

# **SCANNING SYSTEM FOR OBSTETRIC ULTRASOUNDS IN RURAL COMMUNITIES**

## **Team Members**

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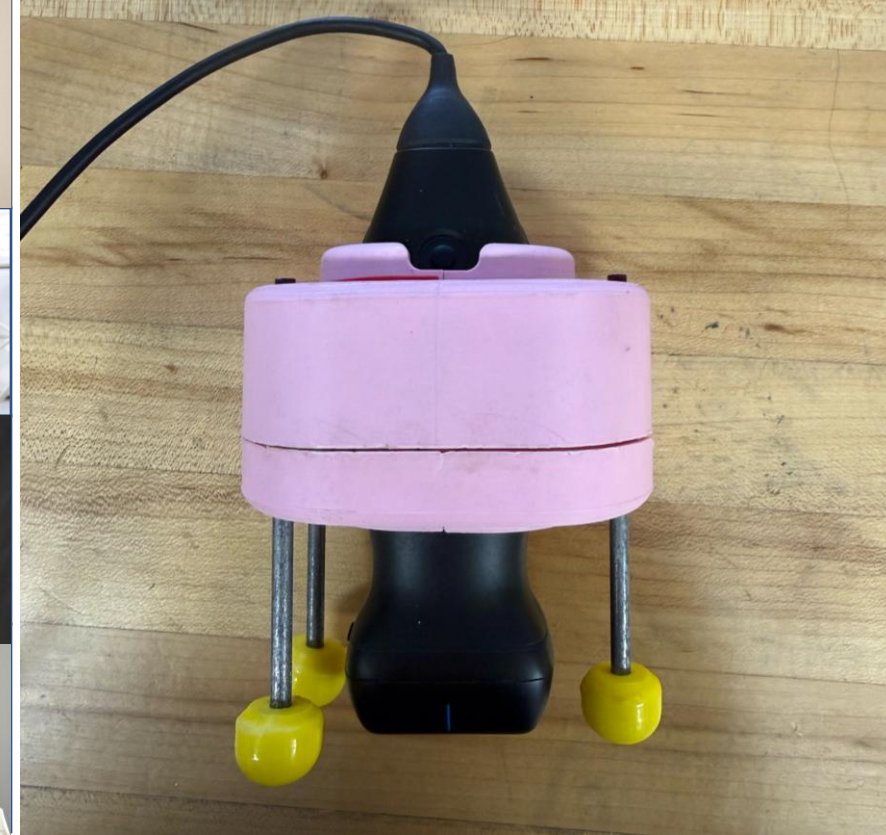
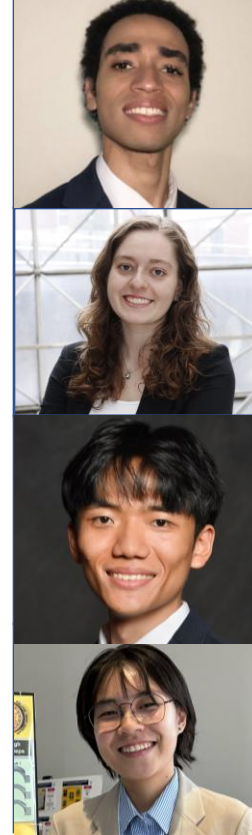
***Bridgit Nguyen***

## **Customer**

***Professor Benjamin Castaneda***

## **Project Overview**

This project aims to increase access to obstetric ultrasound examinations in low- and middle-income communities (LMICs). Accessibility in these areas is currently limited primarily due to the lack of trained ultrasound operators and poor retention. The constructed device enables untrained, non-specialist healthcare workers to provide ultrasound services without extensive training by mechanically providing visual feedback with regards to the probe angle and pressure application to ensure proper execution of the sponsor's volume-sweep-imaging (VSI) protocol.



# Problem Statement

Prenatal complications are prevalent in low- and middle-income countries (LMICs) since healthcare personnel capable of performing an ultrasound are rare. Retention of these personnel is challenging due to a high rotation in rural areas, as once they are educated on the technology and procedure, they are more likely to leave for a larger community with more competitive roles and increased healthcare infrastructure. Transportation to rural areas poses a significant roadblock for visiting healthcare personnel.

The customer works in developing technologies for point-of-care medical devices and wants to make ultrasound screening more accessible to low-resource communities through a device that can help train new users of the VSI (Volume Sweep Imaging) protocol.

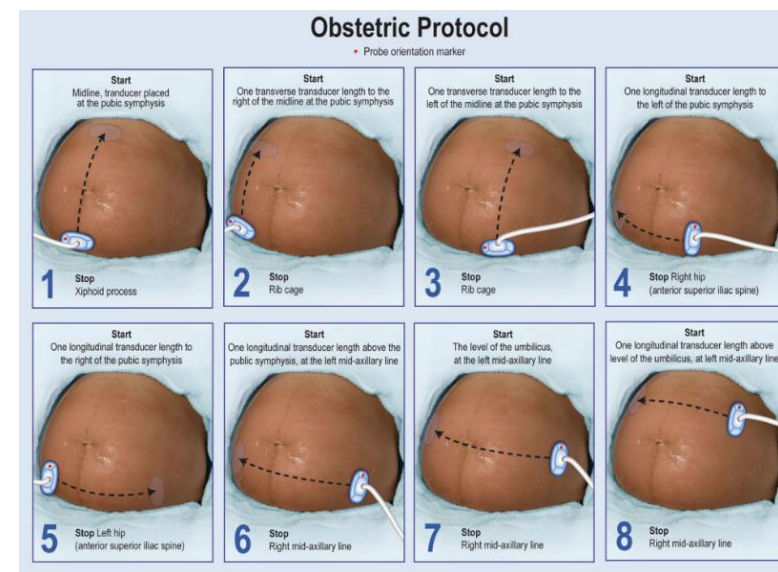


Figure 1: VSI Obstetric Protocol from Professor Castaneda's team

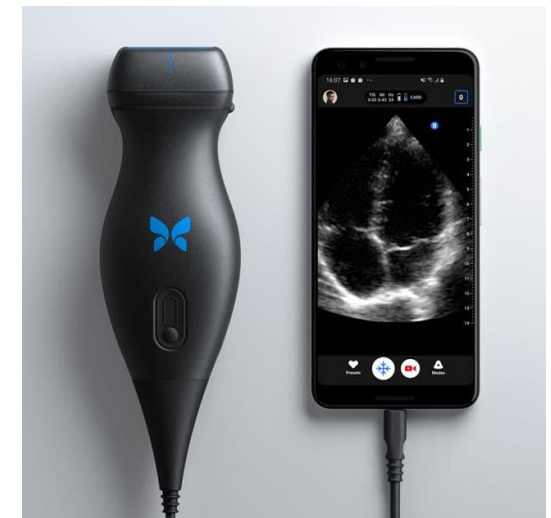


Figure 2: Butterfly iQ+ for the project

**ME205 - Advanced Mechanical Design**



# Deliverables, Requirements and Specifications

## Deliverables:

- *Prototype device that can be tested*
- *Technical report with testing data*
- *Operation manual for device*
- *Website to summarize project work*
- *Poster for design day*
- *Device maintenance manual for technical engineer*

## Requirements:

- *Device must be easily transportable via plane, boat, bus*
- *Manual must provide all necessary information for operation, without specialist assistance*
- *Device must be able to be disassembled and reassembled*
- *Device must consider the safety and comfort of the patients and operators during scanning*
- *Device must not interfere with ultrasound functionality*
- *Device must be able to accommodate the 95th percentile of patients*
- *The probe, when mounted in the device, must remain in normal contact with the patient's abdomen*
- *Gel must not interfere with the function of the device*
- *Device must be compatible with different sized of ultrasound probes*

## Specifications:

- *Total weight of device cannot surpass 22 lbf for international airline travel restrictions*
- *Total size of device must fit within carry-on bag and comply with international airline travel restriction (22"x14"x9")*
- *Maximum force the probe with a contact area of 3.08 in<sup>2</sup> applies is 6.7 lbf*



Figure 3: Learning the VSI Protocol with Naomi

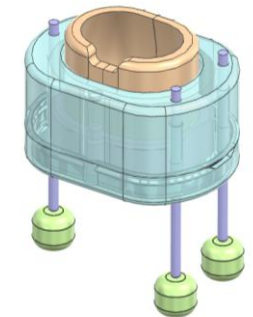


Figure 4: Current CAD Assembly



# Initial Concepts and Design Direction

Initial Design Philosophy:

*Create a device that properly performs the ultrasound operation mechanically.*

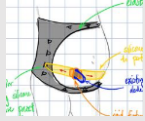


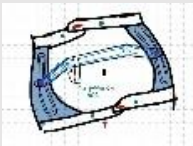
Key design targets:

- Portability
- Standalone functionality
- Multi-axis motion capability
- Force application
- Adaptability to patient geometry

Design features:

- Constant force spring system
  - Maintains vertical pass trajectory
  - Applies downward force
- 3D-printed probe mount
  - Enables preset 90° rotation for vertical/horizontal passes
- Parallel pulley and rail system
  - Maintains parallel horizontal motion
- Elastic harness
  - Adjusts fit to patient geometry
  - Contributes to force application

Table 1: Pugh Matrix

Initial concept selection matrix				
	Design 1 (Baseline)	Design 2	Design 3	Design 4
				
Portability	0	-	-	-
Intuitiveness	0	+	-	-
Patient Conformity	0	-	+	-
Material availability	0	+	+	+
Prototype readiness	0	+	+	-
Manufacturability	0	+	+	+
<b>Total</b>	<b>0</b>	<b>2</b>	<b>2</b>	<b>-2</b>

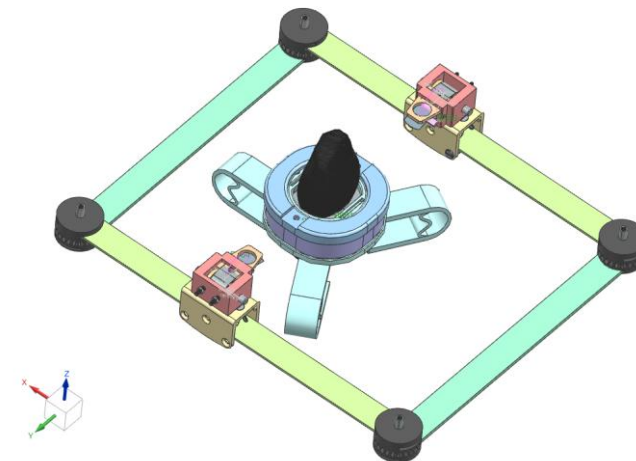


Figure 5: Initial CAD Assembly



## Previous design iterations: Translation stage frame with constant force spring guide rails

### Initial Design Shortcomings:

- Constant force spring unable to transmit force, keep the probe perpendicular, and move the mounting fixture along the correct trajectory at once
- Pulley system did not provide smooth horizontal motion
- Frame somewhat uncomfortable
- Overall design somewhat bulky



Figure 6: 3D Print Iterations from Design Changes



Figure 7: Testing Constant Force Spring with Mounting Fixture

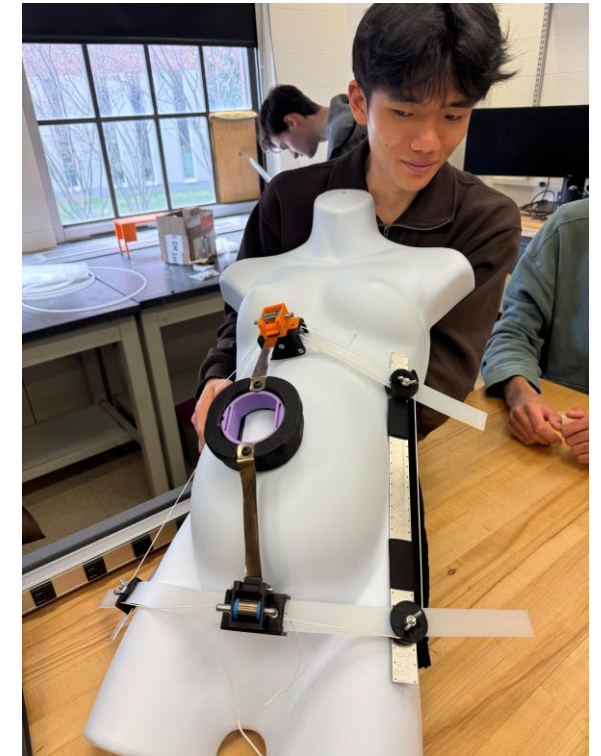


Figure 8: Testing Frame on Mannequin

# Current Project Status: Design Pivot and Final Direction

## Final Design Philosophy:

*Create a device that guides new users to learn and perform the VSI ultrasound protocol with visual indicators.*

## Key design targets:

- Portability
- Standalone functionality
- Adaptability to patient geometry
- Sufficient force application
- Normal contact of the probe on the scanning area

## Design features:

- No longer working on trajectory guidance (Replace with drawing guidelines on patients)
- Spring-loaded force indicator:
  - Inner sleeves with kinematic mounting to accommodate many probe sizes
  - Color bars correlating displacement to force
- Spring-loaded perpendicularity mechanism:
  - 3 points of contact to ensure perpendicularity on local scanning area
  - Matching colors on top of the legs to maintain normal contact

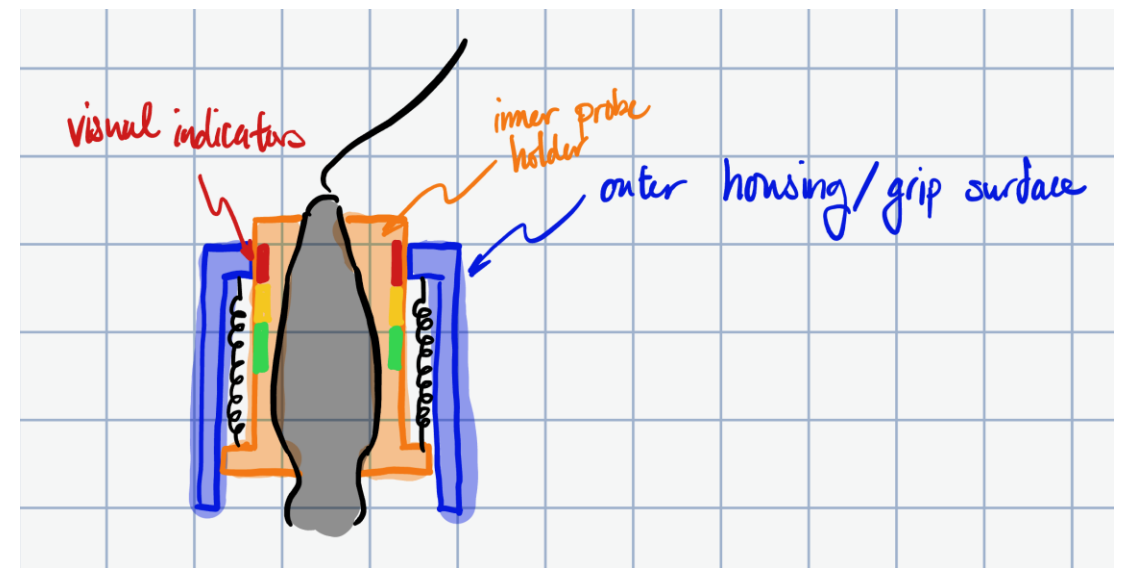


Figure 9: Initial sketch of force indicator

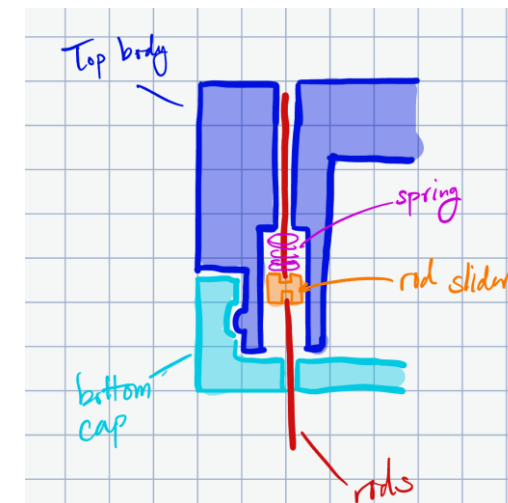


Figure 10: Initial sketch of perpendicularity rods



## Current Project Status: Final design

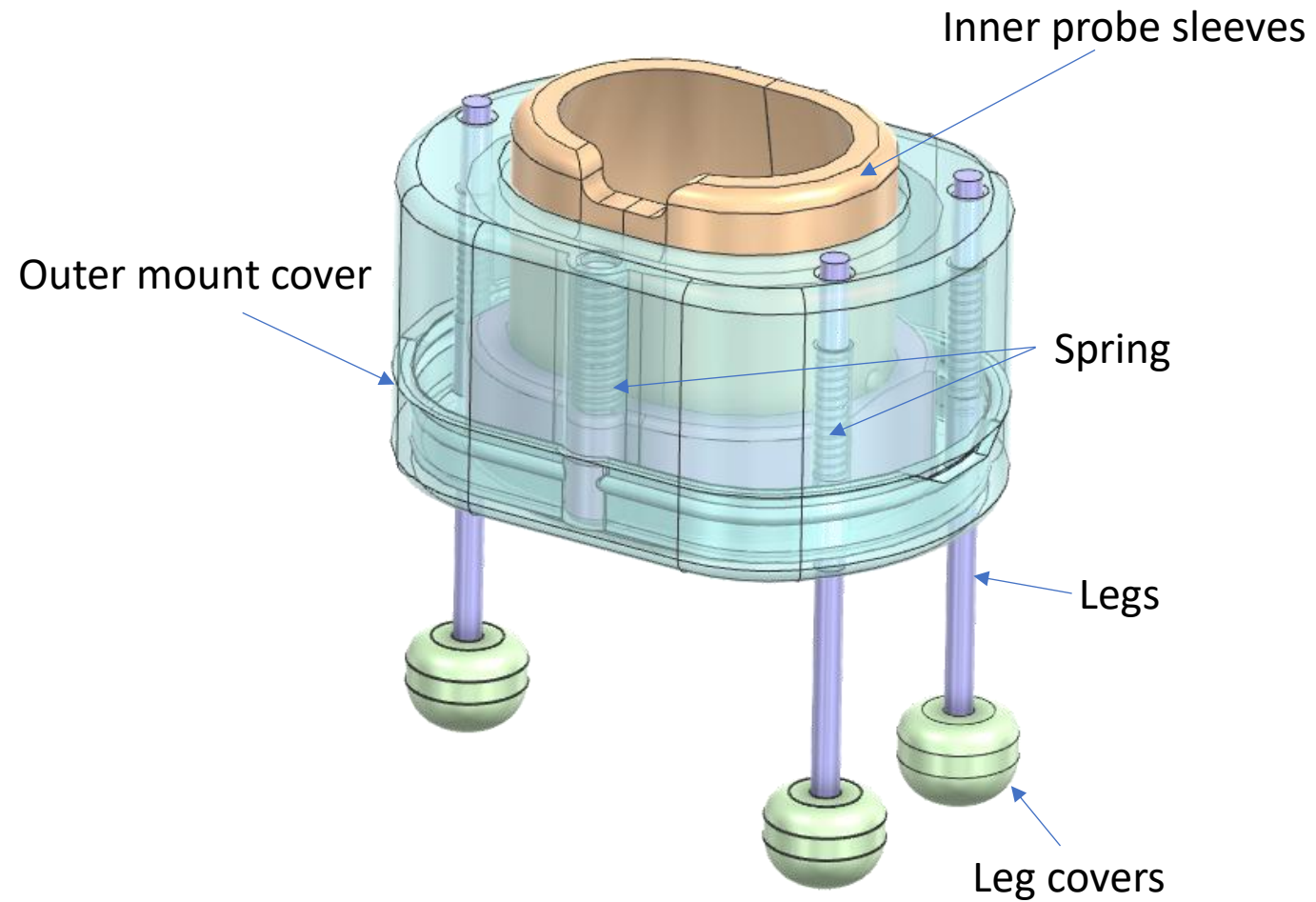


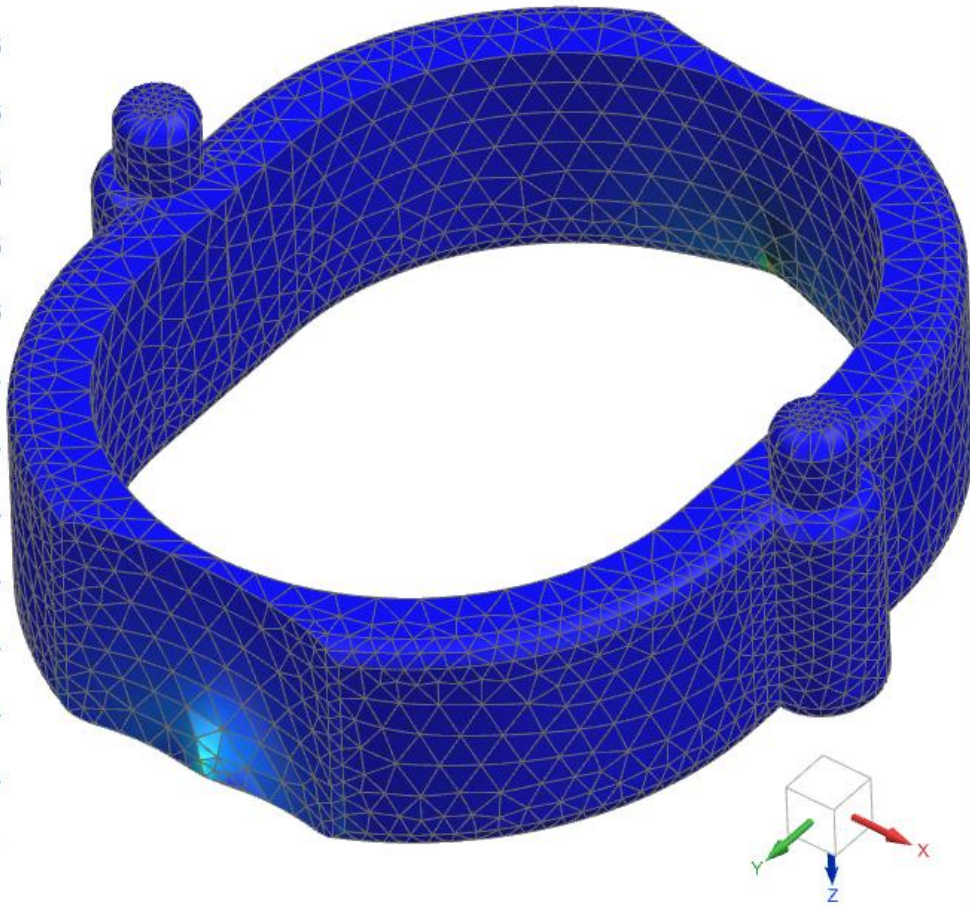
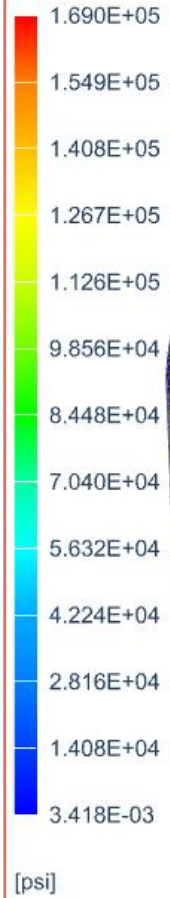
Figure 11: Final CAD of design



Figure 12: Final prototype of device

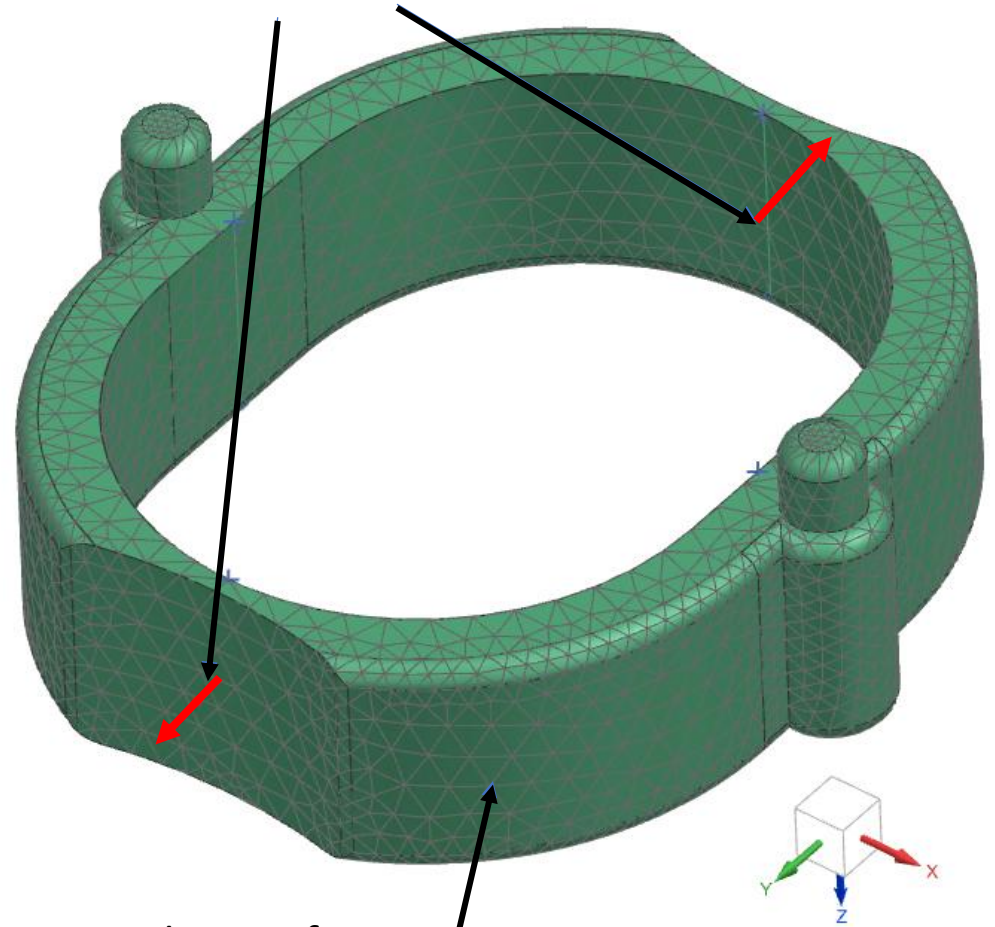
# Analysis/Testing (FEA)

Solution 1 Result : 26c034231\_sim1  
Subcase - Statics 1, Static Step 1  
Stress - Element-Nodal, Unaveraged, Von-Mises  
Min : 3.418E-03, Max : 1.690E+05, Units = psi  
CSYS : Absolute Rectangular  
Deformation : Absolute 1:1, Displacement - Nodal Magnitude



SOL 101  
Tet10 mesh  
Size = 0.125"  
PLA Material

Enforced displacements = 0.0465"

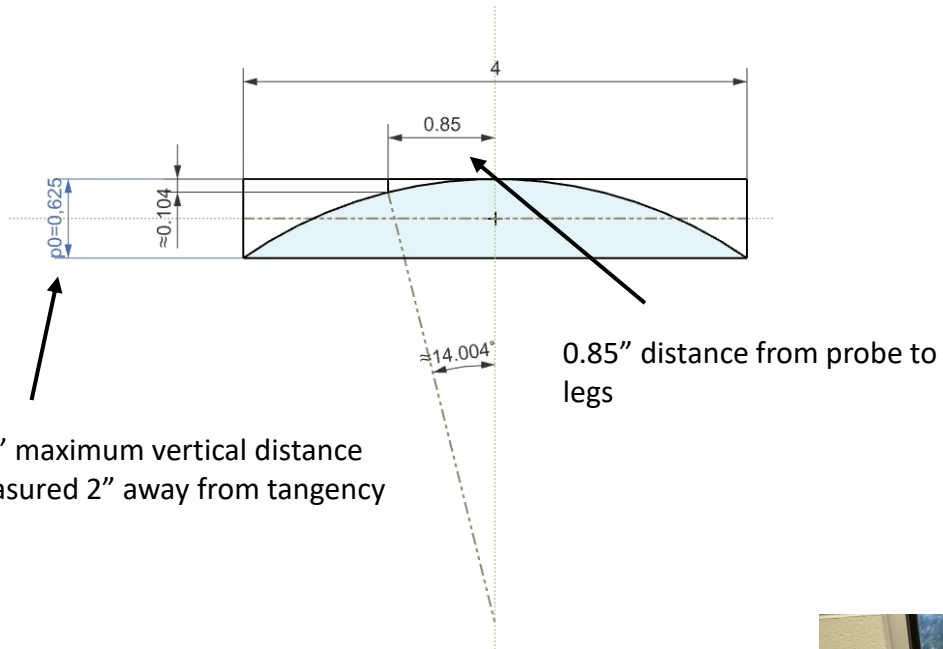


Fixed outer faces



# Analysis/Testing (Curvature Analysis and Indicator Resolution)

## Angle error at maximum curvature



5/8" maximum vertical distance measured 2" away from tangency

0.85" distance from probe to legs

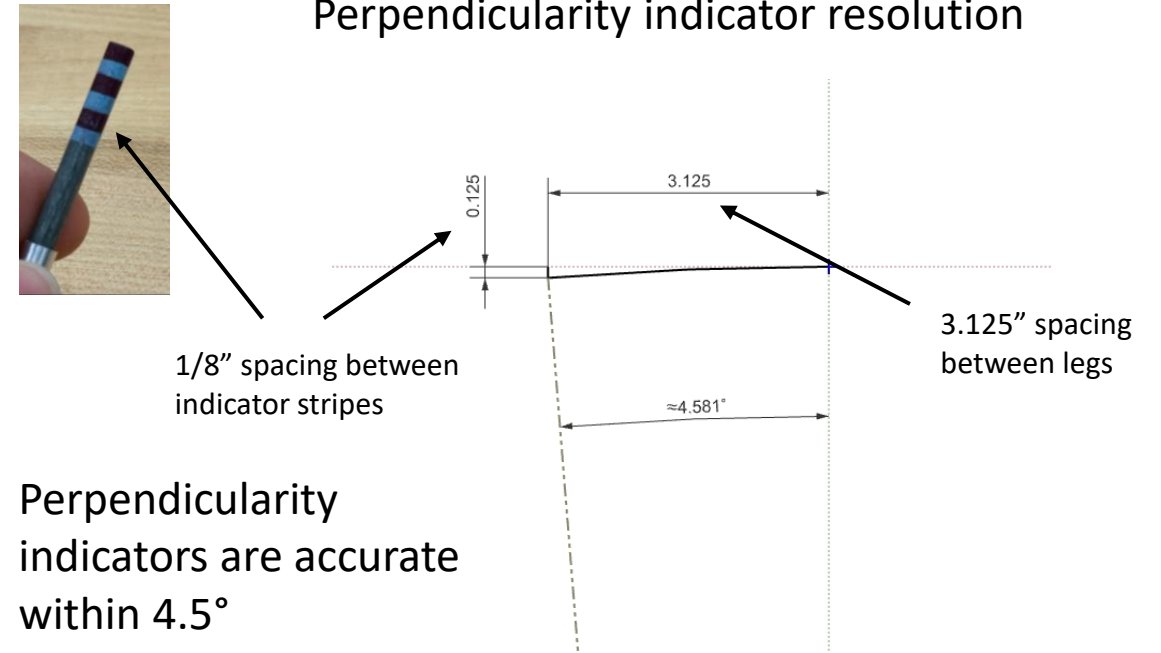
Maximum allowable error =  $10^\circ$   
 Maximum error; 2 leg configuration =  $14^\circ$

2 legs on one side does not sufficiently provide perpendicularity indication



Example curvature measurement

## Perpendicularity indicator resolution



Perpendicularity indicators are accurate within  $4.5^\circ$



## Force indicator resolution

$1/8$ " band thickness in optimal (green) region

Combined spring constant =  $2 * 1.1 = 2.2$  lbf/in

$$Resolution = k(x_{green\ max} - x_{green\ min}) = 0.275\ lb_f$$

Force indicator is accurate within  $0.275\ lb_f$

# Analysis/Testing (Spring sizing/fatigue analysis/tolerance analysis)



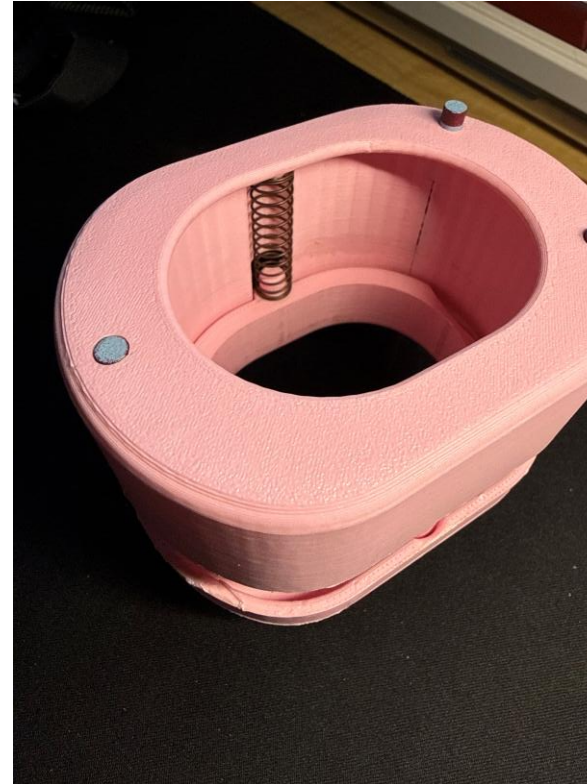
Spring sizing analysis for perpendicularity mechanism

$$S_{sy} = 0.45S_{ut}$$

$$\frac{\Delta \text{length}}{\text{original length}} = \cos 30^\circ$$

$$K_s = \frac{2C + 1}{2C}$$

$$\tau_{max} = \frac{K_s \cdot 8FD}{\pi d^3}$$



Spring fatigue analysis

- Goodman failure criterion with Zimmerli data
- Factor of safety against fatigue-failure for each spring transmitting force

$$\tau_a = K_B \frac{8F_a D}{\pi d^3}$$

$$\tau_m = K_B \frac{8F_m D}{\pi d^3}$$

$$S_{ut} = \frac{A}{d^m}$$

$$S_{su} = 0.67S_{ut}$$

$$S_{se} = \frac{S_{sa}}{1 - \frac{S_{sm}}{S_{su}}}$$

$$n_f = \left( \frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{su}} \right)^{-1}$$



Tolerance analysis on FN5 press fit of steel rod in aluminum sleeves

Table 2: Tolerance Requirements

Component	Nominal Diameter	Tolerance (in)	Limits (in)
Hole (Sleeve)	0.1820	+0.0007/ +0.0000	0.1820-0.1825
Shaft (Rod)	0.1820	+0.0017/ +0.0012	0.1832-0.1837



# Manufacturing and Material Choice

## Material choice (PLA)

- Popular, low-cost (\$25/kg), very accessible
- Other considerations:
  - PETG – highly performant and suitable for higher loads, not ideal considering cost and printing complications

## Additive manufacturing (FDM 3D printing)

- Rapid design iteration
  - Entire model can be printed in under 5 hours on one printbed
- Low costs
  - Each device consumes ~\$4 of material
- Open source and reproducibility
  - Appropriately addresses accessibility mission
  - Files can be shared publicly online and distributed locally with 3D printer access
  - Open source nature opens the door to community-driven design improvements

## Future changes

- Shift more to 3D printed and off-the-shelf (OTS) parts
- Manual machining choice driven by time constraints, largest contributor to system cost in BOM

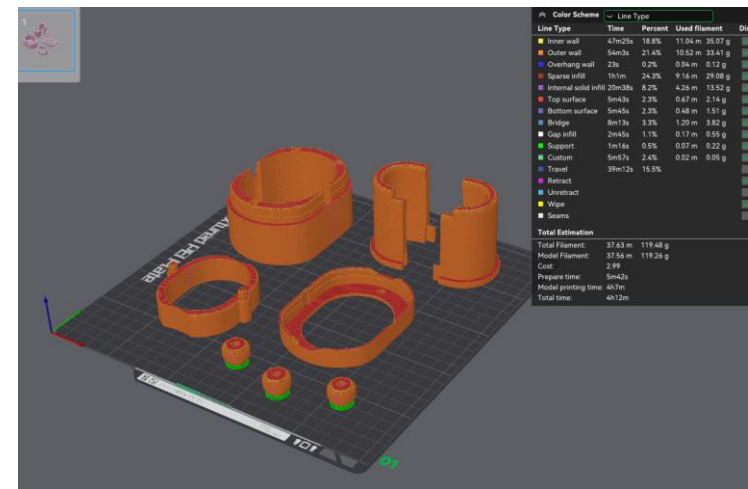


Figure 13: Screenshot of printedbed in slicer



Figure 14: Casted leg covers in silicon

Category	Description	Cost
Purchased Hardware	Steel Rods	\$1.50
	Rubber Bumpers	\$8.99
	Aluminum Stock	\$0.95
Purchased shop time		\$0.00
3D printing Material cost	PLA (119g @ \$25/kg)	\$2.99
Team Member Time	Manufacturing Time	\$1,600
<b>Total</b>		<b>\$1,611.44</b>

Table 3: Bill of Materials



## Conclusions/Future Work

### Conclusions

- Our final design and prototype is best used as an indicator to users of whether they have enough force and are at a right angle
- Since mostly 3D printed, can be open sourced for easy replication/reproducibility

### Future work

- Reduce manufacturing cost by making the product fully 3D printable
- Conduct more testing to see if new learners perform the VSI protocol better or not without the device
- Implement the constant scanning time specifications
- Automate the system by using electronic sensors and robotics
- Add trajectory markers like light/laser lines or net-style markings

### Acknowledgments

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Figure 15: Testing with phantom