<u>Team 13: Partial Gravity Bioreactor Parts</u> <u>10/10/2025</u>

<u>Parts Yet to Be Purchased (Now and Future):</u>

1. **Stepper Motor**

To determine the torque required to rotate the bioreactor continuously, the moment of inertia and the angular acceleration must be calculated. However, since the bioreactor is expected to rotate from 0 rpm to a maximum of 50 rpm, the angular acceleration can be observed in terms of the intended rpm over time. Since RPM provides more information than angular velocity, the torque can be found as seen in Eq. 1.

$$\tau = I * \propto \Longrightarrow \qquad (1)$$
$$\tau = I * \frac{\Delta\omega}{t} \Longrightarrow$$
$$\tau = I * \frac{\frac{2\pi}{60} * RPM}{t}$$

Where:
- τ = torque
- $\propto$ = angular acceleration
- ω = angular velocity
- RPM = revolution per minute
- t = time it takes to change angular velocity

Focusing on the moment of inertia, the bioreactor is a cylinder with some extrusions. Assuming that the bioreactor is a cylinder, the moment of inertia is in Eq. 2.

$$I = \frac{m * r^2}{2} \qquad (2)$$

Where:
- m = mass of the rotating object
- r = radius of the rotating object
- I = moment of inertia

Eq. 2 is the inertia of the rotation along the length of the cylinder, which applies to both the bioreactor and the rod. Focusing on the bioreactor, the radius of the bioreactor would be the 50mL HARV for the most extreme moment of inertia possible for the prototype. A diameter of 99.06mm, corresponding to a radius of 0.04953m, will be used. As for the mass, it was documented from the prior team that the empty mass of the bioreactor is .03kg, and using the volume of 50mL, the density of the water $1{,}000 \frac{kg}{m^3}$, and the prior knowledge of $1mL = 10^{-6}m^3$ the mass of the filled bioreactor can be measured using Eq. 3.

$$m = \rho * V \tag{3}$$

Where:

m = mass of the system
V = volume of the system
ρ = density of the system

Adding the mass of the bioreactor to the mass of the system inside it, the mass of the filled bioreactor is 0.08kg. However, since the actual mass of the total bioreactor is never precisely known, a safety factor of 1.5 is used. For that, the mass of the filled bioreactor is 0.12kg. Plugging the filled mass of the bioreactor and the radius of 0.04953m in Eq. 2, the moment of inertia is $1.47 \times 10^{-4} kgm^2$. If it takes 1 second to go from 0 RPM to a maximum RPM of 50 RPM, plugging the values into Eq. 1 will provide a torque of $2.57 \times 10^{-5} \frac{rev}{s^2}$, which is $1.61 \times 10^{-4} Nm$.

Since the torque is very low, most motors would be suitable for the prototype. However, the accuracy of the motor rotation at 20-50rpm is a must. Therefore, the best way to achieve that is by breaking down the steps per revolution taken by the motor. Most motors have a step angle of 1.8°, which requires 200 steps to complete one complete turn. However, the lowest step angle that can be taken with the stepper motors is 0.9°, requiring 400 steps to complete a turn. This increases the distance the motor travels, which allows for more accurate movements. Additionally, the motor's RPM should include the range from 0 to 50 RPM. For that, the NEMA 23 198.2 in.-oz will be used. The maximum rotation is 400rpm. The speed range expected to be used is 12.5% of the motor's rated speed and has a maximum current per phase of 1.5A. The digital stepper driver used has a current per phase of 0.3-2.2A. Since the current per phase of the motor is in the range of the driver, the driver would be applicable. It has a maximum temperature of 50 °C, exceeding the incubator's temperature. Furthermore, the maximum step resolution is one hundredth, allowing the driver to divide a complete step into 100 smaller steps. This enhances the variation in increments between the angles in the prototype, thereby enabling a broader range of inclination solutions. Using Eq. 4, the number of steps per revolution is 40,000, with a step angle of 0.009 °.

$$Total\ Microsteps = \frac{360 * (Step\ Resolution)^{-1}}{Full\ Step\ Angle} \tag{4}$$

Regarding the inclination plane rotation, the most critical aspect is to ensure that during the stationary motion of the plane, the motor remains stationary. For that, Eq. 5 would be used to calculate the holding torque.

$$\tau = m * g * d \tag{5}$$

Where:

τ = torque

m = mass

d = perpendicular distance from the pivot

The mass of the components acting during the rotation of the motor would be divided into two main components: the acrylic incline plane and the bioreactor with its motor. The acrylic plane has a length of 0.127m, a width of 0.1524 m, a thickness of 0.00635m, and a density of $1190 \frac{kg}{m^3}$, the distance from the pivot point is 0.0635m. As for the bioreactor and motor, their total mass is the sum of 0.08kg and 0.28kg, with 0.0508m from the pivot. Additionally, to ensure safety, a safety factor of 2 would be used. For this, the holding torque is calculated to be 0.542 Nm. Since the camera component was not taken into consideration due to the unknown mass, the acceptable holding torque would be about 0.55-0.6 Nm.

The E Series Nema 17 Bipolar 42Ncm has a maximum holding torque of 0.55Nm. Since the holding torque is on the edge of a high approximated torque, the motor could be suitable. The maximum temperature is 50 °C, exceeding the incubator's temperature. Additionally, the motor has a current rate per phase of 1.50A and has a step angle of 1.8°. Considering that this component is a stepper motor, a stepper driver has been selected to facilitate more precise rotational movement. The digital stepper driver used has a current per phase of 0.3-2.2A. Since the current per phase of the motor is in the range of the driver, the driver would be applicable. It has a maximum temperature of 50 °C, exceeding the incubator's temperature. Furthermore, the maximum step resolution is one hundredth, allowing the driver to divide a complete step into 100 smaller steps. This enhances the variation in increments between the angles in the prototype, thereby enabling a broader range of inclination solutions.

The Nema 23 173.5 in-oz has a maximum holding torque of 1.225 Nm. Since the holding torque exceeds the maximum opposing torque, the motor is suitable. The maximum temperature reaches 266 °F (130 °C), exceeding the incubator's temperature limit. Additionally, the motor has a current rate per phase of 2.8A and has a step angle of 1.8°. Considering that this component is a stepper motor, a stepper driver has been selected to facilitate more precise rotational movement. The digital stepper driver used has a current per phase of 2.35-8A. Since the current per phase of the motor is in the range of the driver, the driver would be applicable. It has a maximum temperature of 85 °C, exceeding the incubator's temperature. Furthermore, the maximum step resolution is one hundredth, allowing the driver to divide a complete step into 100 smaller steps. This enhances the variation in increments between the angles in the prototype, thereby enabling a broader range of inclination solutions.

Since there are two options for this motor, we are currently opting for the NEMA 17, as it is readily available. Additionally, since they both have the same wiring, driver, and Arduino library, if the NEMA 17 did not work, we would replace it with the NEMA 23, which we know would exceed the maximum torque of the prototype. Due to cost limitations, we would rather go with the NEMA 17.

2. **L- Bracket for Motor Support**

We need to hold the motor securely against a sturdy surface to prevent it from moving as it rotates. The other part of the L-bracket would be connected to the base of the prototype.

3. **Motor Stepper Driver**

The driver is used to let the motor know how fast or slow or in which direction we want it to go. Additionally, it adds more resolution in the steps, having smaller steps per rotation.

4. **Motor to Shaft Coupler**

Ensures a precise and secure connection between motors and shafts, reducing vibration and misalignment.

5. **Ball Bearing**

It is 0.5 inches in diameter, matching the diameter of the rod. Provides smooth rotational motion of the shaft and reduces friction. Additionally, the ball bearing provides stability and facilitates easy mounting.

6. **Mounted Ball Bearing**

It is 0.5 inches in diameter, matching the diameter of the rod. This would hold the free end of the rod.

7. **Shaft Support**

They will be connecting the rod to the plane. Two is used to ensure stability on both sides of the plane.

8. **Acrylic sheet (0.5-inch, 0.25-inch)**

Acrylic sheets shall be utilized as the foundational material for the prototype. Given that the prototype will be positioned within the incubator and the tests are anticipated to be conducted therein, the humidity and temperature within the incubator are likely to influence the base material of the prototype. The physical properties of the acrylic sheets, as determined by the ASTM method D648, show that a thickness of 0.236mm has a deflection temperature under a load of 264 psi of 99 °C, and the forming temperature ranges from 170 to 190 °C. The softening point, as determined by the ASTM method D1525, is 115 °C, with a maximum recommended continuous service temperature of 82 °C. Since the incubator would have a temperature significantly lower than the temperatures stated above, the minimum width of the acrylic sheets would be 0.236mm.

Additionally, the electrical properties of the acrylic are those of a good insulator, with a surface resistivity higher than that of most plastics, making it a viable protector of the electrical components in the prototype.

9. **Camera**

Enables real-time visualization of bioreactor operations and conditions. An essential part of our needs. (Holding on to the purchase because it is dependent on the bioreactor)

The following parts should be revised with the advisors and anyone who was involved in Dr. Michael's thesis to ensure the materials match the requirements. Parts needed are highlighted.

The acrylic used is a 3/16-inch cast acrylic that has already been purchased by one of our team members. The use of acrylic (and the functionality of the bioreactor) was based on replicating the bubble-catcher bioreactor designed by Dr. Michael Phelan. The acrylic parts would be the front plate, the back plate, and the central/bubble ring. The bioreactor requires a gas-permeable membrane, which will be made using the **Tegaderm** (medical silicone) on a thin **nylon mesh** (providing structural support) and pressed together. To ensure the bioreactor does not leak, a **0.5mm silicone rubber sheet** is used, two sheets per bioreactor. The bioreactor requires **8 4x16M bolts** with **one nut**, **two washers**, and **one spring washer**. A 5/8" x 11 nut will be attached to the back to connect to the bioreactor rotating system. Before pressing the Tegaderm and nylon mesh, the **methylene chloride** will be used on the nylon mesh to weld the 5/8" x 11 nut to the back plate of the bioreactor. The **contact cement** would be used to hold the nylon nut in place on the acrylic piece. The front plate will be pre-tapped using a **quarter-inch tap** and then fitted with **¼''-28 screw-to-male Luer adapters**. **Two stopcocks** for the inlet and **one standard cap** for emptying and cleaning will be connected in the pre-tapped holes. A **compression Luer fitting** will be used to fill and empty the bubble catch channel. To ensure accuracy, the adapter fitting, caps, and bolts/washers will be reviewed by Temple University labs to verify if the specific sizing are present. Otherwise, adjustments may be made if the sizes are not found. (Vendors found are *MadeInChina*, so we might need the sites that sell such components).

1. **Biocompatible Resin**

If the bolts don't work, there is a high possibility that we will buy them. (If we are going to 3D "highly unlikely", it will be used).

Parts/Supplies Already Purchased/ Gifted by Temple:

1. **Aluminum Rod Shaft**

13 inches in length and 0.5 inches in diameter. Serves as the primary rotating shaft connecting the motor to the apparatus.

2. **Cell Culture Supplies**

It is needed for validation (a negotiable requirement).

3. **Alginate Beads Supplies**

It is needed for validation (a non-negotiable requirement).

4. **Tachometer**

It is needed to validate the RPM, and fortunately, it will be provided by the university.

5. **Square Bracket (x2)**

Height: 1.53 inches

Length: 1.57 inches

Diameter: 0.5 inches

(will 3D print)

6. **L Bracket (x6)**

It is needed to hold the acrylic pieces together.

7. **Arduino Uno Rev 2 Wi-Fi**

This is the microcontroller that connects the “commands” to the driver.

8. **Plastic for 3D printing**

It is necessary to 3D-print the shaft coupler connecting the motor to the bioreactor (the bioreactor has its own connector) and the square brackets.

M5x20 with M5 hex head nuts (need 18)

M5 x25 (need 8)

M3 x 12 with M3 hex head nuts (need 16)

All nails and bolts are required to screw parts together.