Adaptive Sterile Modular ISO Class 7 Biomedical Manufacturing Cleanroom

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Project Description

Project Description:
Design and manufacture an ISO Class 7 cleanroom and convert the current cleanroom into a gowning room.

Importance of the Project:
Construct a space where faculty and students can learn and develop new ways to contribute to the human healthcare system.

Deliverables:
- Literature Review
- Project Proposal
- Engineering Analysis
- Cost Estimation
- BOM
- Detailed Manufacturing Procedures
- Receipts
- Potential Duplication of room

Success Metrics:
Project objectives, deliverables, customer, and engineering requirements were met.

Client/Sponsors:


Timothy Becker


David Willy

Anuevas Technologies Inc

Customer and Engineering Requirements

Customer Requirements:

- **CR1: Modular** – can be assembled and disassembled in a business day with a small crew of people
- **CR2: Transportable** – can be transported in sections
- **CR3: Spacious** – can hold at least 6 people
- **CR4: Safe** – can support the weight of the FFUs
- **CR5: ISO Class 7 Compliant** – meets particle count, airflow, and ceiling coverage requirements.

Engineering Requirements:

- **ER1: Spacious** – room area around 192 ft^2 (12' x 16')

ER2: Particle Count and Size - 0 μg of particles size > 0.5 µm

- **ER3: Airflow** - ≥ 90 ft/min, ≥ 60 air changes/hour
- **ER4: Ceiling Coverage** - ≥ 15%
- **ER5: Reynold's Number** - $< 1 * 10^7$
- **ER6: Deflection** – 0in

System QFD

Project:	Modular Sterile Manufacturing Clean Room
Date:	4-9-24

1	Room Area							
3	Particle Count	6						
4	Particle Size	6	9					
5	Airflow	6	3	3				
6	Ceiling Coverage	9	9	9	6			
	Reynold's Number	6	1	1	9	6		
7	Deflection	9				6		

Legend	
A	Dr. Becker Current Design
B	Clean Air Cleanroom
C	Global Industrial Cleanroom

			Engineering Requirements							Customer Opinion Survey				
	Customer Requirements	Weight	Room Area	Particle Count	Particle Size	Airflow	Ceiling Coverage	Reynold's Number	Deflection	1 Poor	2	3 Acceptable	4	5 Excellent
1	Modular	5	3						1		C		AB	
2	Transportable	3	3						1		C	AB		
3	Spacious	4	9	-1	-1	-1		-1	9		A		C	B
4	Safe	5	9						9					ABC
5	ISO Class 7 Compliant	5	3	9	9	9	9	6					A	BC
	Engineering Requirement Units		ft^2	particles/ m^3	µm	ft/min	%	N/A	in					
	Engineering Requirement Targets		192	352,000	0.5	90	15%	1.00E+07	0					
	Absolute Technical Importance		120	41	41	41	45	26	89					
	Relative Technical Importance		1	4	4	4	3	5	2					

Figure 1: QFD

Design Space Research

Benchmarking:

Current Cleanroom Design – ISO Class 7

Figure 2: Current Cleanroom

Softwall Cleanroom (Clean Air Products) – ISO Class 8-4

Figure 3: Softwall Cleanroom

Hardwall Cleanroom (Clean Air Products) – ISO Class 8-4

Figure 4: Hardwall Cleanroom

Literature Review Topics:

- ISO Class 7 cleanroom standards
- Cleanroom manufacturing – designs and approved contact materials
- FFU functionality
- Material science – aluminum versus steel
- Structural integrity and material connections
- Thermodynamics – FFU properties in different temperatures and humidities

Maximum Number of Particles in Air (Particles per cubic meter)

ISO Class	Fed-Std 209E Class	Particle Size ≥ 0.1µm	≥ 0.2µm	≥ 0.3µm	≥ 0.5µm	≥1µm	≥ 5µm
ISO 1		10	2				
ISO 2		100	24	10	4		
ISO 3	(Class 1)	1,000	237	102	35	8	
ISO 4	(Class 10)	10,000	2,370	1,020	352	83	
ISO 5	(Class 100)	100,000	23,700	10,200	3,520	832	29
ISO 6	(Class 1,000)	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7	(Class 10,000)				352,000	83,200	2,930
ISO 8	(Class 100,000)				3,520,000	832,000	29,300

Figure 5: ISO Class 7 Requirements

Design Concept Generation

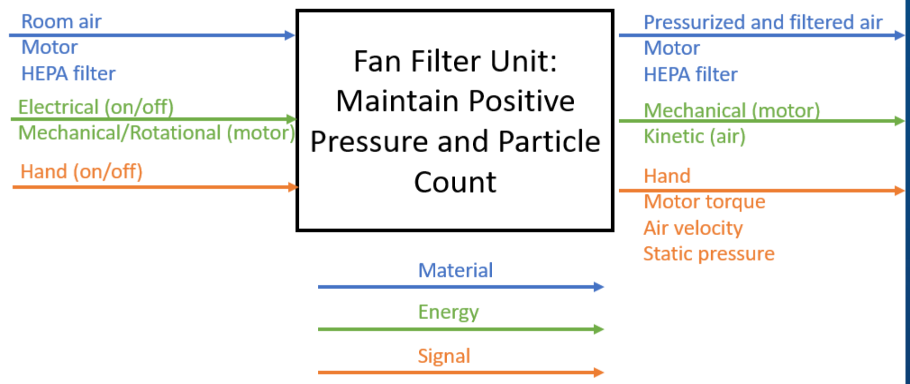


Figure 6: FFU Black Box Model

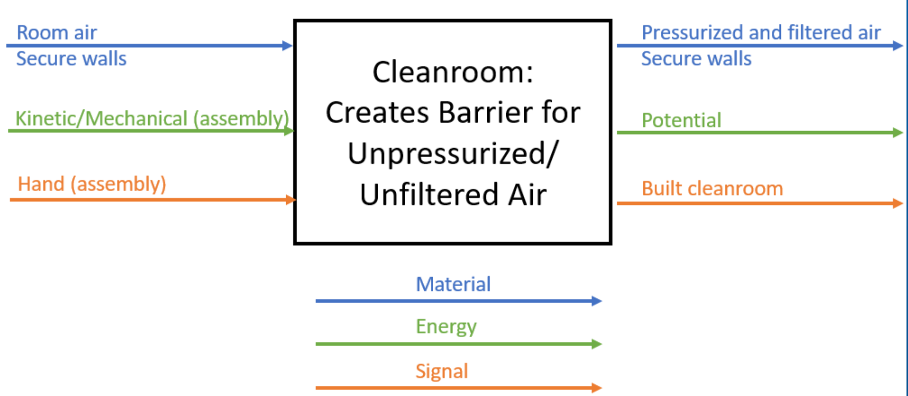


Figure 7: Cleanroom Black Box Model

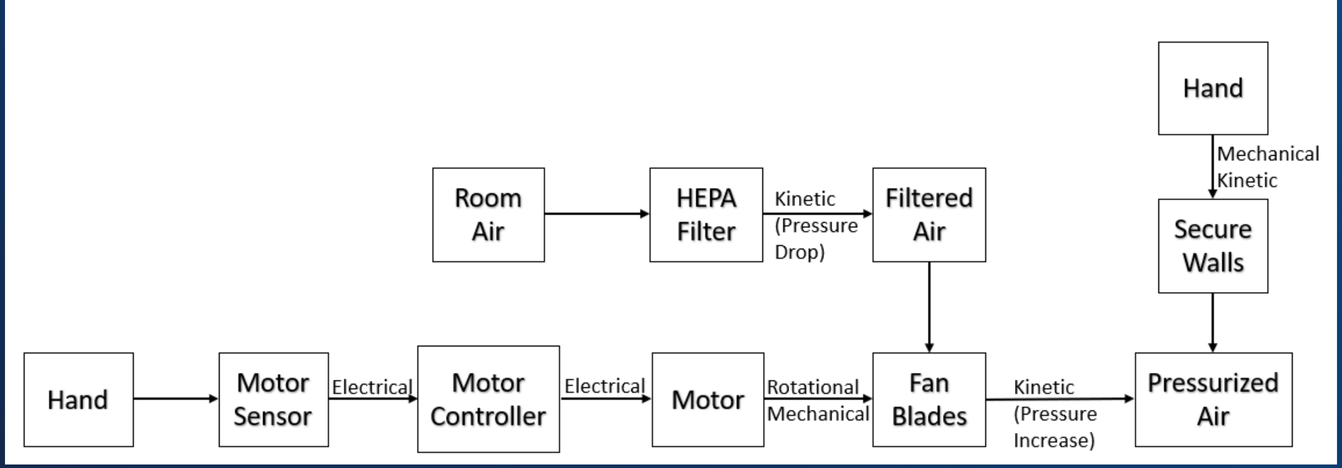


Figure 8: FFU and Cleanroom Functional Model

Design Concept Selection

Table 1: Initial Design Morphological Matrix

Subfunctions	Concept Variants			
Frame Connections	Square Tubing Nylon Connectors 	T-Slots (80/20) 	Welded 	Screwed Joints 
Material Connections	Magnets 	Adhesive 	Slide in Frames 	Screws 
Wall/Ceiling Material	All Vinyl Soft Wall 	All Polycarbonate Hard Wall 	Polycarbonate Walls with Vinyl Ceiling 	Vinyl Walls with Polycarbonate Ceiling 
Fan Number/Locations	1 Centered Fan 	2 Off-Center Fans 	2 Corner Fans 	
Frame Size	10x10 	12x8 		

Table 2: Wall Material Selection Criteria

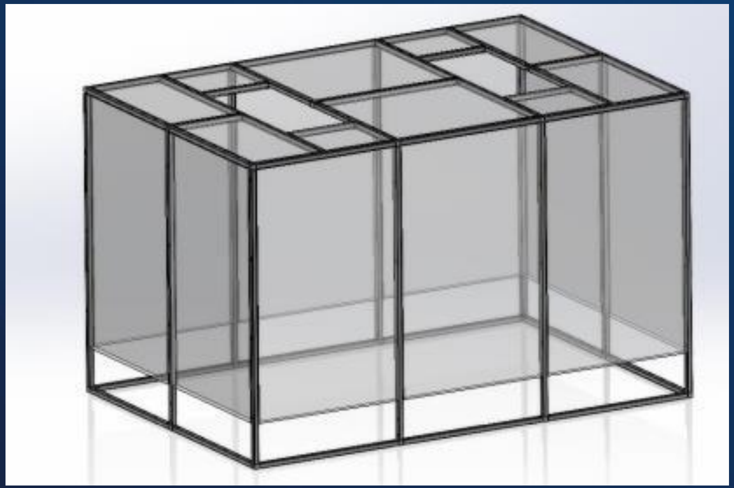
Wall/Ceiling Material	Advantages	Disadvantages
Vinyl Soft Wall/Ceiling 	- Inexpensive	- Contains VOCS - Increased air leakage - Deteriorates over time - Less modular than polycarbonate
Polycarbonate Hard Wall/Ceiling 	-Client preferred - Less air leakage - Longer life span - More professional appearance	- More expensive

Table 3: Wall Material Selection Criteria

		Hard Wall (Polycarbonate)		Soft Wall (Vinyl)	
Selection Criteria	**Weight (%)**	Score	Weighted Score	Score	Weighted Score
Cost	30	2	0.15	3	0.9
Customer preference	30	3	0.9	1	0.3
VOCS	20	2	0.4	1	0.2
Longevity	20	3	0.6	2	0.4
Total	**100**		**2.05**		**1.8**

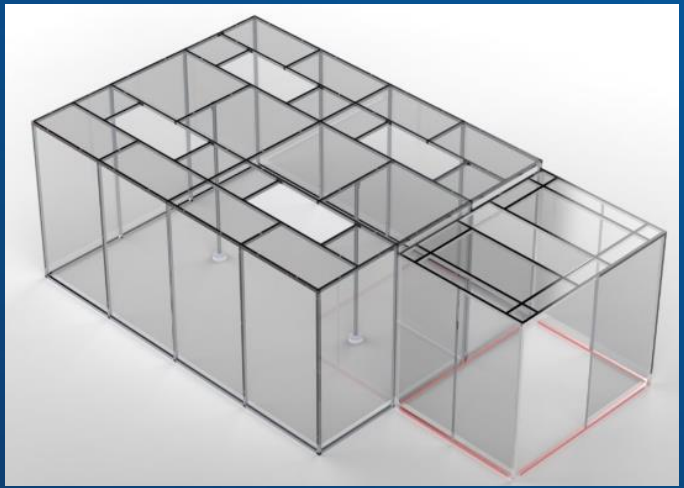
Design Iterations

Iteration 1: 12' x 8' Cleanroom



Iteration 2: 12' x 16' Cleanroom

Iteration 3: 12' x 16' Cleanroom with Support Beams and Attached 8' x 6' Gowning Room



Design Validation – Mathematical Modeling

Cost Analysis:

- Determine: Materials

Table 4: Cost Analysis

Cost Analysis					
Material			Cost ($)		
Aluminum Square Tubing	T-Slot	Steel Square Tubing	2,676.87	4,020.56	747.17
Polycarbonate	Vinyl		2,515.13	450	

Cost Estimate of Powder coating: $5,969.79

Cost Estimate for Welding: $30 - $50 per hour to make 200+ welds.

Computational Fluid Dynamics Analysis:

- Determine: # FFUs, % Ceiling Coverage, FFU Ceiling Configuration, FFU Speed, Polycarbonate Wall Gap Height

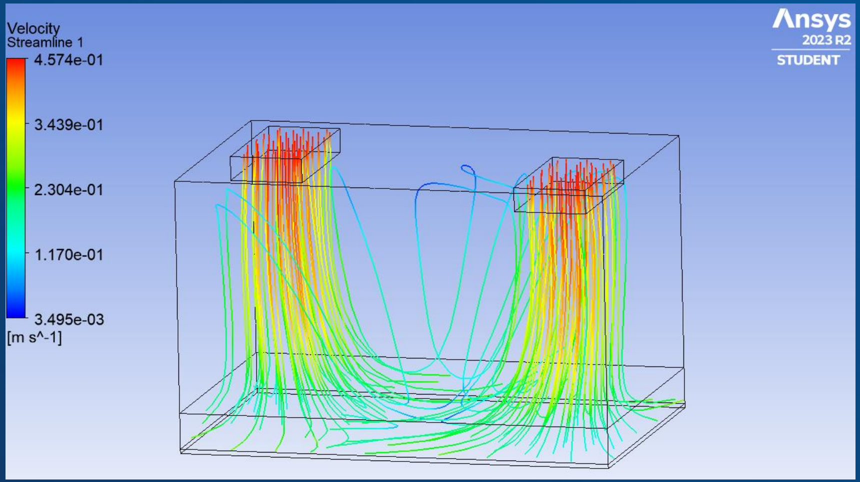


Figure 9: CFD Ansys Simulation Staggered Fans

$$Ceiling\ Coverage = \frac{Area\ FFUs}{Area\ Cleanroom\ Ceiling}$$

$$Ceiling\ Coverage\ (4\ FFUs) = \frac{4(2 * 4)}{12 * 16} = 16.67\%$$

Design Validation – Mathematical Modeling

Polycarbonate SolidWorks Simulation:

- Analyze: Force on bolts from weight of sheets to determine bolt placement.

Figure 10: Ansys Simulation, Force on Bolts

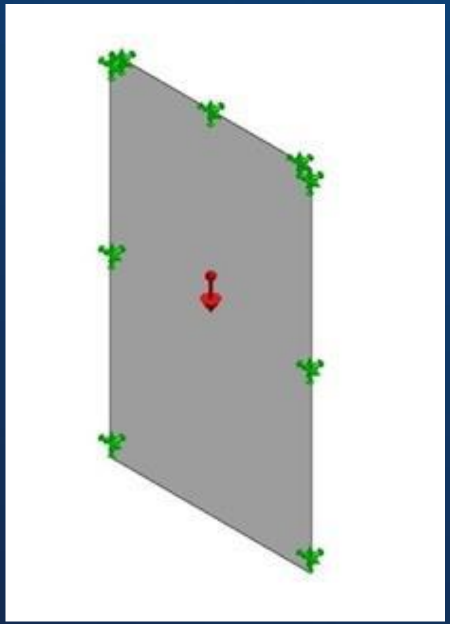


Figure 11: Ansys Simulation, Bolt Placement Force

Frame Structure Ansys Simulation:

- Analyze: Maximum stress, strain, and deflection of ceiling beams from FFU weight.

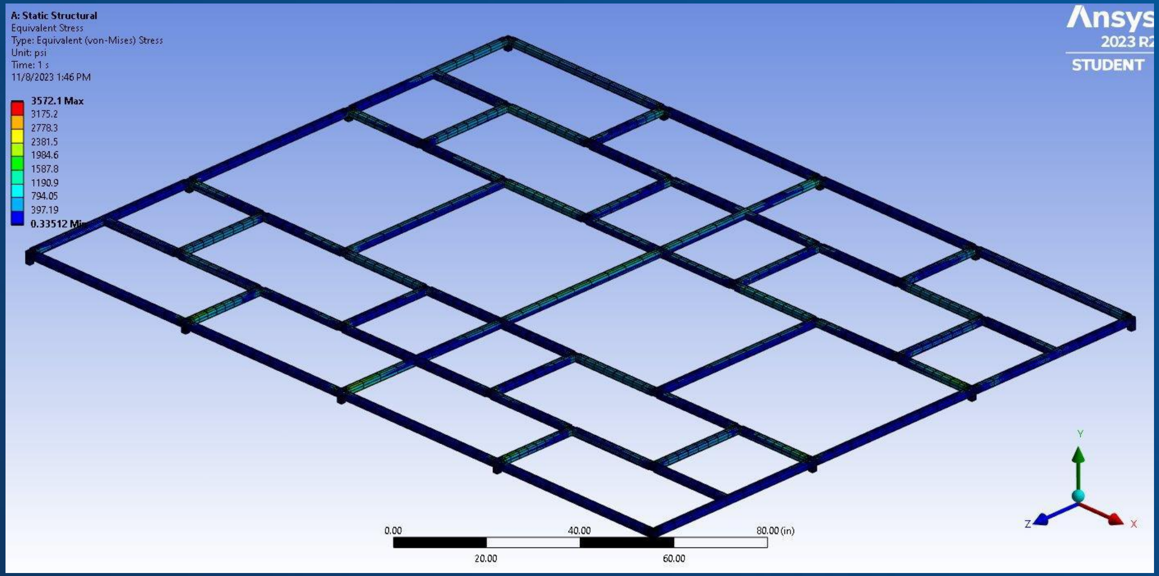


Figure 12: Structural Ansys Simulation

Failure Modes and Effects Analysis

Table 5: FMEA

Product Name: Modular Sterile Cleanroom		Development Team: Logan Bennet, Michelle Borzick, Gia Neve, Aaron Reynoza				Page No 1 of 1 Date: November 2023			
Part 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**
Fan Filter Unit: maintains airflow, pressure, and particle count requirements	HEPA filter needs replaced	Increased particle count	5	Inadequate maintanence	1	Regularly scheduled maintanence	3	15	Replace HEPA filter
	Fan turns off	Increased particle count	5	Power outage	3	Backup battery	1	15	Maintenance or replace battery
		Loss of positive pressure	8	Inadequate power supply	1	Backup battery		8	Maintenance or replace battery
		Decreased airflow	8	Fan motor burnout	1	Regularly scheduled maintanence		8	Replace fan filter unit
		Loss of ISO Class 7 Certification	8					8	
Cleanroom Walls: provide barrier between clean and external environments	Polycarbonate sheet cracks	Increased particle count	5	Damage during assembly, disassembly, or transport	3	Inspection prior to assembly	2	30	Repair (if possible) or replace polycarbonate sheets
						Regularly scheduled maintanence		30	
		Pressure leak	5			SOPs for assembly and disassmbly		30	
						Training to SOPs		30	
	Polycarbonate sheet breaks or falls	Increased particle count	5	Damage during assembly, disassembly, or transport	3	Inspection prior to assembly	1	15	Repair (if possible) or replace polycarbonate sheets
		Loss of positive pressure	8			Regularly scheduled maintanence		24	
						SOPs for assembly and disassmbly		24	
		Loss of ISO Class 7 Certification	8			Training to SOPs		24	
	Unauthorized entry	Increased particle count	5	Inadequate training or signage	1	Training to SOPs	1	5	Train personnel
						Signage on cleanroom entries		5	Add or increase signage
	External or internal pressure on the walls	Decreased wall structural integrity	6	Inadequate training	1	Training to SOPs	4	24	Train personnel
				Accidental human or machine movement	1	Training to SOPs		24	Train personnel

Initial Prototyping

Virtual Prototype 1:
Goal: Determine if support structures are needed to support FFU weights

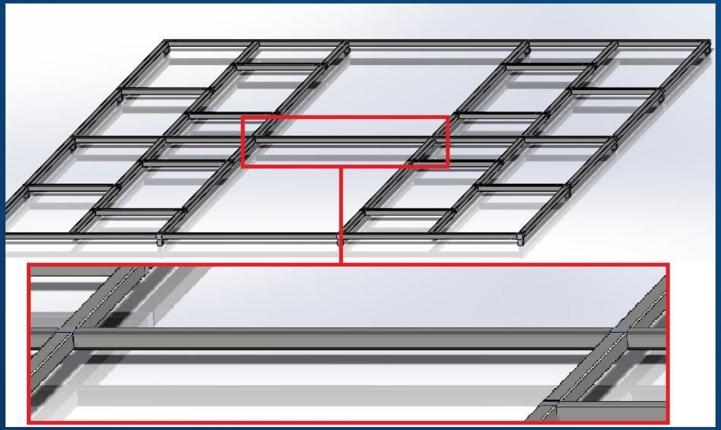


Figure 13: Structural Ansys Simulation

Physical Prototype 1:
Goal: Determine if gasketing material is needed on polycarbonate sheets

Figure 15: Gasket prototype

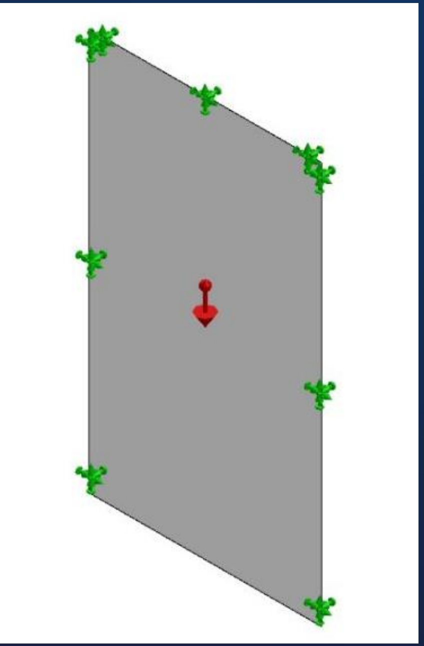


Figure 14: Solidworks Simulation

Virtual Prototype 2:
Goal: Determine how many bolts are needed to support polycarbonate sheets

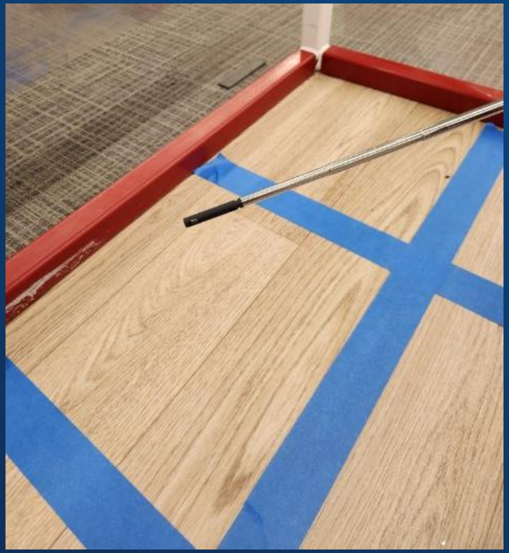


Figure 16: Velocity testing

Physical Prototype 2:
Goal: Determine FFU speed setting and wall gap height

Manufacturing Process

Aluminum Beam Manufacturing:

Figure 17: Vertical Mill

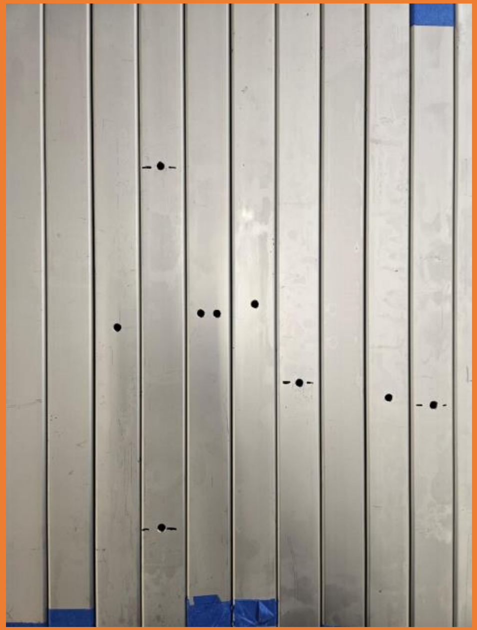


Figure 18: Hole Configuration

Steel Beam Manufacturing:

Figure 20: Ceiling Hole Drilling

Figure 19: Drill Press

Manufacturing Process

Polycarbonate Sheet Manufacturing:

Figure 21: Wall Drilling

Figure 22: Wall Cutting

Figure 23: Drilling Sheet to Ceiling Frame

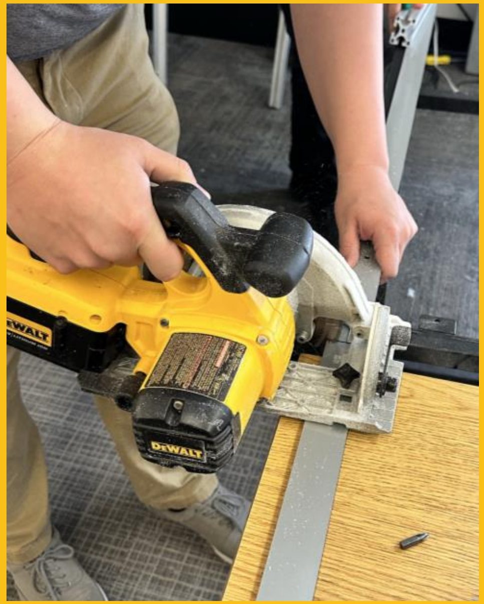


Figure 24: Cutting Aluminum

Manufacturing Process

Support Beam Manufacturing:

Figure 25: Center Support Head

Figure 26: Support Beam Trimming

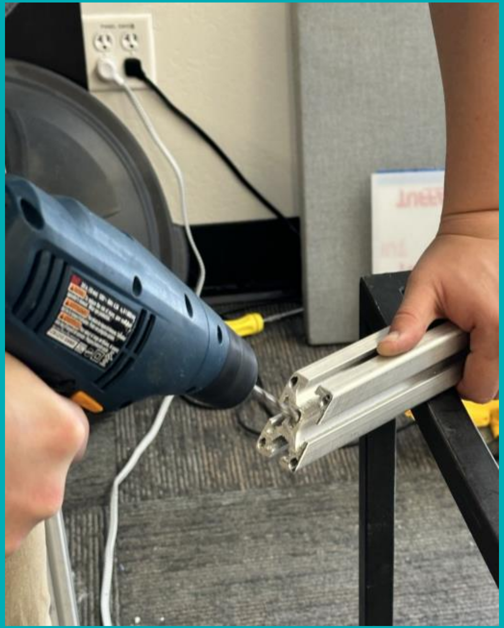


Figure 27: Drilling Holes into Truss

Figure 28: Truss Placement

Testing Summary

Table 6: Test Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed	Goal of Test
Deflection	CR4 (Safe)	Tape measure	Determine Support Beam Configuration
Particle Count	CR5 (ISO Class 7 Compliant), ER2 (Particle Count and Size)	Aerosol mass monitor, sterile gloves, hair net, shoe covers, ethanol solution	Determine if the particle count and size is within acceptable range
Airflow	CR5 (ISO Class 7 Compliant), ER3 (Airflow), ER5 (Reynold's Number)	Hot wire anemometer	Determine average velocities, air changes per hour, and if the cleanroom is laminar/transitional
Area	CR3 (Spacious), ER1 (Spacious), ER4 (Ceiling Coverage)	Tape measure	Determine the cleanroom's ability to accommodate at least 6 people and the percentage ceiling coverage.
Modularity	CR1 (Modular), CR2 (Transportable)	Instruction manual, rubber mallet, ¼" torque wrench, ladder, timer	Determine assembly and disassembly time

Deflection Testing

Goal: Determine Support Beam Configuration

Table 7: Deflection Testing Results

Deflection Point	No Support Beams	Support Beam Config 1	Support Beam Config 2	Support Beam Config 3	Support Beam Config 4
1	88.6"	89.4"	90.0"	88.8"	90.1"
2	88.6"	89.5"	90.0"	88.8"	90.1"
3	88.6"	90.0"	88.9"	90.0"	90.0"
4	88.6"	90.0"	88.9"	90.0"	90.0"
5	88.5"	89.5"	90.0"	88.8"	90.1"
6	88.9"	89.5"	90.0"	88.8"	90.1"
Average Beam Height	88.63"	89.65"	89.63"	89.2"	90.07"
Average Deflection	1.37"	0.35"	0.37"	0.8"	- 0.07"

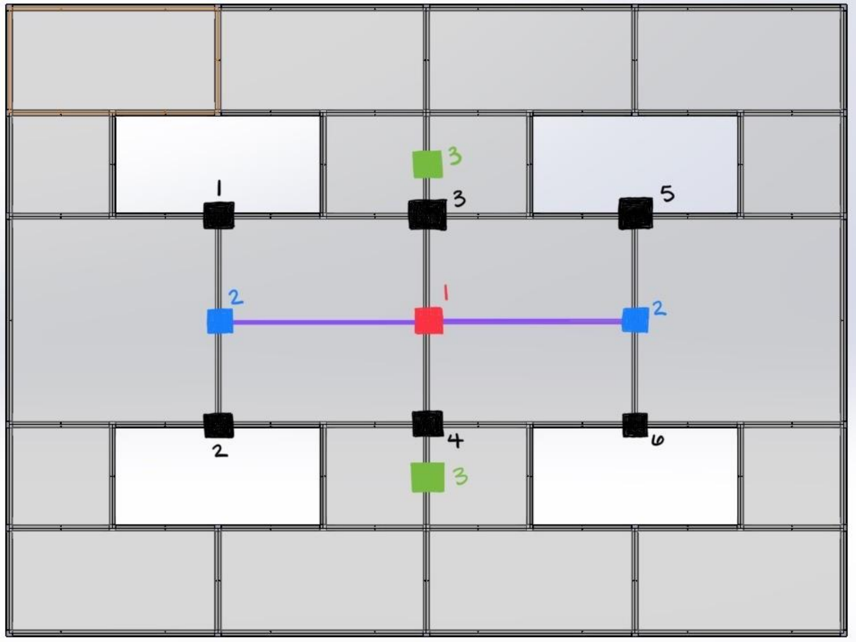


Figure 29: Deflection Points and Support Beam Configuration

Figure 30: Deflection Point Testing

Particle Count Testing

Goal: Determine if the particle count and size is within acceptable range

Figure 31: Particle Count Measurement

Table 8: Particle Count Testing Results

Location	Height (ft)	Aerosol Mass (μg)	Average Aerosol Mass (μg)
Corner 1	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Corner 2	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Corner 3	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Corner 4	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 1	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 2	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	

Location	Height (ft)	Aerosol Mass (μg)	Average Aerosol Mass (μg)
Center Quadrant 3	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 4	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 5	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 6	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 7	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Center Quadrant 8	0	0.0	0.0
	2	0.0	
	4	0.0	
	6	0.0	
Cleanroom Total Average Aerosol Mass (μg)			0.0

Airflow Testing

Goal: Determine average velocities, air changes per hour, and if the cleanroom is laminar/transitional

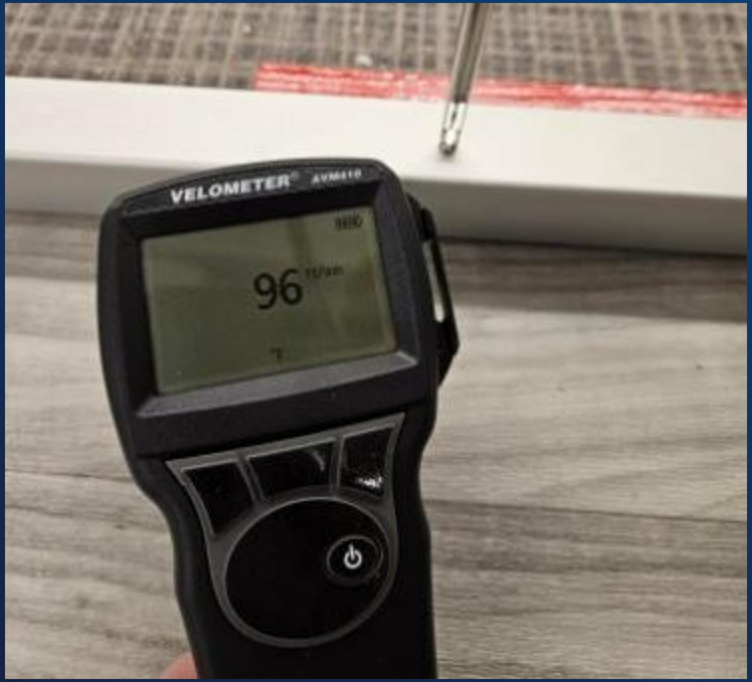


Figure 32: Anemometer

Table 9: Airflow Results

Measurement Location	Minimum Velocity (ft/min)	Maximum Velocity (ft/min)	Average Velocity (ft/min)	Air Changes per Hour	Reynold's Number
FFU 1	63	69	66	54	$7.13 * 10^4$
FFU 2	53	56	54.5	44	$5.89 * 10^4$
FFU 3	68	74	71	58	$7.67 * 10^4$
FFU 4	71	77	74	61	$8.00 * 10^4$
Outlet 1	105	114	109.5	89	$1.18 * 10^5$
Outlet 2	93	111	102	83	$1.10 * 10^5$
Outlet 3	92	104	98	80	$1.06 * 10^5$
Outlet 4	113	118	115.5	94	$1.25 * 10^5$
Outlet 5	126	136	131	107	$1.42 * 10^5$
Outlet 6	105	118	111.5	91	$1.21 * 10^5$
Outlet 7	119	127	123	100	$1.33 * 10^5$
Outlet 8	119	124	121.5	99	$1.31 * 10^5$
Outlet 9	108	114	111	90	$1.20 * 10^5$
Outlet 10	113	118	115.5	94	$1.25 * 10^5$
Outlet 11	108	111	109.5	89	$1.18 * 10^5$
Outlet 12	94	98	96	78	$1.04 * 10^5$
		Cleanroom Averages:	**100.6**	**81.6**	$\mathbf{1.09 * 10^5}$

$$Average\ velocity = \frac{\Sigma\ velocity\ measurements}{Number\ velocity\ measurements}$$

$$Air\ changes = \frac{Average\ Velocity * Outlet\ Area * 60}{Cleanroom\ Volume}$$

$$Reynold's\ \# = \frac{\rho V L}{\mu}$$

Area Testing

Goal: Determine the cleanroom's ability to accommodate at least 6 people and the percentage ceiling coverage.

$$A = L * W$$

$$Ceiling\ Coverage = \frac{Area\ FFUs}{Area\ Cleanroom\ Ceiling}$$

Figure 33: Area Testing

Table 10: Area Results

	Cleanroom	FFU
Length	15.75	3.88
Width	11.77	1.88
Area	185.4	7.29
Ceiling Coverage (%)	15.7%	

Modularity Testing

Goal: Determine the pressure difference inside and outside the cleanroom.

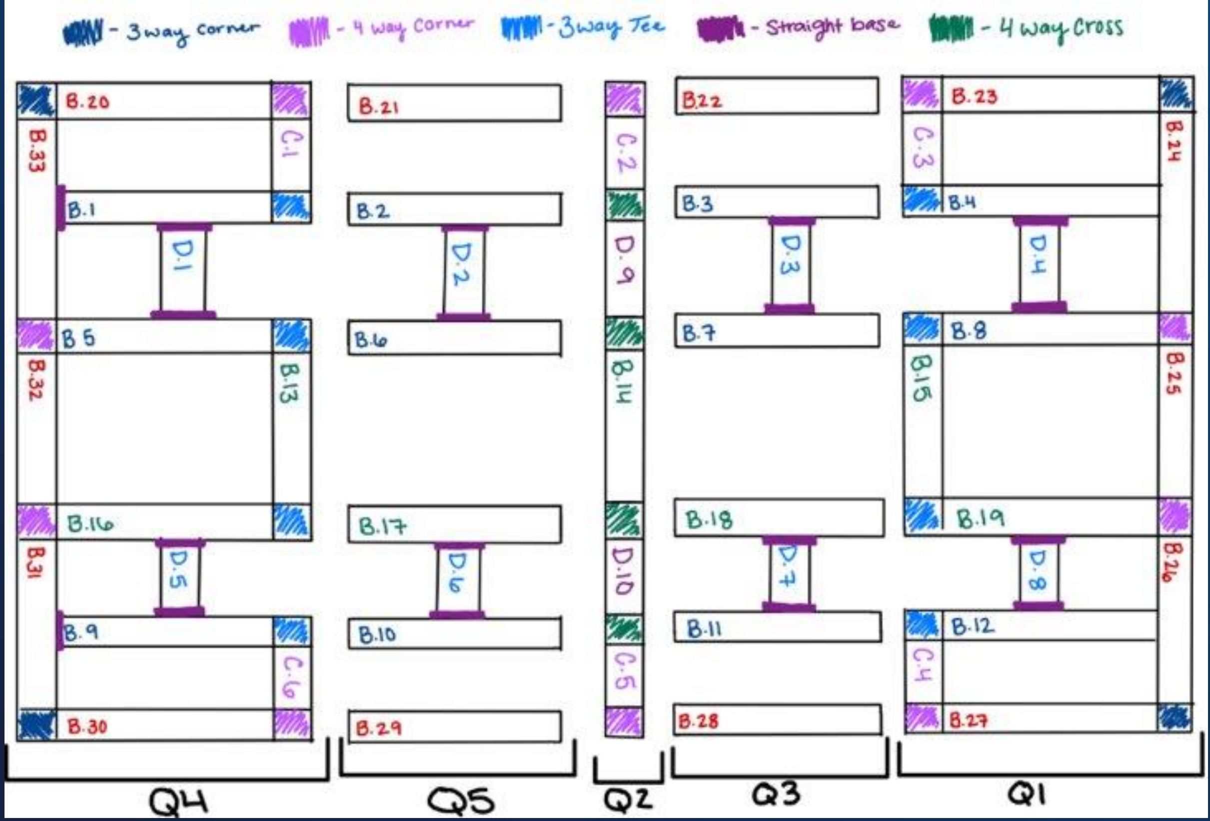


Figure 34: Ceiling Quadrants

Table 11: Modularity Results

Assembly Part	# People Required	Assembly Time (Hrs)	Disassembly Time (Hrs)
Perimeter	1	0.5	1.0
18ft Wall 1	2	0.5	1.0
18ft Wall 2	2	0.5	1.0
12ft Wall 1	2	0.25	0.5
12ft Wall 2	2	0.25	0.5
Ceiling Quadrants	3	1.5	3.0
Polycarbonate Ceiling	3	1.0	1.0
Polycarbonate Walls	2	1.5	1.5
Vinyl Door	1	0.25	0.25
FFUs	4	1.0	1.0
Total Assembly Time:		**7.25**	**10.75**

Specification Sheet

Table 12: Customer Requirement Specification Sheet

Customer Requirement	CR Met? (✓ or X)	Client Acceptable? (✓ or X)
Modular	✓	✓
Transportable	✓	✓
Spacious	✓	✓
Safe	✓	✓
ISO Class 7 Compliant	✓	✓

Table 13: Customer Requirement Specification Sheet

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER Met? (✓ or X)	Client Acceptable? (✓ or X)
Spacious	$192\ ft^2$	$\pm 10 ft^2$	$185.4\ ft^2$	✓	✓
Particle Count	$0\ \mu g\ of\ particles\ size > 0.5$ µm	N/A	$0\ \mu g$	✓	✓
Airflow	$> 90 ft/min,$ $> 60\ air\ changes$	N/A	$100.6\ ft/min,$ $911\ air\ changes$	✓	✓
Ceiling Coverage	$> 15\%$	N/A	15.7%	✓	✓
Reynold's Number	$< 1 * 10^7$	N/A	$1 * 10^5$	✓	✓

Final Design and Hardware

12’ x 16’ cleanroom with aluminum square tubing and nylon connector frame with polycarbonate walls and ceiling. Full vertical and horizontal support integration.

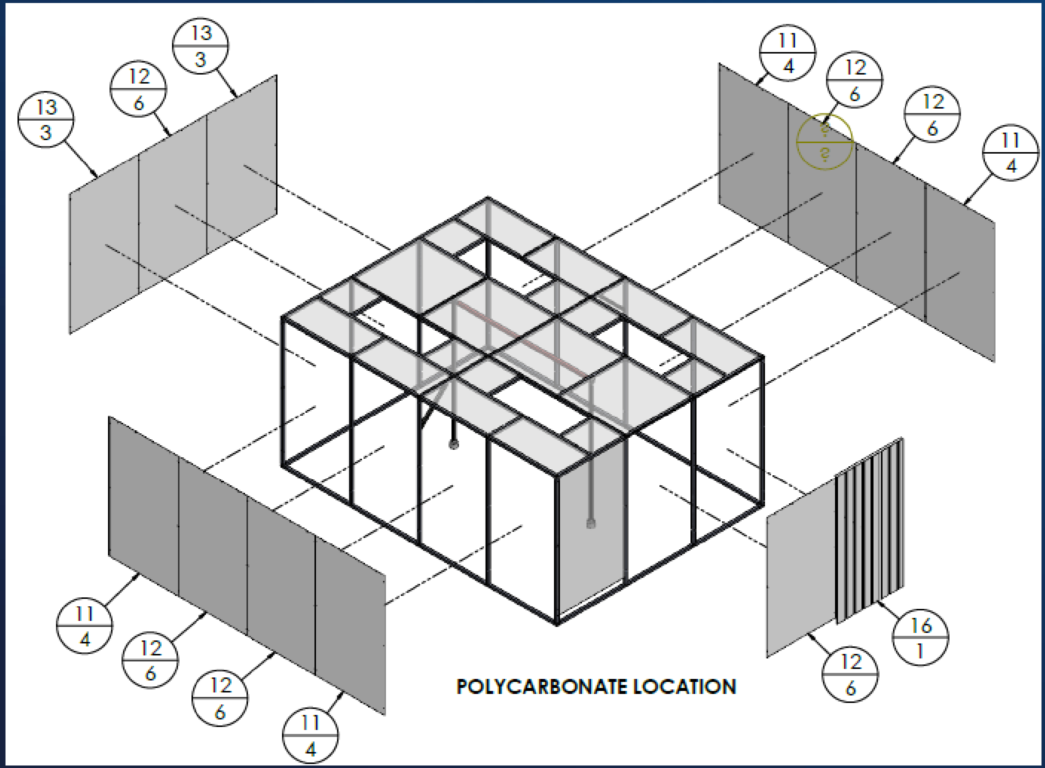


Figure 35: Cleanroom Polycarbonate Structure

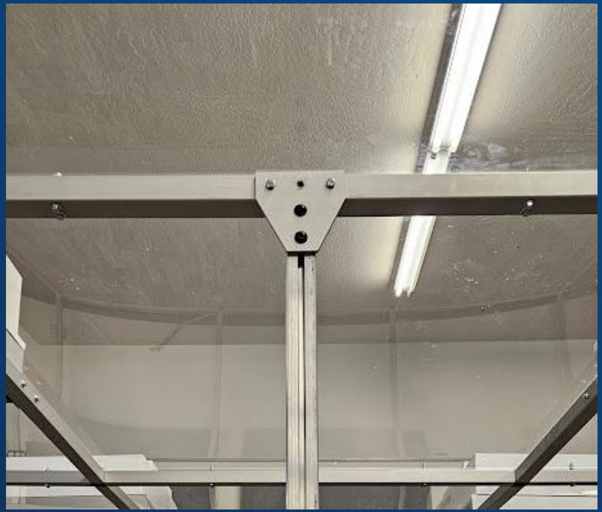


Figure 36: Support Structure

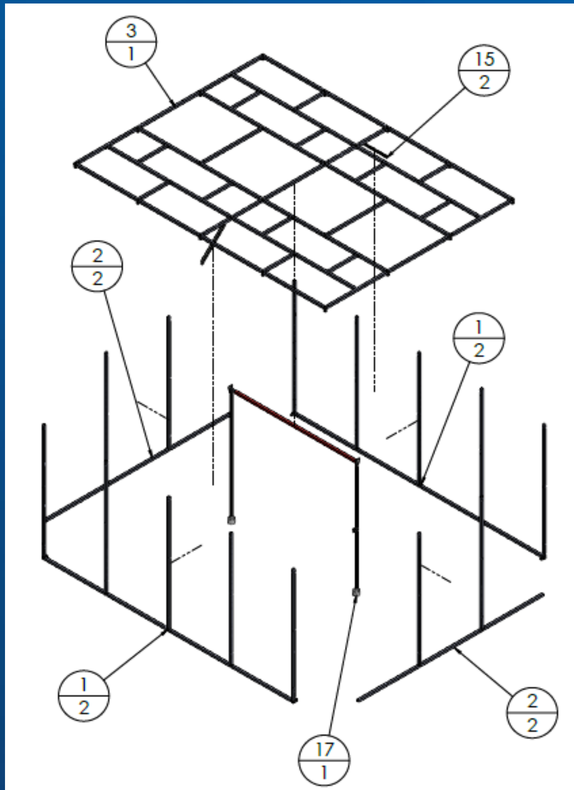


Figure 37: Cleanroom Aluminum Beam Structure

Final Design and Hardware

8' x 6' gowning room with powder coated steel frame, welded connections, and polycarbonate walls

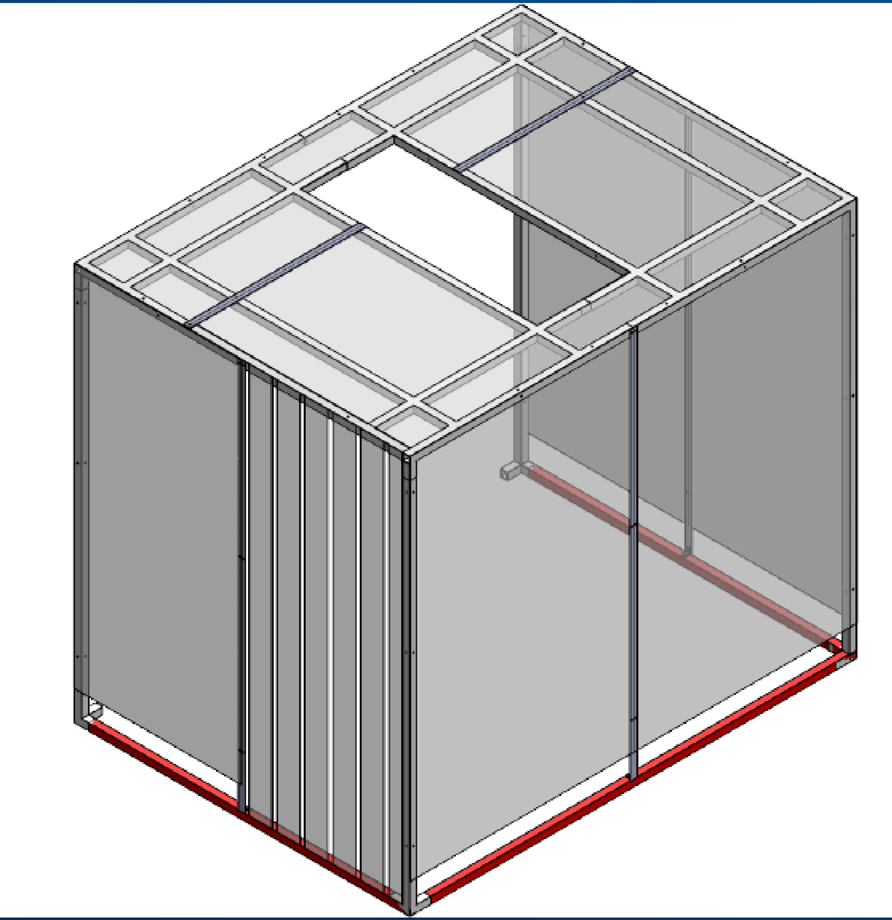


Figure 38: Gowning Room CAD

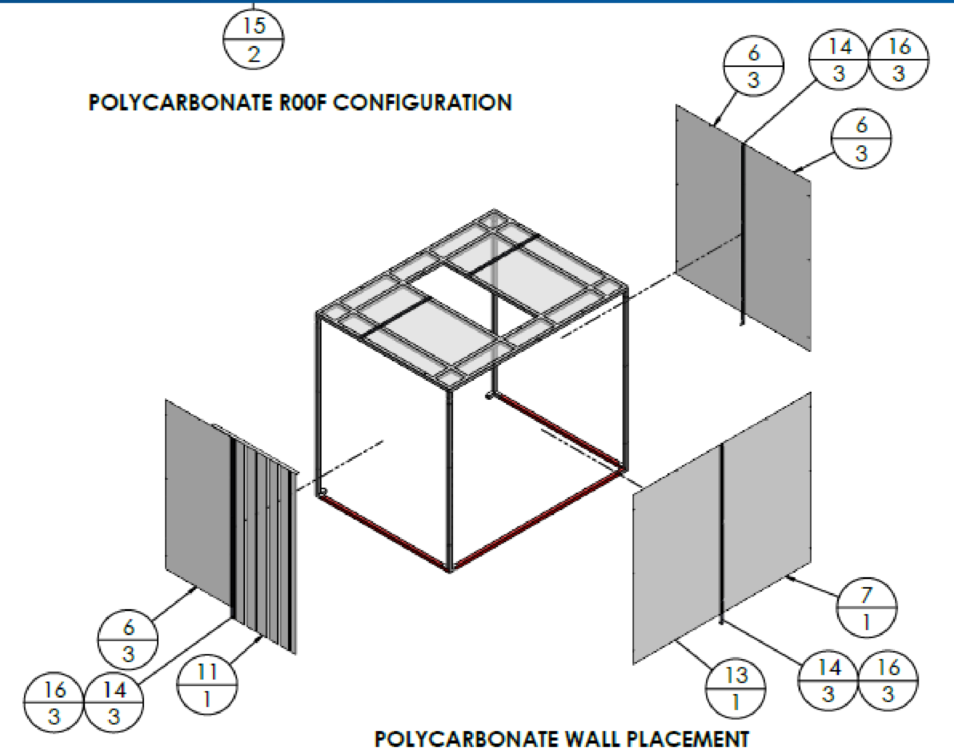


Figure 39: Gowning Room Polycarbonate Structure

Final Design and Hardware

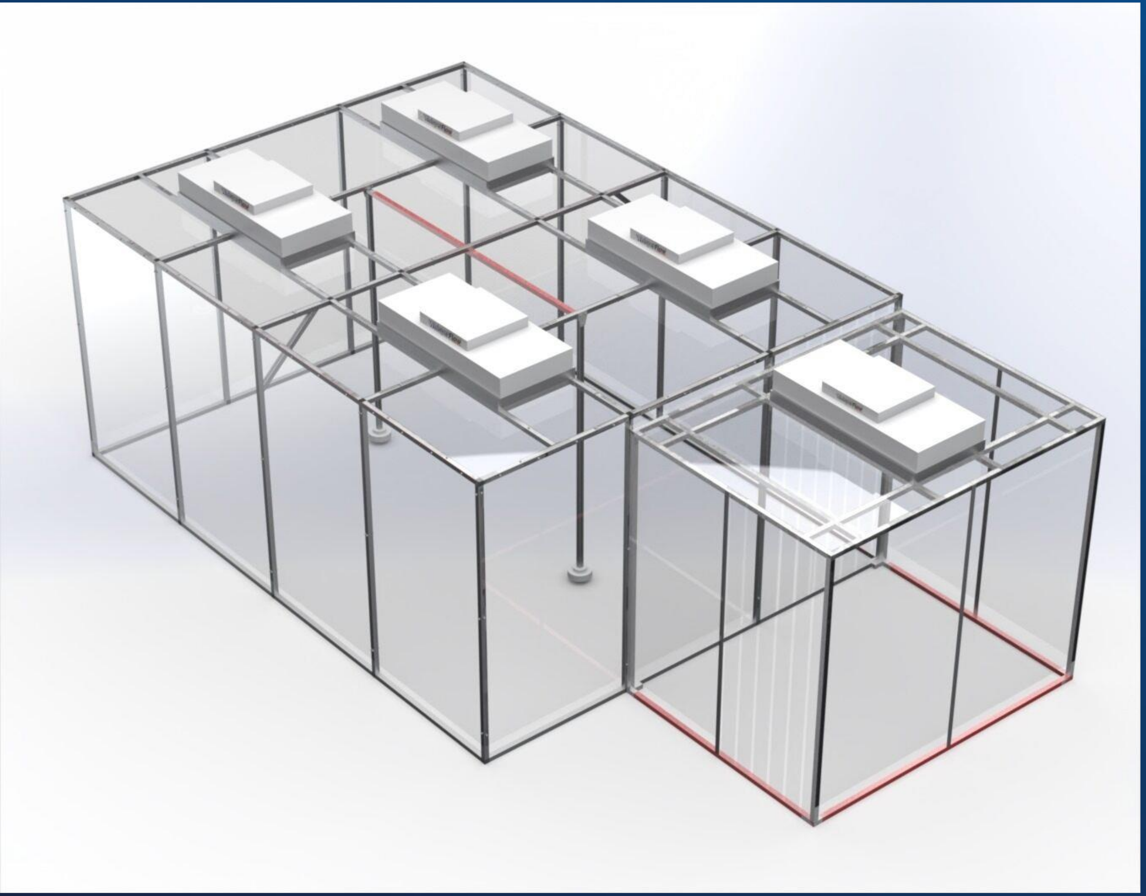


Figure 40: Final CAD Design

Figure 41: Final Build

Budget

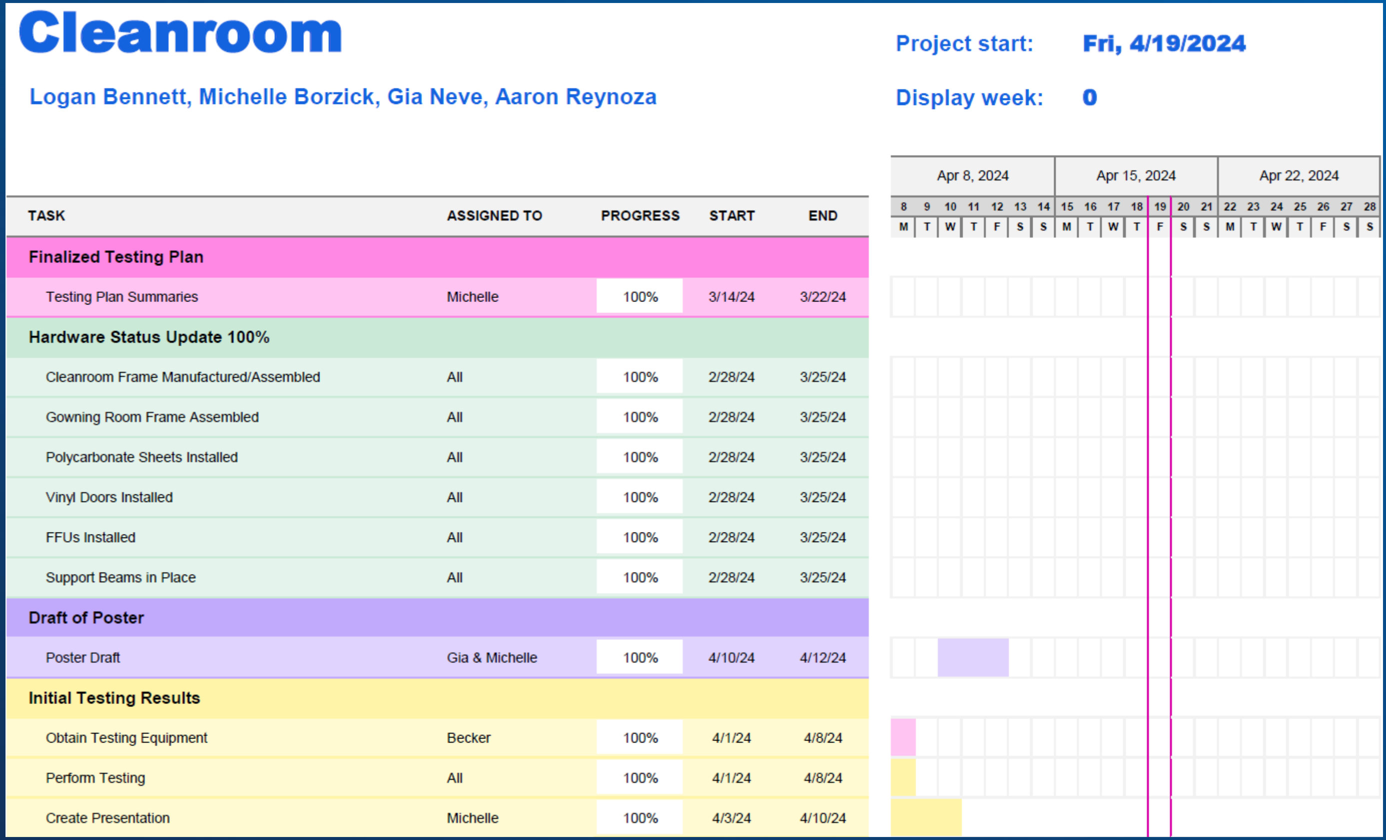
Original Budget: 10K

Additional Fundraising: 2K

Final Budget: 19K

Table 14: Simplified Breakdown of All Purchased Materials

Description	Cost($)
Cleanroom Materials	6,063.44
Gowning Room Materials	732.70
Hardware/Reimbursements	389.78
FFUS	5,360.37
Total	**12,646.42**



TASK	ASSIGNED TO	PROGRESS	START	END
Finalized Testing Plan				
Testing Plan Summaries	Michelle	100%	3/14/24	3/22/24
Hardware Status Update 100%				
Cleanroom Frame Manufactured/Assembled	All	100%	2/28/24	3/25/24
Gowning Room Frame Assembled	All	100%	2/28/24	3/25/24
Polycarbonate Sheets Installed	All	100%	2/28/24	3/25/24
Vinyl Doors Installed	All	100%	2/28/24	3/25/24
FFUs Installed	All	100%	2/28/24	3/25/24
Support Beams in Place	All	100%	2/28/24	3/25/24
Draft of Poster				
Poster Draft	Gia & Michelle	100%	4/10/24	4/12/24
Initial Testing Results				
Obtain Testing Equipment	Becker	100%	4/1/24	4/8/24
Perform Testing	All	100%	4/1/24	4/8/24
Create Presentation	Michelle	100%	4/3/24	4/10/24

Figure 42: Gantt Chart

Purchasing BOM 1

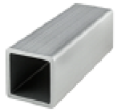
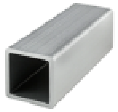
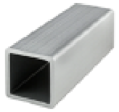
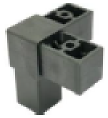
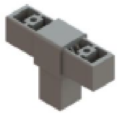
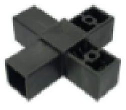
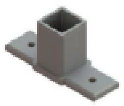
Purchasing BOM											
Part #	Part Name	Qty	Description	Image	Material	Vender	Vender PO #	Lead Time	Cost per Unit ($)	Total Cost ($)	Total Cost with Tax & Shipping
1	Ready Tube	47	46"		Aluminum	80/20	9700	Unknown	$25.33	$1,190.51	$1,513.33
2	Ready Tube	14	87"		Aluminum	80/20	9700	Unknown	$45.42	$635.88	$853.85
3	Ready Tube	6	22.5"		Aluminum	80/20	9700	Unknown	$13.82	$82.92	$121.49
4	Ready Tube	10	22"		Aluminum	80/20	9700	Unknown	$13.57	$135.70	$188.20
5	4-way Corner Connector	12	1.5" Connectors for frames		Nylon	Esto Connectors	545150	Unknown	$9.98	$59.88	$161.83
6	3-way Corner Connector	8	1.5" Connectors for frames		Nylon	Esto Connectors	533150	Unknown	$8.93	$71.44	$85.11
7	3-way Tee Connector	18	1.5" Connectors for frames		Nylon	Esto Connectors	532150	Unknown	$8.93	$160.74	$189.76
8	4-way Cross Connector	4	1.5" Connectors for frames		Nylon	Esto Connectors	544150	Unknown	$16.73	$66.92	$80.59
9	Straight Base Connector	22	1.5" Connectors for frames		Nylon	Esto Connectors	5323150	Unknown	$6.65	$133.00	$175.38

Figure 43: Purchasing BOM

Purchasing BOM 2

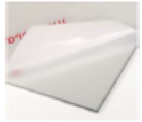
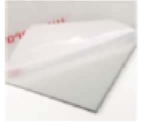
10	Clear Polycarbonate She	31	1/16" X 48" X 96" Wall Matertial		Polycarbonate	Eplastics	Unknown	Unknown		$2,500.00	$2,515.13
11	Clear Polycarbonate She	1	1/8" X 48" X 96" Wall Matertial		Polycarbonate	Eplastics	PCCLR0.125AM48X96	Unknown	$389.53	$389.53	$389.53
12	Clear Polycarbonate She	1	1/16" X 48" X 96" Wall Matertial		Polycarbonate	Eplastics	PCCLR0.060AM48X96	Unknown	$343.17	$343.17	$343.17
13	Fan Filter Unit ; Whisper	4	2'x4', HEPA, 120 V		Powder-Coated Steel	Terra Universal	6601-24-H	1-3 business days	$1,152.00	$4,148.00	
14	Power Cord for Filter Uni	4	300V, 10A,MIN4 PL to 16AWG		Unknown	Terra Universal	6601-13	1-3 business days	$64.00	$256.00	$5,360.37
15	Steel Flanged Hex Head Screws	300	Zinc-Plated Grade 5, Medium-Strength, 1/4"-20 Thread Size, 2" Long		Steel	McMaster Carr	92979A138	1-2 business days	$9.52	$114.24	$114.24
16	Medium-Strength Steel Hex Nut	300	Grade 5, Zinc-Plated, 1/4"-20 Thread Size		Steel	McMaster Carr	95462A029	1-2 business days	$8.95	$26.85	$26.85
17	Wood Beam	12	2x4x2"		Wood	Home Depot	N/A	N/A	N/A	Donated	$0.00
18	80/20 T-Slot Extrusions	4	2x 11.5ft & 2x 6ft		Aluminum	Ryans Garage	N/A	N/A	N/A	Donated	$0.00
19	80/20 aluminum Panels	4	1.5" x 84"		Aluminum	80/20	2635	1 week	N/A	$178.77	$178.77

Figure 44: Purchasing BOM

Purchasing BOM 3

20	Aluminum Square tubing	2	2x 8ft		ALuminum	Machine shop	N/A	N/A	N/A	$108.71	$108.71
21	Bolts	85	40 x 2.5", 20 x 1" , 25 2"		steel	Home Depot	812210 865658 2420	N/A	N/A	N/A	
22	Nuts	55	1/4" x 20		steel	Home Depot	801826	N/A	N/A	N/A	$34.07
23	WeatherWhite Premium Rubber Window Seal	2	5/16 in. x 19/32 in. x 10 ft.		Rubber	Home depot	43374636697	N/A	$10.93	$21.86	$24.07
24	Support Beam Base	2	2 tops, 2 bottoms		PVC pipe couplings	Home Co	4689864	N/A	$40.92	$81.84	$81.84
25	prototype 1	1	wooden beams,duct tape, 4 gasket materials		wood, rubber	home depot	N/A	N/A	N/A	N/A	$100.13
Total Cost											$12,646.42

Figure 45: Purchasing BOM

Manufacturing BOM 1

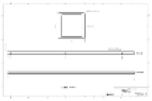
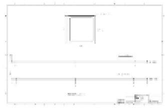
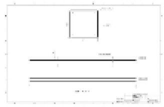
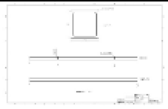
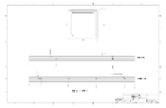
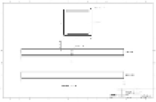
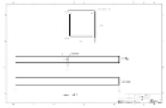
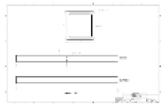
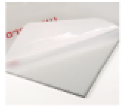
Manufacturing BOM								
Part #	Part Name	Qty	Description	Image Location	Material	Manufacturer	Lead Time (hrs)	Manufacturing Location
A.1 - A.10	87" Variant 1	10	Top: 2 holes at 2", 40.4", 78.8"		Aluminum	Team	8	NAU Machine Shop
A.11 - A.14	87" Variant 2	4	Top: 1 hole at 2", 40.4", 78.8", Front: 1 hole at 2.5", 40.9", 78.3"		Aluminum	Team	3.2	NAU Machine Shop
B.1 - B.12	46" Variant 1	12	Top: 1 hole at 12", 36"		Aluminum	Team	2.4	NAU Machine Shop
B.13 - B.19	46" Variant 2	7	Top: 2 holes at 12", 36"		Aluminum	Team	2.8	NAU Machine Shop
B.20 - B.33	46" Variant 3	14	Top: 1 hole at 12", 36", Front: 1 hole at 5", 17", 29", 41"		Aluminum	Team	8.4	NAU Machine Shop
C.1 - C.6	22.5" Variant 1	6	Top: 2 holes at 11"		Aluminum	Team	1.2	NAU Machine Shop
D.1 - D.8	22" Variant 1	8	Bottom: 1 hole at 11"		Aluminum	Team	0.2	NAU Machine Shop
D.9 - D.10	22" Variant 2	2	Top: 2 holes at 11"		Aluminum	Team	0.4	NAU Machine Shop
F	16" X 48" X 96" Clear Polycarbonate Sheets	31	Hole placement, Bottom wall removal		Polycarbonate	Team	30	Dr. Becker's Lab
G	Steel Beams	33	Hole placement TBD		Powder Coated Steel	Team	9	Dr. Becker's Lab

Figure 46: Manufacturing BOM

Manufacturing BOM 2

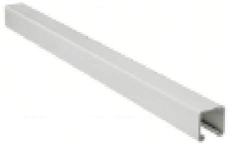
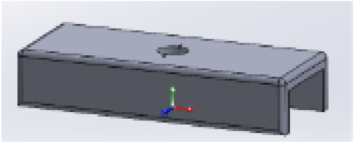
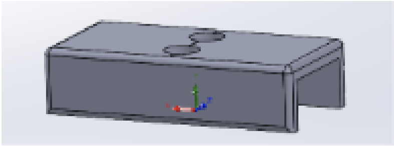
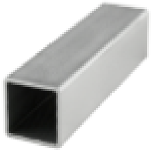
G	Steel Beams	33	Hole placement TBD		Powder Coated Steel	Team	9	Dr. Becker's Lab
H	Drill Template Beam	4	Beams to hold hole guides		Wood	Team	0.5	Dr. Becker's Lab
I	Hole Guides Single	2	3D printed holes guides for drill press		3D Printed Filament	Team	12	Michelle's House
J	Hole Guides Double	2	3D printed holes guides for drill press		3D Printed Filament	Team	12	Michelle's House
K	Cut 1"x1" AL beams to size	2	Cutiing to size		Aluminum	Gia&Logan	0.5	Machine Shop
L	Cut 80/20 Extrusions	2	Cutiing to 87"		Aluminum	Gia&Logan	0.5	Machine Shop
	Total Qty:	121						

Figure 47: Manufacturing BOM

Future Works

What we would change given more time:

- Construct real Door hinges/Mechanisms
- Implement back up power capabilities
- Conduct surface contamination tests after certification process

What we would do if we could start over:

- Utilize Aluminum T-Slots
- Integrate supports into design decision making
- Manufacture in a more efficient manor

THANK YOU!

NAU NORTHERN ARIZONA UNIVERSITY