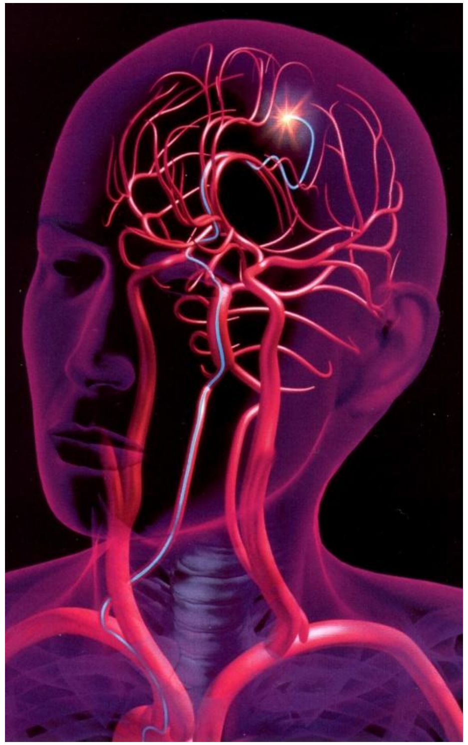
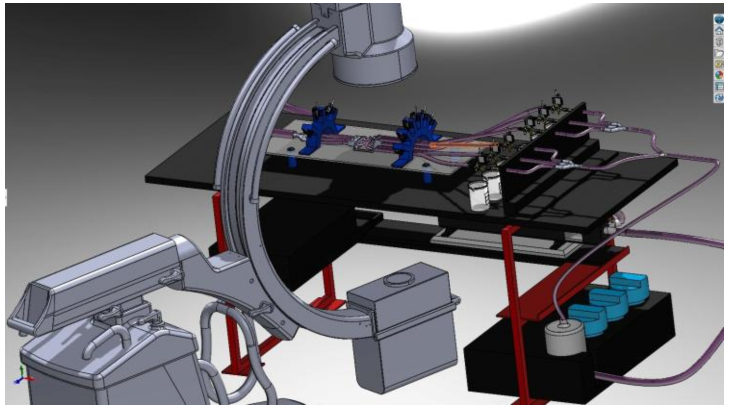


ME 476C Spring 2026 – PIV team V2

Carley Barton
Blake Pottinger
Clinton Nelson
Ryan Abelman

Particle Image Velocimetry integration with the Bioengineering Devices Lab benchtop flow model



Project Description/Importance

Particle Image Velocimetry (PIV):

- Uses lasers to illuminate particles in flow and a camera to capture a sequence of images to be analyzed.
- Allows for analysis of the velocity field which can be used to find stresses, transient behavior, and streamlines.

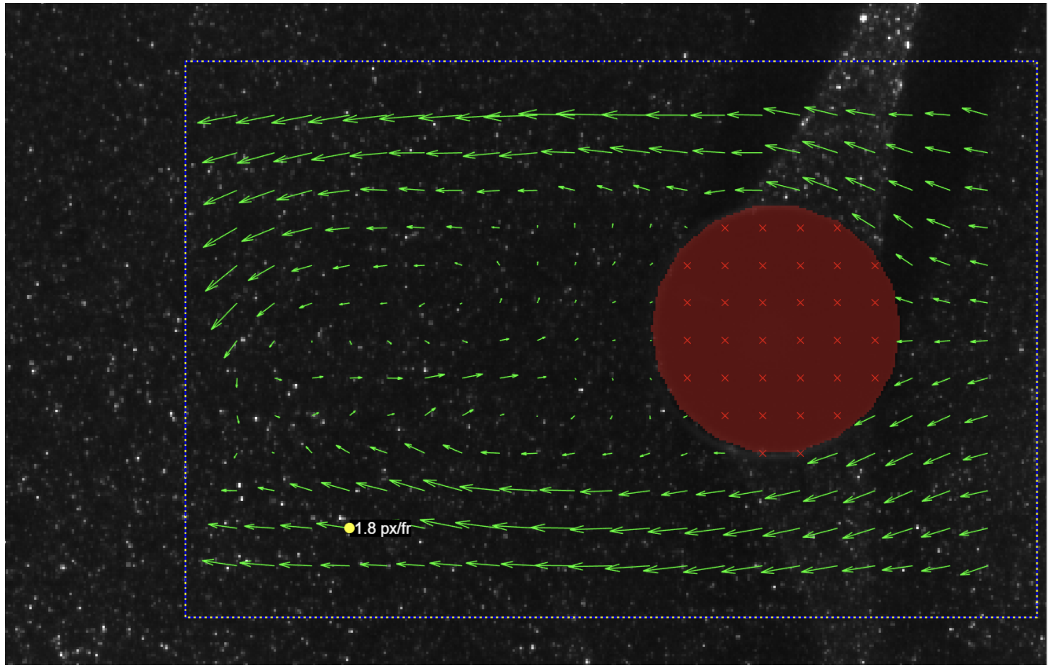


Figure 1: Flow analysis with vectors

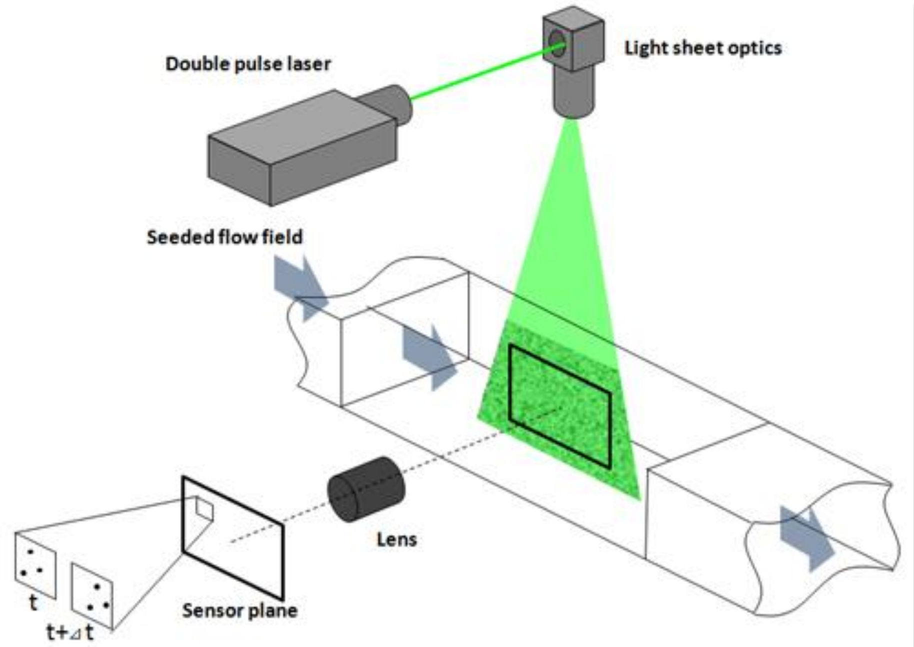


Figure 2: PIV set up

Project Description/Importance

What has been done:

- The previous capstone team created a setup of a PIV system but without the flow loop. Preliminary tests conducted were a proof of concept for setting up the laser and camera.

Goals for the future:

- Incorporating a PIV set up into the BDL benchtop flow model.
- Test medical products on different phantoms with a flow system to see how the flow is behaving around these products.
- PIV will bridge the gap to gain velocity/flow/shear data where our current benchtop model can only collect pressures.

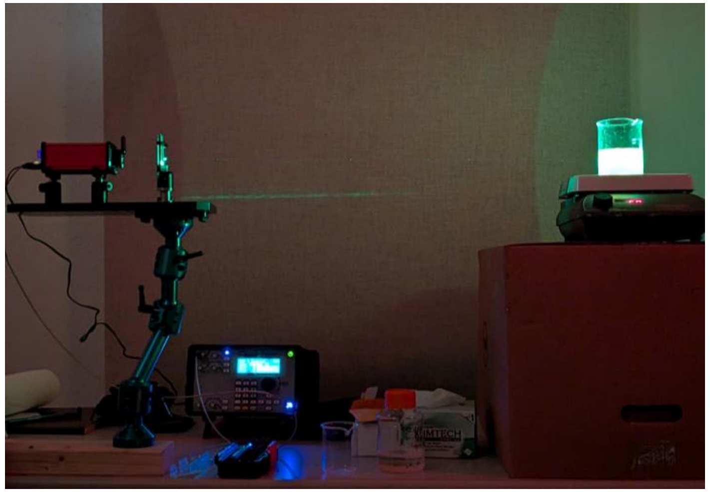


Figure 3: Previous PIV set up

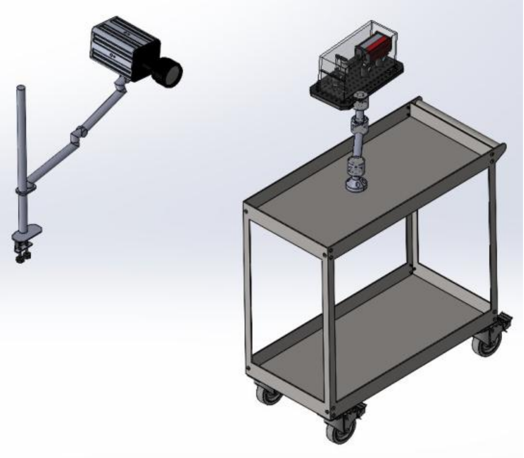


Figure 4: CAD model of previous capstone

Sponsor

Sponsor: Tim Becker, PhD

Associate Professor

Mechanical Engineering Department

Principle Investigator

Bioengineering Devices Lab

Chief Technology Officer

Aneuvas Technologies, Inc. (ATI)

Client: Jesse Wells, B.S.

Lead Engineer

Bioengineering Devices Lab

Lead Engineer

Aneuvas Technologies, Inc. (ATI)

Sponsors:

Western Component Sales
&
JB Industries

Labeled drawing views of design

CAD design balloon labels:

1. Base plate made of 3D printing material with extruded pins.
2. Long side wall made of 3D printing material with extruded cut for pins to fit into.
3. Short Side wall made of 3D printing material with extruded cut on bottom and extruded pins on front face to fit with long side wall.
4. Rectangular clear silicone block (the phantom model).
5. PVA 3D printed inner core that will be dissolved out with water leaving a hollow shape inside of the phantom.

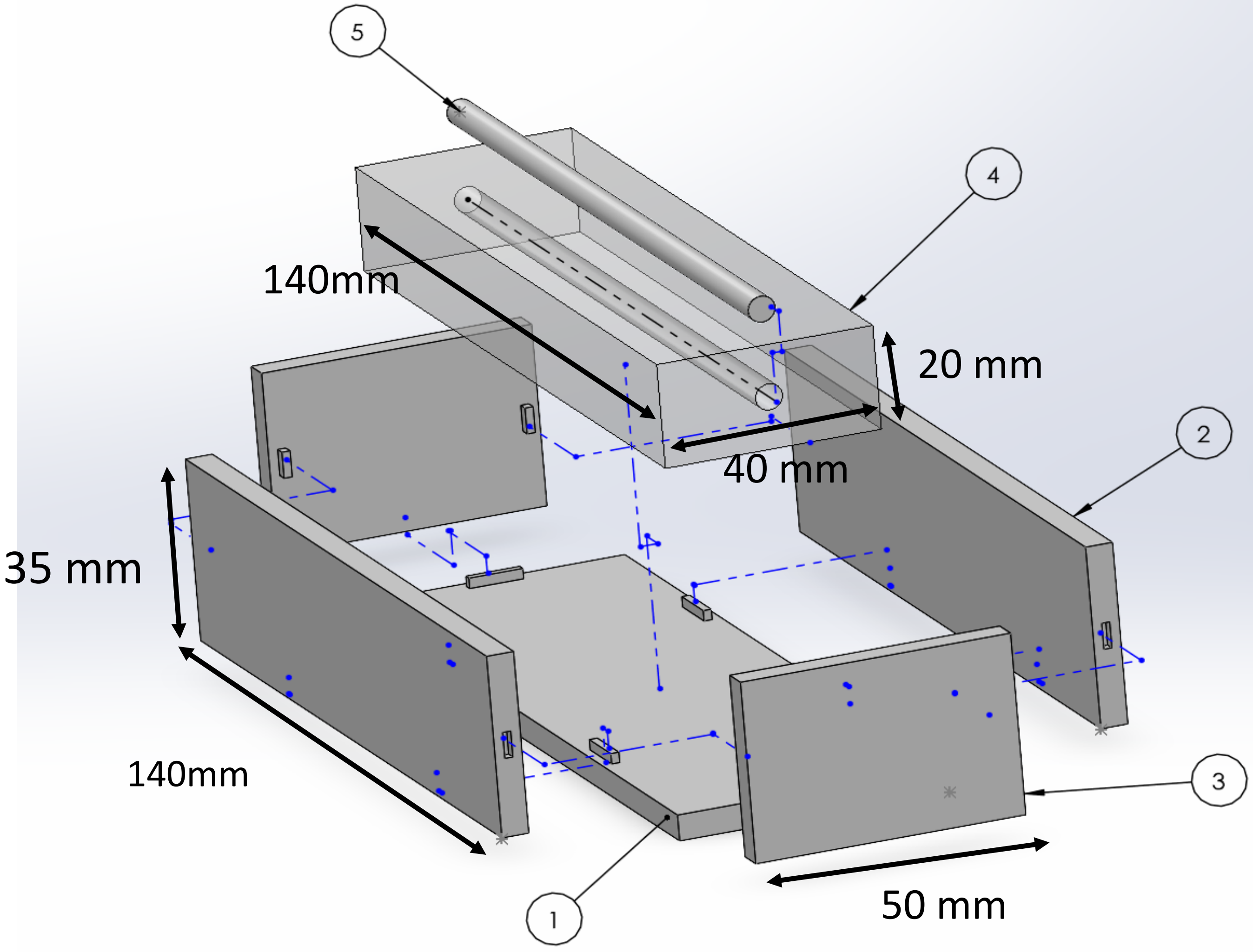


Figure 5: Full assembly CAD model

Top level design functions

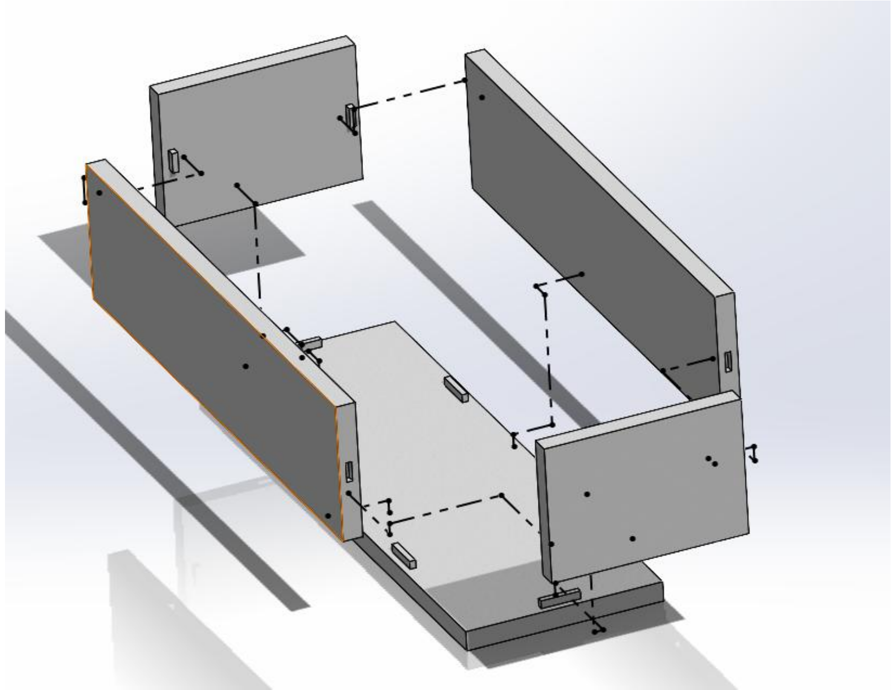


Figure 6: 3D printed box Subassembly

Includes two short walls, two long walls, and one base plate. This assembly includes extruded notches and extruded cuts to fit together like puzzle pieces.

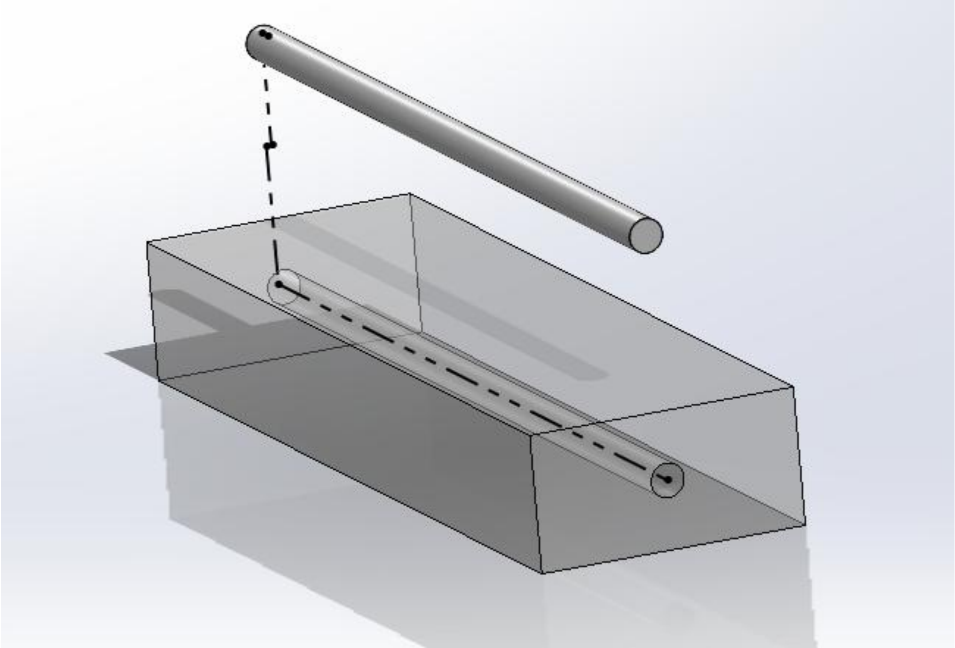


Figure 7: Phantom Mold Subassembly

Simple inner core model of a cylinder, this will be made of PVA, and silicone will be cured around it. This whole assembly will be in the box assembly and removed once cured. Leaving a silicone block with the PVA core inside which will be dissolved out using water.

Customer Requirements

Conversion Time

To incorporate the PIV set up with the BDL benchtop model we will have two flow loops side by side on a table. This conversion time will allow for easy setup of the PIV system and the change between the two loops. How long does it take to switch from PIV flow loop to standard benchtop model loop?

Particle Selection

Two particles will be needed when collecting data, one saturating the fluid flow and another mixed in with the synthetic blood clot solution before they are cured. Each particle must be distinguished from the other to collect two data sets. Which particle is best for visibility? Which particle will be in the flow loop, and which particles will be used in clots?

Laser Wavelength (Color)

The laser that will be illuminating the fluorescent particles can be various colors selected by the team, each color illuminates the particles differently. Which laser color will best illuminate the particles?

Clarity of Silicone

The clarity of silicone is important for data collection. This phantom silicone mold must be clear to collect the most accurate data. Important for visibility when using a camera to capture the particles within the phantom.

Refractive Index Match

When there is a differing refractive index between materials, in this case the HPMC blood analog fluid and the silicone, an offset may be caused creating a skew in the data collected. Matching the two refractive indexes will eliminate the offset and optimize data collection.

Validation

This phantom model and PIV set up will be used by the BDL lab to test medical devices. Validating the Phantoms by molding a more intricate and physiological accurate model will allow for testing of these novel medical devices. Validation will include performing medical procedures by aspirating synthetic blood clots with catheters in the phantom model.

Engineering Requirements

Decrease time to convert between flows

Being able to switch back and forth between two flow loops in under 2 minutes will increase the amount of time to focus on the experiments and not have to wait for the set up to be complete.

Increase particle density in fluid

Calculate the number of particles best fit for a certain volume of fluid so the visibility is 0.1 particles per pixel of an image (ideal particle density in fluid). This will determine the seeding of the particles in the fluid; how many particles are to be dispersed in the fluid and selecting the best diameter and density of the particle we can achieve this.

Change laser color

Find the best fit wavelength for laser color, we are aiming for a green color which is around 532 nm. Test different wavelengths of the laser with different colored particles and analyze capture images in PIVlab to see best visibility.

Visibility of particles

Selecting the best particle size and color to get the best visibility for analyzing images and calculate the particle density for seeding of the particles.

Visibility of silicone

Prototype different methods for casting silicone including removal of male inner mold, eliminating bubbles, and preventing discoloration. This requirement can be calculated using the refractive index.

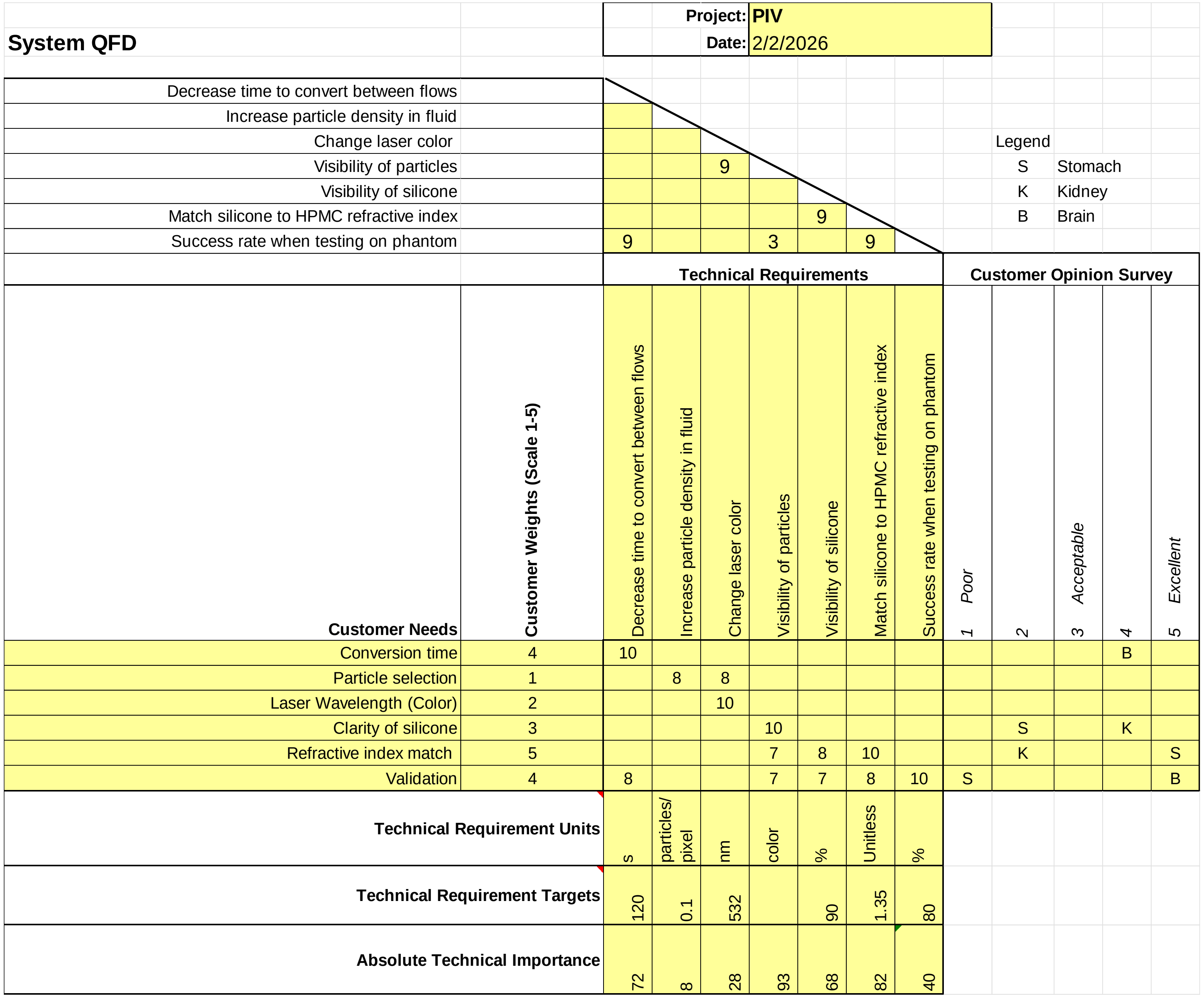
Match refractive index of all materials, silicone, and synthetic blood mixture

Change the properties of either the silicone or blood mixture to match each other. This will eliminate offsets in the images collected and have a clear view of the hollowed phantom model.

Success rate when testing on phantom

An 80% success rate is ideal for a phantom under an aspiration test. Will we be able to track the flow around the catheter and clot? Will visibility be high? Will the software for PIV work accordingly? Will this process and set up be repeatable?

QFD



System QFD

Project: PIV
Date: 2/2/2026

	Decrease time to convert between flows	Increase particle density in fluid	Change laser color	Visibility of particles	Visibility of silicone	Match silicone to HPMC refractive index	Success rate when testing on phantom
Decrease time to convert between flows							
Increase particle density in fluid							
Change laser color							
Visibility of particles			9				
Visibility of silicone							
Match silicone to HPMC refractive index					9		
Success rate when testing on phantom	9			3		9	

Legend
S Stomach
K Kidney
B Brain

		Technical Requirements							**Customer Opinion Survey**				
Customer Needs	**Customer Weights (Scale 1-5)**	Decrease time to convert between flows	Increase particle density in fluid	Change laser color	Visibility of particles	Visibility of silicone	Match silicone to HPMC refractive index	Success rate when testing on phantom	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
Conversion time	4	10										B	
Particle selection	1		8	8									
Laser Wavelength (Color)	2			10									
Clarity of silicone	3				10					S		K	
Refractive index match	5				7	8	10			K			S
Validation	4	8			7	7	8	10	S				B
Technical Requirement Units		s	particles/ pixel	nm	color	%	Unitless	%					
Technical Requirement Targets		120	0.1	532		90	1.35	80					
Absolute Technical Importance		72	8	28	93	68	82	40					

Figure 8: QFD

Engineering calculation #9 – Settling Velocity

Fall or Settling Velocity [4]:

$$V_t = \frac{g * d^2(\rho_p - \rho_m)}{18\mu}$$

V_t is the settling velocity of the particles within the fluid, this is what we are solving for

g = 9.81 $\frac{m}{s^2}$, acceleration of gravity

d = $\frac{27\ -45}{2}$ $\mu m = 36\mu m = 3.6\ x\ 10^{-5} m$, average particle diameter in vial

ρ_p = 0.98 $\frac{g}{mL}$ = 980 $\frac{kg}{m^3}$, particle density [5]

ρ_m = 0.982 $\frac{g}{mL}$ = 982 $\frac{kg}{m^3}$, medium/fluid density, this is the density of HPMC, slightly lower than water because of the additive of ethanol

μ = 0.004 $\frac{N}{m^2}$, viscosity of medium/fluid, this is the viscosity of HPMC which is matched to be the viscosity of blood

$$V_t = \frac{9.81(3.6\ *\ 10^{-5})^2(980 - 982)}{18(0.004)} = -3.5 * 10^{-7}\frac{m}{s} = -0.00035\frac{mm}{s}$$

This number means that every second a particle will rise 0.00035 because of the difference in density. We selected a specific particle that had a density close to that of the fluid and a diameter that is small enough for the vessel but large enough to be seen in captured images.

This process helped select a particle best fit for our fluid. By matching the density of the particle and fluid and selecting one of a medium sized diameter it will not settle in our phantom.

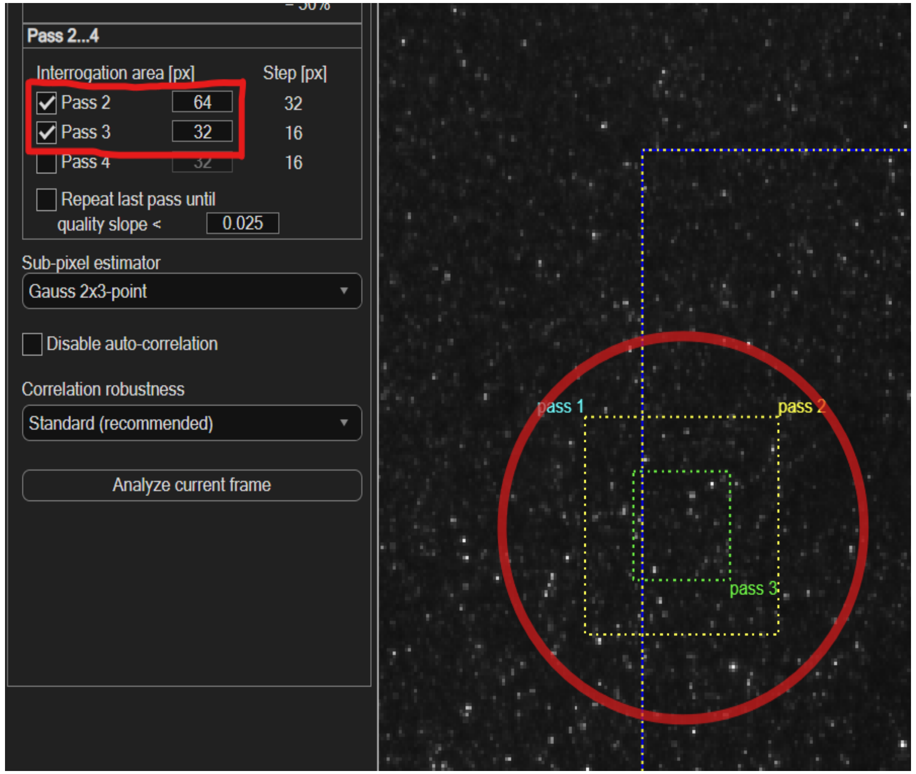
This was validated from the website we will be purchasing the particles from and the equation is given on that website as well as a calculator where you can plug in values.

Engineering calculation #10 – Spatial Resolution

- **X-Stream XS-4 High-Speed Camera**
    - 512 x 512 [pixel] resolution
    - 16 x 16 [µm] pixel size
    - => 512 x 16 [µm] = 8192 [µm] = 8.192 [mm]
    - => 8.192 [mm] x 8.192 [mm] sensor width x height

- **Values set**
    - Focal length of camera f = 50 [mm] (Dependent on Lens)
    - Distance of lens to laser sheet WD (Working Distance) = 300 [mm]

- **Calculations [7]**
    - => FOV = $\frac{Sensor\ Size * WD}{f} = \frac{8.192 * 300}{50} = 49.152\ [mm]$
    - => Image Scale = $\frac{mm}{Pixel} = \frac{49.152\ [mm]}{512\ Pixels} = 0.096\ \left[\frac{mm}{Pixel}\right]$
    - => Spatial Resolution = 32[Pixels] * 0.096 $\left[\frac{mm}{Pixel}\right] = \mathbf{3.072\ [mm]}$



Pass 2...4

Interrogation area [px]		Step [px]
☑ Pass 2	64	32
☑ Pass 3	32	16
☐ Pass 4	32	16

☐ Repeat last pass until quality slope < 0.025

Sub-pixel estimator: Gauss 2x3-point

☐ Disable auto-correlation

Correlation robustness: Standard (recommended)

Figure 9: PIVLAB Analysis

Engineering calculation #10 – Spatial Resolution

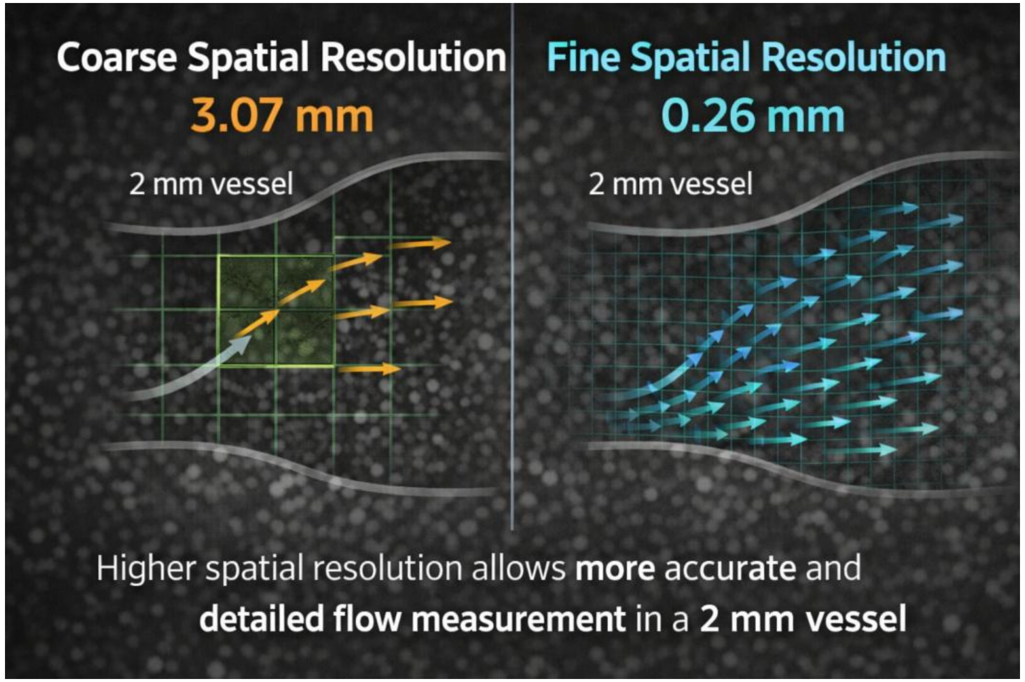


Figure 10: Comparison to cerebral arteries benchmark [2]

Ways to decrease the spatial resolution

- Increase the focal length of the lens
- Decrease the distance of the camera to the PIV phantom

Engineering calculation #11 – Offset

Snell's Law: [6]

Relates Sine Angles to difference Materials Refractive indexes.

$$\frac{sin\theta_1}{sin\theta_2} = \frac{n_2}{n_1}$$

But with small angles we can simplify it into a linear relationship without trig functions

$$\Rightarrow sin\theta \approx \theta$$

$$\Rightarrow n_1\theta_1 = n_2\theta_2$$

We then can simplify Snell's law into:

$$= \theta_2 = \frac{n_1}{n_2}\theta_1$$

But instead of solving for change in angles, we can derive Snell's Equation from angles too:

$$\Delta\theta(Change\ in\ Angles) \propto \frac{\Delta n(Difference\ in\ Indexes)}{n(Average\ of\ Indexes)}$$

$$\delta(Offset) = t * \Delta\theta = t * \frac{\Delta n}{n}$$

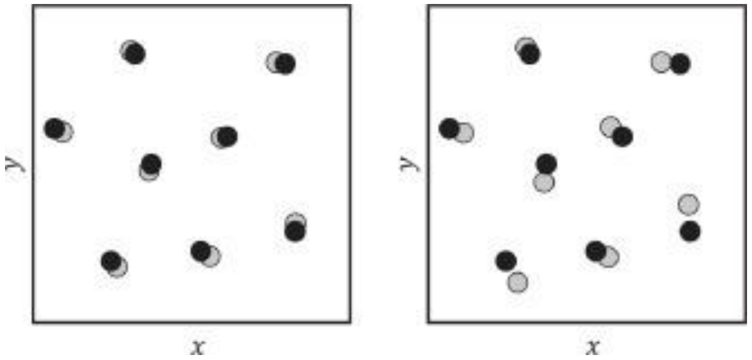


Figure 11: Left side small offset between particles and right-side large offset of particles

Engineering calculation #11 – Offset

Silicone Refractive Index	1.41
Fluid Refractive Index	1.334
Difference	0.076
Average	1.372
Slope(Difference/Average)	0.05539359

Thickness(mm)	Offset(mm)
0.5	0.02769679
1	0.05539359
1.5	0.08309038
2	0.11078717
2.5	0.13848397
3	0.16618076
3.5	0.19387755
4	0.22157434
4.5	0.24927114
5	0.27696793
5.5	0.30466472
6	0.33236152
6.5	0.36005831
7	0.3877551
7.5	0.4154519
8	0.44314869
8.5	0.47084548
9	0.49854227
9.5	0.52623907
10	0.55393586

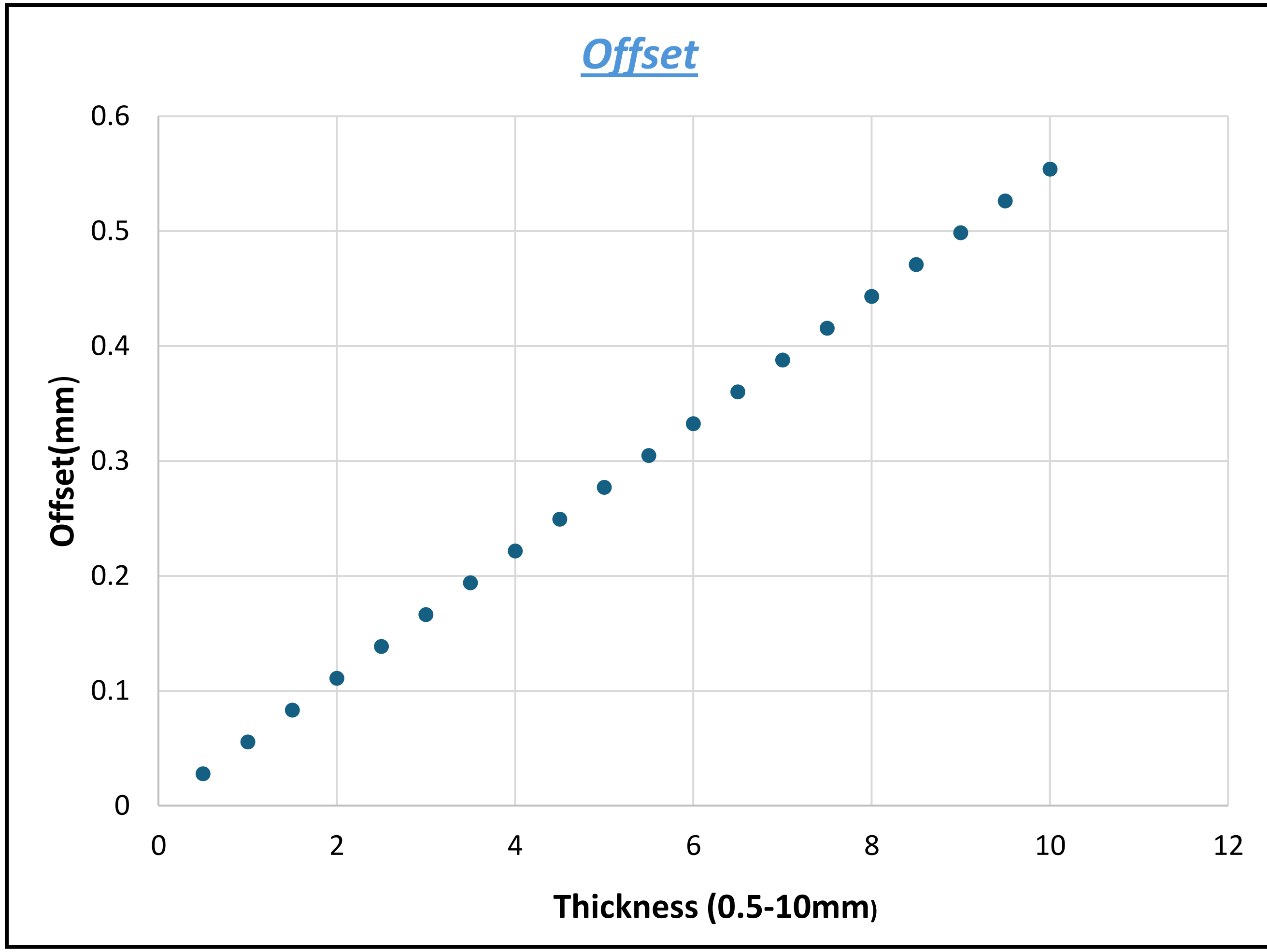


Figure 12: Offset vs thickness graph

Engineering calculation #12 – Relative Distortion

Equations and Variables:

$$relative\ distortion = \frac{offsett}{spacial\ resolution}$$

$$offsett = t\ \frac{\Delta n}{\bar{n}}$$

$t = thickness$

$\Delta n = $ *Difference in refractive index of substance*

$\bar{n} =$ *Average refractive index of substance*

Calculation:

Offset $= (10\text{mm}) \frac{(1.41-1.334)}{\frac{(1.41+1.334)}{2}} = 0.554$ mm

$$relative\ distortion = \frac{0.554\ mm}{3.072\ mm} = 0.180\ (unitless) \approx 18\%\ of\ our\ resoultion\ will\ be\ distorted$$

Resolution through the phantom

How it informed our design:

- About 18% distortion means moderate and possibly acceptable results
- Features in image will be slightly shifted
- Distortion not severe and major adjustments to creation of phantom will not have to be made
- Camera not strong enough to catch the offset

Correction if needed to lower distortion:

- Smaller thickness (t) value to decrease change in "n"

Validation: based off researched strategies and values passed from group mates

Design requirements

Decrease time to convert between flows – Measured while experimenting, the process will be set up and timed. Process will be evaluated to see if time can be cut down anywhere.

Increase particle density in fluid –

Calculation #5: Solved for particle density in a viewing window, needs to be revised

Change laser color – Selected by testing and after particle color is finalized. Various colors illuminate differently under different laser wavelengths. Aiming for green color, should be around 532 nm

Visibility of particles –

Calculation #9: Settling velocity, particle section for fluid is important so the particle does not settle to the top or bottom of the fluid in the phantom.

Visibility of silicone – Adjusted in the manufacturing process of silicone, evacuating the bubbles via a vacuum and pressure chamber.

Match refractive index of all materials, silicone, and synthetic blood mixture –

Calculation #1: solving for the RI of HPMC, RI = 1.334

Calculation #2: Match silicone RI HPMC, 0.71% silicone and 99.29% water. Found to not be possible so we had to pivot.

Calculation #4: Change the RI of HPMC by adding glycerin, 44% HPMC and 56% glycerin

Design requirements

Success rate when testing on phantom –

Calculation #3 & 10: Spatial resolution to see how detailed the data can be in a flow. Recalculated in calculation 10 to be 3.07 mm which is very coarse.

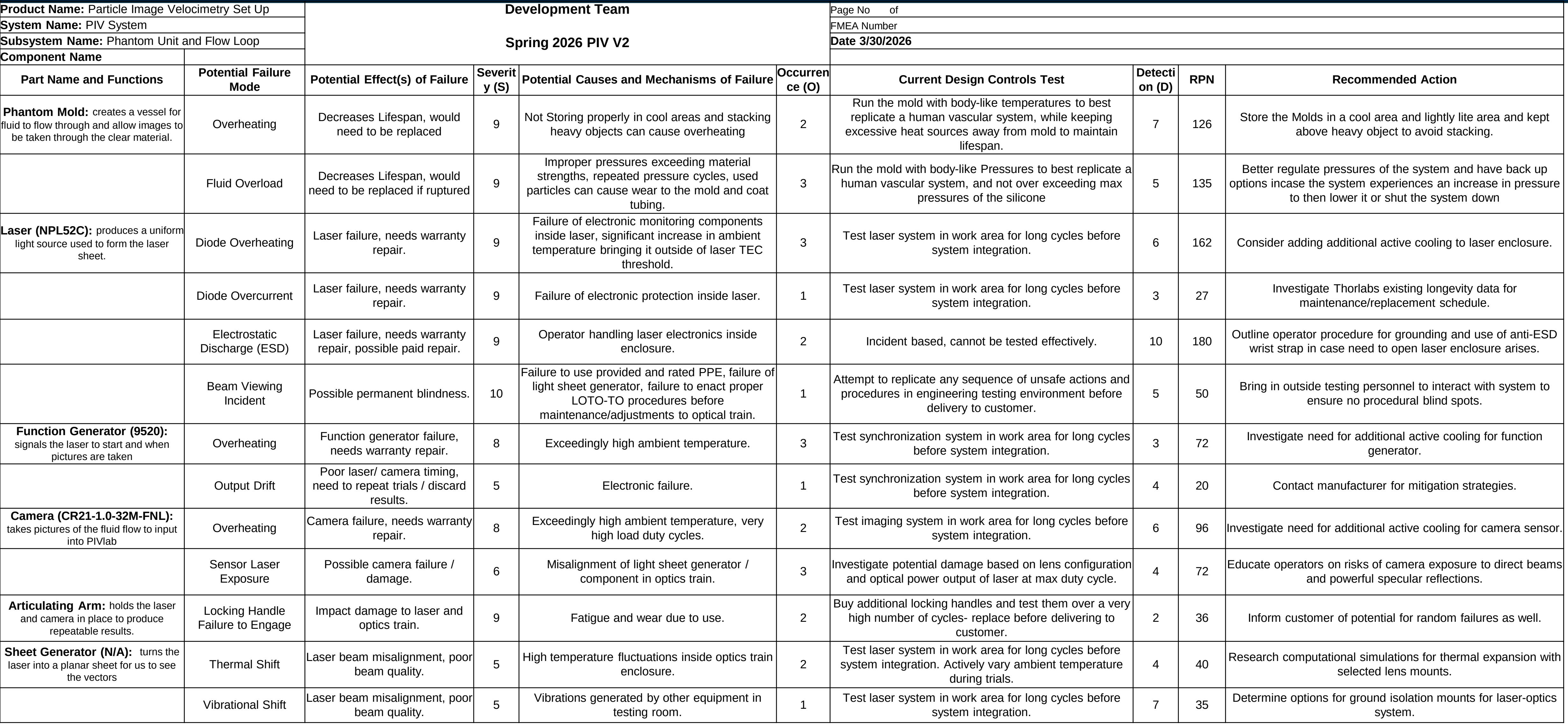
Calculation #6: Minimum wall thickness to withstand internal pressure, found to be 0.0262mm

Calculation #7 & 8: Phantom cost analysis, provides data for the repeatability of the process in the future when multiple molds will be made.

Calculation #11: offset calculation if refractive index does not match. Thickness also effects the offset so a graph was made displaying 0.5-10mm thickness of phantom and what the offset will be.

Calculation #12: Relative distortion based on offset and spatial resolution. Tells us how much of the measurement is being corrupted relative to what can be detected. If between 0.1-0.2 the resolution won't capture the offset, distortion is invisible to our system. Meaning our velocity vectors will be reliable.

Design validation FMEA



Product Name: Particle Image Velocimetry Set Up
System Name: PIV System
Subsystem Name: Phantom Unit and Flow Loop
Component Name

Development Team

Spring 2026 PIV V2

Page No of
FMEA Number
Date 3/30/2026

Part Name and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Phantom Mold: creates a vessel for fluid to flow through and allow images to be taken through the clear material.	Overheating	Decreases Lifespan, would need to be replaced	9	Not Storing properly in cool areas and stacking heavy objects can cause overheating	2	Run the mold with body-like temperatures to best replicate a human vascular system, while keeping excessive heat sources away from mold to maintain lifespan.	7	126	Store the Molds in a cool area and lightly lite area and kept above heavy object to avoid stacking.
	Fluid Overload	Decreases Lifespan, would need to be replaced if ruptured	9	Improper pressures exceeding material strengths, repeated pressure cycles, used particles can cause wear to the mold and coat tubing.	3	Run the mold with body-like Pressures to best replicate a human vascular system, and not over exceeding max pressures of the silicone	5	135	Better regulate pressures of the system and have back up options incase the system experiences an increase in pressure to then lower it or shut the system down
Laser (NPL52C): produces a uniform light source used to form the laser sheet.	Diode Overheating	Laser failure, needs warranty repair.	9	Failure of electronic monitoring components inside laser, significant increase in ambient temperature bringing it outside of laser TEC threshold.	3	Test laser system in work area for long cycles before system integration.	6	162	Consider adding additional active cooling to laser enclosure.
	Diode Overcurrent	Laser failure, needs warranty repair.	9	Failure of electronic protection inside laser.	1	Test laser system in work area for long cycles before system integration.	3	27	Investigate Thorlabs existing longevity data for maintenance/replacement schedule.
	Electrostatic Discharge (ESD)	Laser failure, needs warranty repair, possible paid repair.	9	Operator handling laser electronics inside enclosure.	2	Incident based, cannot be tested effectively.	10	180	Outline operator procedure for grounding and use of anti-ESD wrist strap in case need to open laser enclosure arises.
	Beam Viewing Incident	Possible permanent blindness.	10	Failure to use provided and rated PPE, failure of light sheet generator, failure to enact proper LOTO-TO procedures before maintenance/adjustments to optical train.	1	Attempt to replicate any sequence of unsafe actions and procedures in engineering testing environment before delivery to customer.	5	50	Bring in outside testing personnel to interact with system to ensure no procedural blind spots.
Function Generator (9520): signals the laser to start and when pictures are taken	Overheating	Function generator failure, needs warranty repair.	8	Exceedingly high ambient temperature.	3	Test synchronization system in work area for long cycles before system integration.	3	72	Investigate need for additional active cooling for function generator.
	Output Drift	Poor laser/ camera timing, need to repeat trials / discard results.	5	Electronic failure.	1	Test synchronization system in work area for long cycles before system integration.	4	20	Contact manufacturer for mitigation strategies.
Camera (CR21-1.0-32M-FNL): takes pictures of the fluid flow to input into PIVlab	Overheating	Camera failure, needs warranty repair.	8	Exceedingly high ambient temperature, very high load duty cycles.	2	Test imaging system in work area for long cycles before system integration.	6	96	Investigate need for additional active cooling for camera sensor.
	Sensor Laser Exposure	Possible camera failure / damage.	6	Misalignment of light sheet generator / component in optics train.	3	Investigate potential damage based on lens configuration and optical power output of laser at max duty cycle.	4	72	Educate operators on risks of camera exposure to direct beams and powerful specular reflections.
Articulating Arm: holds the laser and camera in place to produce repeatable results.	Locking Handle Failure to Engage	Impact damage to laser and optics train.	9	Fatigue and wear due to use.	2	Buy additional locking handles and test them over a very high number of cycles- replace before delivering to customer.	2	36	Inform customer of potential for random failures as well.
Sheet Generator (N/A): turns the laser into a planar sheet for us to see the vectors	Thermal Shift	Laser beam misalignment, poor beam quality.	5	High temperature fluctuations inside optics train enclosure.	2	Test laser system in work area for long cycles before system integration. Actively vary ambient temperature during trials.	4	40	Research computational simulations for thermal expansion with selected lens mounts.
	Vibrational Shift	Laser beam misalignment, poor beam quality.	5	Vibrations generated by other equipment in testing room.	1	Test laser system in work area for long cycles before system integration.	7	35	Determine options for ground isolation mounts for laser-optics system.

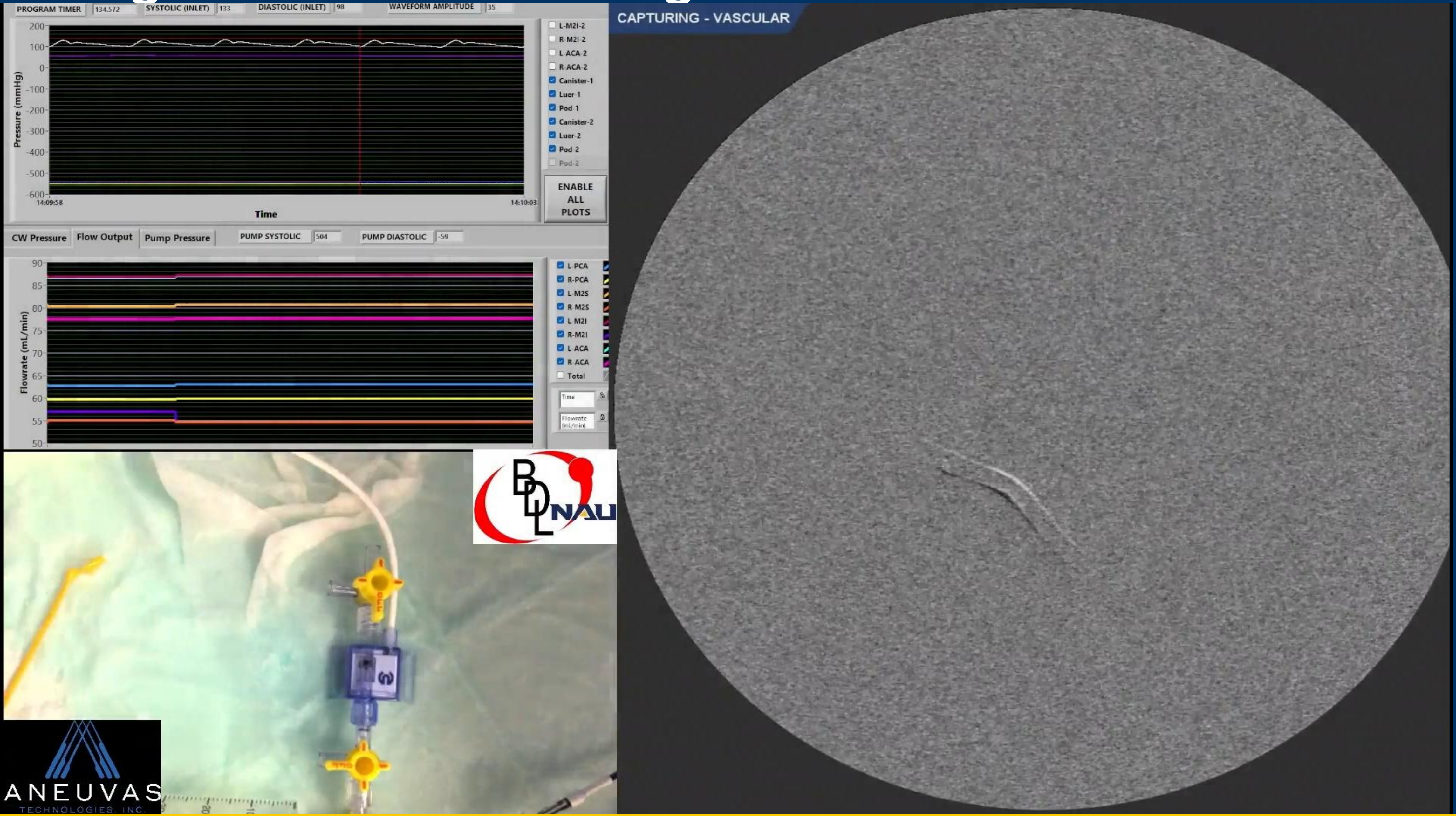
Figure 13: FMEA chart

Design validation FMEA

What we added to the FMEA:

Part Name and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Phantom Mold: creates a vessel for fluid to flow through and allow images to be taken through the clear material.	Overheating	Decreases Lifespan, would need to be replaced	9	Not Storing properly in cool areas and stacking heavy objects can cause overheating	2	Run the mold with body-like temperatures to best replicate a human vascular system, while keeping excessive heat sources away from mold to maintain lifespan.	7	126	Store the Molds in a cool area and lightly lite area, and kept above heavy object to avoid stacking.
	Fluid Overload	Decreases Lifespan, would need to be replaced if ruptured	9	Improper pressures exceeding material strengths, repeated pressure cycles, used particles can cause wear to the mold and coat tubing.	3	Run the mold with body-like Pressures to best replicate a human vascular system, and not over exceeding max pressures of the silicone	5	135	Better regulate pressures of the system and have back up options incase the system expriences an increase in pressure to then lower it or shut the systme down

Design Validation Testing Procedures



PROGRAM TIMER 134.572
SYSTOLIC (INLET) 133
DIASTOLIC (INLET) 98
WAVEFORM AMPLITUDE 35

☐ L-M2I-2
☐ R-M2I-2
☐ L-ACA-2
☐ R-ACA-2
☑ Canister-1
☑ Luer-1
☑ Pod-1
☑ Canister-2
☑ Luer-2
☑ Pod-2
☐ Pod-2

PUMP SYSTOLIC 504
PUMP DIASTOLIC -59

☑ L-PCA
☑ R-PCA
☑ L-M2S
☑ R-M2S
☑ L-M2I
☑ R-M2I
☑ L-ACA
☑ R-ACA
☐ Total

Design Validation Testing Plans

Our plan is to preform clot aspirations in our phantom model
Small outline of procedure as seen in the video shown before:

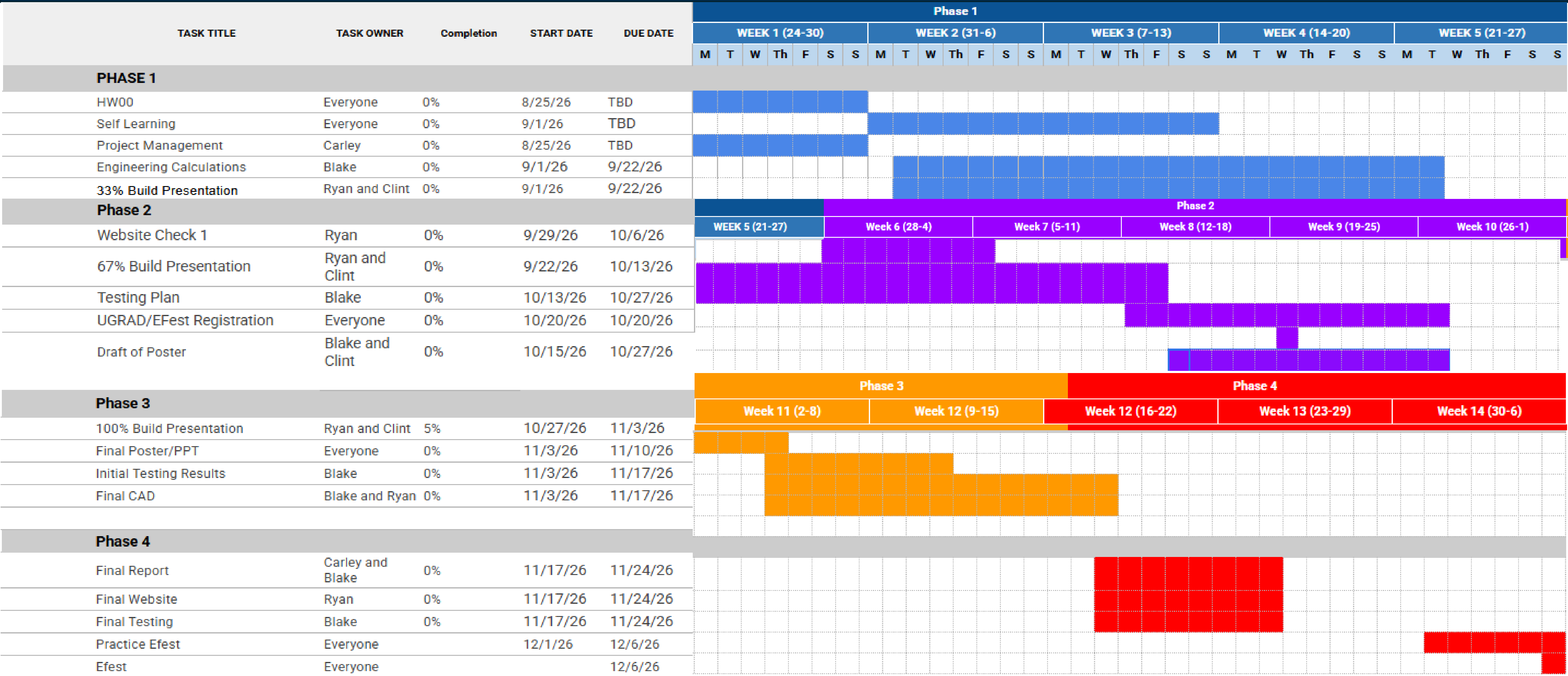
1. Includes inserting a synthetic blood clot into a certain part of a vessel in the model.
2. Then bring a catheter to the tip of the clot.
3. Turn on an aspiration pump or use a syringe vacuum to attach to the blood clot.
4. Then, slowly remove the catheter holding the clot until removed fully from model.

While all of this is happening, we will be collecting data illuminating particles in the flow and capturing images at high frame rates to track the particles.
The data collected will give us:

- Velocity of the particles including magnitude, direction, and fields over time
- Transient behavior: visualize the flow evolution during aspiration
- Shear rate/velocity gradients: taking the change in velocity between vectors and dividing by the distance between those vectors
- Visualize streamlines/path lines in flow
- Directly shows how the clot moves, also tracks if the clot particulates (particles break off the clot and move down stream)

Experiments will be conducted in the BDL surgical suite. We will be using donated catheters and synthetic blood clots produced by the lab.

Schedule (Gantt Chart)



TASK TITLE	TASK OWNER	Completion	START DATE	DUE DATE
PHASE 1				
HW00	Everyone	0%	8/25/26	TBD
Self Learning	Everyone	0%	9/1/26	TBD
Project Management	Carley	0%	8/25/26	TBD
Engineering Calculations	Blake	0%	9/1/26	9/22/26
33% Build Presentation	Ryan and Clint	0%	9/1/26	9/22/26
Phase 2				
Website Check 1	Ryan	0%	9/29/26	10/6/26
67% Build Presentation	Ryan and Clint	0%	9/22/26	10/13/26
Testing Plan	Blake	0%	10/13/26	10/27/26
UGRAD/EFest Registration	Everyone	0%	10/20/26	10/20/26
Draft of Poster	Blake and Clint	0%	10/15/26	10/27/26
Phase 3				
100% Build Presentation	Ryan and Clint	5%	10/27/26	11/3/26
Final Poster/PPT	Everyone	0%	11/3/26	11/10/26
Initial Testing Results	Blake	0%	11/3/26	11/17/26
Final CAD	Blake and Ryan	0%	11/3/26	11/17/26
Phase 4				
Final Report	Carley and Blake	0%	11/17/26	11/24/26
Final Website	Ryan	0%	11/17/26	11/24/26
Final Testing	Blake	0%	11/17/26	11/24/26
Practice Efest	Everyone		12/1/26	12/6/26
Efest	Everyone			12/6/26

We are currently on track with our schedule

Projects Budget

- **Income**
  - Materials from previous PIV team
  - Fundraising
- **Fundraising update**
  - A JB Eliminator vacuum pump was donated via Western Component Sales and JB Industries which values over $500 completing our fundraising goals.
- **Predicted Expenses**
  - $665.77 in testing materials
  - ~ $2,000 3D printer
  - ~ $200 Vacuum Chamber
- **Expenses to date**
  - None
- **Resulting Balance**
  - $134.23

JB Industries Eliminator Vacuum Pump

Projected budget		
Item	Cost	Quantity
PVA material	35.99	1 roll
PLA material	22.99	1 roll
1/8"IDx3/16"OD Tubing	7.26	25 ft
1/4"IDx3/8"OD Tubing	3.28	10 ft
Vial of particles color #1	200	1 vial
Vial of particles Color #2	200	1 vial
Liquasil clear silicone	196.25	5.5 kg
PVA 3D Printer	2,000*	1 Printer
Vacuum Chamber	200*	1 Chamber
Total:	2,865.77	* = Estimation
Remaining Budget:	134.23	

Table 1: Project expenses estimation

Thank you
Any questions?

Works Cited

[1] F. Adams *et al.*, "Soft 3D-printed phantom of the human kidney with collecting system," *Annals of Biomedical Engineering*, vol. 45, no. 4, pp. 963–972, Nov. 2016. doi:10.1007/s10439-016-1757-5

[2] C. A. Luisi *et al.*, "Investigation of cerebral hemodynamics during endovascular aspiration: Development of an experimental and numerical setup," *Cardiovascular Engineering and Technology*, vol. 14, no. 3, pp. 393–403, Feb. 2023. doi:10.1007/s13239-023-00660-8

[3] C. Özcan, Ö. Kocatürk, C. Işlak, and C. Öztürk, "Integrated particle image velocimetry and fluid–structure interaction analysis for patient-specific abdominal aortic aneurysm studies," *BioMedical Engineering OnLine*, vol. 22, no. 1, Dec. 2023. doi:10.1186/s12938-023-01179-8

[4] "Cospheric LLC," Cospheric Microspheres - Precision Spherical Particles Globally, https://www.cospheric.com/microsphere-settling-time-calculation.aspx

[5] "Rhodamine B polyethylene microspheres 0.98g/CC - 10UM to 1000um (1mm)," Cospheric, https://www.cospheric.com/RHBPMS_solid_polymer_rhodamine_B_spheres.htm

[6] Snell's law -- the law of refraction, https://personal.math.ubc.ca/~cass/courses/m309-01a/chu/Fundamentals/snell.htm (accessed Mar. 30, 2026).

[7] Scharnowski, S., & Kähler, C. J. (2020). Particle image velocimetry - Classical operating rules from today's perspective. *Optics and Lasers in Engineering*, *135*, 106428. https://doi.org/10.1016/s0143-8166(20)31843-1

Prototype demo

Physical prototype: Basic phantom mold to start the process of silicone casting.
Question asked: Is this process repeatable, is there anything we need to change about this process?

1. 3D print inner core, this prototype included a twist and remove core
2. Piece together acrylic box and sealed with hot glue
3. Mix 2-part silicone mixture, measure based on weight, not volume
4. Place cup of mixed silicone in vacuum chamber
5. Place inner core print in outer mold
6. Pour silicone into outer mold
7. Place whole mold into vacuum chamber again
8. Place whole mold into pressure chamber and leave until cured ~7-9 hours
9. Remove outer mold
10. Remove inner core

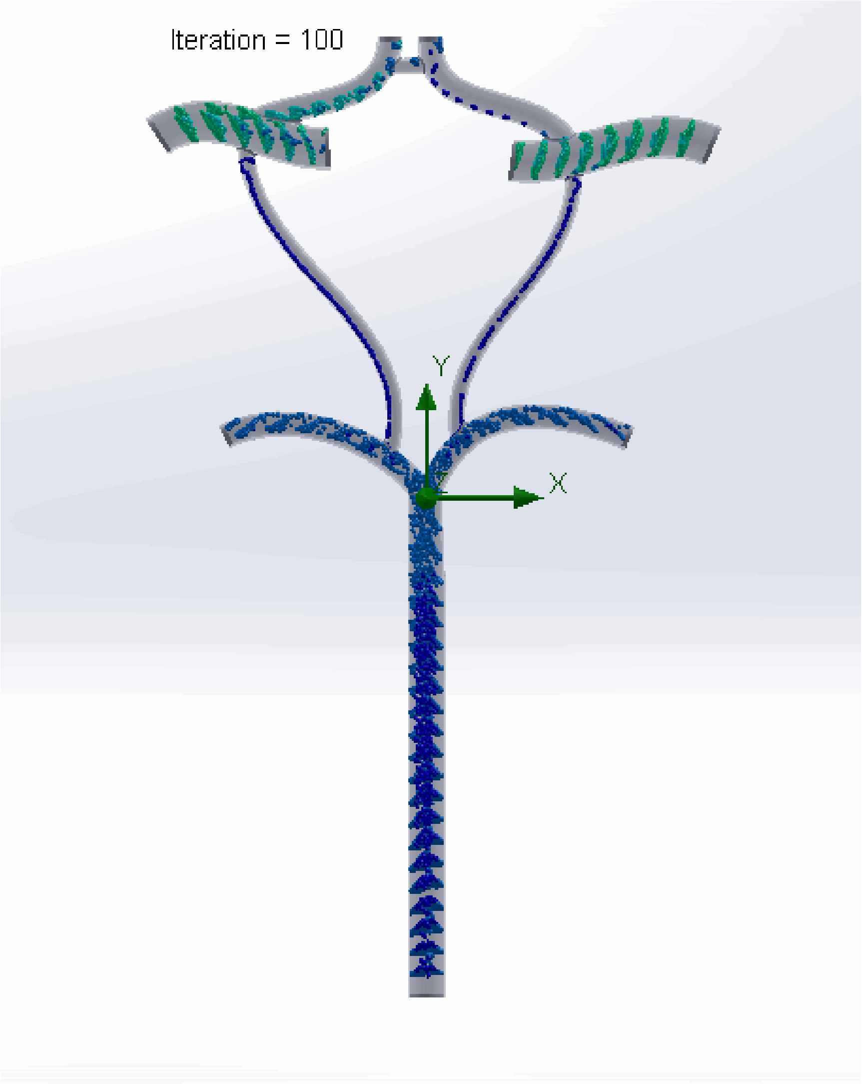
This prototype reused materials from the BDL lab, for example the laser cut acrylic box and the 3D printed twist core. This mold produced a 101.6 X 37.75 X 33.02 mm silicone block.

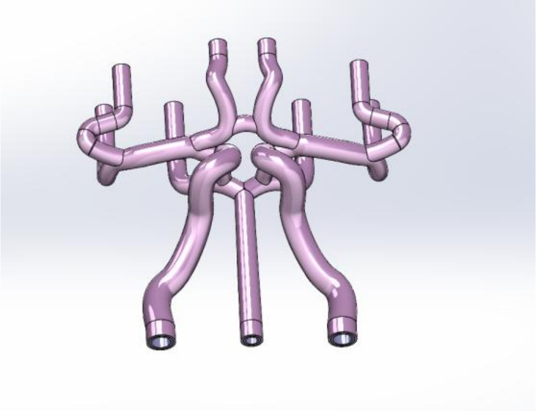
Our next prototype will use a 3D printed box with specific dimensions and if needed sealed with electrical tape because that was found to be better than hot glue due to the removal process, the hot glue had to be reheated using a heat gun and left residue.

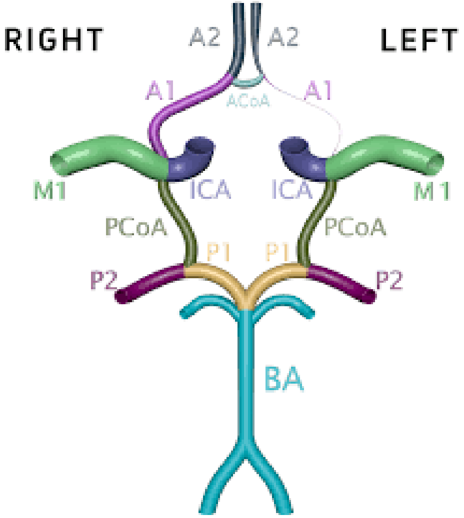
Virtual prototype

The purpose of the virtual model was to visualize how the flow moves around a simulated clot in a rough Circle of Willis.

This virtual demo was able to show us that a simulated clot in a rough model still heavily decrease the blood flow and that we can use this flow simulation in a more advanced 3D model.







Next steps

Create a phantom model using the PVA core to get a more intricate design.

3D print the box assembly that will seal in the silicone better than our prototype.

Increase the amount of time in vacuum and pressure chamber

Be more aware of the working cure time to avoid prototypes like prototype 1