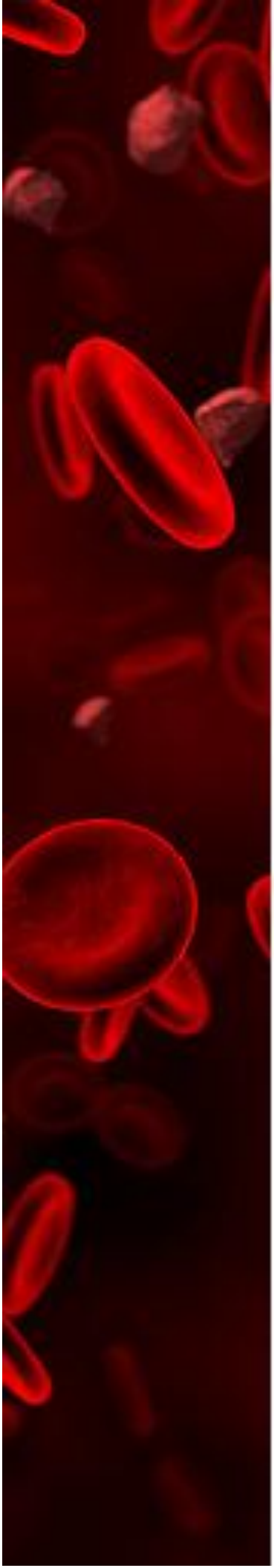

Automated Fluid Perfusion System for a Tissue Synthesis Bioreactor

ME493 Final Report - Year 2010

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Executive Summary

Millions of people suffer from some type of tissue loss, damage, or bone defect every year. Tissue engineering provides a medical solution to these problems by the development of substitutes that restore and maintain tissue functions. A bioreactor device is specifically designed to stimulate tissue growth using synthetic scaffolds seeded with cells and supplied with a nutritive fluid or gel. The nutritive fluid in the PSU bioreactor system needs to be replaced periodically in order to supply the cells with fresh nutrients and remove waste products.

The Bioreactor Capstone team mission was to design, prototype and install a device that transports a nutrient gel into small square test cells. The proposed device should fit inside an incubator with the bioreactor system and it is automatic, environmentally resistant, and easy to install.

The design selected to be produced was a dovetail system. This design utilizes a tool less mounting system. This was selected due to the design's advantage in ease of manufacture, flexibility in sample type and shape, quick setup and repair, and ease of access to the side panel.

The designed system was manufactured in the PSU workshop. The implemented system was then assembled and tested for leakage, flow characteristics and overall performance to make sure it complies with the PDS requirements dictated by the customer.

A demonstration of the system in operation was attended by the customer for validation of the main requirements. The customer was satisfied with the performance of the fluid perfusion system developed by the Bioreactor capstone team.

Contents

Introduction and Background

Millions of people suffer some type of tissue loss, damage, or bone defect every year. Medical treatments for such conditions include autografts (a tissue graft obtained from one part of the patient's body for use on another part), allografts (a tissue graft from a donor genetically unrelated to the recipient), and metallic implants. These methods suffer from limited availability, reliance on a limited number of volunteer donors, and there are issues of potential immune system reaction from allografts and metallic implants resulting in rejection of the graft. For that reason, many patients are still suffering from tissue loss or bone defects.

However, the science of tissue engineering provides medical solutions to these problems by the development of substitutes that restore and maintain tissue functions. An in vitro (outside of the body) tissue-engineered bone for subsequent implantation in vivo (inside of the body) is being developed as one of these solutions. In particular, an in vitro engineered cartilage replacement is being pursued as a way to repair injuries and damage to cartilage,

Bioreactor devices are designed specifically to support such tissue engineering applications. A typical Bioreactor system will hold test samples consisting of synthetic scaffolds seeded with cells which form the base of the final engineered-tissue. These scaffolds are then supplied with a nutritive fluid or gel consisting of cells, biomaterials, and growth stimulants. Tissue growth is then encouraged by stimulating the cells. This can be done via several methods, including fluid proliferation through the scaffolds, and mechanical loading stimulation. The full device is placed in an incubator that maintains the temperature, gas percentages, and humidity at certain levels to simulate the environment inside of the human body.

The nutritive fluid in the bioreactor system needs to be replaced periodically in order to supply the cells with fresh nutrients, to remove waste products, and to allow effective scaffold proliferation. However, the current bioreactor system in development by the Portland State

University (PSU) bioengineering department research team does not have a perfusion system and the fluid replacement is done manually. The manual process involves opening the incubator and changing the fluid by hand. This disrupts the equilibrium within the incubator, which slows down tissue growth. Therefore, the capstone team was asked to design and fabricate a fluid perfusion system to be installed to the current bio reactor system to allow automated fluid replacement.

Mission Statement

The Bioreactor Capstone team will design, prototype and install a device that will transport a nutrient gel into small square test cells. The device will fit inside an incubator with bioreactor and not interfere with the other testing devices that monitor the cells. In addition the system will be automatic, pressure resistant, and easy to install. The project will be documented extensively with reports, visual aids, and presentations. A working prototype is to be installed by the end of June.

Product Design Specifications

Dr. Sean S. Kohles and the PSU Reparative Bioengineering lab are the main costumers for the bioreactor fluid perfusion system. The system is to be installed in the current bioreactor device to allow automated fluid replacement. After working with Dr. Kohles and the Bioengineering Lab team, the team developed the following major design specifications:

A. **The assembly must survive the incubator environment**.

The system must be able to withstand the inside temperature of the incubator which can reach up to 50 ^{o}C along with specific ranges of CO_2, O_2, and humidity for extended

periods of time (up to 7 days). CO_2 percentage ranges between 0.2 – 20 %, O_2 percentage ranges between 5 – 20 %, and the humidity percentage reaches up to 95 % RH`.

B. Time needed to replace any failed component.

During the replacement of any failed component, the open incubator time must not exceed 15 minutes

C. Unattended Runtime

The fluid system is required to run for up to 7 days without direct supervision.

D. Time needed to disassemble, clean, and reassemble.

The process of taking apart the system for cleaning and reassembly must not take more than 180 minutes.

E. Perfusion system physical specifications.

The system to be installed must interface with the current bioreactor system and at the same time fit inside the incubator. The inside dimensions (in mm) of the incubator are 520(W) x 426(L) x 690(H).

F. Flow Rate.

The nutritive fluid must be supplied to the test samples at a minimum flow rate of 4 mL/min.

G. Cost:

All purchased parts and materials, fabrication, prototyping and testing processes are funded with a 1000 USD budget provided by the customer.

Top Level Design Decisions

Cantilevered Sleeve:

One of the design decisions our team made was to extend the sleeves away from the tray in order to gain access to the left and right sides of its main body. This allowed us to drill holes into center chamber from opposite sides so fluid could be transported through the sleeve. The original designs had these faces blocked by the aluminum tray and were completely inaccessible. In addition the PDS specifications prevented us from altering the front and bottom faces. The team determined that moving the body of the sleeve horizontally provided the best geometry to create the simplest and controllable flow path inside the sleeve. The dovetail design also reduced the overall dimensions of the tray/sleeve system, minimizing material use and cost.

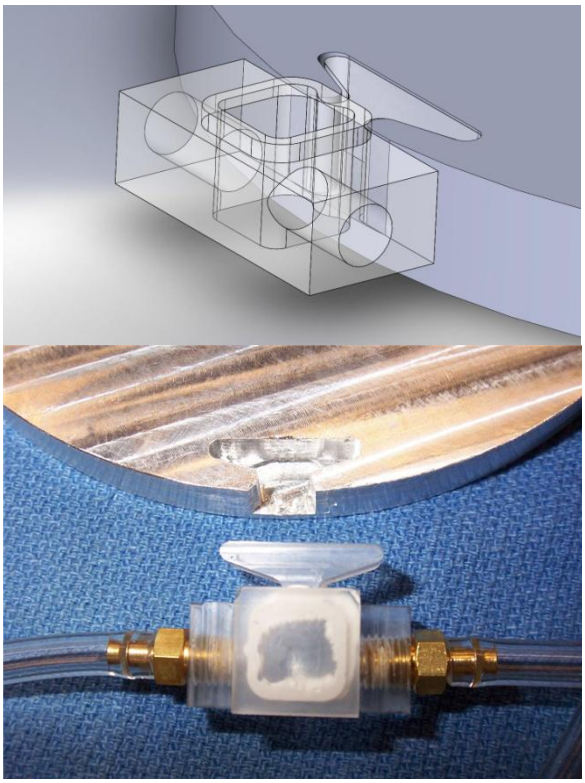


Figure 1 – Sample sleeves

Dovetail Fixture:

The original bioreactor system uses sleeves with rectangular screw tapped flanges for fixing the sleeves to the tray using two screws. This system requires unscrewing and screwing back the screws whenever a sleeve is needed to be replaced which is time consuming. The proposed dovetail design utilizes a tool less mounting system to attach the sleeves to the outer ring of the

sample tray. Five dovetail slots are cut into the carrying tray, and each individual sleeve has a dovetail shaped protrusion that allows the sleeve to slide into a slot with a tight fit. Highlights of this design include quick and simple installation and maintenance due to its tool less nature, simple machining requirements to produce the parts, and a reduction in material consumption due the reduced tray size. The Dovetail fixture also allows the applied load produced by the pistons to be distributed on the lateral surface of the dovetail which decreases stresses in the sleeves.

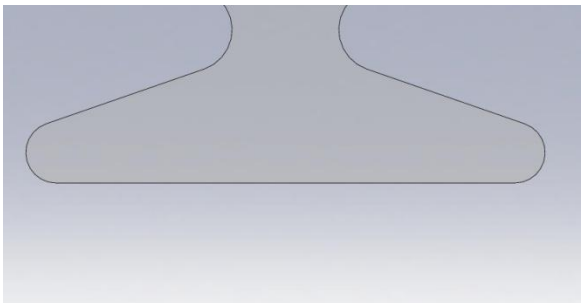


Figure 2 – Dovetail Detail

Fluid Recirculation shape:

The team initially looked cutting a square sample chamber into the carrier sleeve for the sake of simplicity. Examination of the design revealed a concerning level of fluid recirculation in the corners of the cubic sleeve. Due to the need to flush biological contaminants and waste products, this was considered unacceptable. The team utilized computational fluid dynamic models of the system to optimize the flow design. The selected design utilized rounded corners, and an indentation on the side of the chamber to create a uniform flow throughout the chamber, over the sample cube to minimize recirculation.

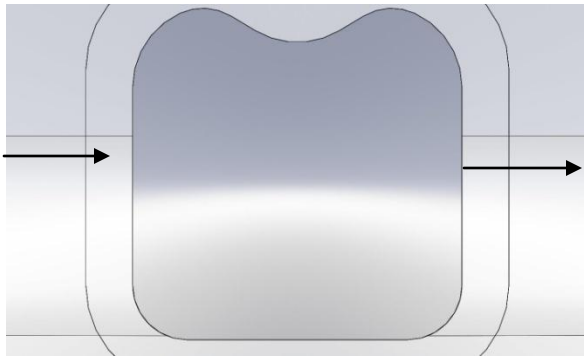


Figure 3 – Sample Chamber Detail

Materials:

Materials for the bioreactor device must withstand the incubator environment without corrosion or contamination of the nutrient fluid.

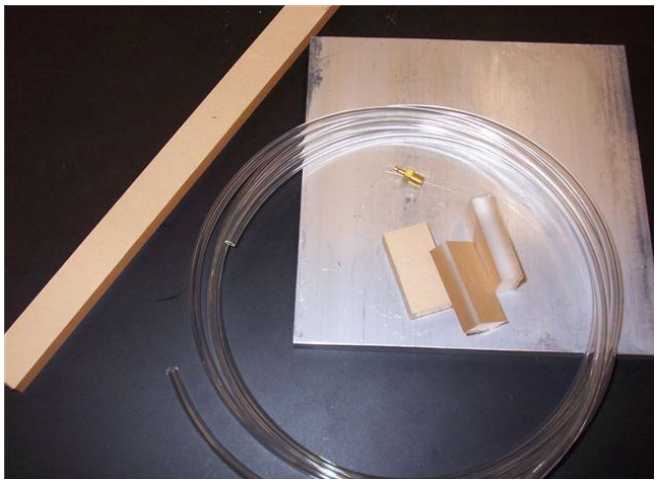


Figure 4-Materials used to create prototype

Tray – Aluminum; Aluminum is relatively light and easy to manufacture compared with other materials. The whole assembly must be placed inside the incubator at 50°C. At this temperature the properties of aluminum won't be changed (Mangonon, 1999), so Aluminum is safe to use in the incubator with any adverse affect. 20~200N of loads are applied to each sleeve, but this loads are too low to result in deformation. Stainless steel can be used as an alternative material for the tray. Stainless steel has a strong resistant to corrosion and rust so it is suitable material. However, it is harder material than aluminum, so it is more difficult to manufacture it.

Sleeves – Acrylic; Acrylic is transparent material, so it does not disturb observation of tissue growth by ultrasound transducer and digital microscope that is part of customer's requirements. The sleeves are inserted in the aluminum tray, so they also have to be available to be used at the incubator temperature, 50℃. It is safe to be used up to 200℉ (93.3℃), so incubator temperature won't affect the sleeves. (Mangonon, 1999) Loads are applied to the sleeves, but the analysis proves that acrylic can be used safely (Appendix A).

Final Design

Tray:

The tray is an aluminum disk that holds five sample sleeves. It is fixed to the bioreactor on a rotating base using three mounting screws. The tray has a U shaped slot cut into it to allow it to be fixed to the base without interfering with the center column that holds five load transducers. A circular array of five dovetail shaped slots is cut into the tray to attach the sleeves to the trays' outer ring. Figure 5 shows the shape of the designed tray which allows the testing of five samples simultaneously. The disk shape is used so that the tray can be rotated without interfering with the back column of the bioreactor and to align the sleeves with the load transducers. The tray is rotated periodically for sample inspection. It is fabricated from a square (8x8x0.5) in^3 aluminum slab. The diameter of the tray is 5.8 in and its thickness is 0.5 in. The dovetail slots are not cut all the way through the part but are 0.38 in deep.

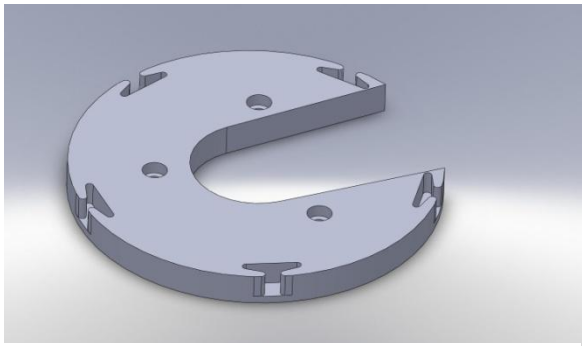


Figure 5 – Solid Model of Tray

Sleeve:

The sleeve has a square main body connected to a dove shape cut into the back for mounting. The overall dimensions of this part are 30mmx20mmx12mm. In the center there is a hole drilled through it used to house the bioreactor

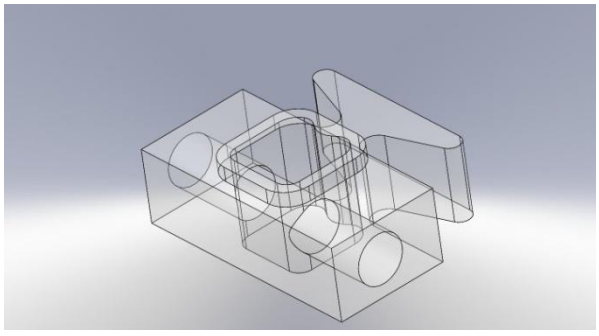


Figure 6 – Solid model of Sleeve

cartilage samples. The curvature of this hole in the center was designed to reduce recirculation and help direct steady flow for a 5x5x5mm samples. There are two access ports that are used connect the chamber to a reservoir and transport the fluid through the sleeve and out to waste receptacles. On the top is an extruded rectangular shape that will fit into the sleeve cap. The bottom will be glued sleeve base which with provide the sample holder and rest gently on the surface of the bioreactor platform. Lastly the dovetail backside fits snuggly with the tray so that no hand tools are necessary to secure this component of the fluid perfusion system

Sleeve Base:

Sleeve Base is made from acrylic, and its shape is square which dimension is 13 mm×14.5 mm. The thickness is 4 mm. This thickness corresponds to the tray thickness, so when the sleeve is inserted to the tray, the bottom of sleeve is aligned to the bottom of the tray.

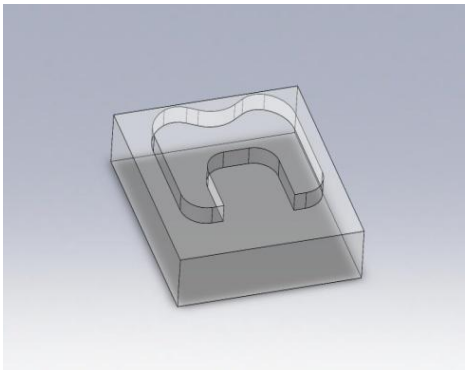


Figure 7- Solid Model of Base

There is a void, which is 5 mm×5 mm, on the base. This is for the scaffold. The scaffold is stuck against the wall and the material of sleeve is acrylic that is transparent, so a digital microscope and an ultrasound transducer can observe the growth of tissue from the side and the bottom of sleeve respectively.

Sleeve Cap:

Sleeve Cap is also made from acrylic. It is also square shape and its size is 16 mm ×16 mm. This sleeve cap fits over the top of the body sleeve. This cap is for preventing the nutrient fluid

from spilling out of the inner chamber. A hole will be cut in this sleeve cap, and a force applicator goes through it and applies force to a scaffold. The cap is water sealed with and adhesive putty in order for the part to be removed during installation and disassembly.

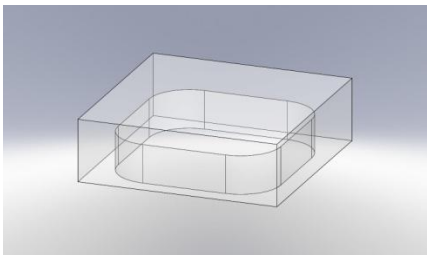


Figure 8 – Cap Model

Fluid Input: (Reservoir, Pump, Manifold)

Fluid input is handled by means of a peristaltic pump and a large beaker. A peristaltic pump was selected to maintain sterility of the solution. The pump draws the solution from the reservoir beaker, and pushes it to the manifold. The manifold then distributes the solution to each of the five sleeves. The pump is powered by an ATX 12 volt power supply.

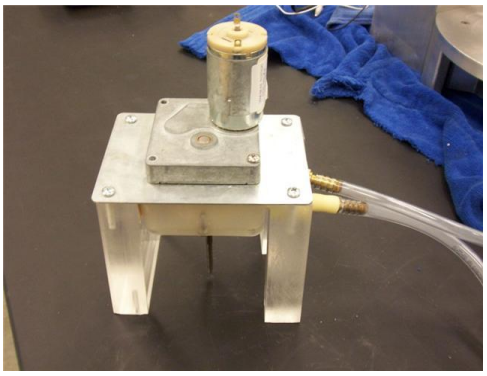


Figure 10 – Peristaltic Pump

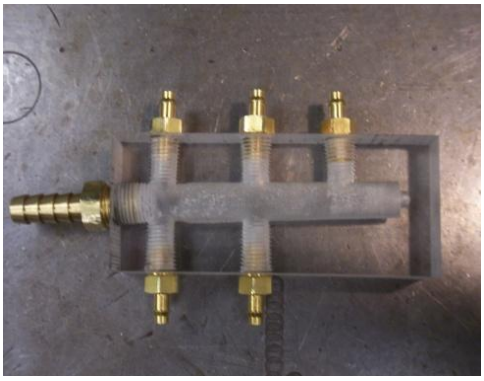


Figure 9 – Distribution Mainfold

Fluid Output: (Waste Containers)

For prototype demonstration purposes, the used fluid flows out of each sample sleeve through a medical tube and is directed into a graduated beaker to monitor the flow rate through each sleeve and to make sure all sleeves are equally supplied with fluid. The final product can maintain this setup, or allow for a single outflow tank that holds all used fluid flowing out of the five sleeves, depending on the needs of the current experiment.

Microcontroller Pump Control:

To meet the requirements for variable flow control, a custom digital pump controller was developed. This system uses an ATMega168 microprocessor with a DS1307+ real time clock. This allows runtime and interval to be set from zero to 1 year duration. The microprocessor uses pulse width modulation to control the speed of the pump, allowing adjustment from zero to 80 mL/min for each sleeve.

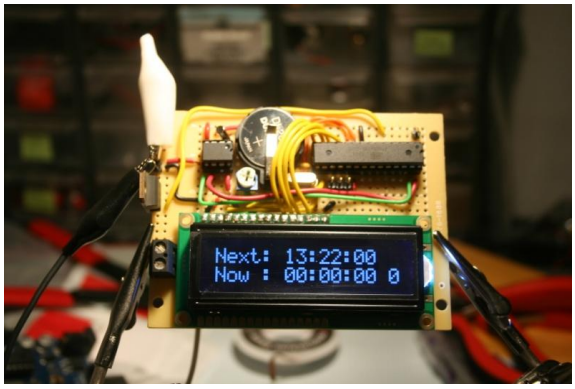


Figure 11- Controller, first light

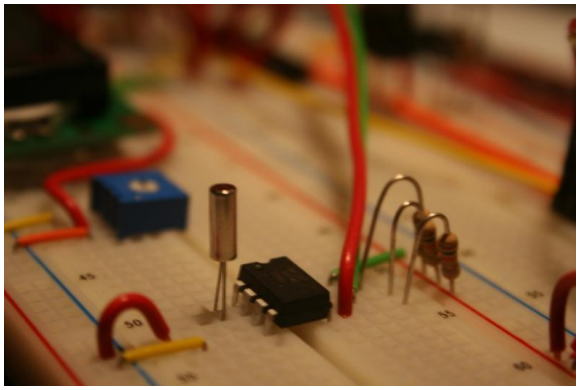


Figure 112-Prototyping the controller

Evaluation and Verification

Once the complete prototype was assembled, the various design requirements were measured to ensure compliance with the PDS (see Appendix D)

Specification	Target	Metric	Verification	Evaluation	
Flow rate	4	mL/min	Prototype	0 to 80 mL/min	☑
Unattended Run Time	7	Days	Prototype	0-1 year	☑
Adjustable Run Interval	0-72	Hours	Design	0-1 year	☑
Temp Tolerance	50	°C	Design	80°C (tubing)	☑
CO_2 Tolerance	0.2-20	%	Design	Materials Stable in these gasses Al, Brass, Acrylic	☑
O_2 tolerance	5-20	%	Design		☑
People Needed to Install	1		Prototype	1	☑
Time to Replace Failed Component	<15	Minutes	Prototype	<10 (estimated)[1]	☑[1]
Physical Dimensions	mm	520x426x690	Design		☑
Complete Maintenance Time	min	<180	Prototype	<60 (estimated)[1]	☑[1]
Cost	1000	USD$	Prototype	<$200	☑

[1]The bioreactor apparatus that the team's project will interface with is not yet complete. As a result complete assembly/disassembly testing of the system cannot yet be performed. Estimates based on testing performed ex-situ show the targets should easily be met.

Conclusion

After our final design was completed, our team met with our customer and discussed the prototype. We demonstrated the fluid perfusion system and all the different capabilities of the design. He agreed with our results in the product verification/evaluation section and that the PDS requirements were met short of being able to install the device with the completed bioreactor. It was the intention of our customer to have the bioreactor up and running by the time our team completed the fusion perfusion system. Currently the lab bioreactor is unfinished and some components are either still in production or have yet to be ordered. This prevented us from being to verify some of the PDS requirements. However we are confident that when the bioreactor is finish our fluid perfusion system will satisfy the rest of the requirements. As for our final prototype design, all verifiable product specifications were met, delivered on time, and within the budget, therefore the project overall was a success.

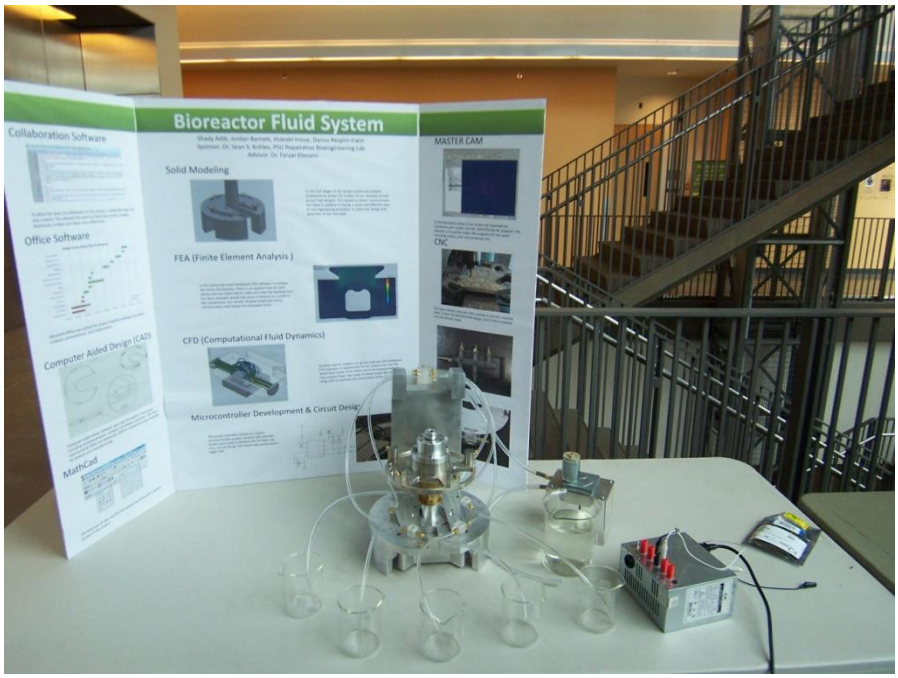


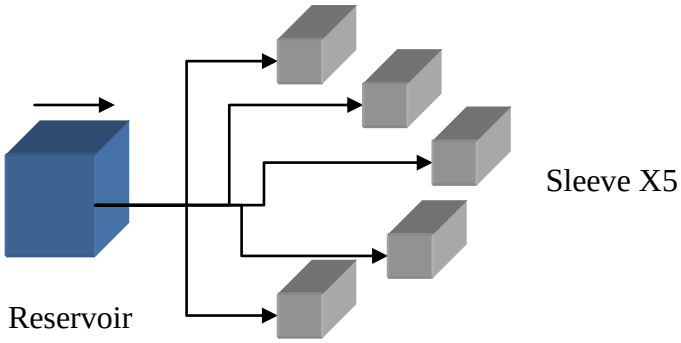
Figure 12-Final Prototype on Display

Appendix A - Analysis

Appendix A-1: Volumetric Flow Analysis

Summary:

The objective of this analysis is to determine the proper size of the fluid reservoir for our fluid perfusion system to run uninterrupted for a period of 7 days. The incubator that the system has to fit into has a limited amount of space, and if a significant amount of gel is needed to operate over this time period then our team would need to changed the size of other components or alter the flow rate of the system. The figure to the right is a diagram of fluid flow in our system. This analysis will help us determine the limitations of our device.



Given:

5 sleeves with inner dimension of roughly 10mmx10mmx9.25mm

5 tubes with inner diameter .125in and 2ft long

1 inlet tube with inner diameter .25in and 1 ft long

Volume recycles every 4-6 hours

Target flow rate 4ml/min

Find:

Determine the minimum volume of nutrient gel to supply five sleeves for a period of 7 days.

Solution:

Flow Rate = Volume Sleeves / Recycle Time

$H_{Sleeve} := 9.25mm$ $W_{Sleeve} := 10mm$ $L_{Sleeve} := 10mm$

$V_{Sleeves} := 5 \cdot H_{Sleeve} \cdot W_{Sleeve} \cdot L_{Sleeve} = 4.625ml$ $Cycle_{Sleeves} := 4hr$

$$U_{Sleeves} := \frac{V_{Sleeves}}{Cycle_{Sleeves}} = 0.019 \frac{mL}{min}$$

$$V_{Week} := U_{Sleeves} \cdot 7 \cdot 24hr = 194.25ml$$

Total Volume of Resevior = Volume Sleeves + Volume Tubes + Volume per Week

$$D_{Tube} := \frac{1}{8}in \qquad L_{Tube} := 2ft \qquad D_{Inlet} := \frac{1}{4}in \qquad L_{Inlet} := 1ft$$

$$V_{STubes} := 5 \frac{\pi}{4} \cdot D_{Tube}^{2} \cdot L_{Tube} = 24.132ml \qquad V_{Inlet} := \frac{\pi}{4} \cdot D_{Inlet}^{2} \cdot L_{Inlet} = 9.653ml$$

$$V_{Week} + V_{Sleeves} + V_{STubes} + V_{Inlet} = 232.66ml$$

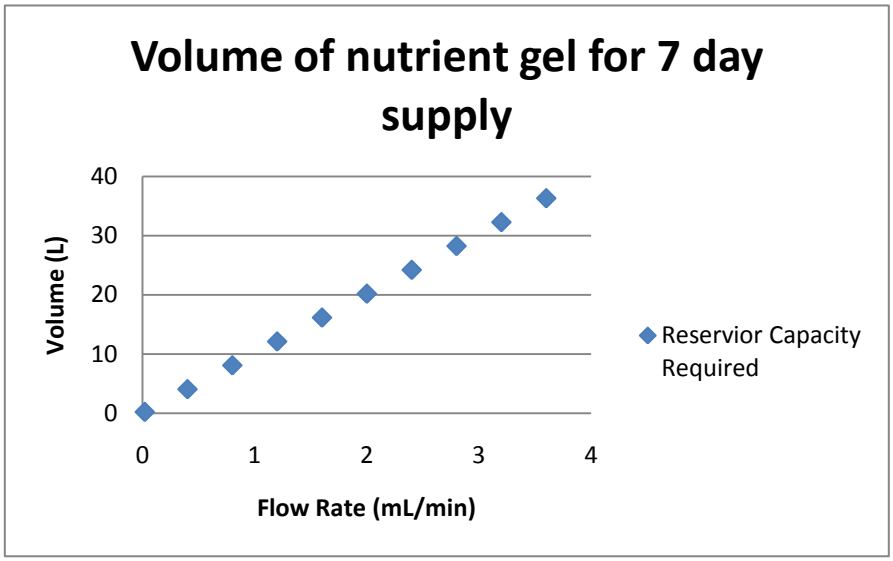


Figure 13 – Constant flow reservoir requirements

Conclusion:

The reservoir in the incubator should be at a minimum able to hold 400 mL of nutrient gel. At the maximum flow rate of 4mL/min the reservoir would need to hold 40L in order to maintain the growth environment for a 7-day period, if a constant flow rate were used. Utilization of the intermittent flow features will allow a longer run times with smaller fluid capacities.

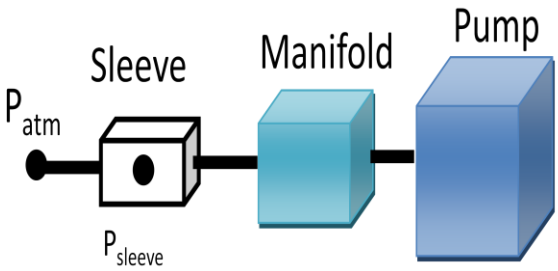
Appendix A-2 Sleeve Pressure

Summary:

The objective of this analysis is to determine the maximum pressure in a sleeve. The sleeve needs to be designed in order to withstand the calculated pressure.

Given:

Maximum flow rate of the pump Q; 0.261 [gpm]
Approximate Atmospheric Pressure P; 14.7[psi]
Inner diameter of sleeve tube; 0.125 [inch]
Inner diameter of inlet tube; 0.25 [inch]
Tube length; 9 [in]
Assume change in elevation is negligible
Assume constant velocity
Assume nutrient gel properties are approximately the same as water at room temperature



$$\nu_{water} := 1.21 \cdot 10^{-5} \frac{ft^2}{s} \qquad g = 9.807 \frac{m}{s^2} \qquad \gamma_{water} := 9.8 \frac{kN}{m^3}$$

Find:

Maximum pressure in the sleeve

Solution:

The exit velocity of the pump

$$D_{Inlet} := .125in \qquad A_{Inlet} := \frac{\pi}{4} D_{Inlet}^{2}$$

$$V_{Inlet} := \frac{Q_{Inlet}}{A_{Inlet}} = 2.08 \frac{m}{s}$$

The maximum exit velocity of each sleeve

$$D_{Sleeve} := .125in \qquad A_{Sleeve} := \frac{\pi}{4} D_{Sleeve}^{2}$$

$$V_{Sleeve} := \frac{\frac{1}{5} \cdot Q_{Inlet}}{A_{Sleeve}} = 0.416 \frac{m}{s}$$

Calculating the Reynolds number for flow through sleeve tubes

$$Re_{Sleeve} := \frac{V_{Sleeve} \cdot D_{Sleeve}}{\nu_{water}} = 1.175 \times 10^{3}$$ Laminar

The major and minor losses

$A_{Chamber} := 10.11mm^2$ $L_{tube} := 9in$ $f_{tube} := \frac{64}{Re_{Sleeve}}$

$A_{ratio} := \frac{A_{Sleeve}}{A_{Chamber}} = 0.072$ $H_{Lmajor} := f_{tube} \cdot \frac{L_{tube}}{D_{Sleeve}} \cdot \frac{V_{Sleeve}^2}{2 \cdot g} = 1.362in$

$K_L := .4$ (Munson Young Okiishi Figure 8.26)

$H_{Lminor} := K_L \cdot \frac{V_{Sleeve}^2}{2 \cdot g} = 0.167in$

The pressure inside a sleeve is calculated using a modified Bernoulli equation assuming negligible changes in velocity and elevation.

$$P_{Inlet} := P_{atm} + \gamma_{water} \cdot (H_{Lmajor} + H_{Lminor}) = 14.755psi$$

Calculating the difference in pressure gives

$$P_{\Delta} := P_{Inlet} - P_{atm} = 0.055psi$$

Conclusion:

According to the calculation, the maximum pressure at each sleeve is 14.755 psi. This is when the pump is supplying maximum flow rate.

Appendix A-3 Computational Flow Dynamics Analysis

Summary:

The initial design used a simple square chamber to hold the tissue samples. This resulted in recirculation of the fluid within the chamber. Due to the biological nature of the samples, this is unacceptable. The shape of the chamber must be optimized to minimize such recirculation

Find:

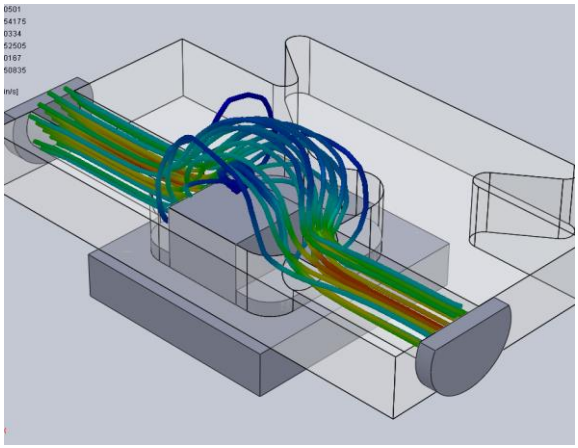
Optimize sleeve shape for the test chamber.

Solution:

The team had neither the time nor funds to create multiple prototypes and test them. The team utilized the computational fluid dynamic capabilities of SolidWorks to simulate the flow through several designs. The sleeve flow profile was refined from one run to the next, until the flow was sufficiently uniform over the sample scaffold.

Conclusion:

By simulating several prototype designs, the team was able to minimize recirculation. The final profile involved rounding the corners of the chamber, and adding a flow area reduction over the flat portion of the cube, to accelerate the fluid through the straight stretch.



Appendix A–4 Sleeve Stress Analysis

Summary:

The sample sleeves project from the sides of the carrier tray. When the bioreactor applies compressive loads to the scaffold structures, the sample sleeves can be subjected to load as though they were cantilevered beams. The factor of safety of the design must be determined to ensure it will take the applied loading without breaking.

Given:

The applied load will be less than 10N

The narrowest part of the dovetail shape is 4.6mm, with a height of 9.25 mm

Acrylic Yield Strength is110 MPa on average, Shear Strength is 62 MPa

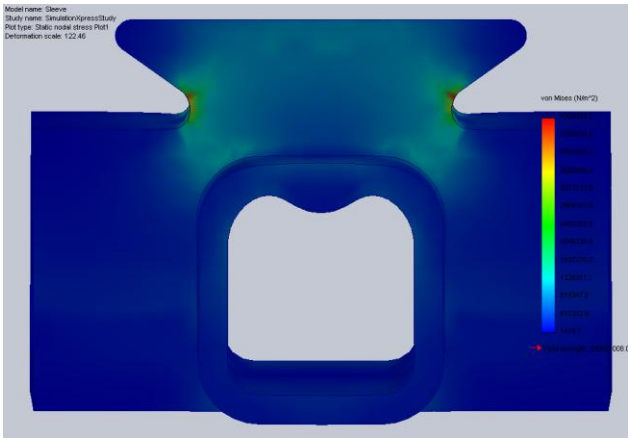
Load is applied approximately 4.2 mm from the clamped dovetail.

Find:

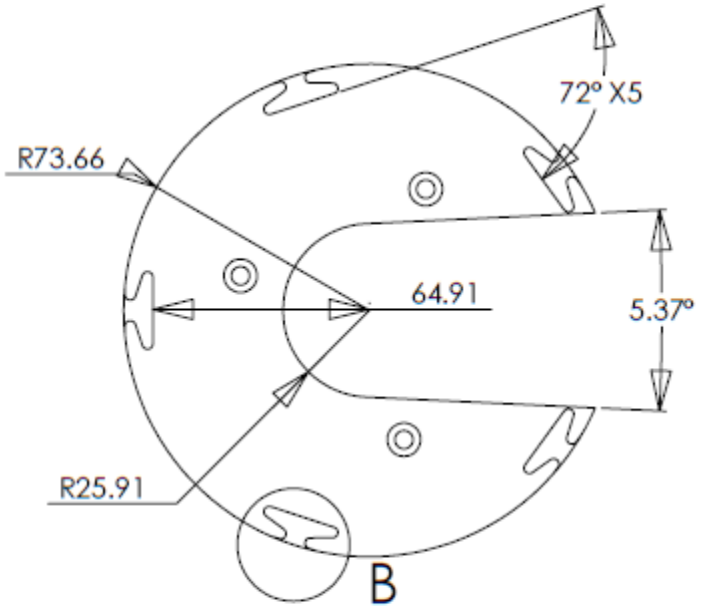
Factor of Safety

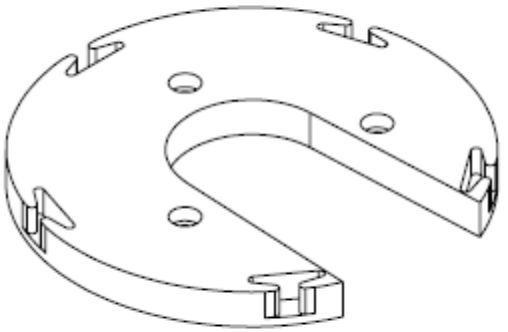
Solution:

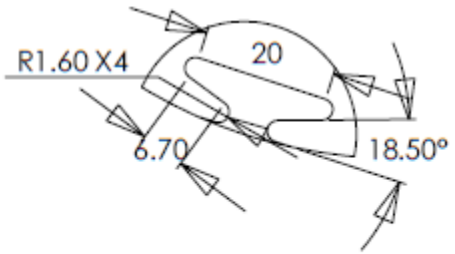
An analysis of the design was performed using SolidWorks integrated finite element analysis capabilities. It was determined that the safety factor of the design was 46. This is high enough that neither moderately large errors in the software analysis nor statistical variances in the strength of the polymer compound would not result in failure.



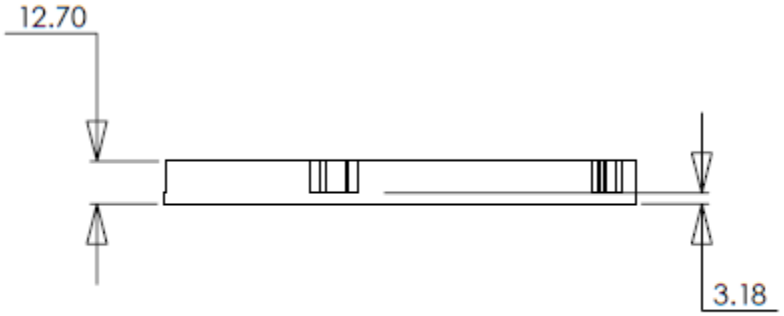
Appendix B – Part Drawings







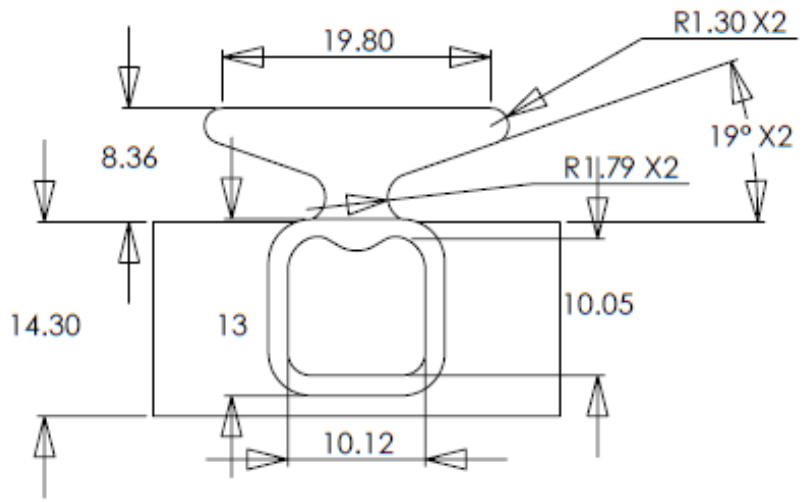
DETAIL B
SCALE 1 : 1

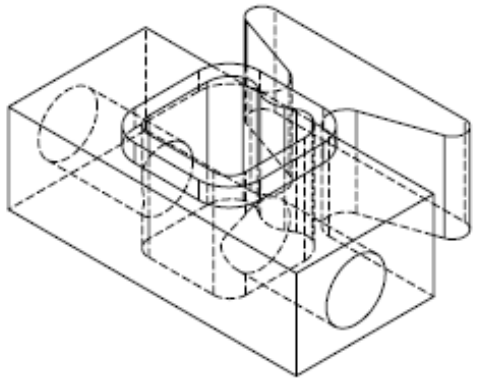


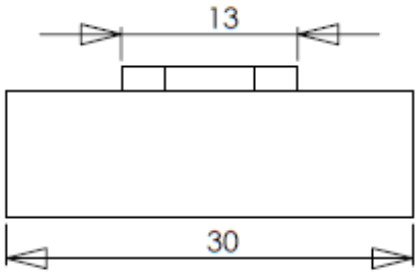
DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	Q.A.		
	COMMENTS:		
MATERIAL —			
FINISH —			
DO NOT SCALE DRAWING			

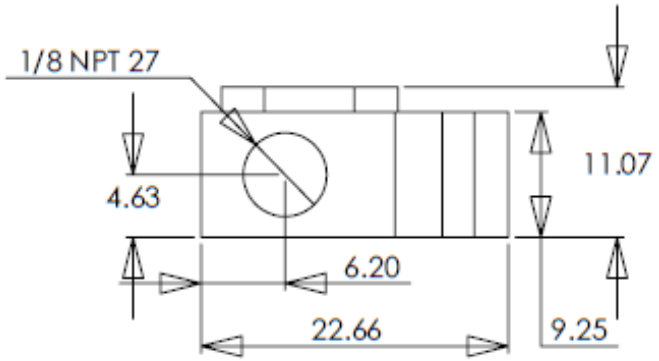
BIOREACTOR

SIZE	DWG. NO.	REV.
A	TRAY	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1









DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
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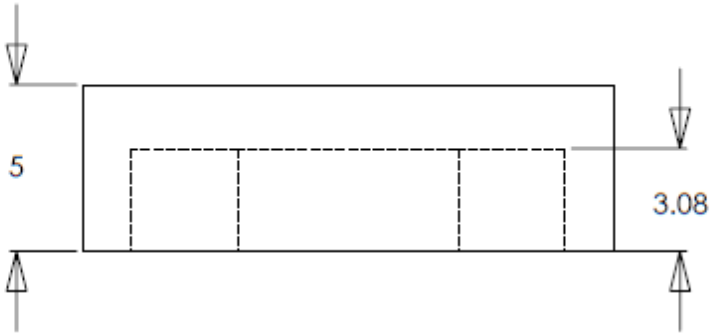
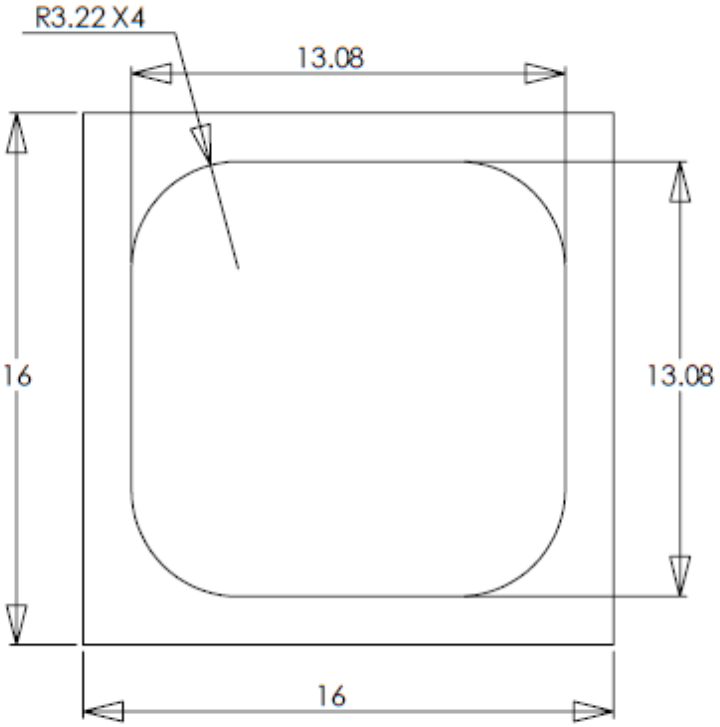
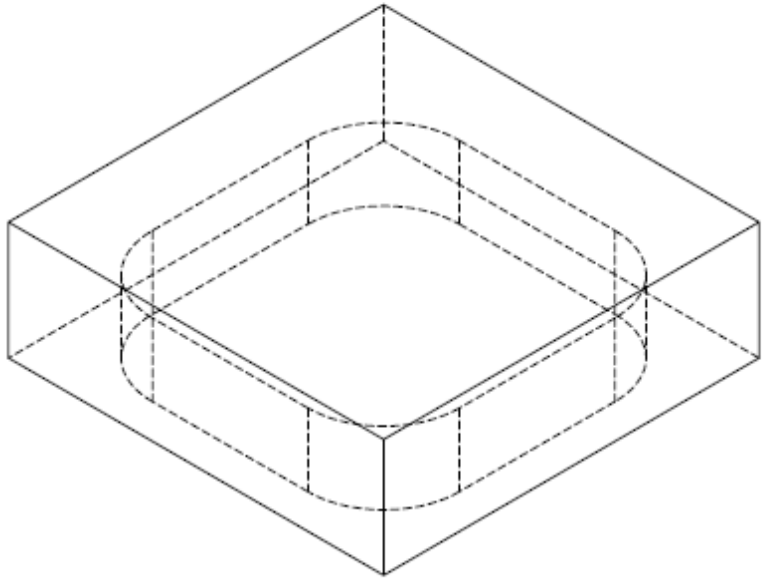
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	Q.A.		
	COMMENTS:		
MATERIAL —			
FINISH —			
DO NOT SCALE DRAWING			

BIOREACTOR

SIZE	DWG. NO.	REV.
A	SLEEVE	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



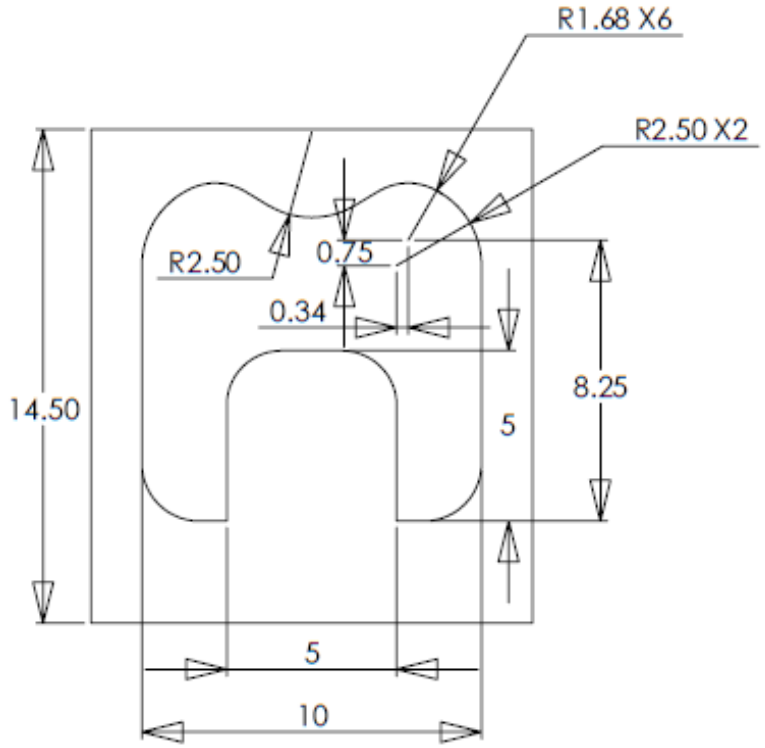


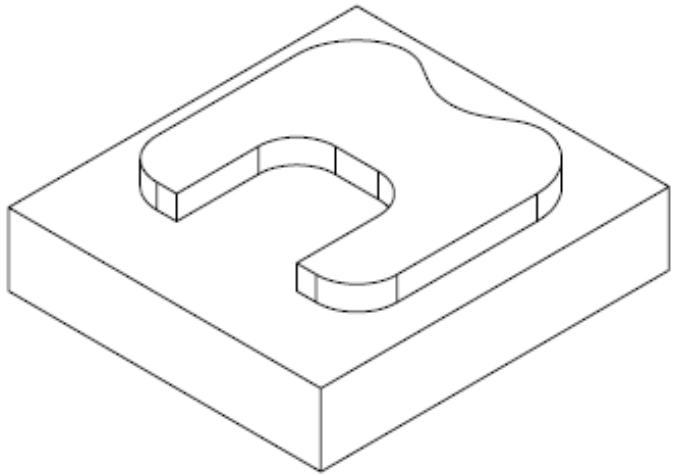


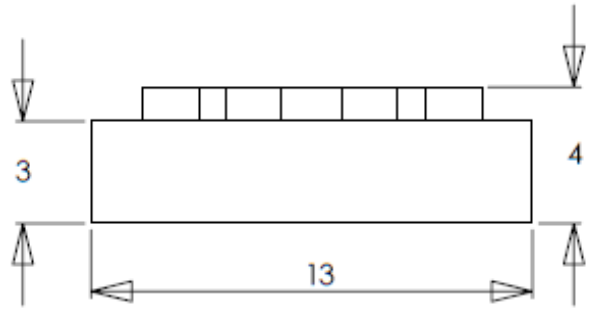
DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	Q.A.		
MATERIAL —	COMMENTS:		
FINISH —			
DO NOT SCALE DRAWING			

BIOREACTOR

SIZE A	DWG. NO. SLEEVE CAP	REV.
SCALE:5:1	WEIGHT:	SHEET 1 OF 1







DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
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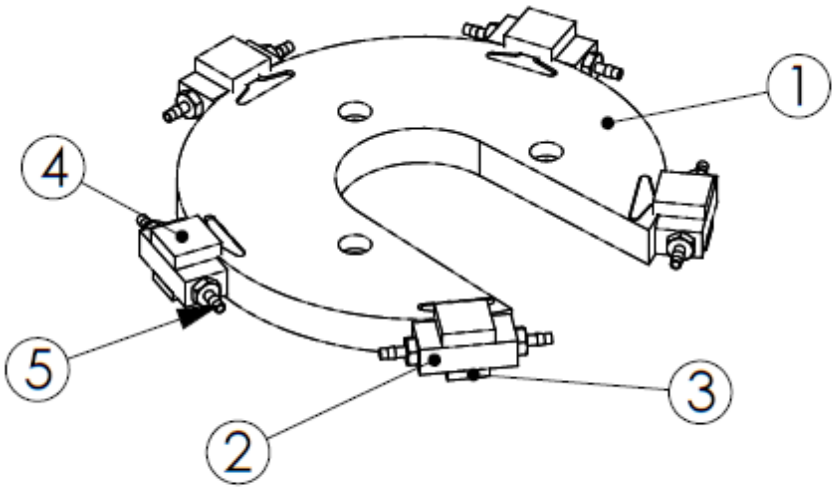
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	Q.A.		
	COMMENTS:		
MATERIAL —			
FINISH —			
DO NOT SCALE DRAWING			

BIOREACTOR

SIZE A	DWG. NO. SLEEVE BASE	REV.
SCALE: 5:1	WEIGHT:	SHEET 1 OF 1

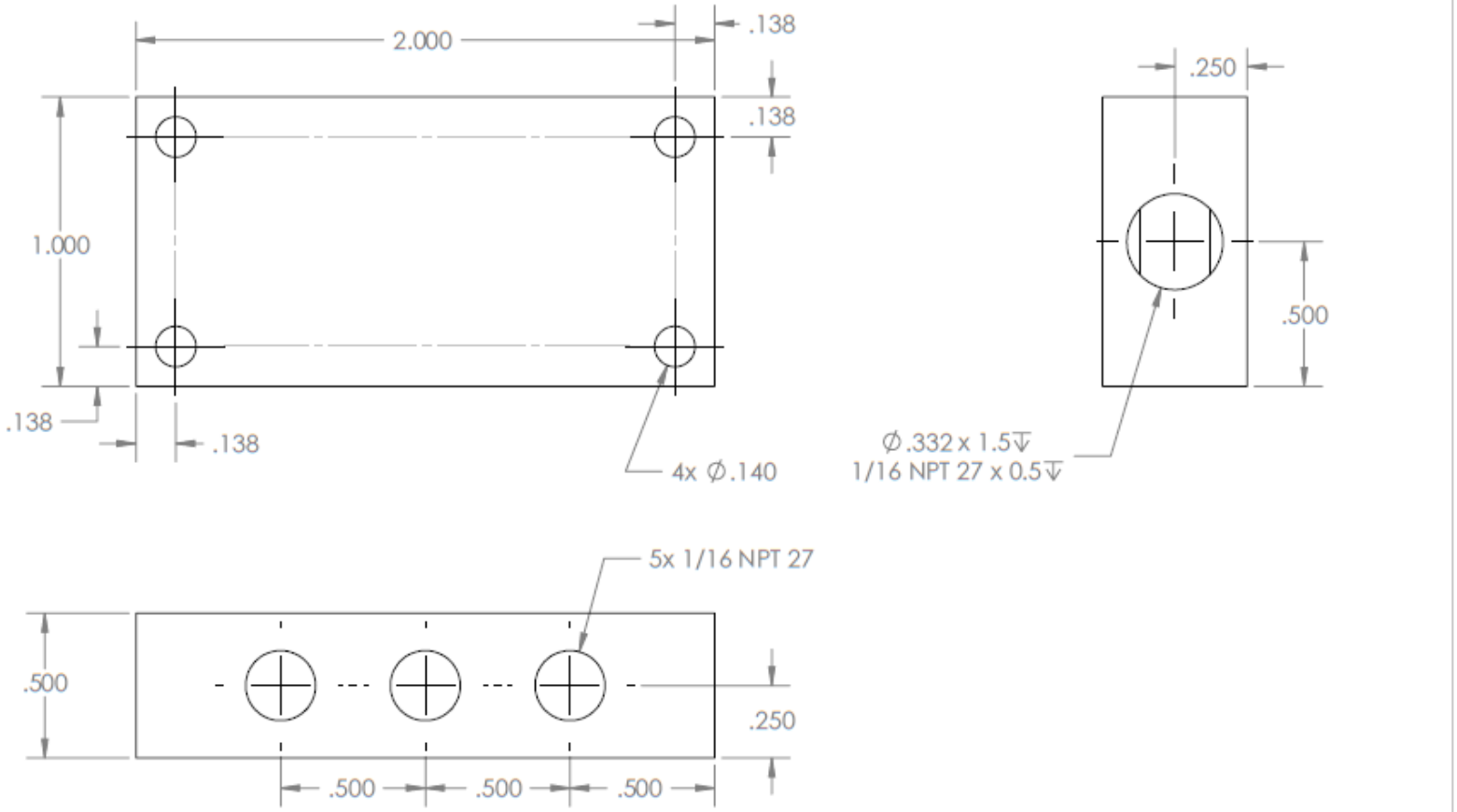
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tray		1
2	Sleeve		5
3	Sleeve Base		5
4	Sleeve Cap		5
5	Hose Adapter		10



		NAME	DATE
DIMENSIONS ARE IN MM	DRAWN		
TOLERANCES:	CHECKED		
FRACTIONAL ±	ENG APPR.		
ANGULAR: MACH ± BEND ±	MFG APPR.		
TWO PLACE DECIMAL ±	Q.A.		
THREE PLACE DECIMAL ±	COMMENTS:		
MATERIAL —			
FINISH —			
DO NOT SCALE DRAWING			

BIOREACTOR

SIZE	DWG. NO.	REV.
A	TRAY ASSEM	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
A	Manifold	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Appendix C – Bill of Materials

Description	Source	Price	Quantity	Line Total
Aluminum Plate, 8"x8"x0.5"	MMC	$26.28	1	$26.28
1/8" ID Polyurethane Tube, 25ft	MMC	$13.00	1	$13.00
Acrylic, Cast, 1"x0.5"x4'	MMC	$7.54	2	$15.08
1/16" thread tube adapter, x10	MMC	$9.18	2	$18.36
1/8 NPT 27 tap	MMC	$17.53	1	$17.53
1/4 NPT 27 tap	MMC	$18.74	1	$18.74
Atmel ATMegea168-20PU mcu	MOU	$4.32	1	$4.32
Dallas DS1307+ RTC	MOU	$4.18	1	$4.18
Newhaven 16x2 LCD	MOU	$11.90	1	$11.90
NPN Darlington Transistor	MOU	$0.74	1	$0.74
32.768Khz crystal	MOU	$0.24	1	$0.24
16Mhz crystal	MOU	$1.53	1	$1.53
10K ohm trimmer pot	RS	$1.99	1	$1.99
protoboard, 417 tie	RS	$1.99	2	$3.98
CR2032 battery holder	RS	$1.49	1	$1.49
ATX Power supply	ANY	$16.99	1	$16.99
TOTAL				$156.35

Table 1 - Bill of materials for prototype fluid perfusion system

Sources:

MMC - McMaster-Carr - http://www.mcmaster.com

MOU - Mouser Electronics - http://www.mouser.com

RS - Radio Shack - http://www.radioshack.com

Appendix D – PDS Summary

Requirement	Customer	Metric	Target	Target Basis	Verification
Performance					
Flow Rate	Dr. Kohles	mL/min	>4	Journal Article	Prototype
Unattended Run time	Bioengineering Research Team	Days	>7	Sponsor	Design
Adjustable Run Interval	Dr. Kohles	Hours	Continuous to 72 hrs	Sponsor	Design
Environment					
Able to withstand elevated temperatures	Dr. Kohles	°C	50	Incubator Specifications	Design/Material Selection
Able to withstand wide range of CO_2 Levels	Dr. Kohles	%	0.2-20	Incubator Specifications	Design/Material Selection
Able to withstand wide range of O_2 Levels	Dr. Kohles	%	5-20	Incubator Specifications	Design/Material Selection
Able to withstand high humidity	Dr. Kohles	%RH	95	Incubator Specifications	Design/Material Selection
Installation And Maintenance					
Number of people needed to install	Bioengineering Research Team	# of people	1	Research Team	Prototype
Open incubator time needed to replace any failed component	Dr. Kohles	Minutes	<15	Sponsor	Prototype
Time needed to disassemble, clean, and reassemble	Bioengineering Research Team	Minutes	<180	Sponsor	Prototype
Manufacturing					
Cost	Dr. Kohles	USD$	<1,000	Sponsor Budget	Design
Can be made in PSU machine shop	Bioengineering Research Team	--	No outside manufacturing	Sponsor	Design

Requirement	Customer	Metric	Target	Target Basis	Verification
Physical Specifications					
Width	Dr. Kohles	mm	<520	Incubator Specifications	Design
Depth	Dr. Kohles	mm	<426	Incubator Specifications	Design
Height	Dr. Kohles	Mm	<690	Incubator Specifications	Design
Weight of any component	Bioengineering Research Team	Lbf	<30	Easy 1 person installation	Design

Appendix E – Concept Generation and Selection

The internal search portion of the product development process consisted of several steps. The team started by discussing ways in which the unique challenges presented by the design requirements could be overcome. The team then spent a week independently developing new ideas. During the following weekly meeting, the ideas were presented to the group, and discussed. A further brainstorming session took place during the meeting, and the next iteration debated. The team settled on six final contenders.

- Fluid tank – Rather than utilize individual sample sleeves, all samples are submerged in a large common pool of nutrient solution
- Dovetail – This system utilizes a tool less mounting system to attach the sleeves to the outer ring of the sample tray.
- Slot ports – Attaching machined rectangular tubes to the rear surface of the sleeves allowed this design to avoid some of the potential tangling issues, and may help minimize fluid recirculation
- Raised sleeve – By lifting the sample sleeves above the surface of the carrier tray, this design facilitates the needed access to the side panels of the sleeves.
- Raised tray – Similar to the raised design, this system drops sleeves below the tray by lifting the carrier with a horseshoe. This both allows access to the side panels, and gives an alternative hose routing option under the carrier tray.
- Channel routing – Machining the fluid flow channels into the surface of the tray, and then capping them with a secondary lid, minimized use of hoses in this design.

After a final panel of six candidates was selected, a scoring matrix was used to

objectively evaluate the ability of each design to handle the challenges presented. The team assigned a numeric value to each of the primary categories of criteria, the sum of which yielded an overall score for each design. The highest score determined the winner.

Top-Level Final Design Evaluation and Selection

The process of selecting the final design consisted several steps. First the team identified what criteria should be followed in the selection process. After meeting with the customer over a period of time the team had a vivid idea of the main customer requirements which were listed in our product design specification document. The customer made it clear that the main goal is to make a fluid perfusion system that is easy to install and maintain and that interfaces with the current bioreactor system. The team was also required to stick to the budget provided by the sponsor. Therefore, the main design selection criteria according to the PDS are:

1. Maintenance: All parts of the perfusion system have to be easily cleaned, accessible and have satisfactory service lifetimes.

2. Installation: The system has to interface with the existing device. The process of system disassembly and reassembly for maintenance purposes or for sample replacement has to be simple and quick.

3. Cost: All purchased parts and materials, fabrication, prototyping and testing processes are funded with a 1000 USD budget.

All design specifications described in the PDS document were revisited before the design process began to make sure that all the proposed designs comply with the main specifications as described by the customer. However, during the design process other criteria used in selecting

our final design were dictated by technical design parameters which the team found to be necessary for creating an efficient and reliable system. These criteria are fluid recirculation, tubing system and manufacturing and are explained below.

4. Fluid recirculation: Recirculation of the used fluid inside the sample wells has to be minimized to guarantee that the samples are always supplied with fresh nutritive fluid.

5. Tubing system: Fluid distribution system cannot interfere with other equipment fixed to the bioreactor. In case of using medical tubing, tangling of the tubes has to be avoided.

6. Manufacturing: The fabrication processes of implementing the prototypes and final product need to be simple and time efficient. After the first designs were finished, the team discussed the main pros and cons of each design and the results are shown on the next page.

	Raised Tray	Raised Sleeve	Dove-Tail	Slot Ports	Channel Routing	Fluid Tank
Main Advantages	• Hanging the sleeves provides more space for connecting the tubes. • Existing tray can be used. • Accessing the sleeves from beneath the tray avoids interference between the tubing and the actuators.	• Raising the sleeves provides more space for connecting the tubes. • Acrylic is cheap and easy to fabricate. • Sleeves can be of larger volume. • Tube connections can be easily checked.	• Cantilevering the sleeves provides more space for connecting the tubes. • Not too many restrictions on the sleeve size. • Samples are subjected to a direct cross flow. • Sleeves are easy to install and replace. • Tube connections can be easily checked.	• Not too many restrictions on the sleeve size. • Easy to install. • Tube connections can be easily checked. • Tangling is reduced by the use of slot ports and short hoses.	• No tangling of tubes. • Current tray can be modified to fit with the new system.	• No tangling of tubes. • Can hold various sample sizes.
Main Disadvantages	• Assembling and disassembling the sleeves are time consuming. • Difficult to check connections hidden underneath the tray.	• Assembling and disassembling the sleeves are time consuming. • Tubes can be easily tangled together. • The tray and brackets assembly is too fragile. • Requires fabricating a new tray.	• Requires fabricating a new tray.	• Difficult and expensive to fabricate. • Slot port connectors are too fragile. • Requires fabricating a new tray.	• Difficult to fabricate. • Difficult to detect leakage in tubes and disconnections hidden underneath the cover. • Taking out the tubes to be cleaned requires unscrewing the cover which is time consuming.	• Difficult and expensive to fabricate. • Only used in the case of static fluid.

Finally, a scoring matrix was used to objectively evaluate the ability of each design to handle the challenges presented. The team assigned a numeric value to each of the primary categories of criteria, the sum of which yielded an overall score for each design.

Top Level Scoring Matrix

PDS Criteria	Raised Tray	Raised Sleeve	Dove-Tail	Slot Ports	Channel Routing	Fluid Tank
Maintenance	5	4	5	3	2	1
Installation	4	4	5	4	3	1
Cost	2	3	3	3	2	1
Fluid Recirculation	3	3	4	5	5	1
Tubing	3	3	3	4	4	4
Manufacturing	3	3	3	1	1	1
Total	20	20	23	20	17	9

The final design selected to move forward to the final refinement stage was the dovetail system. This was selected due to the design's advantage in ease of manufacture, flexibility in sample type and shape, quick setup and repair, and ease of access to the side panel.

Appendix F - Bibliography

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