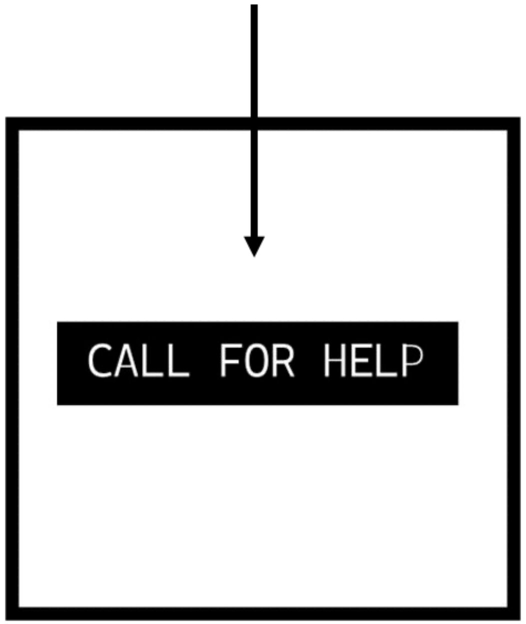
Problem Statement

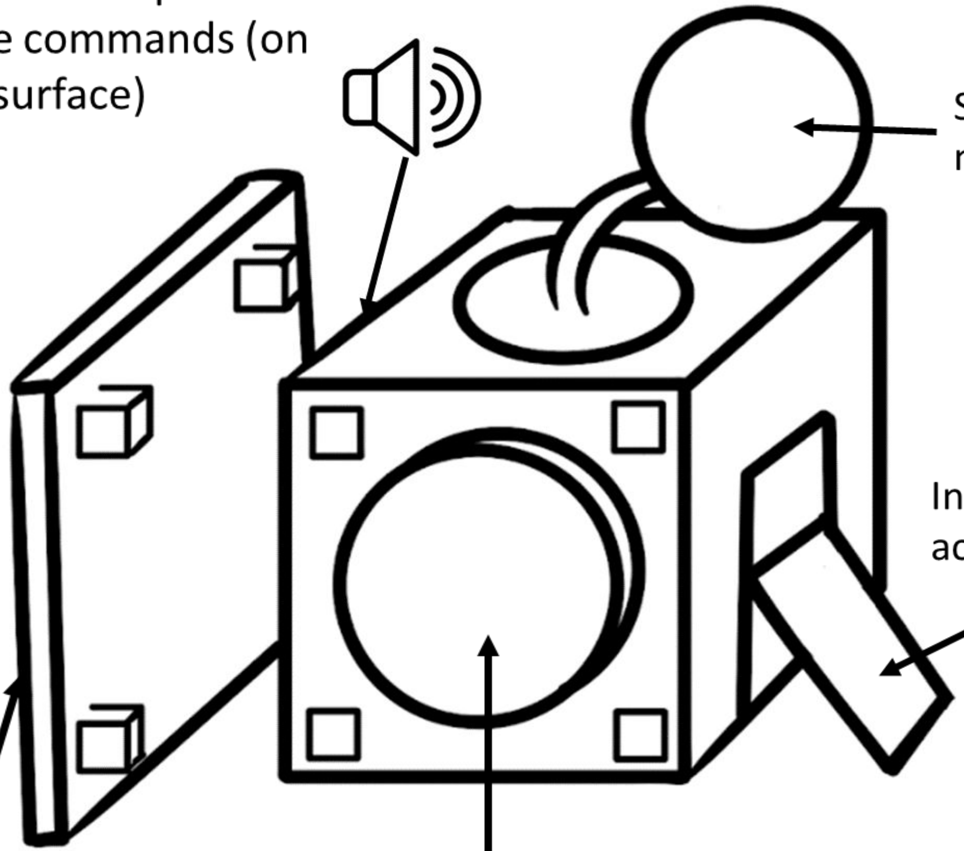
Issue	Target Audience	Novelty
Call bells do not cater to patients with differing levels of mobility or function	Limited mobility patients and medical providers in healthcare facilities	Modular solution that configures to the patient's needs based on user functionality

Objective Statement

The objective of the project is to design and prototype a **specialty call bell** that reliably establishes a line of communication between nurses and limited mobility patients, is **configurable**, **easy to use**, and can be seamlessly **integrated** into a healthcare facility's existing nurse call system.

Initial Concept





Risks & Concerns

Configurable

Patients With Limited Mobility and Speech

Ease of Use

Size + Weight Limitations

Seamless Integration

Exposure to Liquids & Contaminants

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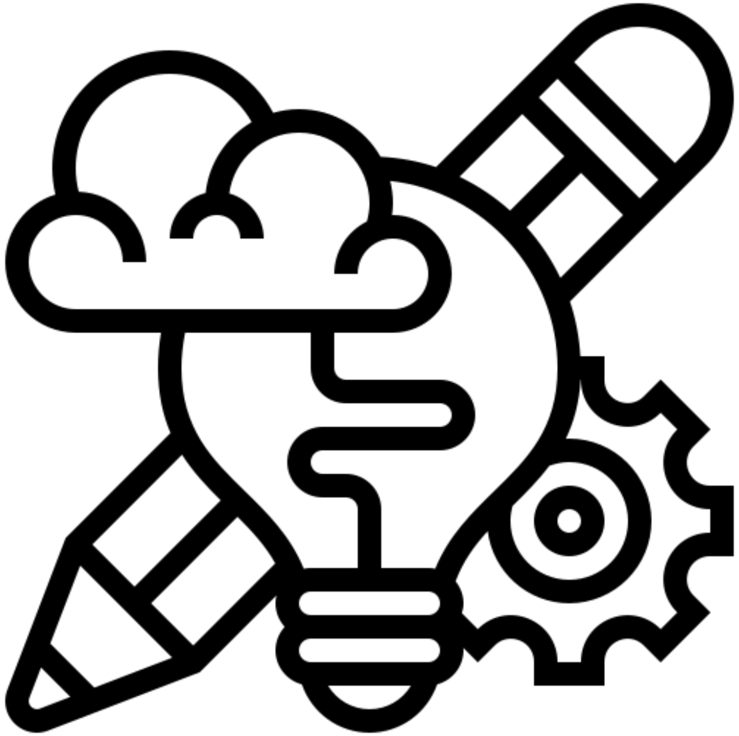
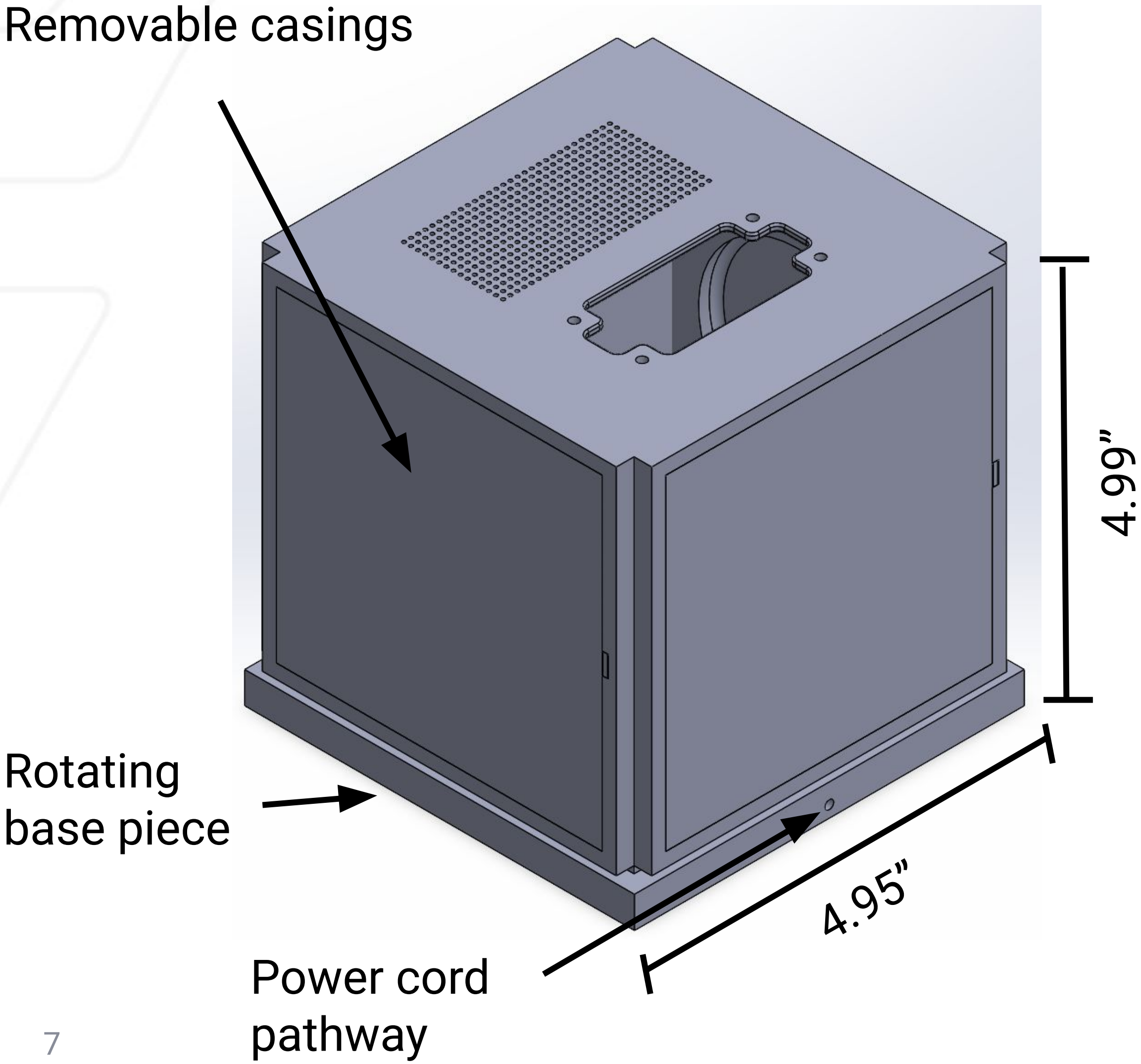
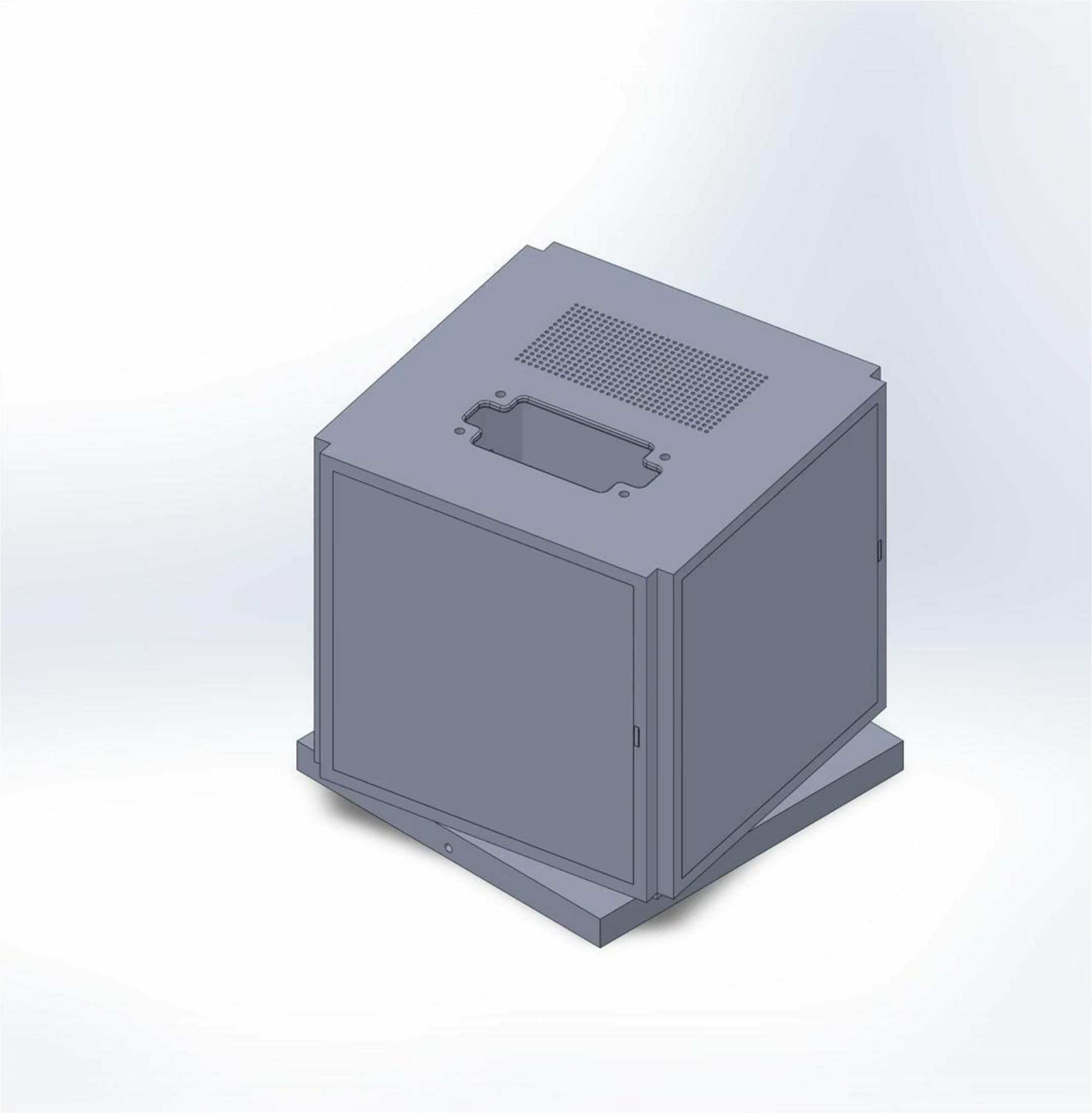
Current Design

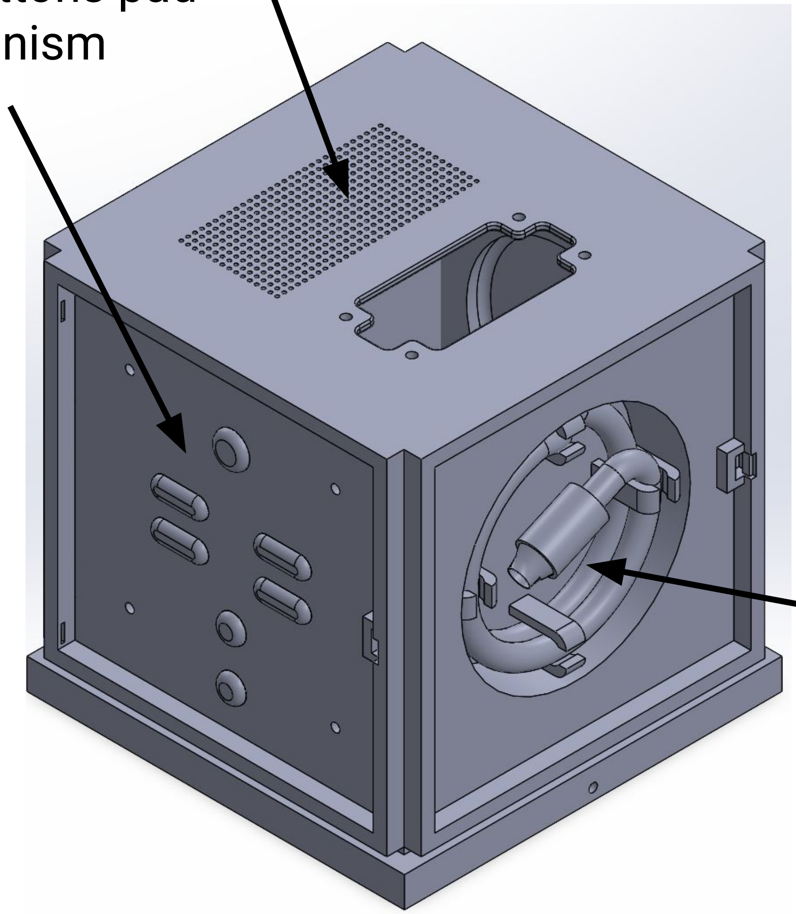


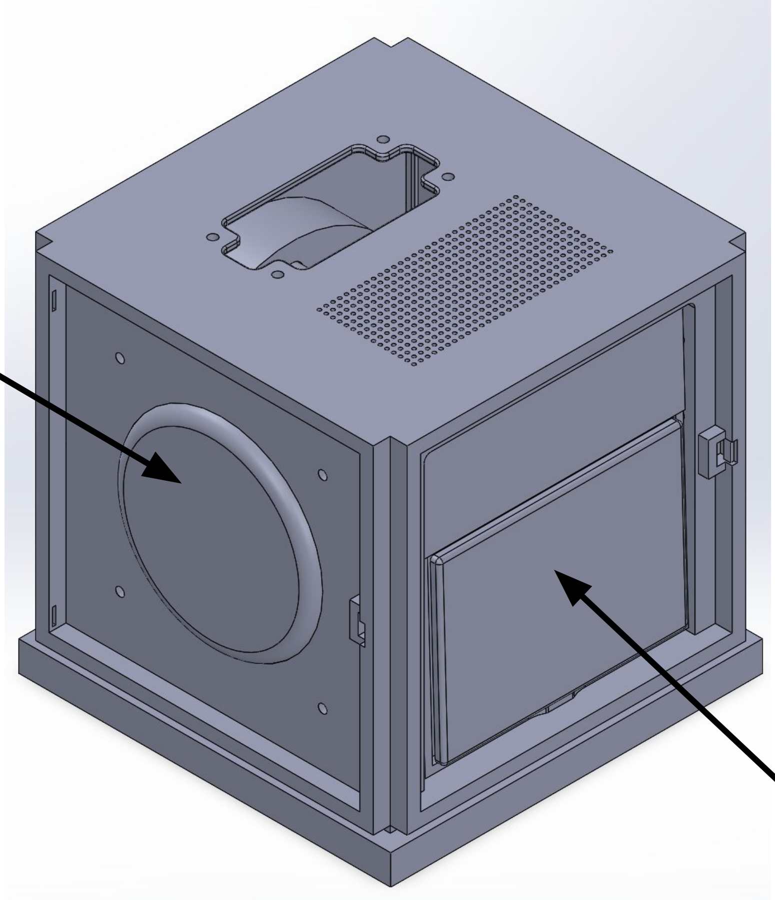
Enclosed Full Assembly



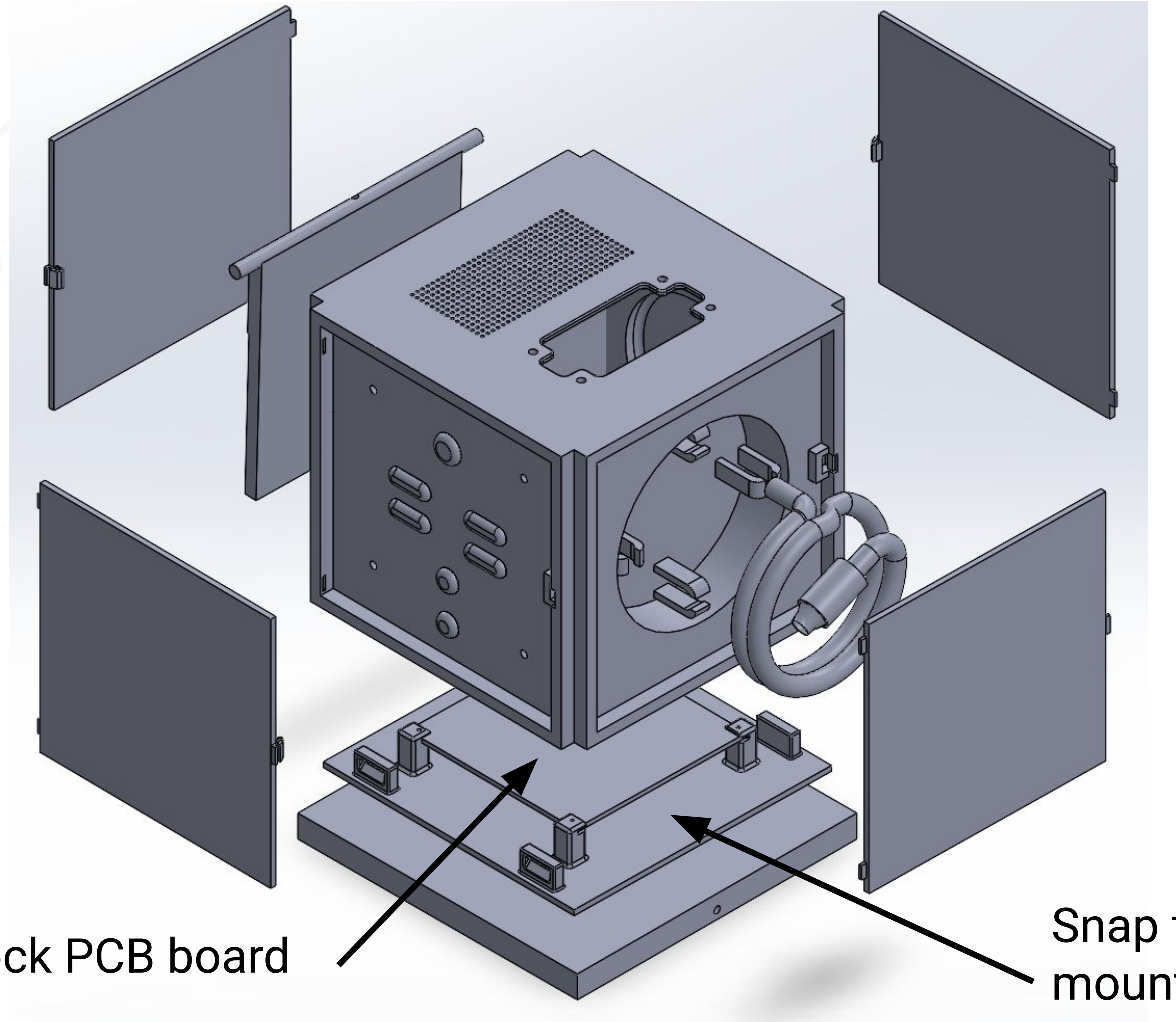


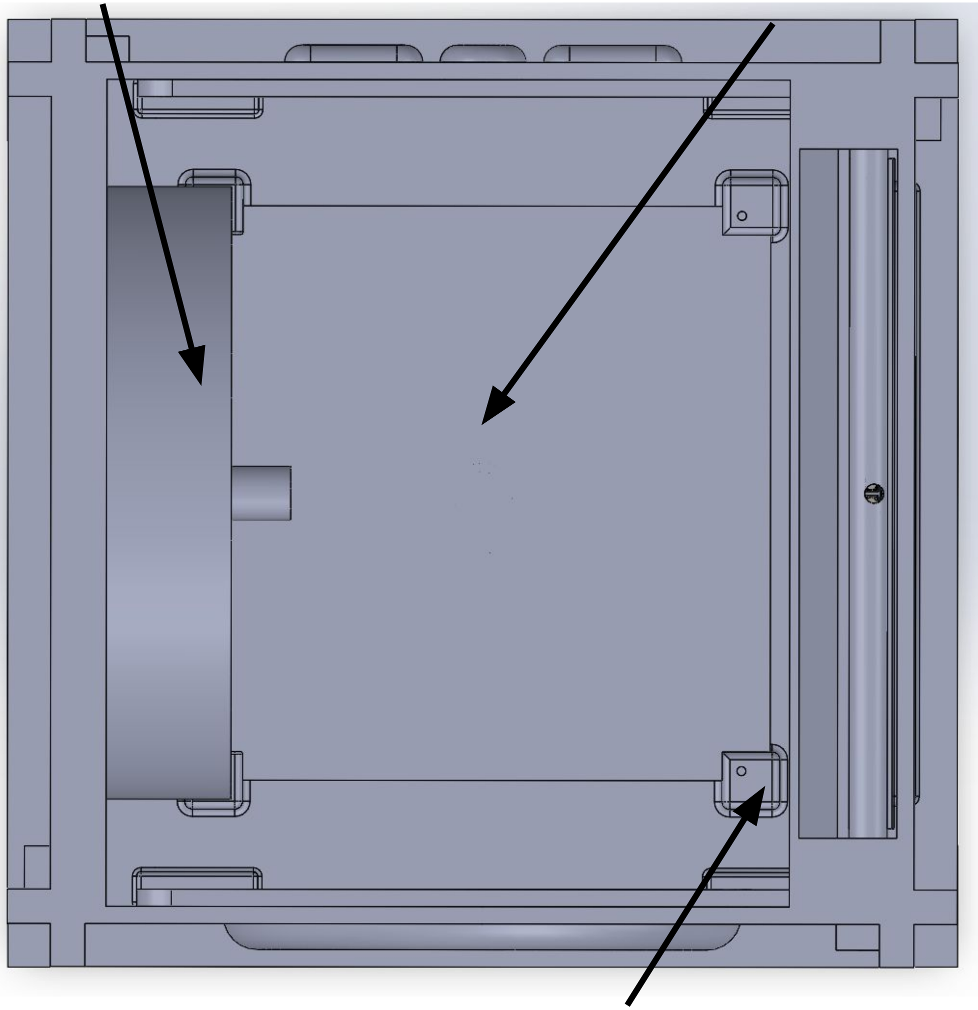
Exposed Full Assembly





Exploded View & Interior





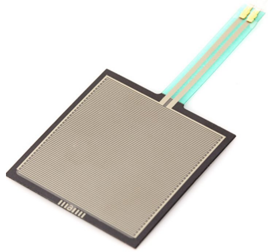
Electrical Sensor Selection

Key Considerations:

- Documentation
- Compatibility
- Conceptual Validity
- Low-Power

Necessary Components

Microcontroller



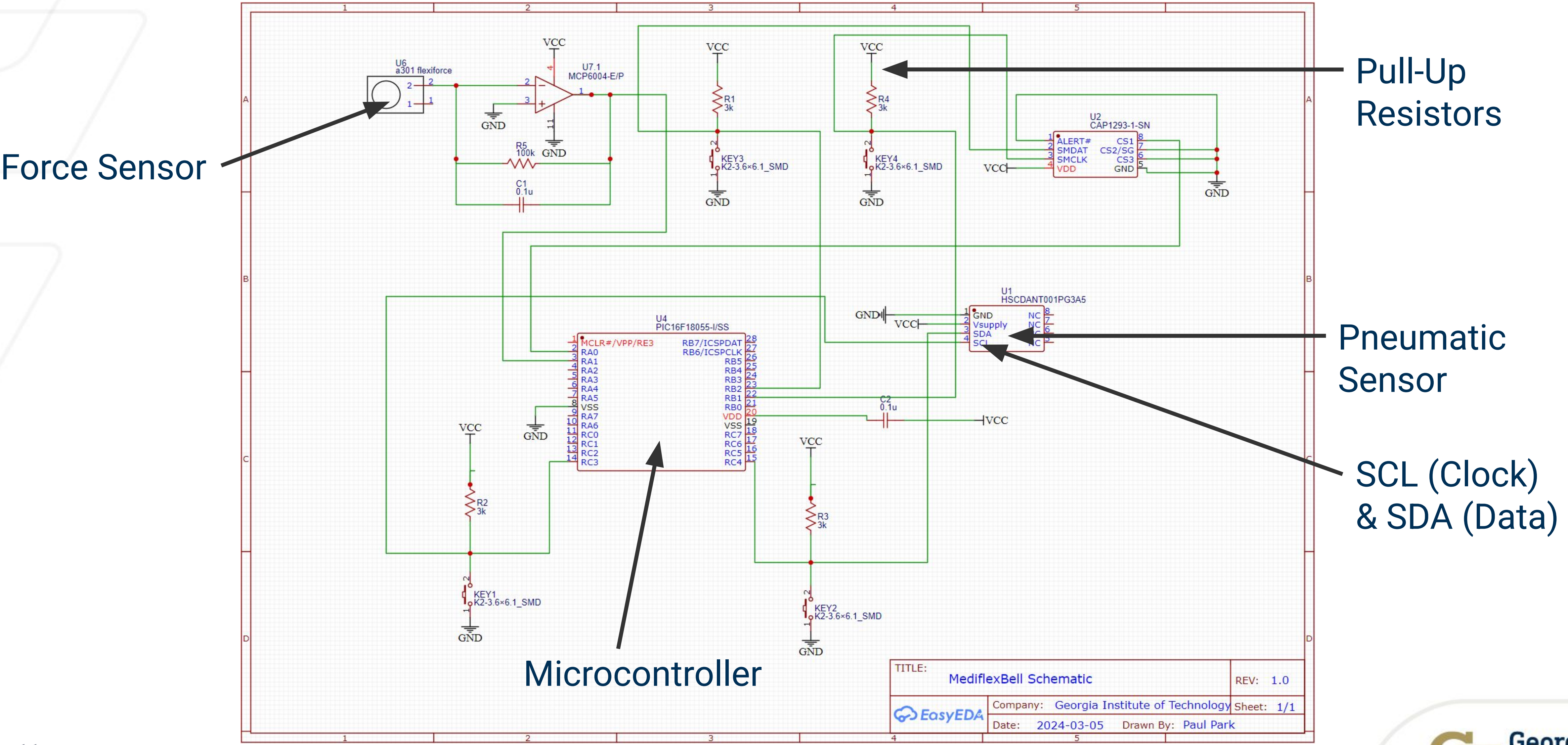
Force Sensor

Pneumatic Sensor

Microphone

Speaker

Electrical PCB Design



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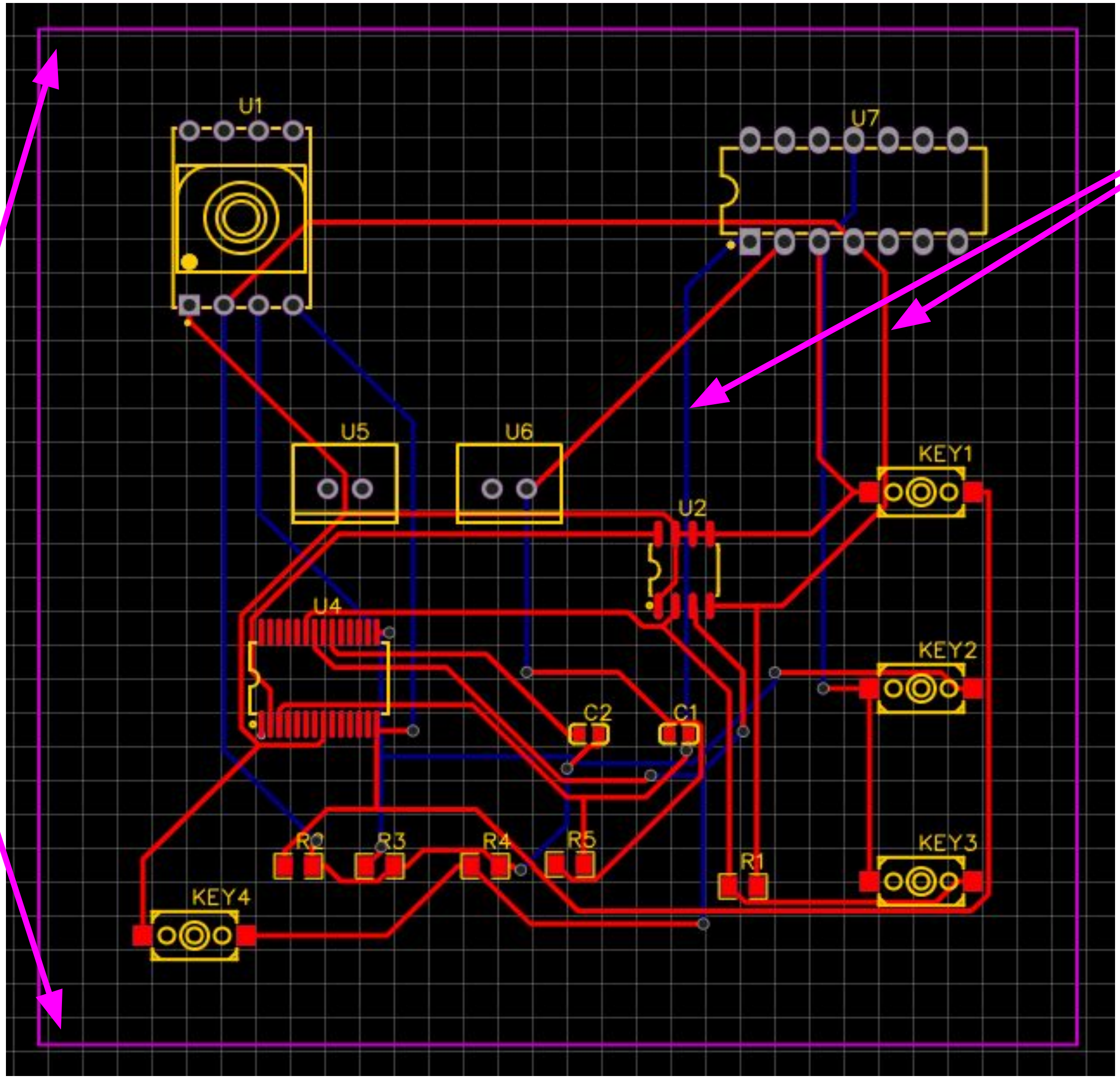
Electrical PCB Design

Via Diameter: 0.9 mm

Via Drill Diameter: 0.7 mm



Copper Traces - 2 Layers (Red & Blue)

Trace Width (Min):

0.381 mm

Clearance (Min):

0.254 mm

Engineering Analyses

Material Selection: Bell Frame, Casings, and Turntable

Function

House One or More Mechanisms

Constraints and Objectives

Constant Geometry & Applied Force

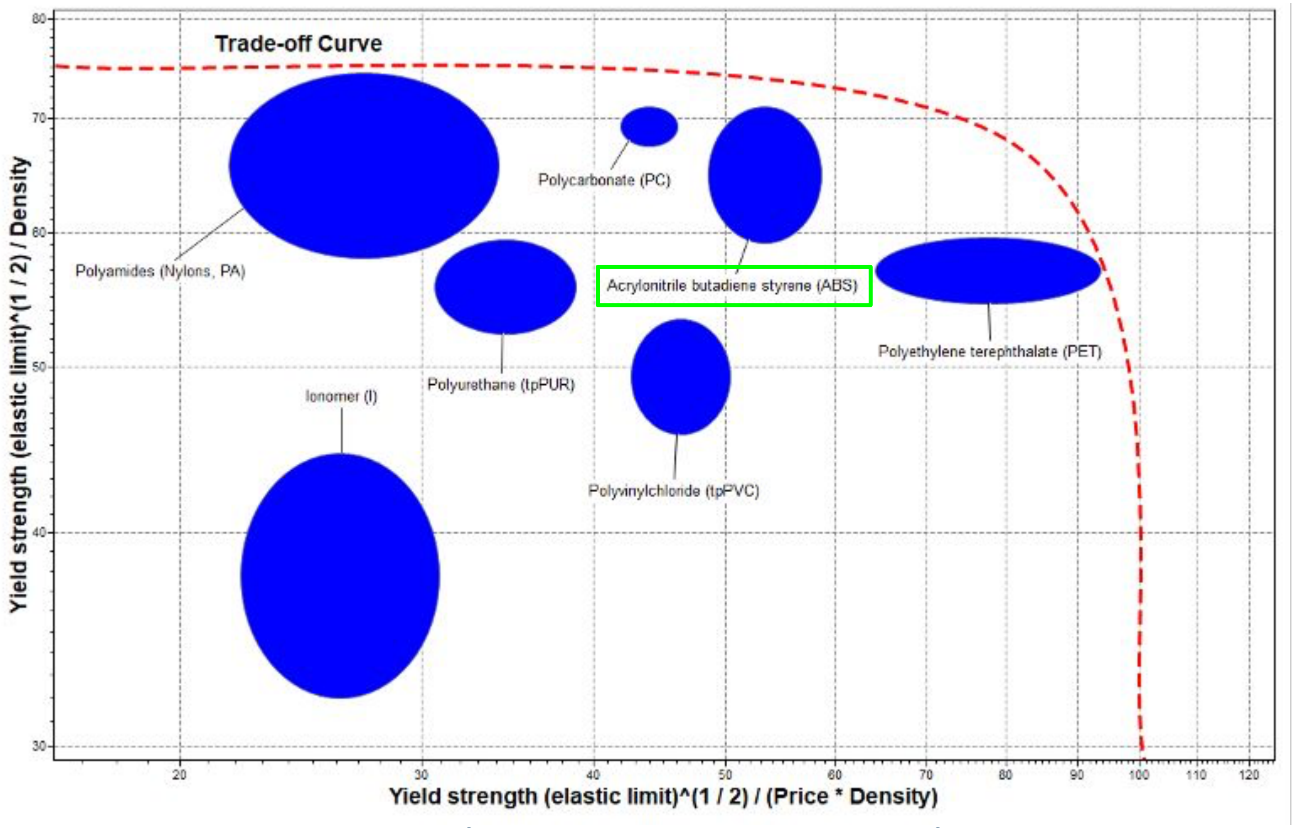
↓ Mass ↓ Cost

Material Indices

Mass: $M_1 = (\sigma_y)^{1/2} / \rho$

Cost: $M_2 = (\sigma_y)^{1/2} / \rho * c_m$

Ansys Granta Edupack Analysis



Limitations: Lightweight (<0.05lb/in^3), Inexpensive (<$2/lb), Tough (>2ksi*in^3)
Restrictions: Water Resistant, Latex-Free

Material Selection: Soft Button and Remote Buttons

Function

Trigger Signal when Pushed

Constraints and Objective

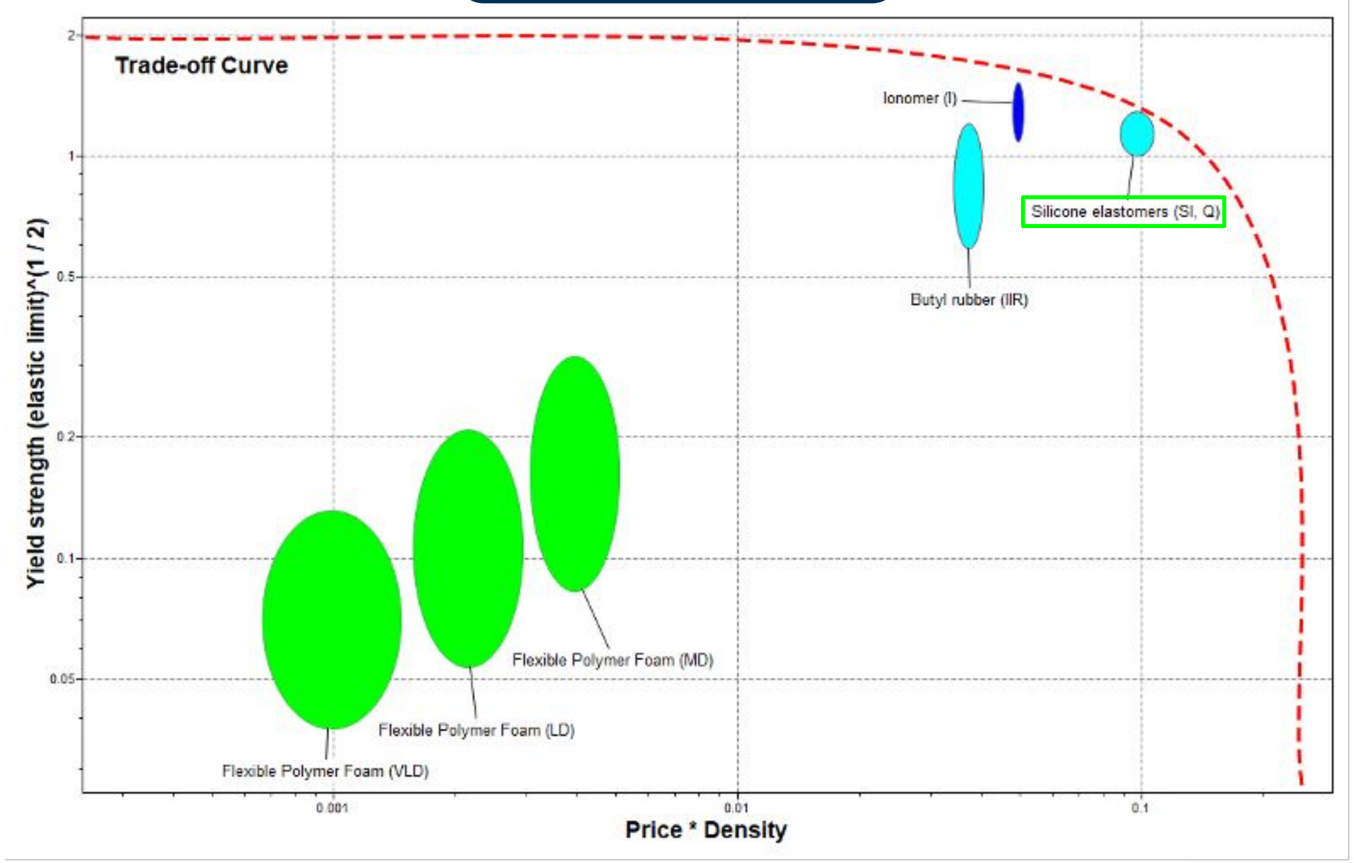
Constant Geometry & Applied Force

↓ Cost

Material Index

Cost: $M_2 = (\sigma_y)^{1/2} / \rho * c_m$

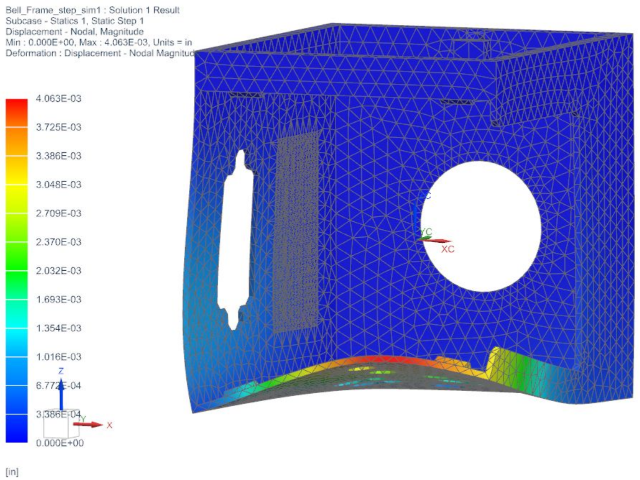
Ansys Granta Edupack Analysis



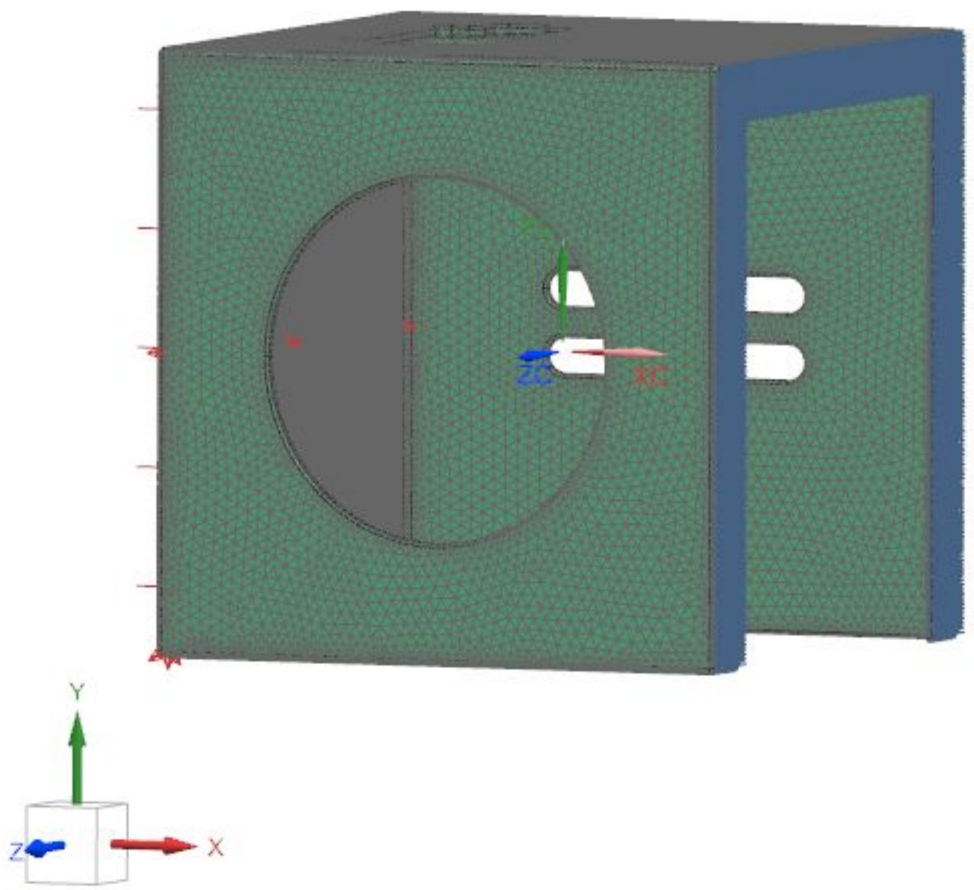
Limitations: Hardness (<3 HV), Elongation (>100% strain)
Restrictions: Water Resistant, Latex-Free

FMEA Major Concerns

Item - Failure Mode	Severity	Occurrence	Detection	Risk Priority Number
Bell Frame - Deformation	9	5	3	135
Incline Plane - Deformation	8	5	4	160
Breathcall Mouthpiece - Lifespan	7	4	4	112
Soft Button - Lifespan	7	4	4	112



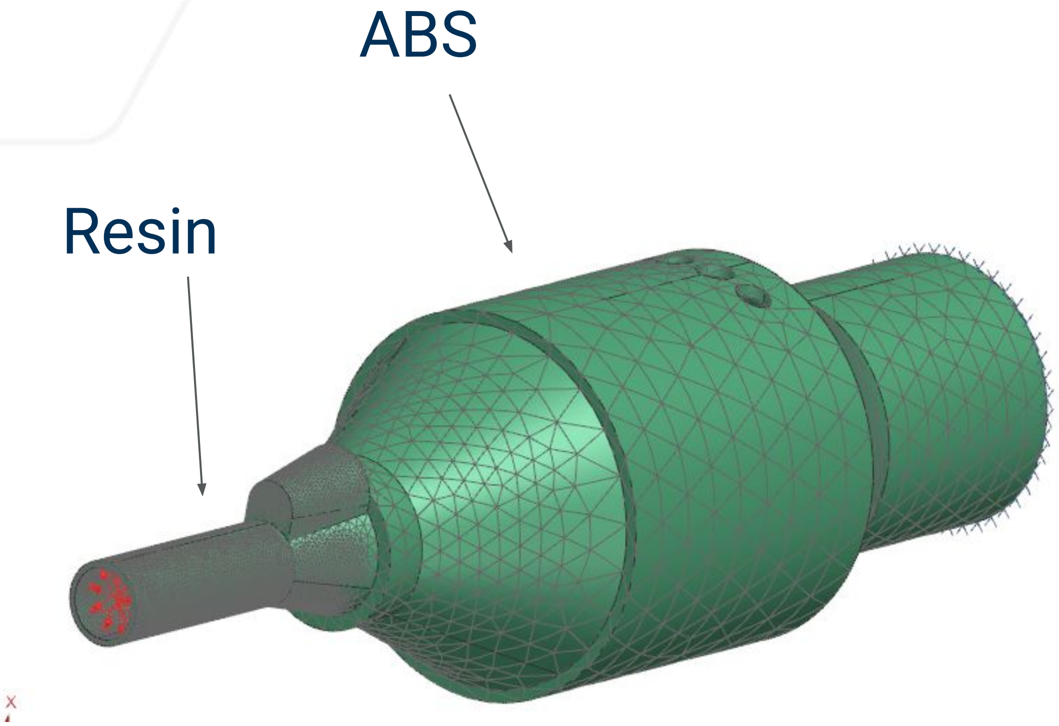
Engineering Analyses (Bell Frame)



Compression Test:
Identify Critical Force that causes Frame Yield Deformation

Material	ABS (σ_y = 40 MPa)
Axial Forces Applied	250 N - 400 N
Constraints	Pinned Face of Frame
Assumptions	Geometric Simplifications

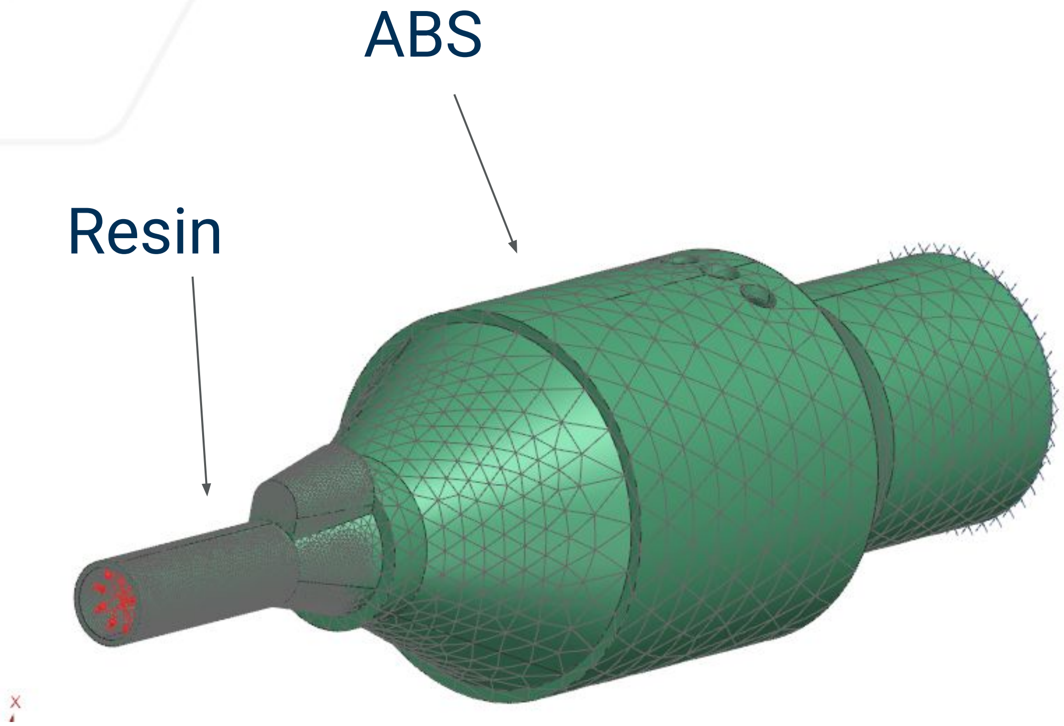
Engineering Analyses (Mouthpiece)



User Load Test:
Identify Stresses associated with User Use

Material(s)	ABS (σ_y = 40 MPa) Flexible 80A resin (σ_y = 1.5 MPa)
Load Applied	1 PSI
Constraints	Pinned end of Mouthpiece
Assumptions	Thin Walled Pressure Vessel

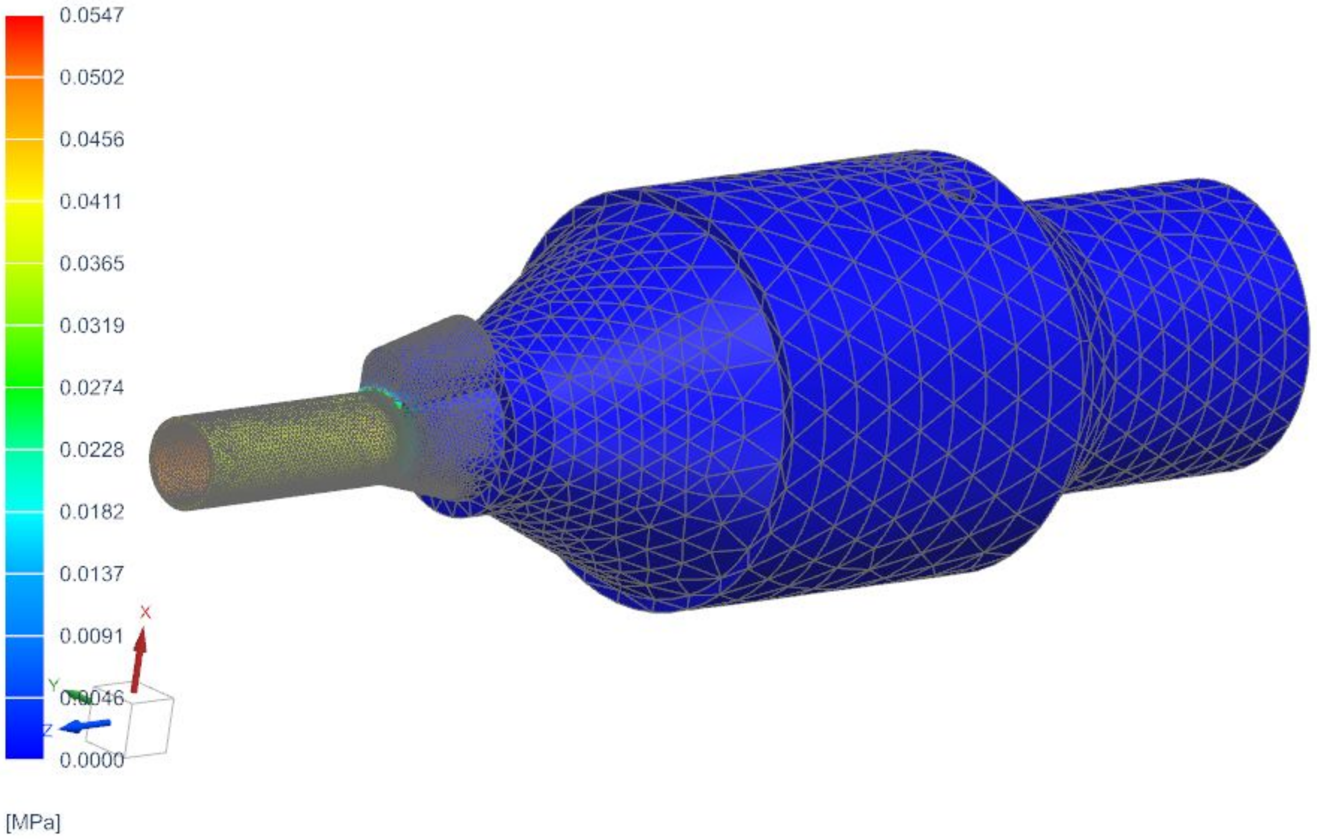
Engineering Analyses (Remote Buttons)



User Load Test:
Identify Stresses associated with User Use

Material(s)	ABS (σ_y = 40 MPa) Flexible 80A resin (σ_y = 1.5 MPa)
Load Applied	1 PSI
Constraints	Pinned end of Mouthpiece
Assumptions	Thin Walled Pressure Vessel

Engineering Analyses (Mouthpiece)



Max Stress: 0.0547 MPa
Safety Factor: 26 (Reliable)

Hoop Stress Estimate

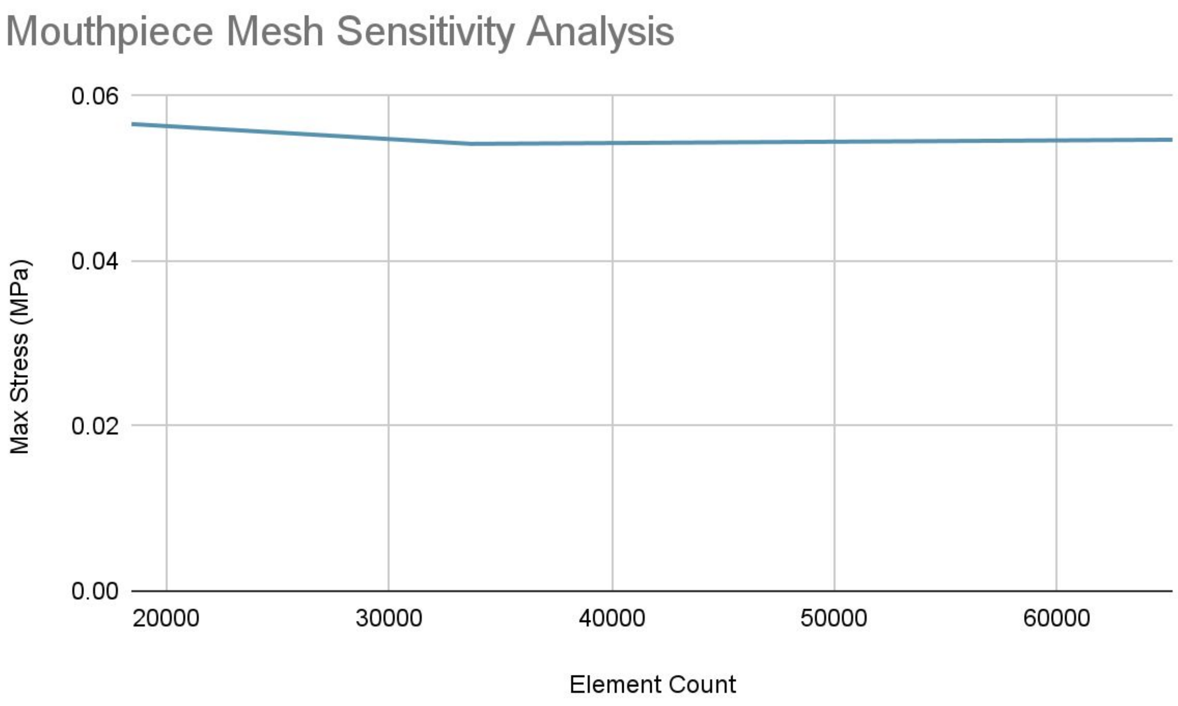
$$\sigma_h = \frac{p \cdot d}{2 \cdot t}$$

σ_h= (1 psi)(0.175 in) / (2)(0.0125 in)

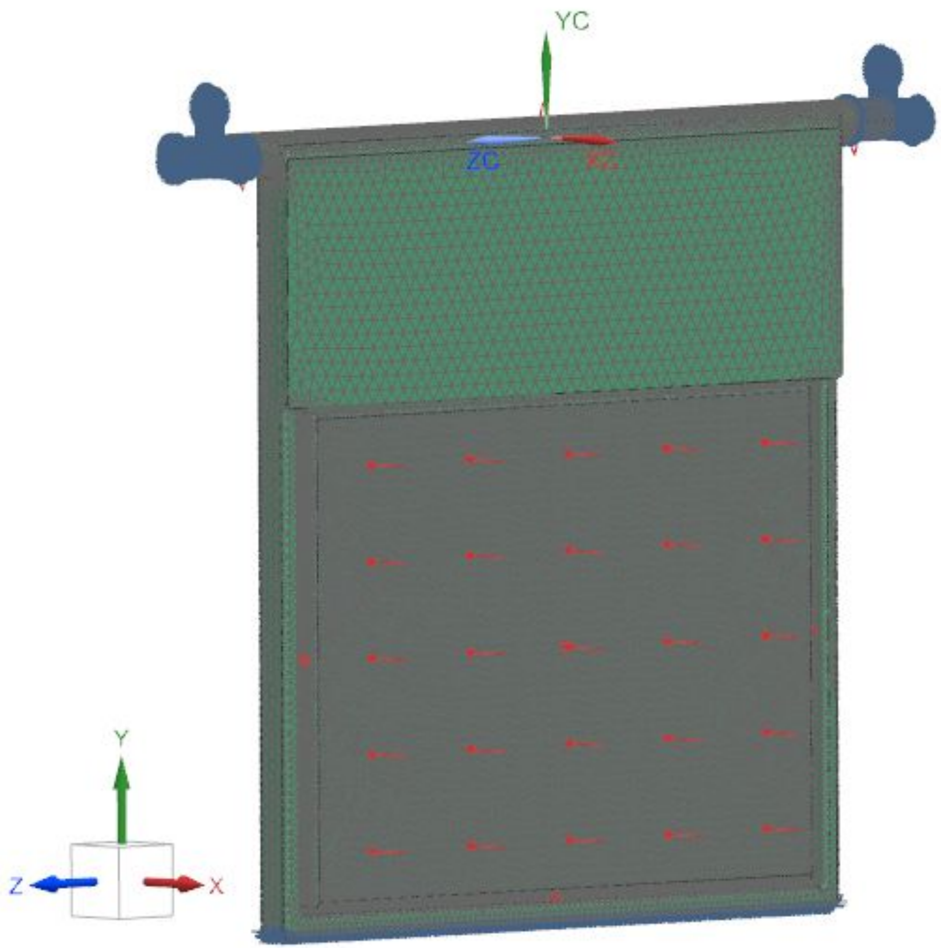
σ_h= 7 psi ≅ 0.05 MPa

Appendix - Engineering Analyses (Mouthpiece)

Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA10)	Element Count	Test Load	Max Stress	Safety Factor (1.5 / Max Stress)
1	0.025 in	18430	1 PSI	0.0566 MPa	26
2	0.01 in	33703	1 PSI	0.0542 MPa	27
3	0.01 in	65204	1 PSI	0.0547 MPa	27



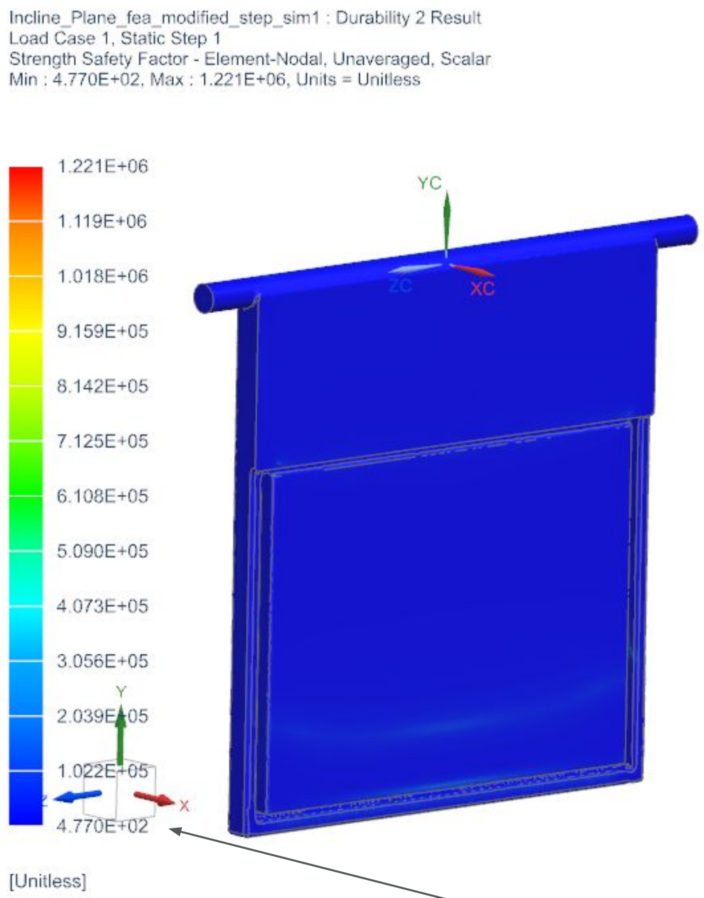
Engineering Analysis (Incline Pad)

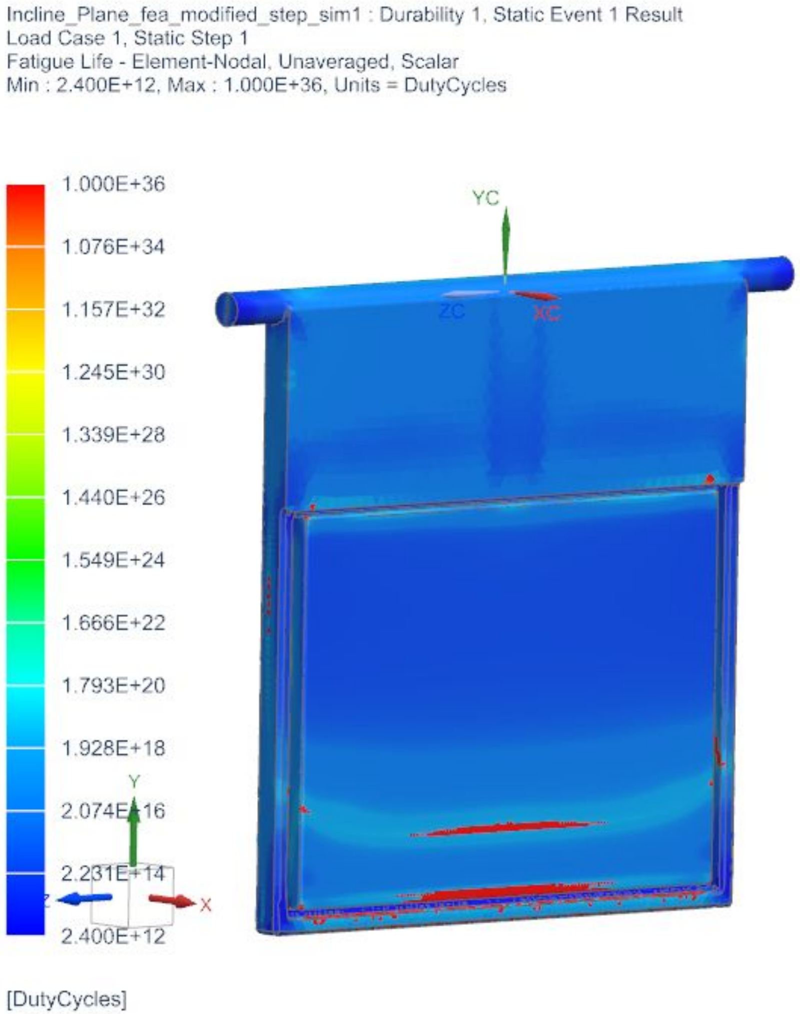


Fatigue Life Test:
Identify Life Cycle of Part given repeated loading

Material	ABS (σ_y = 40 MPa)
Axial Force Applied	0.5 N (Pad Activation Force)
Constraints	Fixed Bottom, Fixed Hinge Ends
Assumptions	Geometric Simplifications

Engineering Analysis (Incline Pad)





Final Minimum Factor of Safety:
477 for an single input force of 0.5N

Final Fatigue Life Estimate:
2.4 * 10^12 cycles

Electrical Analysis - PCB

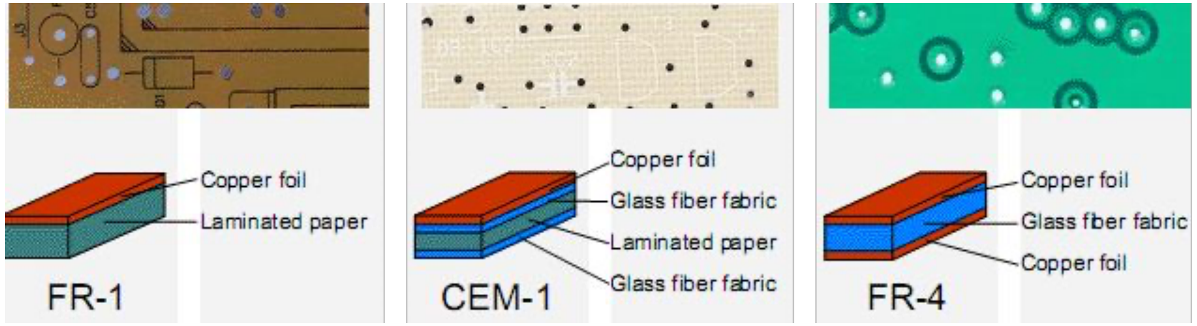
Low Voltage/Current/Power System

18 Volts / 2 Amp / 36 Watt

Minimized thermal concerns

FR-1 & FR-4 are designed to be Flame-Retardant

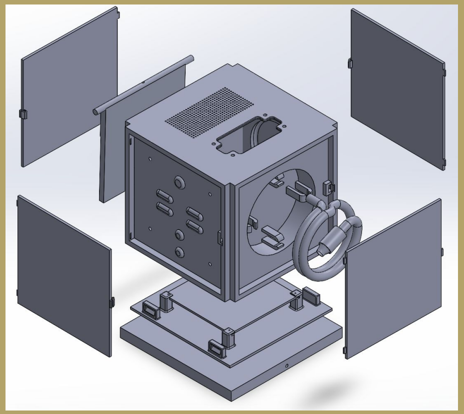
Material	Operating Temperatures (Celcius)	Thermal Conductivity (W/(m*K))	Dielectric Strength (kV/mm)
FR-1	130	0.3	18 - 24
FR-4	100	0.3 - 2	20 - 25
CEM-3	130	0.3 - 1	20 - 25
Polyimide	250	0.25	24 - 30



Conclusions

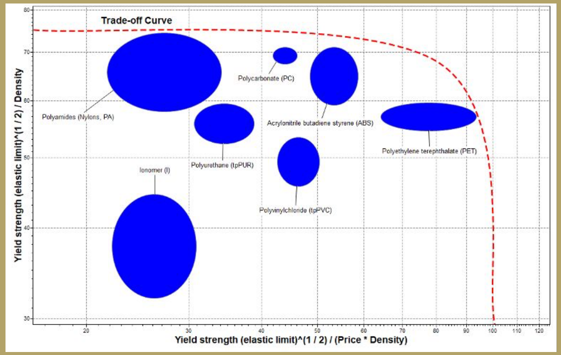
Configurable

Design
Casings & Mechanisms
Turntable
Custom PCB



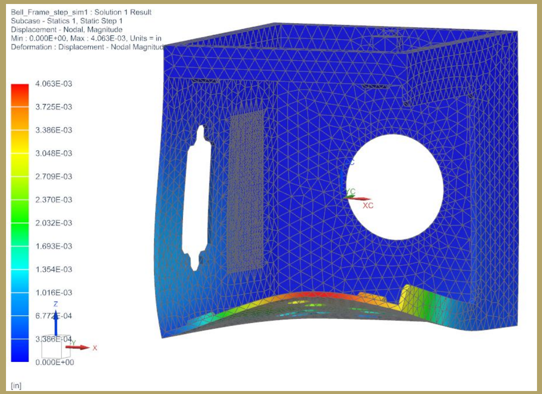
Easy to Use

Material: ABS
Lightweight
Chemical Resistant
Durable



Integrable

FEA & Elect. Analysis
Strength
Lifespan
Sensor Capability



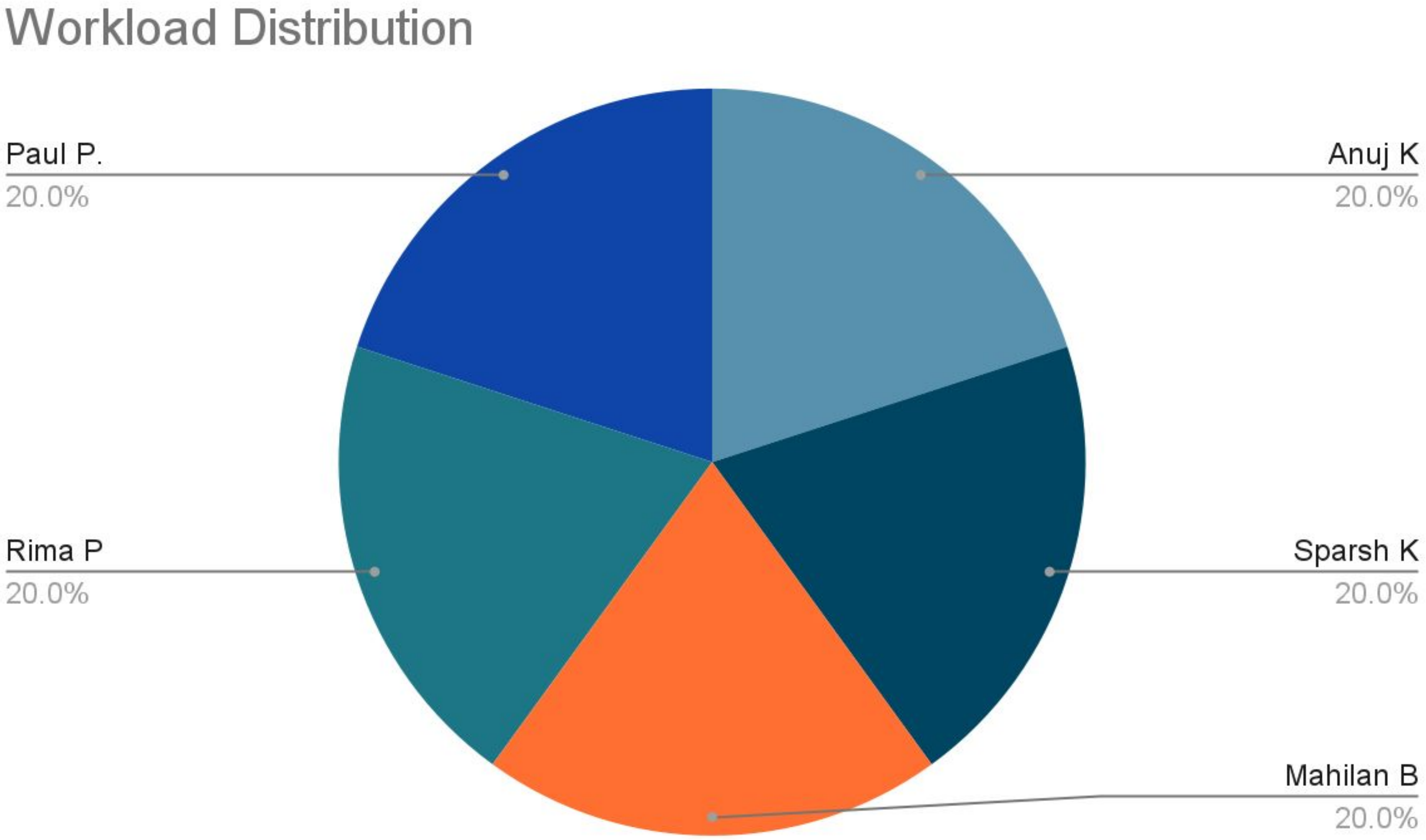
Next Steps & Prototyping Considerations

1. **Component Selection**
   - Sensors, Power Supply
1. **CAD Design**
   - Integration with material and spacing
1. **Analysis**
   - Thermal, Contamination, Lifespan
1. **Prototyping**
   - 3D-Print, Milling, Wiring

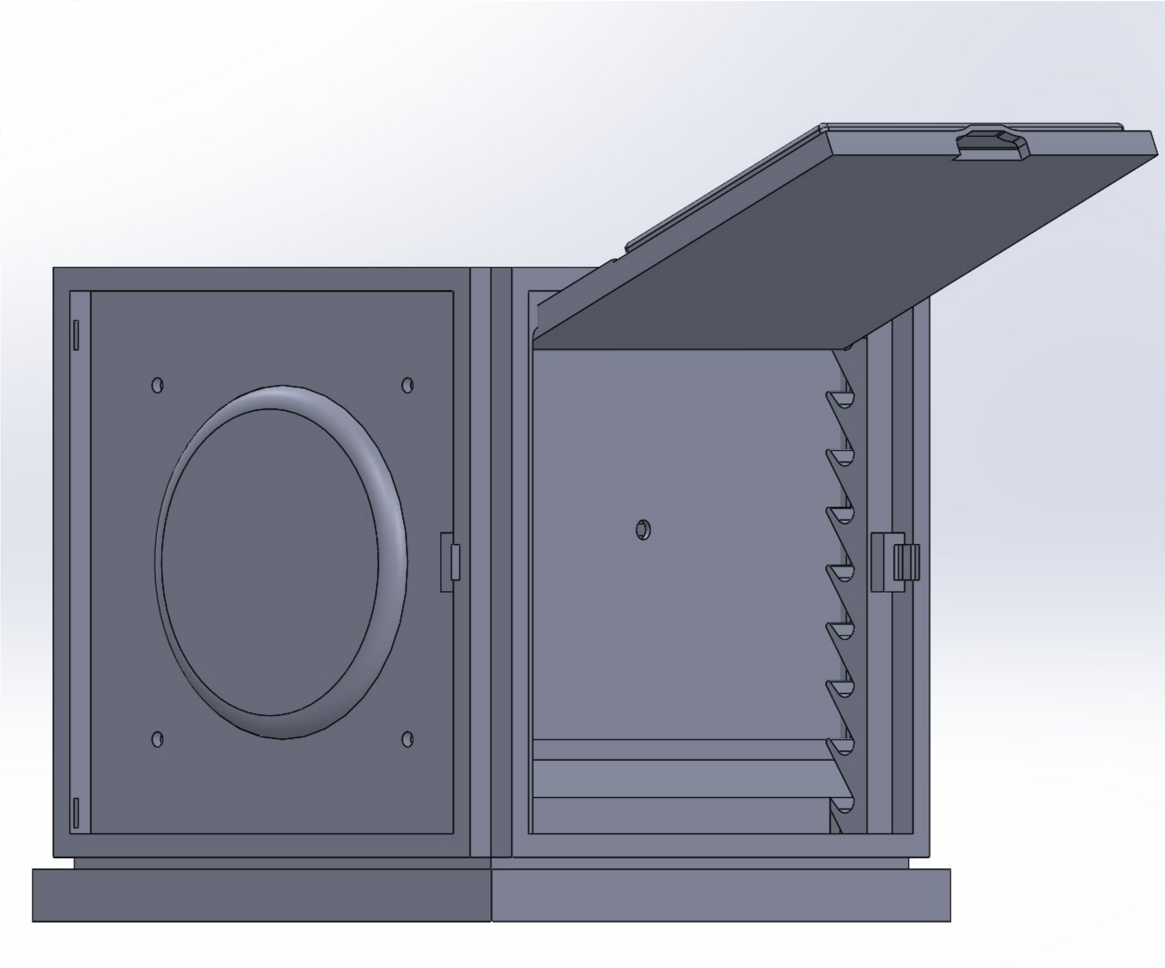
Thank You!

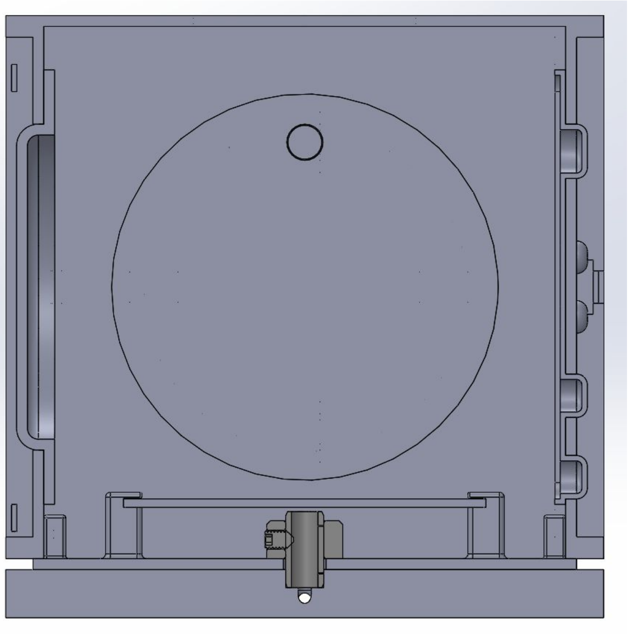
Any Questions?

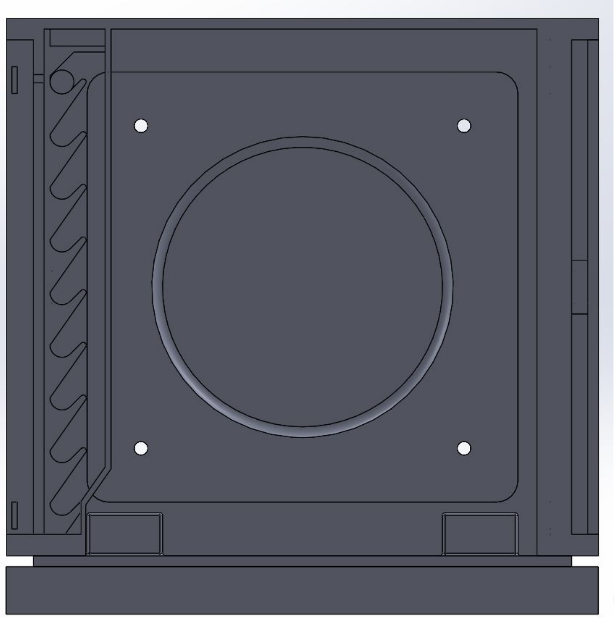
Contribution Distribution



Appendix - Additional CAD Views





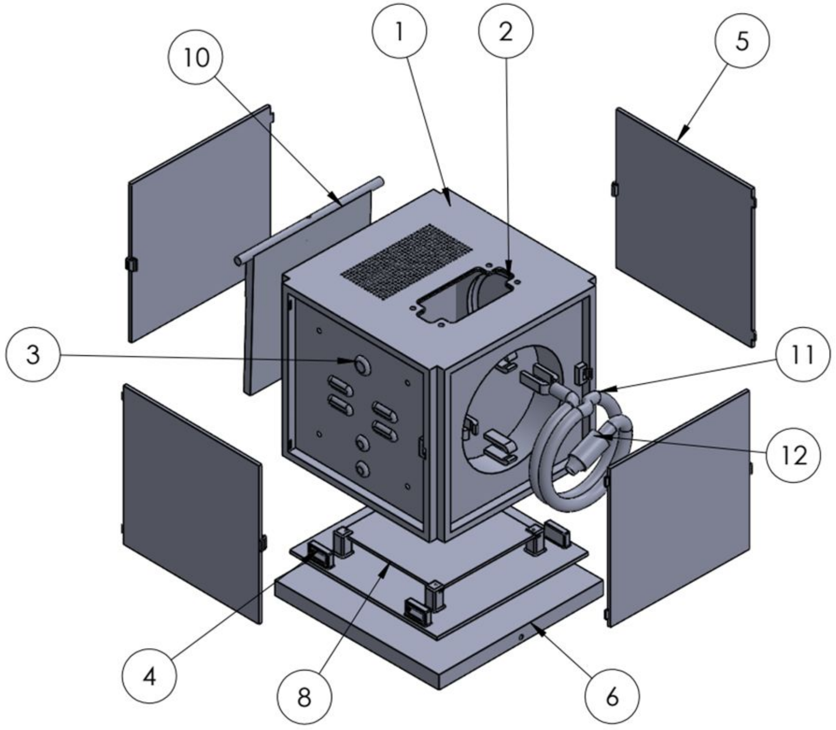


Appendix - Fabrication Drawings

2 1

B

ITEM NO.	PART NUMBER	QTY.
1	Bell Frame	1
2	Mechanical Pad	1
3	Remote Buttons	1
4	Base Plate	1
5	Casing	4
6	Turntable Base	1
7	Hollow Dowel Pin	1
8	PCB Board	1
9	Set Screw Shaft Collar	1
10	Inclined Plane Sub-Assembly	1
11	Gooseneck	1
12	Breathcall Mouth Piece	1



B

A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Bell Assembly

SIZE A | DWG. NO. 1 | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

A

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2 1

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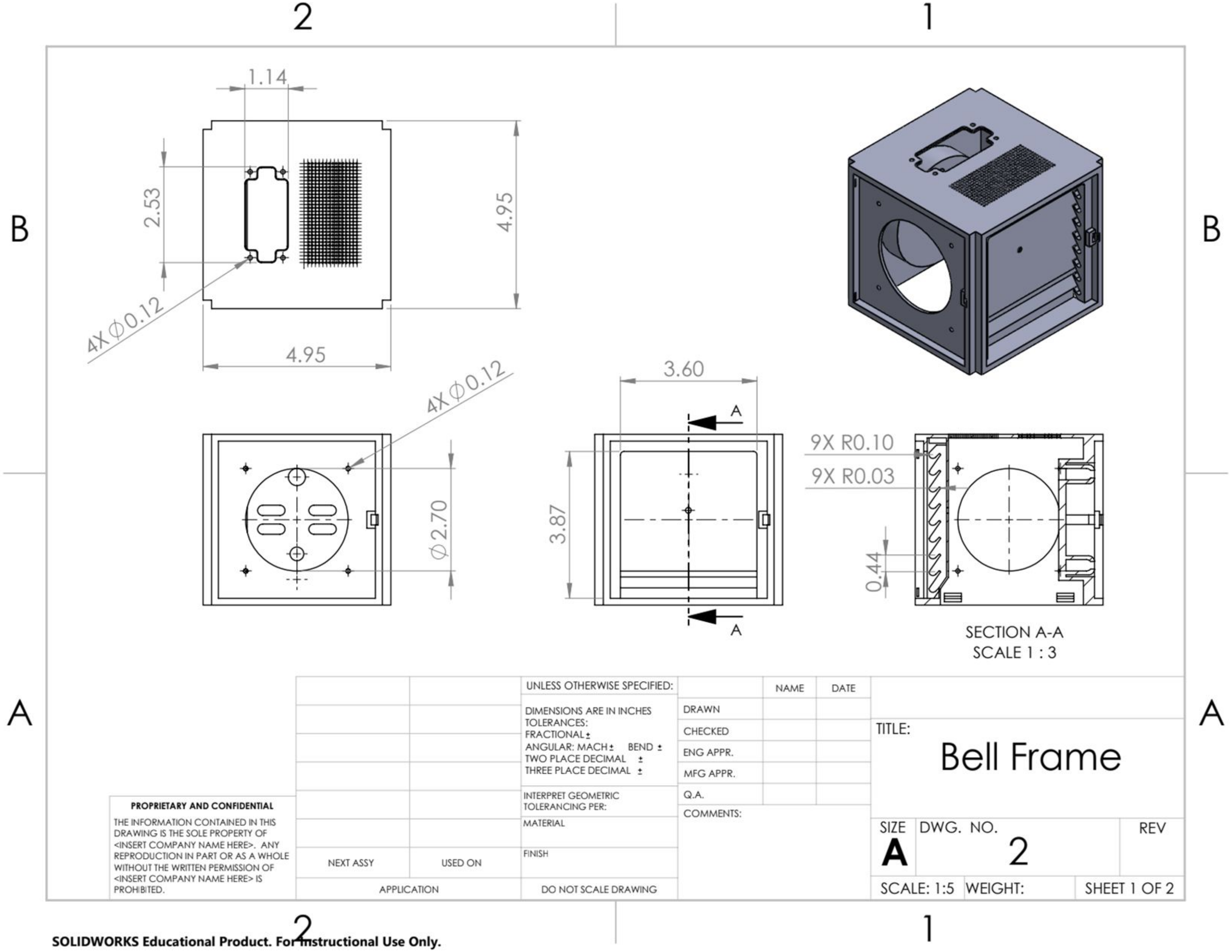
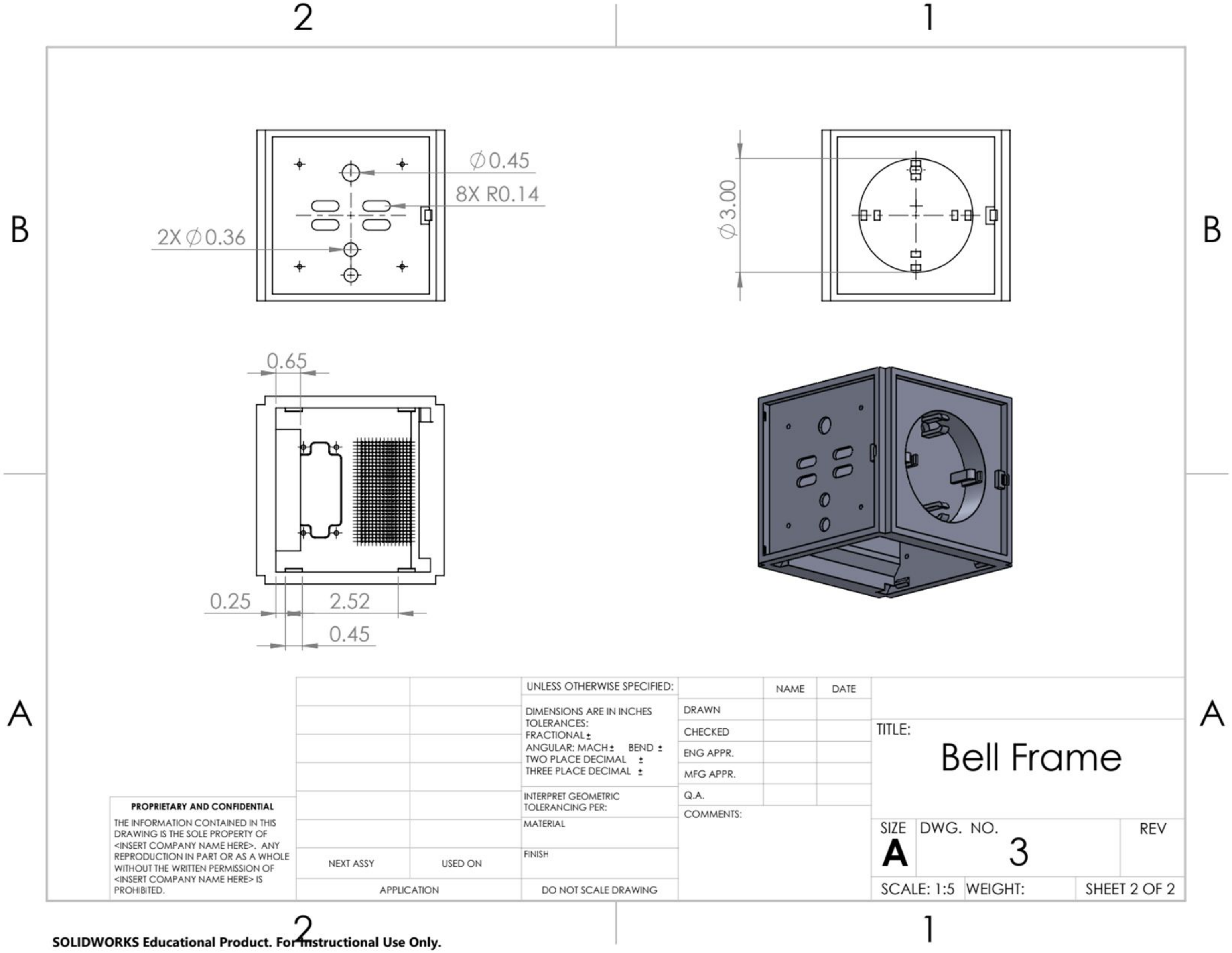
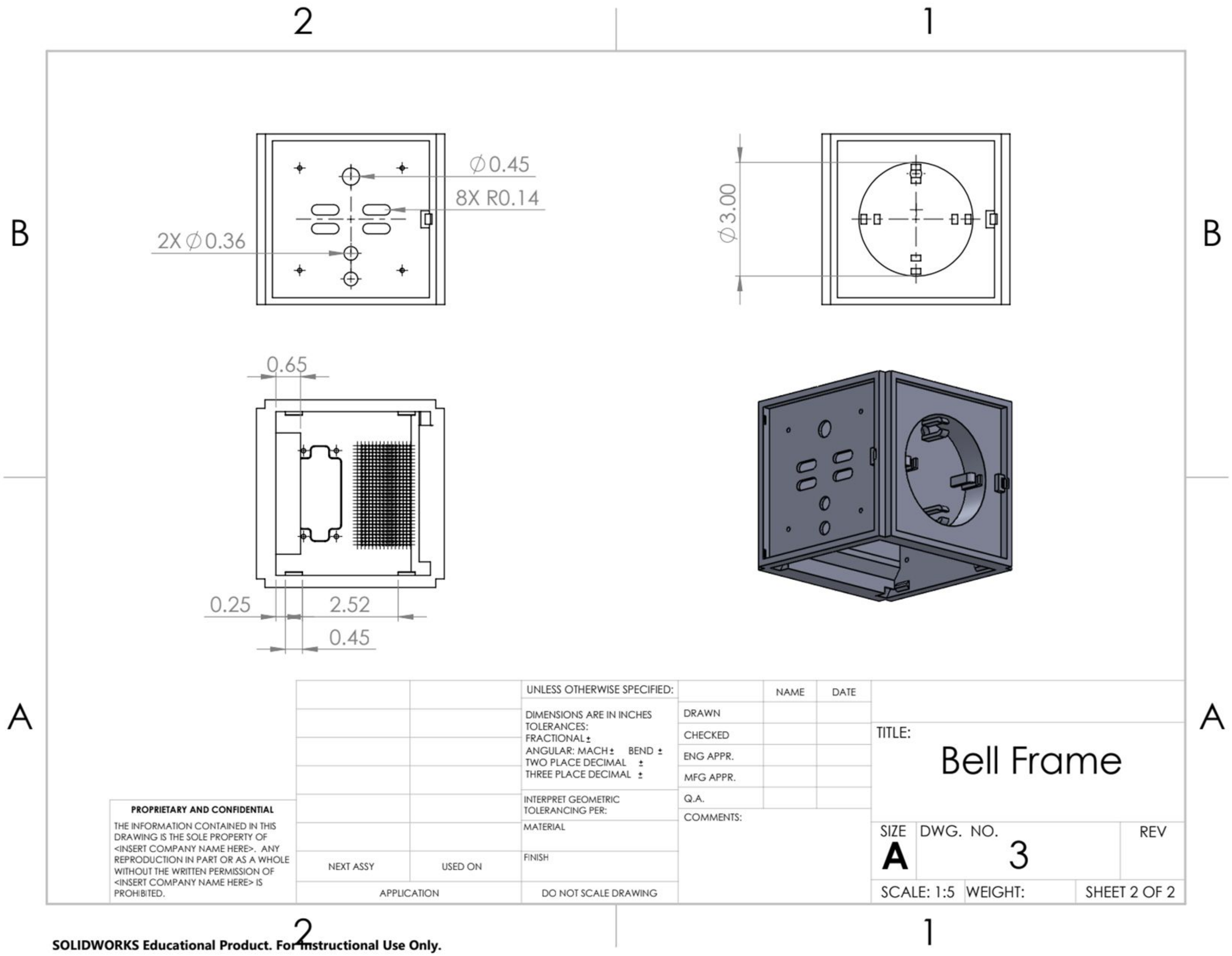
Appendix - Fabrication Drawings



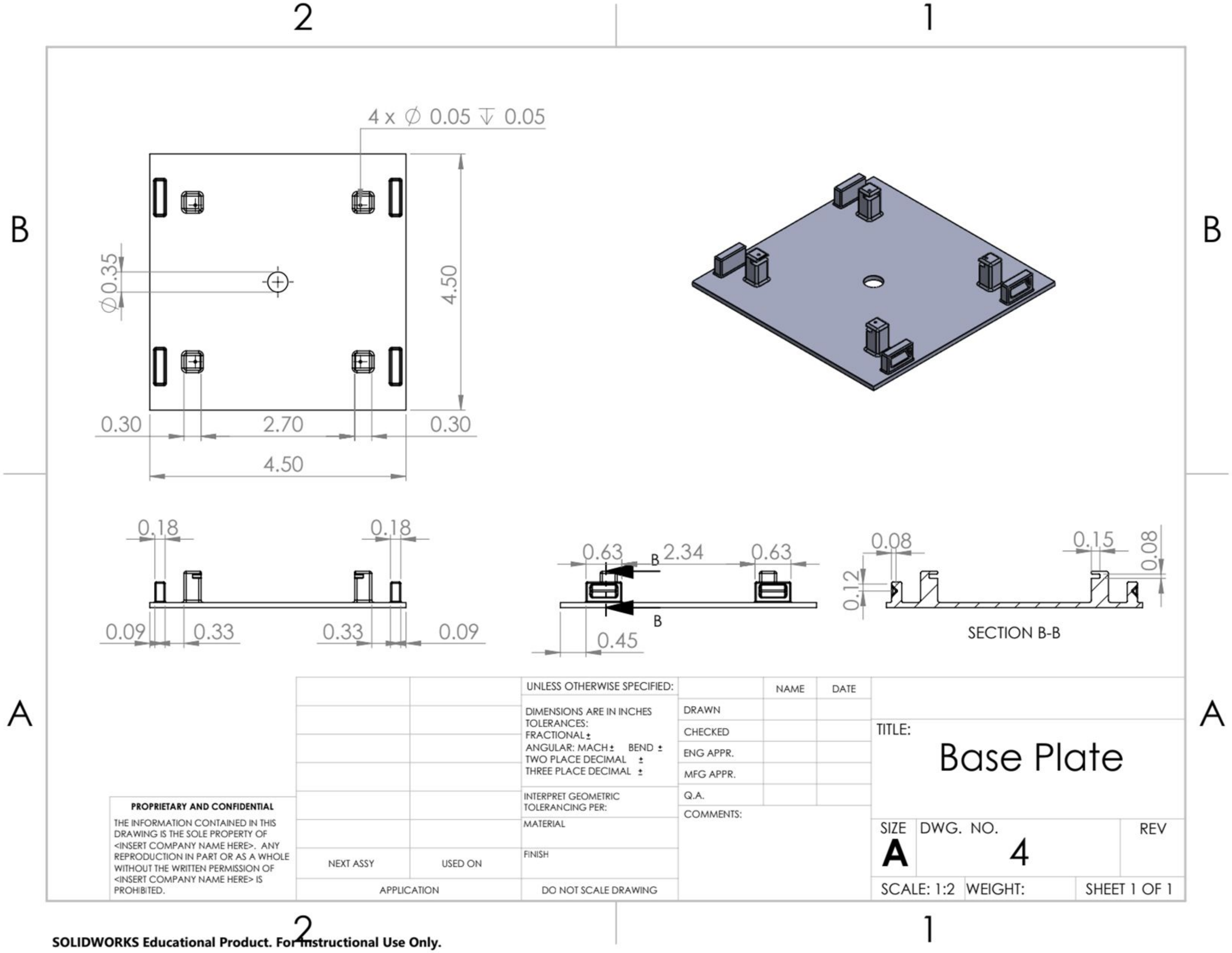
Appendix - Fabrication Drawings



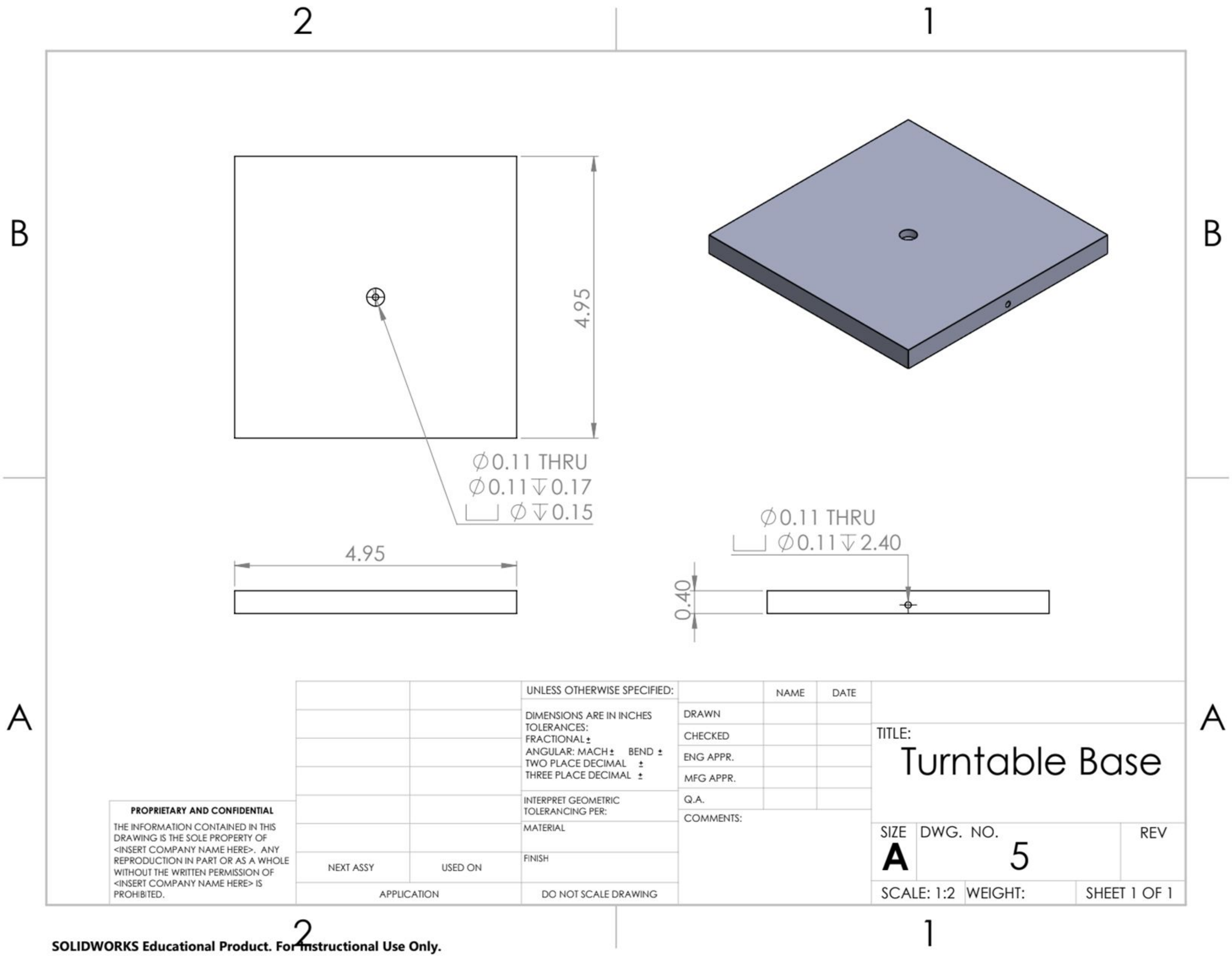
Appendix - Fabrication Drawings



Appendix - Fabrication Drawings



Appendix - Fabrication Drawings



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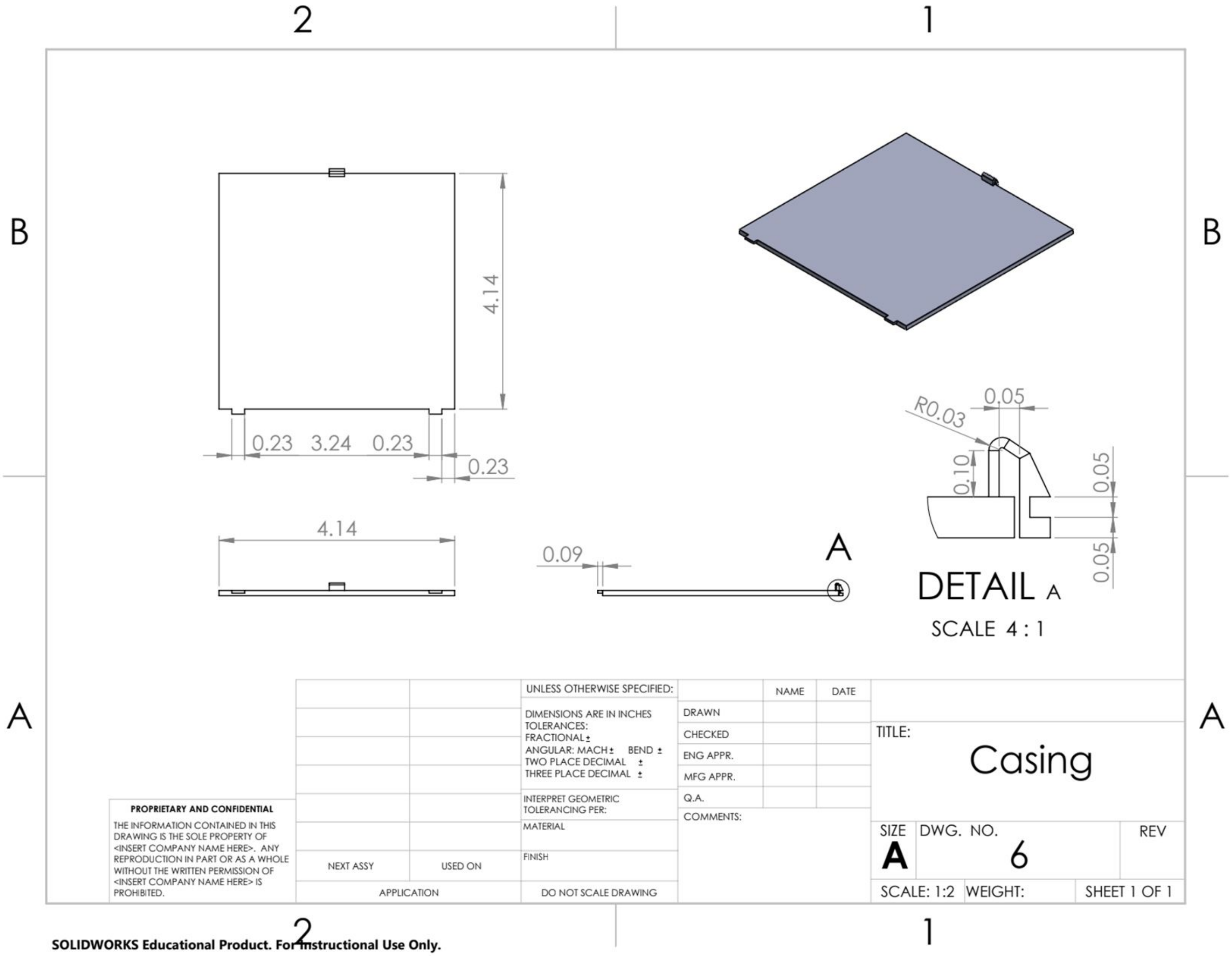
Appendix - Fabrication Drawings



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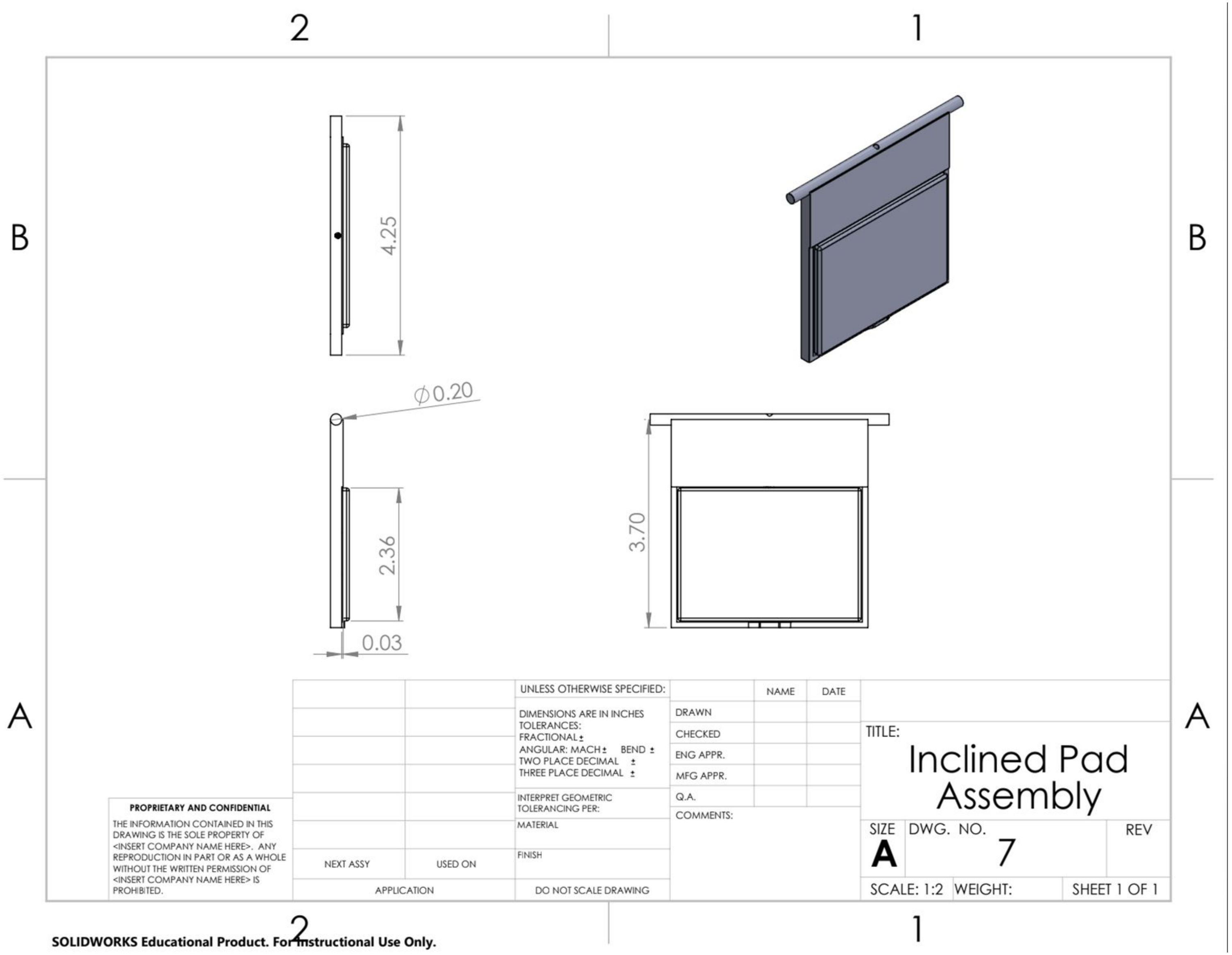
Appendix - Fabrication Drawings

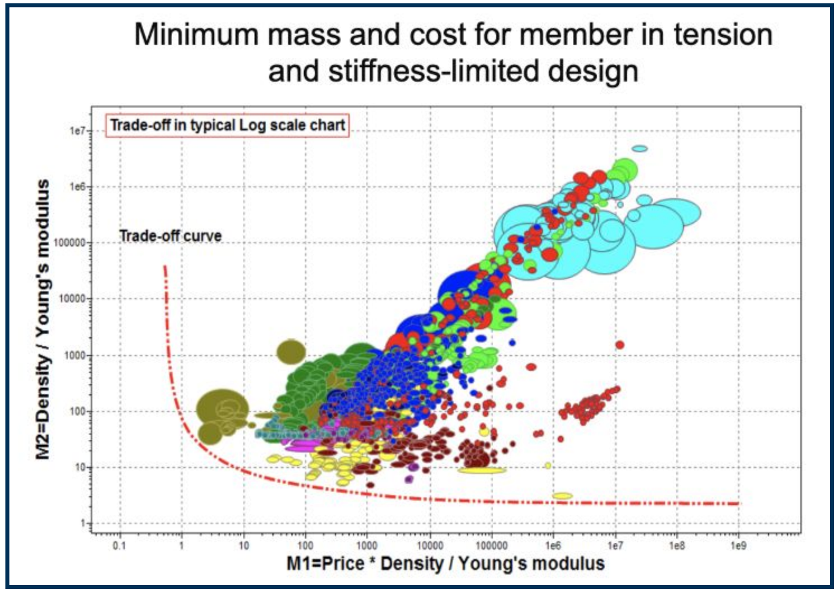


Appendix - Codes and Standards

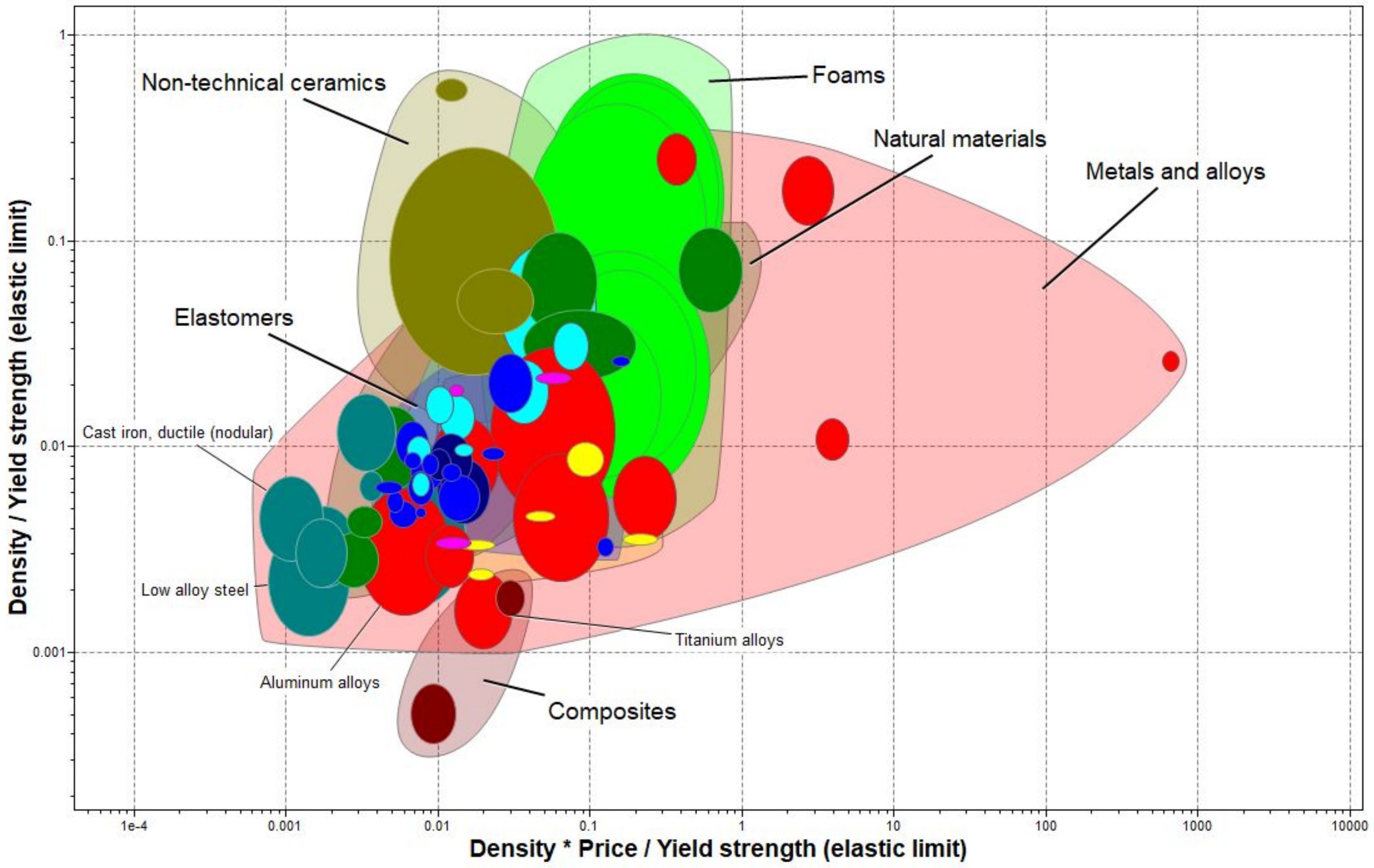
Code/Standard	Relevant FEAs (if applicable)	Design Changes?
IEC 60601-1 (safety and performance of electronic medical devices)	Mechanical Stress Analysis on Frame and Mechanisms	- Modify Push Button Pad - Modify Incline Pad - Modify Breath Call
UL 1069 (nurse call reliability)	N/A	- Ensure sensors can be activated reliably
AAMI HE75 (usability, design, and product life cycle)	N/A	- Standardize design to make changes easily
IEC 80601-2-49 (safety and performance of patient monitor devices)	Mechanical Stress Analysis on Frame and Mechanisms	- Restrict patients from mechanism access
NFPA 99 (Fire & Electrical Safety)	Thermal FEA Analysis	- PCB and Power Supply Placement within Design

Appendix - Engineering Analysis - Material Selection Strategy

Order	*Goals*	*Methods*
1.	**Understand Objectives and Constraints**	e.g. Operate for Patients w/ Little Mobility; Cost (Min.)
2.	**Rank Objectives**	e.g. UL 1069 - (Standard for Hospital Signaling and Equipment)
3.	**Ansys Granta Edupack Analysis**	



Appendix - All Materials



Appendix - Material Selection: Gooseneck

Function

Holds Mouthpiece for Breathcall

Constraints and Objectives

Constant Geometry & Applied Tension

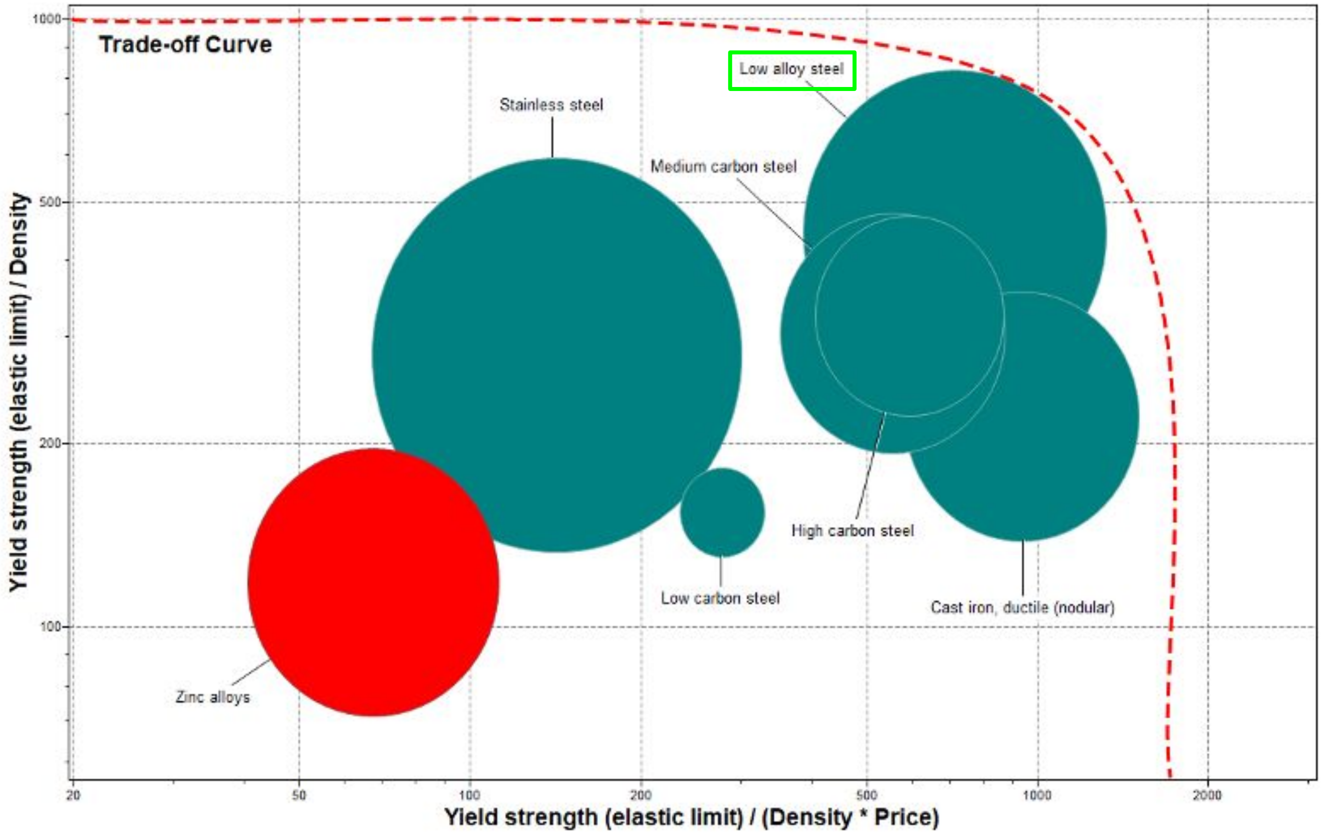
↓ Mass ↓ Cost

Material Indices

Mass: $M_1 = \sigma_y / \rho$

Cost: $M_2 = \sigma_y / \rho * c_m$

Ansys Granta Edupack Analysis



Limitations: Inexpensive (<$2/lb), Tough (>35 ksi*in^3)
Restrictions: Water Resistant, Latex-Free

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Appendix - Material Indices: Bell Frame, Casings, and Turntable

Objective: Mass

$$m = \rho * A * L = \rho * b * h * L \ (1)$$

$$h = \frac{m}{\rho * b * L} \ (2)$$

$$\sigma = \frac{3 * F * L}{2 * b * h^2} \ (3)$$

$$\sigma = \frac{3 * F * L}{2 * b * \left(\frac{m}{\rho * b * L}\right)^2} \ (4)$$

$$m^2 = \frac{3 * F * L^3 * b * \rho^2}{2 * \sigma} \ (5)$$

$$m = \frac{\rho}{\sigma^{1/2}} \sqrt{\frac{3 * F * L^3 * b}{2}} \ (6)$$

$$M_1 = \frac{\rho}{\sigma^{1/2}} \ (7)$$

Objective: Cost

$$c_t = c_m * m = c_m * \rho * A * L = c_m * \rho * b * h * L \ (8)$$

$$h = \frac{c_t}{c_m * \rho * b * L} \ (9)$$

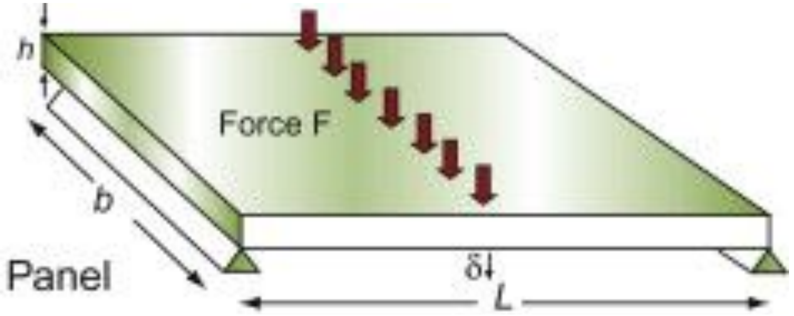
$$\sigma = \frac{3 * F * L}{2 * b * h^2} \ (10)$$

$$\sigma = \frac{3 * F * L}{2 * b * \left(\frac{c_t}{c_m * \rho * b * L}\right)^2} \ (11)$$

$$(c_t)^2 = \frac{3 * F * L^3 * b * \rho^2 * c_m{}^2}{2 * \sigma} \ (12)$$

$$c_t = \frac{c_m * \rho}{\sigma^{1/2}} \sqrt{\frac{3 * F * L^3 * b}{2}} \ (13)$$

$$M_2 = \frac{c_m * \rho}{\sigma^{1/2}} \ (14)$$



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Appendix - PC v PET v ABS

PC v. PET

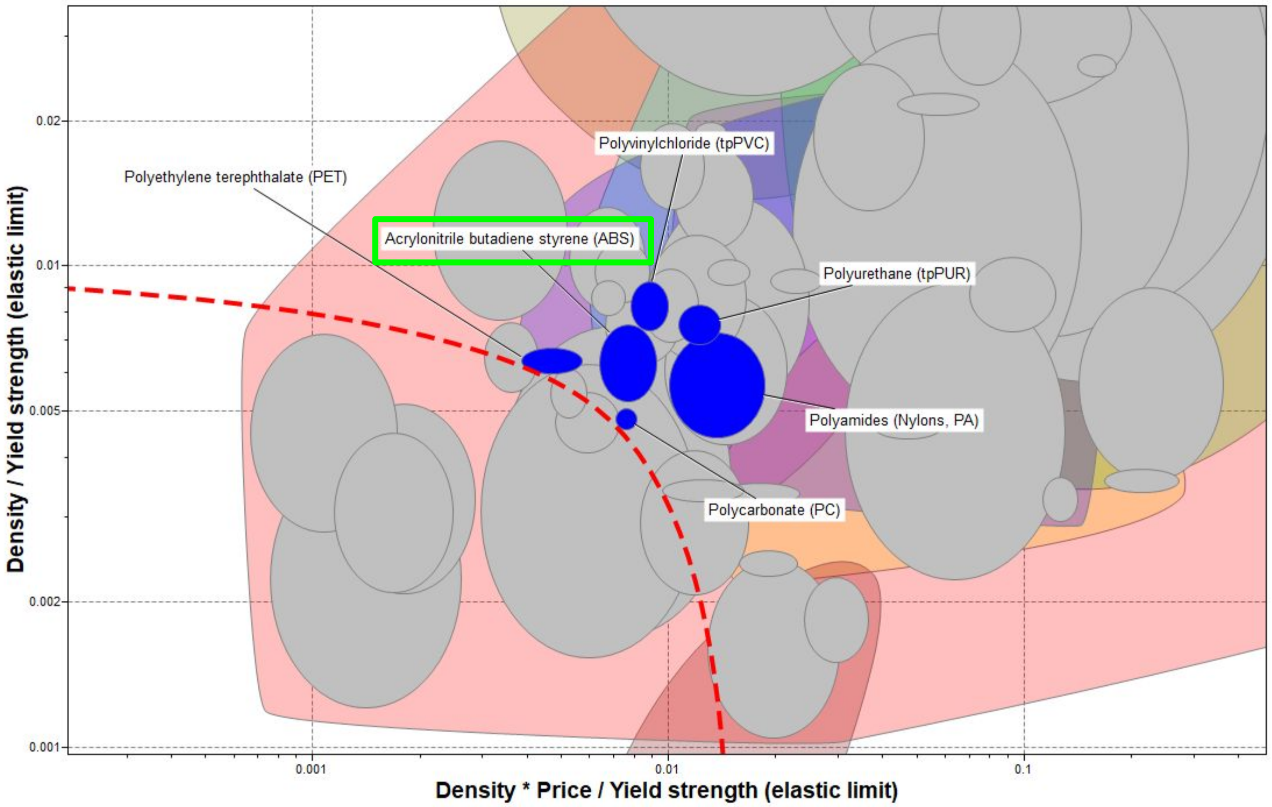
- PC: more durable
- PET: harder to manufacture

ABS v. PC

- ABS: cheaper to manufacture
- PC: more durable

ABS v. PET

- ABS: more durable
- PET: better chemical resistance, (ABS can withstand disinfectant chemicals)



Appendix - Material Indices: Gooseneck

Objective: Mass

$$m = \rho * A * L \ (15)$$

$$A = \frac{m}{\rho * L} \ (16)$$

$$\sigma = \frac{F}{A} \ (17)$$

$$\sigma = \frac{F * \rho * L}{m} \ (18)$$

$$m = \frac{F * L * \rho}{\sigma} \ (19)$$

$$M_3 = \frac{\rho}{\sigma} \ (20)$$

Objective: Cost

$$c_t = c_m * m = c_m * \rho * A * L \ (21)$$

$$A = \frac{c_t}{c_m * \rho * L} \ (22)$$

$$\sigma = \frac{F}{A} \ (23)$$

$$\sigma = \frac{F * c_m * \rho * L}{c_t} \ (24)$$

$$c_t = \frac{F * c_m * \rho * L}{\sigma} \ (25)$$

$$M_4 = \frac{c_m * \rho}{\sigma} \ (26)$$

(a) Tie

Appendix - Material Index: Soft Button and Remote Buttons

Objective: Mass

$$m = \rho * A * L = \rho * b * h * L \ (1)$$

$$h = \frac{m}{\rho * b * L} \ (2)$$

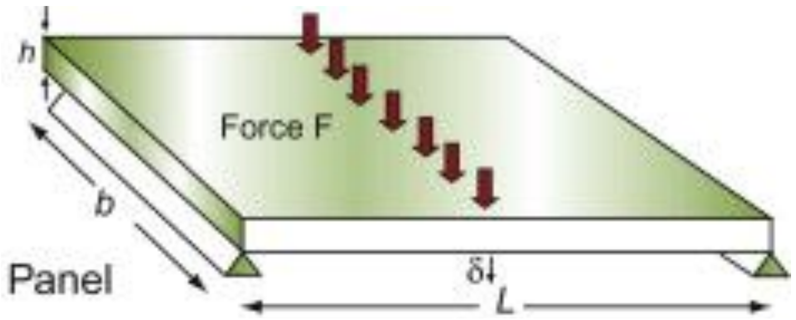
$$\sigma = \frac{3 * F * L}{2 * b * h^2} \ (3)$$

$$\sigma = \frac{3 * F * L}{2 * b * \left(\frac{m}{\rho * b * L}\right)^2} \ (4)$$

$$m^2 = \frac{3 * F * L^3 * b * \rho^2}{2 * \sigma} \ (5)$$

$$m = \frac{\rho}{\sigma^{1/2}} \sqrt{\frac{3 * F * L^3 * b}{2}} \ (6)$$

$$M_1 = \frac{\rho}{\sigma^{1/2}} \ (7)$$



Appendix - FMEA Criteria

Frequency of Exposure	Severity			
	Catastrophic	Critical (2)	Marginal (3)	Negligible (4)
Frequent	A1	A2	A3	A4
Probable	B1	B2	B3	B4
Occasional	C1	C2	C3	C4
Remote	D1	D2	D3	D4
Risk Levels	High	Medium	Low	
1	Catastrophic	major injury to patient, nurse		
2	Critical	damage to property, and or minor injury		
3	Marginal	damage to product only		
4	Negligible	reparable damage to product only, no injuries		
A	Frequent	every time product is operated		
B	Probable	every time product is newly installed		
C	Occasional	during/following maintenance		
D	Remote	not expected during life of product		

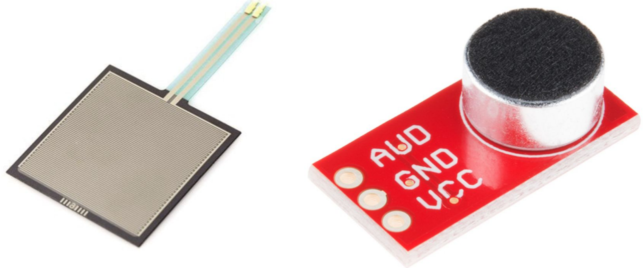
Appendix - Next Steps & Prototyping Considerations (Full)

Original Equipment Manufacturer (OEM) Parts

- 3D Prints
  - Box Housings
    - Fillets & Chamfers
  - Sensor Frames
    - Sensor Integration
- Resin Prints
  - Soft Button
  - Remote Buttons
  - Mechanical Seals

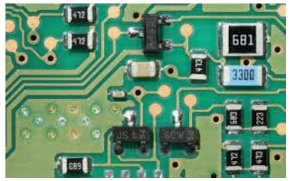
Commercial Off the Shelf Parts (COTS)

- Sensors
  - Tekscan
- Power Supply
  - [Manufacturer]
- Microphone & Speaker
  - Digikey
- Power Cord
  - [Manufacturer]



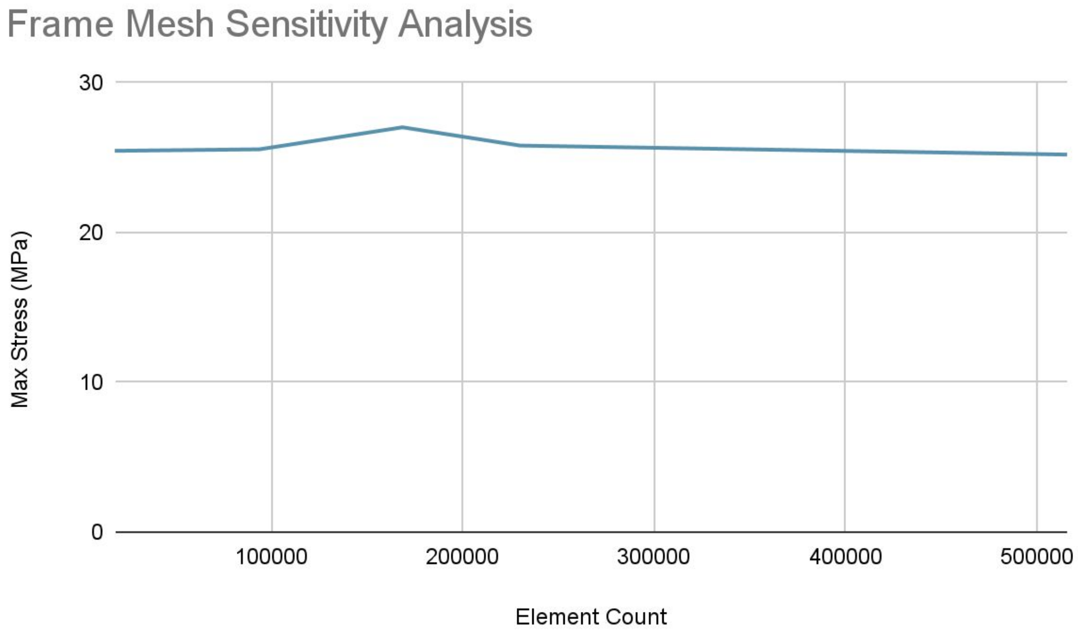
Electrical

- PCB Design
  - PCB Milling
- Sensor Selection & Placement
  - Thermal FEA
- Wiring Plan
- Soldering Connections

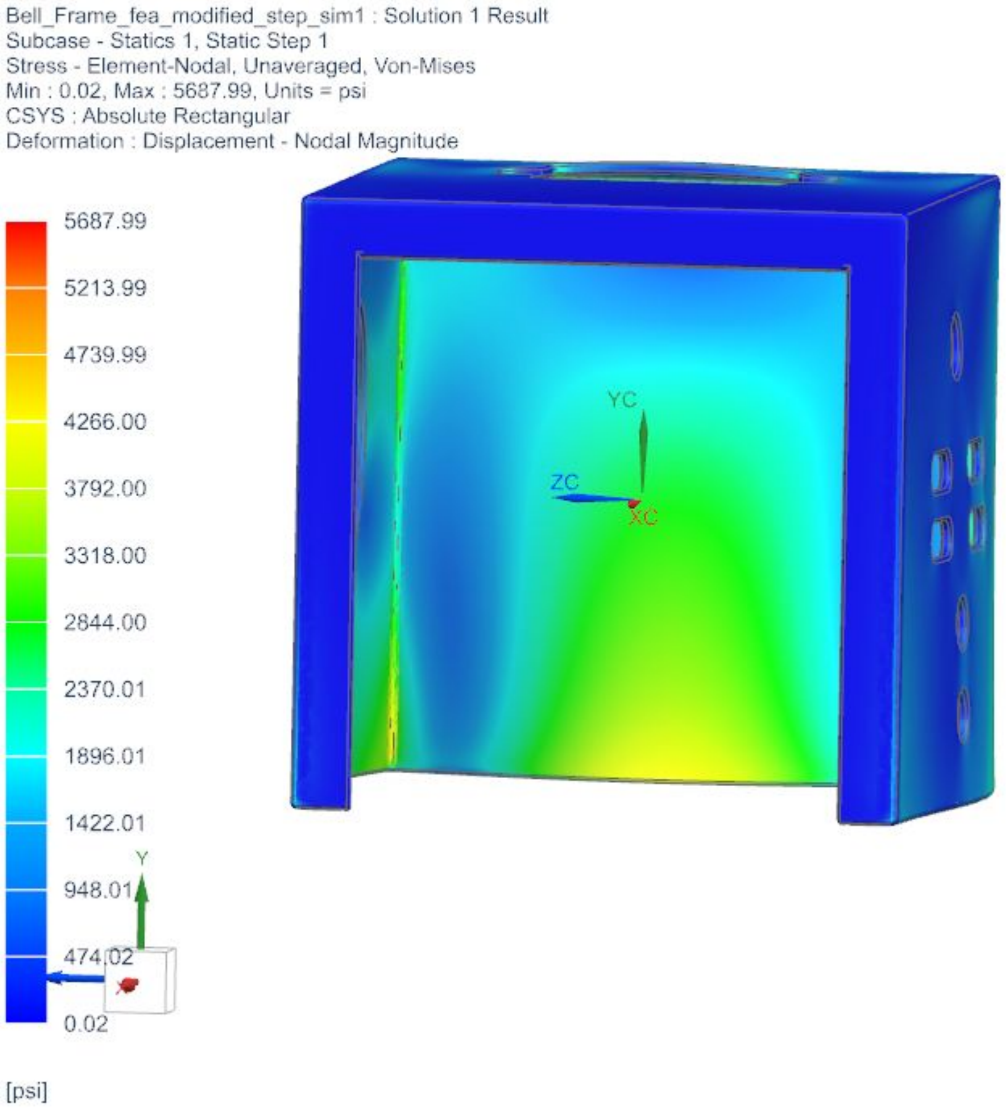


Appendix - Engineering Analysis (Bell Frame)

Frame Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA 10)	Element Count	Test Force	Max Stress	Safety Factor (40 / Max Stress)
1	0.25 in	18338	250 N	25.45 MPa	1.57
2	0.1 in	93830	250 N	25.55 MPa	1.57
3	0.075 in	168616	250 N	27.02 MPa	1.48
4	0.1 in (0.04 in Mesh Control)	230051	250 N	25.80 MPa	1.55
5	0.01 in (0.03 in Mesh Control)	515751	250 N	25.20 MPa	1.59



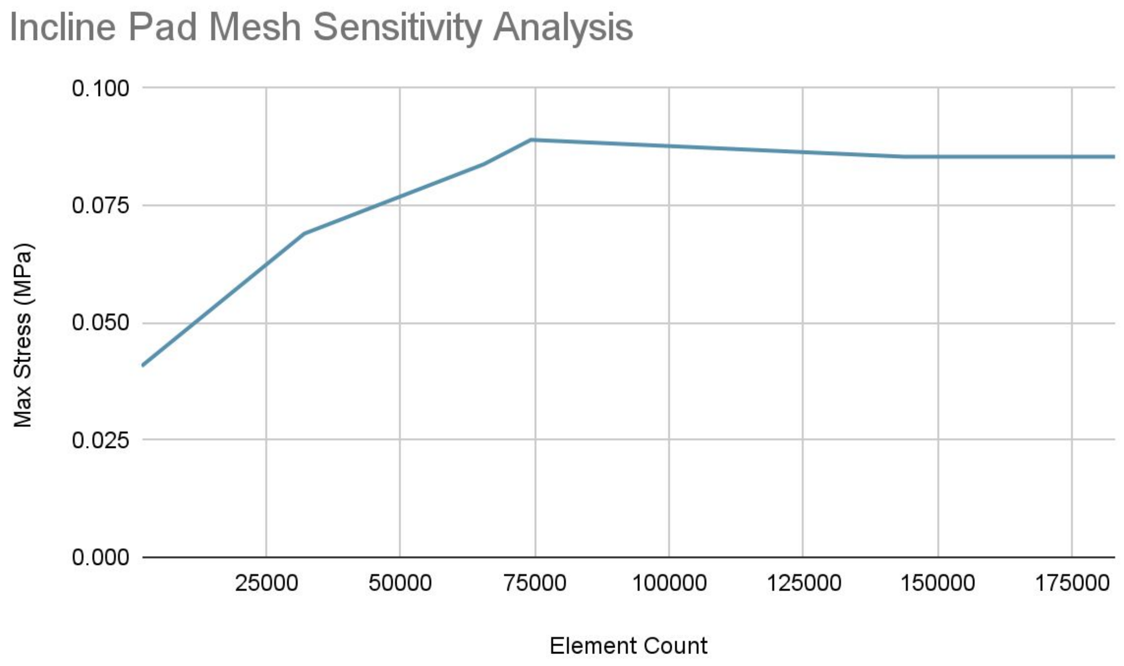
Appendix - Engineering Analysis (Bell Frame)



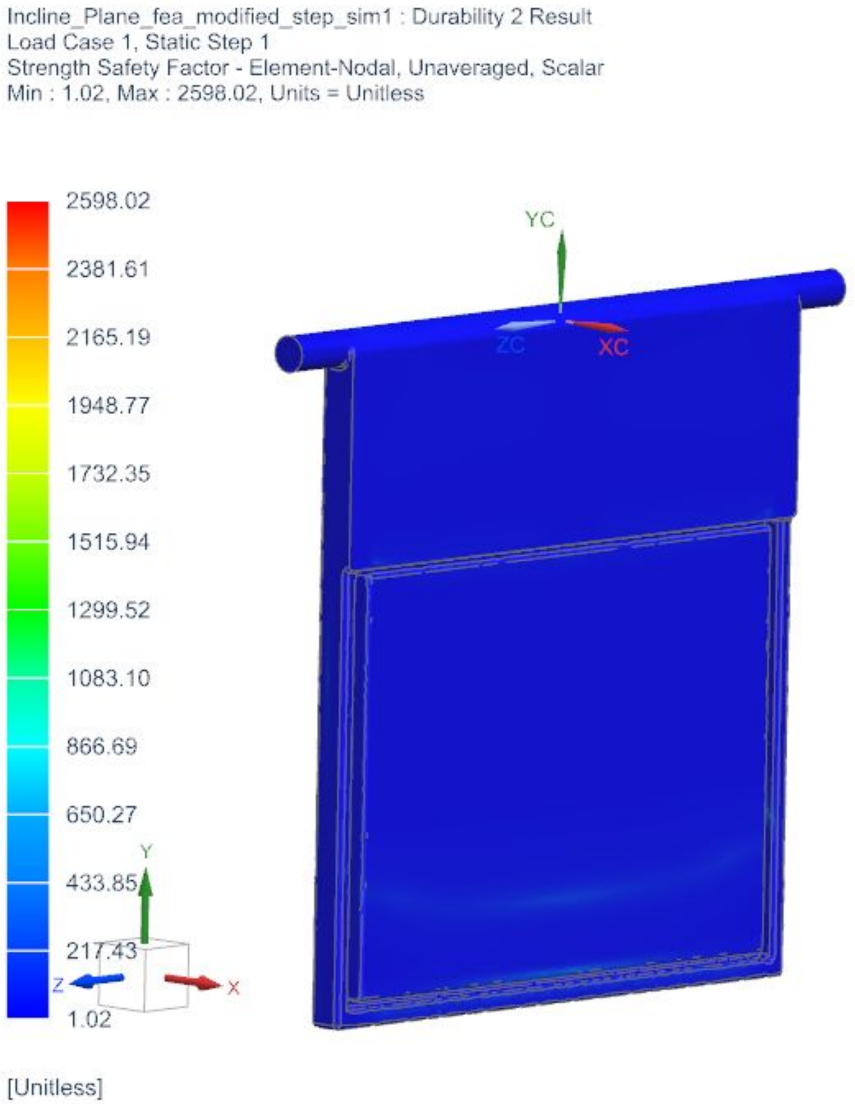
Location of Max Stress in the bottom and corners of impact side

Appendix - Engineering Analysis (Incline Pad)

Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA10)	Element Count	Test Force	Max Stress	Safety Factor (40 / Max Stress)
1	0.5 in	1692	0.5 N	0.04076 MPa	981
2	0.1 in	32021	0.5 N	0.069 MPa	580
3	0.075 in	65477	0.5 N	0.0838 MPa	477
4	0.0.075 in (0.05 in Mesh Control)	74244	0.5 N	0.089 MPa	449
5	0.075 in (0.03 in Mesh Control)	143784	0.5 N	0.0854 MPa	468
6	0.075 in (0.025 in Mesh Control)	183110	0.5 N	0.0854 MPa	477



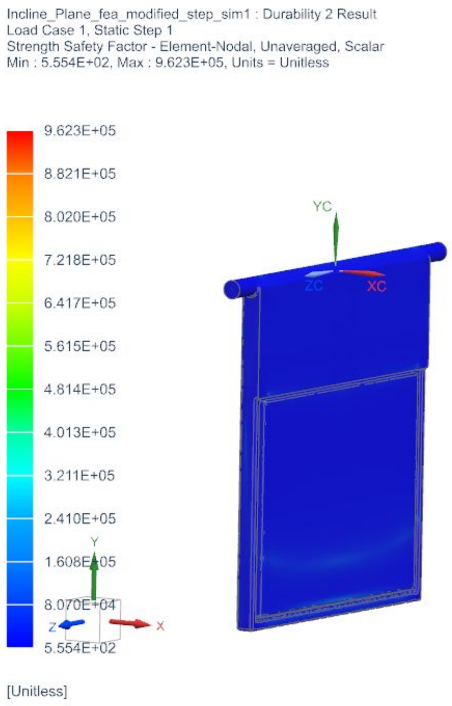
Appendix - Engineering Analysis (Incline Pad)

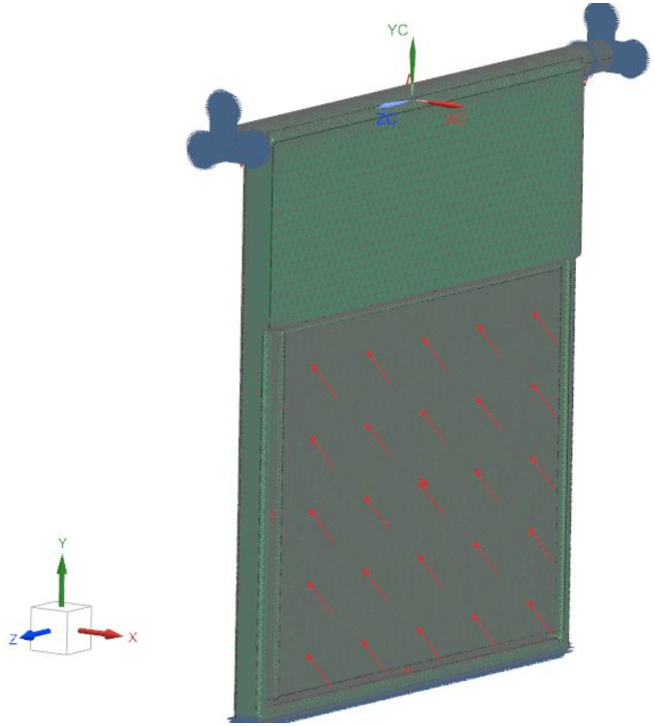


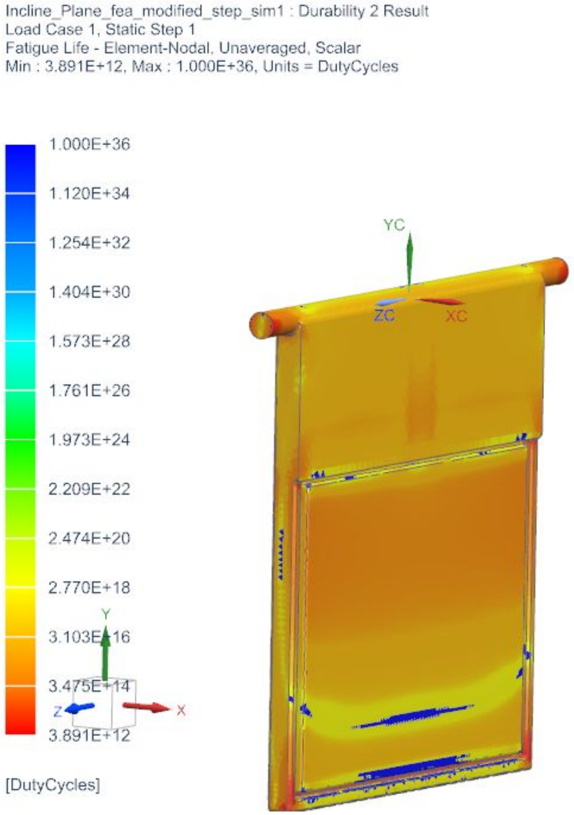
Applied Force of approximately 230N on the Pad results in near Yield Failure (Near FOS of 1)

Georgia Tech

Appendix - Engineering Analysis (Incline Pad)



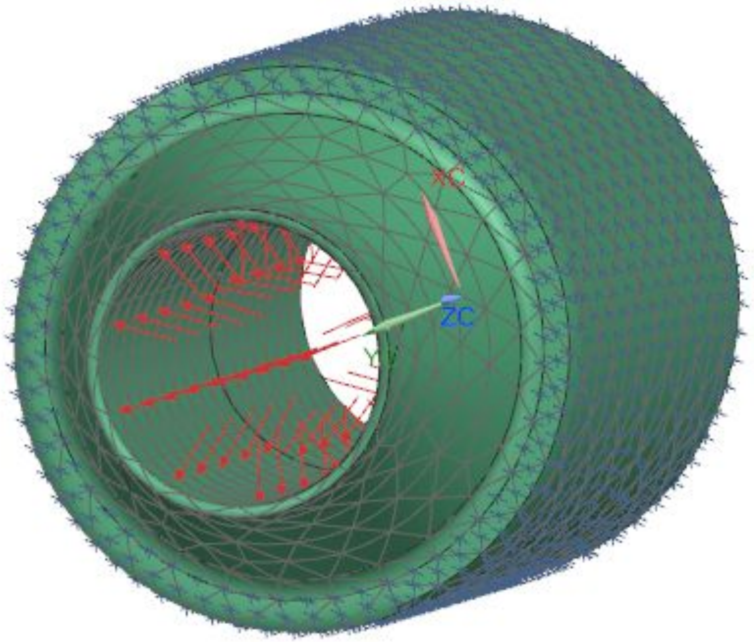




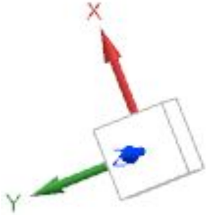
Final Minimum Factor of Safety:
555 for an single input force of 0.5N

Final Fatigue Life Estimate:
3.89* 10^12 cycles

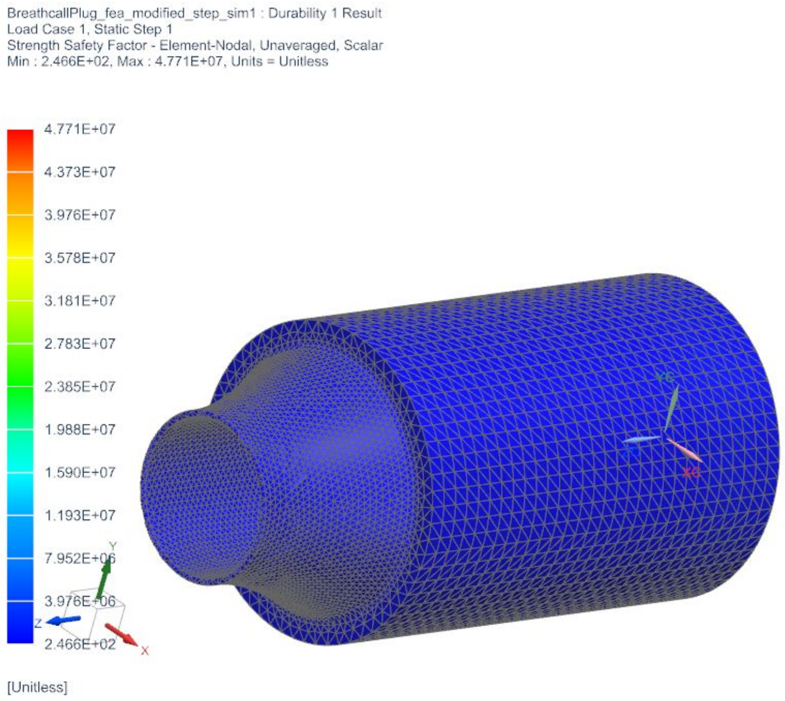
Appendix - Engineering Analysis (Breathcall Mouthpiece)

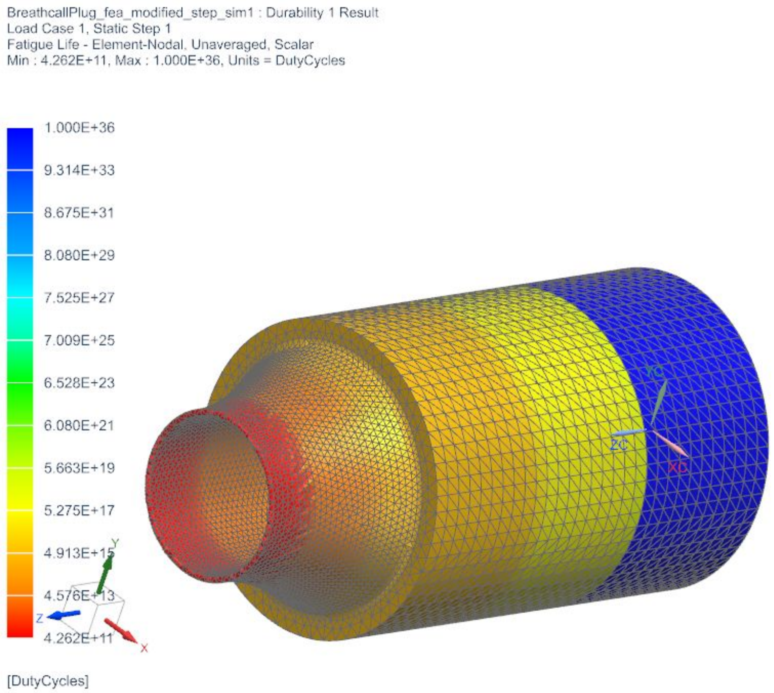


Material	ABS (σ_y = 40 MPa)
Force Applied	**Pressure Load (1 psi) radially inside mouthpiece**
Constraints	Fixed End of Mouthpiece
Assumptions	Geometric Simplifications



Engineering Analysis (Breathcall Mouthpiece)



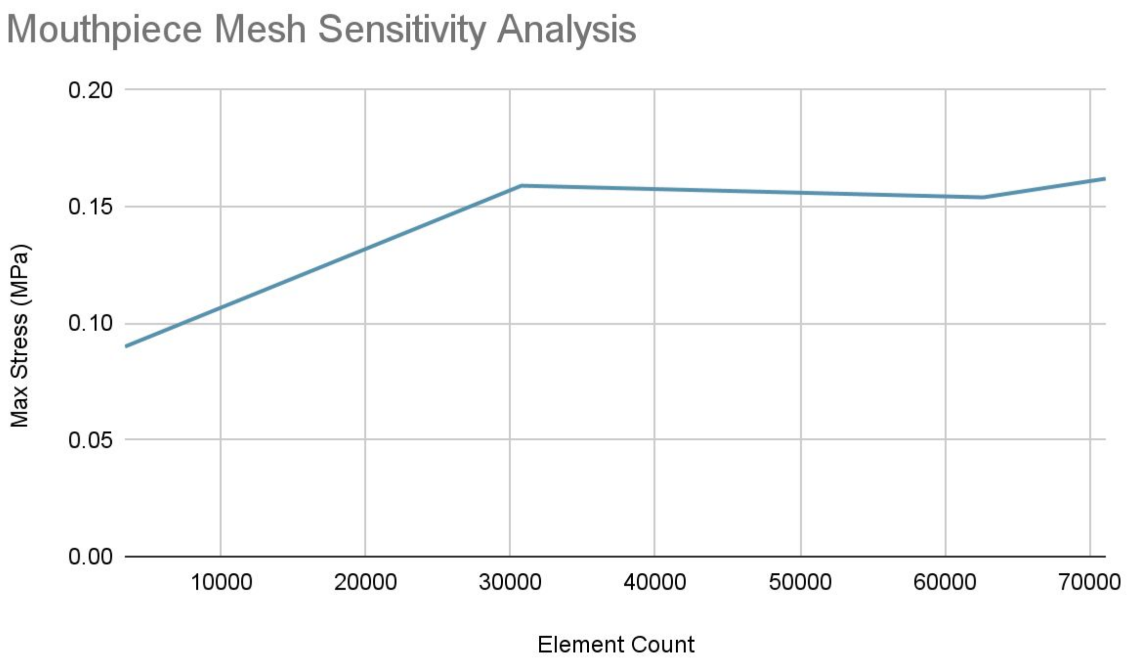


Final Minimum Factor of Safety:
246.6 for an input load of 1 PSI (Very Reliable)

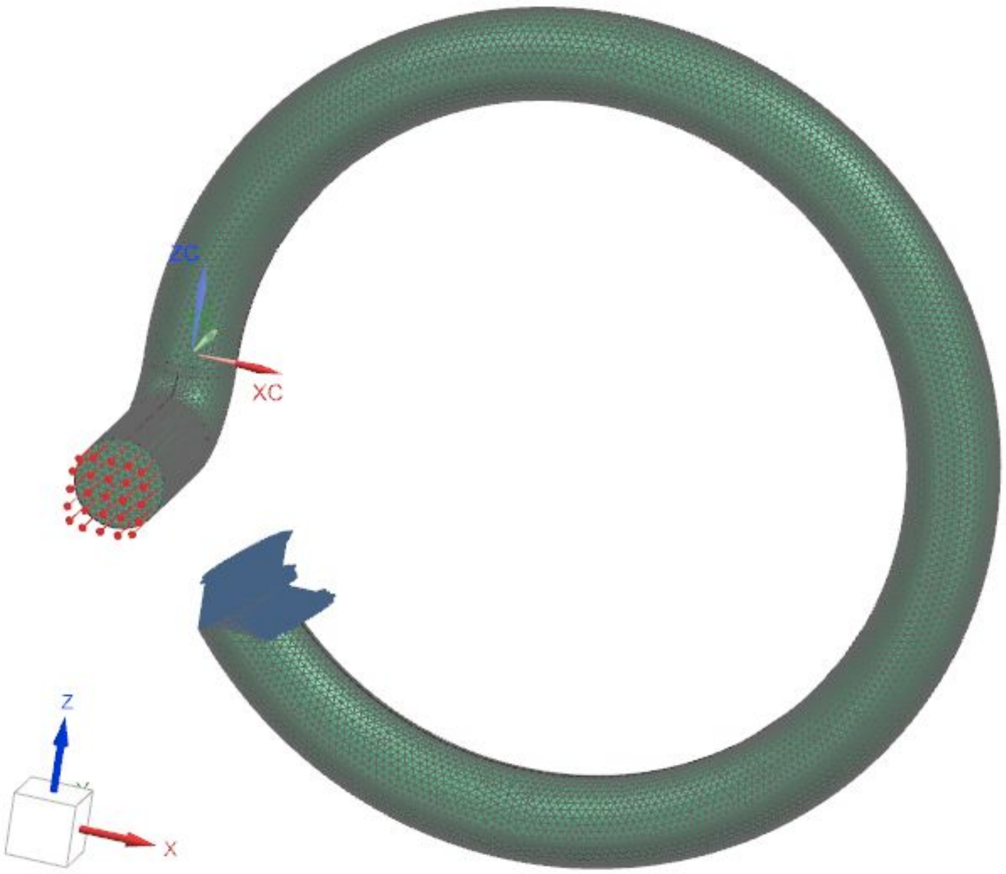
Final Fatigue Life Estimate:
4.262 * 10^11 cycles

Appendix - Engineering Analysis (Breath Call)

Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA10)	Element Count	Test Pressure	Max Stress	Safety Factor (40 / Max Stress)
1	0.1	3384	1 psi	0.090 MPa	444
2	0.025 in (0.0125 in Mesh Control)	30754	1 psi	0.159 MPa	252
3	0.025 in (0.0115 in Mesh Control)	62637	1 psi	0.154 MPa	260
4	0.025 in (0.05 in Mesh Control)	71086	1 psi	0.162 MPa	247

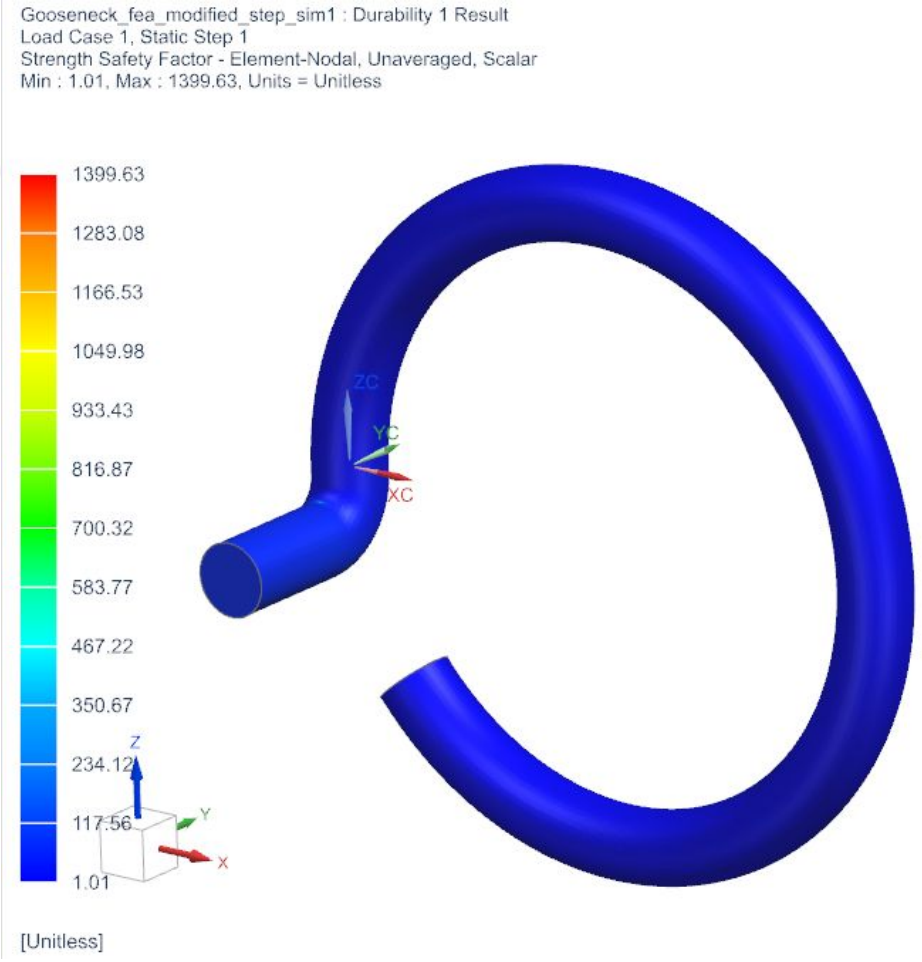


Appendix - Engineering Analysis (Gooseneck)



Material	Steel at 20C (σ_y = 137.895 MPa)
Force Applied	80N
Constraints	Fixed at End attached to Frame
Assumptions	Pull Force is axial load

Appendix - Engineering Analysis (Gooseneck)

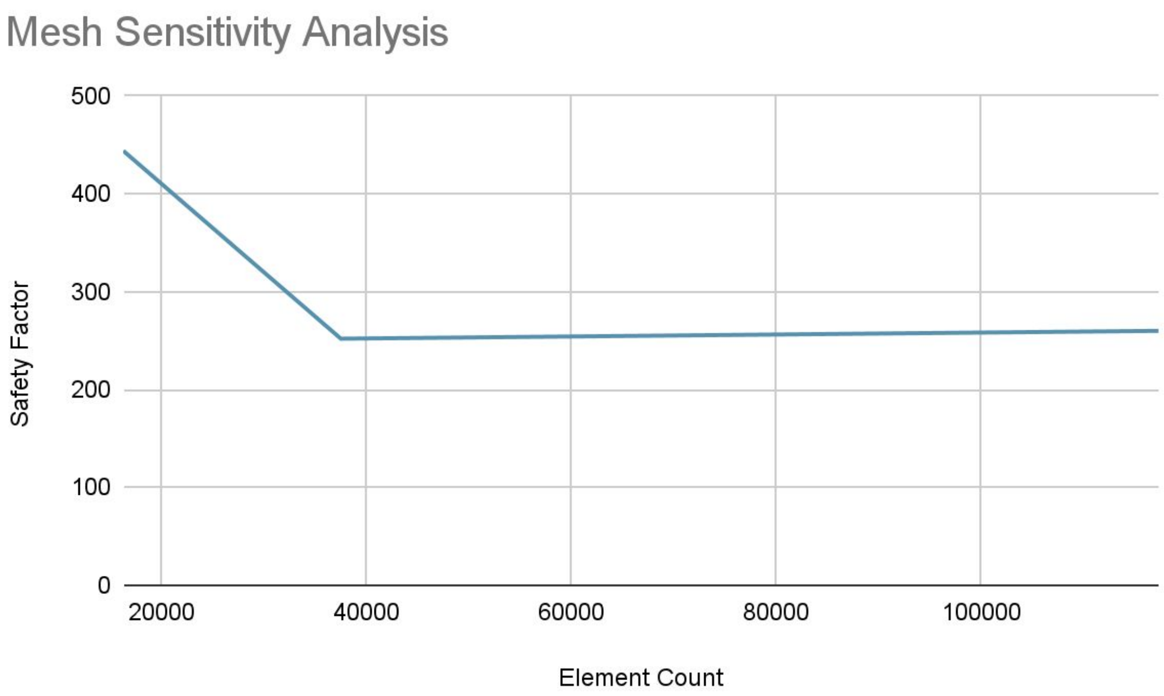


Maximum Pull Force Gooseneck can withstand before yielding is 80N

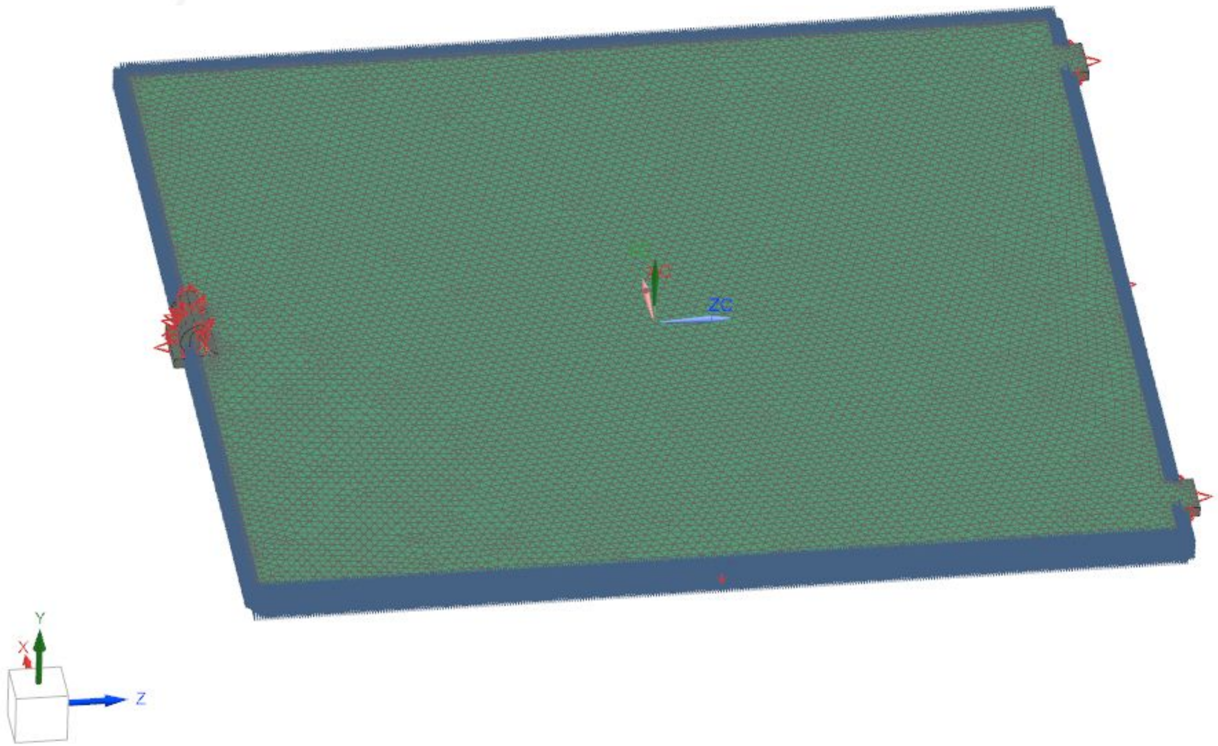
Final Minimum Factor of Safety:
1.01 for an axial load of 80N

Appendix - Engineering Analysis (Gooseneck)

Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA10)	Element Count	Test Force	Max Stress	Safety Factor (40 / Max Stress)
1	0.1 in	16252	10 N	0.090 MPa	444
2	0.05 in	37488	10 N	0.159 MPa	252
3	0.025 in	117296	10 N	0.154 MPa	260

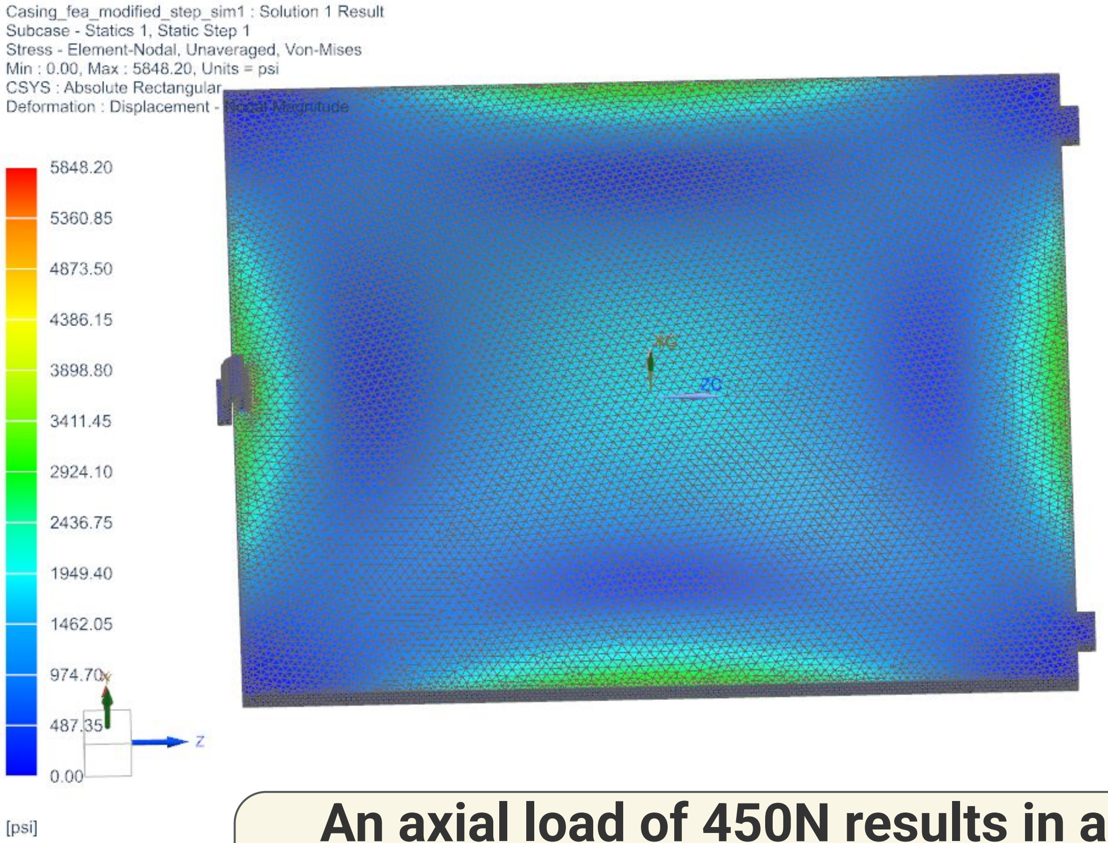


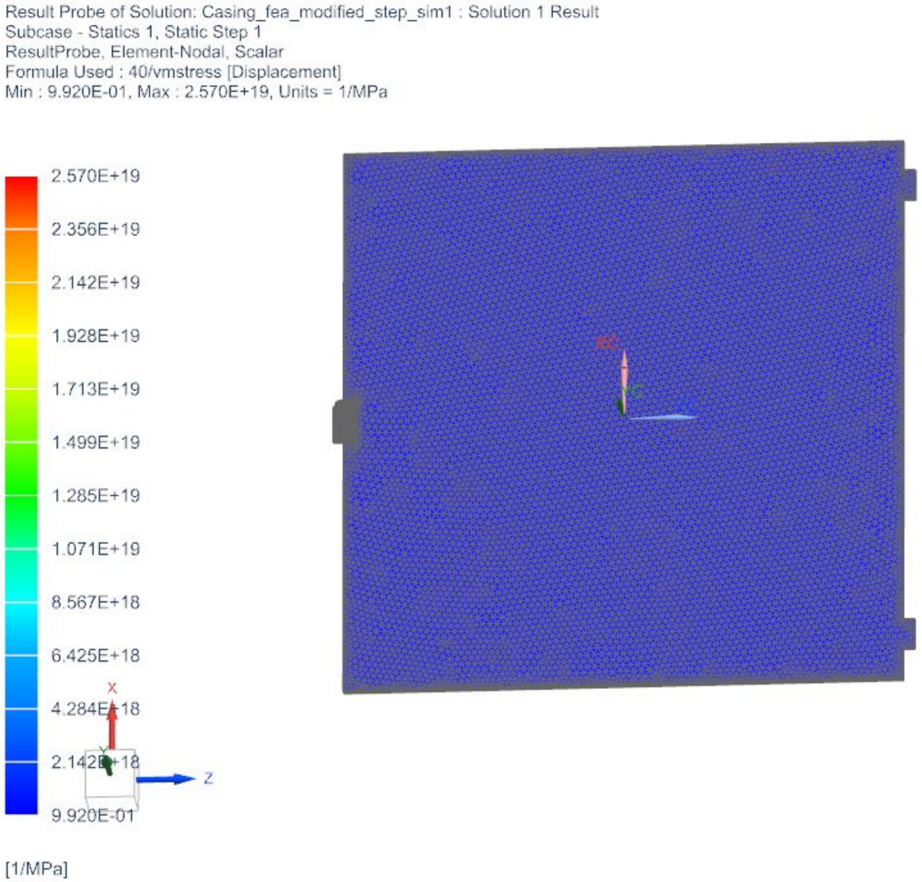
Appendix - Engineering Analysis (Casing)



Material	ABS (σ_y = 40 MPa)
Forces Applied	10N, Yield Failure Force (TBD)
Constraints	Fixed at End attached to Frame
Assumptions	Axial Force applied uniormly

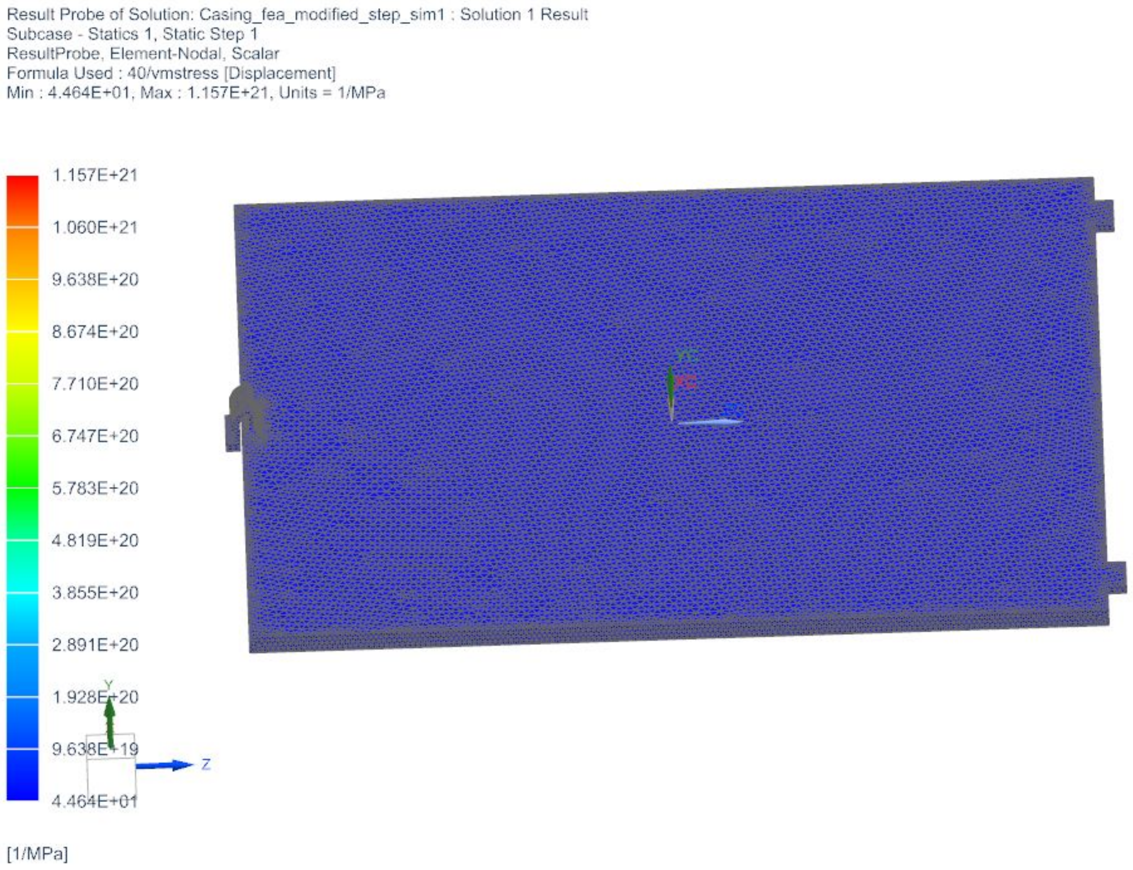
Appendix - Engineering Analysis (Casing)

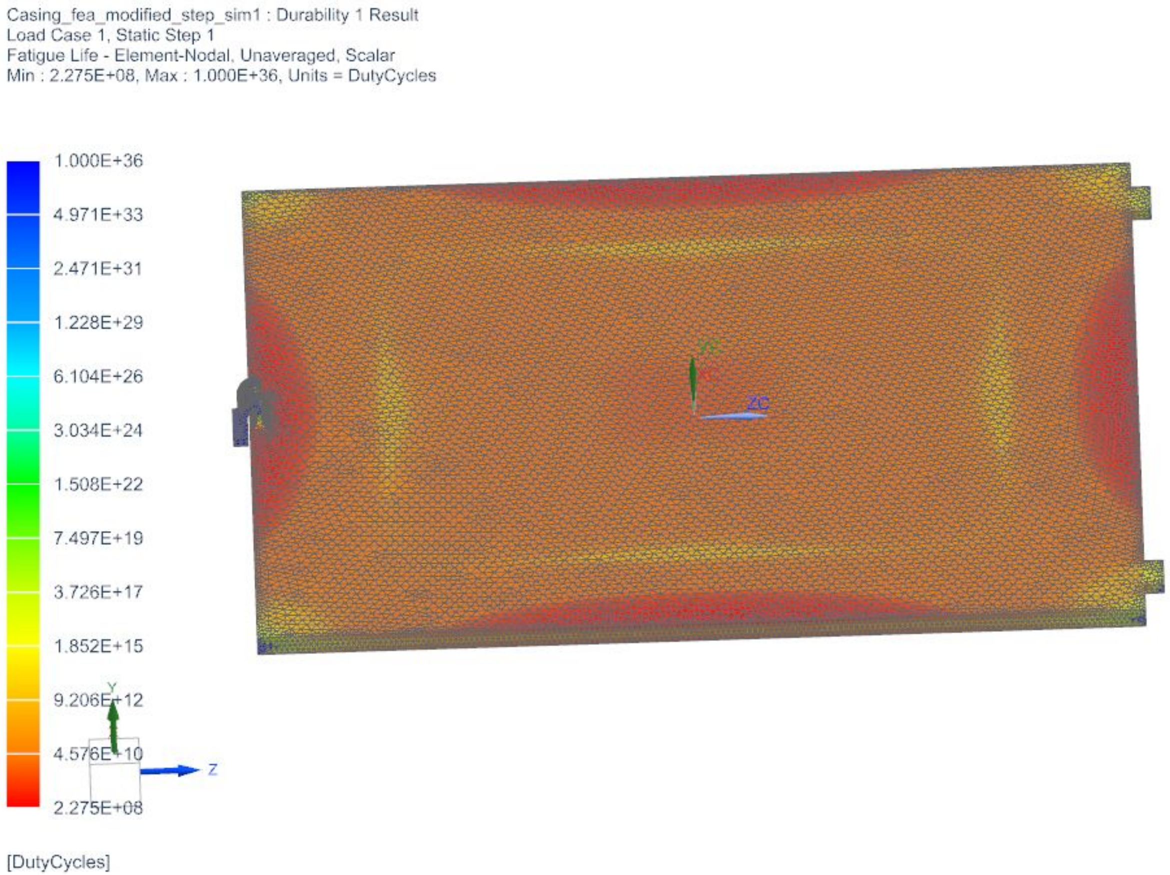




An axial load of 450N results in a safety factor of 0.992 indicating yield failure

Appendix - Engineering Analysis (Casing)





Factor of Safety for 10N Force:
464

Final Fatigue Life Estimate:
2,275 * 10^6 cycles

Appendix - Engineering Analysis (Casing)

Mesh Convergence/Sensitivity Analysis					
Iteration #	Element Size (CTETRA10)	Element Count	Test Force	Max Stress	Safety Factor (40 / Max Stress)
1	0.1 in	12756	100 N	7.36 MPa	5.43
2	0.05 in	90769	100 N	8.52 MPa	4.69
3	0.05 in (0.025 inmesh control)	99386	100 N	8.95 MPa	4.47