Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Reactigator

EML 4501, Group 1

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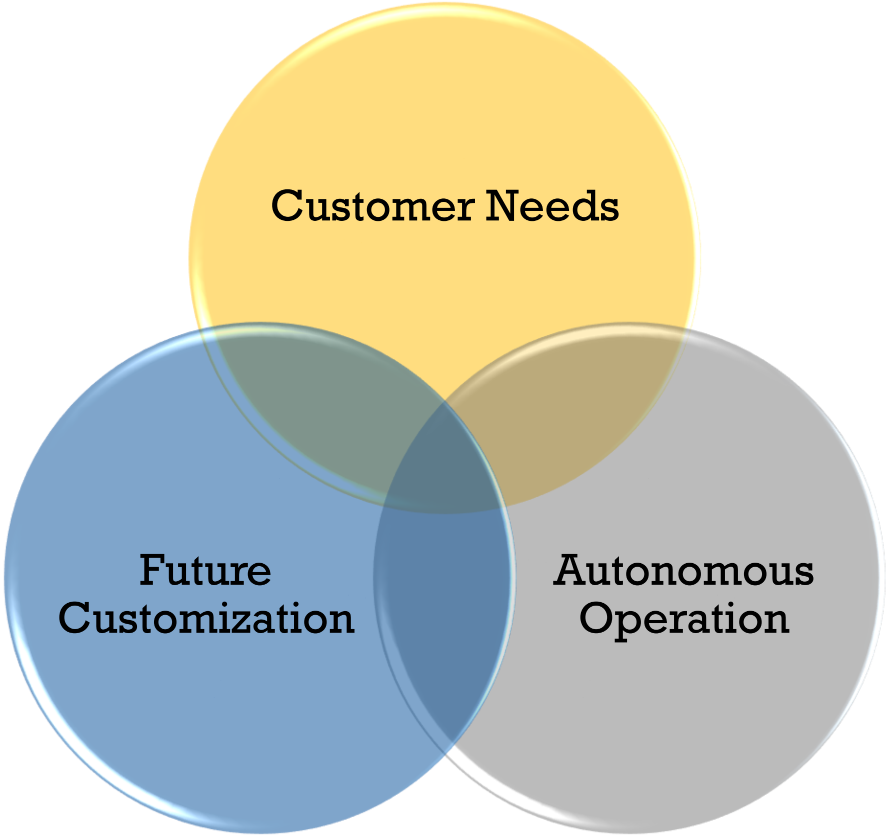
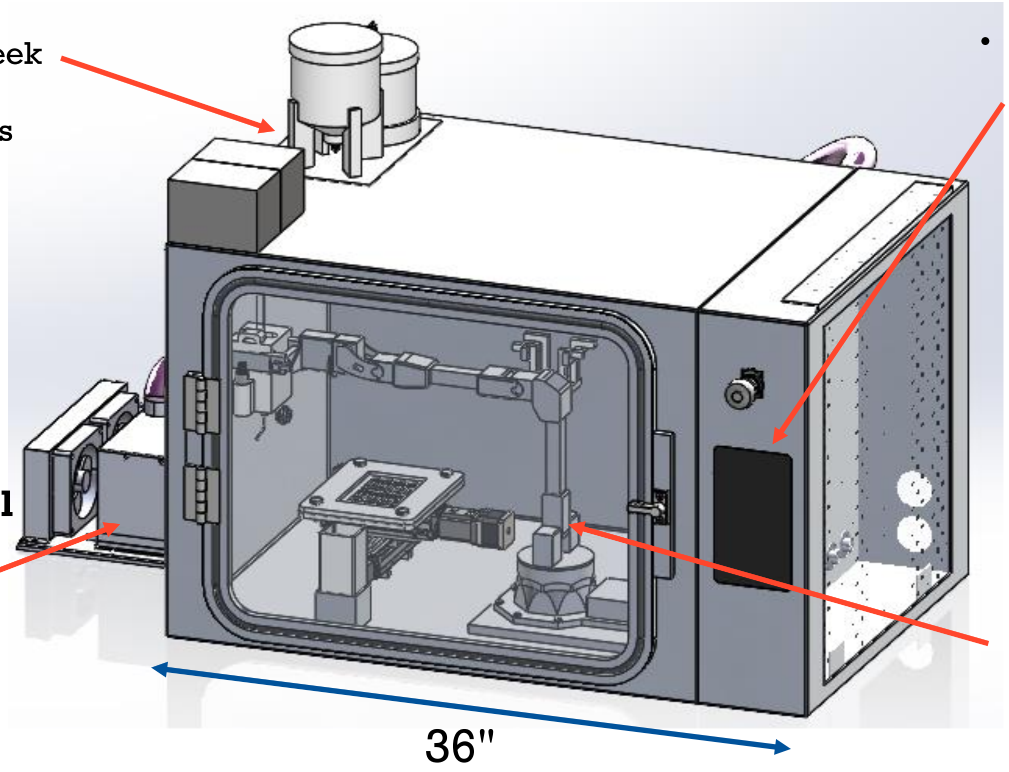
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

- **Customer Needs:** the design intends to meet all of the needs specified by the UF Biofoundry
- **Autonomous Operation:** the design features autonomous operation so that the user can set the conditions and not worry with monitoring the process
- **Future Customization:** the 3D printable parts allow the design to be customized for future applications if necessary



Reservoir and Pump Subsystem
- Autonomous for 2-week operations
- Luer lock syringe tips

Display Panel
- Simple UI via LCD touch screen
- Emergency Stop



Temperature Control Subsystem
- External vapor compression heat exchanger

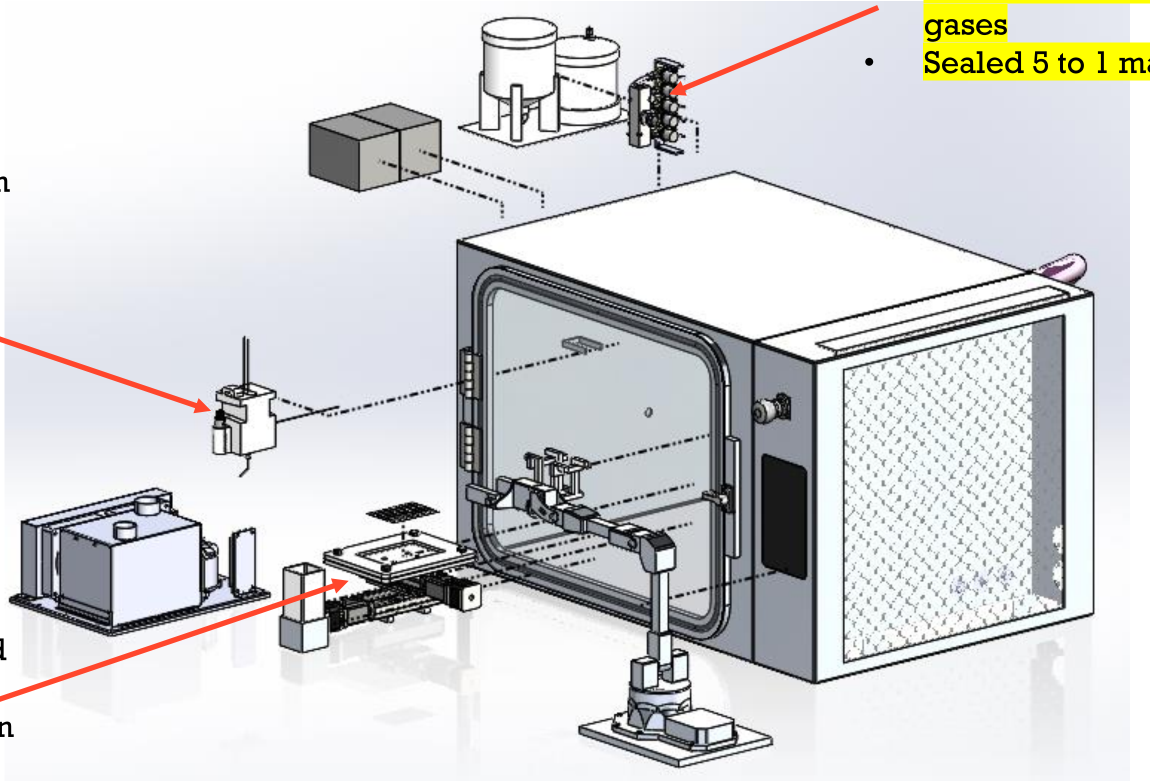
Tool Delivery Subsystem
- Robotic Arm
- Reconfigurable

Gas Control System

- Individual flow valves for all gases
- Sealed 5 to 1 manifold input

Fluid and OD Tool Block

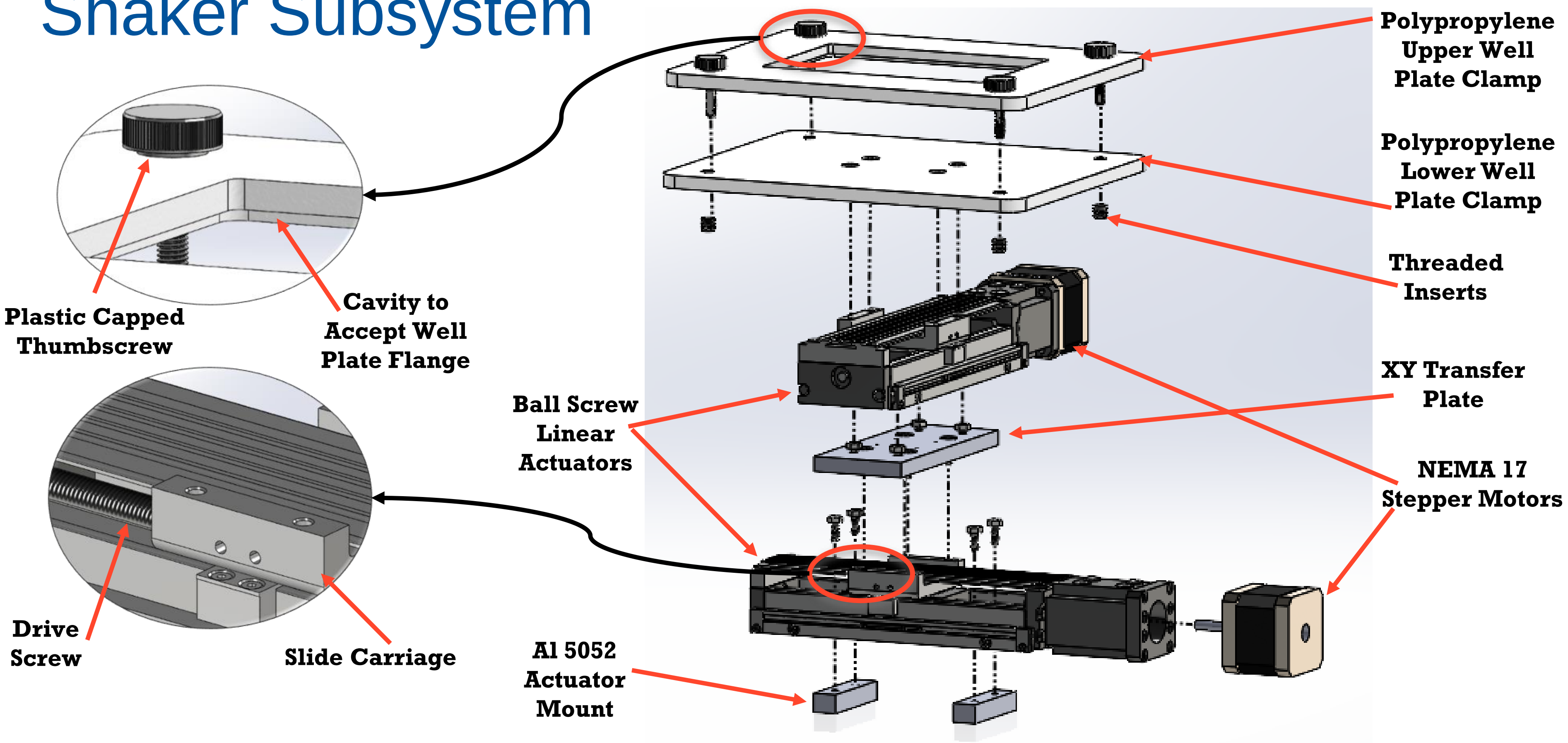
- Polypropylene construction
- Custom fit for robotic grippers



Shaker Subsystem

- Custom Brackets for Standard Well Plate and Tubes
- 12 m/s^2 Linear Acceleration in 2 Axes

Shaker Subsystem



Required Shaking Speed

$$h = \frac{V}{\frac{\pi d^2}{4}} = \frac{90\ mm^3}{\frac{\pi * 3.5^2\ mm^2}{4}} = 9.35\ mm$$

$$\frac{F_C}{F_G} = \frac{2h}{d} = \frac{2 * 9.35\ mm}{3.5\ mm} = 5.34$$

$$\frac{\left(D + \frac{d}{y}\right) * n^2}{g} = n^2 * \frac{\left(2\ mm + \frac{3.5\ mm}{4}\right) * \left(\frac{2 * \pi \frac{radians}{rotation}}{60 \frac{sec}{min}}\right)^2}{9.8 \frac{m}{s^2} * 1000 \frac{mm}{m}} => n = 1289$$

Table of Variables:

$V = Working\ Volume = 90\ mm^3$

$d = Well\ Diameter = 3.5\ mm$

$D = Orbital\ Shaking\ Diameter = 2.0\ mm$

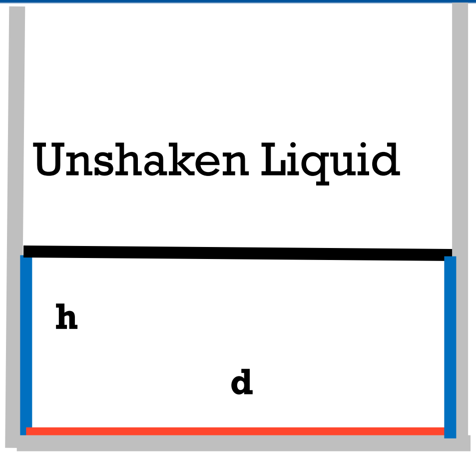
$y = Effective\ Diameter\ Factor = 4$

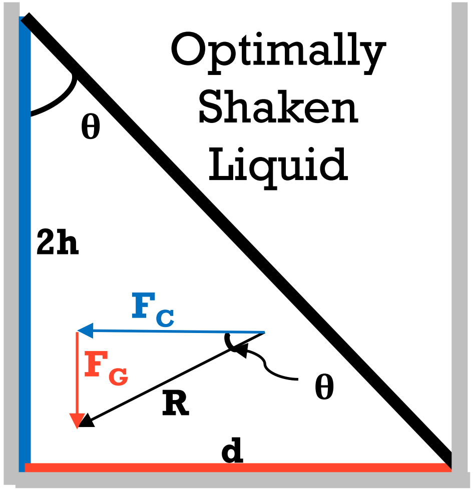
$h = Height\ of\ the\ Unshaken\ Liquid$

$F_C = Centripetal\ Force$

$F_G = Gravitational\ Force$

$n = Rotational\ Speed$





Shaker Motor Analysis

$$a_C = n^2 * \frac{D}{2} = \left(1289\,rpm * \frac{2*\pi\frac{radians}{rotation}}{60\frac{sec}{min}}\right)^2 * \frac{2\,mm}{2} * \frac{1\,m}{1000\,mm} = 18.2\frac{m}{s^2}$$

$$J_L = m * \frac{\left(\frac{L}{2\pi}\right)^2}{\eta} = \frac{2.25\,kg * \left(\frac{0.005\,m}{2*\pi}\right)^2}{0.85} = 1.676\,kg*mm^2$$

$$J_t = J_m + J_A + J_L = 6.768\,kg*mm^2 + 0.741\,kg*mm^2 + 1.676\,kg*mm^2 = 9.185\,kg*mm^2$$

$$\alpha = \frac{2*\pi*a_C}{L} = \frac{2*\pi*18.2\frac{m}{s^2}}{0.005\,m} = 22896\frac{rad}{s^2}$$

$$T = \alpha * J_t + \frac{m*g*L}{2*\pi*\eta} = 22896\frac{rad}{s^2} * 9.185\,kg*mm^2 + \frac{2.25\,kg*9.8\frac{m}{s^2}*0.005\,m}{2*\pi*0.85} = 0.231\,Nm$$

Table of Variables:

$n = Angular\ Velocity = 1289\,rpm$

$D = Orbital\ Diameter = 2\,mm$

$m = Mass\ of\ the\ Load = 2.25\,kg$

$L = Screw\ Lead = 0.005\,m$

$\eta = Actuator\ Efficiency = 85\%$

$J_A = Actuator\ Inertia = 0.741\,kg*mm^2$

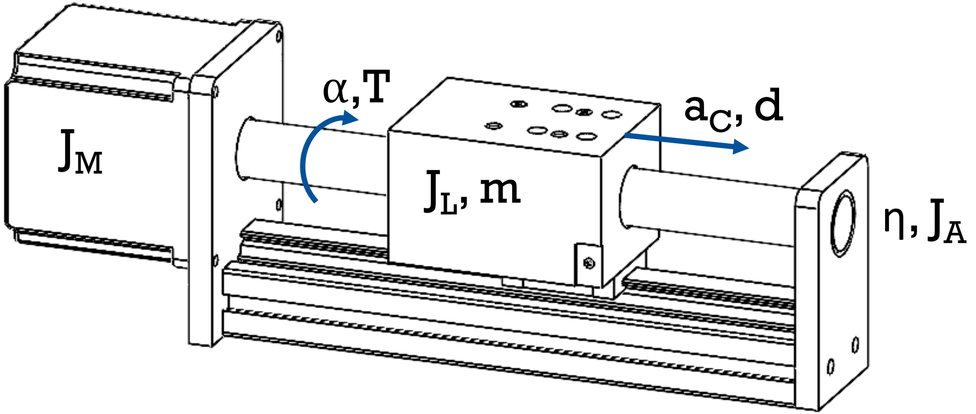
$J_M = Motor\ Inertia = 6.768\,kg*mm^2$

$J_L = Load\ Inertia$

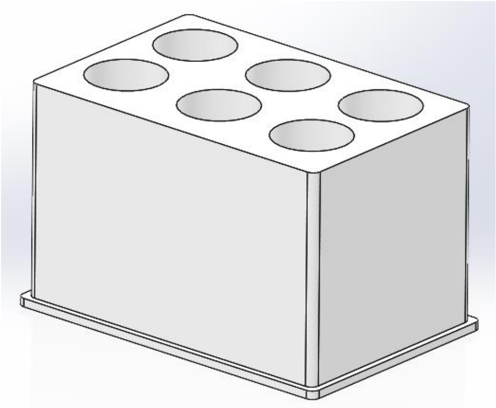
$a_C = Centripetal\ Acceleration$

$\alpha = Angular\ Acceleration$

$T = Peak\ Required\ Torque$



Chosen Components



Custom Polypropelyne Test Tube Holder

Need 26: Configurations for holding 50 ml and 15 ml Test tubes.

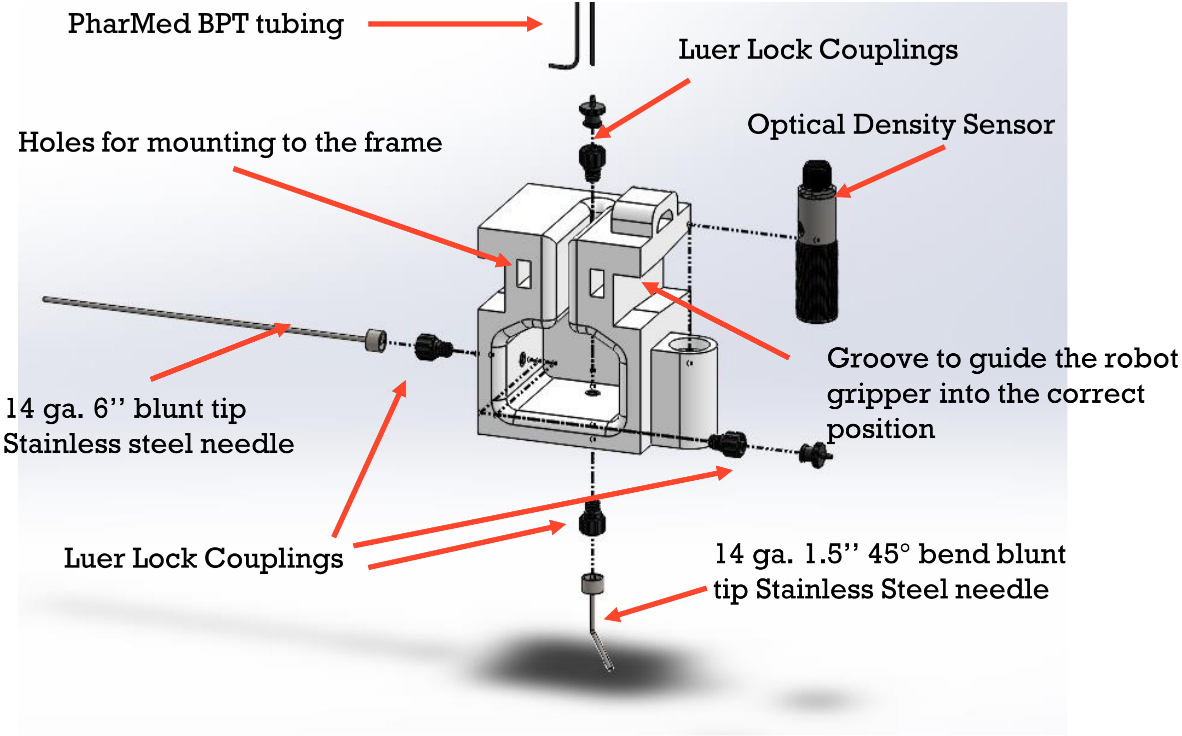
Lin Engineering NEMA 17 Motor

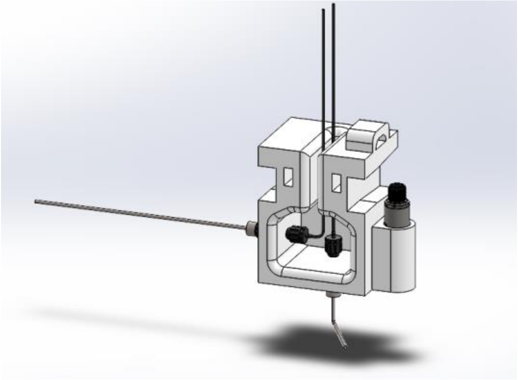
Need 5: 25 Watts each (less than 2% of total power)
Need 20: Functions in ambient temperatures of up to 80° C
Need 28: Max torque of 0.59 Nm will accelerate plates for optimal mixing

Parker 402XE Linear Actuator

Need 1: Life of over 100,000km (approx. 40 yrs)
Need 28: Maximum acceleration of 20 m/s^2

Fluid and Optical Density Tool





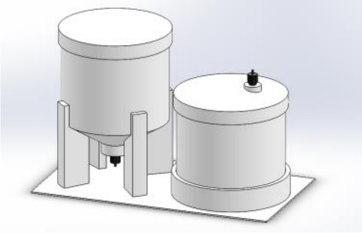
45° bend in needle allows nutrients to be added to the inner wall of the container to reduce splashing

PharMed BPT tubing provides good chemical resistance and 10,000 hrs. of use.

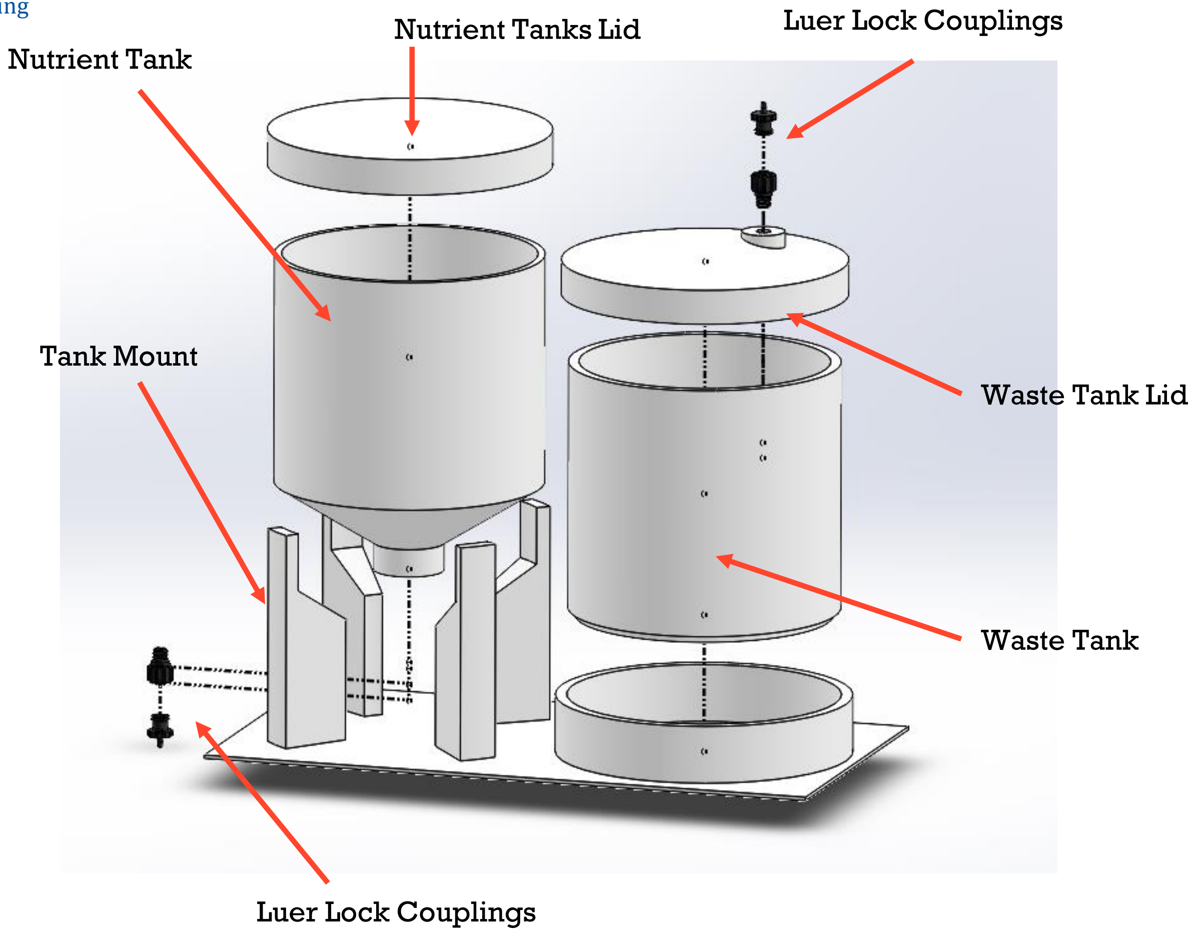
$$\frac{min}{0.0191L} * \frac{hrs.}{60\ min} * \frac{1\ L}{ex} * \frac{1\ ex}{day} * \frac{365\ days}{year} * 10\ years$$

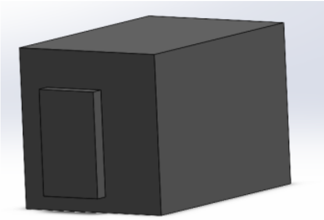
$$= 3184.99\ hrs < 10{,}000\ hrs.$$

Nutrient and Waste Tanks



- Nutrient Tank
  - 1 L total volume
  - Fills 50 mL rack => 8 times
  - Fills Deep 96 plate => 5 times
- Waste Tank
  - 1 L total volume
  - Inlet on top to prevent potential back flow





MasterFlex C/L

- Single Channel Pump head with 4 rollers
- Runs from 50 to 300 rpm
  - With 0.06'' ID tubing => 53-318 $\mu L/s$
- Max Operating Pressure = 103.4 kPa

$$\left(\frac{P}{\rho g} + \frac{\alpha \bar{u}^2}{2g} + h\right)\Bigg|_{out} - \left(\frac{P}{\rho g} + \frac{\alpha \bar{u}^2}{2g} + h\right)\Bigg|_{in} = \frac{\dot{W}_{in}}{\dot{m} g} - H_{lT}$$

- The control volume does not include the pump so there is no work in, the flow rate is constant, we're neglecting minor losses and we're using gauge pressure

$$\Delta h - \frac{P_{required}}{\rho g} = -H_{lT}$$

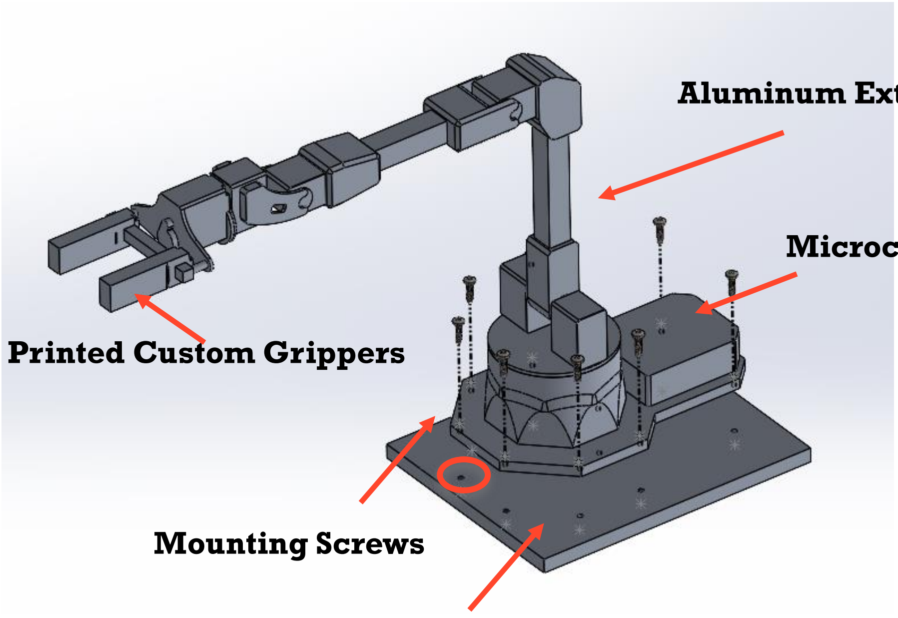
- We estimate the height change to be 1 ft., $R_{eD} = 249 < 2300$ so we have a laminar flow so our darcy friction factor becomes 0.275 and the tube length is estimated at 2 ft.

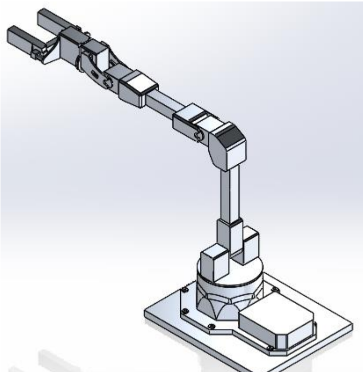
$$P_{required} = \rho g \left[f \left(\frac{L}{D}\right)\left(\frac{\bar{u}^2}{2g}\right) + \Delta h \right] = 4.5\ kPa$$

$$P_{required} < 103.4\ kPa$$

Tool Delivery Subsystem

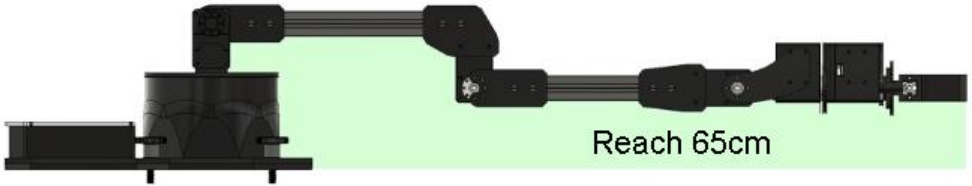
WidowX 250 Robot Arm by Trossen Robotics

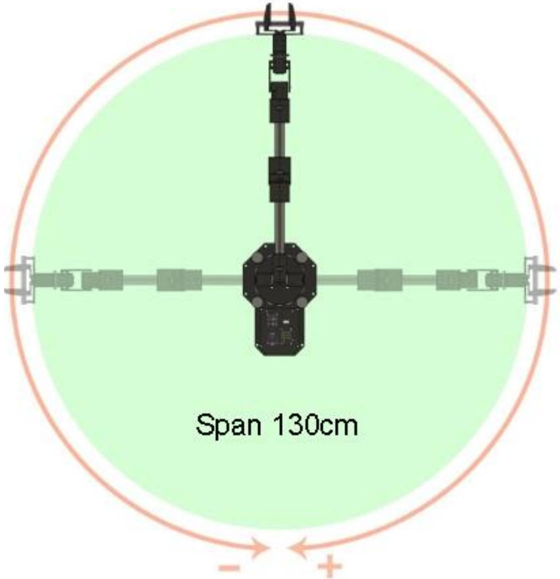




Tool Delivery Subsystem

WidowX 250 Arm	
Degrees of Freedom	5
Accuracy	1mm
Working Payload	250g
Total Servos	8
Wrist Rotate	Yes



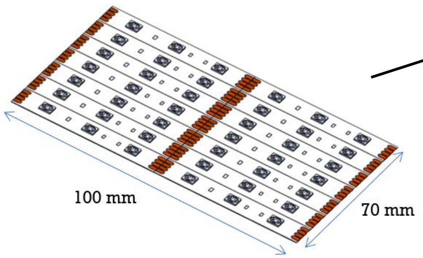


3D Printed Custom Grippers allow for interchangeability

90-degree elbow design

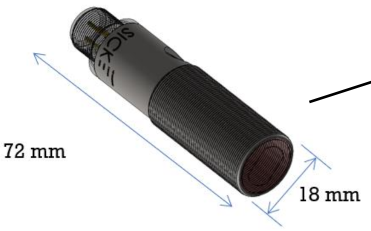
OD/FI Subsystem

5050 RGBW LED Bed



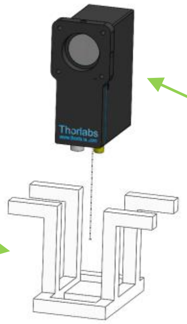
- Red 630 nm
- Green 520 nm
- Blue 466 nm
- Cool white 6500k for photobioreactor mode
- 128/326/82/432 lumens/meter

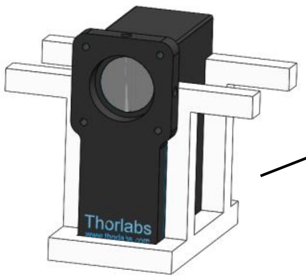
Optical Density Sensor



- Photoelectric Receiver
- -25 to 80° C operating temperature
- Receives red light (630 nm)

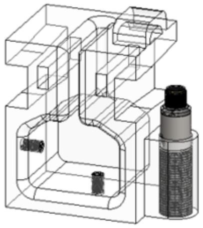
Photomultiplier Tube FI Sensor





- 280-630 nm range
- 80 mA/W
- <10 seconds warm up time
- Sensor is 3.65" x 1.60" x 2.46"

OD/FI Subsystem



$P = power\ output = 16\ W/m$

$d = culture\ tube\ diameter = 6.96\ mm$

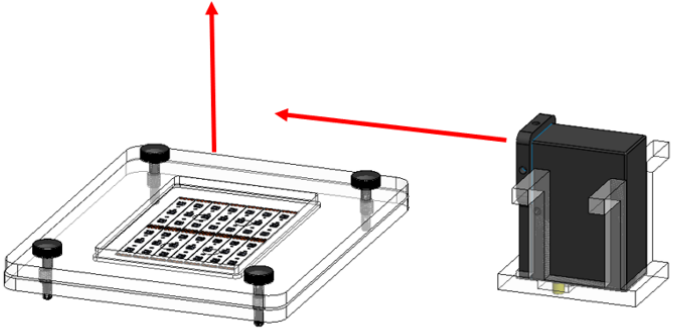
$\emptyset = Lumens\ (lm)$

$\eta = luminous\ efficacy\ \ (lm/W)$

$A = area\ (m^2)$

$I = light\ intensity\ (lux)$

Luminosity output is 128 lm/m



Max light intensity for a single well culture with red light:

$$\frac{16\ W}{1000\ mm} = \frac{x}{6.96\ mm} \longrightarrow x = 0.11\ W$$

$$\eta = \frac{\frac{128\ lumens}{m}}{\frac{16\ W}{m}} = \left(\frac{128\ lm}{m}\right)\left(\frac{m}{16\ W}\right) = 8\ lm/W$$

$$\emptyset = P\eta = (0.11\ W)(8\ lm/W) = 0.89\ lumens$$

$$A = \pi r^2 = \pi(3.48\ mm)^2 = 38.05\ mm^2 = 3.80 \times 10^{-5}\ m^2$$

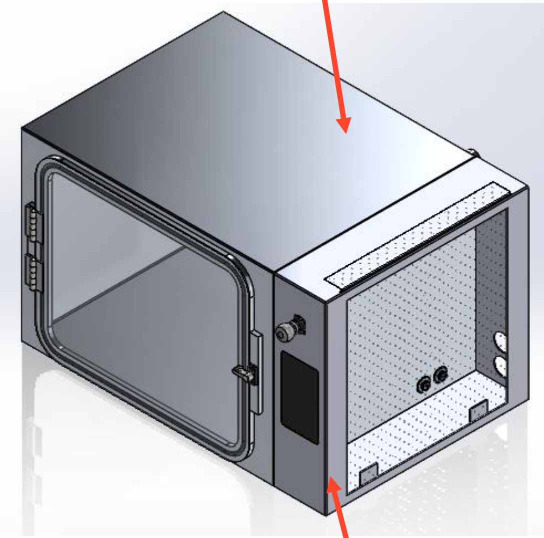
$$I_0 = \frac{\emptyset}{A} = \frac{0.89\ lm}{3.80 \times 10^{-5} m^2} = 23415.9\ lux$$

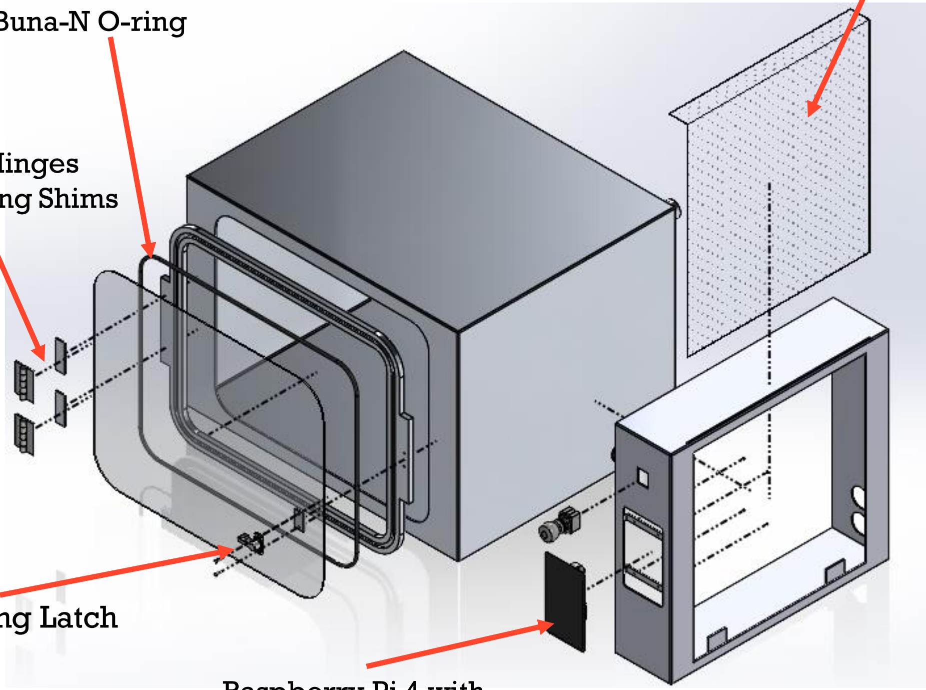
Well plates allow 90% light transmission so

$$I_0 = 23415.9\ lux \times 0.90 = 21074.31\ lux$$

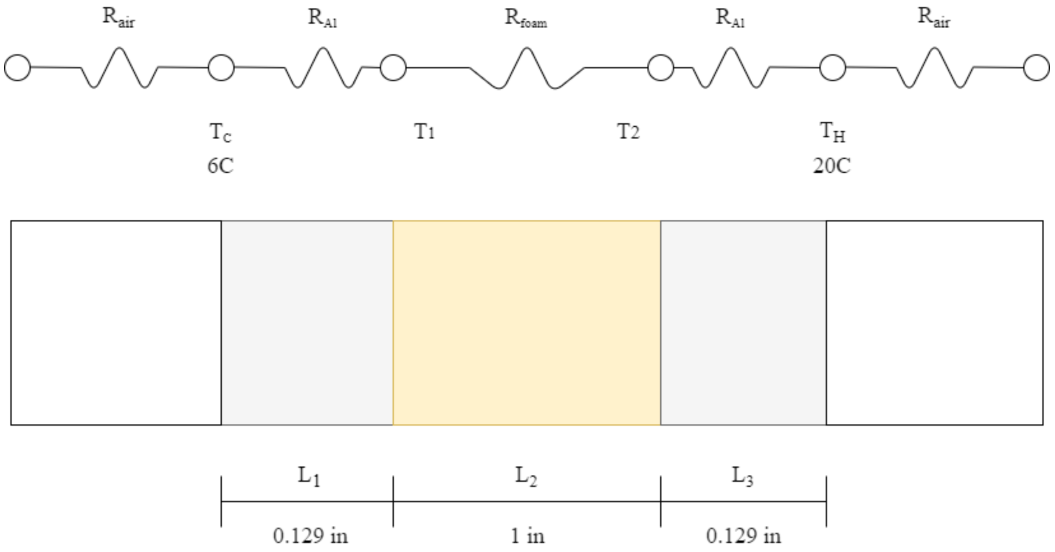
Doing the same calculation for the photobioreactor mode with 432 lm/m gives 71125.8 lux, which is within the range of direct sunlight and thus, good for illuminating photosynthesis-capable cell cultures

Frame and Structure Subassembly





Insulation Heat Loss Analysis



$$\dot{Q}_{in} = A \times \frac{T_H - T_C}{\sum R} = \dot{Q}_{out} - \dot{W}_{in}$$

$$R = \frac{L(m)}{K(\frac{w}{mK})}$$

$$\dot{Q}_{in} = 5.558(m^2) \times \frac{20 - 0}{\frac{L(m)}{0.02\frac{W}{mk}} + 2 \times \frac{0.0033(m)}{152\frac{W}{m*K}}} = 100W - 61.6W$$

Temperature Control Subsystem

$$\Delta E = \dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \Delta V = mc_{total}\frac{dT}{dt}$$

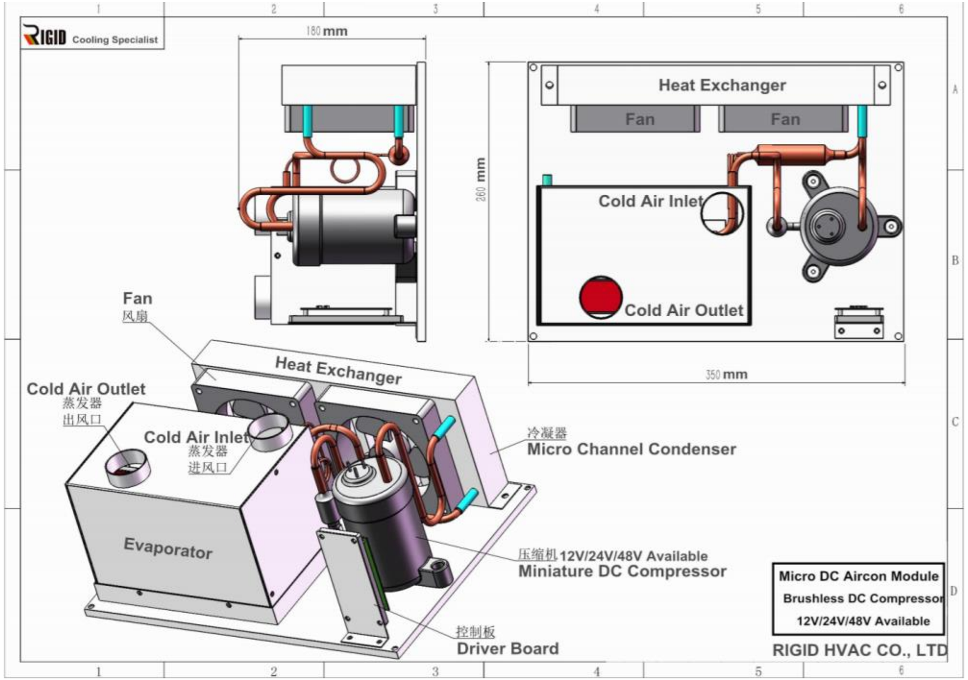
$$mc_{total} = \sum mc_{solid} + mc_{liquid} + mc_{gas}$$

$$\dot{Q}_{in} = A \times \frac{T_h - T}{\sum R}$$

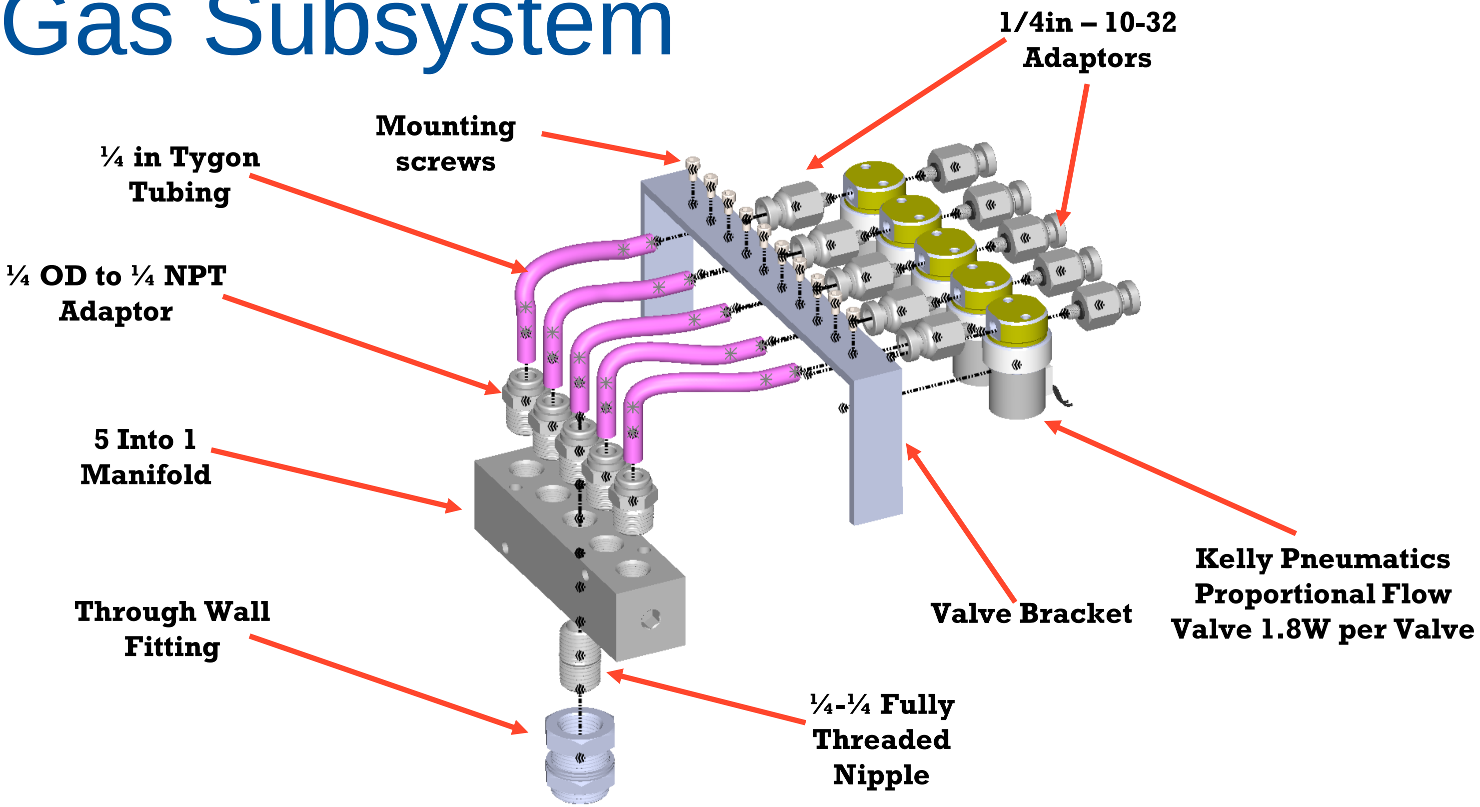
$$mc_{total}\frac{dT}{dt} = (\dot{W}_{in} - \dot{Q}_{out} + \frac{A \times T_h}{\sum R}) - (\frac{A \times T}{\sum R})$$

$$A\frac{dT}{dt} + BT + C = 0$$

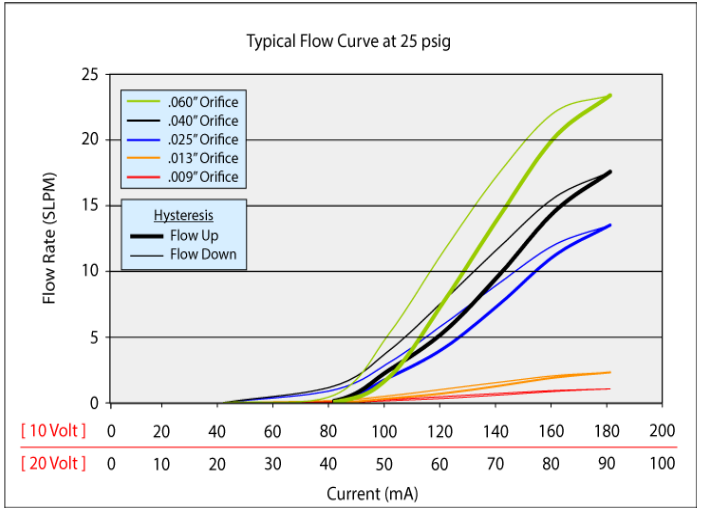
$$T(t) = T_{\infty}e^{-\frac{B}{A}t} + C$$



Gas Subsystem



Gas Subsystem Analysis



Bernoulli's equation as a starting point

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Derivation of Flow Rate vs System Leakage from Bernoulli's

$$Q = 2610 * A * (dP)^{0.5}$$

Area of Leakage and Maintaining Atmosphere Flow Rate Calculation

$$A = L * W = 26.1d * 0.01 * \frac{1}{12^2} = 0.00018125$$

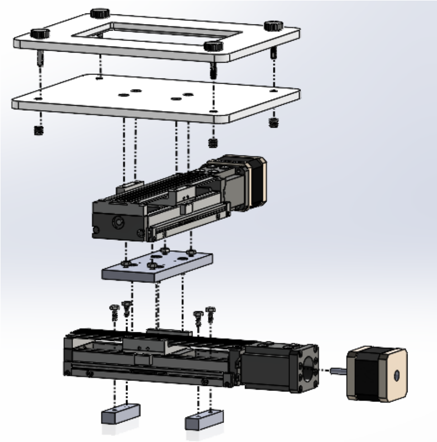
$$Q = 2610 * A * (dP)^{0.5} = 2610 * 0.0018125 * (.01)^{0.5} = 0.1495955\ CFM = 4.2360728\ LPM$$

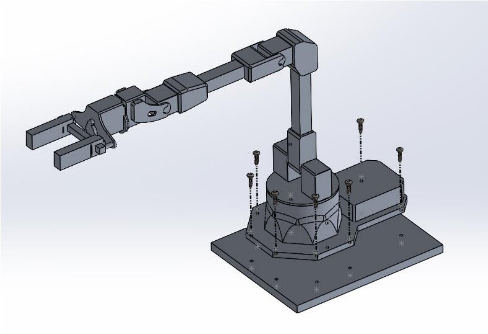
Purge Flow Rate Calculation

$$Q = 2610 * A * (dP)^{0.5} = 2610 * 0.0018125 * (2.5)^{0.5} = 0.7479770\ CFM = 21.1803500\ LPM$$

Design Highlights and Features

- Customizable tool delivery system
- Explosion proof flow valves
- Touch screen display
- Robust small diameter shaker
- Large access for cleaning
- Easily accessible electronics
- Simplistic codability
- Small footprint on a desktop



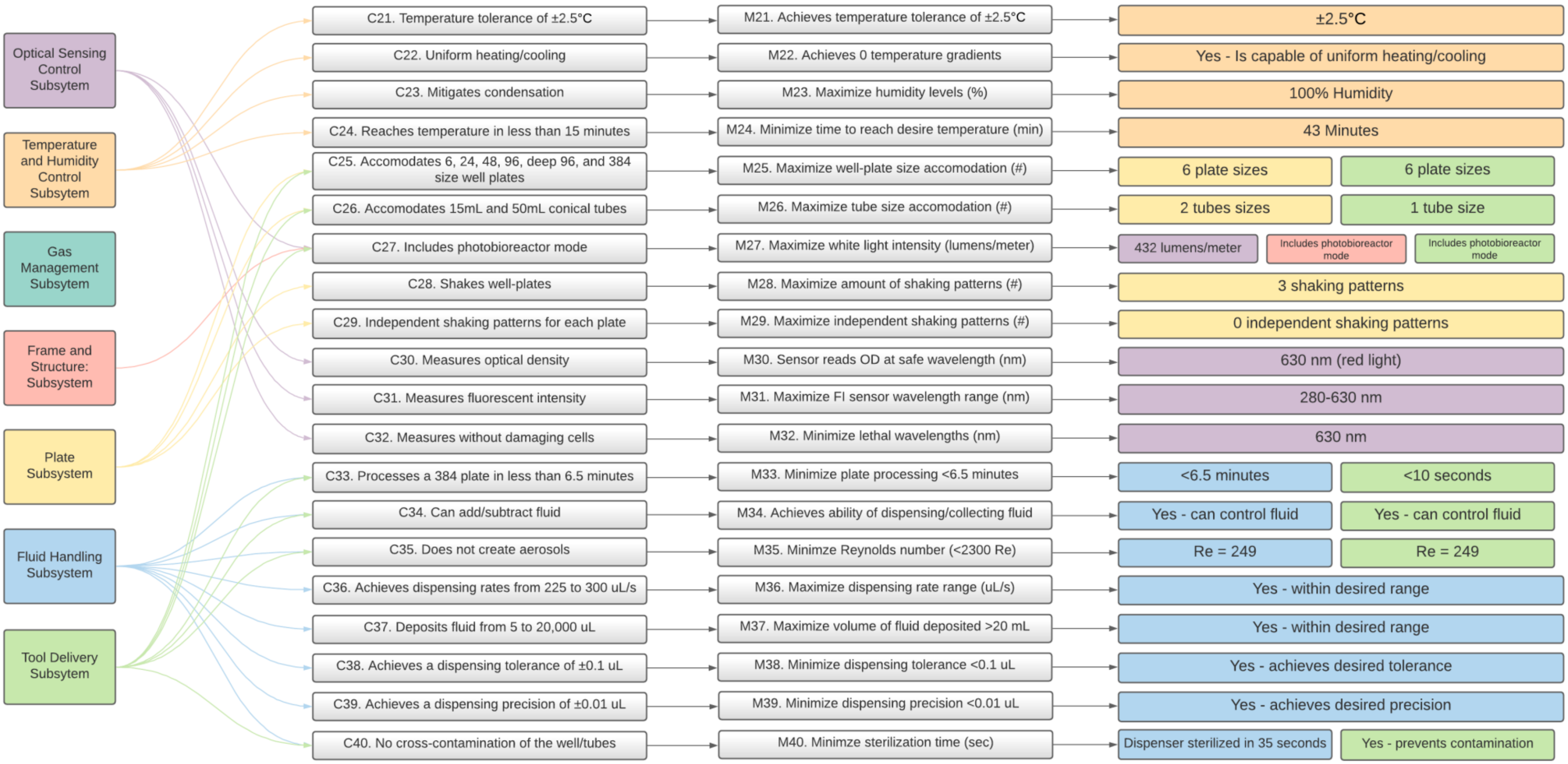


Cost Analysis

Cost Breakup	Total Cost
OTS Cost	$8949
Raw Cost	$2160
Manufacturing Labor	$1073
Assembly Labor	$112
Energy Consumption	$4
Total Cost	$12298

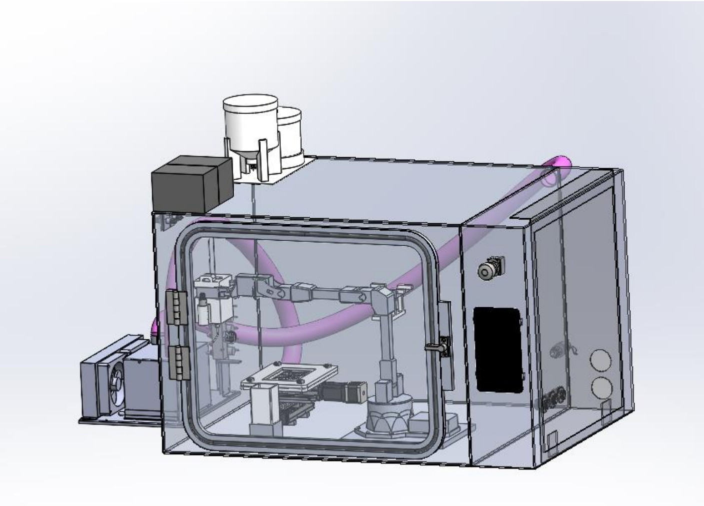
- Optical Sensing Control: Subsytem
- Temperature and Humidity Control Subsytem
- Gas Management Subsystem
- Frame and Structure Subsystem
- Plate Subsystem
- Fluid Handling Subsystem
- Tool Delivery Subsystem

Customer Need	Metric	Values
C1. 10-year life	M1. Maximize oprational lifetime >10 years	10 years; 10 years; 22 years; 10 years; 11.42 years; 30 years; 15 years
C2. $10,000 Production Cost	M2. Minimize production cost <$10,000	$2573.20; $550; $601.85; $450; $2500; $2103.91; $2653.87
C3. Moveable by 1 person	M3. Minimize mass (kg)	26 kg
C4. Fits on a benchtop	M4. Minimize length (in)	26 in
C5. Runs from a 120 VAC outlet	M5. Minimize power required (W)	11.2; 450 W; 35 W; 8.9 W; 50.4 W; 57.6 W; 60 W
C6. Easy access for cleaning	M6. Maximize gap (in)	15 in
C7. Emergency stop	M7. Minimize time to reach emergency stop (sec)	2 seconds
C8. Intuitive user interface	M8. Minimize buttons (#)	2 buttons/interface
C9. Easy to see indicator	M9. Maximize size of indicator (in)	7 in
C10. Easily programmable	M10. Low difficulty rating	Yes - simple custom programing available
C11. Only nonporous materials contact cultures	M11. Minimize amount of nonporous material (%)	100%; 98.5%; 99%; 100%
C12. Only nonreactive materials contact cultures	M12. Achieves chemical rating of 1	Chem rating: 1; Chem rating: 1; Chem rating: 1; Chem rating: 1
C13. Apporpriate for a BSL-2 space	M13. Within national standards (no violations)	Yes - Within national standards
C14. Not too hot to touch	M14. Minimize exterior temperature (°C)	58°C
C15. Deals with its own waste	M15. Minimize time to dispose of waste (sec)	15 seconds; 67 seconds; Yes (is capable of waste management)
C16. Fully enclosed interchangeable compartments	M16. Achieves 0 non-enclosed compartments	Yes; Yes; Yes; Yes
C17. Independent enviornment for each compartment	M17. 100% independent enviornment per compartment	Yes; Yes; Yes; Yes
C18. Handles N2, O2, OH4, and H2	M18. Maximize amount of gases to handle (#)	Handles 5 gases
C19. Two week run time	M19. Maximize autonomous run time >2 weeks	2 weeks; 2 weeks; 2 weeks; 2 weeks; 2 weeks; 2 weeks
C20. Constant temperature ranging from 4 to 70°C	M20. Maximize temperature range (°C)	Yes - Is capable of that range


Optical Sensing Control Subsystem
Temperature and Humidity Control Subsystem
Gas Management Subsystem
Frame and Structure: Subsystem
Plate Subsystem
Fluid Handling Subsystem
Tool Delivery Subsystem
C21. Temperature tolerance of ±2.5°C
M21. Achieves temperature tolerance of ±2.5°C
±2.5°C
C22. Uniform heating/cooling
M22. Achieves 0 temperature gradients
Yes - Is capable of uniform heating/cooling
C23. Mitigates condensation
M23. Maximize humidity levels (%)
100% Humidity
C24. Reaches temperature in less than 15 minutes
M24. Minimize time to reach desire temperature (min)
43 Minutes
C25. Accomodates 6, 24, 48, 96, deep 96, and 384 size well plates
M25. Maximize well-plate size accomodation (#)
6 plate sizes
6 plate sizes
C26. Accomodates 15mL and 50mL conical tubes
M26. Maximize tube size accomodation (#)
2 tubes sizes
1 tube size
C27. Includes photobioreactor mode
M27. Maximize white light intensity (lumens/meter)
432 lumens/meter
Includes photobioreactor mode
Includes photobioreactor mode
C28. Shakes well-plates
M28. Maximize amount of shaking patterns (#)
3 shaking patterns
C29. Independent shaking patterns for each plate
M29. Maximize independent shaking patterns (#)
0 independent shaking patterns
C30. Measures optical density
M30. Sensor reads OD at safe wavelength (nm)
630 nm (red light)
C31. Measures fluorescent intensity
M31. Maximize FI sensor wavelength range (nm)
280-630 nm
C32. Measures without damaging cells
M32. Minimize lethal wavelengths (nm)
630 nm
C33. Processes a 384 plate in less than 6.5 minutes
M33. Minimize plate processing <6.5 minutes
<6.5 minutes
<10 seconds
C34. Can add/subtract fluid
M34. Achieves ability of dispensing/collecting fluid
Yes - can control fluid
Yes - can control fluid
C35. Does not create aerosols
M35. Minimze Reynolds number (<2300 Re)
Re = 249
Re = 249
C36. Achieves dispensing rates from 225 to 300 uL/s
M36. Maximize dispensing rate range (uL/s)
Yes - within desired range
C37. Deposits fluid from 5 to 20,000 uL
M37. Maximize volume of fluid deposited >20 mL
Yes - within desired range
C38. Achieves a dispensing tolerance of ±0.1 uL
M38. Minimize dispensing tolerance <0.1 uL
Yes - achieves desired tolerance
C39. Achieves a dispensing precision of ±0.01 uL
M39. Minimize dispensing precision <0.01 uL
Yes - achieves desired precision
C40. No cross-contamination of the well/tubes
M40. Minimze sterilization time (sec)
Dispenser sterilized in 35 seconds
Yes - prevents contamination

Conclusion

The Reactigator can solve all customer needs and competes with commercial competitors using its autonomous structure and extreme flexibility in customizability according to the user.



Thank You

We would like to thank our corporate sponsors Cummins and Northrop Grumman for their support of this project.