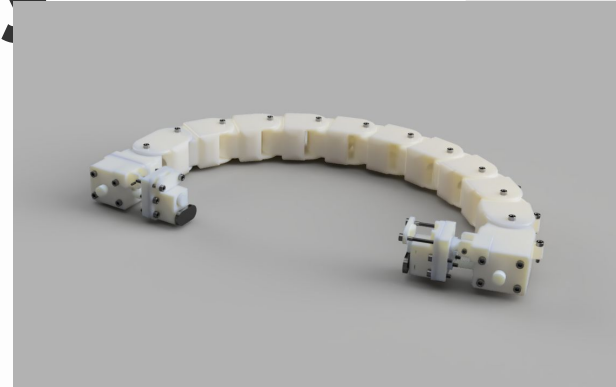


Blood Monitor Device for the Carotid Artery

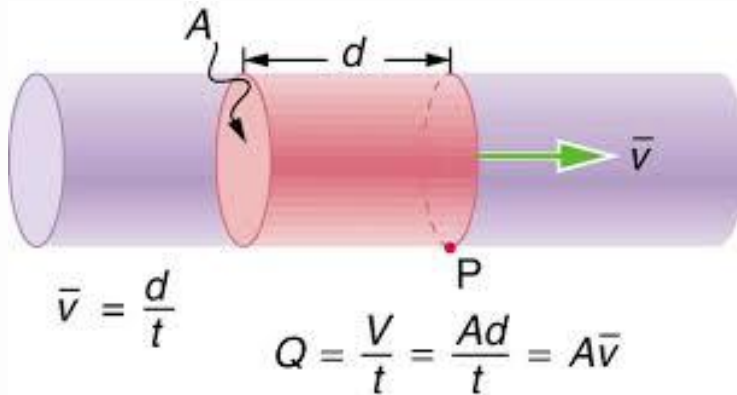
Andrew D'Onofrio - *Undergrad. Researcher*
Dr. Yi-Xian Qin's Lab
August 23rd, 2024



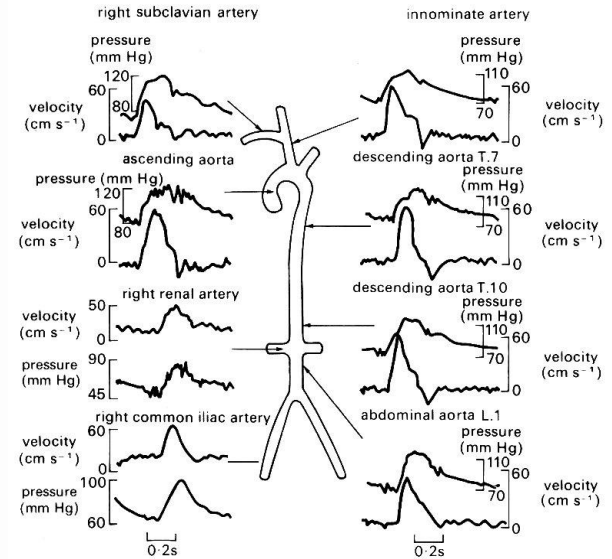
Redefined Goals

Volumetric Blood Flow: $Q = A\bar{v}$

1. Vessel Area
2. Time Average Velocity



BP and Velocity Profiles



Mathematical Derivations

Blood Vessel Cross-Section Area Derivation (Moens-Korteweg, Laplace's):

Two Options: Assume an initial condition with BMI Calculations or Imaging (initial blood vessel radius, Elastic Modulus, Reynold's Number)

Moens-Korteweg's Pulse Wave Velocity Formula

$$c = \sqrt{\frac{Eh}{2r\rho_{\text{Blood}}}}$$

$$2r\rho_{\text{Blood}}c^2 = Eh$$

$$r_i = \frac{Eh}{2\rho_{\text{Blood}}c^2} \text{ or } E = \frac{2r\rho_{\text{Blood}}c^2}{h}$$

Laplace's Law for Thin-Walled Cylinder Approximation

$$E = \frac{\sigma}{\epsilon}, \quad \sigma = \frac{Pr_i}{h}$$

$$\epsilon = \frac{\Delta r}{r_i}$$

$$E = \frac{Pr_i r_0}{h\Delta r}$$

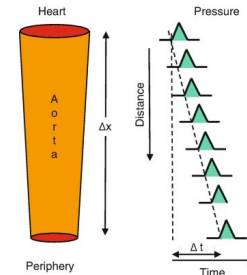
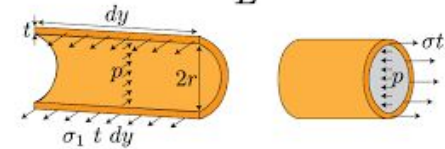
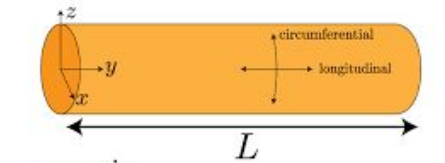
Moens-Korteweg and Laplace

$$\frac{Pr_i r_0}{h\Delta r} = \frac{2r\rho_{\text{Blood}}c^2}{h}, \quad \frac{Pr_0}{(r_i - r_0)} = 2\rho_{\text{Blood}}c^2, \quad \frac{r_0}{(r_i - r_0)} = \frac{2\rho_{\text{Blood}}c^2}{P}, \quad Pr_0 = 2\rho_{\text{Blood}}c^2(r_i - r_0), \quad Pr_0 + 2\rho_{\text{Blood}}r_0c^2 = 2\rho_{\text{Blood}}r_i c^2$$

$$r_i = \frac{Pr_0 + 2\rho_{\text{Blood}}r_0c^2}{2\rho_{\text{Blood}}c^2}, \quad r_i = \frac{Pr_0 + 2\rho_{\text{Blood}}r_0c^2}{2\rho_{\text{Blood}}c^2}$$

$$r_i = \frac{Pr_0}{2\rho_{\text{Blood}}c^2} + r_0$$

$$A = r_i^2 \pi$$



Wave speed, c , is

$$c = \Delta x / \Delta t$$

Wave speed is a function of area compliance, $C_A = \Delta A / \Delta P$, wall elastic modulus (E_{wv}), wall thickness, h , and blood density is:

$$c = \sqrt{A/p C_A} \quad (\text{Newton-Young, or Frank, or Bramwell-Hill equation})$$

$$c = \sqrt{E_{wv} h / \rho D}$$

(Moens-Korteweg equation)

Mathematical Derivations

P_i = Standing Pressure

ρ_{Water} = Water Density

v = Velocity

h = Height

c = Blood Velocity

E = Elastic Modulus (Arterial Thickness)

h = Wall Thickness

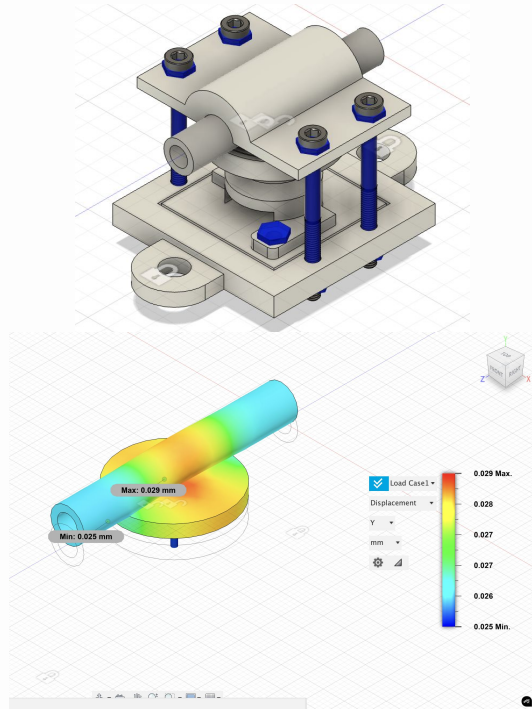
r_i = Inner Wall Radius

ρ_{Blood} = Blood Density

P_{int} = Internal Pressure

Δr = Change in Radius

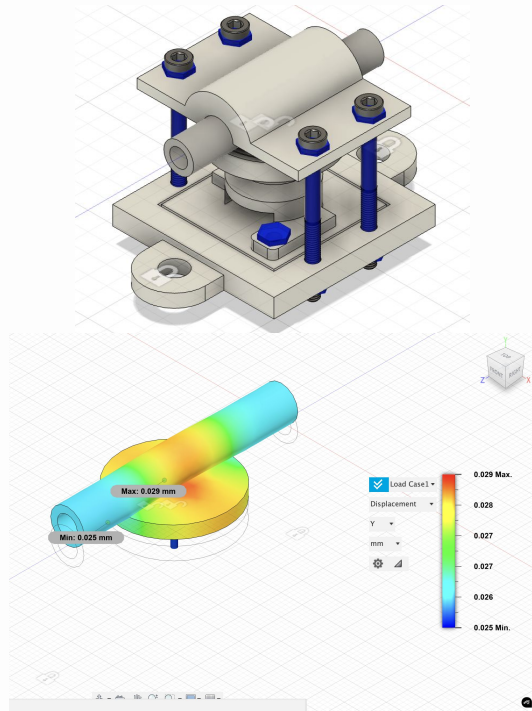
Revisiting Pressure Sensor Data



Spring Characteristics (Measurements)		Pipe Characteristics	
Spring Diameter (in)	0.4375	Material	PVC Vinyl
Free Length (in)	0.9375	I.D. (in)	0.1875
Max Load (lbs)	7.77	O.D. (in)	0.3125
Number of Coils	9	Flexural Modulus (GPa)	2.85
Wire Gauge (in)	0.041	Elasticity Modulus (GPa)	2.8
Spring Rate (lbs/in)	13.282	Strain	$\Delta L/L$
Material	302/304 Stainless Steel	Stress	F/A
Deformation Calculations		Basic Simulations	
Rubber Piece (in)	0.25	Av. Pipe Inward Deformation (in)	0.00098425197
All Free Height (in)	1.5	Av. Pipe Deformation Width (in)	0.04956566268
Support Height (in)	0.875	Av. Pipe Deformation Length (in)	0.551181
Spring Compressed Height (in)	0.625	Pipe Applanation Area (cm ²)	0.1762663916
Spring Deformation (in)	-0.3125	Complex Simulations	
Spring Force (lbs)	4.150625	Av. Pipe Inward Deformation (in)	0.001525593651
Spring Force (N)	18.46289314	Av. Pipe Deformation Width (in)	0.06168204264
		Av. Pipe Deformation Length (in)	0.984252
		Pipe Applanation Area (cm ²)	0.3917052676

Pressure Sensor Deformation Google Sheet

Revisiting Pressure Sensor Data

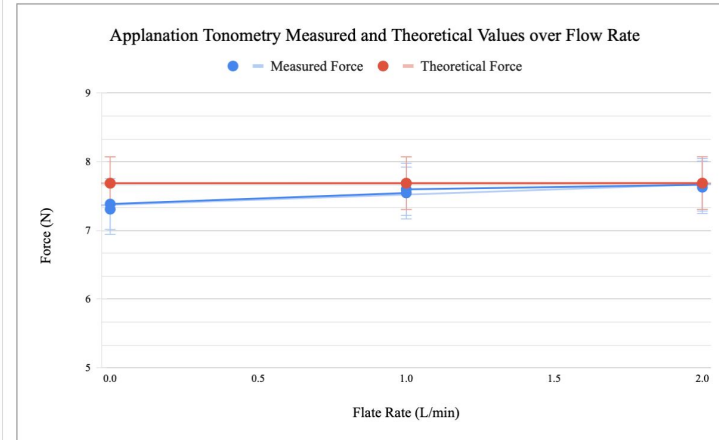


1. Define Model Parameters and Constraints for Design
2. Run an ANSYS Static Stress Calculation for Structure Deformation
3. Filter Results with a Threshold for Deformation and Determine Average Y-Axis Deformation (x)
4. Determine Length of Chord Intersecting x distance into Radius of Tube
5. Determine the Percentage of Tube Applanated with Deformation Threshold and Multiple by Applanator Length
6. Multiple the Applanator Length by Width for Area

Tester Finite Element Analysis

Revisiting Pressure Sensor Data

Area Applanaated	0.392 cm ² (2.5 cm by 0.157 cm)	0.392 cm ² (2.5 cm by 0.157 cm)	0.392 cm ² (2.5 cm by 0.157 cm)	0.392 cm ² (2.5 cm by 0.157 cm)	0.392 cm ² (2.5 cm by 0.157 cm)	0.392 cm ² (2.5 cm by 0.157 cm)	Estimated Force			
	Measured Force (N)	7.309203117	7.385821652	7.546011615	7.599037791	7.665959541	7.629096755	Flow Pressure	0.0008571349156	Flow Rate
Calculated Force (N)	7.6884136	7.6884136	7.688749597	7.688749597	7.689657588	7.689657588	Gravitational Pressure	9.80665	Height (cm)	10
Flate Rate (L/min)	0	0	1	1	2	2	Standing Pressure (N/cm ²)	10.1325	Radius Inner (cm)	0.47625
Percent Error	-4.932233131	-3.9356877	-1.856452471	-1.166793183	-0.3081807858	-0.7875621514	Applanated Area (cm ²)	0.392	Radius Outer (cm)	0.79375
							Force (N)	7.688749597		



Formula Derivation

$$F_t + \frac{1}{2}\rho v^2 + \rho gh = P_t + \frac{1}{2}\rho v^2 + \rho gh$$

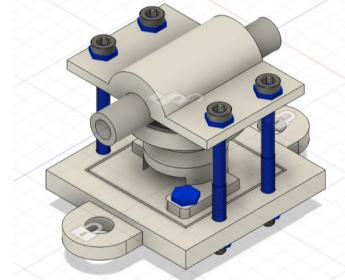
$$F_t = P_t + \frac{1}{2}\rho v^2 + \rho gh - \frac{1}{2}\rho v^2 - \rho gh$$

$$F_t = P_t + \frac{1}{2}\rho(v_1^2 - v_2^2) + \rho g(h_1 - h_2) \text{ where } h_1 = 0 \text{ cm}$$

$$Q = A_1 v_1 = A_2 v_2 = v_{avg} \cdot F_t = P_t + \frac{1}{2}\rho v^2 \left(\frac{1}{r_1^2} - \frac{1}{r_2^2} \right) - \rho g h_1$$

$$F_t = \left(\frac{1}{2} \rho v^2 \left(\frac{1}{r_1^2} - \frac{1}{r_2^2} \right) - \rho g h_1 \right) \cdot A \text{ where } P_t = 10.1325 \frac{N}{cm^2}, h_1 = 10 \text{ cm}$$

$$\text{Force} = \left(\frac{1}{2} \rho v^2 \left(\frac{1}{r_1^2} - \frac{1}{r_2^2} \right) - \rho g h_1 \right) \cdot A \text{ where } P_t = 10.1325 \frac{N}{cm^2}, h_1 = 10 \text{ cm}$$



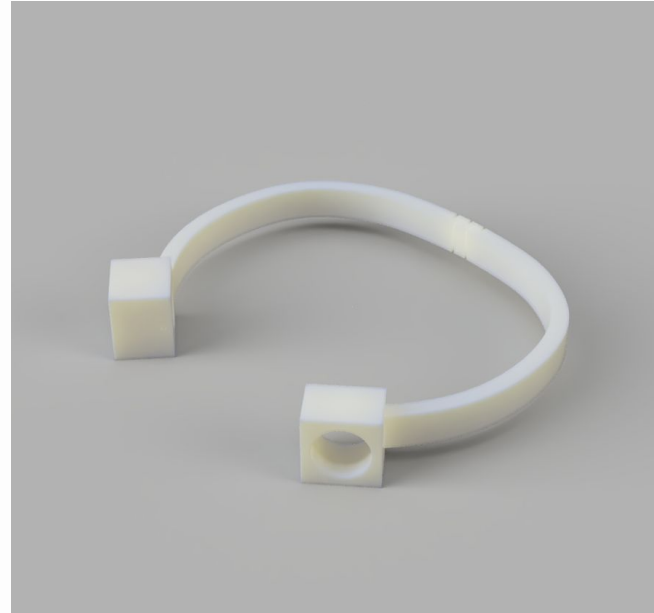
[Pressure Sensor Data Recording Google Sheet](#)

Winter Semester Issues

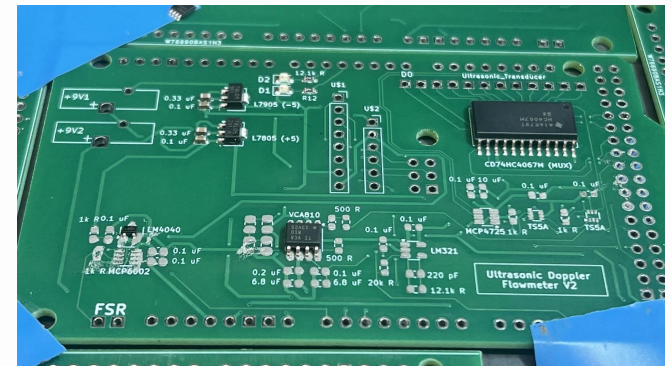
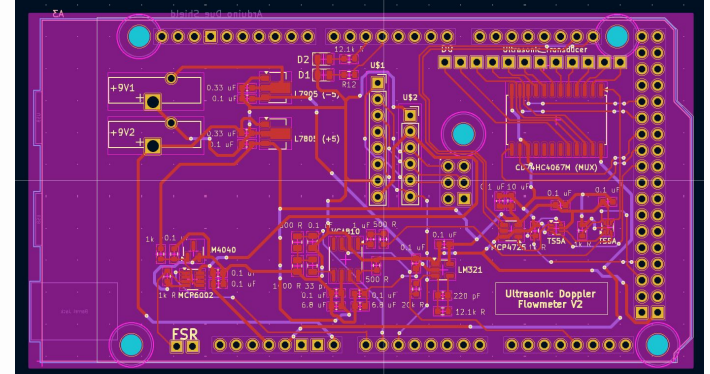
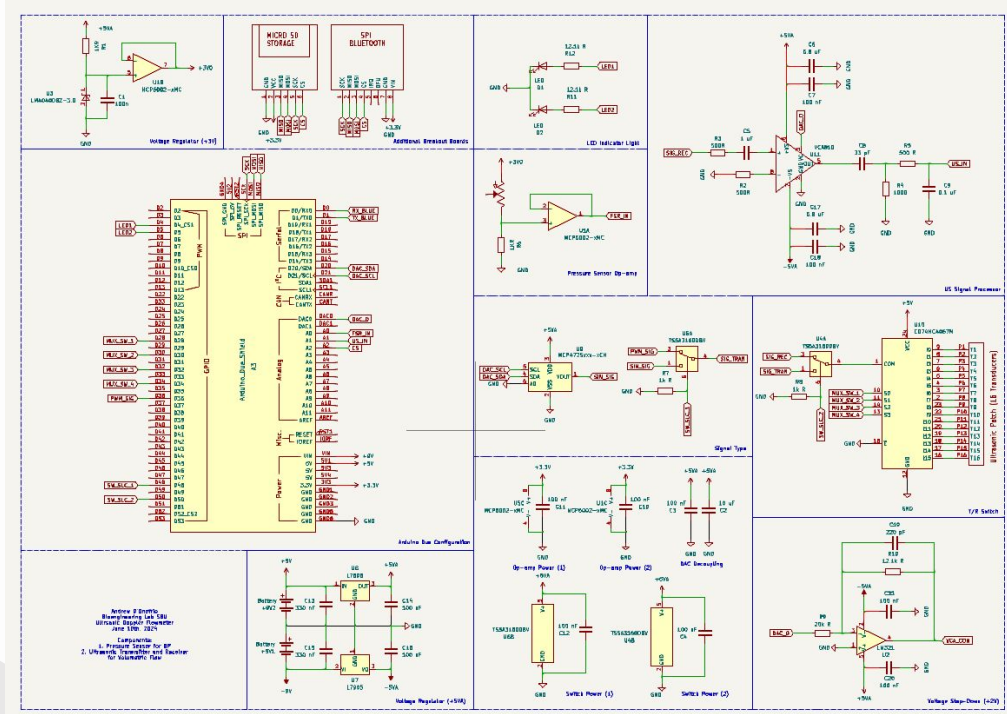
1. Breakout Board Limitations



2. Instable Sensor Holder



New Schematic and PCB Designs



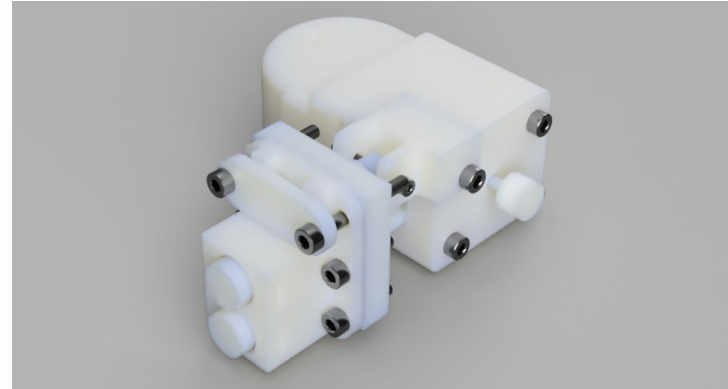
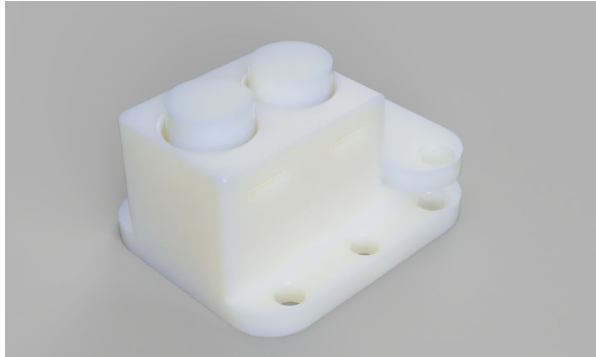
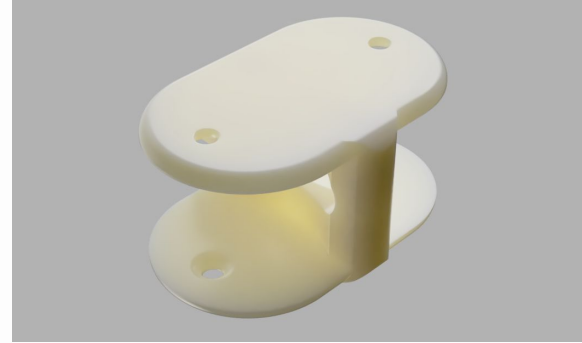
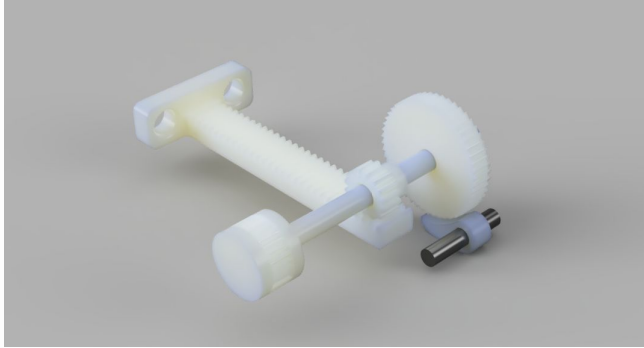
New Testing Apparatus



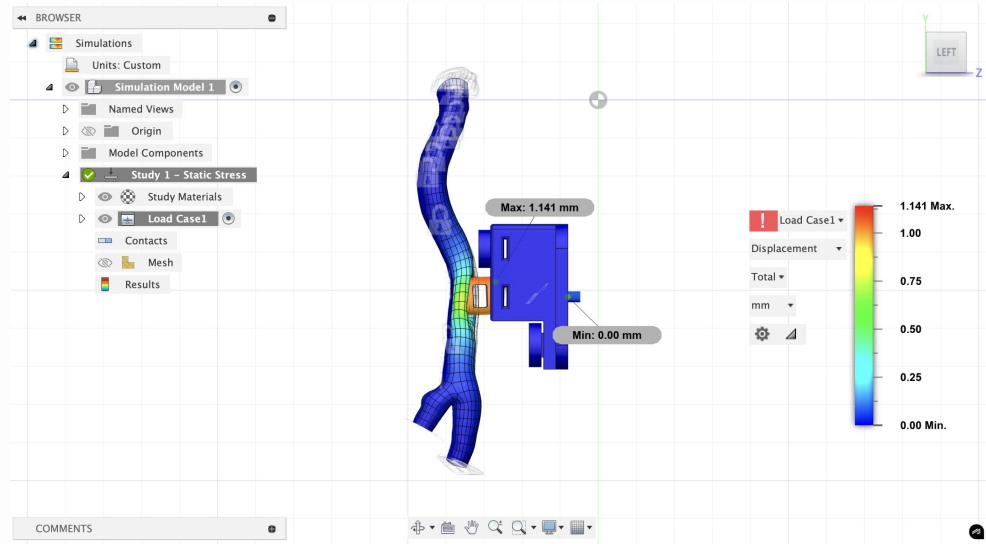
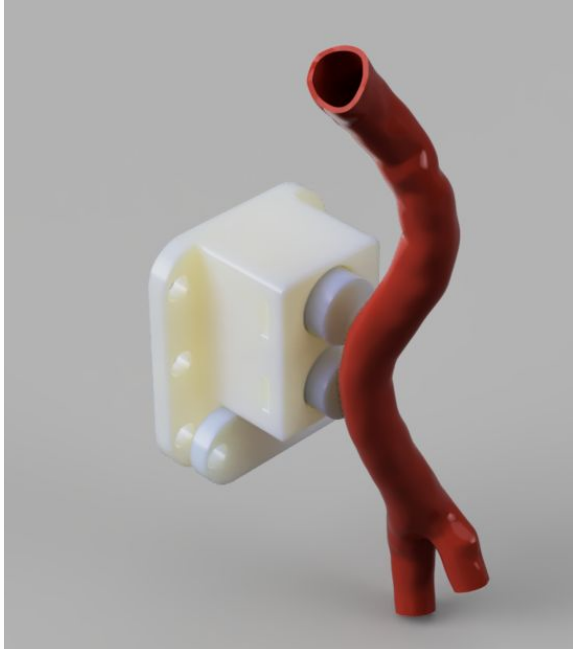
SBU Orthopedic Bioengineering Research Lab		Cardiac Output Monitor Arduino Shield Bill of Materials					Date Created		August 18th, 2024	
Part Number	Name	Description	Datasheet	Supplier	Supplier Link	Unit Cost	Net Cost	Quantity	Ordered	Received
1	A00062	Arduino Due Microcontroller	Link	DigiKey	Link	\$48.40	\$48.40	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2	MC7902	Operational Amplifier	Link	DigiKey	Link	\$0.41	\$0.82	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
3	LM4040-3.0V	3 V Voltage Regulator	Link	DigiKey	Link	\$2.10	\$2.10	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
4	L7905	5 V Voltage Regulator	Link	DigiKey	Link	\$0.83	\$0.83	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
5	L7905	-5 V Voltage Regulator	Link	DigiKey	Link	\$1.06	\$1.06	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
6	TSSA3140	T/R Switch	Link	DigiKey	Link	\$0.53	\$1.06	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
7	VCAR10	Variable Gain Amplifier	Link	DigiKey	Link	\$15.62	\$15.62	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
8	CD74HC4067M	16-Channel Multiplexer	Link	DigiKey	Link	\$1.12	\$1.12	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
5	LM321	Step-Down Amplifier	Link	DigiKey	Link	\$0.65	\$0.65	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
10	SML-LXFM0603SIC-TR	Indicator Lights	N/A	DigiKey	Link	\$0.35	\$0.70	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
11	MicroSD Storage Board	N/A	Link	Adafruit	Link	\$7.50	\$7.50	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
12	HC-05 Bluetooth Board	N/A	Link	Adafruit	Link	\$8.00	\$8.00	1	<input type="checkbox"/>	<input checked="" type="checkbox"/>
13	SMD 1k R	Resistors	N/A	DigiKey	Link	\$0.10	\$0.40	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
14	SMD 510 R	Resistors	N/A	DigiKey	Link	\$0.10	\$0.20	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
15	SMD 12.1k R	Resistors	N/A	DigiKey	Link	\$0.10	\$0.20	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
16	SMD 20k R	Resistors	N/A	DigiKey	Link	\$0.10	\$0.10	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
17	SMD 6.8 uF	Capacitors	N/A	DigiKey	Link	\$0.44	\$0.88	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
18	SMD 100 nF	Capacitors	N/A	DigiKey	Link	\$0.13	\$1.30	10	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
19	SMD 10 uF	Capacitors	N/A	DigiKey	Link	\$0.17	\$0.17	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
20	SMD 330 nF	Capacitors	N/A	DigiKey	Link	\$0.40	\$0.80	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
21	SMD 220 pF	Capacitors	N/A	DigiKey	Link	\$0.10	\$0.10	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
22	R276 Solder Paste	Solder Paste	Link	DigiKey	Link	\$39.81	\$39.81	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
23	9 V Batteries	N/A	N/A	MacMaster-Carr	Link	\$4.89	\$9.78	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
24	9 V Battery Clips	N/A	N/A	MacMaster-Carr	Link	\$1.08	\$2.16	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
25	Arduino Shield	Custom PCB Board for Device	N/A	PCBWay	See Invoice	\$1.12	\$5.60	5	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
26	PLA Printed Materials	N/A	N/A	MacMaster-Carr	Link	\$0.02	\$16.24	650	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
27	850K239	1/8" Clear 12" by 12" Acrylic	N/A	MacMaster-Carr	Link	\$11.44	\$11.44	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
28	850K745	1/8" Black 24" by 36" Acrylic	N/A	MacMaster-Carr	Link	\$48.58	\$48.58	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
29	91290A013	M2 6 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.16	\$0.31	2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
30	91290A049	M2 20 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.15	\$0.30	3	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
31	90591A265	M2 Nuts (100 pk)	N/A	MacMaster-Carr	Link	\$0.02	\$0.07	3	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
32	97163A146	M2 Heat-Set Inserts (10 pk)	N/A	MacMaster-Carr	Link	\$0.60	\$0.60	1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
33	91290A111	M3 6mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.11	\$0.45	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
34	91290A115	M3 10 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.13	\$0.52	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
35	91290A119	M3 14 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.15	\$3.44	23	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
36	91290A125	M3 25 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.17	\$0.69	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
37	91290A171	M3 30 mm Bolt (100 pk)	N/A	MacMaster-Carr	Link	\$0.72	\$4.30	6	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
38	91287A026	M3 35 mm Bolt (10 pk)	N/A	MacMaster-Carr	Link	\$0.83	\$10.75	13	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
39	90591A250	M3 Nuts (100 pk)	N/A	MacMaster-Carr	Link	\$0.03	\$1.18	42	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
40	97164A112	M3 Heat-Set Inserts	N/A	MacMaster-Carr	Link	\$0.31	\$3.70	12	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
TOTAL COST						\$252.09				

[Bill of Materials Google Sheet](#)

New Testing Apparatus

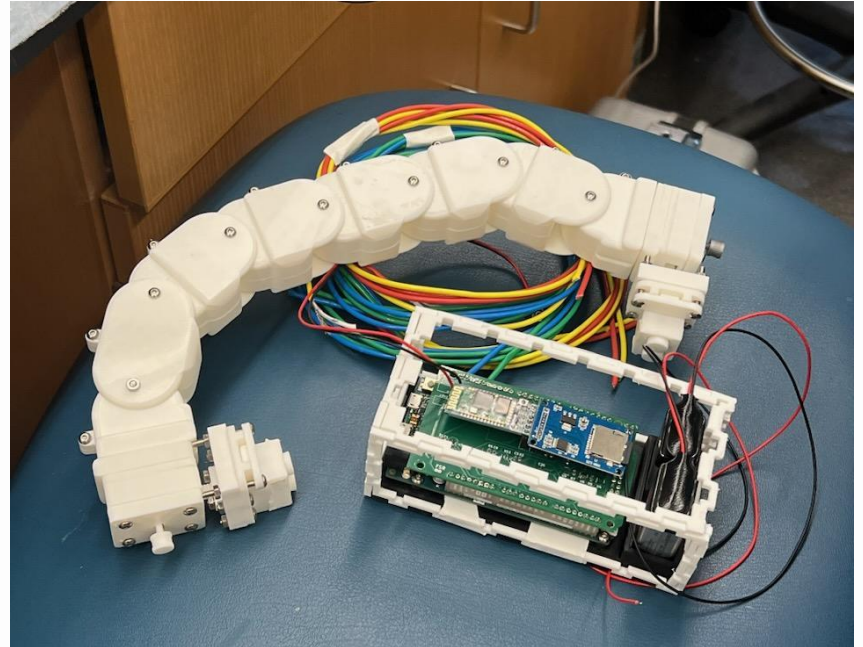
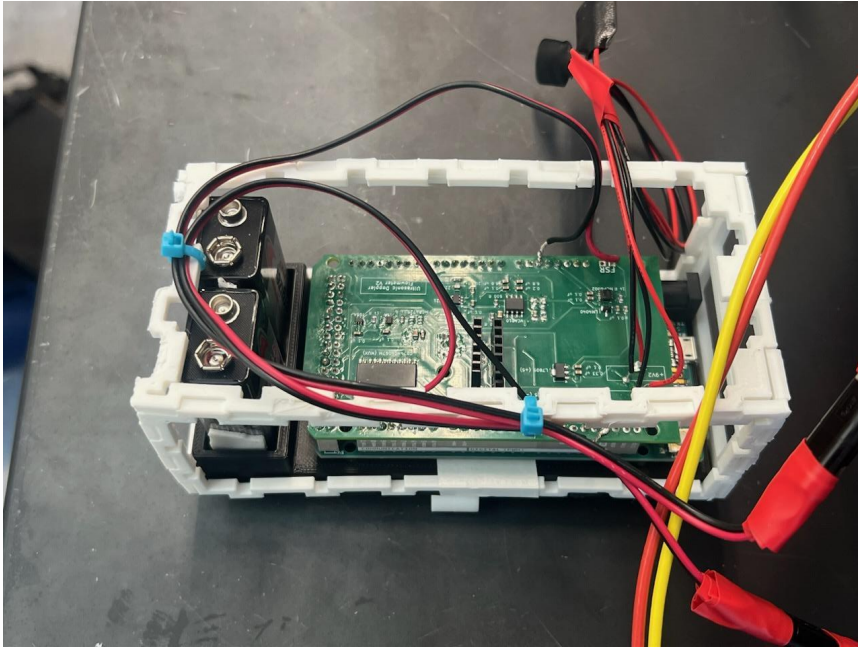


Expected Applanation



Realistic Finite Element Analysis

Assembled Device



Final Steps

1. Troubleshooting (CAD and wiring)
2. Including Documentation into the Paper
3. Updating Methods Section and Completing the Discussion Section
4. Improved Comparative Measure

Post-Experiment Recommendations

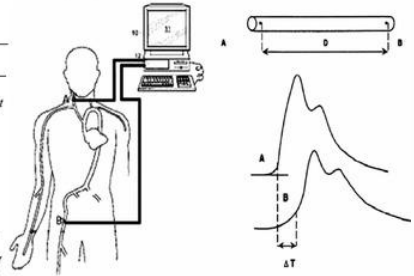
1. Assumptions for Vessel Radius , Arterial Stiffness, or Wall Thickness
 - BMI Estimation (Krejza et al.)
 - Pulse Wave for dP/dA
 - Imaging

- Pulse wave velocity (PWV) measurement

$$PWV = D/\Delta T$$

$$PWV = \sqrt{\frac{1}{\rho \cdot D_{ist}}}$$

- ρ = blood density
- D_{ist} = vessel distensibility



Pulse Wave Velocity (PWV) (m/sec) = D (m) / T (sec)
 D: Distance between carotid and femoral arteries
 T: Time difference of delay between carotid and femoral arteries

