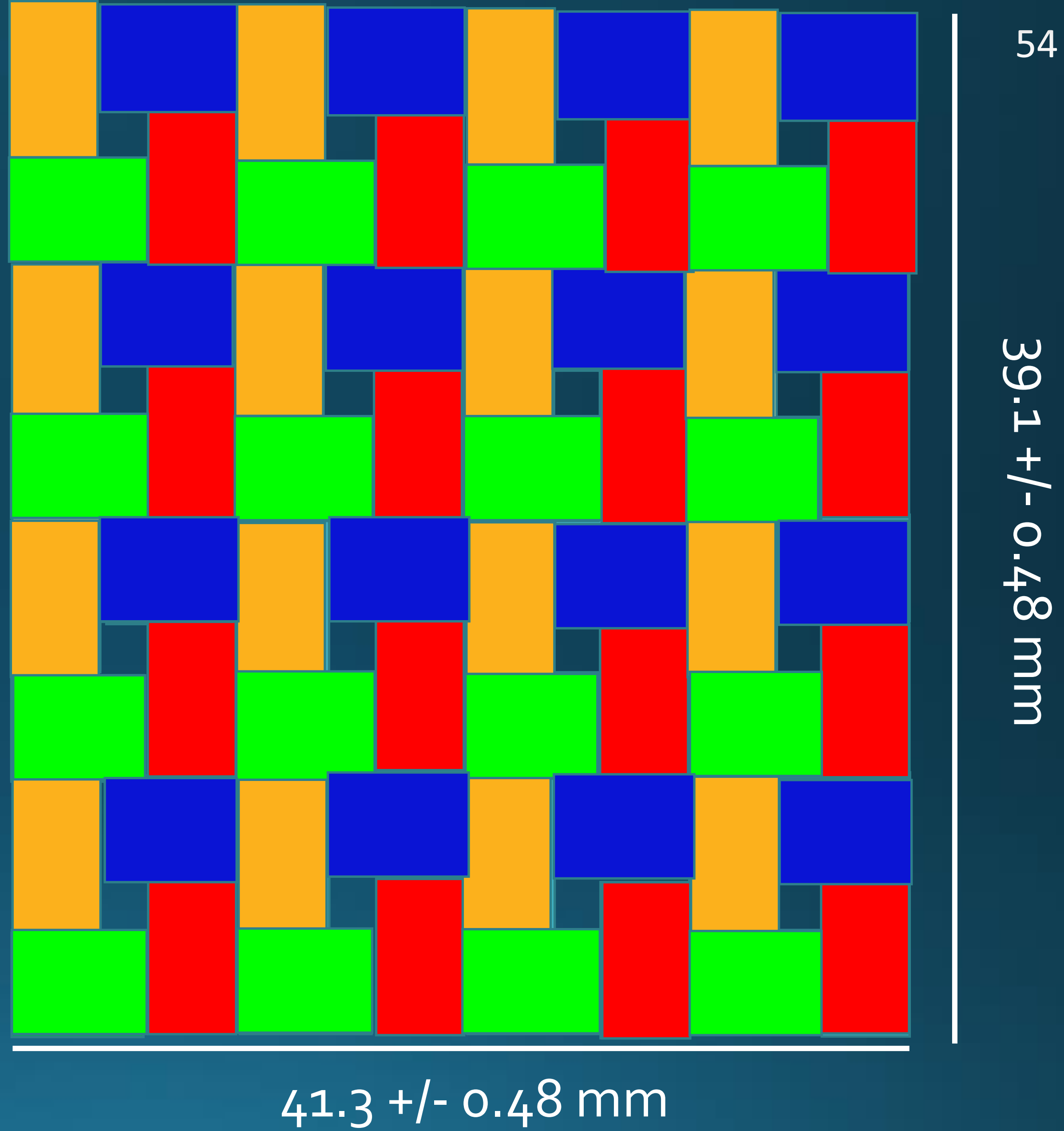


Stray Light Test Set Up

- Light Source
  - Using 64 LEDs
  - 4 different colors

  - Simulating white light with spectrums of LED colors
    - 440-645 nm

  - Want to match Zemax light sources



Project Risks

Pre-Mitigation

🟥 = Very High Likelihood, Project Failure
🟨 = Medium Likelihood, Moderate Schedule Slip
🟩 = Very Low likelihood, No effect

Severity

Likelihood

	1				5
5	🟨	🟨	🟥	🟥	🟥
	🟩 Baffle deflection	🟨	🟨 Using dark room	🟥	🟥 Exceeding radial force limit
	🟩 Exposure to bright light	🟩	🟨	🟨 - Exposure to Aeroglaze - Shop availability	🟥
	🟩	🟩	🟩	🟨 Inaccurate machining	🟨
1	🟩 Exceeding budget limitations	🟩	🟩	🟩	🟨

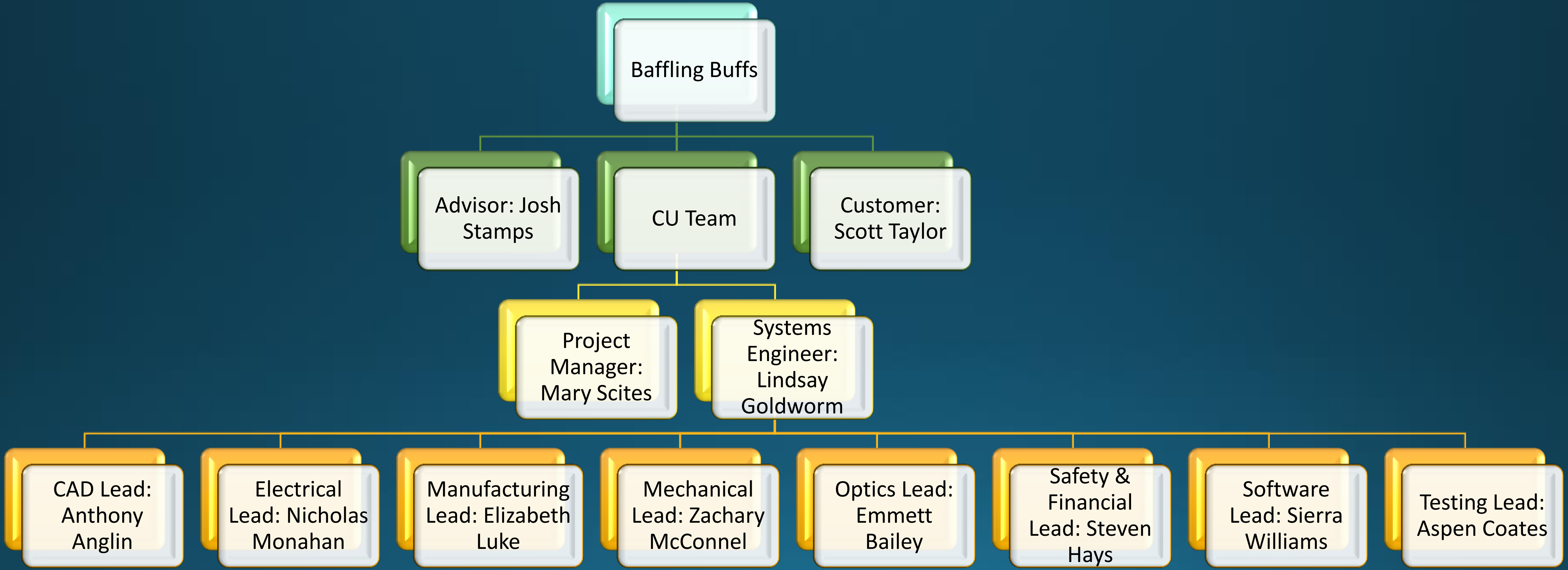
Post-Mitigation

🟥 = Very High Likelihood, Project Failure
🟨 = Medium Likelihood, Moderate Schedule Slip
🟩 = Very Low likelihood, No effect

			Severity		
	1				5
5	🟨	🟨	🟥	🟥	🟥
	🟩	🟨	🟨	🟥	🟥
Likelihood	🟩 Baffle deflection	🟩 Using dark room	🟨	🟨	🟥
	🟩 Exposure to bright light	🟩 Inaccurate machining	🟩 Shop	🟨	🟨
1	🟩 Exceeding budget limitations	🟩	🟩 Exposure to Aeroglaze	🟩 Exceeding radial force limit	🟨

Project Planning

Organizational Chart



Baffling Buffs

Advisor: Josh Stamps

CU Team

Customer: Scott Taylor

Project Manager: Mary Scites

Systems Engineer: Lindsay Goldworm

CAD Lead: Anthony Anglin

Electrical Lead: Nicholas Monahan

Manufacturing Lead: Elizabeth Luke

Mechanical Lead: Zachary McConnel

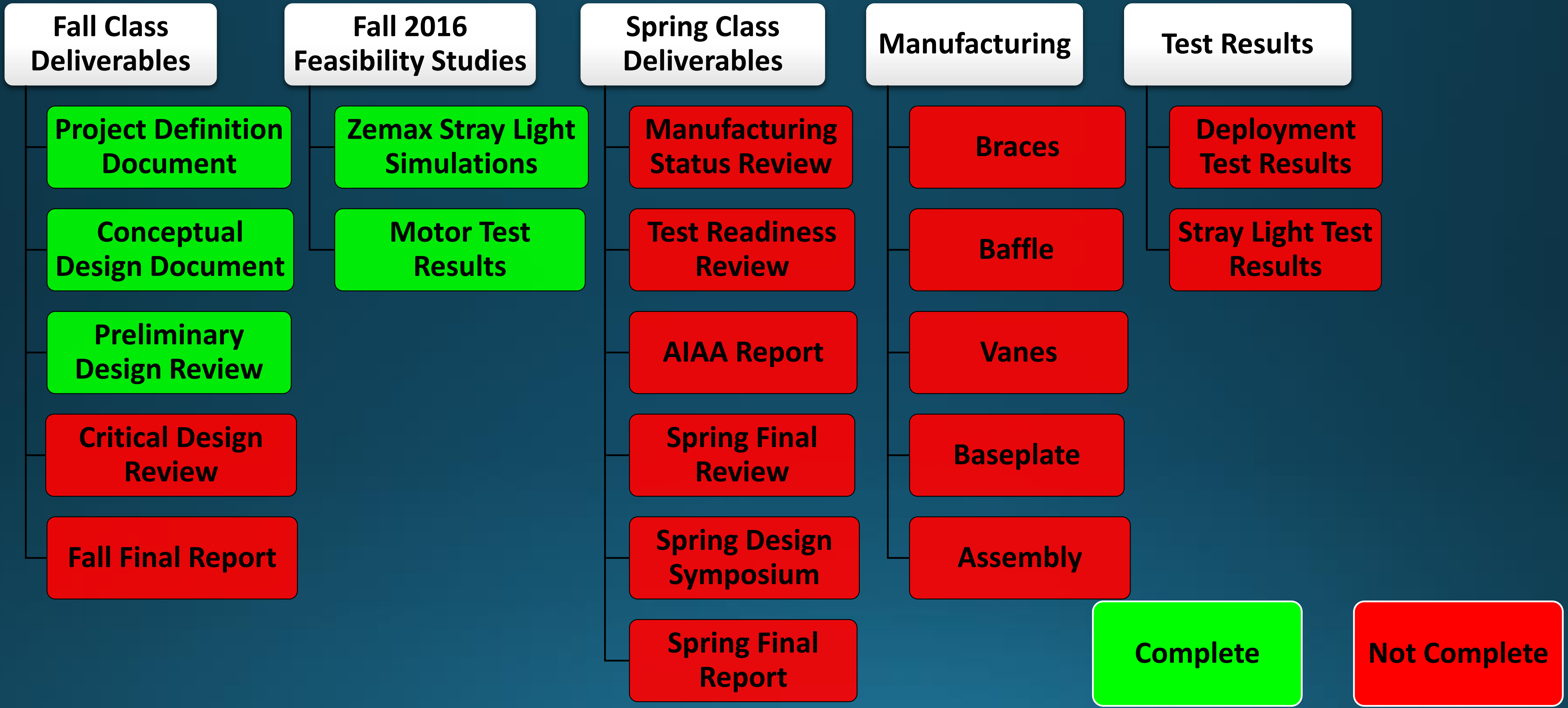
Optics Lead: Emmett Bailey

Safety & Financial Lead: Steven Hays

Software Lead: Sierra Williams

Testing Lead: Aspen Coates

Work Breakdown Structure



Fall Class Deliverables
- Project Definition Document
- Conceptual Design Document
- Preliminary Design Review
- Critical Design Review
- Fall Final Report

Fall 2016 Feasibility Studies
- Zemax Stray Light Simulations
- Motor Test Results

Spring Class Deliverables
- Manufacturing Status Review
- Test Readiness Review
- AIAA Report
- Spring Final Review
- Spring Design Symposium
- Spring Final Report

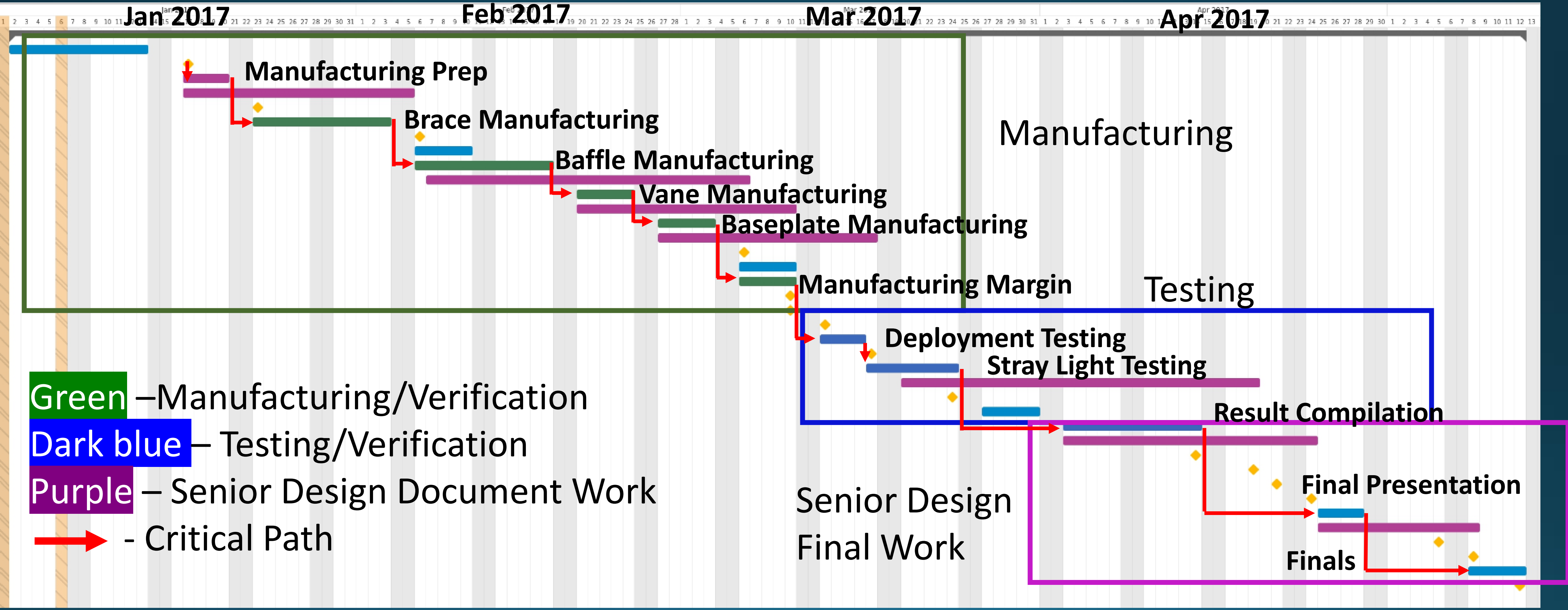
Manufacturing
- Braces
- Baffle
- Vanes
- Baseplate
- Assembly

Test Results
- Deployment Test Results
- Stray Light Test Results

Complete

Not Complete

Work Plan



Green –Manufacturing/Verification

Dark blue – Testing/Verification

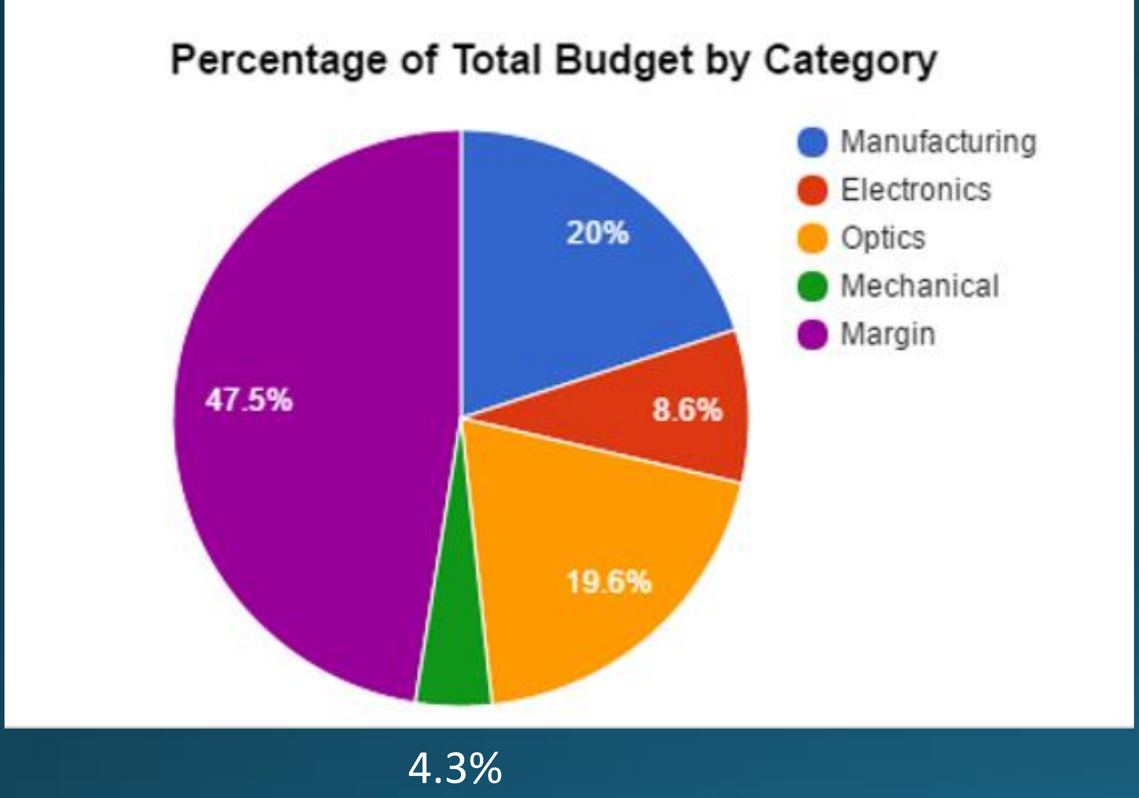
Purple – Senior Design Document Work

➡ - Critical Path

Testing Plan

Dates	Goal	Specialized test equipment / facility
Jan 23 - Feb 3	Brace Manufacturing and Verification	Aero Shop
Feb 6 - Feb 17	Baffle Manufacturing and Verification	Aero Shop ACME tap
Feb 20 – Feb 24	Vane Manufacturing and Verification	Aero Shop
Feb 27 – Mar 3	Baseplate Manufacturing and Verification	Aero Shop
Mar 6 – Mar 10	Coating Application and Verification	Maaco Auto Painting Air Brush
Mar 13 – Mar 16	Deployment Testing	Dark Tunnel Under ECCE Wing
Mar 17 – Mar 24	Stray Light Testing	Dark Tunnel Under ECCE Wing

Cost Plan



Manufacturing – $1,002
Electronics – $430
Optics – $982
Mechanical – $213

Total – $2,627

Margin - $2,373

Flight Readiness

Component	Space Worthy?	Why?
Tier/vane material: Aluminum 2024-T4	No	Corrosion
Screw Material: Stainless Steel 304	Yes	Limited Corrosion
Adhesive	No	Operational Temperature
Coating	Yes	Low Outgassing
Motor	No	High Outgassing
Linear Bearing	No	Lubricants Insufficient for Space
Sensor	No	Not a Star Tracker Sensor
Screw and Casing Mechanism	No	Cold Welding

Additional tests required

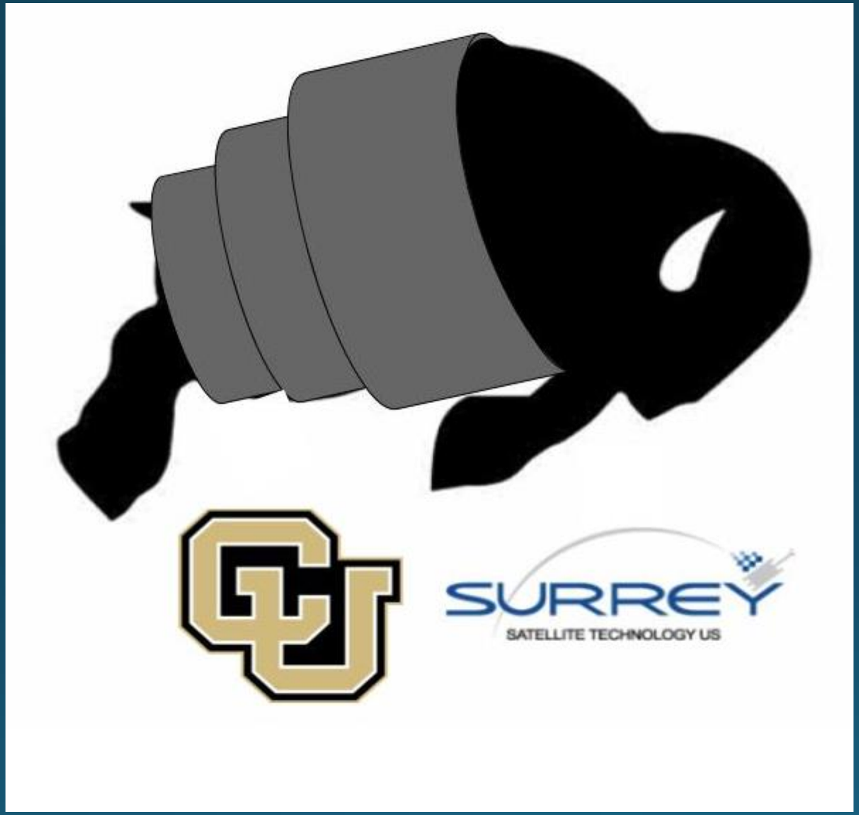
- Vibration testing
- Thermal vacuum testing

Special Thanks…

UCAR/NCAR High Altitude Observatory

- Scott Sewell
- Phil Oakley

Questions?



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Resources

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[13]Heckman, Kurt. "Square Thread Power Screws(Torque Required to Raise)." *Square Thread Power Screws(Torque Required to Raise)*. Vcalc, 24 Mar. 2016. Web. 01 Oct. 2016.

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[16]"McMaster-Carr." *McMaster-Carr*. N.p., n.d. Web. 1 Nov. 2016.

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[20]Mass Properties Control for Space Systems." *American National Standard*. American Institute of Aeronautics and Astronautics, n.d. Web. 15 Nov. 2016.

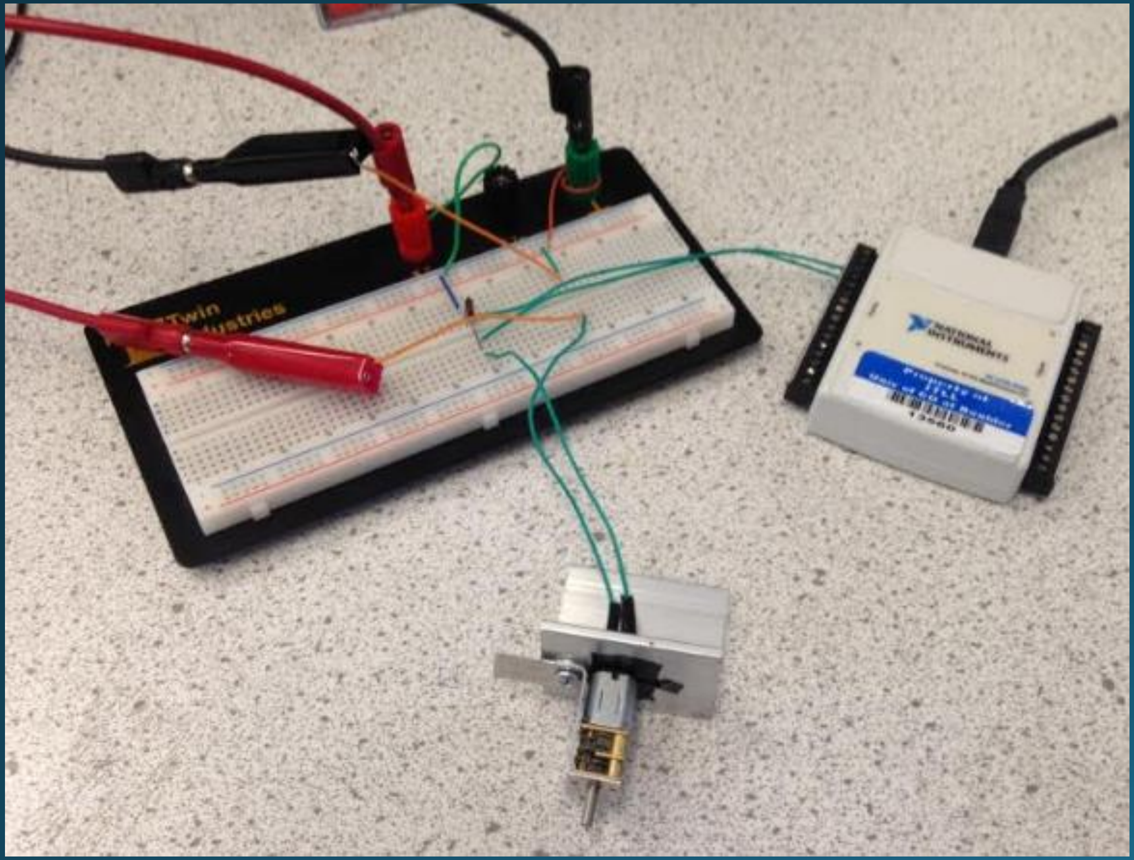
[21]http://www.optotronics.com/proddetail.php?prod=Opto5, Optotronics, 2013, Web

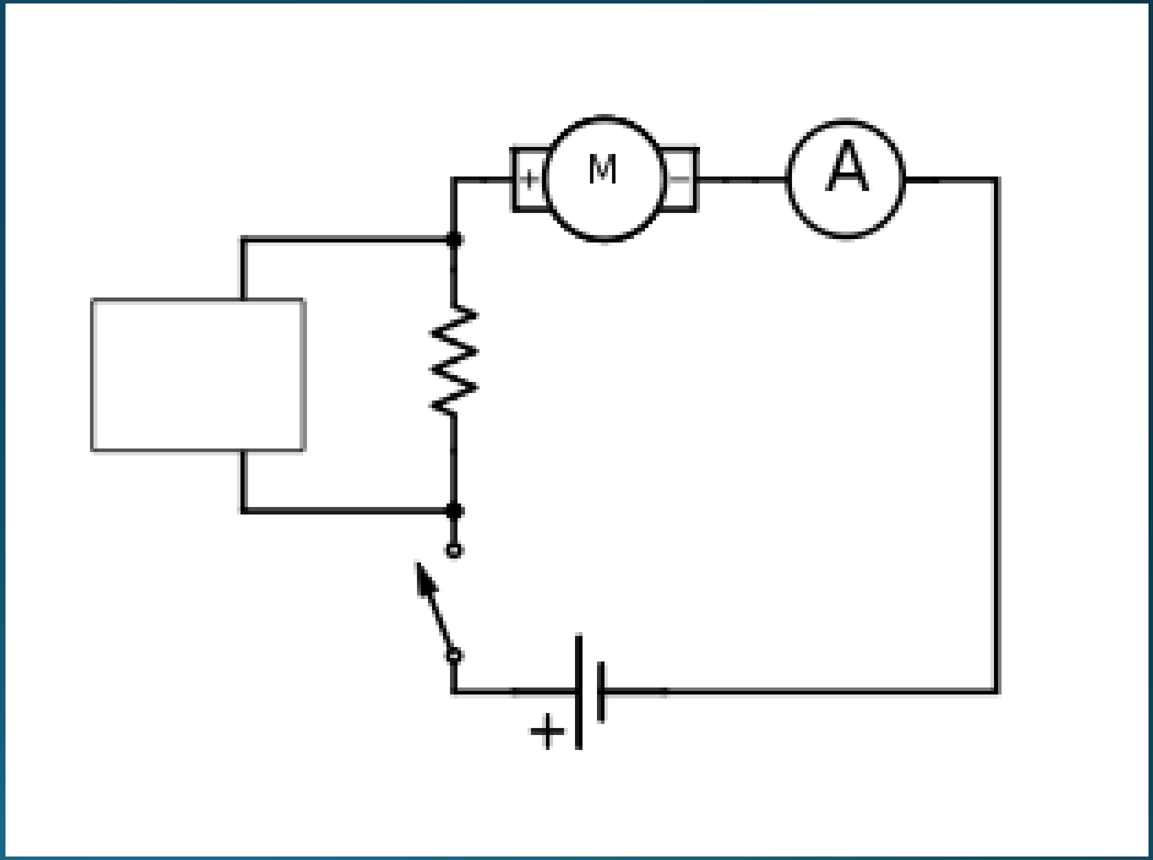
Backup Slides

Backup Slides

Motor Testing

DC Motor Radial Load Test

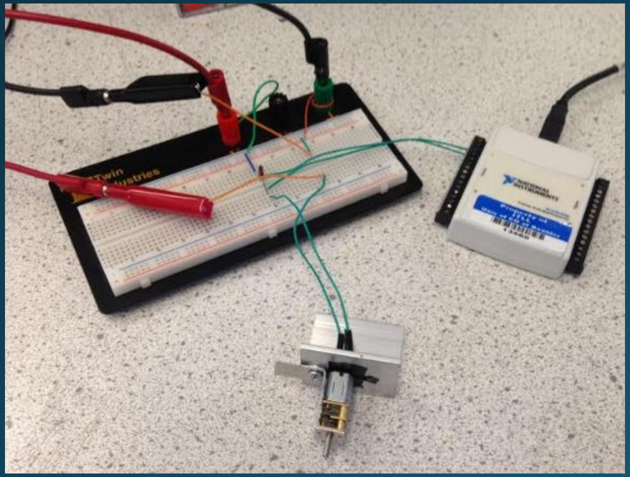


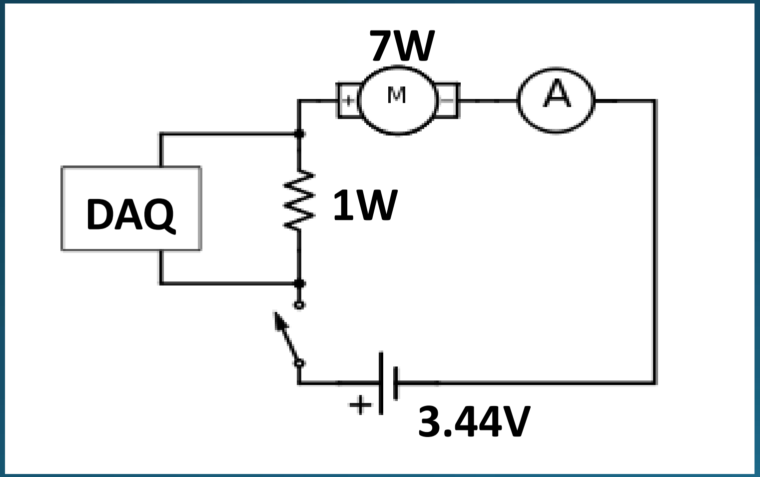


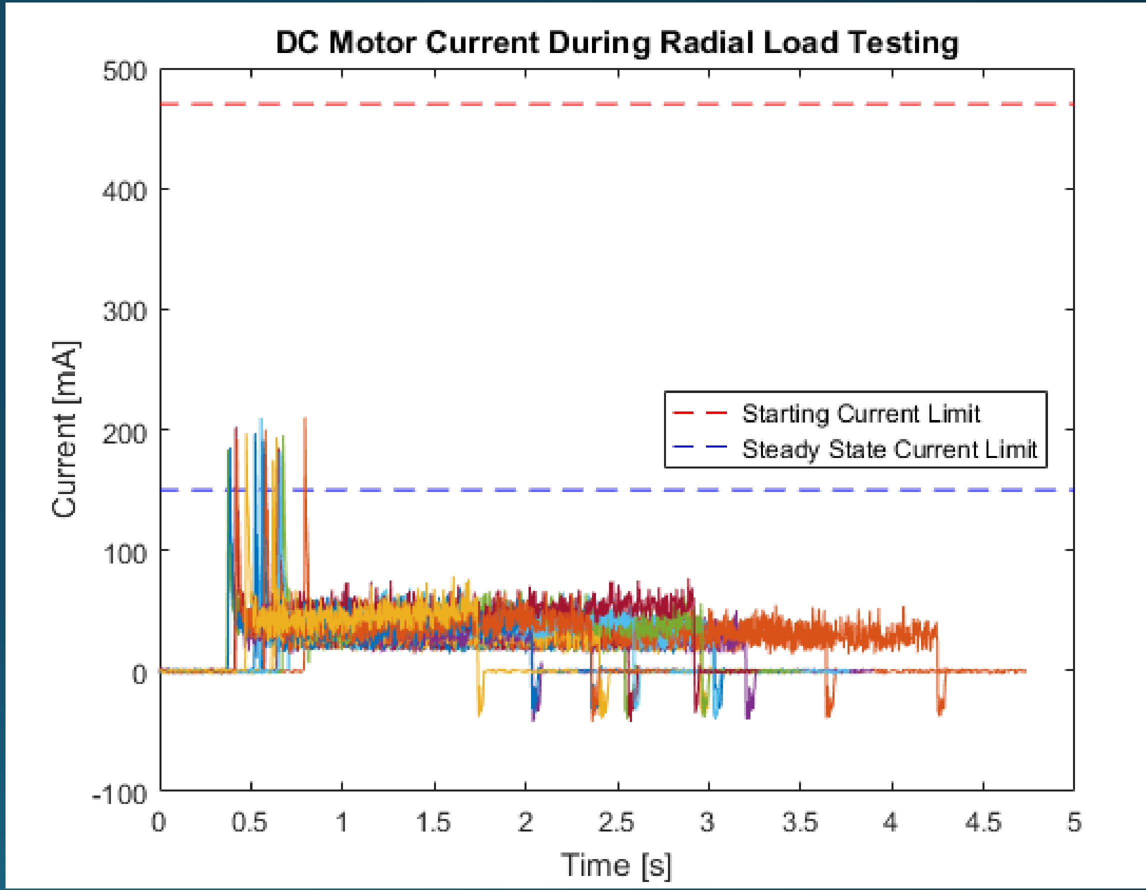
DC Motor Radial Load Test

Method: Hang weights in increments until shaft stalls or motor current limit violated

- Largest mass 2500 g (24.5N)
  - Datasheet limit was 4 N
  - Requirement: 18.7 N
- No shaft stall or current violations observed







DC Motor Holding Torque Test

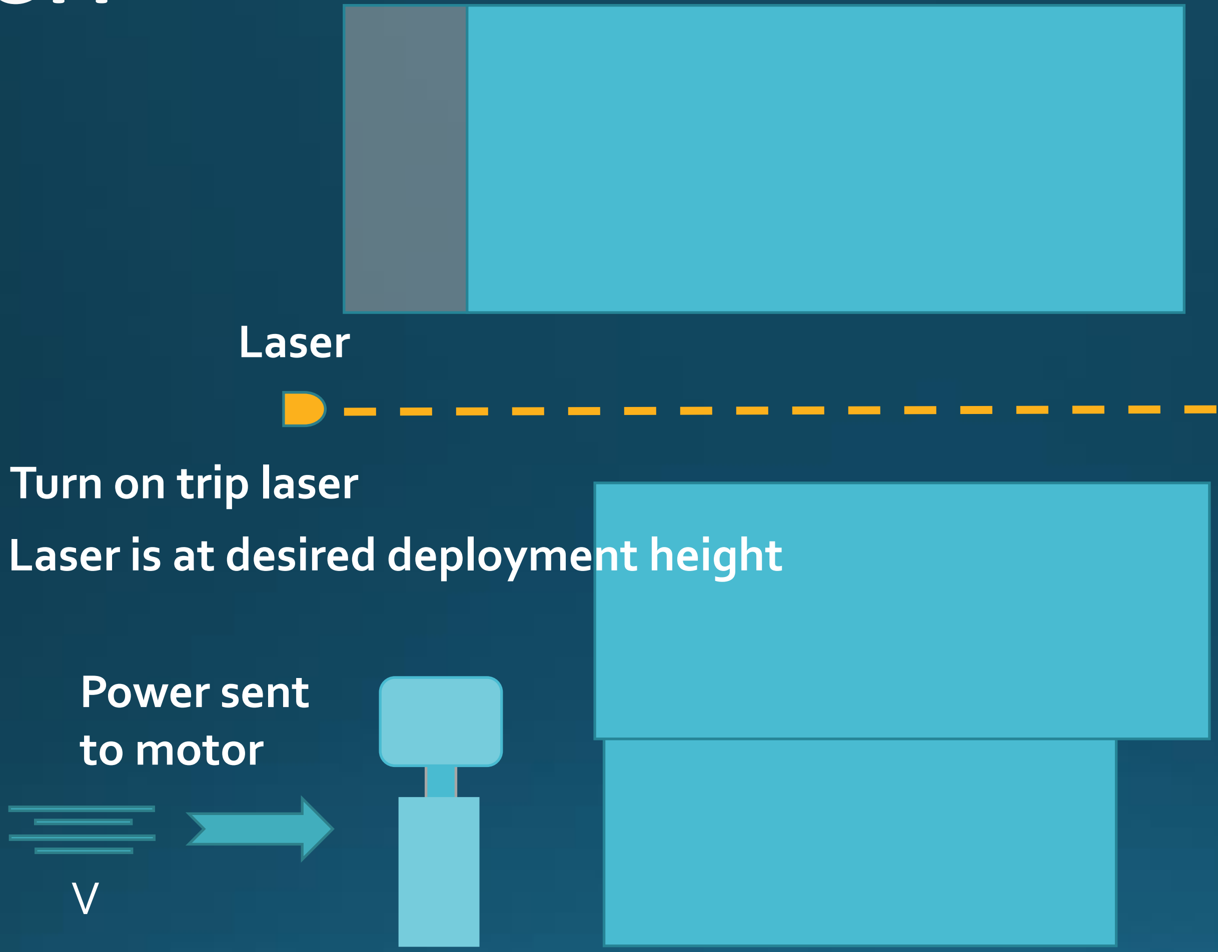
- Test Set Up
  - L-Bracket with hole for motor leads
  - Z-Brace to attach motor to bracket
  - Shaft coupling with set screw against flat surface of D-shaft
  - Weights were hung from set screw

Deployment Testing

Motor Selection

- **Precision Microdrives 212-117 DC Motor**
  - Mass: 10.3 grams
  - Operating Voltage: 3 V
  - Rated load: 100 mN*m
  - Operating Power: 450 mW @ 150 mA
  - Speed: 8 RPM

Kill Switch



Light beam interrupted when baffle is fully deployed

Laser

Phototransistor

Turn on trip laser

Laser is at desired deployment height

Phototransistor stops conducting and current stops flowing to motor windings

Power sent to motor

Power Screw Rotates
Baffle Deploys

Deployment Testing

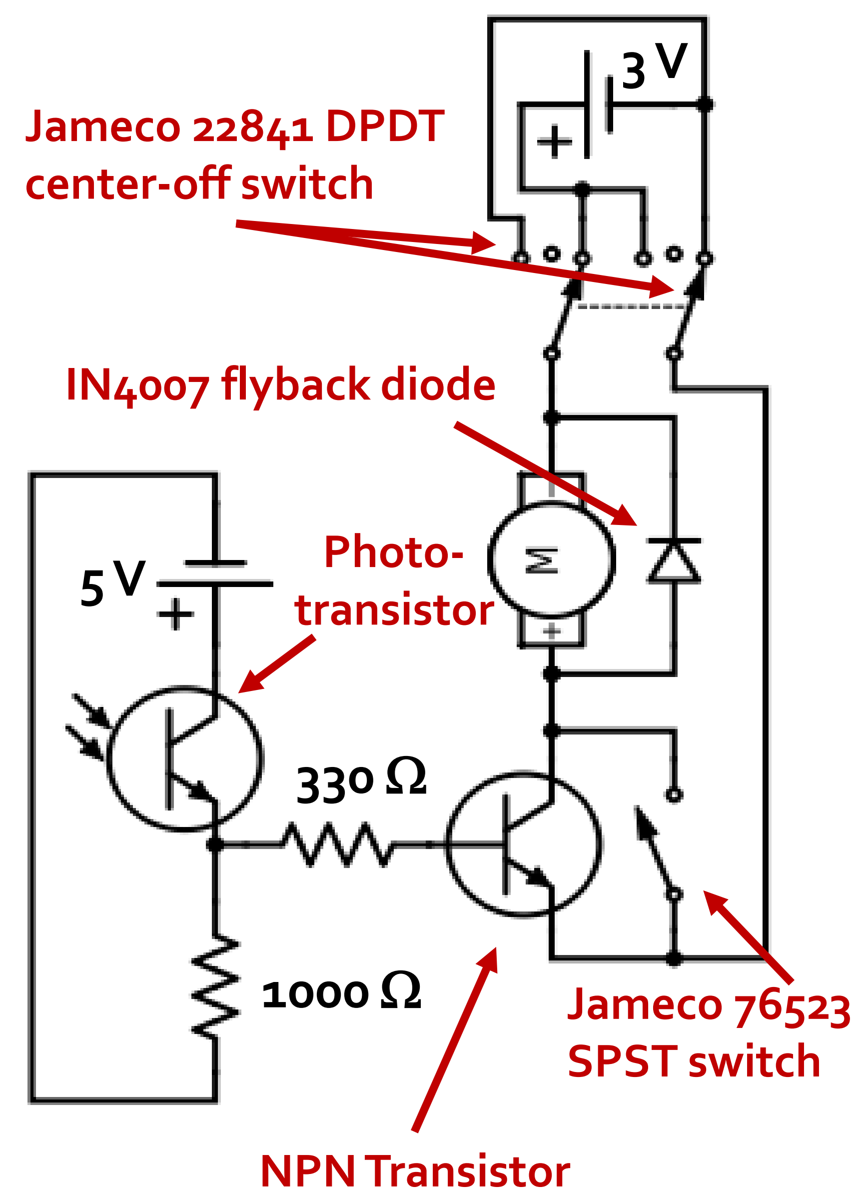
- Deployment height: **87 ± 1 mm**
- Test for under & over deployment

- **Minimum-Deployment**
  - Place laser & phototransistor at **86 mm height**
  - Baffle will block laser and current to motor will stop

- **Maximum-deployment**
  - Place laser & phototransistor at **88 mm height**
  - Baffle should not block laser – current will continue to power motor
  - Mechanical thread stop will stop deployment

Kill Switch

- **HW5P-1 Phototransistor**
  - For BC337 NPN transistor base biasing
- **Jameco 22841 DPDT center-off switch**
  - For polarity reversal to reset baffle deployment
- **Jameco 76523 SPST switch**
  - Removes NPN transistor from circuit to allow motor operation with reversed polarity
- **IN4007 flyback diode**
  - Protects NPN transistor from voltage spike when motor secured



Kill Switch Laser Pointer

Optotronics Laser Pointer

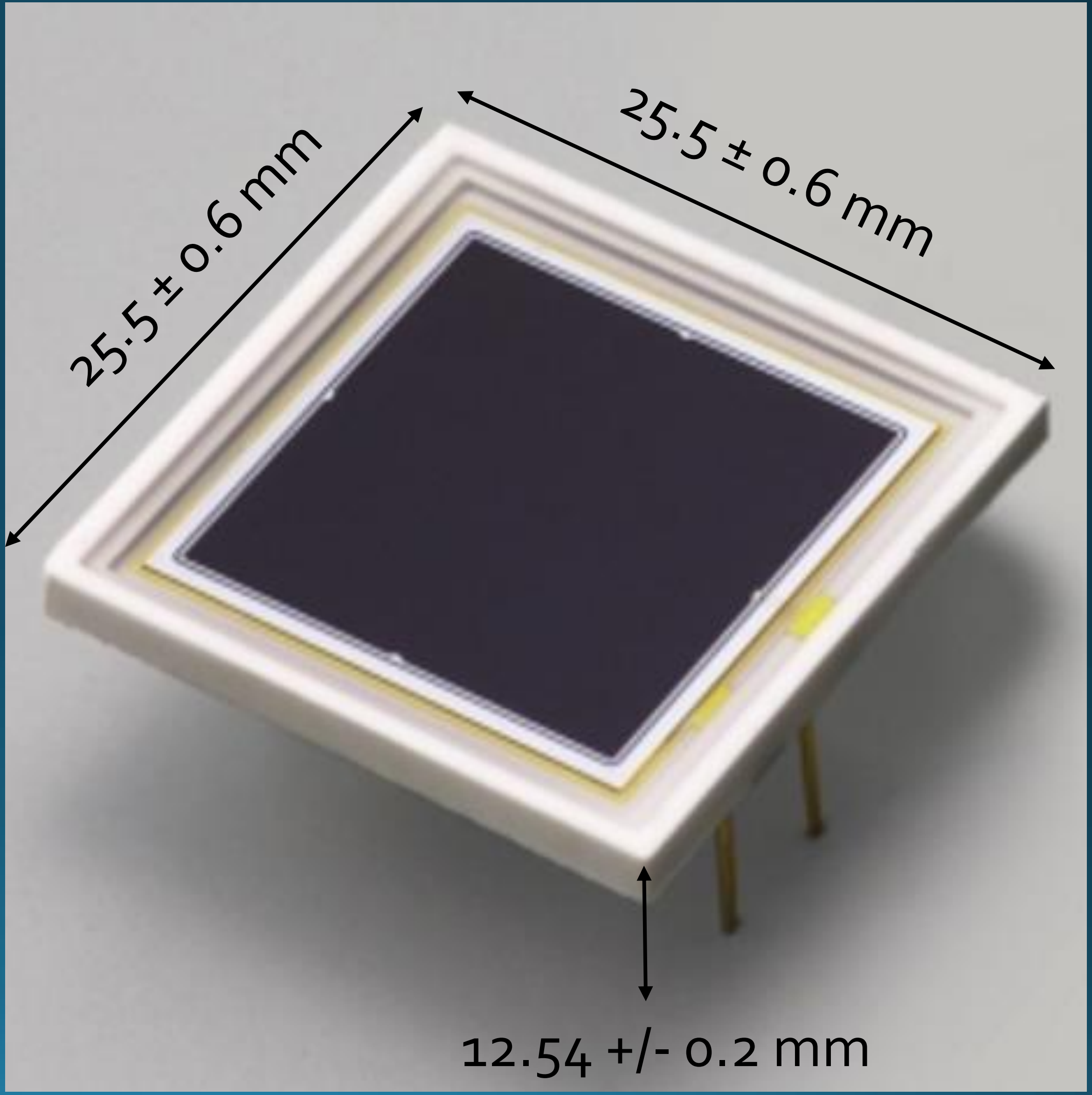
- 250 mW laser diode power
- 4.99 mW average power output
- 1.5 mm beam diameter
- 1.2 mrad beam divergence
    - Tighter beam width per distance over competing products – increased kill switch circuit accuracy
- 5.1 mm spot size at distance of 3 m
- $29.95 + shipping

Light Attenuation Testing

Sensor

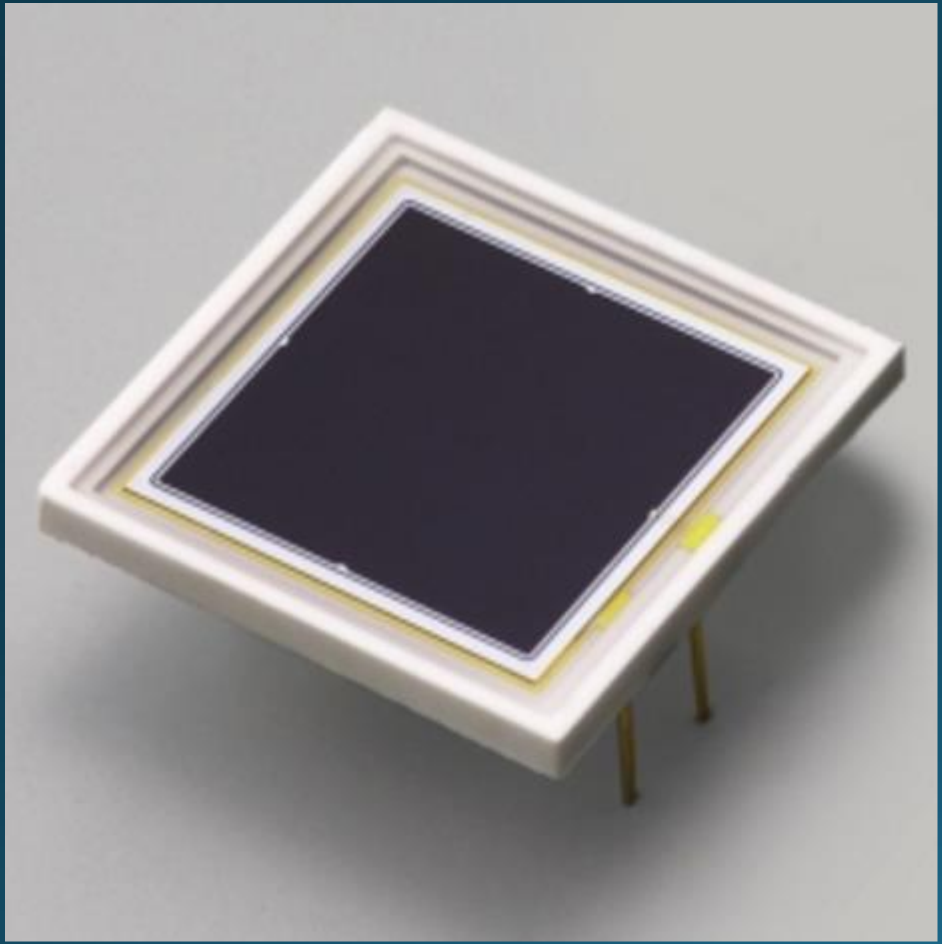
- Absorbs light photons and outputs current
- Will be used with a visible light filter to exclude IR from test environment
- Current will be measured and analyzed to ensure requirements are met

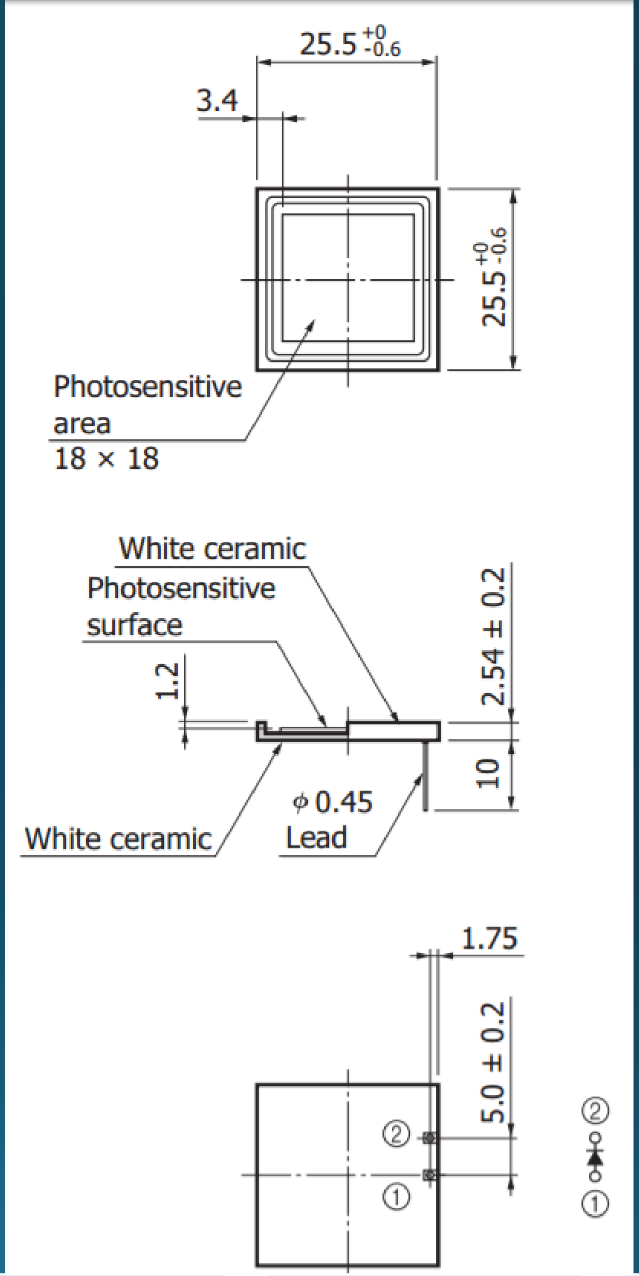
Hamamatsu Si Photodiode S1337-21



Sensor

Hamamatsu Si Photodiode S1337-21





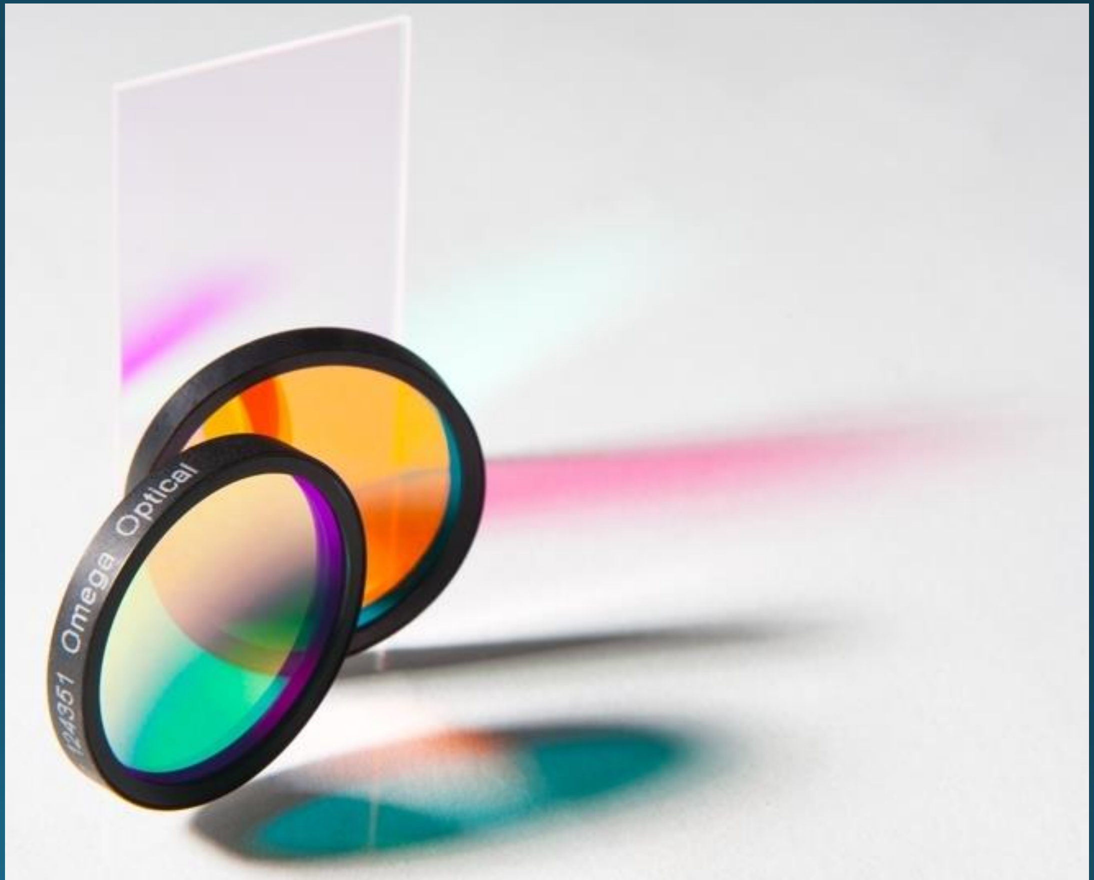
Visible Light Filter

- 700SP RADIDEDGE from Omega Optical

- 25 ± 0.1 mm diameter
- 3.5 mm thick

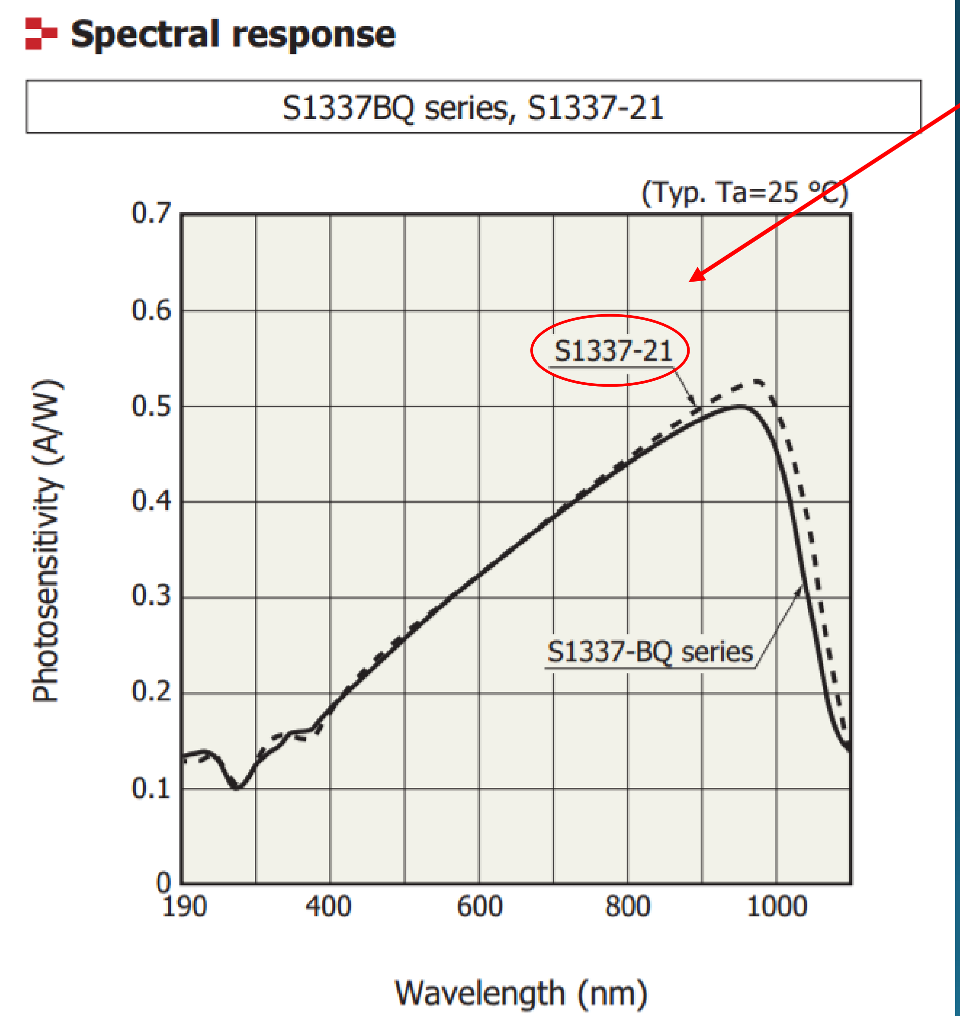
- >90% transmission (typ.)

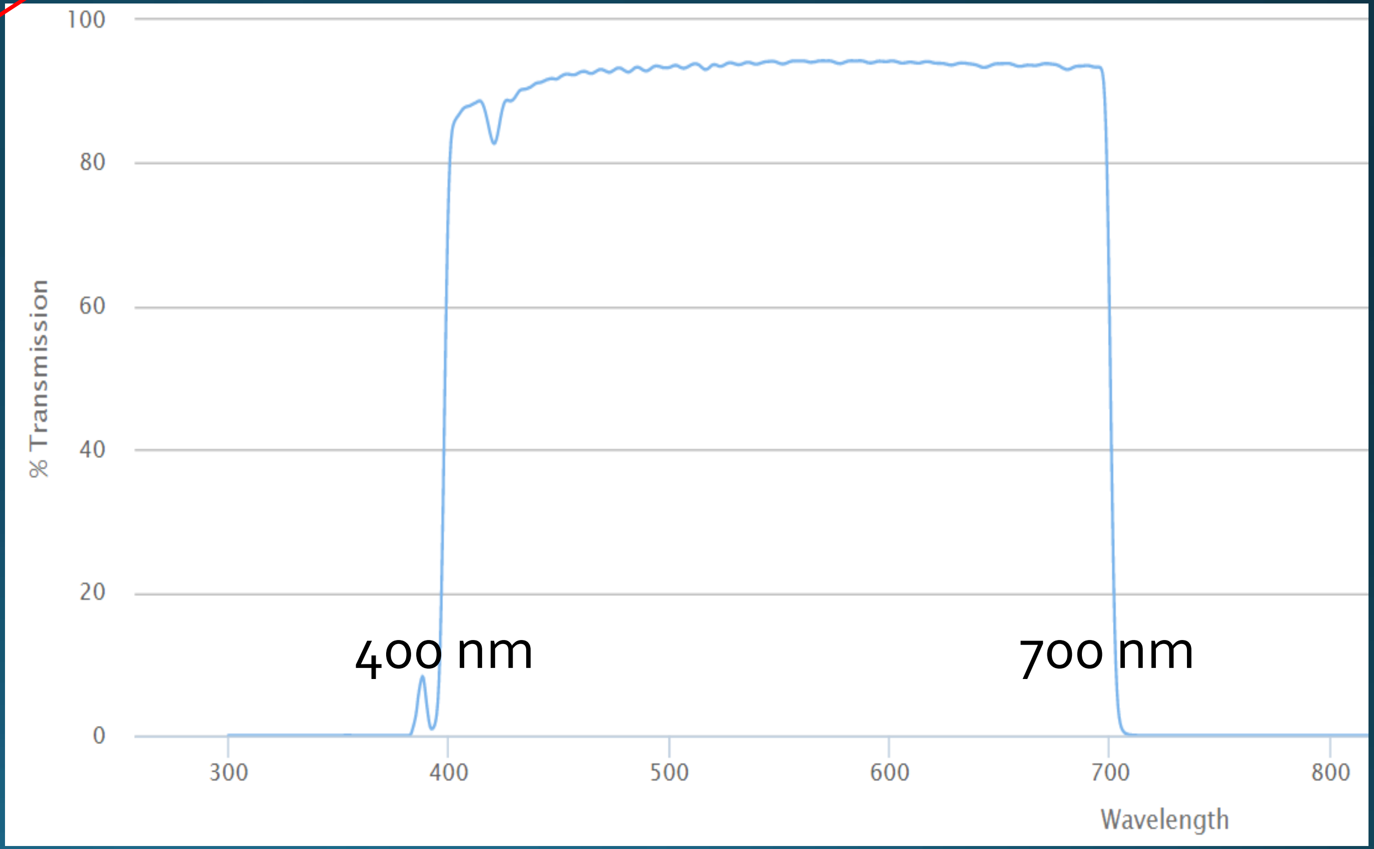
- $100 + tax & shipping



Sensor & Filter

Sensor is sensitive in visible spectrum



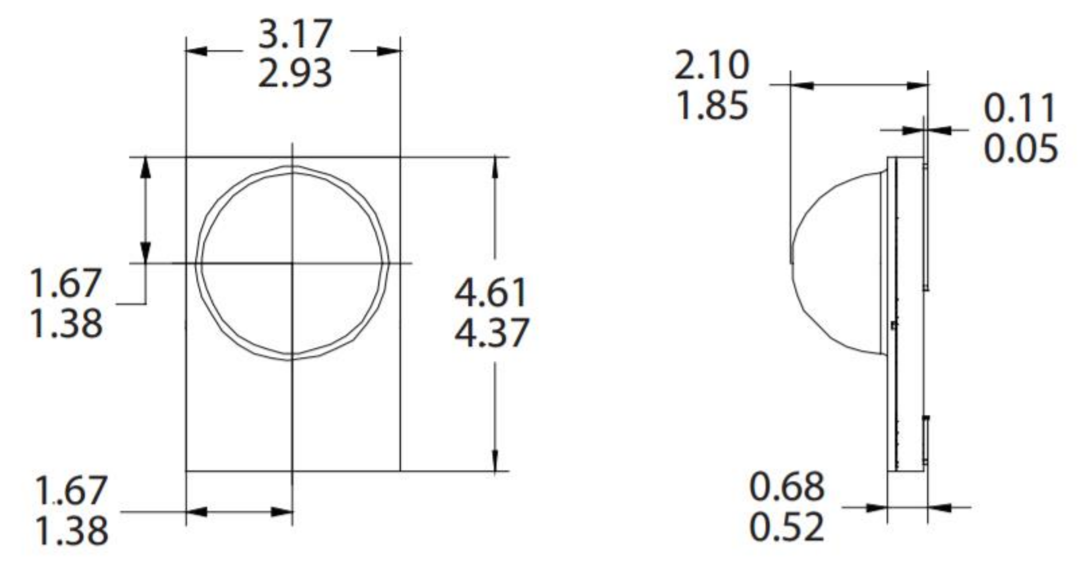


Filter Transmission Curve

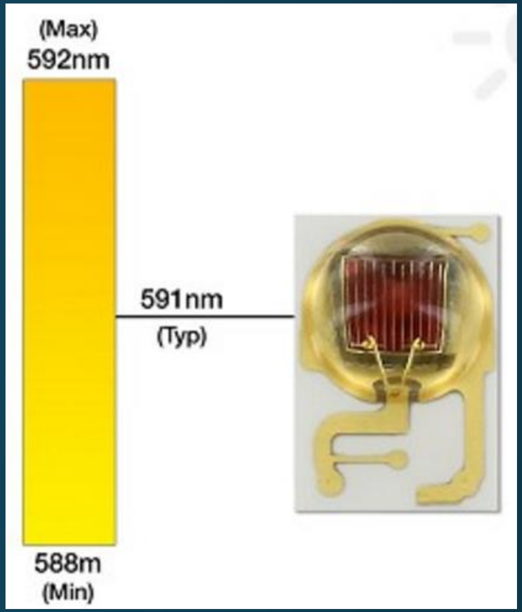
Rotary Table

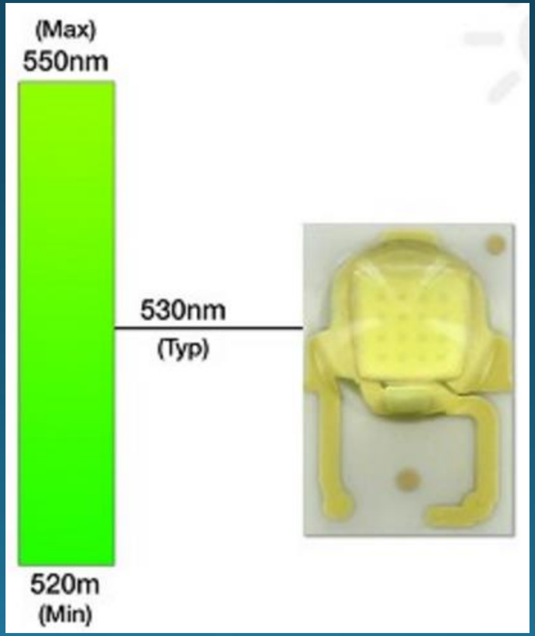
- 3700 4” Rotary Table from Sherl
  Products
- 2” high and 4” diameter
- Accuracy to 0.1°
- $283.50 + tax & shipping

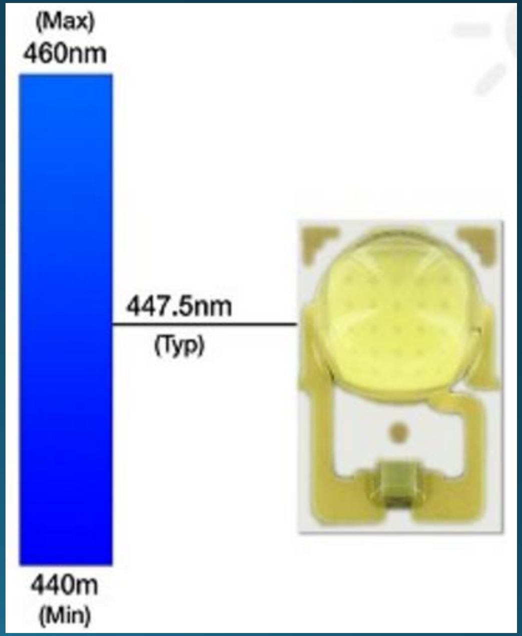
LEDs



Dimensions are in mm



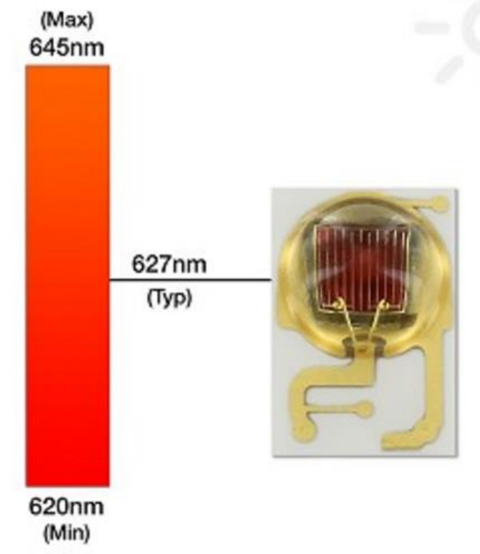


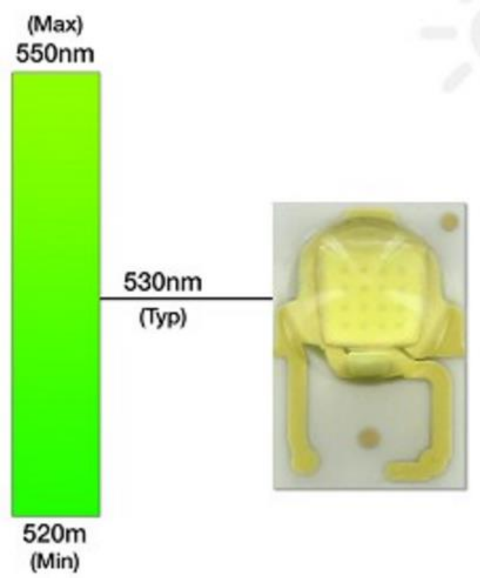


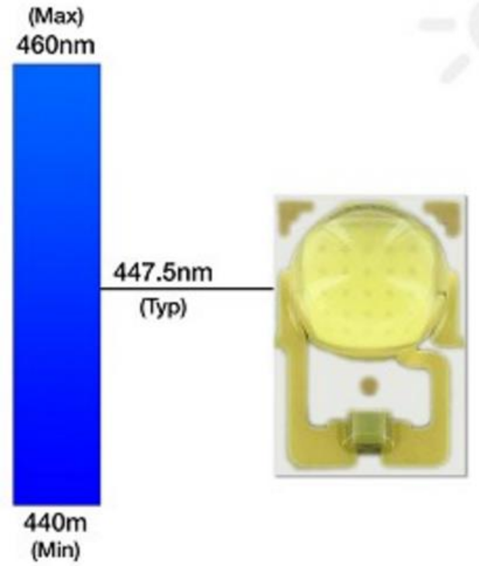
Stray Light Testing

- LEDs:
  - Red
    - $3.65 x 16 = $58.40
  - Amber
    - $4.04 x 16 = $64.64
  - Green
    - $9.18 x 16 = $146.88
  - Royal Blue
    - $7.76 x 16 = $124.16

  - **Total: $394.08 + shipping**







Stray Light Testing

- Hamamatsu Si Photodiode S1337-21
  - Responsivity [Amps/Watts]

$$R = \eta \frac{q}{hf} \approx \eta \frac{\lambda_{(\mu m)}}{1.23985\left(\mu m * \frac{W}{A}\right)}$$

η = quantum efficiency

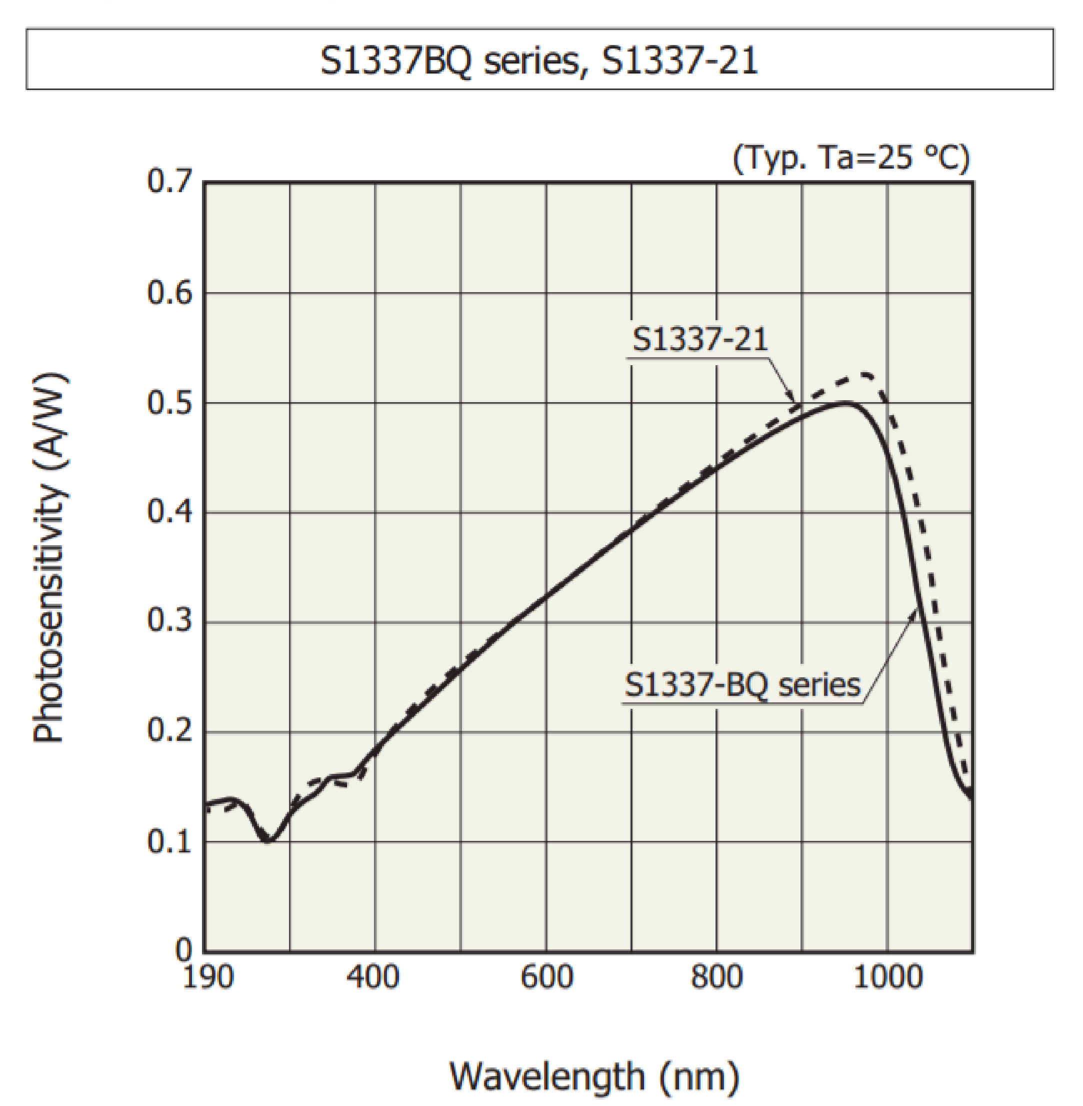
q = electron charge

h = Planck's constant

f = frequency of optical signal

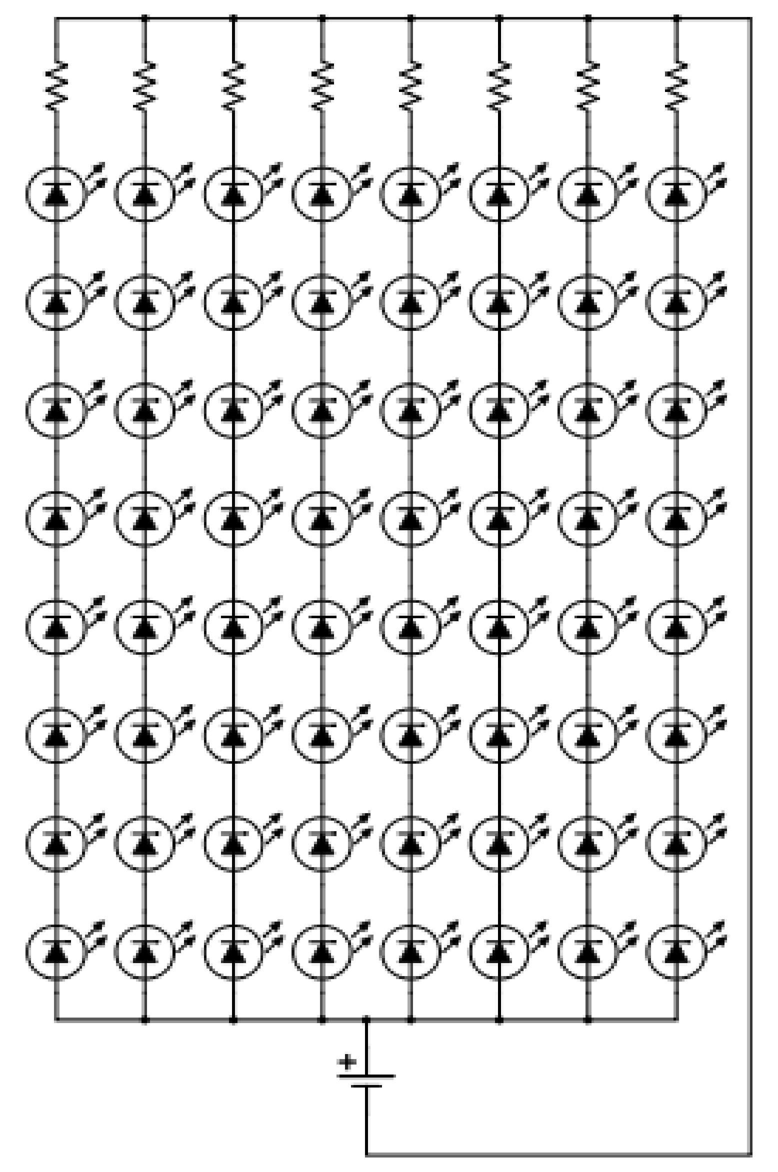
λ = wavelength of optical signal

- Quantum Efficiency
    - Conversion efficiency of photons to ele



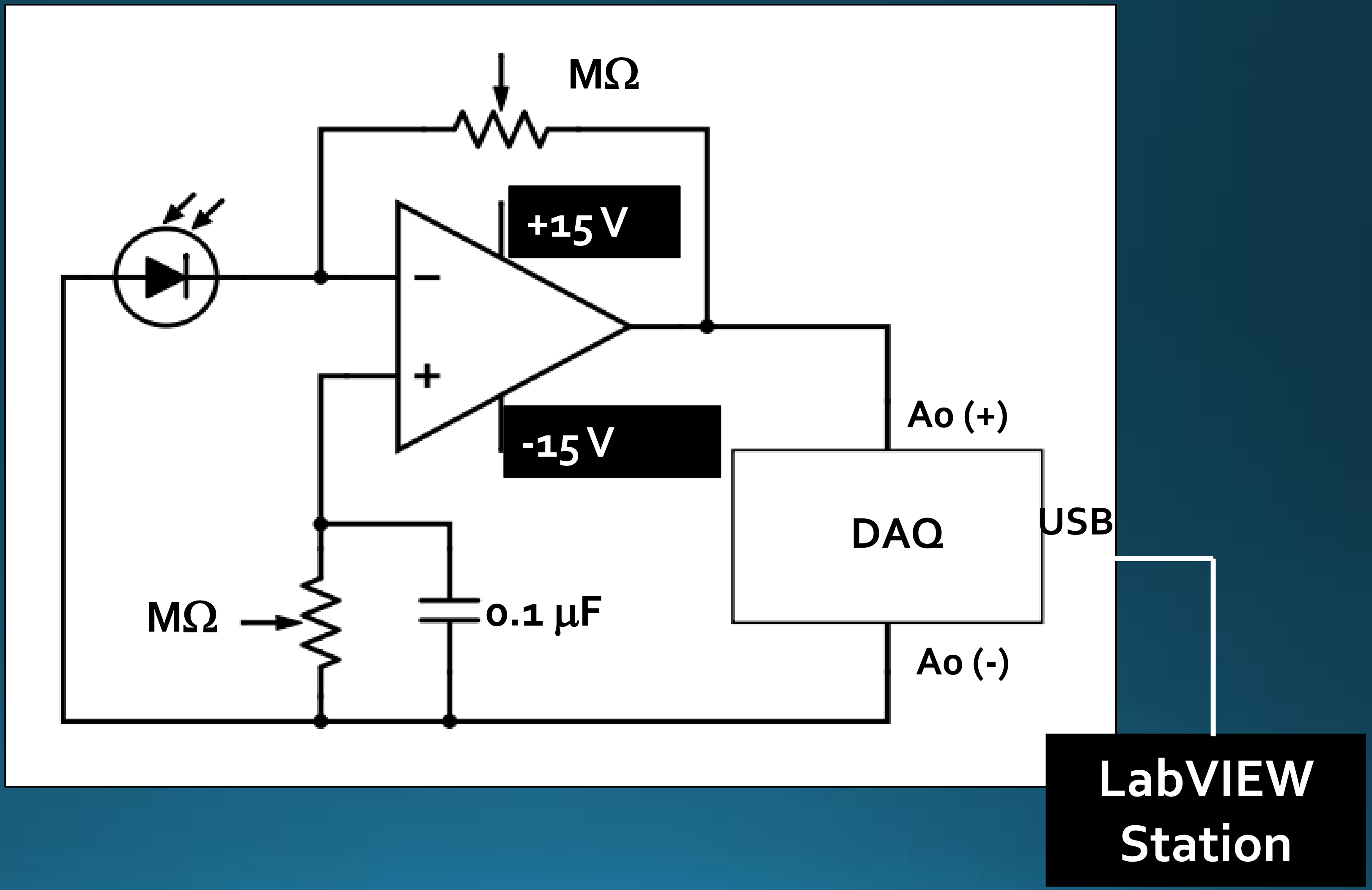
Test Set Up

- Light Source Circuit
  - 30 V power supply
  - 12 W limiting resistance in each branch
  - Split between six Vetco 2 W, 1W resistors
  - 0.887 W power dissipation per resistor
  - 700 mA per branch
  - 2.8 V across each LED



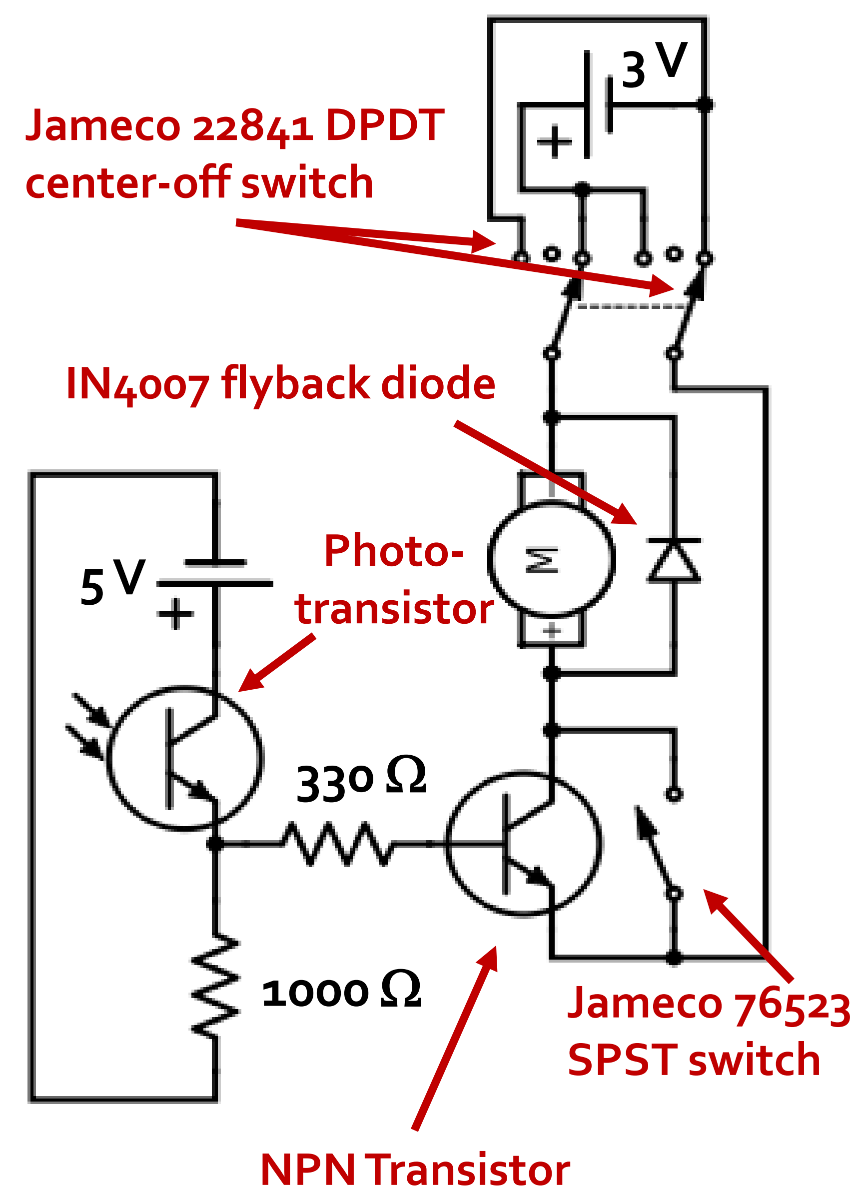
Light Detection Circuit

- Single 18 x 18 mm Hamamatsu S1337-21 Photodiode for light detection
- LM741 Op-Amp for current-to-voltage amplification
- NI USB-6009 DAQ connected to computer station running a LabVIEW voltage module for data collection



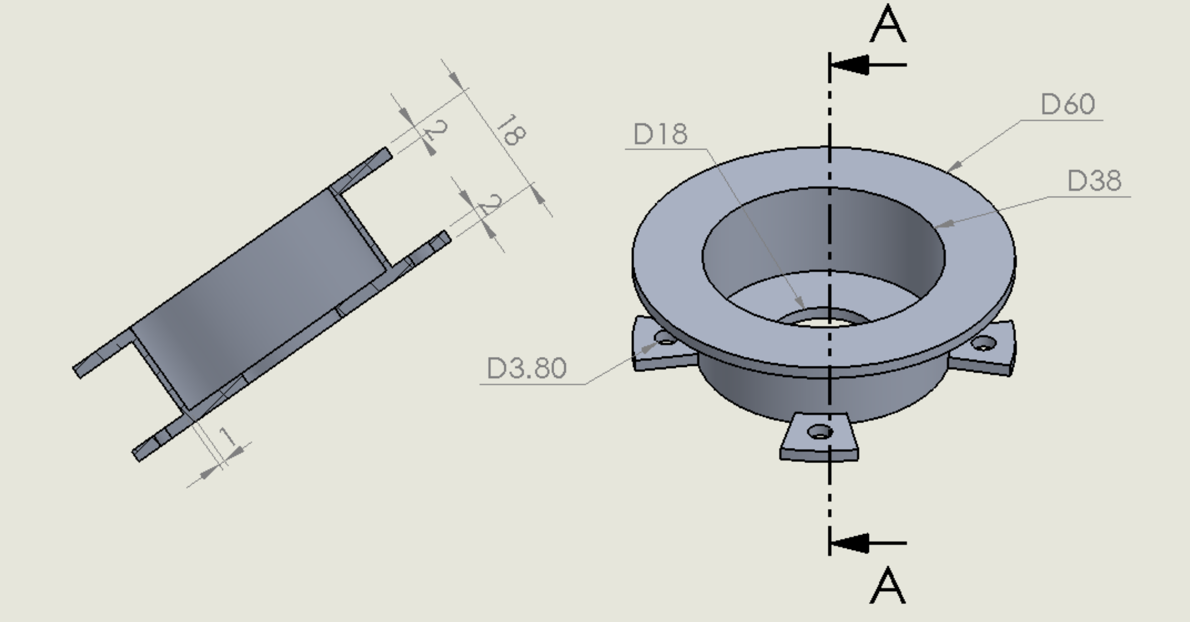
Kill Switch

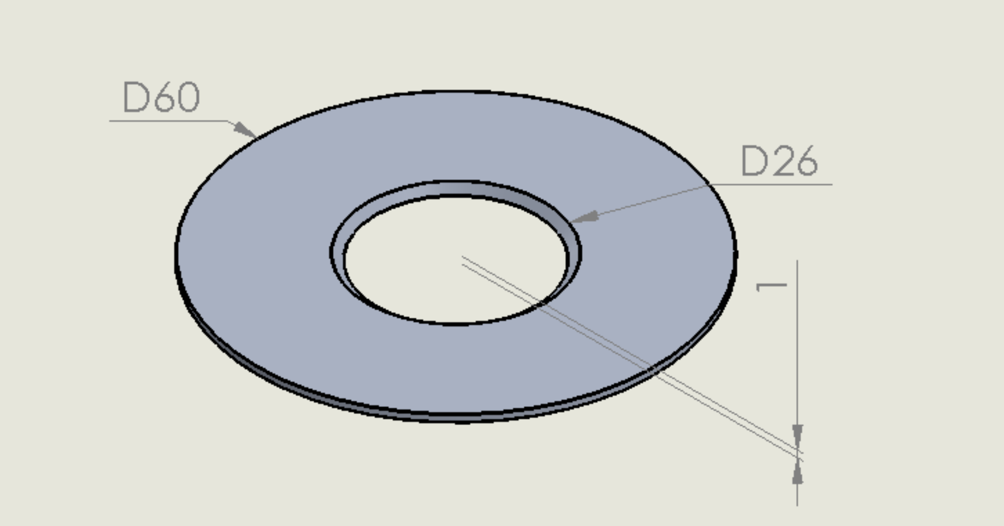
- **HW5P-1 Phototransistor**
  - For BC337 NPN transistor base biasing
- **Jameco 22841 DPDT center-off switch**
  - For polarity reversal to reset baffle deployment
- **Jameco 76523 SPST switch**
  - Removes NPN transistor from circuit to allow motor operation with reversed polarity
- **IN4007 flyback diode**
  - Protects NPN transistor from voltage spike when motor secured



Baffle Tier and Vane 1

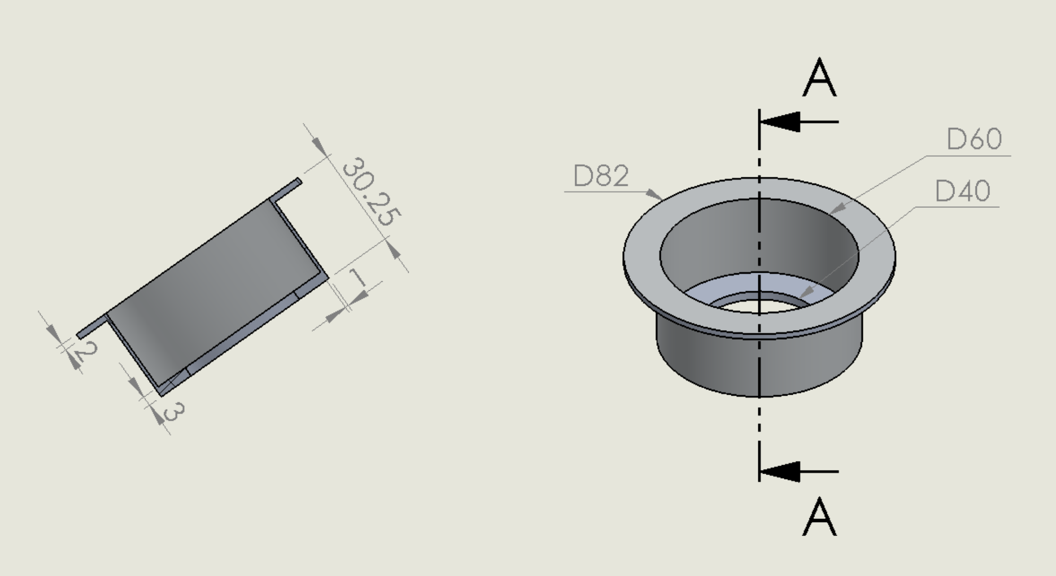
- Aluminum 2024-T4
- Manufactured from 5 in round
- Holes sized for 6-32 bolts

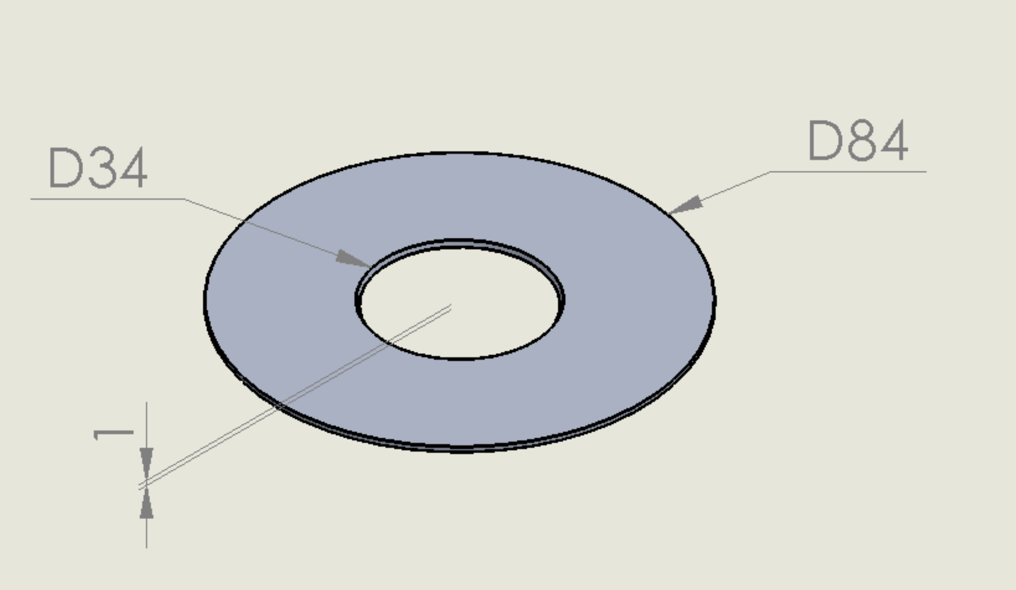




Baffle Tier and Vane 2

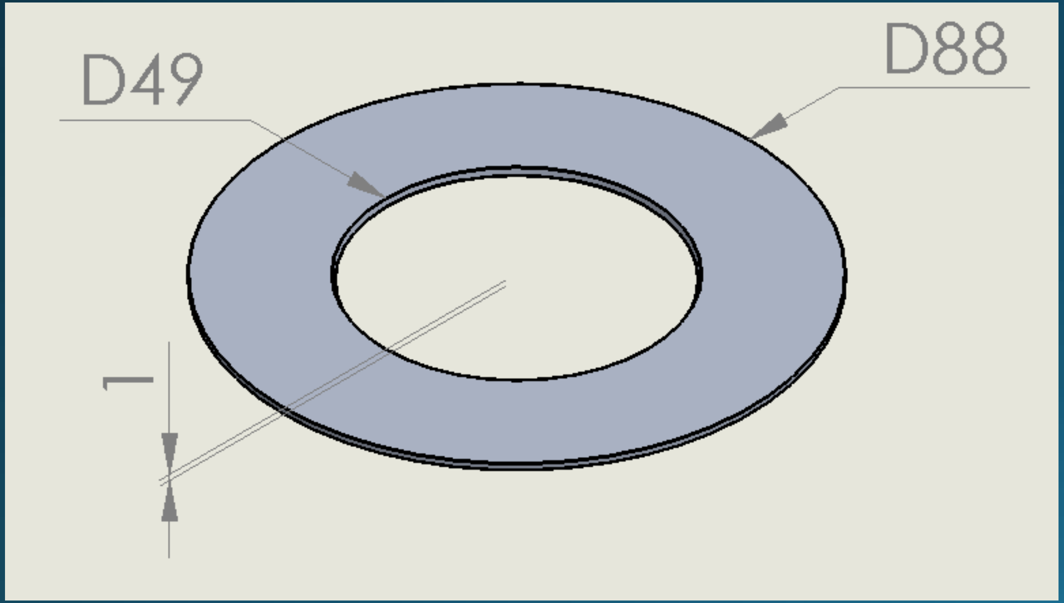
- Aluminum 2024-T4
- Manufacture from 5 in round

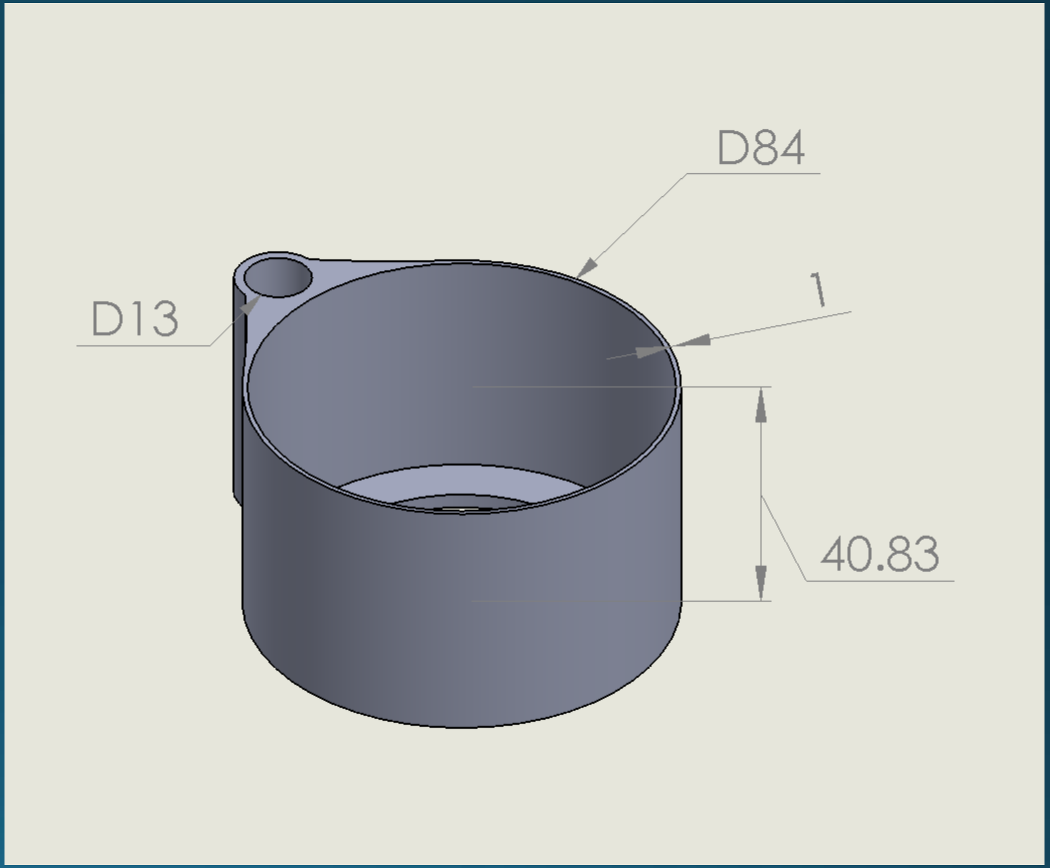




Baffle Tier and Vane 3

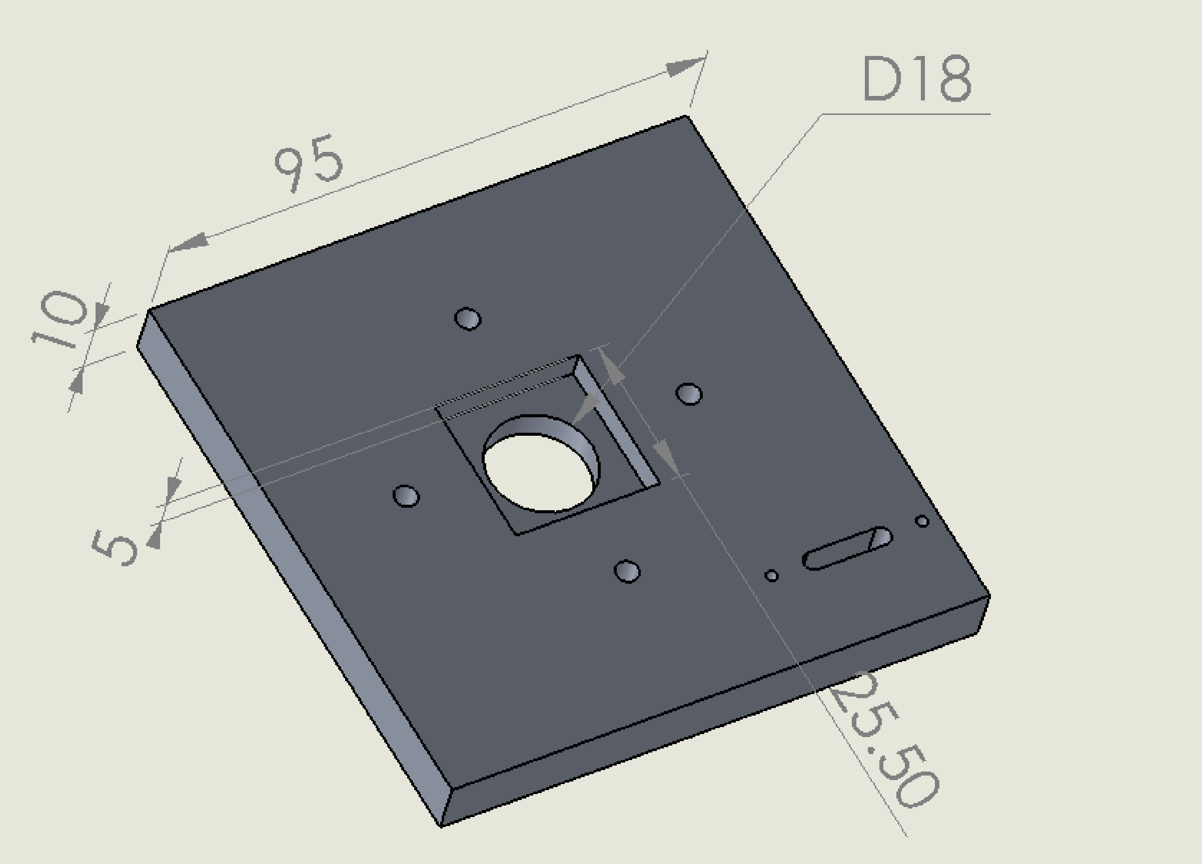
- Made of Aluminum 2024-T4
- Manufactured from 5in Round





Baseplate

- Made From 10 mm thick sheet aluminum 2024-T4
- Bolt holes sized for 6-32

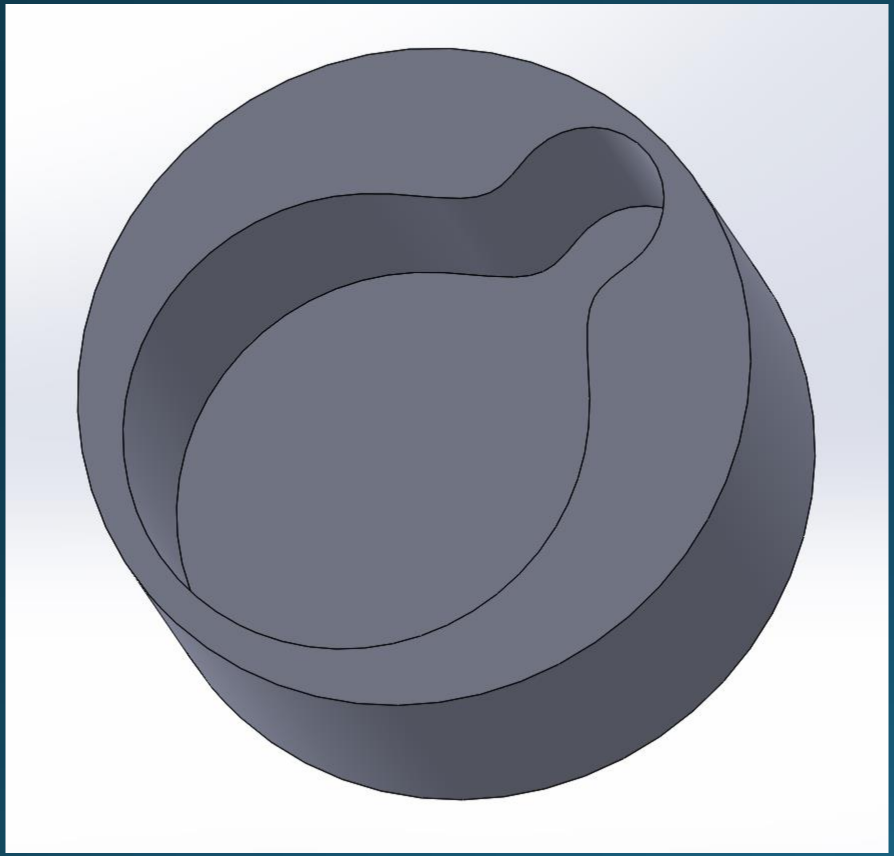


Linear Bearing

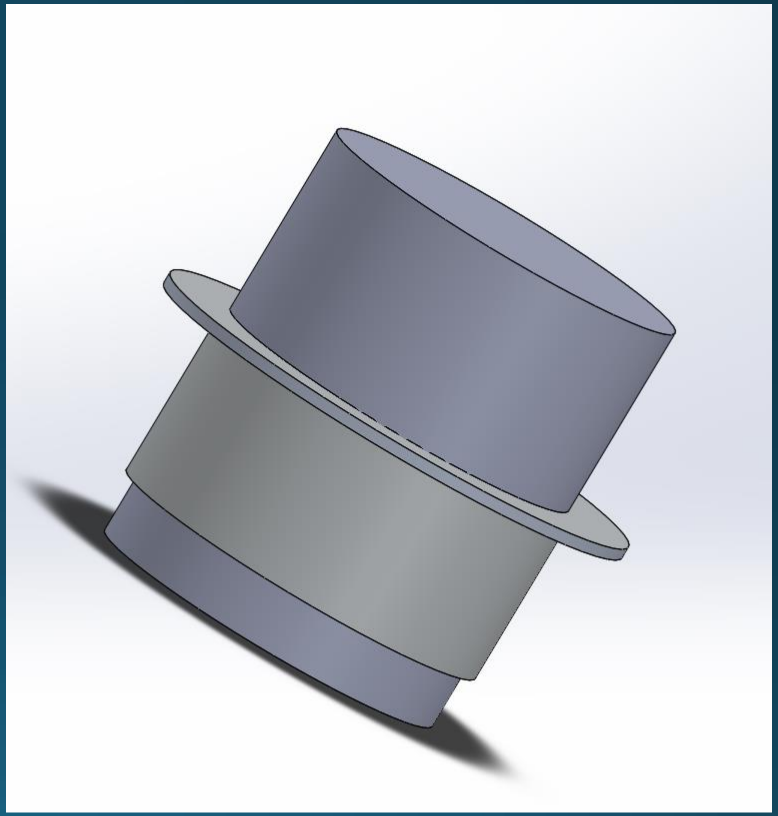
- Prevents Twisting of Baffle
- Connected to Baffle using Adhesive
- Allows motion in only one linear direction

- Good Pic of linear bearing goes here.

Manufacturing Brace



Top Section



Middle and Bottom Sections

Assumptions for adhesive

- 24 hr cure time for adhesive
- Sandblasted aluminum material
  - More surface area than non-sandblasted aluminum
  - Approximately 10 times larger
- Tensile strength of adhesive
- Perfect adheasion

Adhesive

- Tensile strength of adhesive: 2271psi = 1947.33g/mm^2
- Minimum contact surface: 45.mm^2
- Bond strength = adhesive strength x contact surface area
- Bond strength: 48702 g

- Bond strength required: <200g

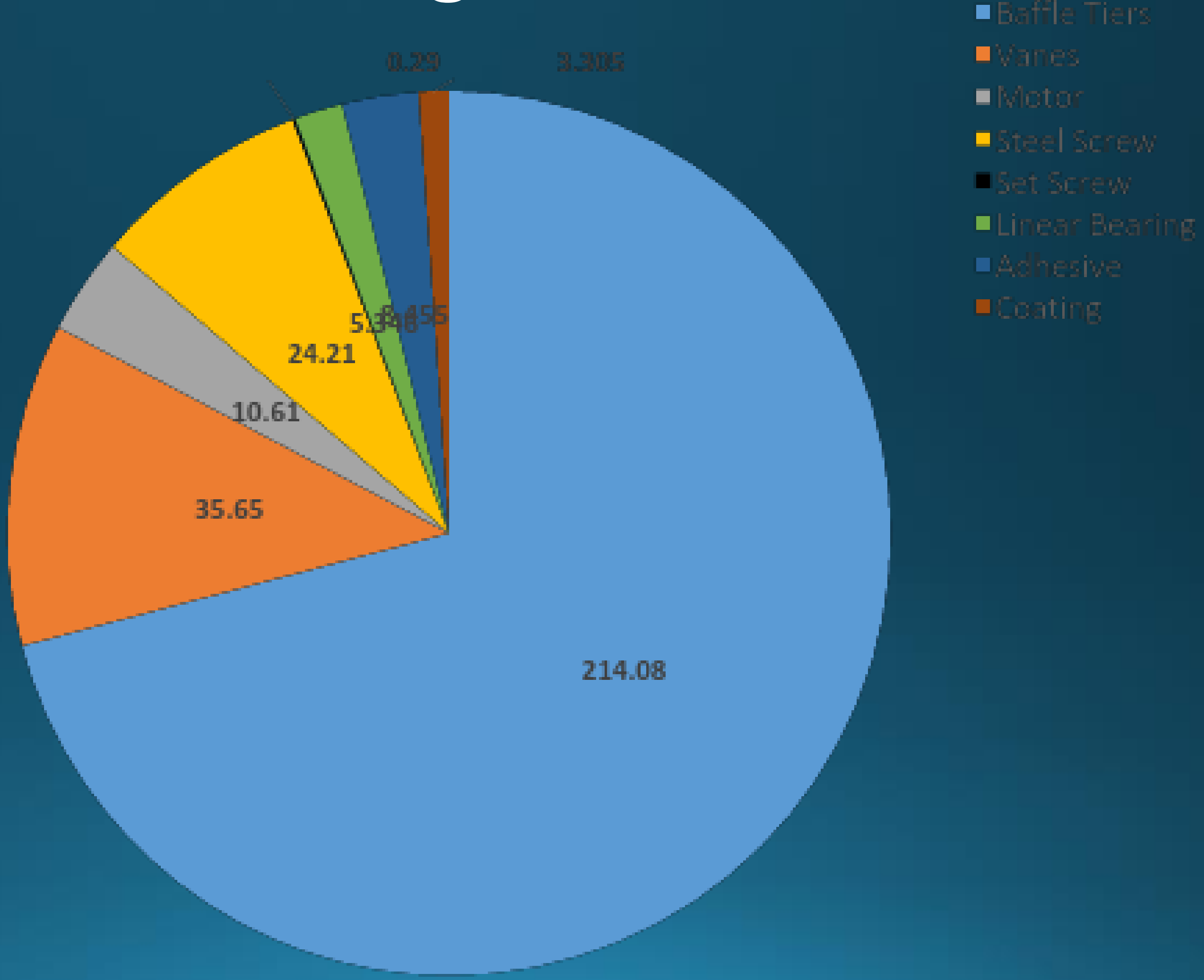
Preliminary Design Mass Budget [grams]

AIAA Percentage mass growth allowance

- 4-15% for mechanism/ structure
  - Tiers
  - Vanes
  - Steel screw
- 1-3 % for existing hardware
  - Motor
  - Linear bearing
  - Set screw

Spec sheet application uncertainty

- Coating
- Adhesive



Total mass= 301.946 g

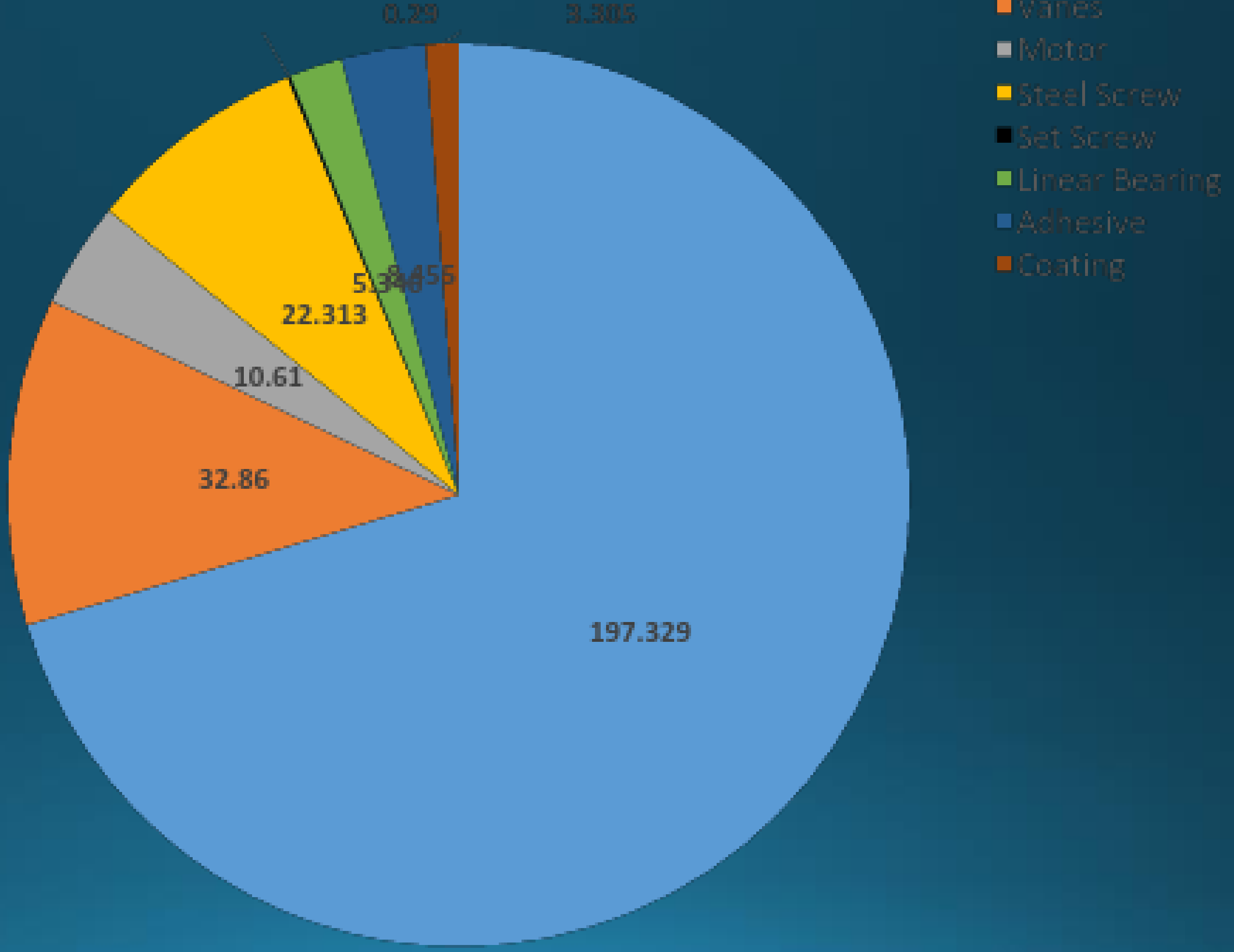
- Tier 1 requirements mass < 300g
- Tier 2 requirements mass < 500g

Released Design Mass Budget [grams]

AIAA Percentage mass growth allowance
- 2-6% for mechanism/ structure
    - Tiers
    - Vanes
    - Steel screw
- 1-3 % for existing hardware
    - Motor
    - Linear bearing
    - Set screw

Spec sheet application uncertainty
- Coating
- Adhesive

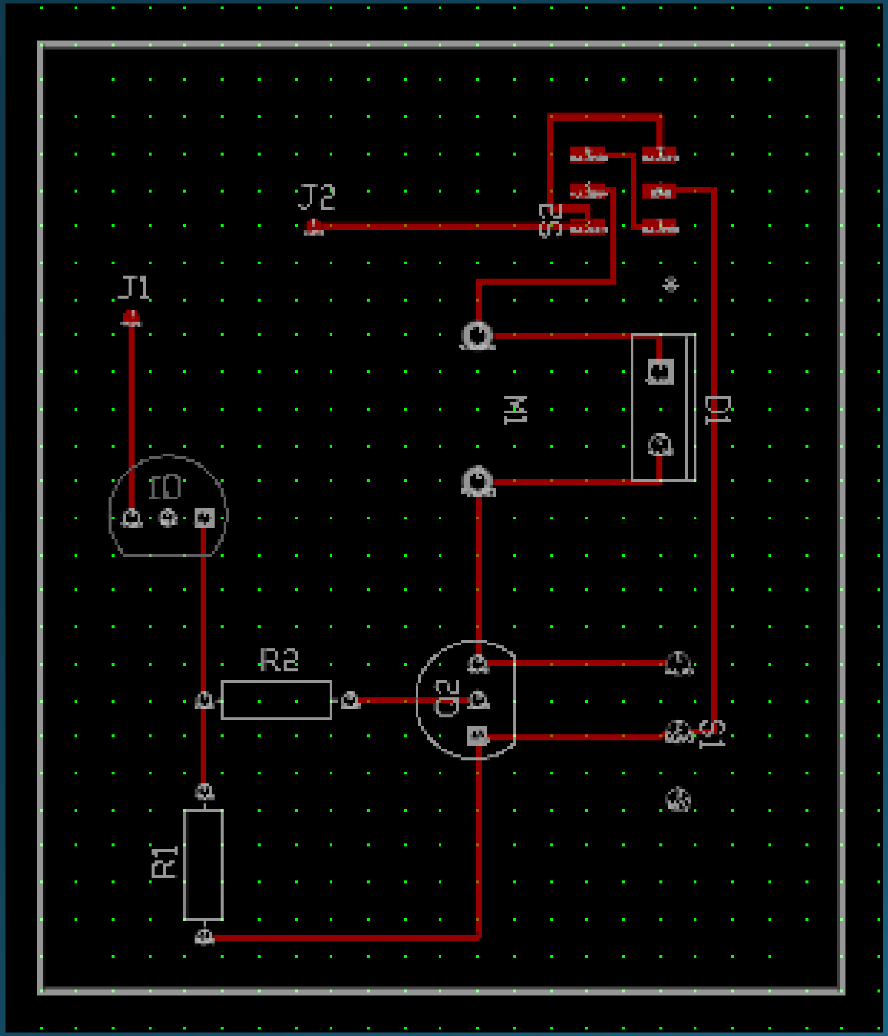
Total mass= 280.508 g
- Tier 1 requirements mass < 300g
- Tier 2 requirements mass < 500g



Cost Plan

Item:	**Price:**
Aeroglaze	$374
Aluminum 145mm	$304
Aluminum 44.45mm	$17
Resistors	$12
LED	$374
Photo Transistor	$1
2 DC Motors	$50
Photo Diode	$608
Rotary Table	$284
Air Brush	$50
Coating Application	$10
Transistor	$1
Laser Pointer	$30
Linear Bearing	$19
Thread Tap	$103
Toggle Switch	$2
Linear Motion Shaft	$20
Option Board	$50
Aluminum Plate	$23
Loctite Epoxy Weld	$4
Fully Threaded Rod	$13
5 in Round Aluminum	$90
3.5 in Round Aluminum	$134
Margin	$3264

Motor Controller PCB Design

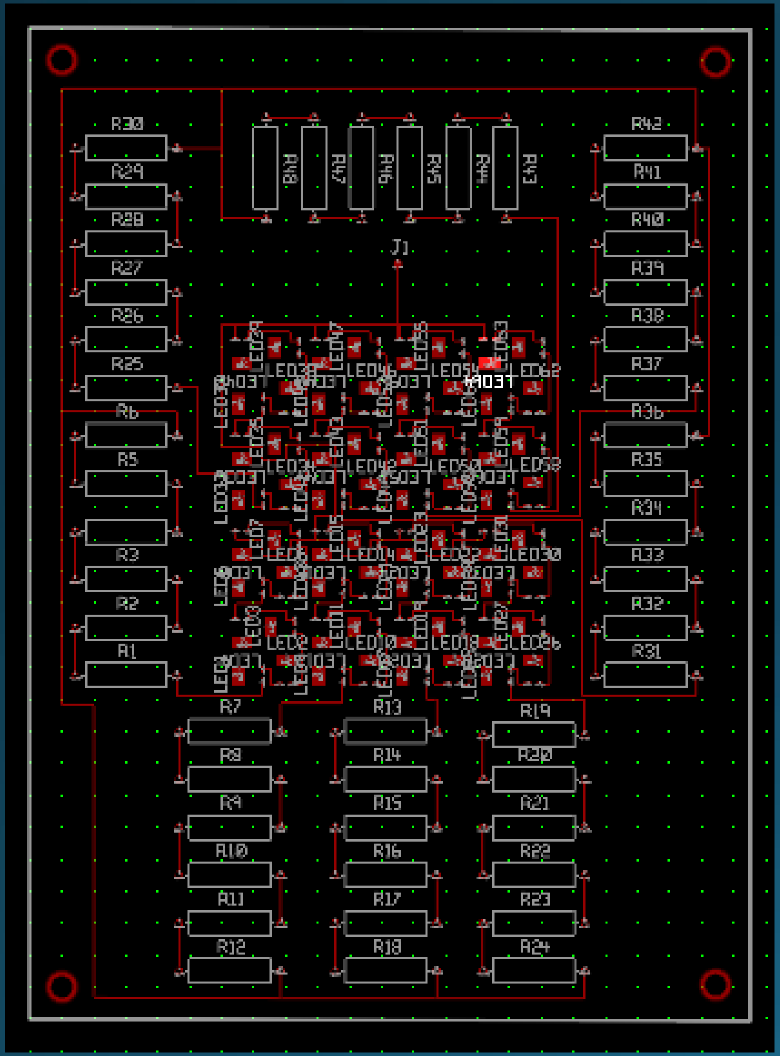


Board Dimensions:

66.3 x 56.2 mm

24.26 mm

LED Array PCB Design

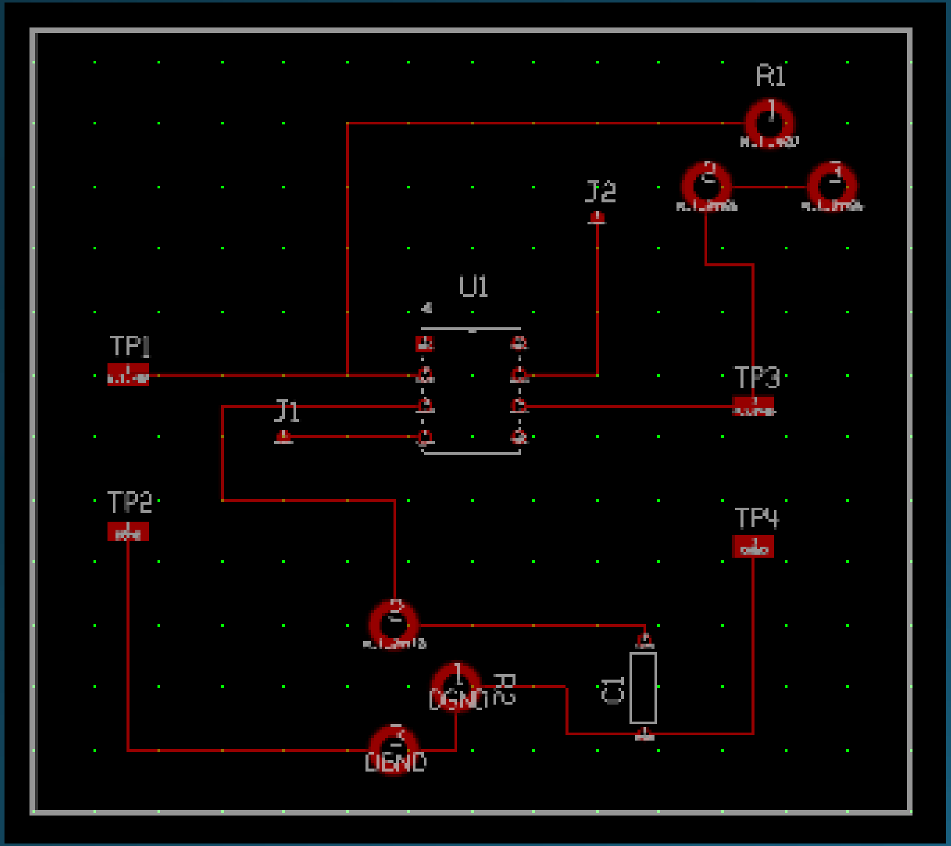


Board Dimensions:

124.5 x 90.7 mm

24.26 mm

Light Detection PCB Design



Board Dimensions:

71.5 x 64.0 mm

24.26 mm

Cantilever Beam Simplification

Assumptions:

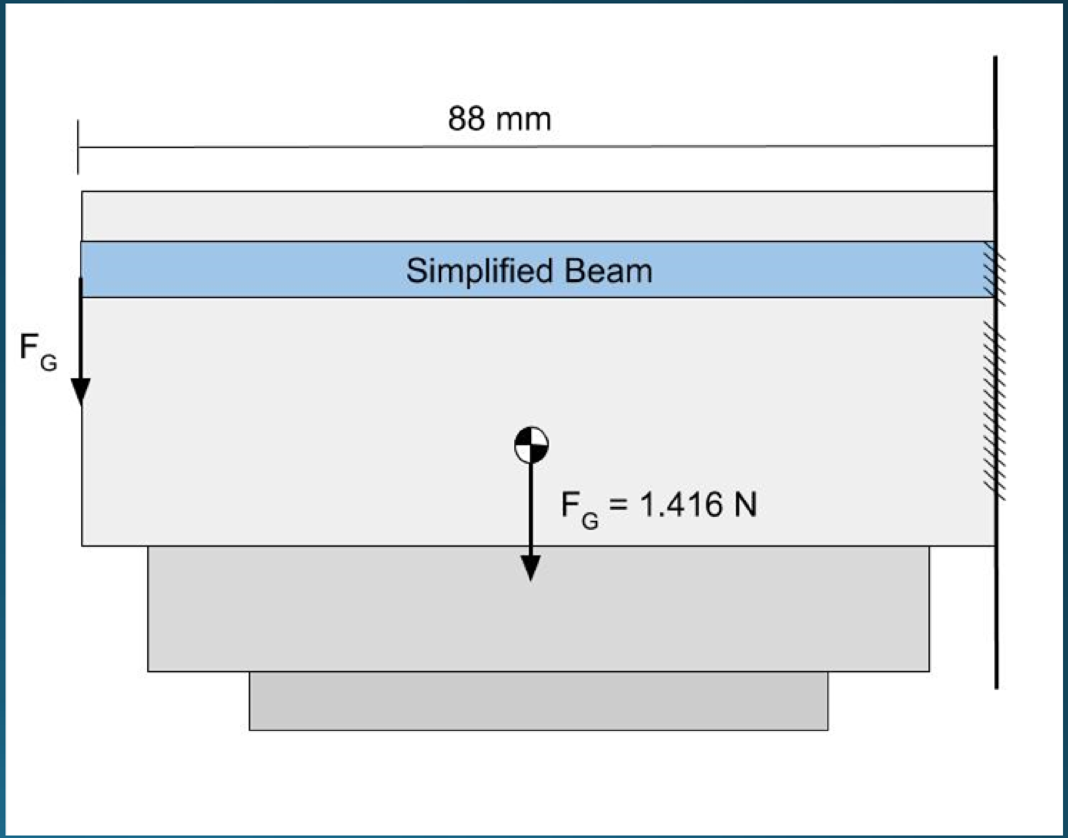
-Beam mass = lifted mass

-Beam length = Baffle Diameter

-Fixed end, Force of Gravity placed on opposite end

-5mm square beam cross section

-Worst case scenario of deflection

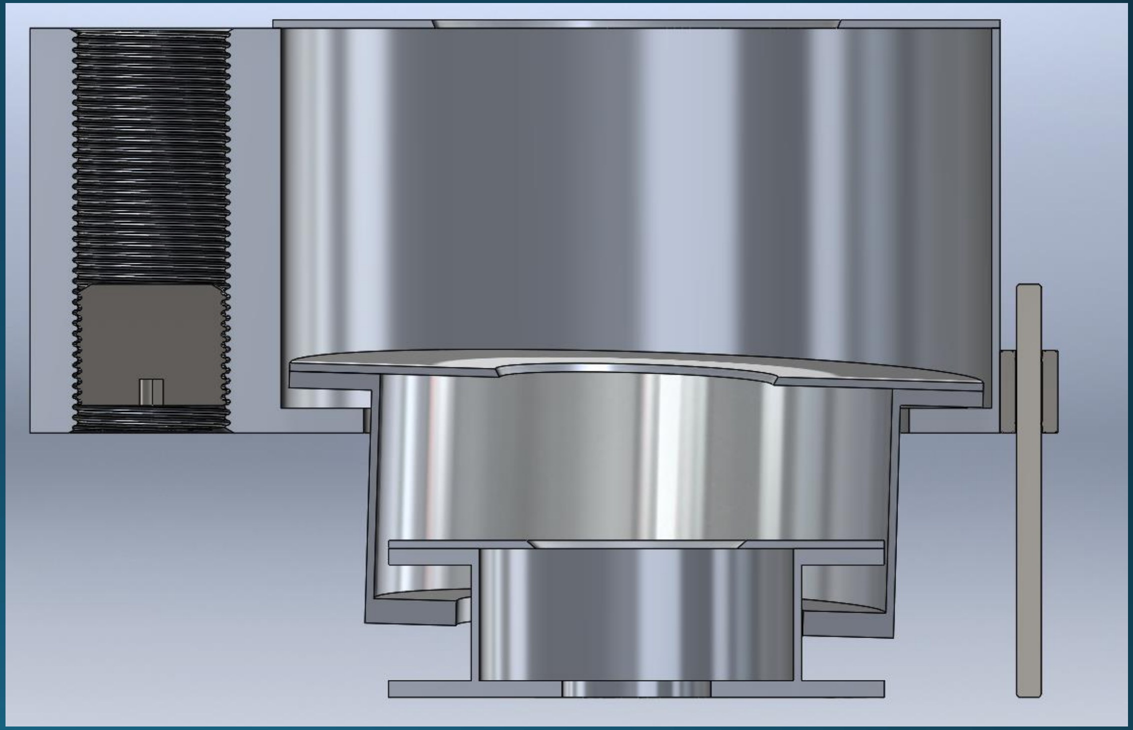


Binding concern

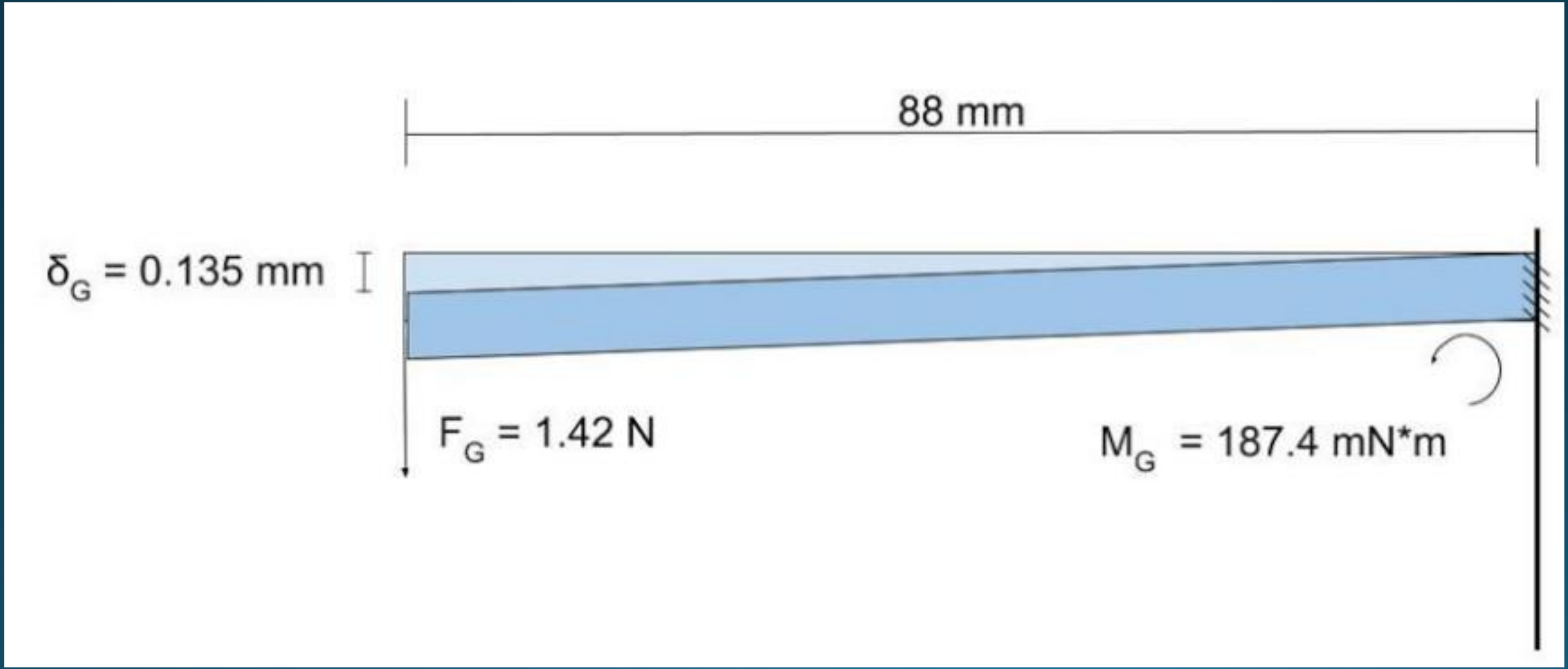
- Worst case scenario modeled:
- 45° half deployed

- Normal force of middle tier = 0.424 N

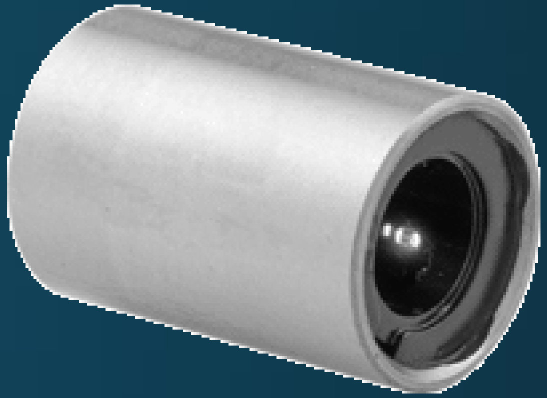
- Force of friction between tiers = 0.572 N



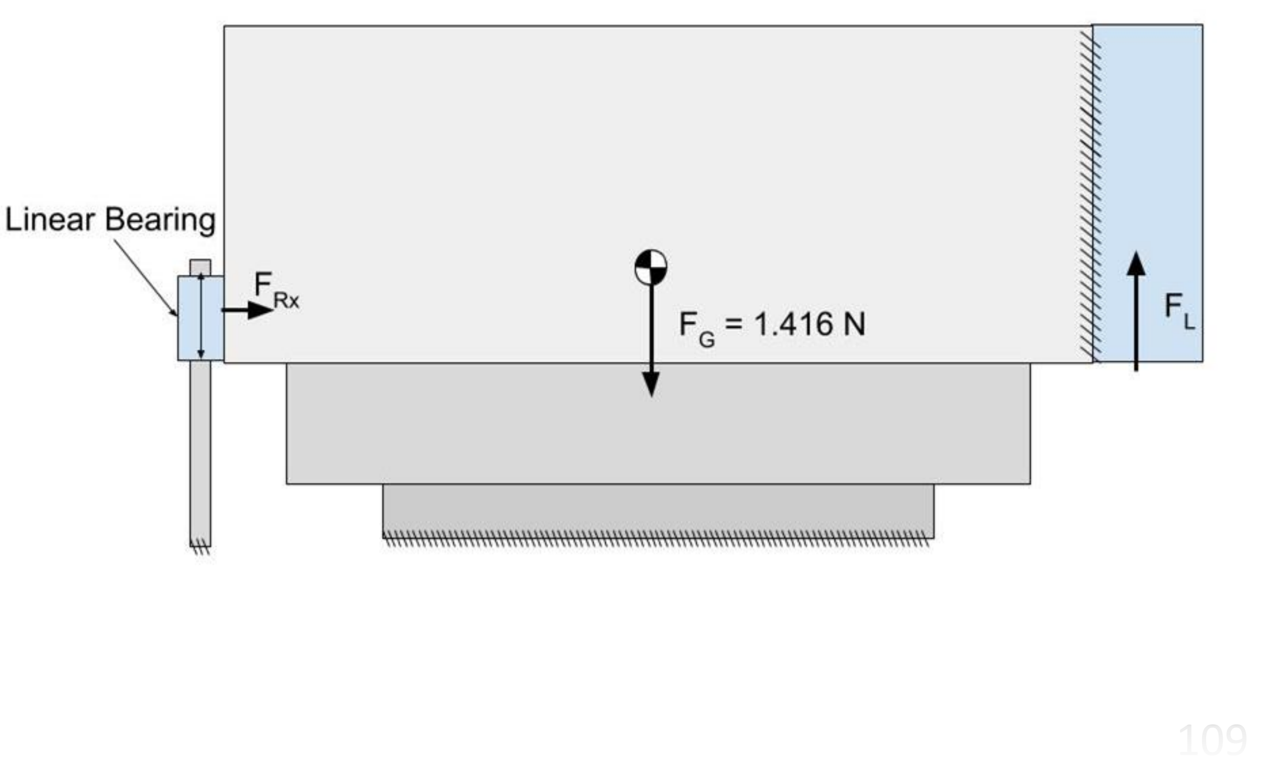
Cantilever Beam Deflection



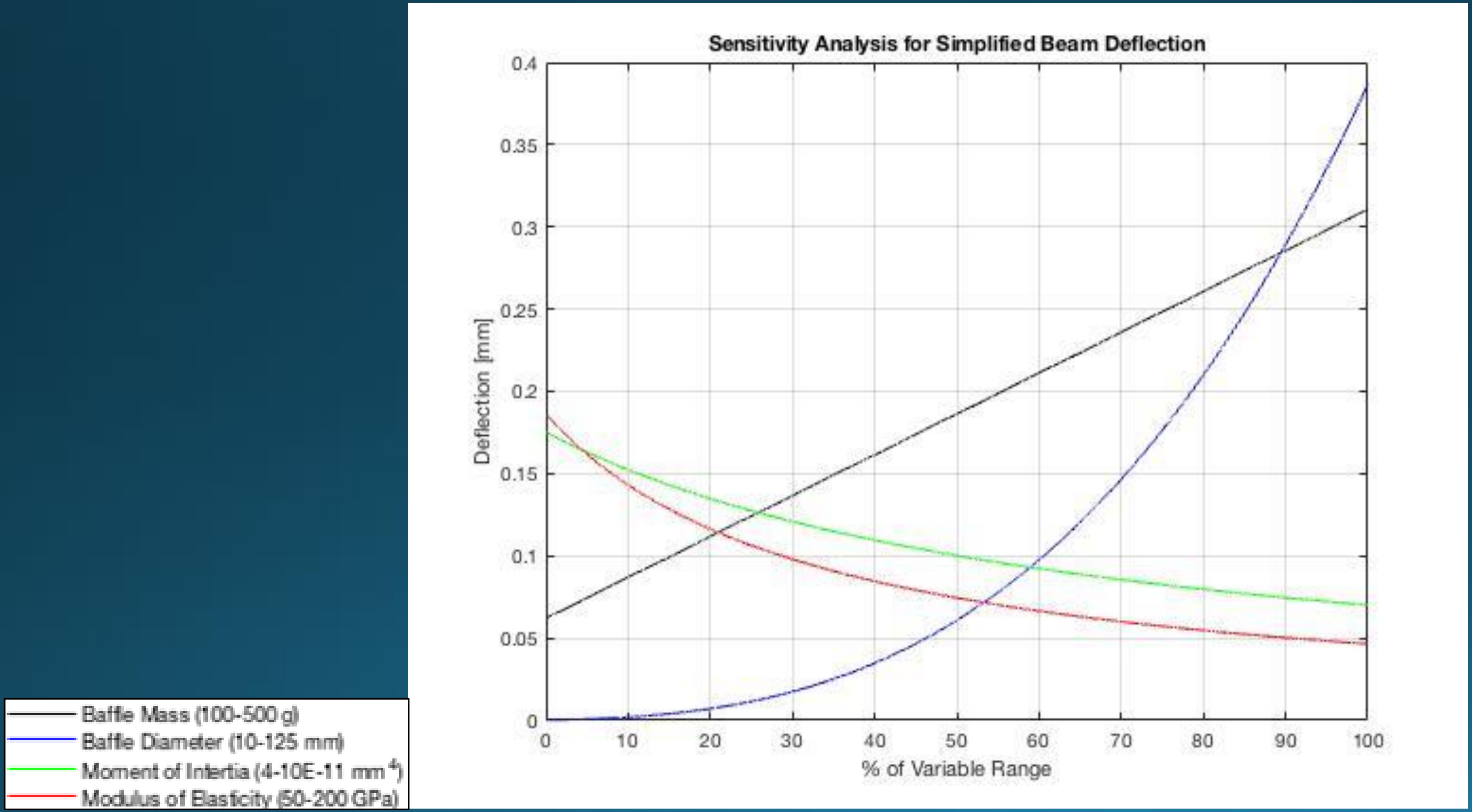
Solution to Moment Concerns: Linear Bearing



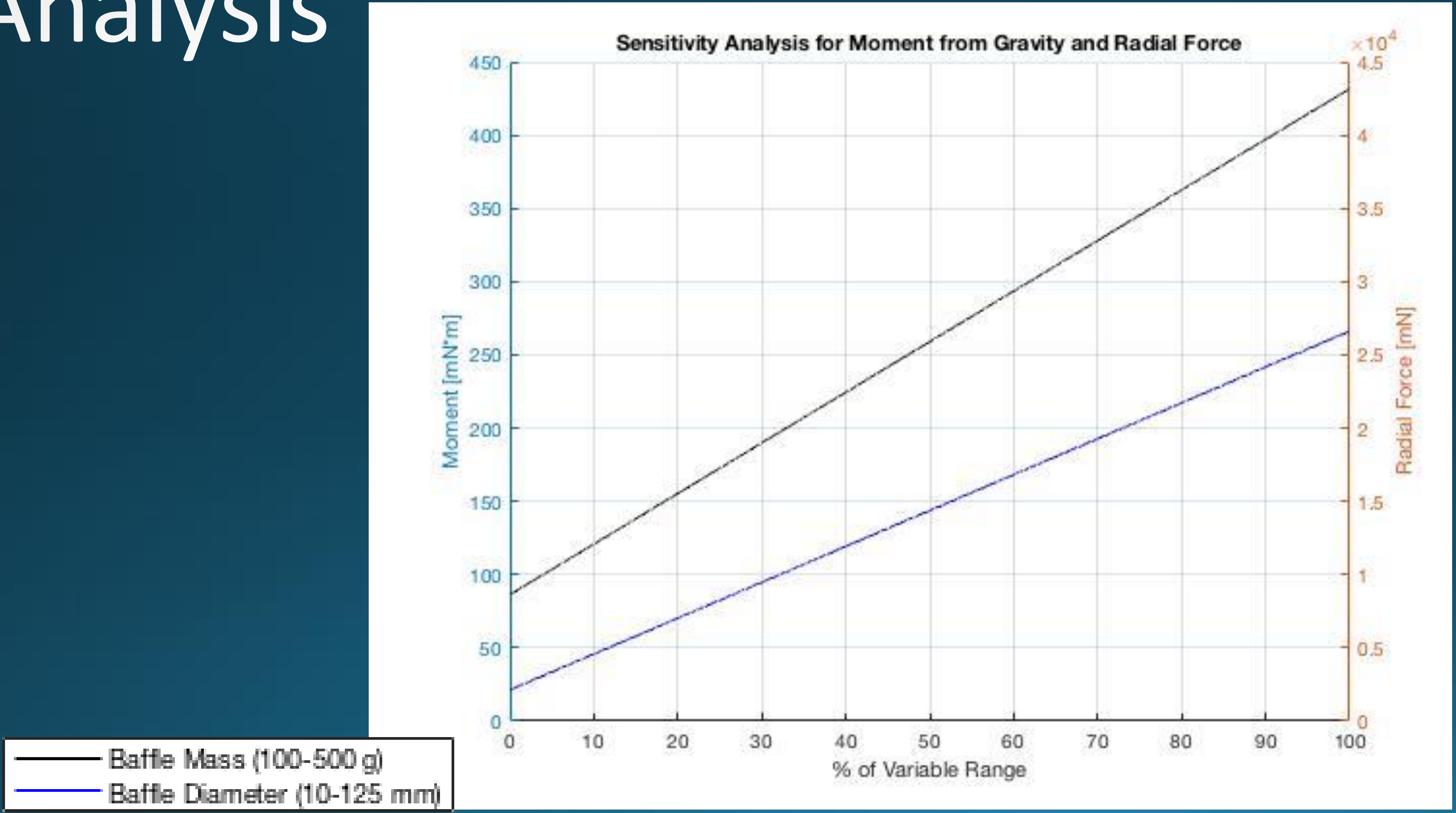
- Only allows motion along the shaft it's sliding along
- Implemented in our design to move with top baffle tier in, supporting the axle and adds reaction moment to whole baffle gravitational moment



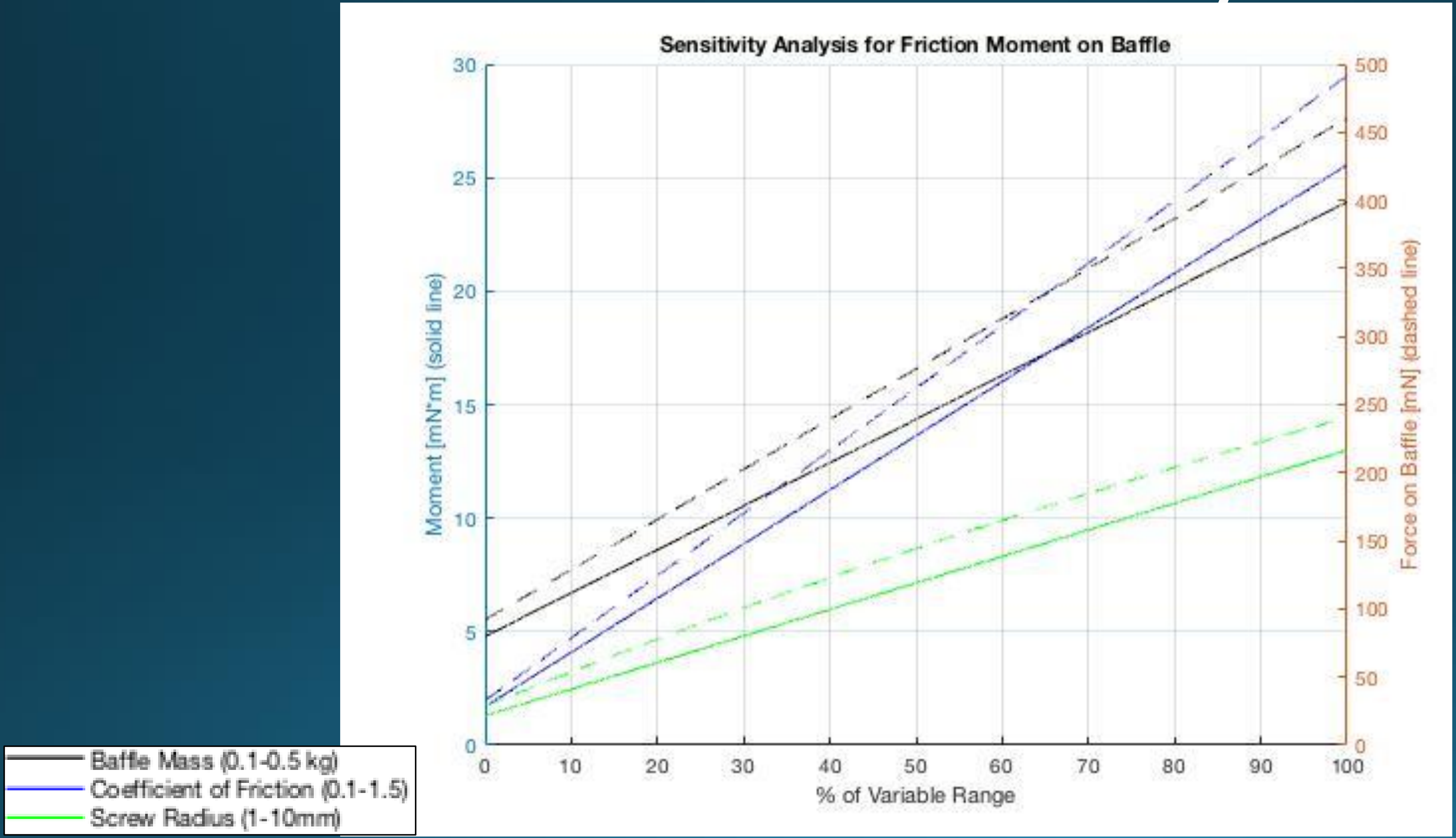
Cantilever Beam Simplification - Sensitivity Analysis



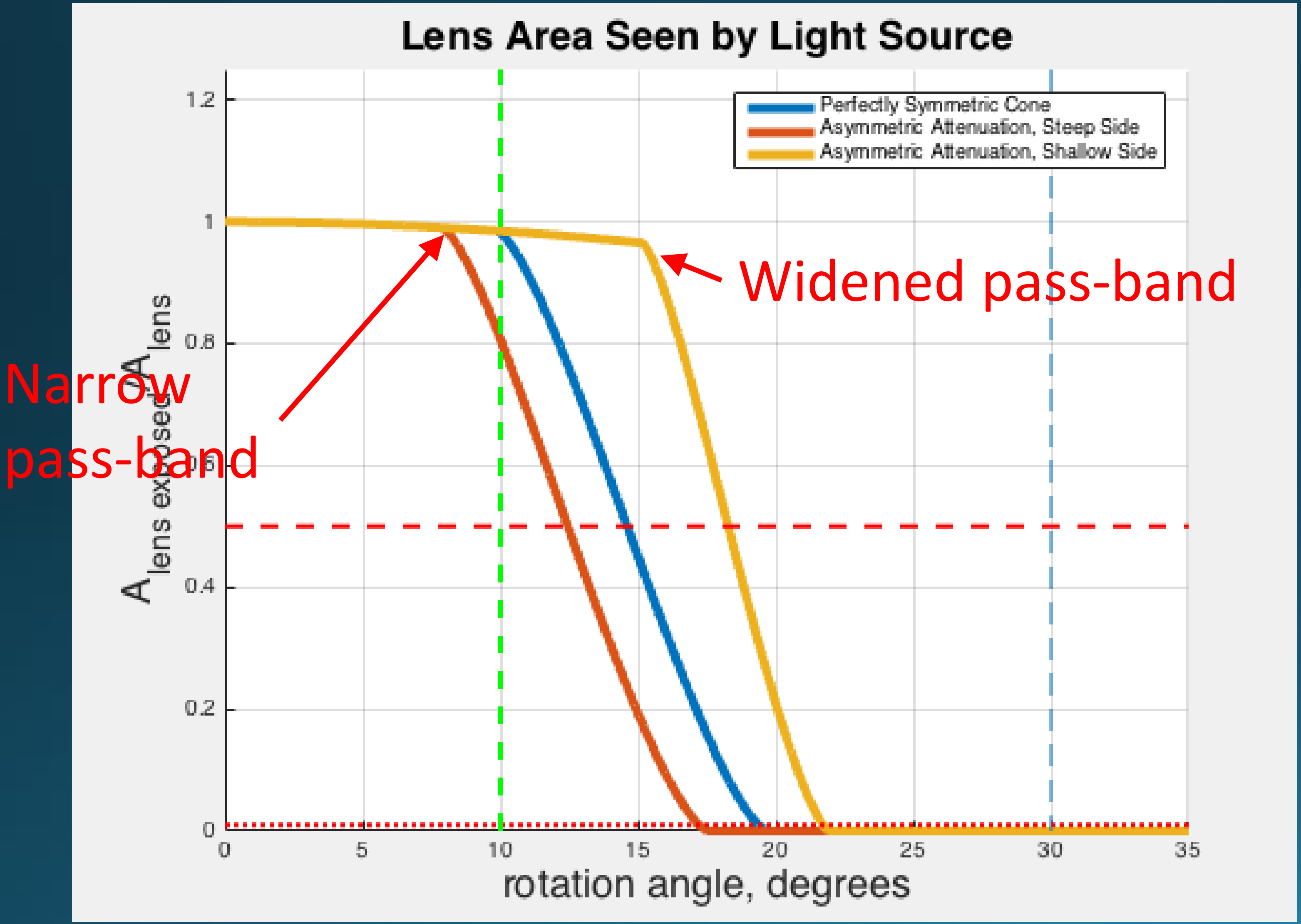
Radial Force on Motor Axle - Sensitivity Analysis



Friction Moment - Sensitivity Analysis



Twisting Baffle Problem – Optical Effects



If left unrestrained:

- Geometric half-angle increases by 50%
- Widened pass-band increases by 50%!

Severity

Likelihood

🟨	🟥	🟥	🟥	🟥
🟩	🟨	🟨	🟥	🟥
🟩	🟩	🟨	🟨	🟥
🟩	🟩	🟩	🟨	🟥
🟩 Exceeding budget limitations, Exposure to bright light	🟩 Insufficient data points in Zemax	🟩 Exposure to aeroglaze, Using dark room	🟩	🟥 Insufficient force to lift baffle, Exceeding radial force limit

Risk Assessment - Mechanical and Electrical

Risk	Description	Mitigation
RP1: Motor failure	Motor failure from exceeding radial force limit resulting in jammed gearbox	Linear bearing placed opposite the motor to counterract radial force from the shaft.
RP2: Insufficient Force	Insufficient Force to lift baffle with power screw resulting in motor bindings burning up. Results in failure.	Verify machining was done within required accuracy by testing the smoothness via torque testing.
RP3: Baffle Deflection	Shifted or Decreased exclusion angle due to baffle deflection	Measure the shifting in tiers when the prototype is turned 90 degrees

Risk Assessment – Machining and Human Safety

Risk	Description	Mitigation
RP4: Tolerances	Baffle, vanes, base plate, motor casing machined outside of calculated tolerances resulting in baffle not deploying properly due to binding	Measure the dimensions of every manufactured part with calpers to ensure they are within required tolerances.
RP5: Exposure to Bright Light	Exposure to bright light causing temporary blindness or eye pain	Determine bright light zone and wear protective glasses while staying clear of light zone
RP6: Exposure to aeroglaze Material	Exposure to aeroglaze material resulting in skin and respiratory inflammation	We already know of the dangers of aeroglaze. Carefully and professionally apply
RP7: Using a Dark Room	Using a dark room resulting in personal injury from bumping into objects in the dark	Determine tripping hazards. Identify location of sharp and sensitive objects in room.

Risk Assessment – Budget and Software

Risk	Description	Mitigation
RP8: Insufficient data points	Insufficient number of data points tested in Zemax simulation of light rays	Check processed data to verify that enough data points have been tested to accurately model sunlight penetration
RP9: Exceeding budget	Exceeding budget limitations and being unable to acquire funds necessary to complete project	Keep a master budget sheet, update it routinely, maintain positive fiscal planning practices and plan space for contingency costs

Mechanical and Electronics Risks

- Risks: 1. Motor failure from exceeding radial force limits. 2. Insufficient force to lift baffle with power screw.
- Consequences: 1. Jammed gearbox. 2. Motor bindings burn up from high motor currents from motor stall. Both require motor replacement and result in non-deployment of baffle.
- Likelihood: 1. 4 out of 5 (validated by preliminary calculations). 2. 2 out of 5. (unexpected friction from imprecise machining).
- Severity: 5 out of 5 for both. Inability to deploy would result in a failed project.

Mechanical and Electronics Mitigation

- Detection: 1. Perform force analysis of free body diagram to determine the expected radial force. Motor testing will be done to determine actual force value at which failure is reached. 2. Torque analysis performed with power screw equation given in PDR. Ammeters placed in series with motor during testing to monitor motor current.
- Mitigation: 1. Linear bearing placed opposite the motor to counterract radial force from the shaft. 2. Verify actual mass of baffle is within limits provided by CAD model. Verify machining was done within required accuracy by testing the smoothness via torque testing.
- Post mitigation likelihood: 1 out of 5 for both
- Post mitigation severity: Still 5 out of 5 for both. Deployment is still integral part of project.

Machining Risks

- Risks: Baffle, vanes, base plate, motor casing machined outside of calculated tolerances.
- Consequences: Baffle will not deploy properly due to binding.
- Likelihood: 2 out of 5. Machining tolerances are within 5/1000 inches. Tolerances for all parts is significantly higher.
- Severity: 4 out of 5. Binding can result in impartial deployment.

Machining Mitigation

- Detection: Measure the dimensions of every manufactured part with calpers to ensure they are within required tolerances.
- Mitigation: Be careful and patient while manufacturing. Be attentive to detail and ensure that no mistakes are made in the process.
- Post mitigation likelihood: 1 out of 5. Very minimal. We have access to very accurate, precise machining tools, as mentioned before
- Post mitigation severity: 3 out of 5. Binding would still result in partial deployment, but to a lesser extent with more finely produced parts.

Budget Risks

- Risks: Exceeding budget limitations and being unable to acquire funds necessary to complete project.
- Consequences: Unable to acquire funds necessary to perform testing or complete physical production of the baffle.
- Likelihood: 1 out of 5. Our current budget forecasts considerable room for contingency costs within the 5000 dollar limit.
- Severity: 1 out of 5. Again. Money is not a concern for us at this point, and if unexpected costs were to arise, we could apply for additional funding.

Budget Mitigation

- Detection: Keep a master budget sheet, update it routinely, maintain positive fiscal planning practices.
- Mitigation: Plan space for contingency costs, thoroughly explore testing and material needs early on to minimize number of unplanned costs arising in future months.
- Post mitigation likelihood: 1 out of 5.
- Post mitigation severity: 1 out of 5.

Software Risks

- Risks: Insufficient number of data points tested in Zemax simulation of light rays.
- Consequences: Inability to validate the baffle ability to deflect stray light.
- Likelihood: 1 out of 5. Zemax is a formidable software tool, capable of performing very accurate sensitivity analyses.
- Severity: 3 out of 5. If we were unable to adequately simulate light penetration and scattering, this could compromise the performance of our baffle and its coating.

Software Mitigation

- Detection: Check processed data to verify that enough data points have been tested to accurately model sunlight penetration the baffle and the sensor.
- Mitigation: Plan enough time to work on coding for Zemax to perform sensitivity analysis with appropriate number of data points.
- Post mitigation likelihood: 1 out of 5.
- Post mitigation severity: 2 out of 5.

Human Safety Risks

- Risks: 1. Exposure to bright light. 2. Exposure to aeroglaze material. 3. Using a dark room.
- Consequences: 1. Temporary blindness or eye pain. 2. Skin and respiratory inflammation. 3. Personal injury from bumping into objects in the dark.
- Likelihood: 1. 3 out of 5. 2. 1 out of 5. Aeroglaze will be professionally applied. Very low chance of exposure. 3. 2 out of 5. Shouldn’t be a major concern.
- Severity: 1 out of 5. 2. 3 out of 5. Aeroglaze is a toxic, hazardous material. 3. 3 out of 5. Human and equipment damage must be considered.

Human Mitigation

- Detection: 1. Clearly determine bright light zone. 2. We already know of the dangers of aeroglaze. 3. Determine tripping hazards. Identify location of sharp and sensitive objects in room.
- Mitigation: 1. Wear protective glasses. Stay clear of light zone. 2. Carefully and professionally apply aeroglaze to baffle. 3. Design a clear test apparatus. Move carefully around the room.
- Post mitigation likelihood: 1 out of 5 for all.
- Post mitigation severity: 1. 1 out of 5. 2. 3 out of 5. 3. 3 out of 5.

Mechanical Risks

- Risks: Baffle deflection.
- Consequences: Shifted or decreased exclusion angle.
- Likelihood: 4 out of 5. Minor mechanical imperfections will ultimately create some shift in exclusion angle
- Severity: 1 out of 5. Not a major issue if there is a marginal change in exclusion angle.

Mechanical Mitigation

- Detection: Measure the shifting in tiers when the prototype is turned 90 degrees (sideways).
- Mitigation: Factor in attenuation tolerances.
- Post mitigation likelihood: 3 out of 5
- Post mitigation severity: 1 out of 5

Zemax Assumptions

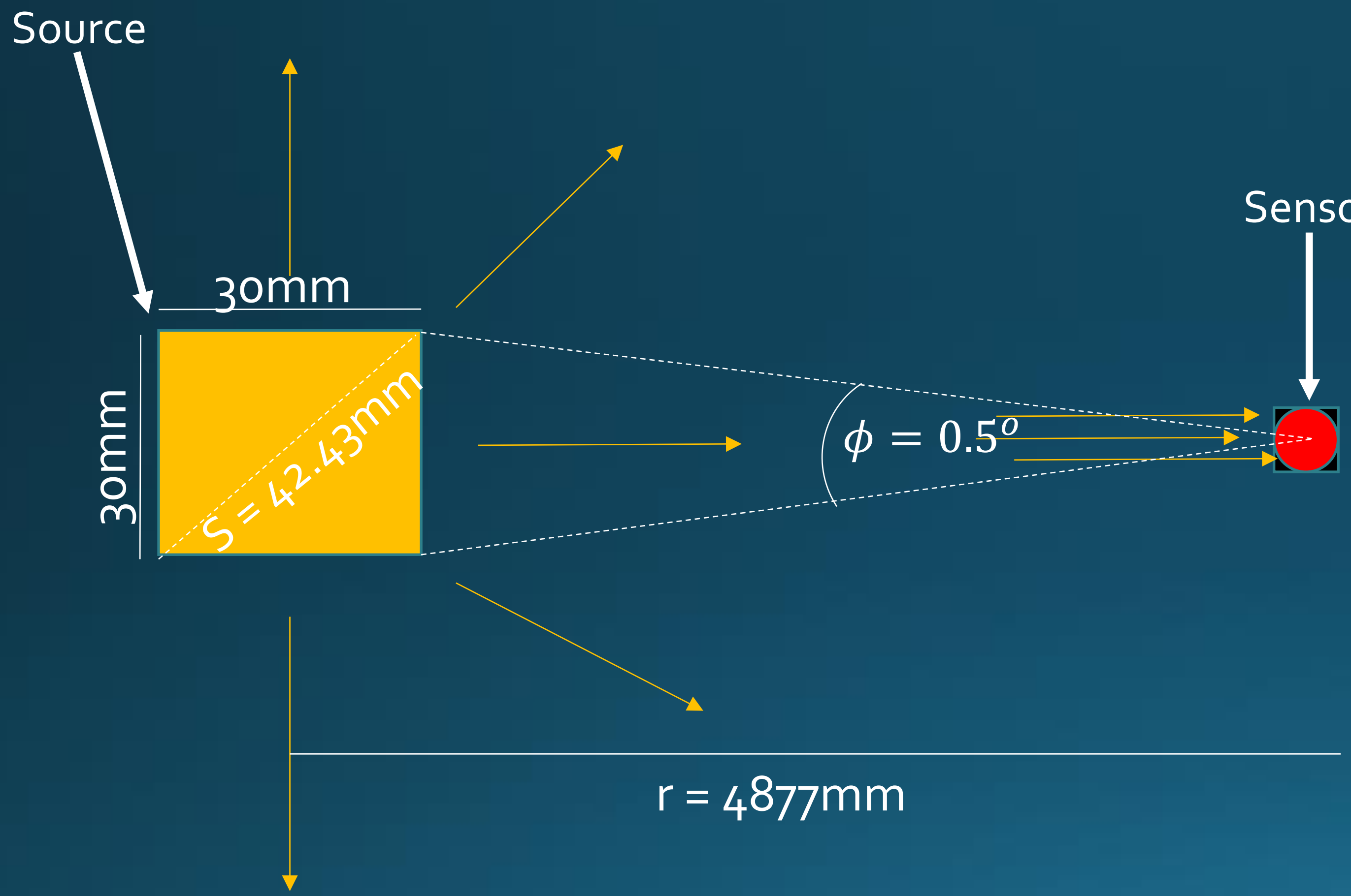
- Completely rigid baffle
  - No cantilever deflection
- Symmetric Baffle
- Tolerances:
  - 99% Baffle deployment (for tier displacement check)
    - 0.88mm between tier 1 and tier 2
  - 1mm between bottom of baffle to sensor
- Coating
  - Lambertian Scattering
    - Ideal diffuse reflection
    - Scattered rays have equal probability of hitting any object on projected plane
    - Scattered intensity varies like $\cos(q_s)$
    - Scattered intensity is independent of incident angle
  - All surfaces of baffle covered in coating

Source Specs

8 by 8 LED’s converted to 1 source

- Total Power: 99 W
- Size: 30mm by 30mm
- Wavelengths: 440-645 nm
- Distance: 4.877 m
- Incident Rays maximum angle: 0.11^o
- Sensor to source FOV: 0.5^o

Source: Sun Size Approximation



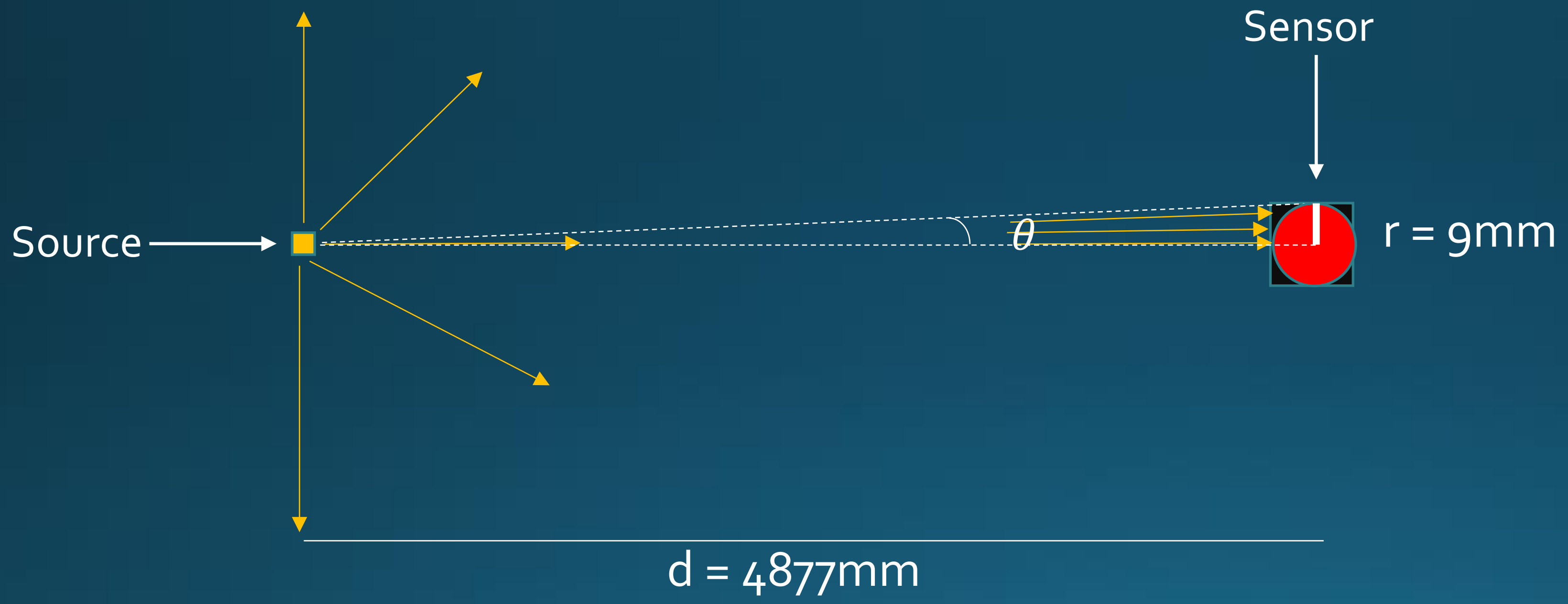
Arc Length Formula

$$r = \frac{S}{\phi}$$

$$r = \frac{42.43mm}{0.0087rad}$$

$$r = 4877\text{mm}$$

Source: Sun Rays Angle Approximation

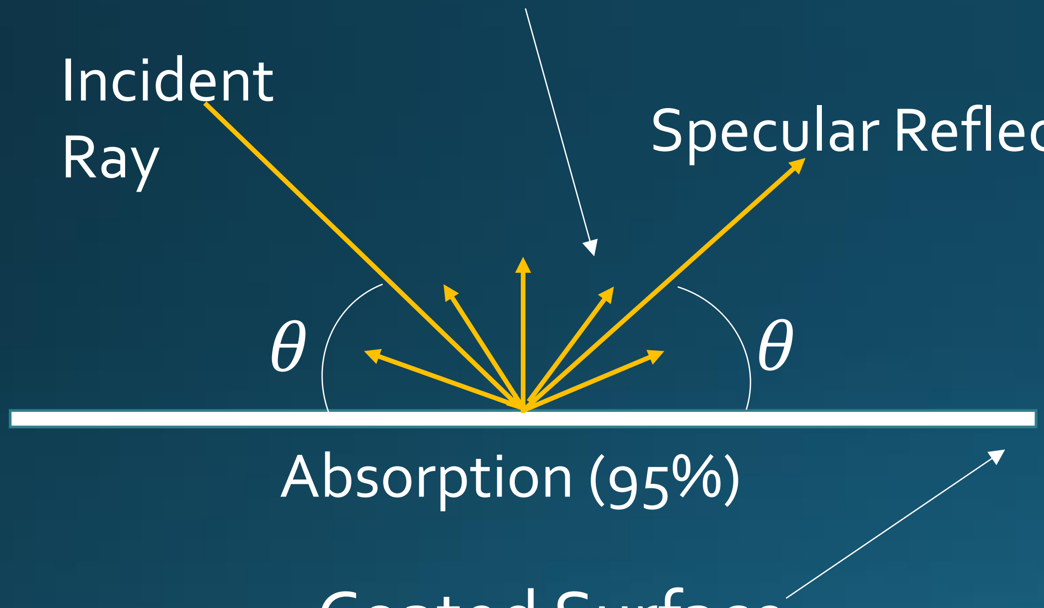


$$\theta = \tan^{-1}\frac{r}{d}$$

$$\theta = \tan^{-1}\frac{9}{4877}$$

$$\theta = 0.11^o$$

Coating



Lambertian Diffuse Reflection-50 Rays (1.6%)

Incident Ray

Specular Reflection (3.4%)

θ θ

Absorption (95%)

Coated Surface

Lambertian Scattering

$$\mathrm{BSDF} = \frac{\rho}{\pi}$$

$$\mathrm{BSDF} = \frac{0.05}{\pi}$$

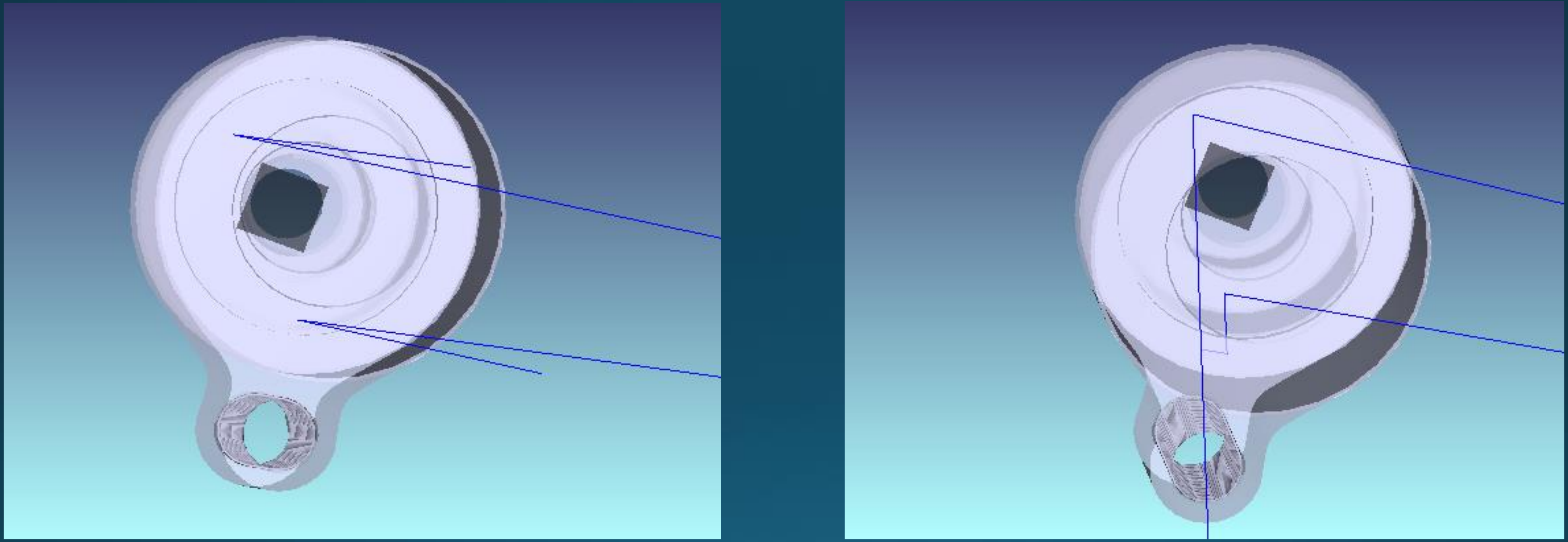
$$\mathrm{BSDF} = 0.016$$

Total Reflection (5%) = ρ

BSDF = Bi-directional Scattering Distribution Function

Light Rays Inside Baffle

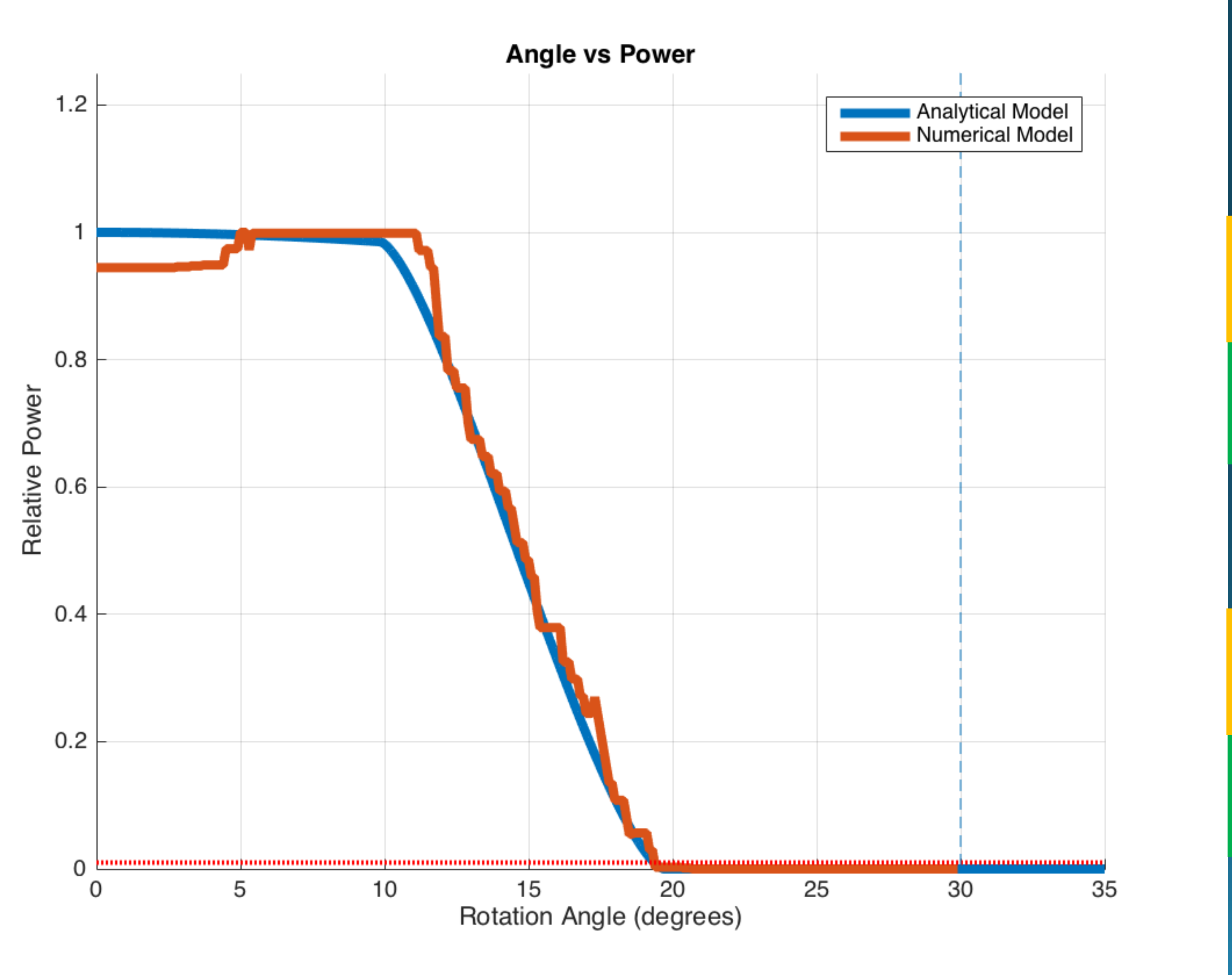
20,000 Rays



Incident Angle of 0°

Incident Angle of 10°

Analytical vs Numerical Model



Numerical Model

Pre-Obscuration Angle = 11.5°

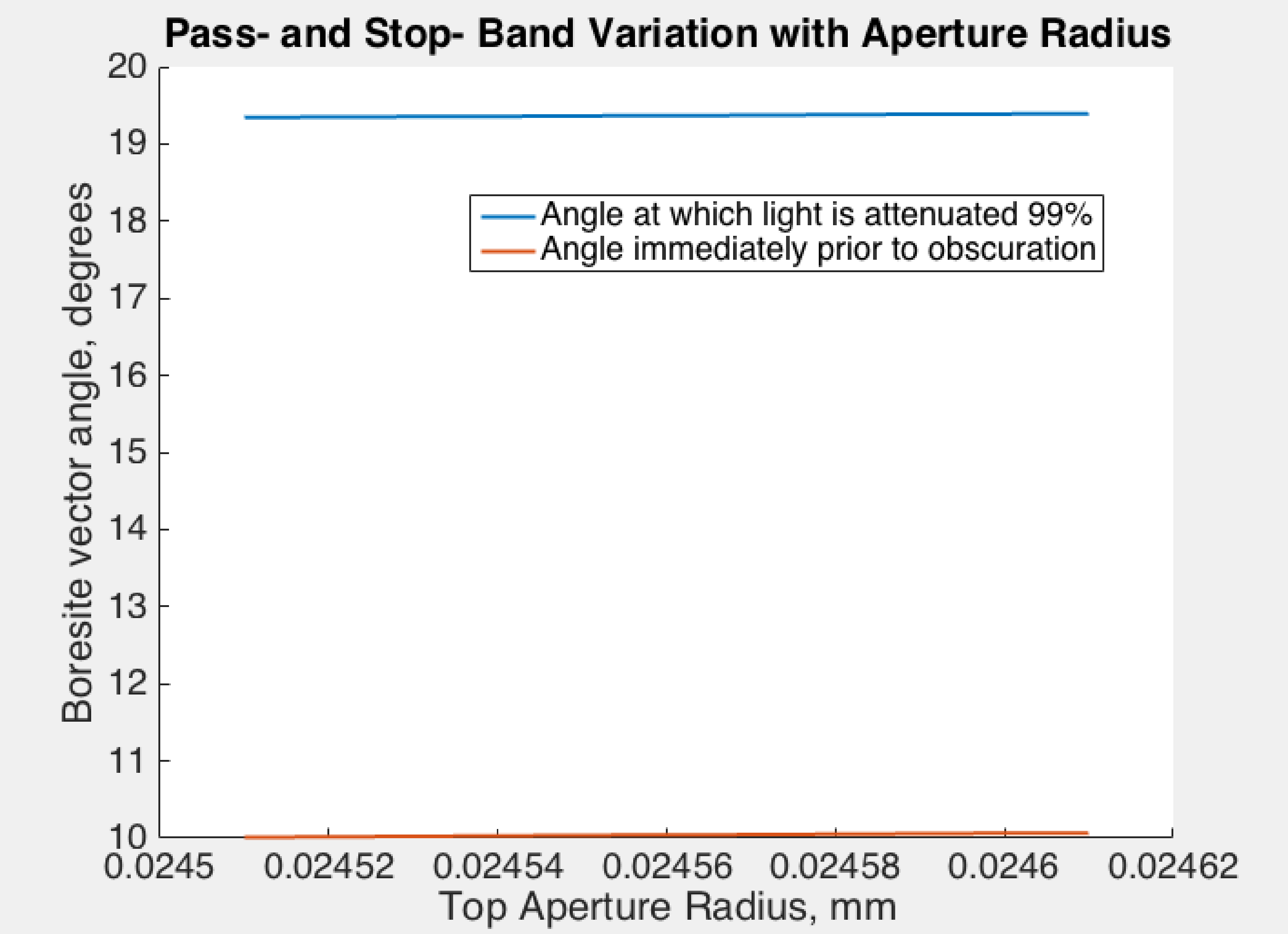
Obscuration Angle = 21.1°

Analytical Model

Pre-Obscuration Angle = 10.0°

Obscuration Angle = 19.4°

Error – Aperture Radius

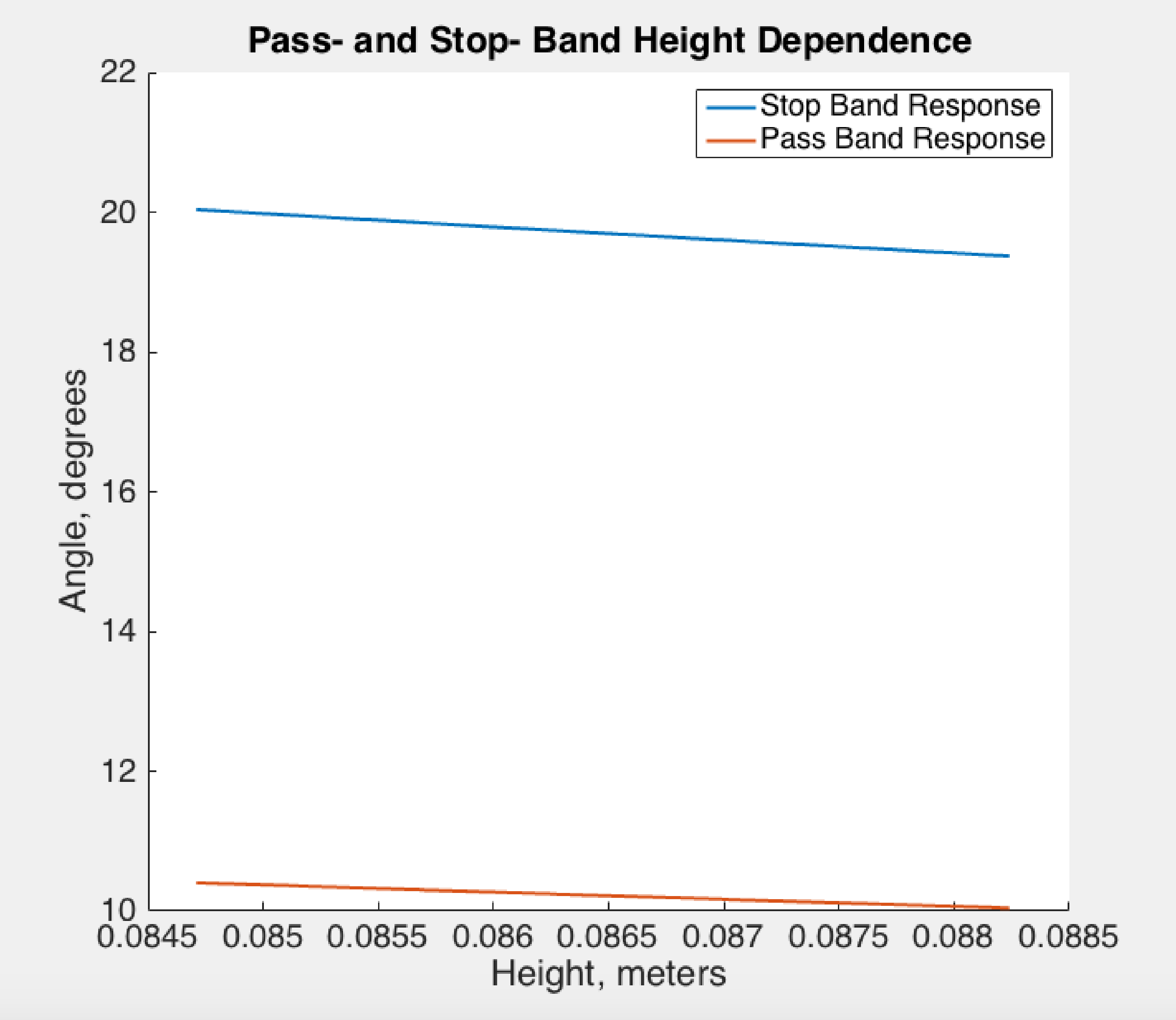


Resolution of the CNC is 0.05mm.

Associated Error:
All aperture radii vary +/- 0.05mm

Band	Change in angle, degrees
Pass-Band	+/- 0.0280
Stop-Band	+/- 0.0280

Error – Partial Deployment



Assume +/- 2% of maximum deployment.

Associated error: deployed baffle height varies 84.7 to 88.25 mm.

Band	Change in angle, degrees
Pass-Band	+/- 0.1820
Stop-Band	+/- 0.3325

Pass-Band

Set the baffle’s half-angle equal to the field of view of the tracker.

"On the Testing and Validation of Stray Light Attenuation for Microsatellite Star Tracker Baffles."

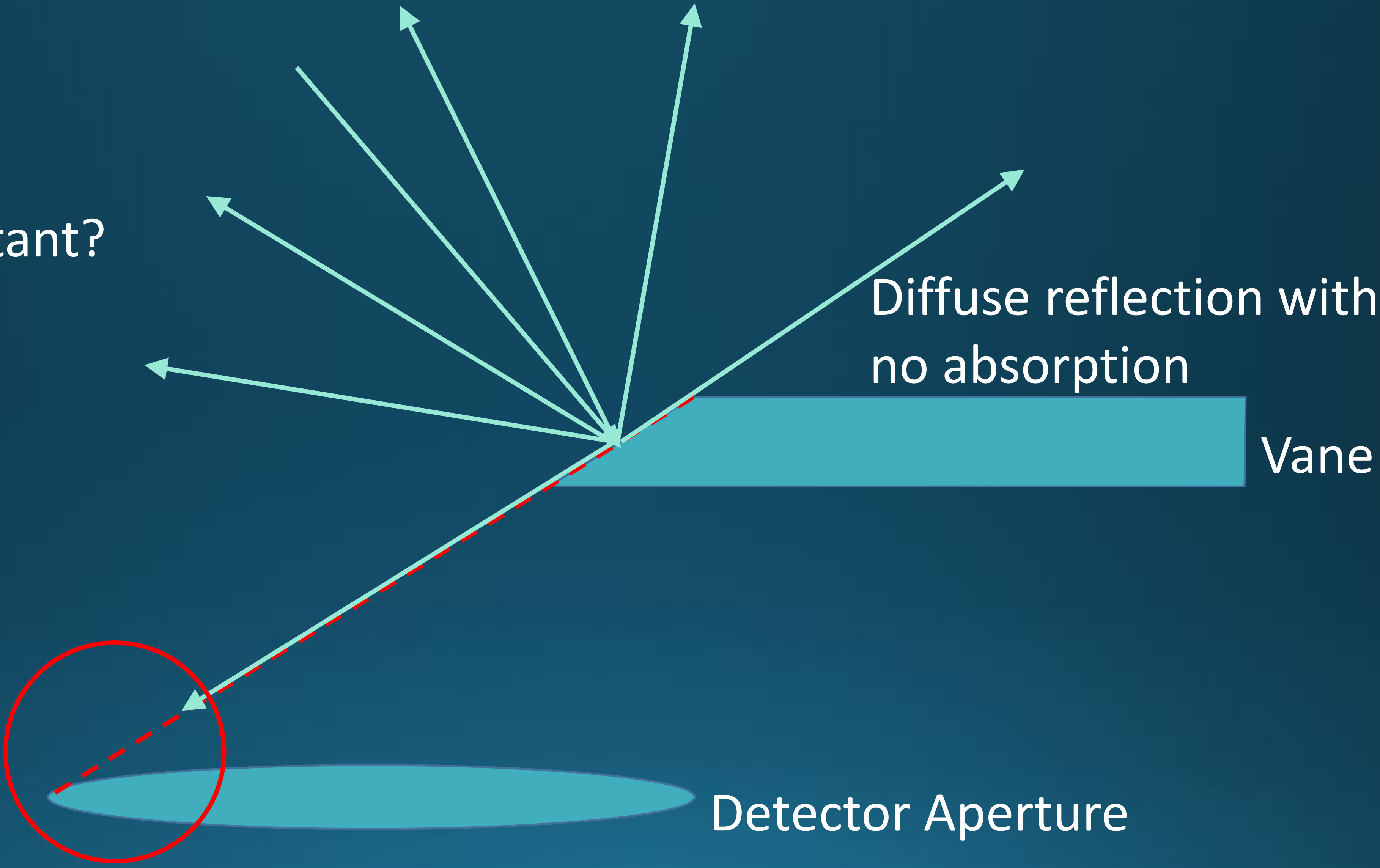
Obscuration Angle Changes

Beyond the obscuration angle of 19 degrees.

- Energy continues to enter the detector through reflections
- Energy from primary *and* secondary reflections shall be attenuated 99.9% at incidence of 30 degrees.

Vane Angle

Why is it important?



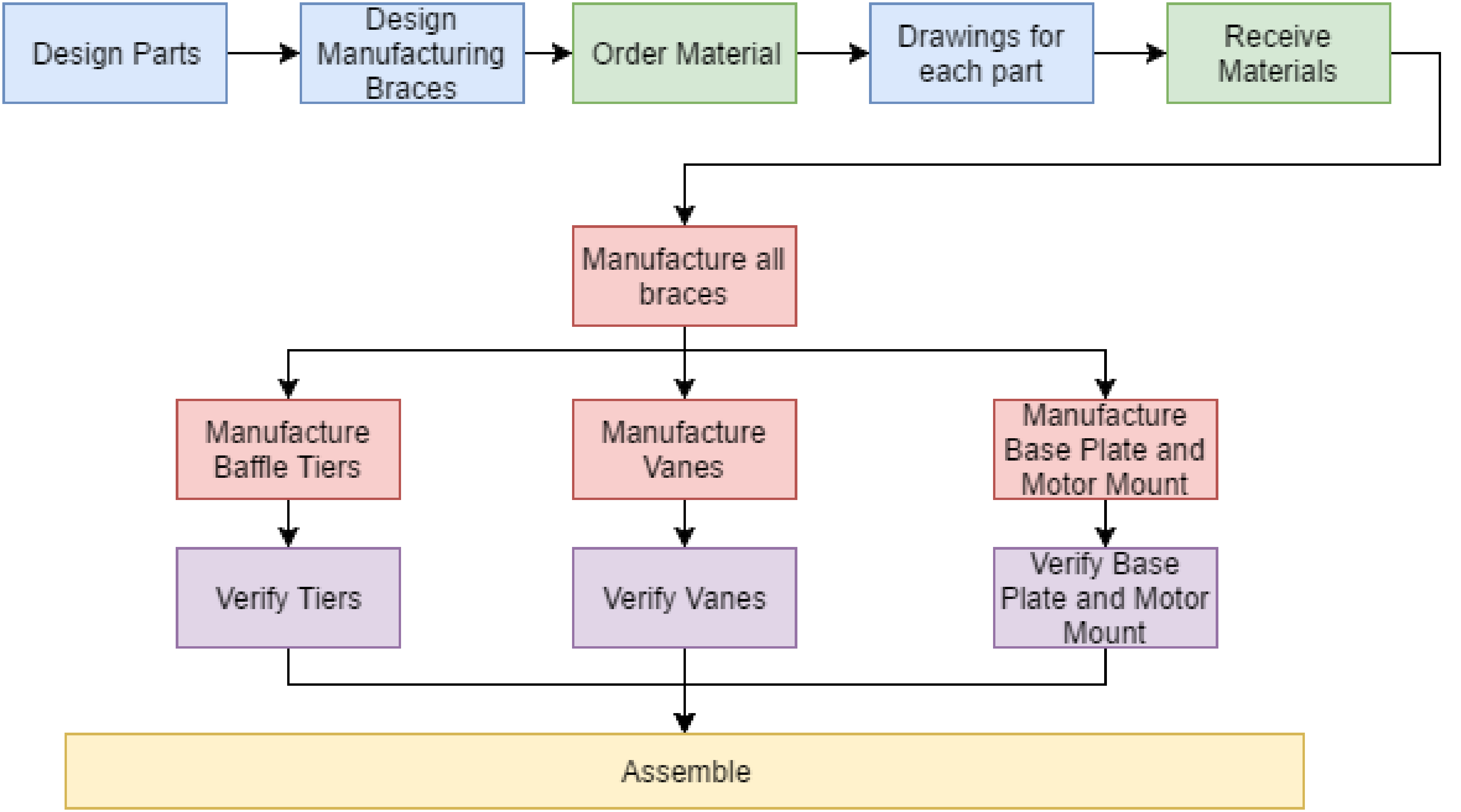
Diffuse reflection with no absorption

Vane

Detector Aperture

Stray light is deflected away!

Manufacturing Flow



Design Parts

Design Manufacturing Braces

Order Material

Drawings for each part

Receive Materials

Manufacture all braces

Manufacture Baffle Tiers

Manufacture Vanes

Manufacture Base Plate and Motor Mount

Verify Tiers

Verify Vanes

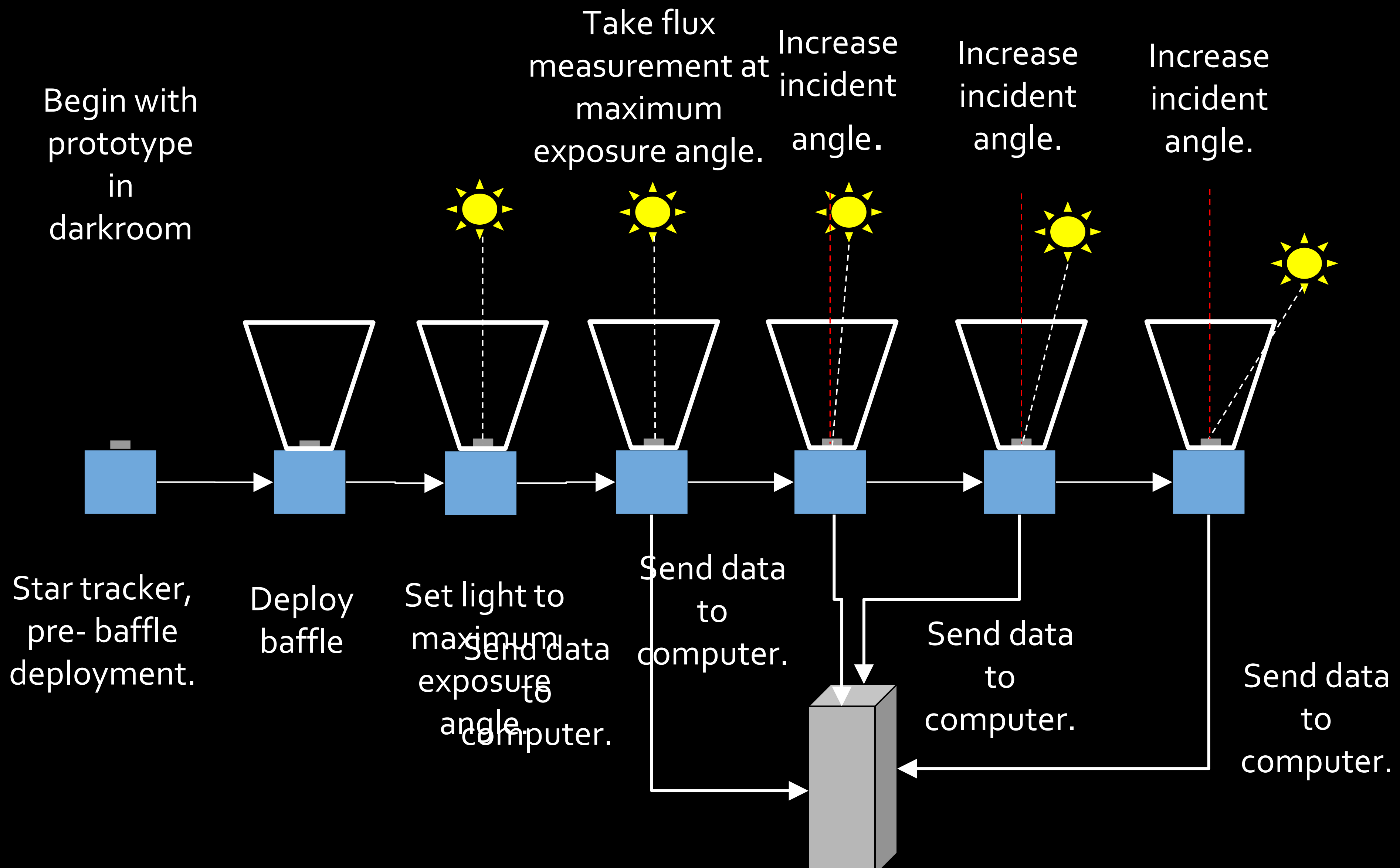
Verify Base Plate and Motor Mount

Assemble

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

Testing CONOPS



Begin with prototype in darkroom

Take flux measurement at maximum exposure angle.

Increase incident angle.

Increase incident angle.

Increase incident angle.

Star tracker, pre- baffle deployment.

Deploy baffle

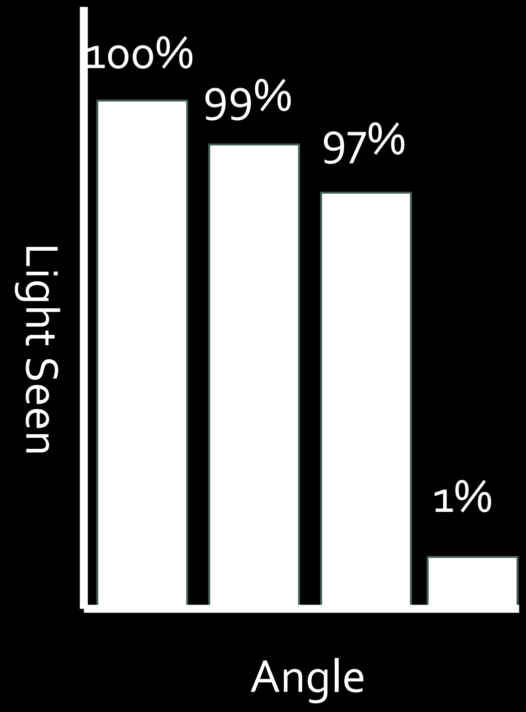
Set light to maximum exposure angle.

Send data to computer.

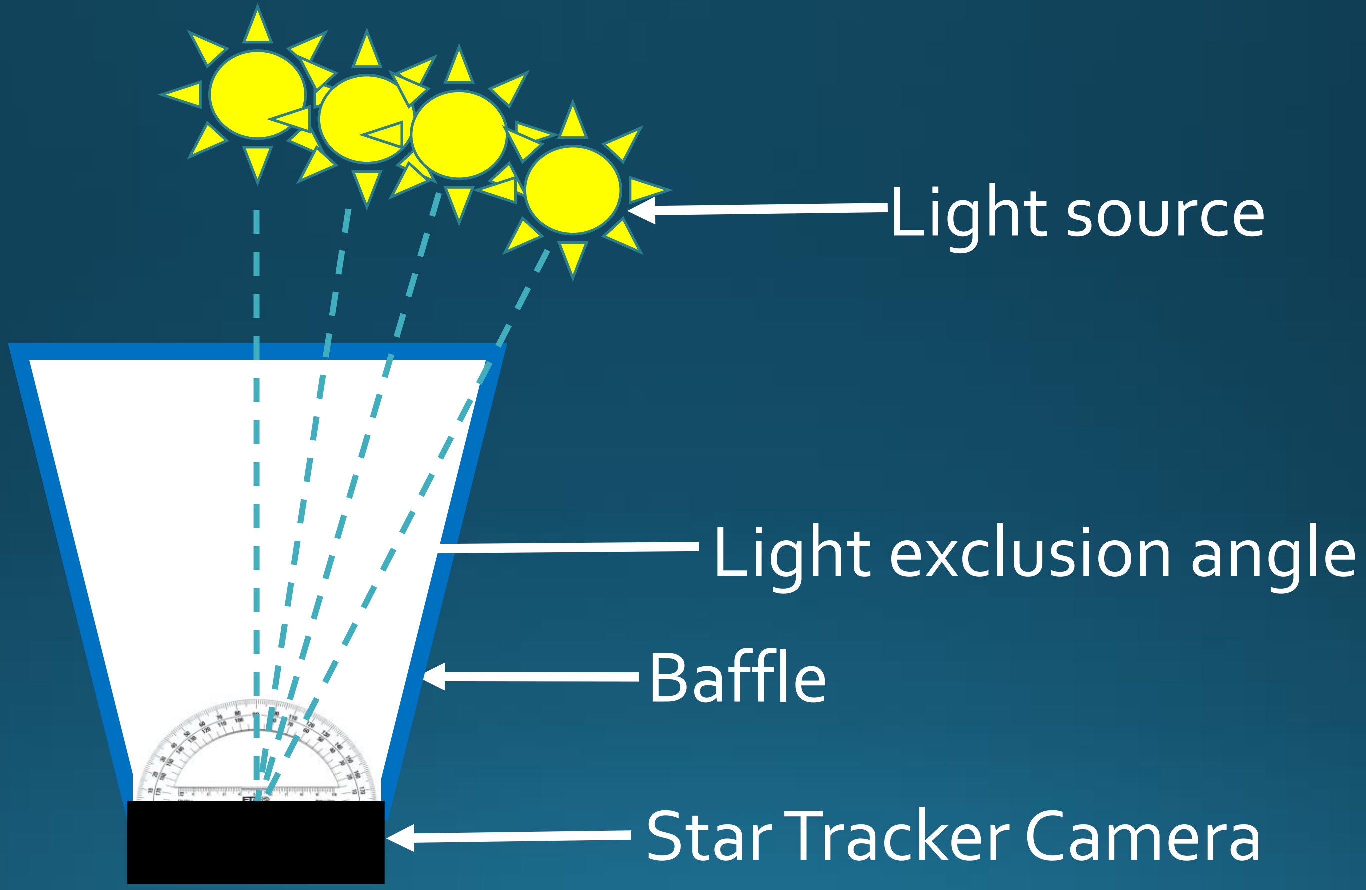
Send data to computer.

Send data to computer.

Send data to computer.



Light Exclusion



Light source

Light exclusion angle

Baffle

Star Tracker Camera