Team A2: UltraLight Final Presentation

July 21st, 2020

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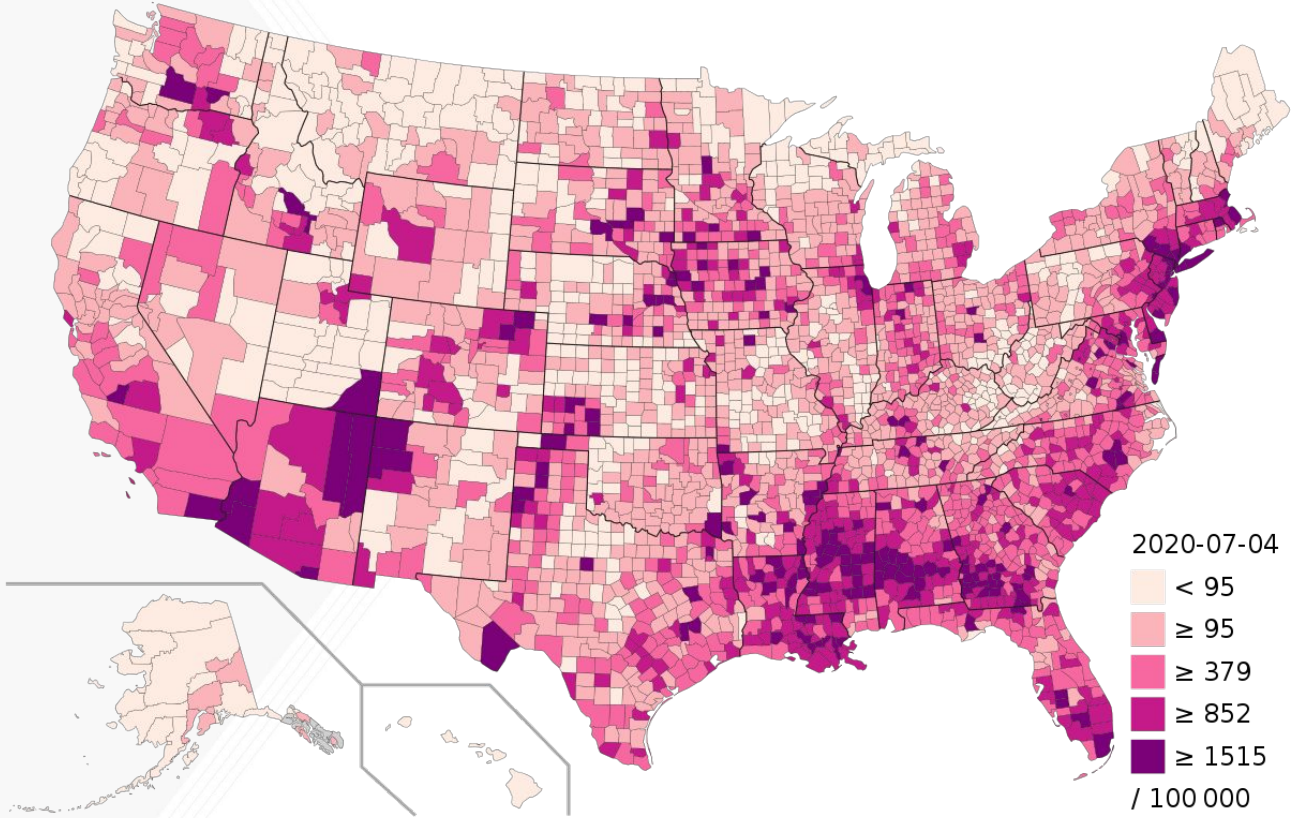
Background

Problem Background



COVID-19 Cases in the United States [2]

~4,000,000 confirmed cases

~140,000 thousand confirmed deaths [1]

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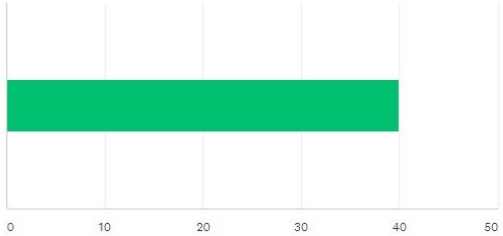
Problem Background

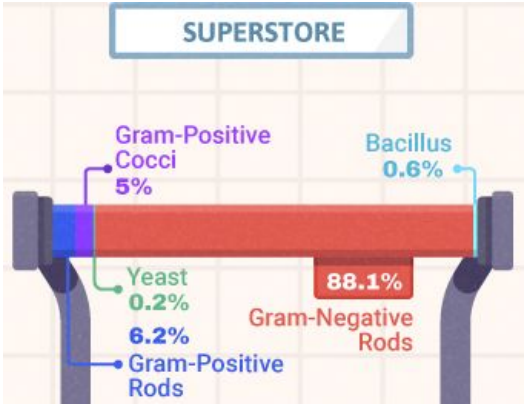
- Shopping carts have been shown to have a **higher bacteria count per square foot than bathroom surfaces**, and may even be home to fecal matter. [3] [4]
- In addition to these bacterial threats, current **pandemic concerns** are changing the shopping experience. [5]

On a scale of 1 to 100, with 1 being dirty and 100 being clean, how clean do you think shopping carts and baskets are ?

Answered: 145 Skipped: 0



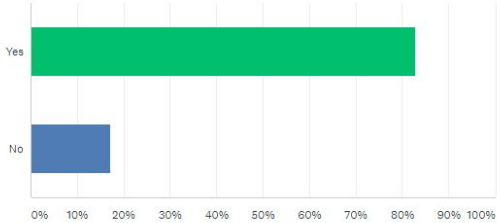
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	40	5,800	145
Total Respondents: 145			



[3]

If a grocery store can implement a system to sanitize shopping carts, would you shop there more often than stores that don't?

Answered: 145 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	82.76%	120
No	17.24%	25
TOTAL		145

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Problem & Customer Needs Statement

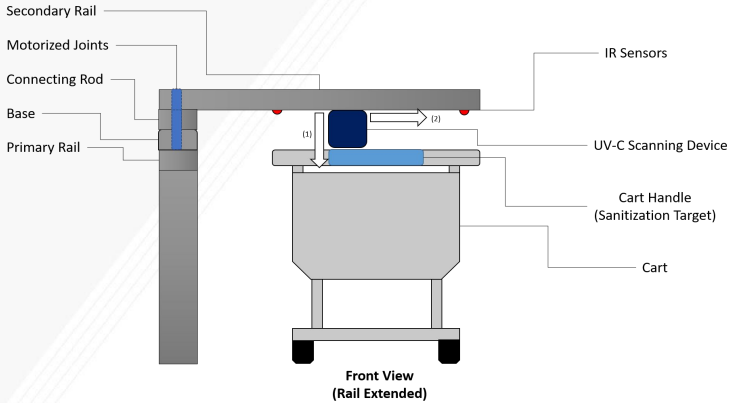
- A way to eliminate bacteria and viruses on **commonly contacted surfaces** becomes critical to ensuring the **welfare** of shoppers and employees, and **operational capacity** of stores. [6]

- To ensure the health of their businesses, retail and grocery stores must be able to **ensure the health of their customers** (the most loyal of whom are often the most vulnerable), **inspire confidence** in their ability to continue operation in a post COVID-19 world, and **do their part** to prevent possible future pandemics. [7] [8]

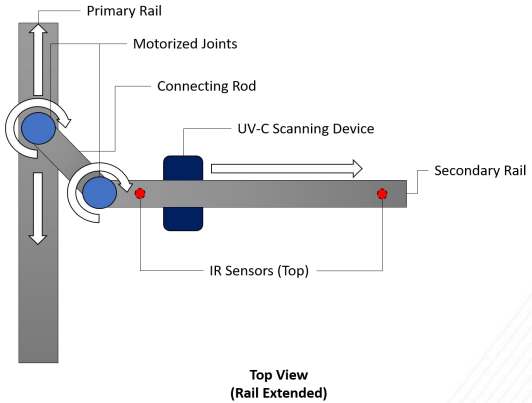
- **GOAL: Reduce pathogen spread within grocery stores by focusing on the disinfection of one of the most commonly contacted surfaces**

Solution: UltraLight Sanitizing System

- UV-C ultraviolet germicidal light for sanitizing cart handles
- System placed in cart return to sanitize stored carts
- Linear actuator system for translation to carts
- Rotational component to allow for deviations in cart orientation
- Ultrasonic sensors for detection of cart handle
- **99.9% disinfection rate in 35 seconds**



Front View
(Rail Extended)



Top View
(Rail Extended)

Preliminary Design

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Solution

UltraLight System Setup

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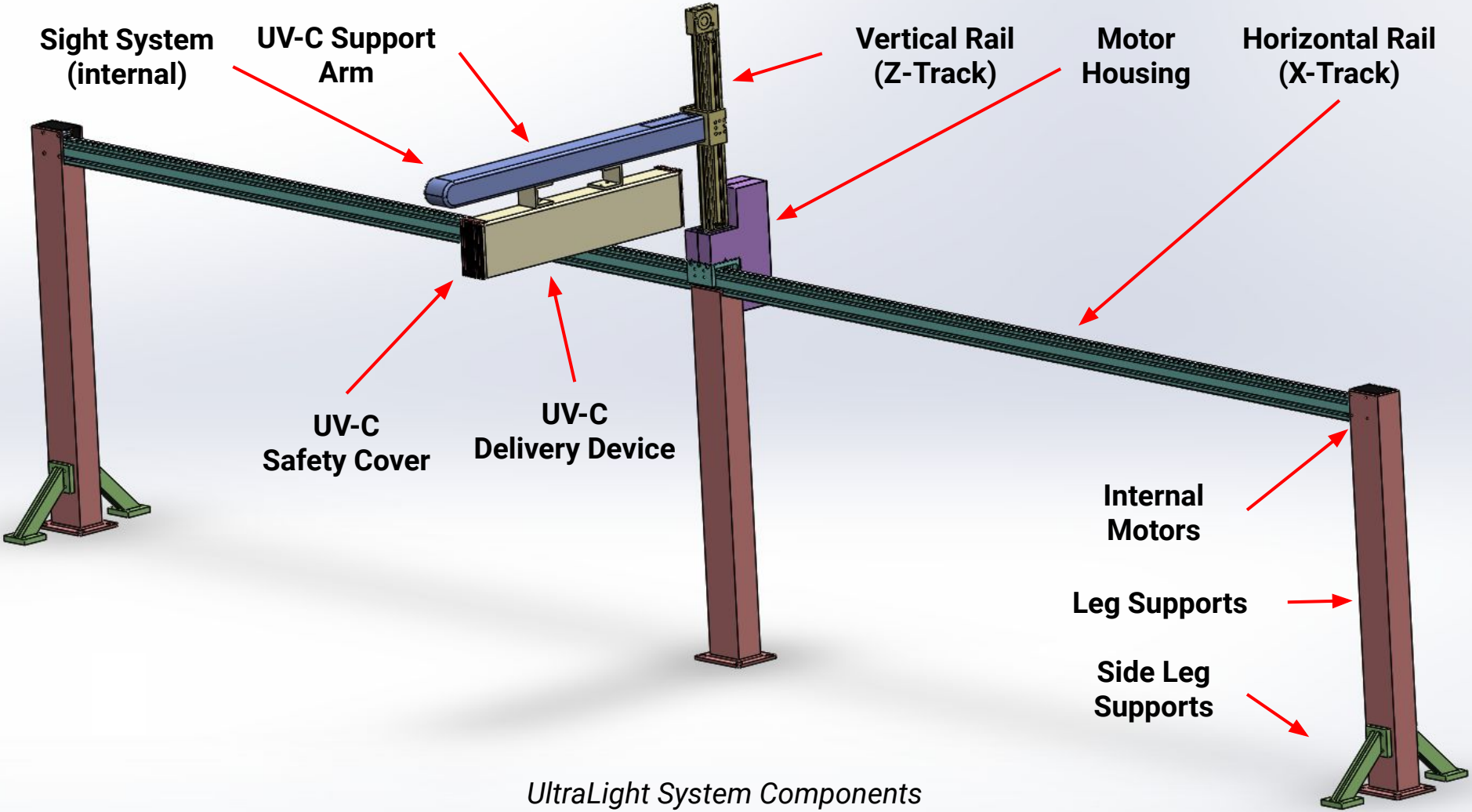
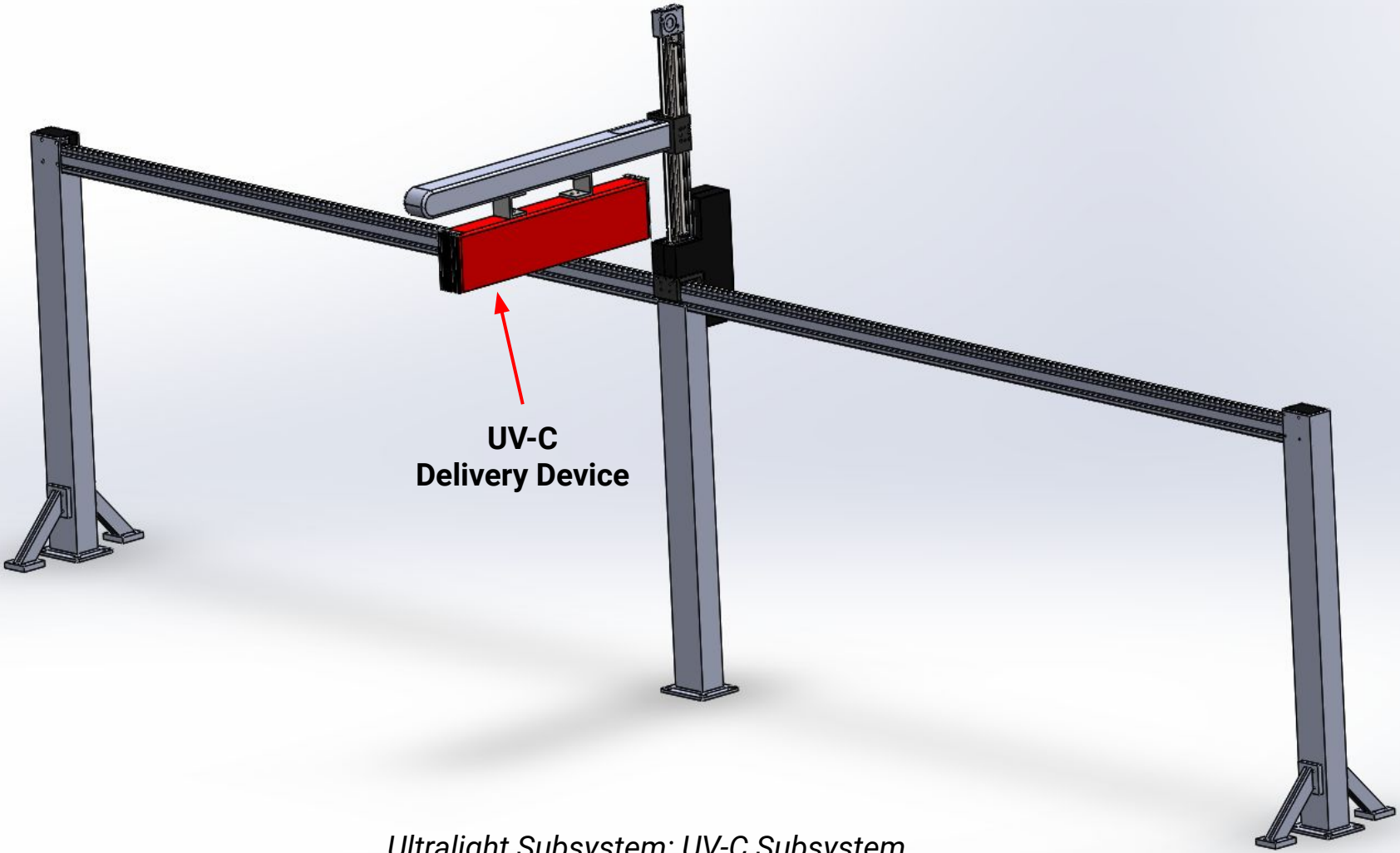


UltraLight System Components

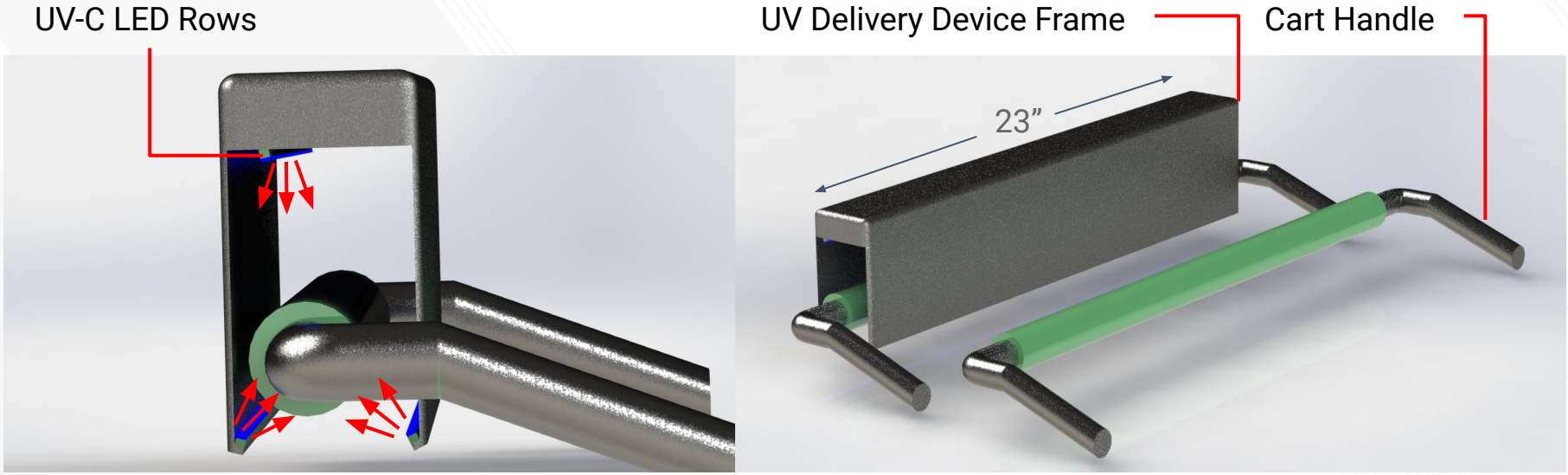
UV-C Subsystem



Ultralight Subsystem: UV-C Subsystem

UV-C Subsystem

- **“Heart”** of the system
- UV-C Delivery Device delivers ultraviolet light to the **entire circumference** of cart handle
- Positioning ensures full surface area application without line of sight from below
- Geometrically optimized operation for various carts (**Walmart, Kroger, Publix, and Sprouts**)



UV-C Subsystem

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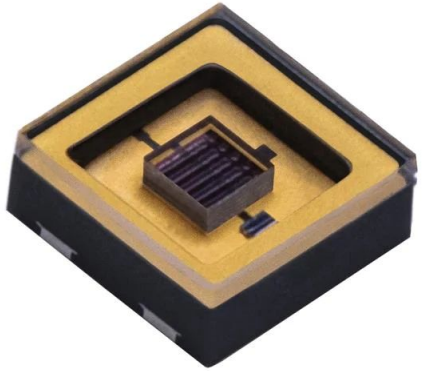
UV-C LED Design Choice

- LED bulbs are more expensive per unit of delivered power than fluorescent bulbs, but have multiple beneficial properties
  - Higher Efficiency
  - Long Lifetime
  - Small Geometry
  - No Warm-Up Time
  - No Cyclical Usage Degradation

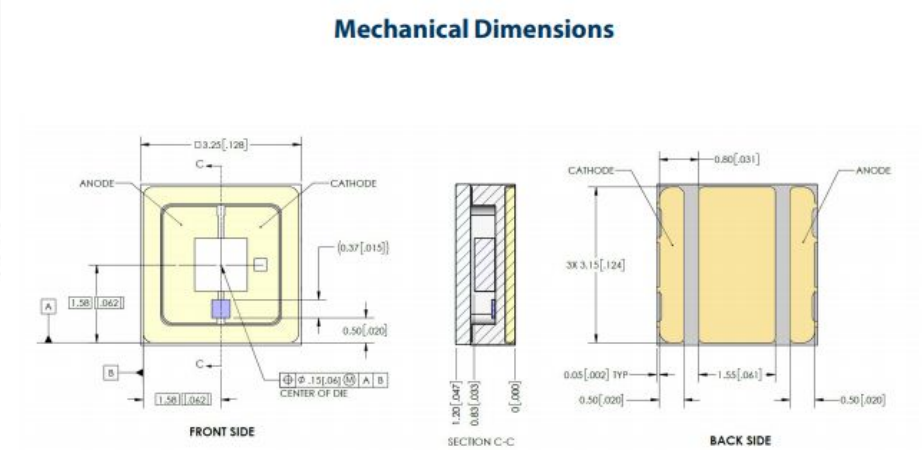
- **Benefit: Smaller, More Powerful Lights**



UV-C LED Illustration

UV-C LED Design Choice

- LED Choice: Luminous XBT-3535-UV Surface Mount UVC LED [9]
  - Broke price barrier at **$0.10/mW**, for lowest cost on market [10]
  - UV-C power: **80 mW**
  - Size: 3.5 mm x 3.5 mm x 1.2 mm
  - Viewing Angle: 130°



Luminous XBT-3535-UV Dimensions

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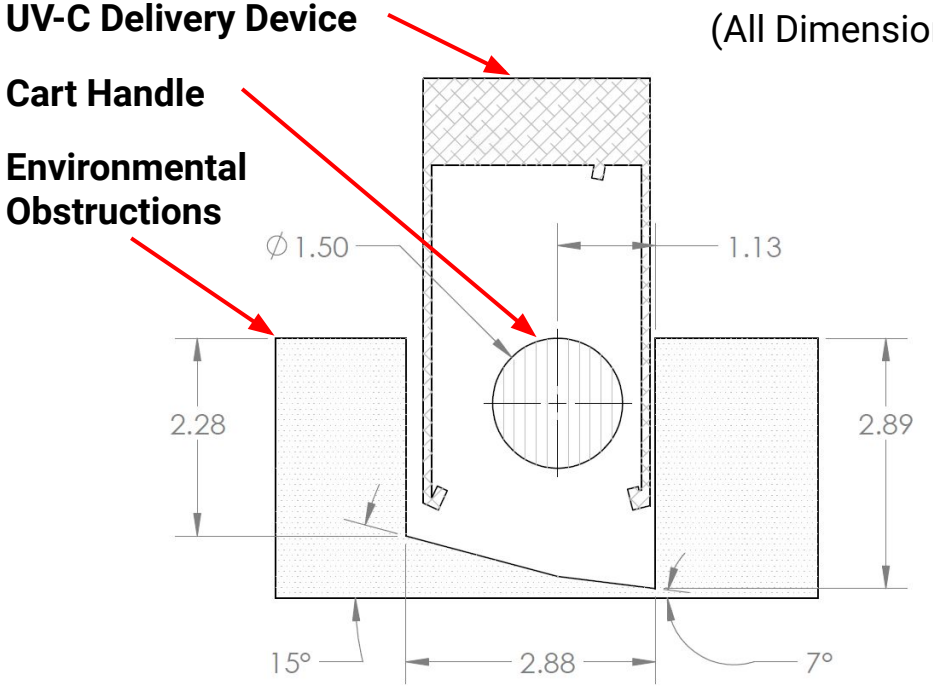
UV-C Delivery Device

- Design Parameters:
  - Triangular configuration for least number of rows of LEDs to deliver UV-C light to the **entire circumference** of the cart handle
  - Fits within gap provided, with clearance of **±0.06 inches** both vertically and horizontally to account for the linear actuator resolution
  - Bottom light rows oriented so that 130° view factor is contributing only to the cart handle, and **not visible from ground**

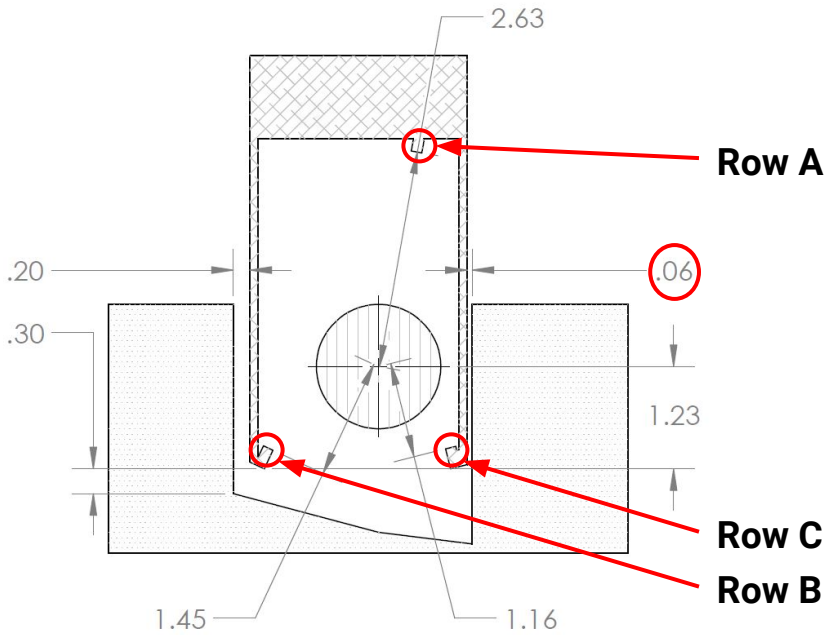
- Optimized using SOLIDWORKS **geometric constraints** to achieve fully defined parameters

UV-C Delivery Device

(All Dimensions in Inches)



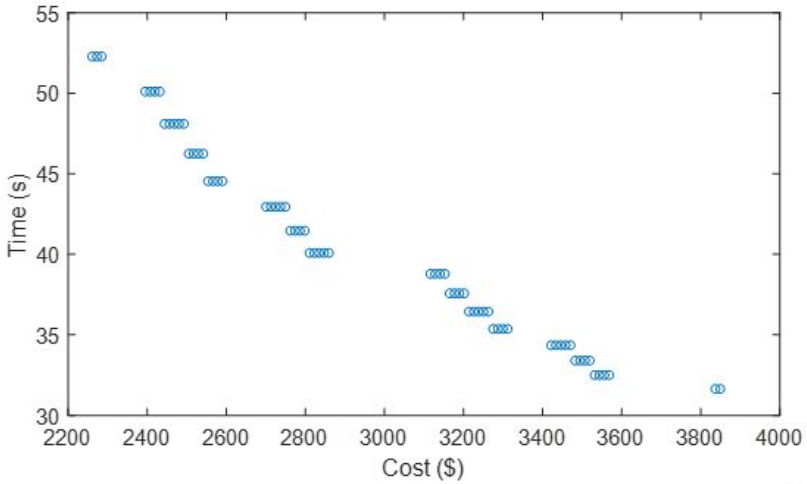
Cross Section: Spatial Envelope



Cross Section: Distances & Tolerances

LED Optimization

- Developed an algorithm to optimize disinfection time to deliver irradiance using the **Inverse Square Law**
  - **35 s @ $3,837.08**
  - **95 mJ/cm²** for 99.9% disinfection rate [11]
  - Allowable handle diameters: **0.75” to 1.5”**
  - Allowing for rate of **10% degradation** in LED power output



Disinfection Time per Handle vs. Cost of UV-C LEDs

- Total LEDS: 314
  - Row A: 164 LEDs
  - Row B: 90 LEDs
  - Row C: 60 LEDs

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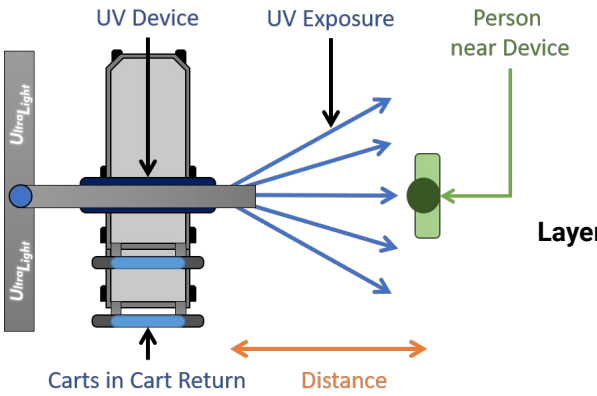
LED Optimization

- **Assumptions:**
  - Inverse Square Law valid for light source **(distance dependent)**
  - Maximum number of LEDs on furthest row for **minimum time**
- **Calculations:**
  - Calculated **time for LED row at maximum distance** to achieve 95 mJ/cm² on the cart handle surface
  - Calculated **equivalent power** (number of evenly spaced LEDs) to achieve the same time value for other rows, at varying distances
- **Considerations:**
  - Allowed for maximum distance of 1.5” inches, minimum distance of 0.75”, to account for **range of diameters** needed
  - Allowed for **degradation** of power output, subject to change across the lifetime of the bulb

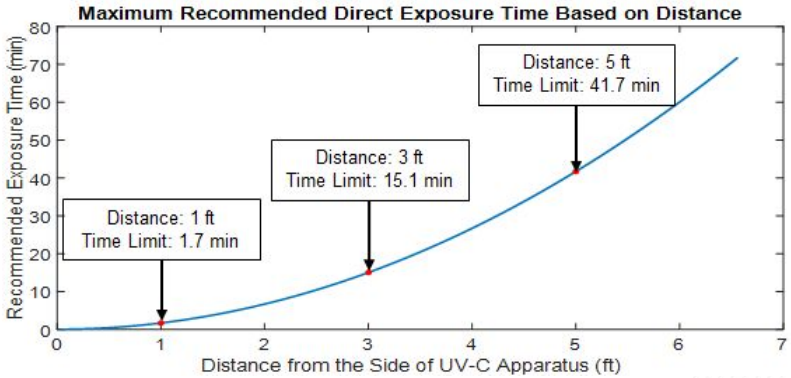
UV-C Safety

- Referenced CDC and ASHRAE guidelines on safe UV-C exposure [12]
- Designed **safety cover** for sides of UV-C delivery device **to limit exposure**
- Experimental data required to gage safety cover **effectiveness**
- Evaluated exposure times from Row B and C for **“worst-case” scenario**, without safety cover



Visual Representation of Exposure

Side of Delivery Device with Safety Cover



“Worst-Case” Direct Exposure Limits

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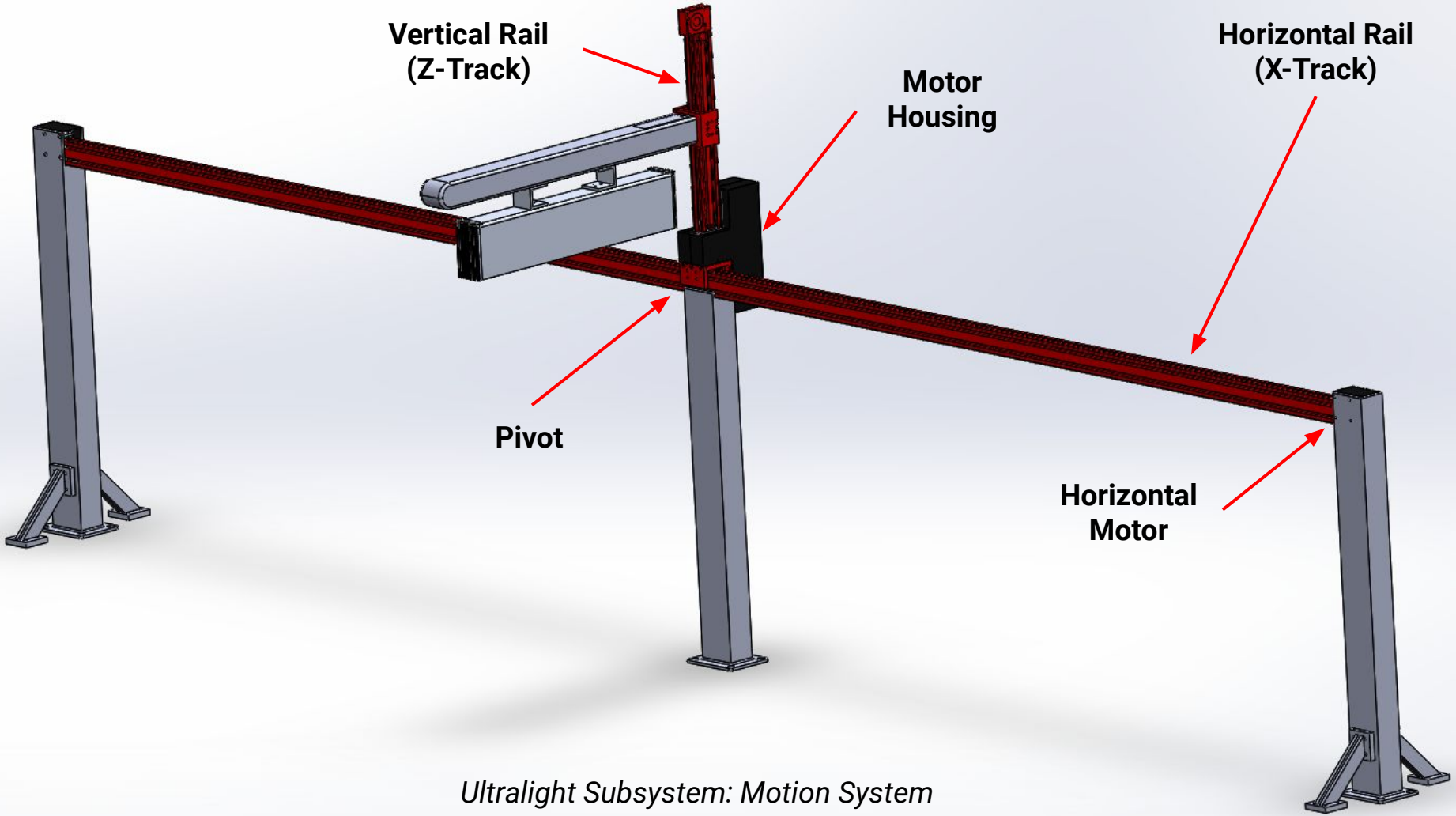
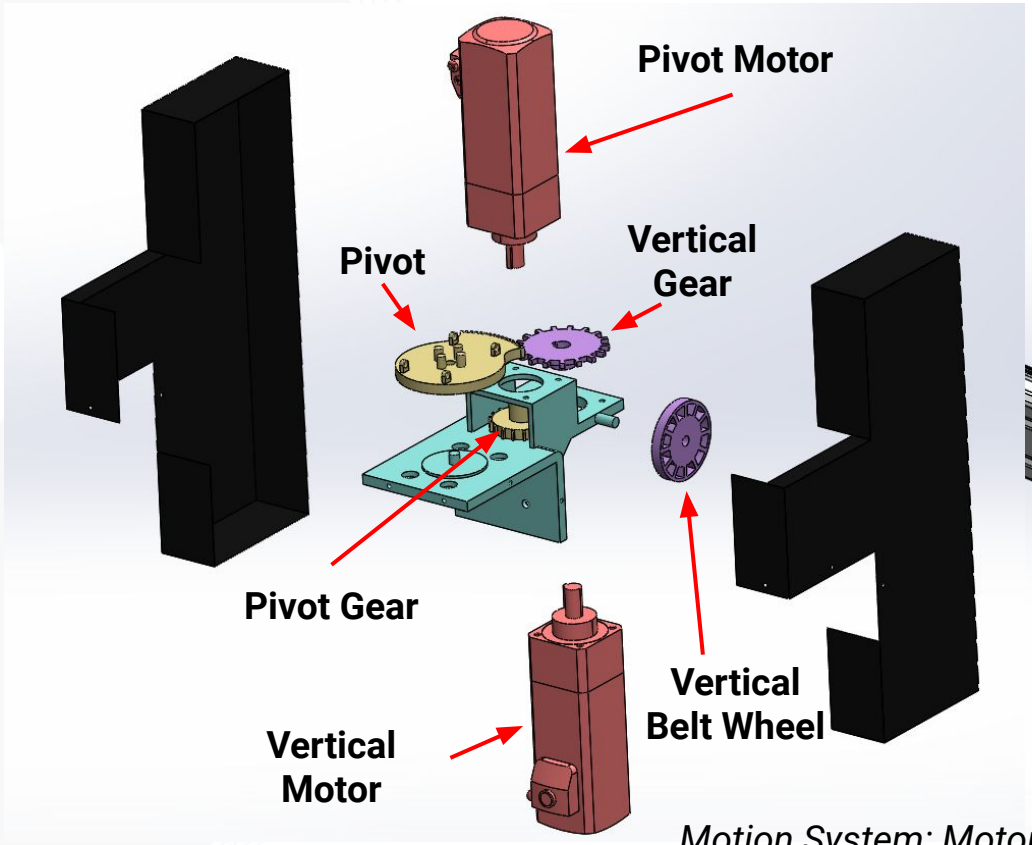
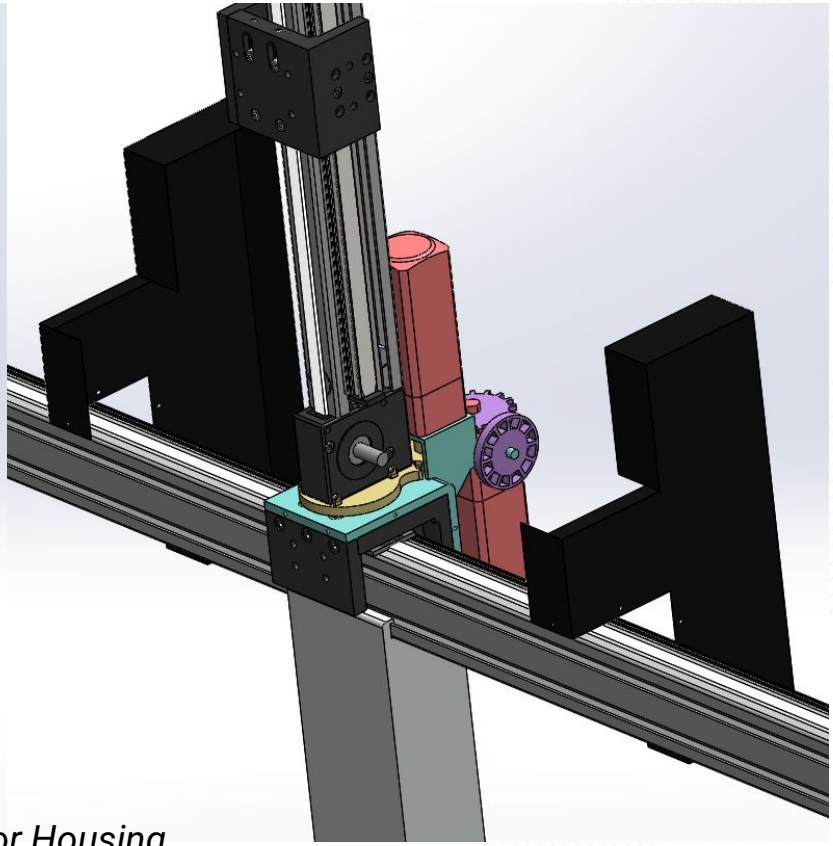
Motion System



Ultralight Subsystem: Motion System

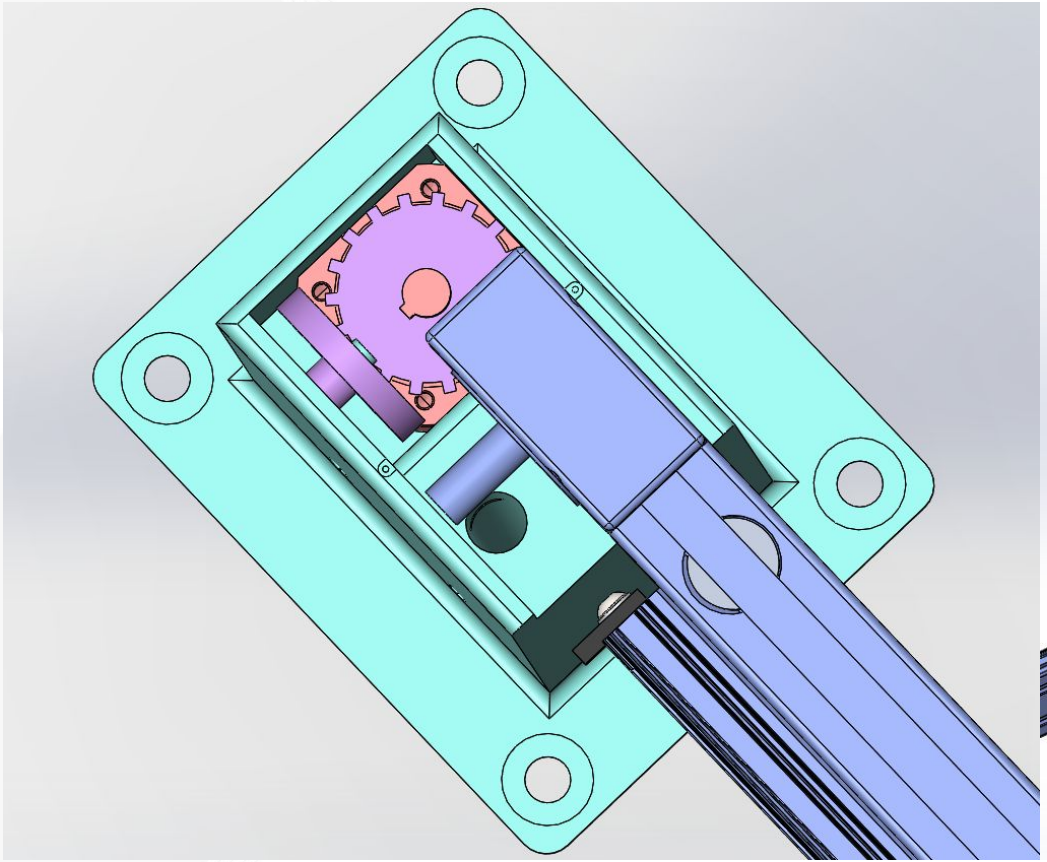
Motor Housing

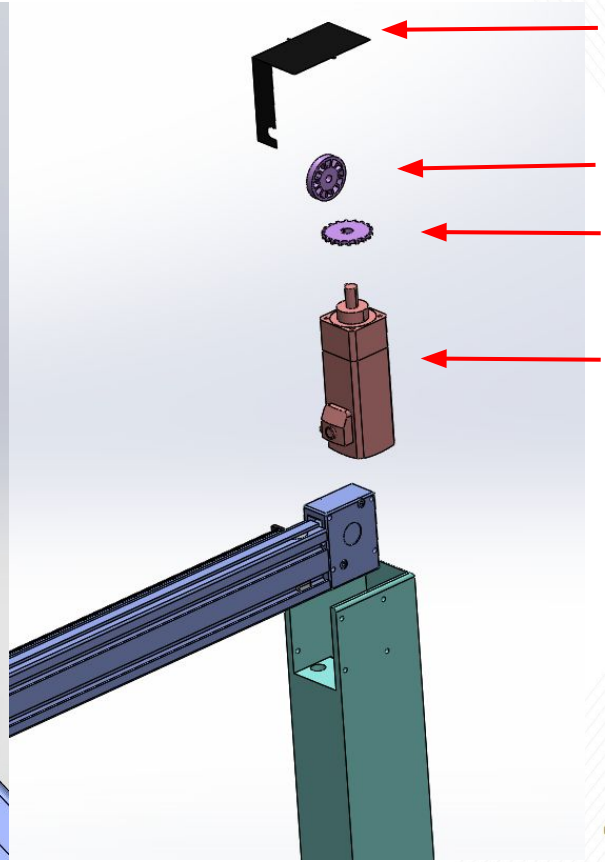




Motion System: Motor Housing

Horizontal Motor



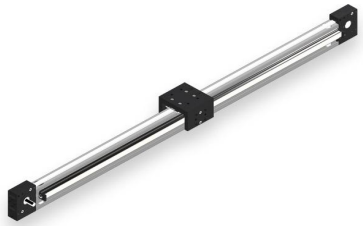


Motion System

- **“Muscles” of the system**
- Allow the UV-C delivery device to **move to the cart handles**
- Motors drive the vertical and horizontal rails to position the UV-C device
- Pivot allows the UV-C device to rotate and **accurately orient** itself over cart handle before dropping

Oriental Motor ARM46AC-PS25

[13]



Macron Dynamics Inc.: MSA-R15 Actuator

[14]

Oriental Motor ARM66AC-N25

[15]

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Motion System

- **Macron Dynamics** MSA-R15 Actuator chosen for both **vertical** and **horizontal** rails.
- Resolution of 0.4 mm/m
- Customizable rail lengths to account for variations

Macron Dynamics Inc.: MSA-R15 Actuator

Specifications

Motion	**Horizontal or Vertical**
Max Speed – horizontal [vertical] – mm/sec	**5000 [5000]**
Max Load – horizontal [vertical] – lbs.	**50 [25]**
Repeatability – mm	**+/- 0.025**
Moment Load Max – in.-lbs. [Nm]	**310 [35]**
Positional Accuracy – mm/meter	**+/- 0.4**
Acceleration max – G's	**20**
Ultimate tensile strength of belt – lbs. [N]	**800 [3559]**
Recommended belt running load – lbs. [N]	**200 [889]**
Cart Guide	**Linear bearing with profile rail**

[14]

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Motion System

Horizontal Rail and Pivot

ARM46AC-PS25, 1.65 in. Closed Loop Stepper Motor

- Required **torque** of 1.5 Nm
- **Resolution**: 0.0144 °/Pulse
- Stop Position **Accuracy**: ±4 arc minutes (±0.067°)

Oriental Motor ARM46AC-PS25

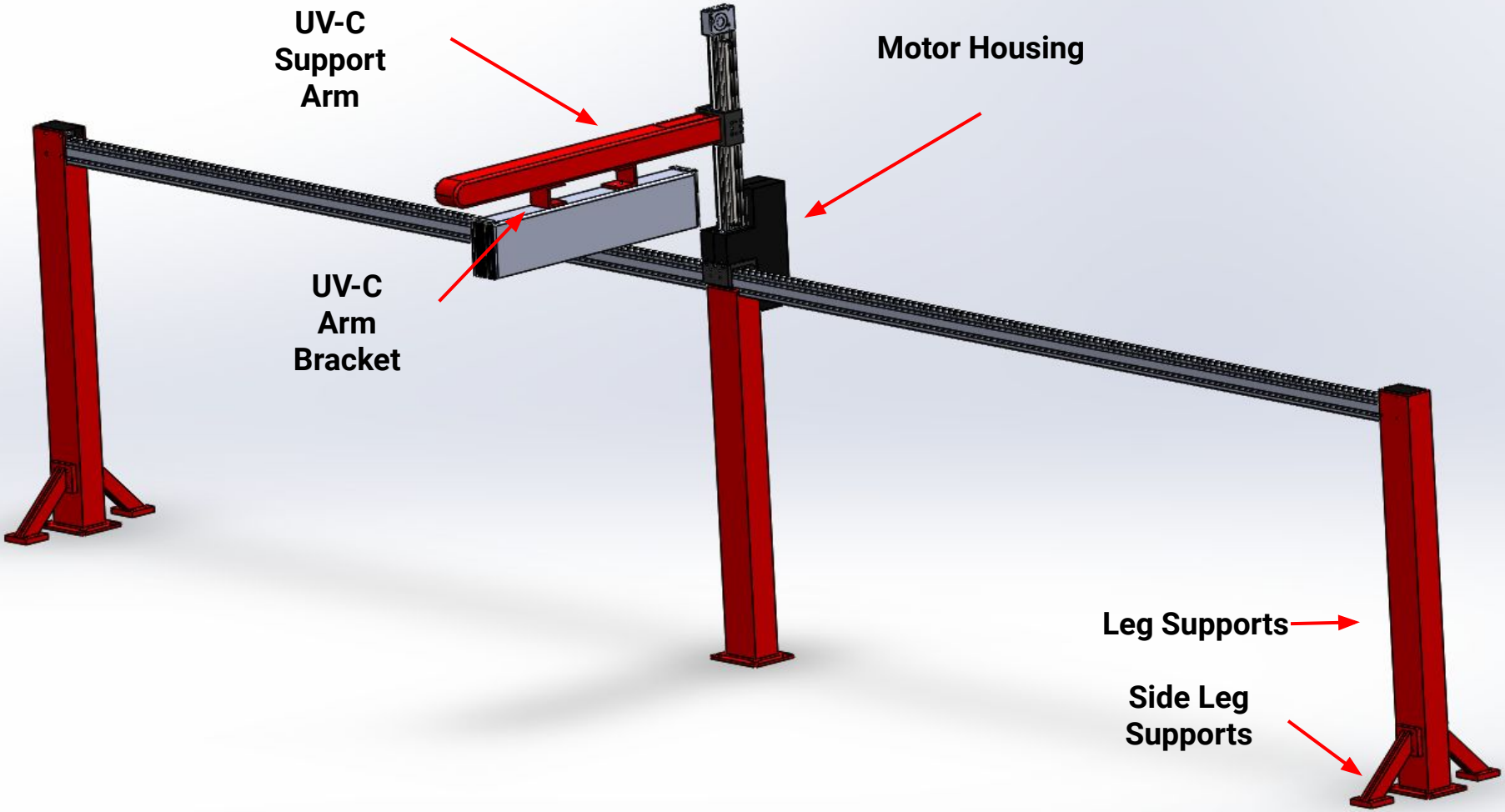
Motion System

Vertical Rail
ARM66AC-N25, 2.36 in. Closed Loop Stepper Motor

- Required **torque** of 6.57 Nm
- **Resolution**: 0.0144 °/Pulse
- Stop Position **Accuracy**: ±4 arc minutes (±0.067°)

Oriental Motor ARM66AC-N25

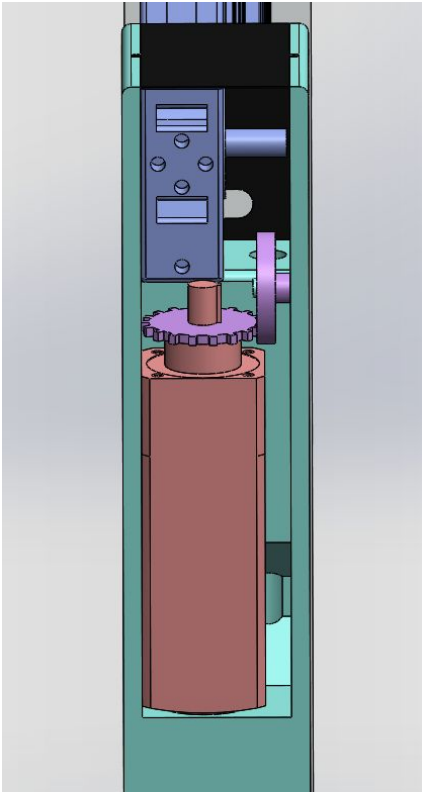
Support System



Ultralight Subsystem: Support System

Support System

- **“Skeleton” of the system**
- **Support** and **house** the motion system and enables stability of the structure
- Custom designed to achieve specific support goals
- Designed iteratively to ensure appropriate support
  - Can a **250 lb person** lean on the rails?



Support System: Support Leg Cross Section

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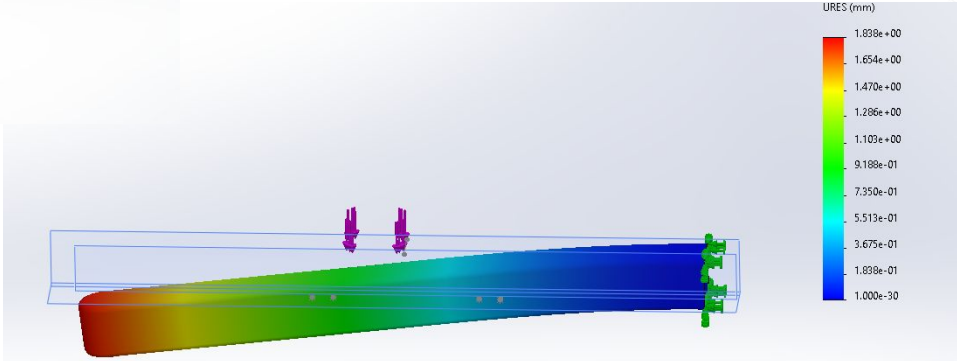
FEA- Support Arm

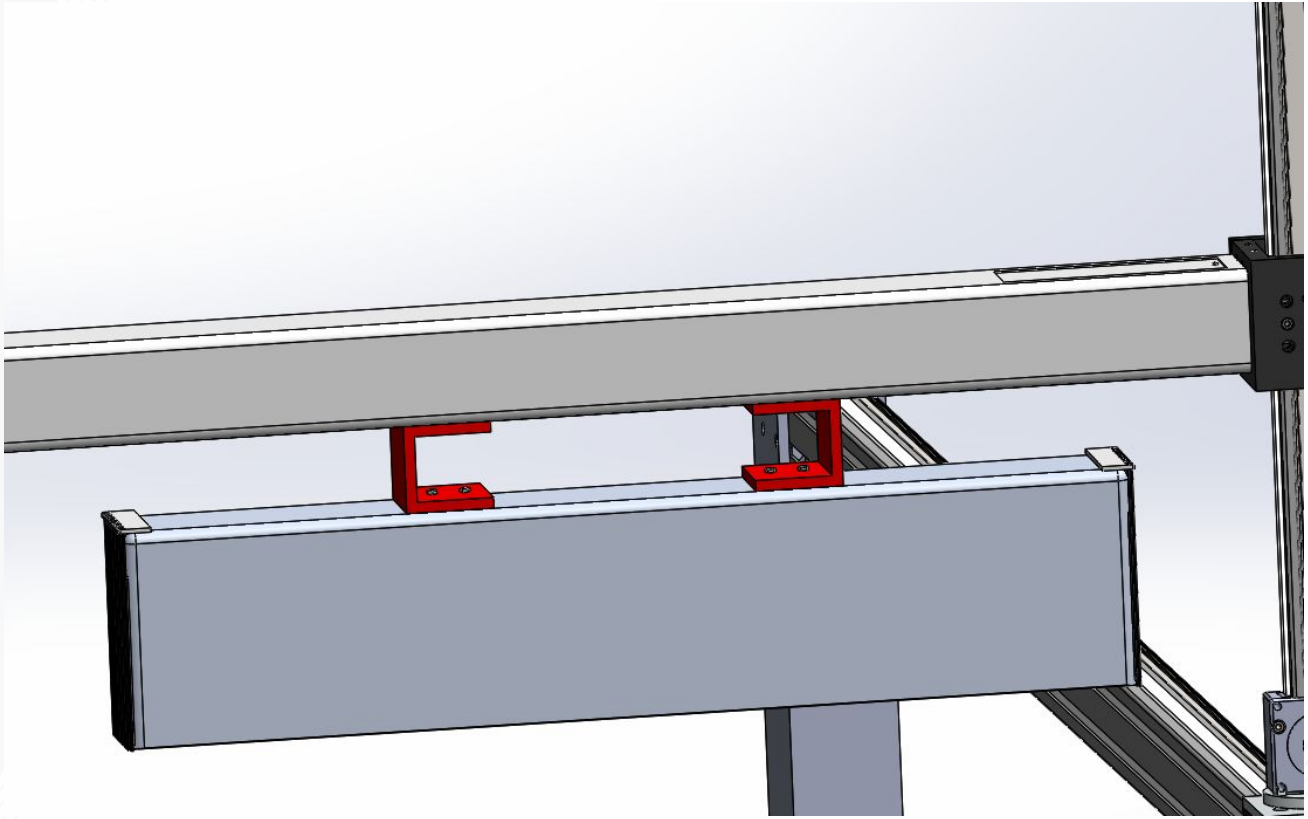
UV-C Support Arm: Stress Analysis

Elongation at Break	10 - 50 %
Elongation at Yield	1.7 - 6 %
Flexibility (Flexural Modulus)	1.6 - 2.4 GPa
Hardness Shore D	100
Stiffness (Flexural Modulus)	1.6 - 2.4 GPa
Strength at Break (Tensile)	29.8 - 43 MPa
Strength at Yield (Tensile)	29.6 - 48 MPa
Toughness (Notched Izod Impact at Room Temperature)	200 - 215 J/m
Toughness at Low Temperature (Notched Izod Impact at Low Temperature)	20 - 160 J/m
Young Modulus	1.79 - 3.2 GPa



UV-C Support Arm: Amplitude Analysis

FEA- UV Bracket



Support System: UV Brackets

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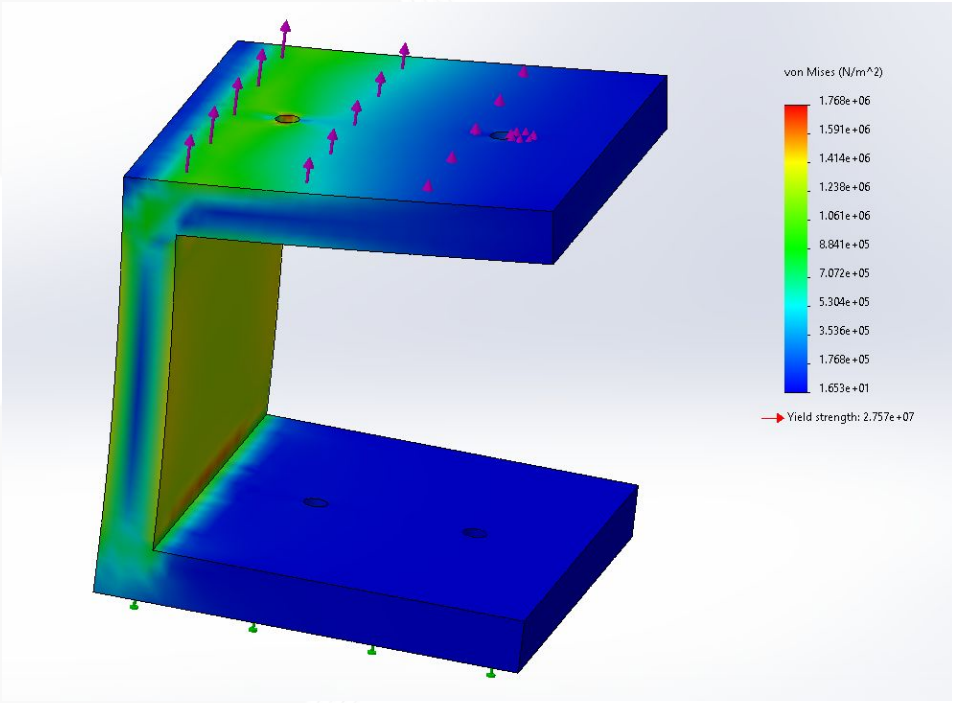
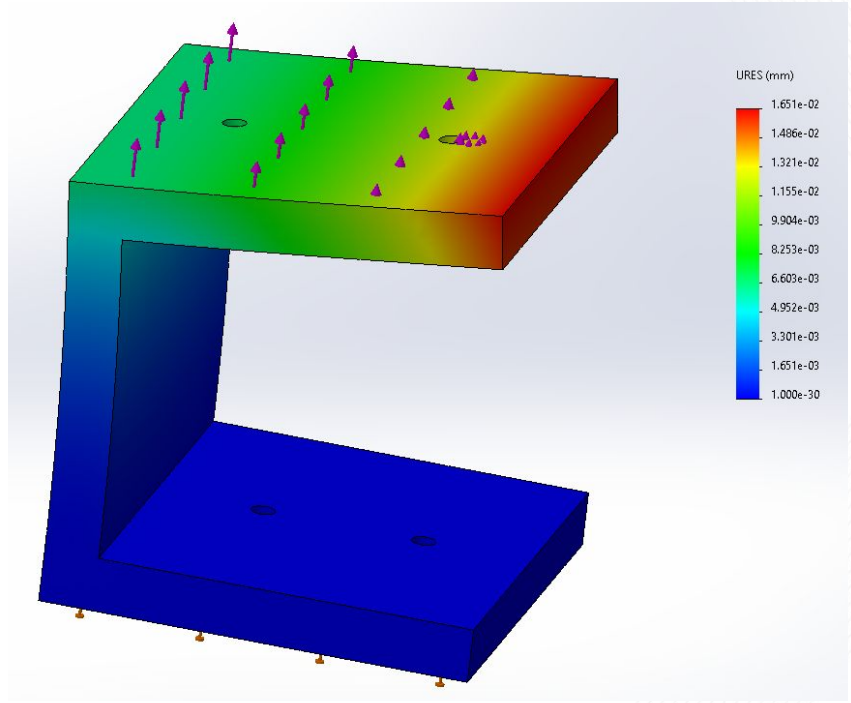
FEA - UV Bracket



UV-C Bracket:
Stress Analysis



UV-C Bracket:
Amplitude Analysis

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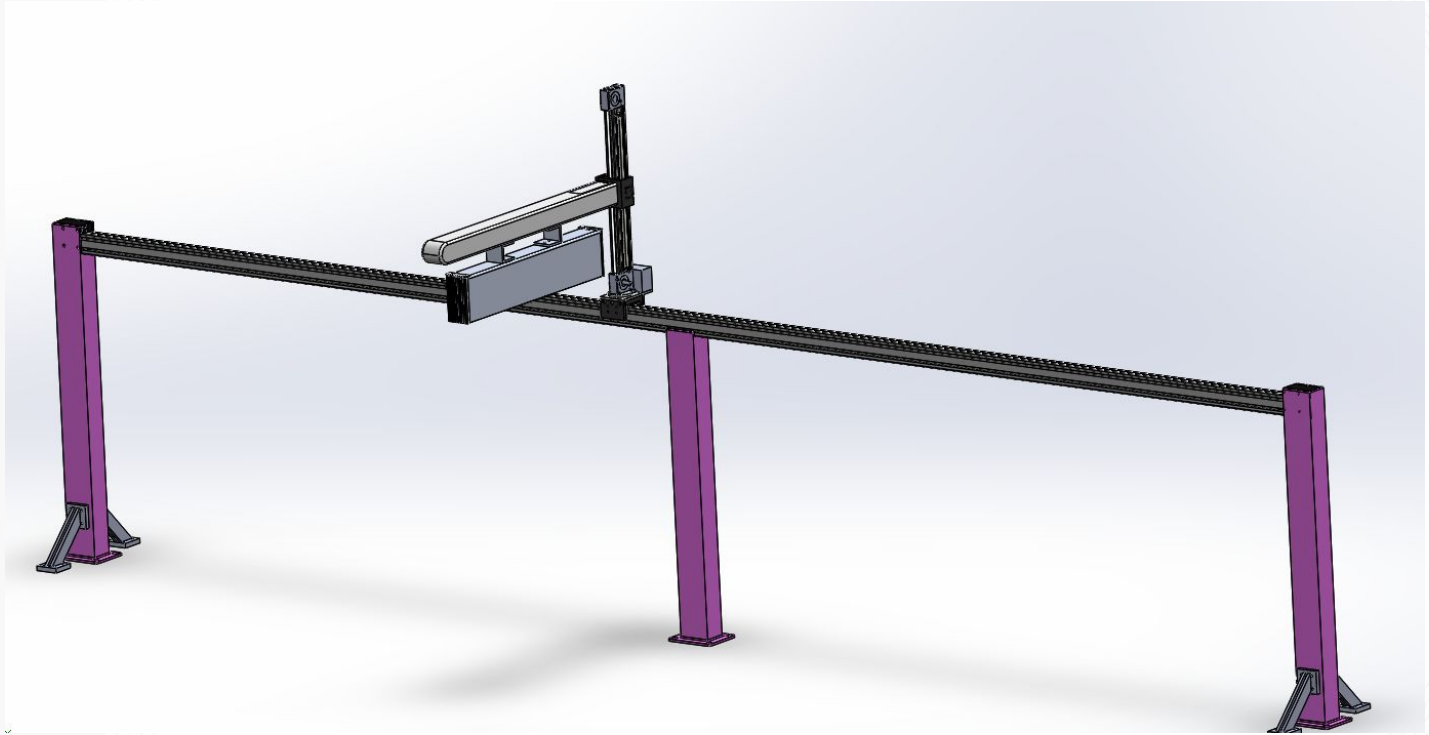
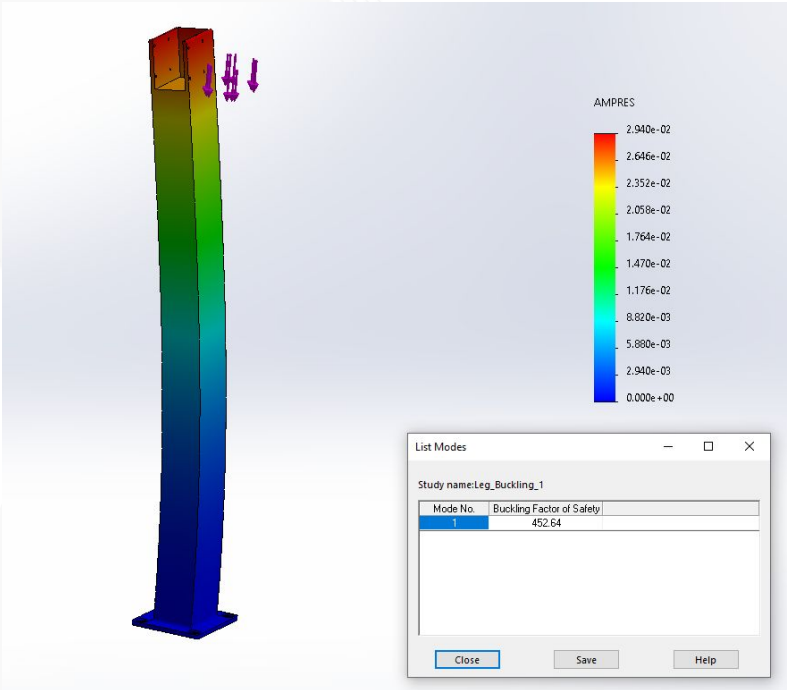
FEA - Leg Support

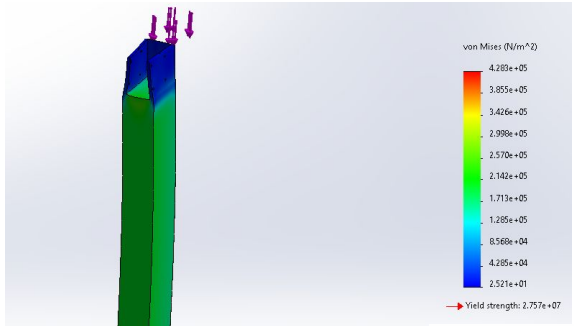


Support System: Support Legs

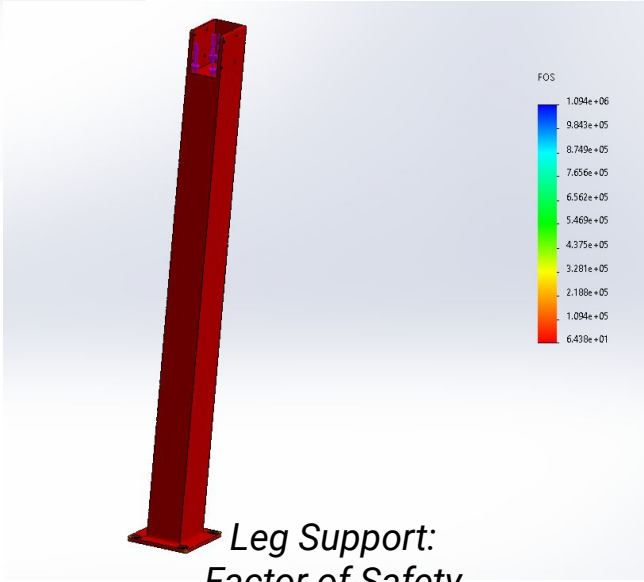
FEA - Leg Supports



Leg Support:
Buckling Force

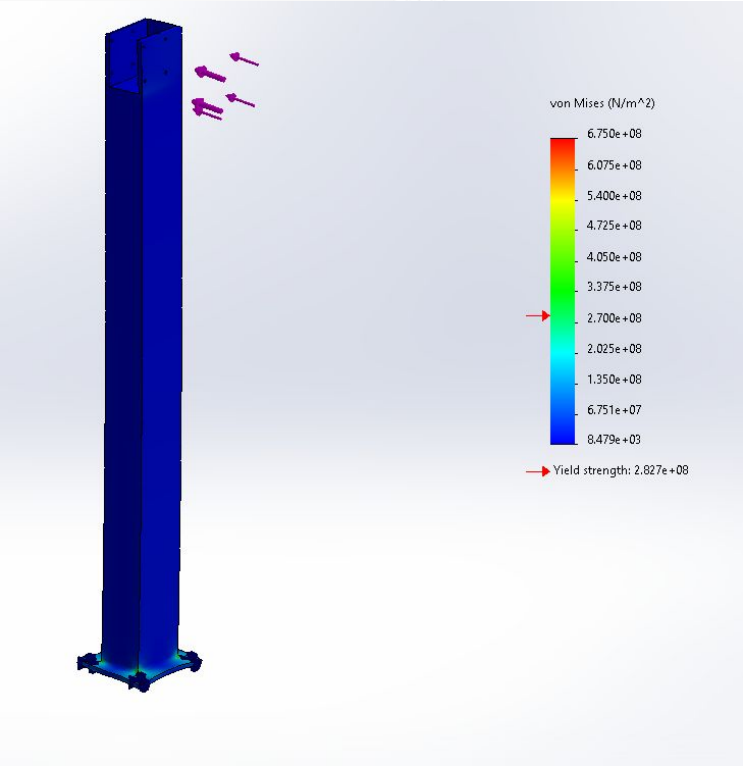


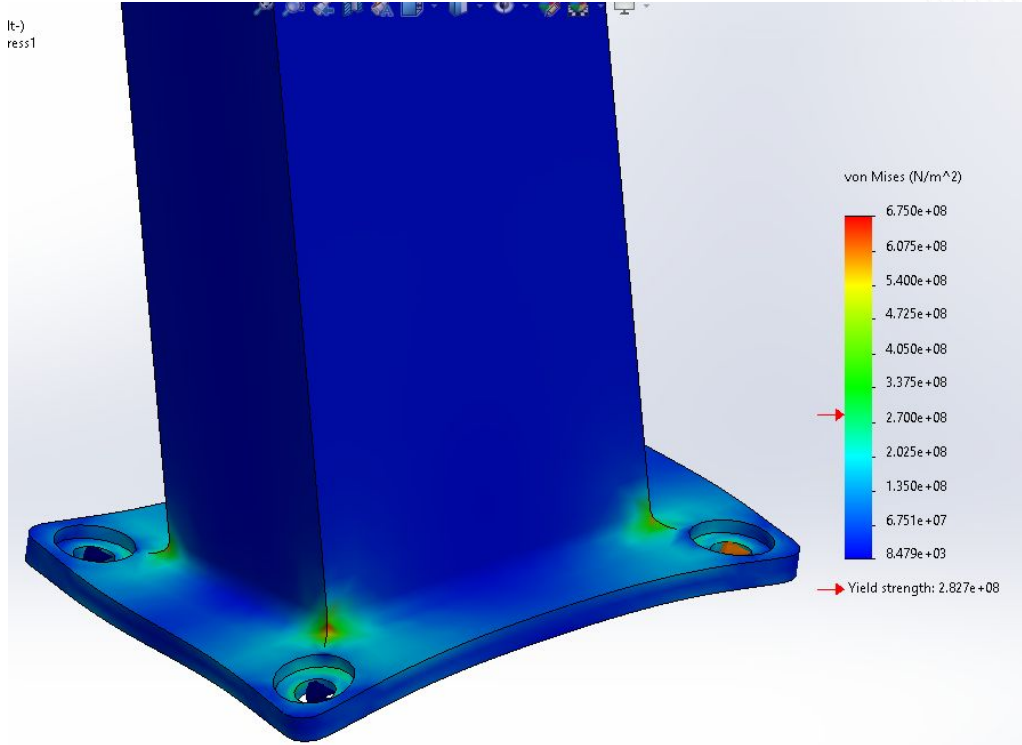
Leg Support:
Stress Analysis



Leg Support:
Factor of Safety

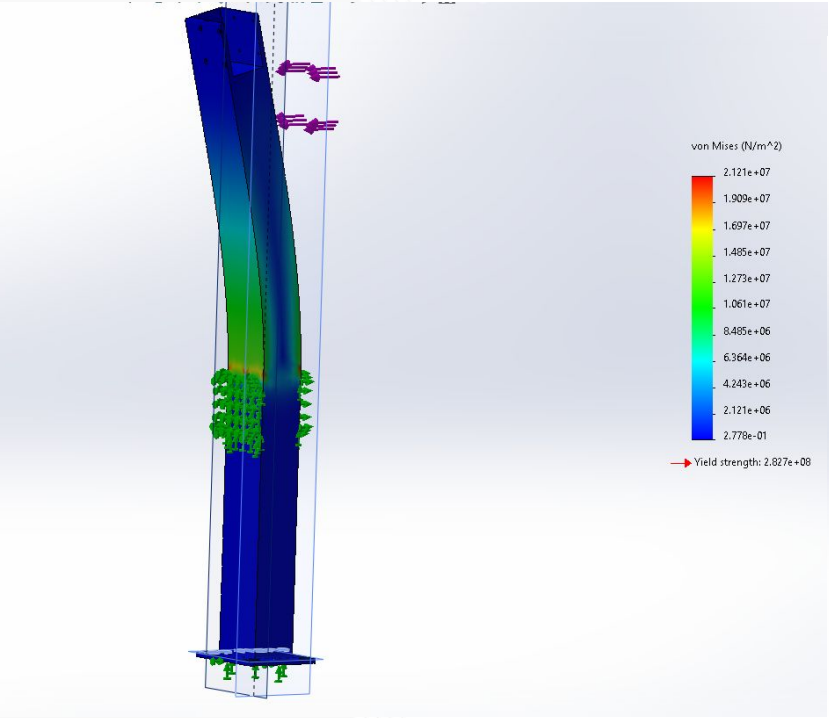
FEA- Leg Tipping Force



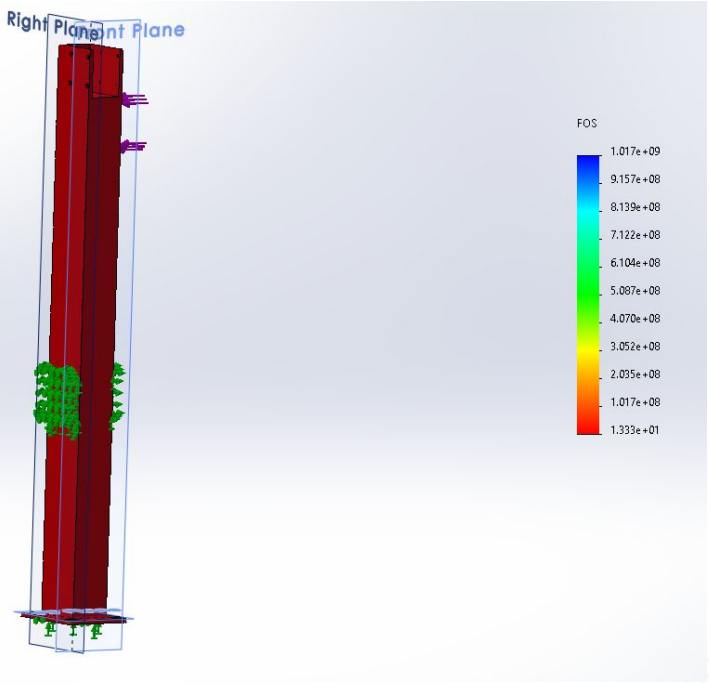


Leg Support: Tipping Force Analysis

FEA- Leg Tipping with Side Leg Supports



Leg Support with Side Leg Support: Tipping Force Analysis



Leg Support with Side Leg Support: Factor of Safety Analysis

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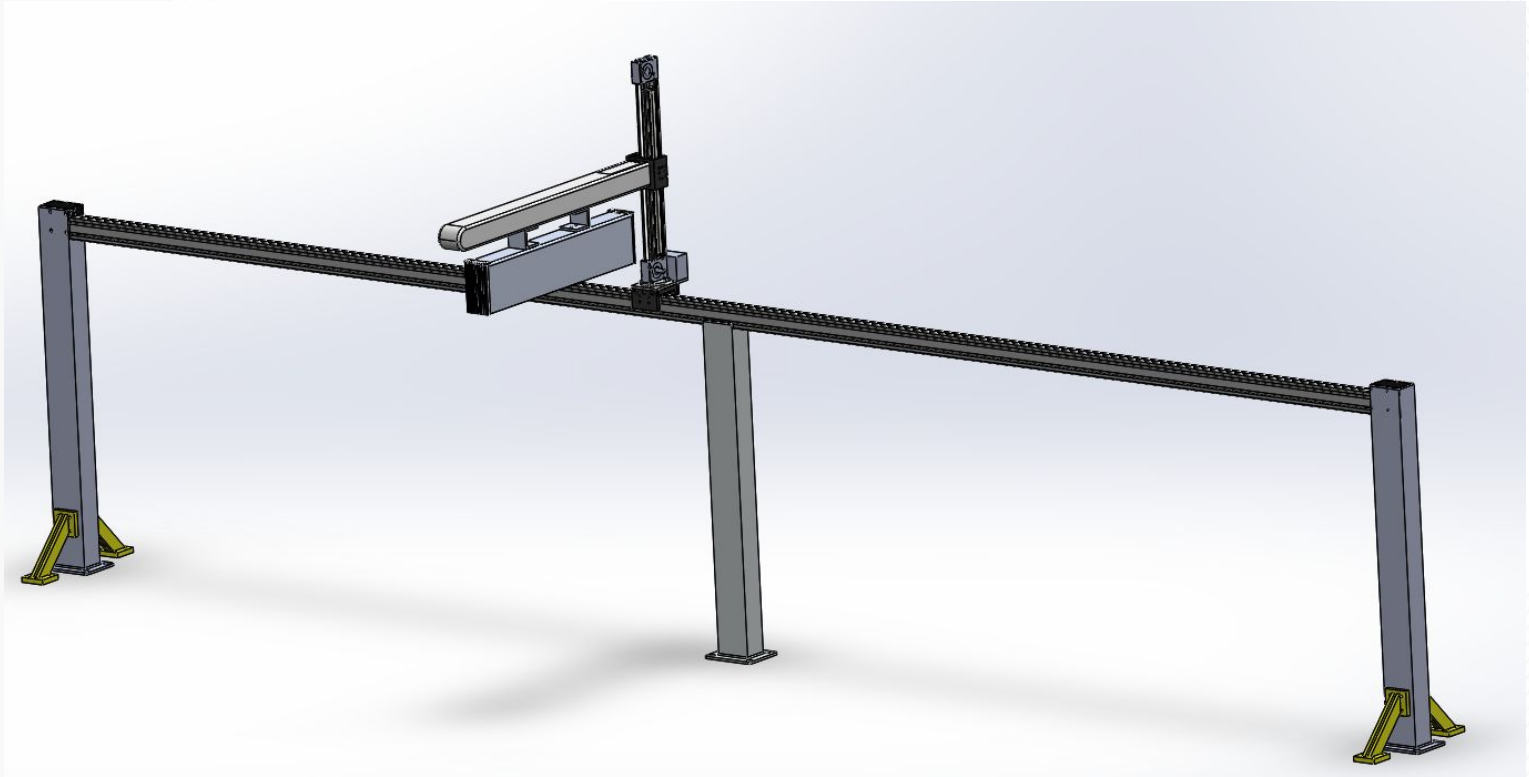
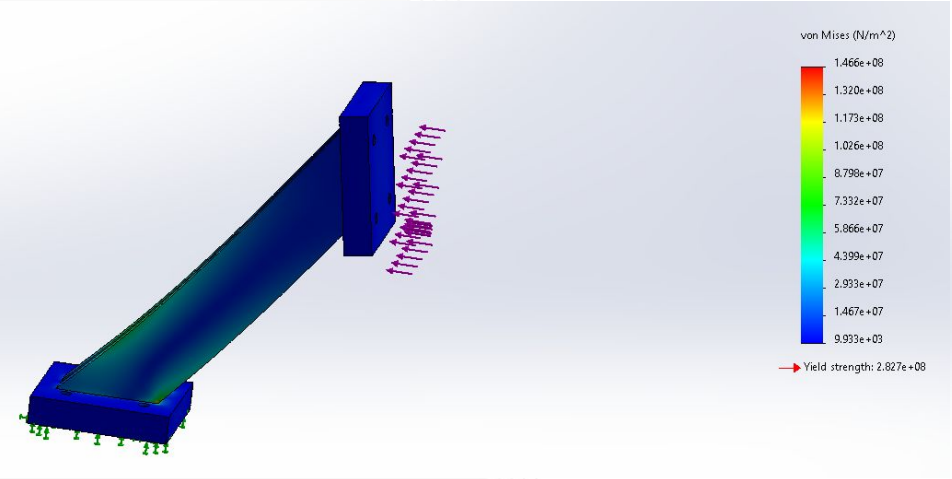
FEA - Side Leg Support

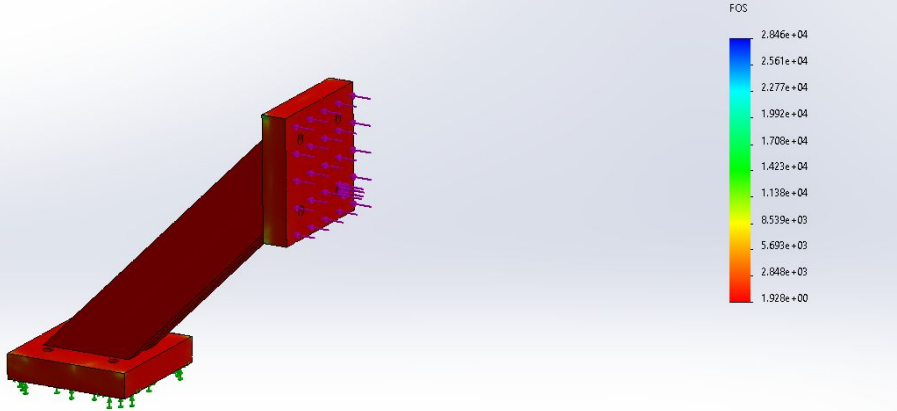


Support System: Side Support Legs

FEA - Side Leg Support



Side Leg Support:
Stress Analysis



Side Leg Support:
Factor of Safety

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Chosen Fasteners

All required safety factors: **1.3-1.5**

- **Securing to Ground**: Stainless steel 316, ¼” diameter bolts
  - Required shear strength 1590 lb
  - Chosen bolt provides safety factor of 3.11
- **Securing Legs to Rails**: Grade-8 Steel with Coarse Threads 1¼” diameter, plated
  - Required withstandable torque 1101.02 ft-lbs
  - Safety factor of 1.86
- **Securing Support Arm**: Grade-8 Steel, ⅞” diameter, 9 threads/inch
  - Required withstandable torque 388.404 ft-lbs
  - Safety factor of 1.55 allowing for lubrication

Sight System

Sight Sensor

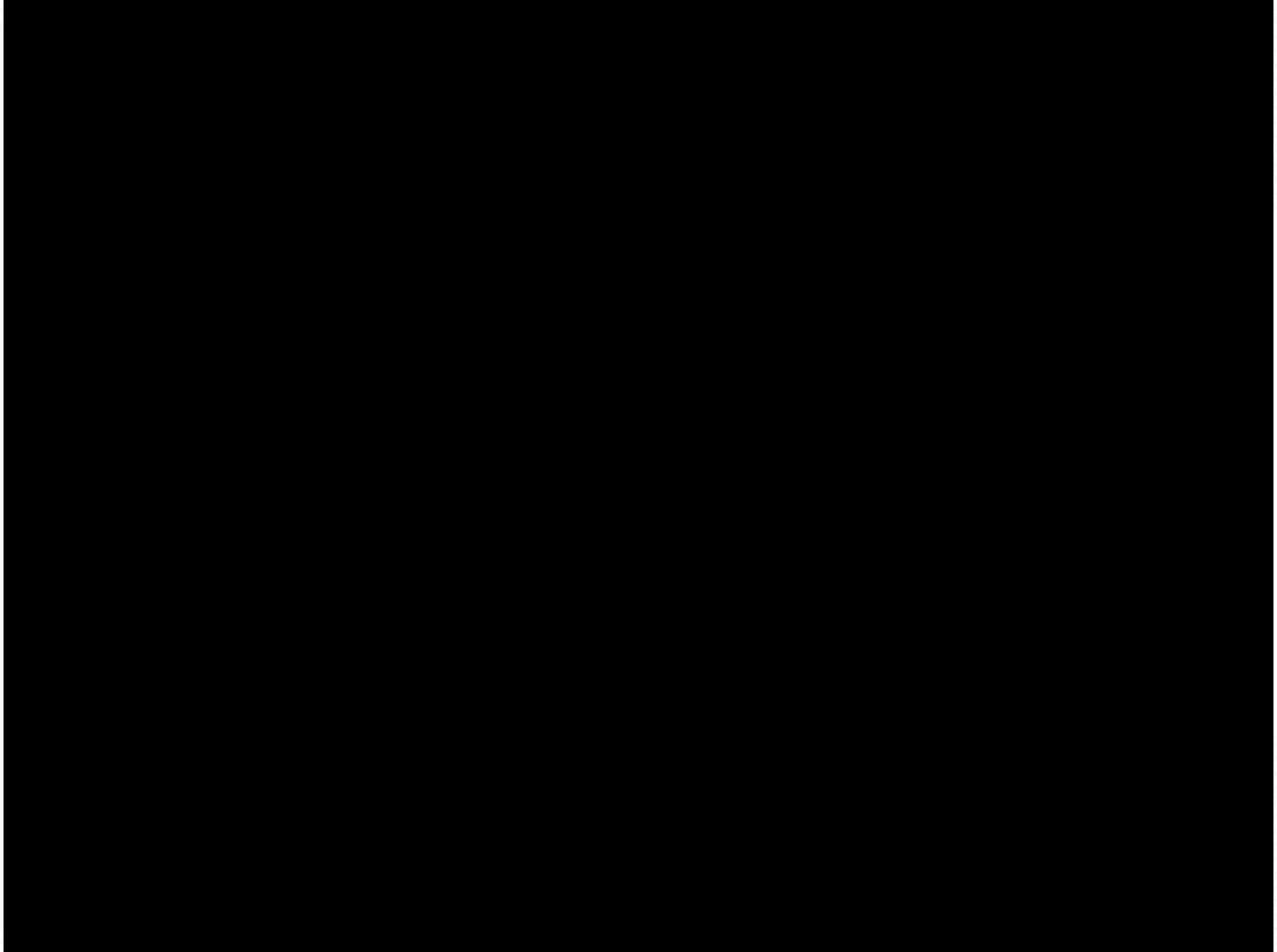
- **Ultrasonic sensors** use sound for detection, and therefore are not prone to detection issues stemming from [16]:
  - Colors
  - Reflectivity
  - Transparency
  - Wet Surface
  - Dirty Surface
- Model a cost effective solution for ≤1mm resolution

Baumer U500.PAO.2-GP1J.72F Sensor [17]

Materials & Manufacturing

Component	Number	Vendor	Model/Material	Manufacturing Method	Selection Justification
UV-C Delivery Device Frame	1	N/A	Aluminum Alloy 1060	Casting	Low density, high melting point
UV-C LEDs	314	Luminus	XBT-3535-UV Surface Mount UVC LED	N/A	Best price per power at $0.10/mW
UV-C Support Arm	1	N/A	ABS Plastic	3D Printing	Low weight, low cost for strength
UV-C Side Safety Cover	1	N/A	Rubber Silicone	3D Printing	Flexible, resistant to UV-C
Motion System Leg Supports	1	N/A	Carbon Steel	Casting	Meets strength requirements, more cost effective than stainless steel
Motion System “X-track”	1	Macron Dynamics, Inc.	MSA-628 Actuator	N/A	Resolution of ± 0.4 mm/m of travel
Motion System “Z-track”	1	Macron Dynamics, Inc.	MSA-628 Actuator	N/A	Resolution of ± 0.4 mm/m of travel
Motion System Horizontal & Pivot Motors	3	Oriental Motor	ARM46AC-PS25, 1.65” Closed Loop Stepper Motor	N/A	Capable of achieving required torque of 1.5 Nm, 0.0144°/pulse
Motion System Vertical Motor	1	Oriental Motor	ARM66AC-N25, 2.36 in. Closed Loop Stepper Motor	N/A	Capable of achieving required torque of 1.5 Nm, 0.0144°/pulse
Sight System Ultrasonic Sensor	2	Baumer	U500.PAO.2-GP1J.72F	N/A	Best price for range and ≤1mm resolution

System in Action



Safety, Cost, & Impact

Safety, Risk & Liabilities

- Ultraviolet Light warnings to **avoid direct exposure**
  - Warning labels required
- Structural stability
  - Warning labels required
- Wiring
  - Routing, spooling, resolving **entanglement** issues, trip hazard
- Force sensors
  - Force transducers for **interference detection**
  - **Emergency stop**
- System operation warnings
  - Warning regarding process start
  - **Indicator** when operating
- Misuse, Mishandling
  - **Keycode** or other preventative measure so only employees may access
  - Indicator to show which carts are **clean**

Cost Analysis

Disinfectant Wipes
(Assumptions: 14 hours a day, $7.25/hr labor, $0.71/hr material)

- Daily Cost: $111.44/day

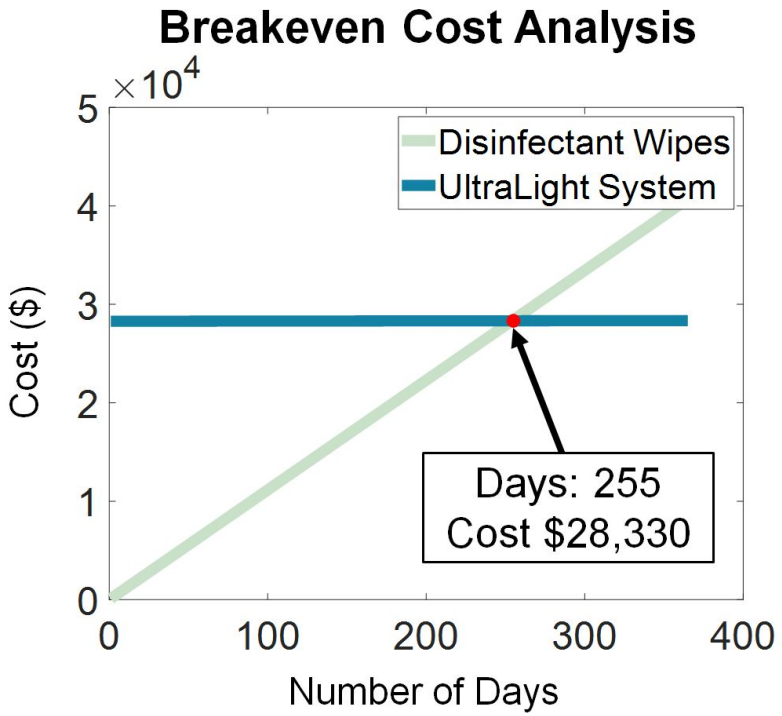
UltraLight System
(Assumption: $0.09/kWh)

- Initial Cost of System: $28,284
- Daily Cost: $0.19/day

Break-even Point: **9 months**

Yearly Savings: **$40,606/year**

(Yearly Savings after break-even point)



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Impact

Societal Impact

- Reduced pathogen spread with implementation
- Pre-existing insurance for future pandemics
- More affordable, accurate than pre-existing disinfection methods
- Higher customer confidence with minimum changes to experience

Environmental Impact

- Unlike other types of UV, UV-C does not produce ozone
- Low risk of UV exposure for human contact

Sustainability Impact

- Low energy, especially compared to other UV-C disinfection devices
- Zero-waste, unlike gloves, or disinfection wipes, or sanitizer fluids

Future Work

“Nervous” system

- Wiring (outsource the electrical system to an electrical engineer)
- Central control (“brain” to control systems)
- Start/stop controls, emergency stop functions

“Signals” system

- Visual indicators to demonstrate when carts are clean or dirty
- Emergency sensors (force transducers)

Experimental validation

- UV-C safety covers
- Disinfection rates
- Physical prototypes

UltraLight

99.9% Disinfection Rate in 35 Seconds

Wear a Mask!

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Questions?

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