UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Cell Shaking Device

Group 486Q: Cells Undergo Biological Evolution Stimulated by Active Table

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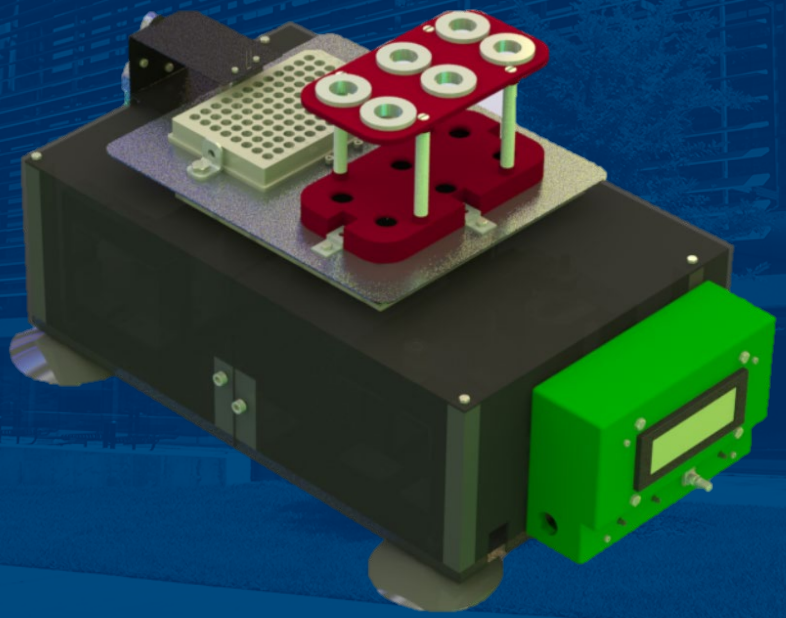
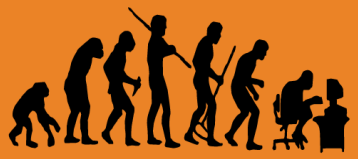


Presentation Outline

Hedgehog Concept

Testing Results

Design Evolution

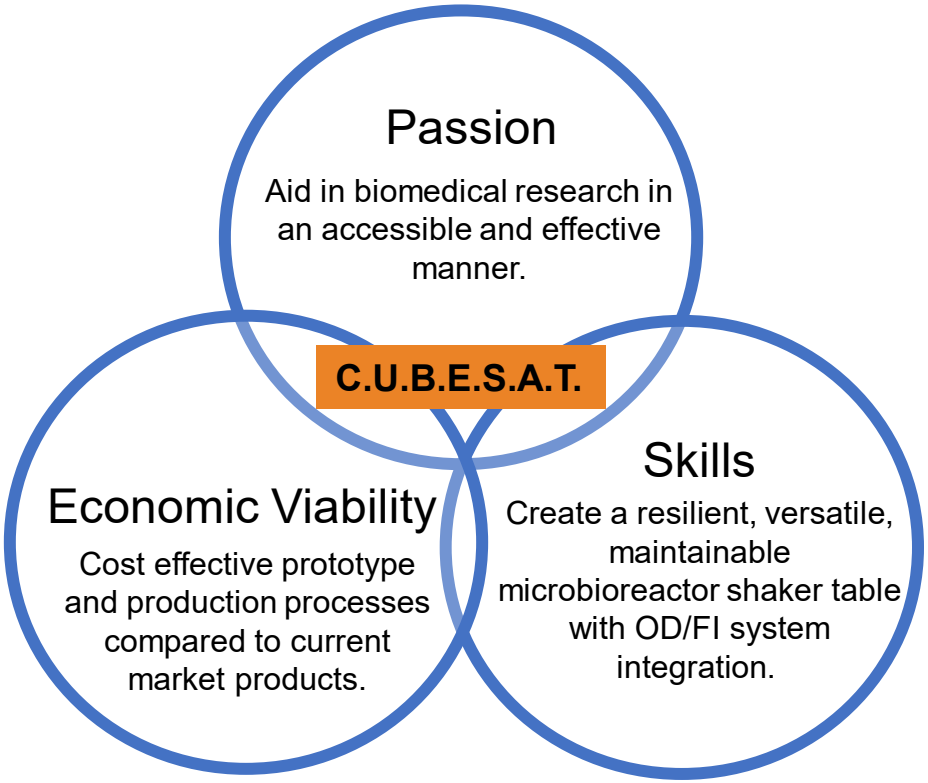


Key Features

Costs

Conclusion

Hedgehog Concept



C.S.D: BIG table, BIG results.

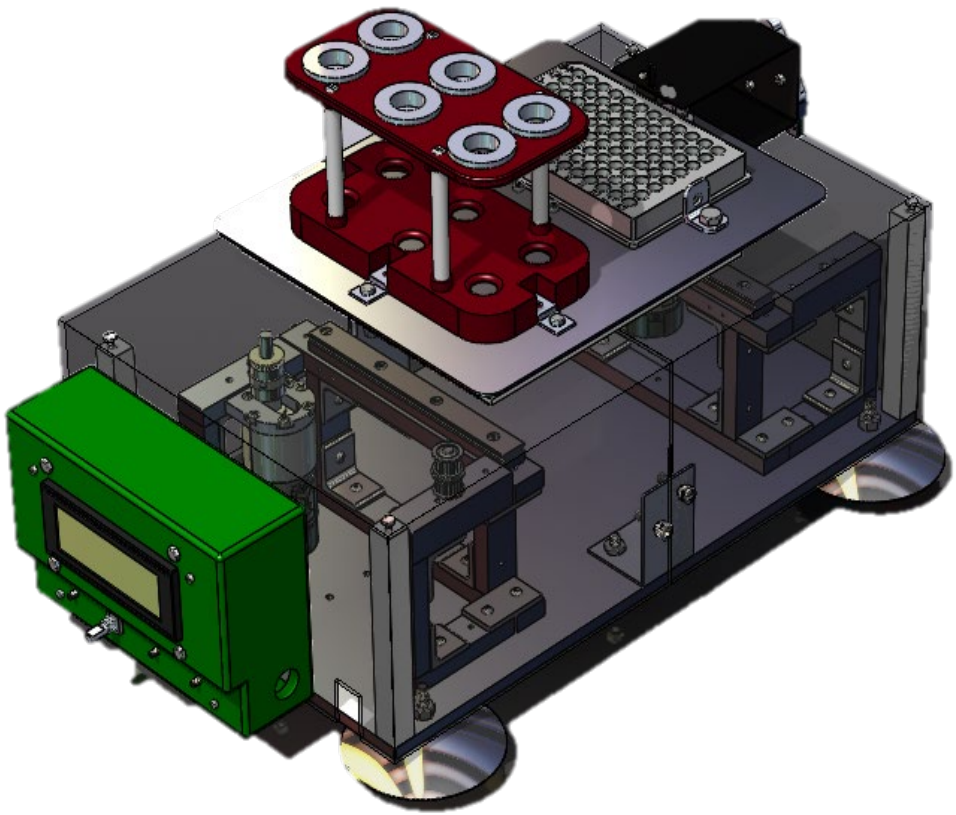
Experience the ultimate tool for microorganism research. With its advanced design and revolutionary features, our shaker table provides the following benefits:

- Versatility: Sleek and compact OD/FI system integration.
- Reliability: Variable belt tensioning and suctioned feet, and user-friendly interface.
- High Performance: Can withstand temperatures between 0-60°C

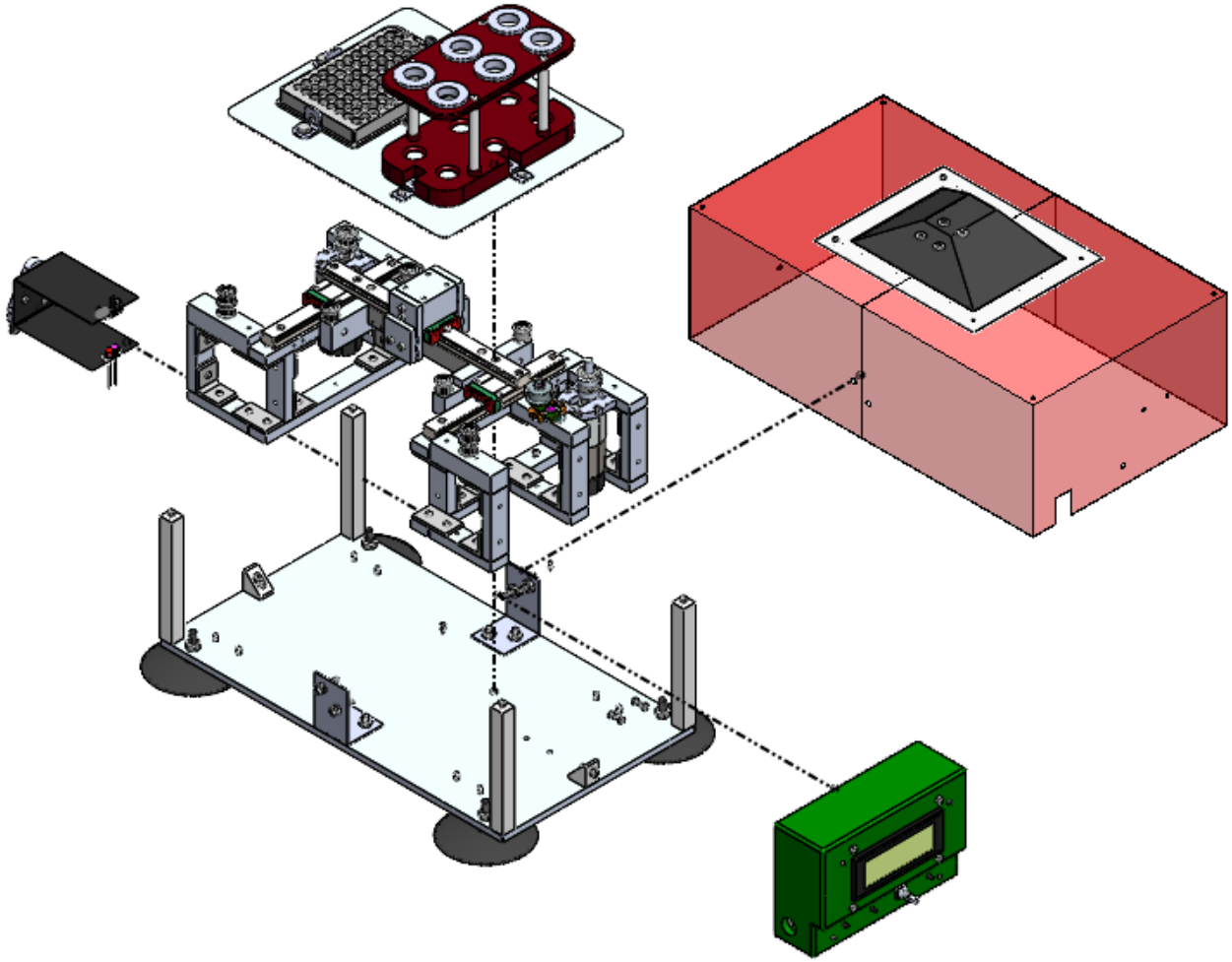
Elevate your research to new heights with C.U.B.E.S.A.T's CSD. Launch your cells to new levels of aggravation and agitation.

Key Product Specifications

Parameters	Metric
Dimensions	271 X 445 x 160 mm (w x l x h)
Weight	18.7 lb
Top Speed	768 rpm
Temperature Range	0 to 60 C
Shaking Patterns	Linear, Orbital, Double Orbital
Shaking Diameter	25mm
Projected Production Cost	$826

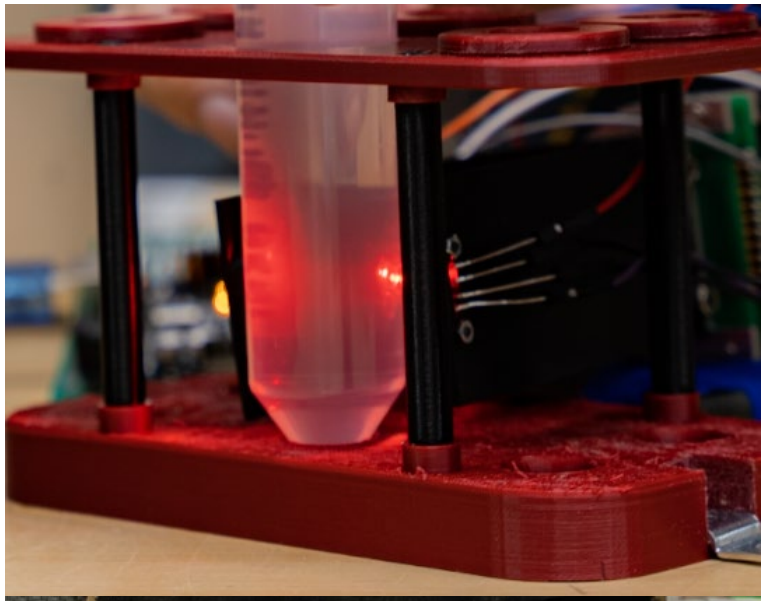


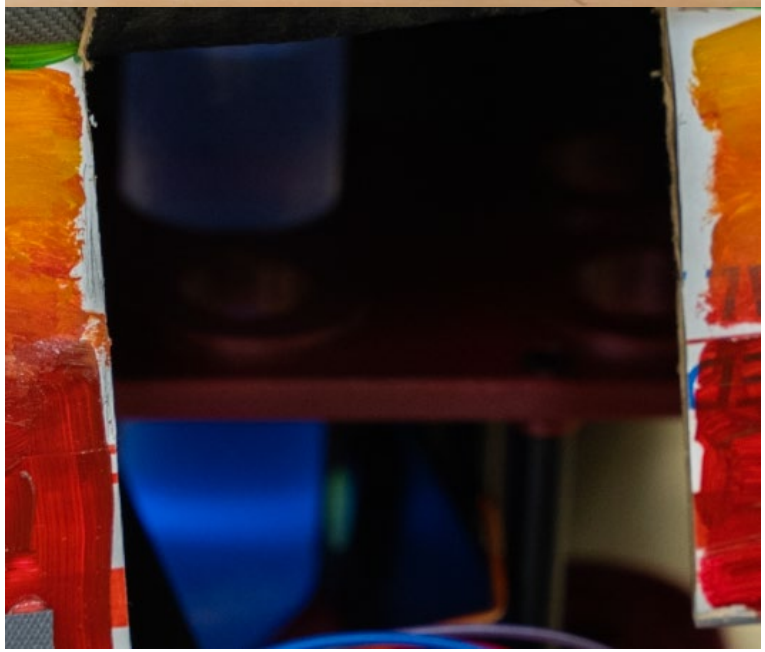
Exploded CAD View



Successful Testing

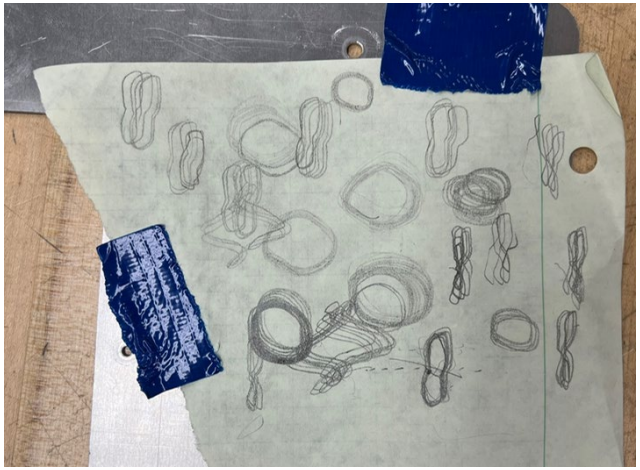
- ODFI testing
- OD: Successfully identified milk concentration in 3 test solutions
- FI: Successfully identified quinine concentration in 6 test solutions
- All samples within 15% of tested range

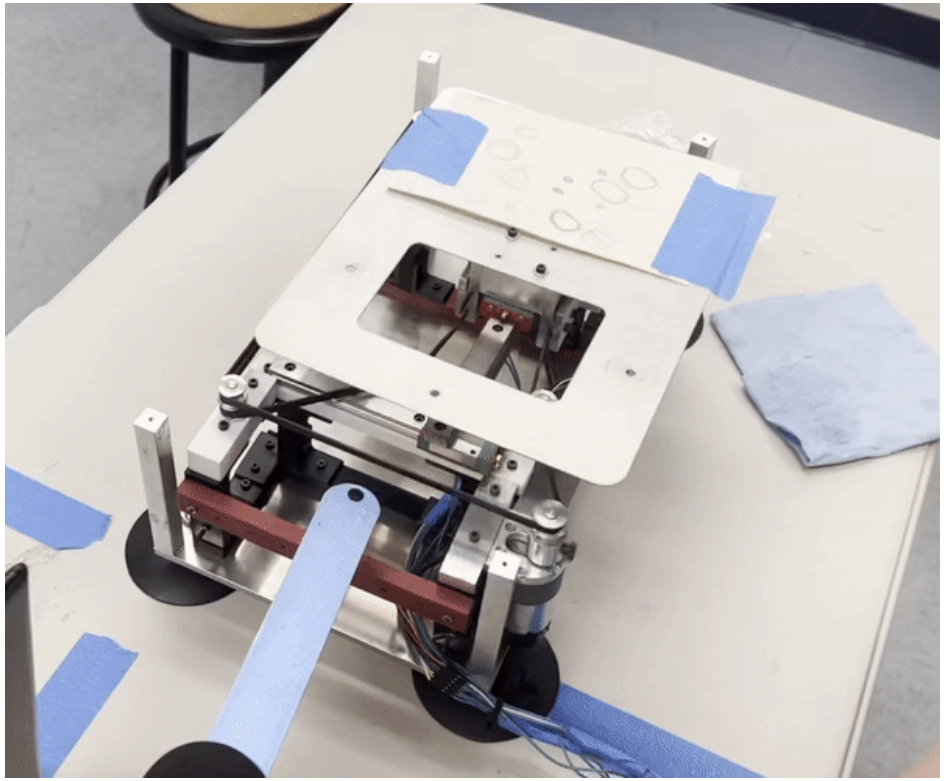




Successful Testing

- Acoustic testing
- Running the test with the enclosure, the sound level reduced to 55-56dB.

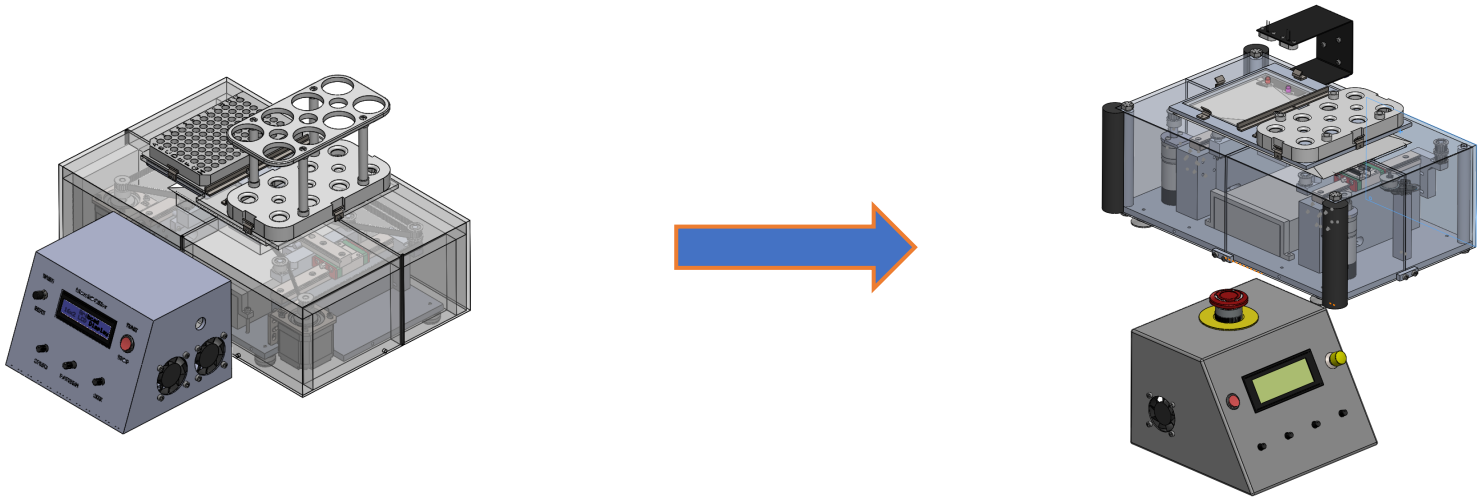




Position	Linear (dB)	Orbital (dB)	Double Orbital (dB)
1	61	63	63
2	62	62	64
3	61	62	63
4	61	62	62
5	64	65	65

Evolution of Design

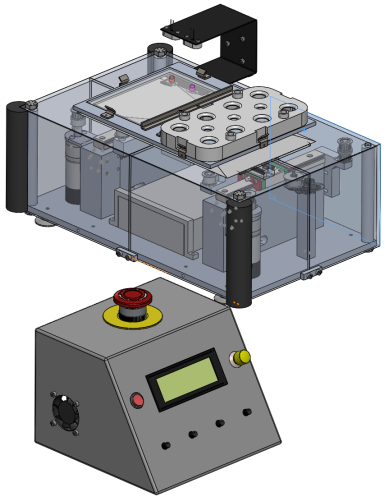
- Initial Design ⟶ Design Report 1

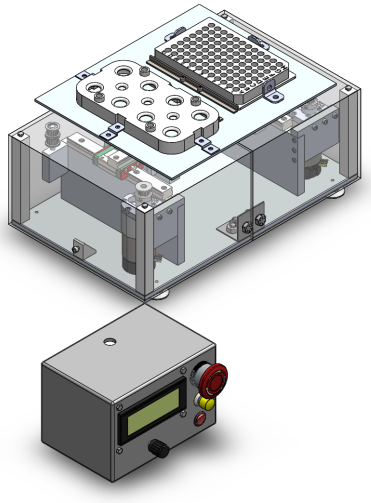


- Added ODFI Integrated functionality
- Added padding and metal pillars to corners to increase ruggedness
- Added waterproof cloth cover on top opening to waterproof device
- Replaced rubber feet with suction cup feet
- Replaced stepper motors with DC motors
- Added spring tensioner to tension belt for ease of replacement

Evolution of Design

- Design Report 1 ⟶ Design Report 2

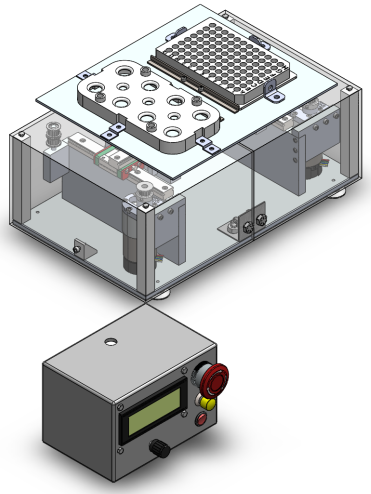


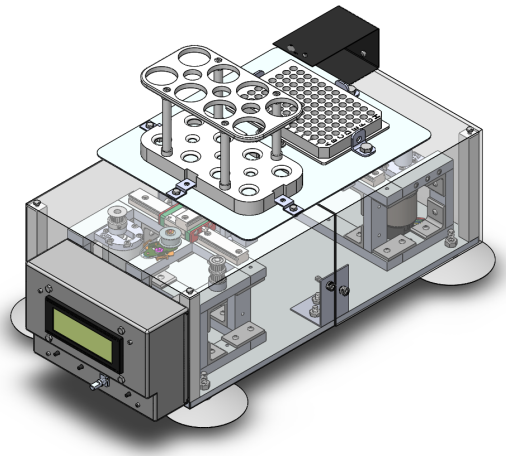


- Simplified control box and moved microcontroller to the controller box
- Re-designed enclosure with angle brackets and gussets
- Redesigned top plate with OTS clips and machinable parts
- Increased machinability of belt support structure

Evolution of Design

- Design Report 2 ⟶ Milestone 2

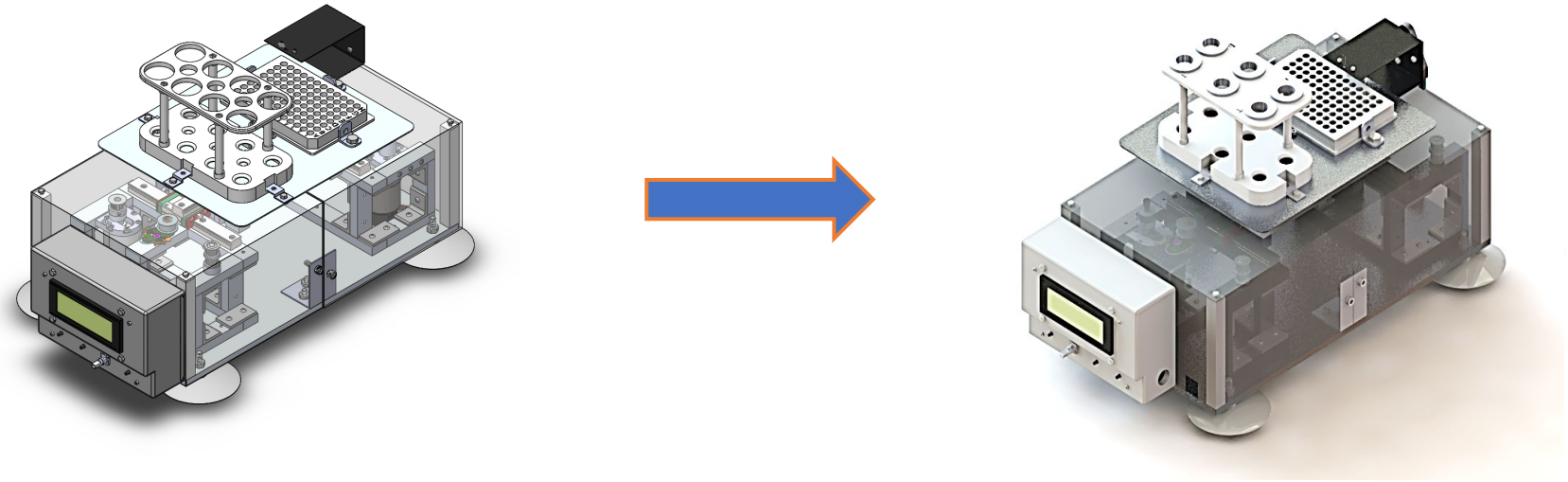




- Attachable control box feature
- Increased suction cup size and effectiveness
- Redesigned belt support system for manufacturability
- Redesigned top plate and top plate connection for manufacturability

Evolution of Design

- Milestone 2 ⟶ Final Design



- Added thru holes wherever possible for structural integrity and ease of maintenance
- Continued redesigning for manufacturability
- Flipped motors to be on the same side of the rail support system

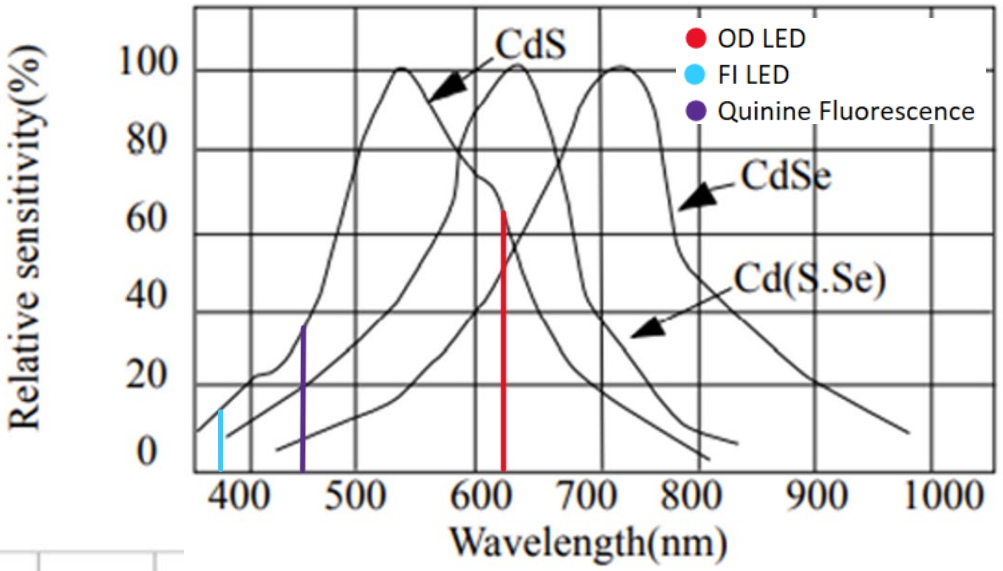
Key Features: ODFI

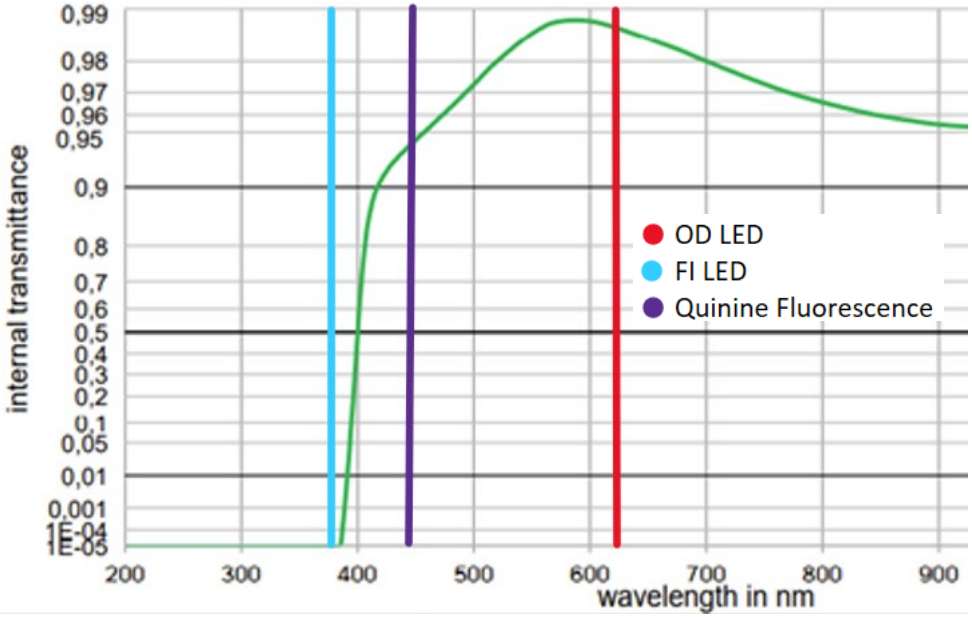
- The ODFI system consists of a single filtered LDR positioned opposite 2 LED lights
- 625 nm LED for OD
- 375 nm LED to excite fluorescence for FI measurement
- Lights and sensor are spaced to accommodate diameter of 50 mL tube
- Measuring through side of tube minimizes path length, maintaining high light intensity:

$$Luminosity \propto \frac{1}{distance^2}$$

Key Features: ODFI

Sensor Selection: Cadmium Sulfide LDR was used because of its sensitivity to low wavelength emissions

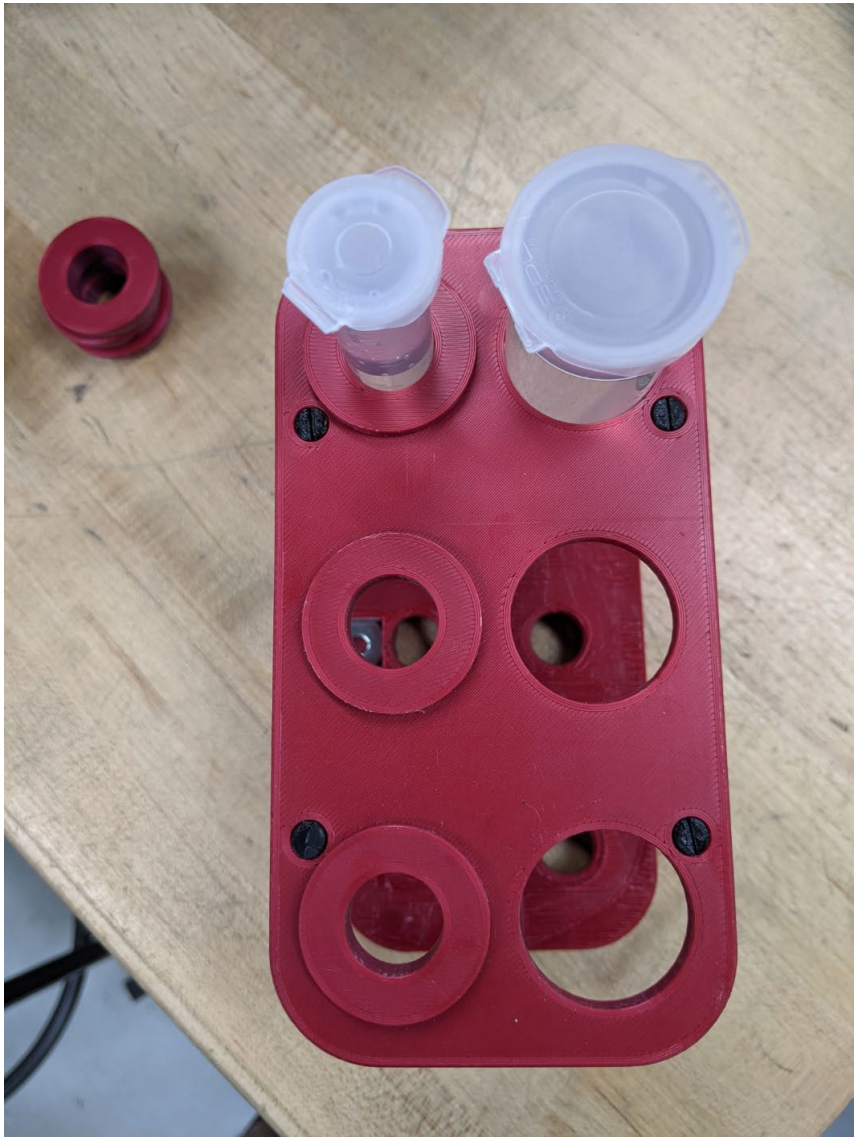




Filter Selection: 400 nm glass long-pass filter is used to block the FI excitation light source

Key Features: Tube Rack with Inserts

- Individually removable inserts allow any combination of up to six 15 mL and 50 mL test tubes to be loaded
- Tubes spaced to allow OD/FI access to all tube locations



Key Features: Suction Feet

- Previous design team reported entire table would drift at 350 RPM but no problems at 120 RPM, previous design utilized rubber feet, which rely on friction to hold table in place. Coefficient of friction between rubber and wood is 0.95, holding force per foot is found to be 8.7 N.
- At 120 RPM holding force per foot required is 4.1 N. At 350 RPM each foot has to counter-act 35 N of force while the table is shaking due to mass accelerating rapidly.

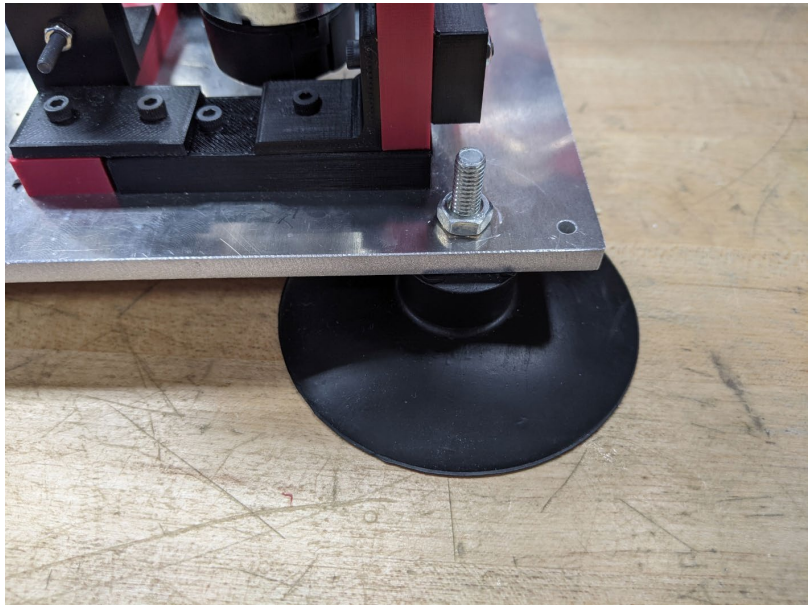
$$a_c = R\omega^2$$

$$F_c = mR\omega^2$$

- The force that each suction cup exerts is given by the equation

$$F = P_{atm}A_{cup}$$

- Where P_{atm} is the standard pressure of the atmosphere and A_{cup} is the cross-sectional area of the cup.
- Each cup can provide 51 N of support giving an F.O.S of 1.46
- Neoprene rubber suction feet were chosen to hold the table in place while shaking. Neoprene thermal expansion is low, because suction cups produce vacuum, air inside cups insignificant, therefore expansion insignificant.



Key Features: DC Motors

- 24V 3A stall current 6.3:1 Gearmotor with 64 CPR Encoder
  - System friction analysis performed, but values insignificant
  - No-load performance: 1600 RPM

  For 25mm orbitals:

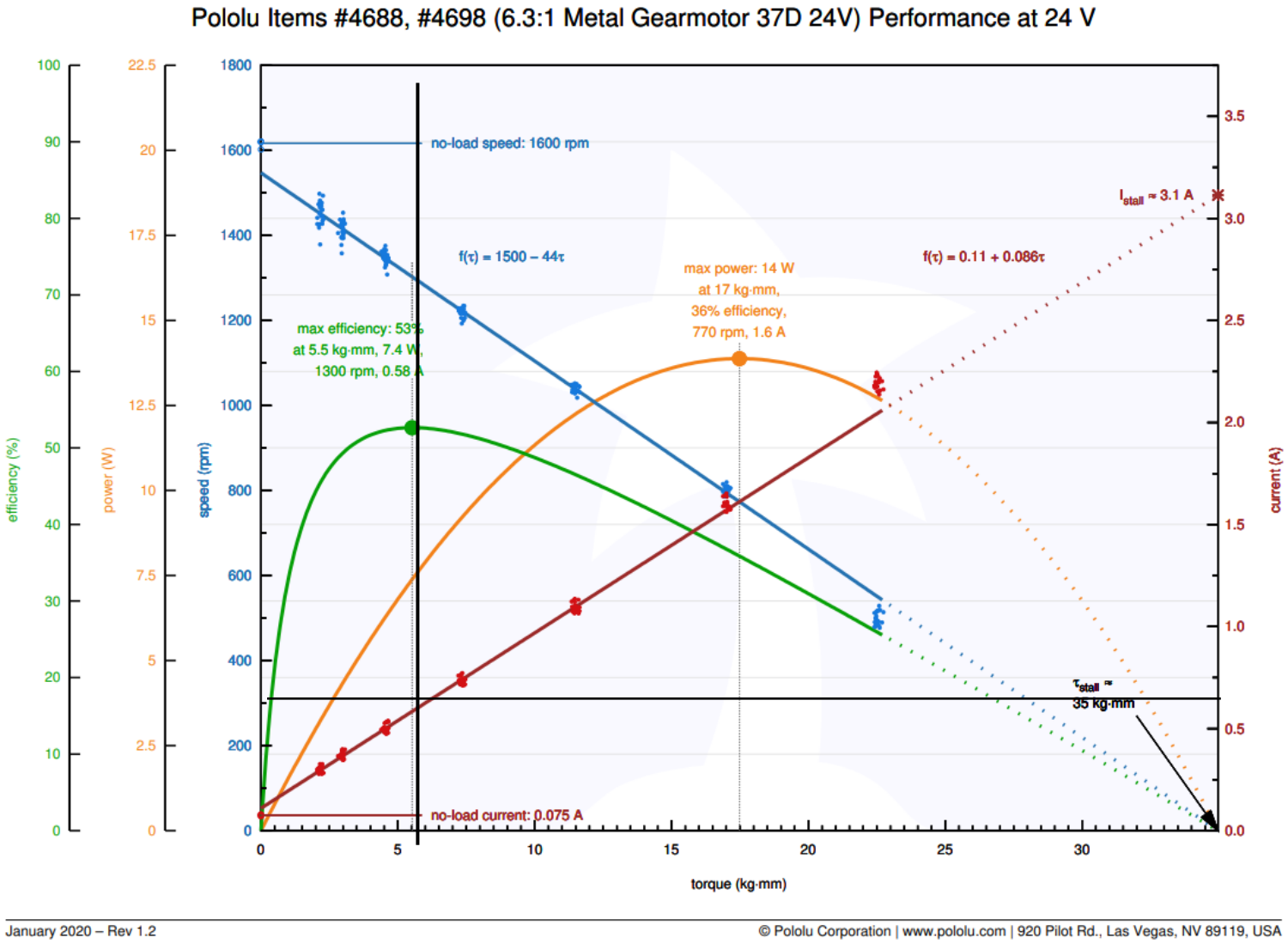
  Travel distance: $0.025\pi\ (m)$

  Pulley diameter: $0.012\ (m)$

  $$\frac{1600\ rev}{min} \times \frac{0.012\pi(m)}{rev} \times \frac{1\ orbital}{0.025\pi\ (m)} = 768\frac{orbitals}{m}$$

  - Built in dual encoders measure 64 counts per revolution of the input shaft and 403.41 counts per revolution of the output shaft. Resolution of over 1 count per degree.
  - PID controller per motor controlling motor position

Motor Performance sheet



Heat Transfer To belts

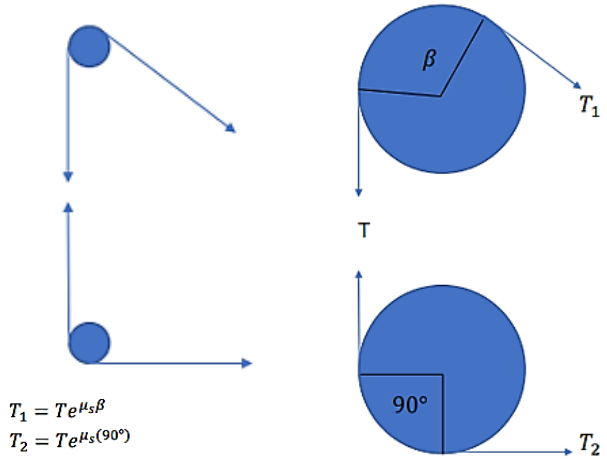
- Given enough time belts will reach the temperature of the air in the oven 70 ℃, then friction from the motors will heat one side of the belt higher than the ambient temperature, the lost power due to inefficiency of the motor is assumed to all be converted to heat and conducted to the belts from the motor. Motor parameters: efficiency 53%, 0.75 A, and 24V.
- $Q = P_{motor}\eta = \Delta ThA = \frac{(T_{belt} - T_\infty)kA}{\Delta x}$
- $T_{belt} = \frac{\Delta x}{kA} P_m(1-\eta) + T_\infty = 343.15\ K + \frac{8.46\ W\left(1.39\times10^{-3}\ m\right)}{\left(0.2\frac{W}{m-K}\right)(0.012\ m^2)} =$

$348K = 74.85℃$

- Neoprene timing belts max operating temperature 79.44℃

Key Features: Belt Tensioners

Pulley system without tensioner

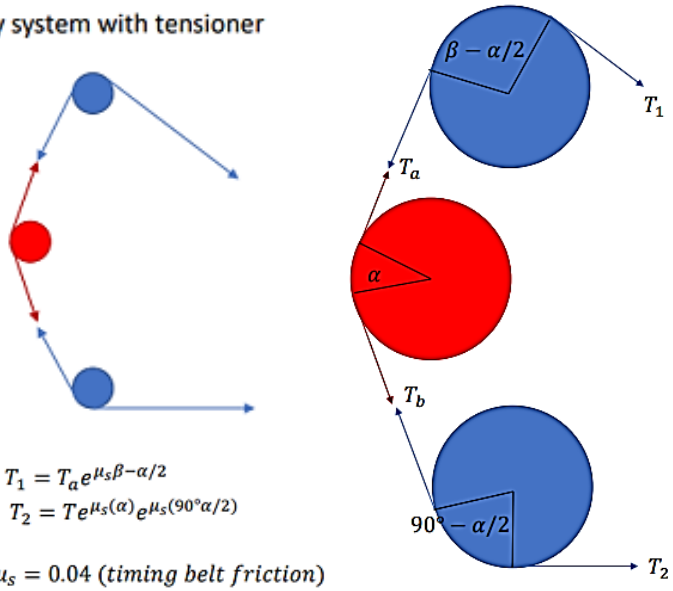


$T_1 = Te^{\mu_s \beta}$

$T_2 = Te^{\mu_s (90°)}$

$\mu_s = 0.04$ (*timing belt friction*)

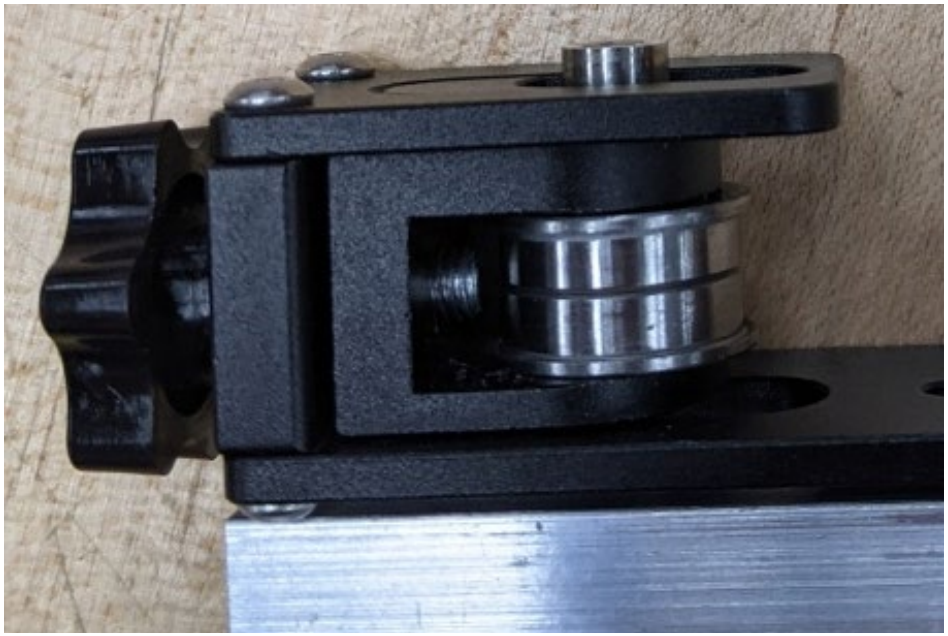
Pulley system with tensioner



$T_1 = T_a e^{\mu_s \beta - \alpha/2}$

$T_2 = Te^{\mu_s (\alpha)} e^{\mu_s (90° \alpha/2)}$

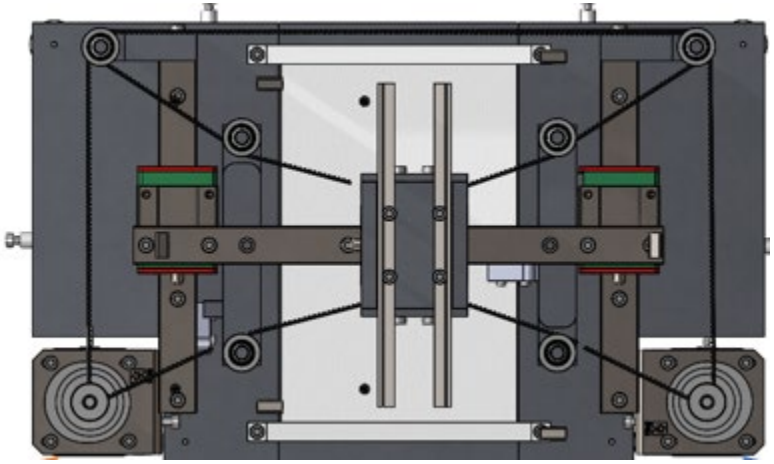
$\mu_s = 0.04$ (*timing belt friction*)

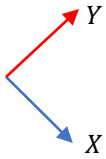


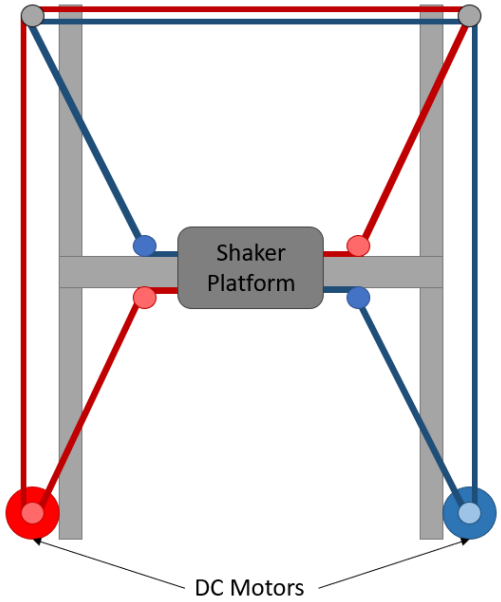
- Ensures a synchronous drive, by allowing the belts to move smoothly.
- Allows easy removal of belts for maintenance, thus extending product life.
- Reduces risks of inadvertent over tensioning.

Core X-Y belt pattern

- High accuracy and high speeds
- Compact design
- Offset Coordinate system where one motor rotation moves the platform at 45 degrees in relation to the edge of the table
- One motor dedicated to x-direction motion, one dedicated to y-direction motion







Patterns

- Linear, circular, and double orbital patterns achieved by feeding PID controllers sine and cosine functions. Speed of pattern is controlled by changing the frequency. Motor 1 is considered purely in y-direction, motor 2 considered x-direction.
- Linear:

$$x = r\sin(f\theta)$$

$$y = r\sin(f\theta)$$

- Orbital:

$$x = r\cos(f\theta)$$

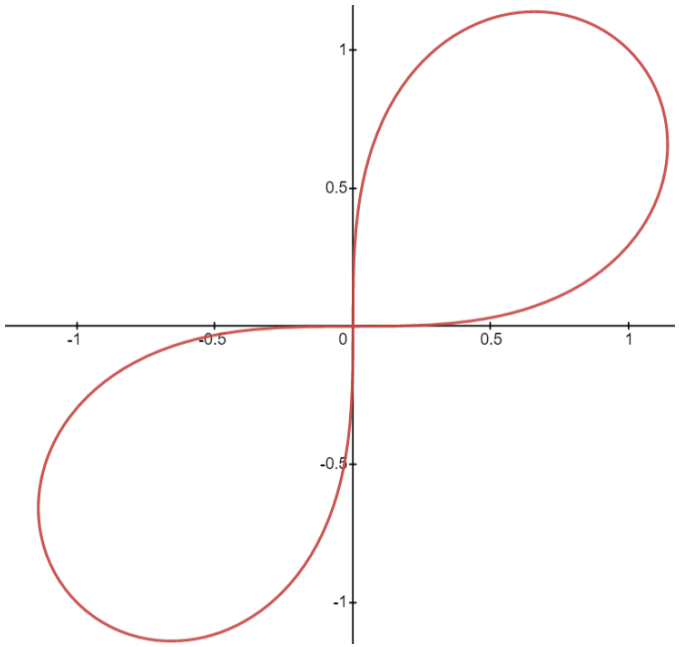
$$y = r\sin(f\theta)$$

- Double Orbital:

Polar function: $r = 2\sqrt{\sin(\theta)\cos(\theta)}$ used in cartesian coordinate

$$x = 2r\sqrt{\sin(f\theta)\cos(f\theta)}\cos(f\theta)$$

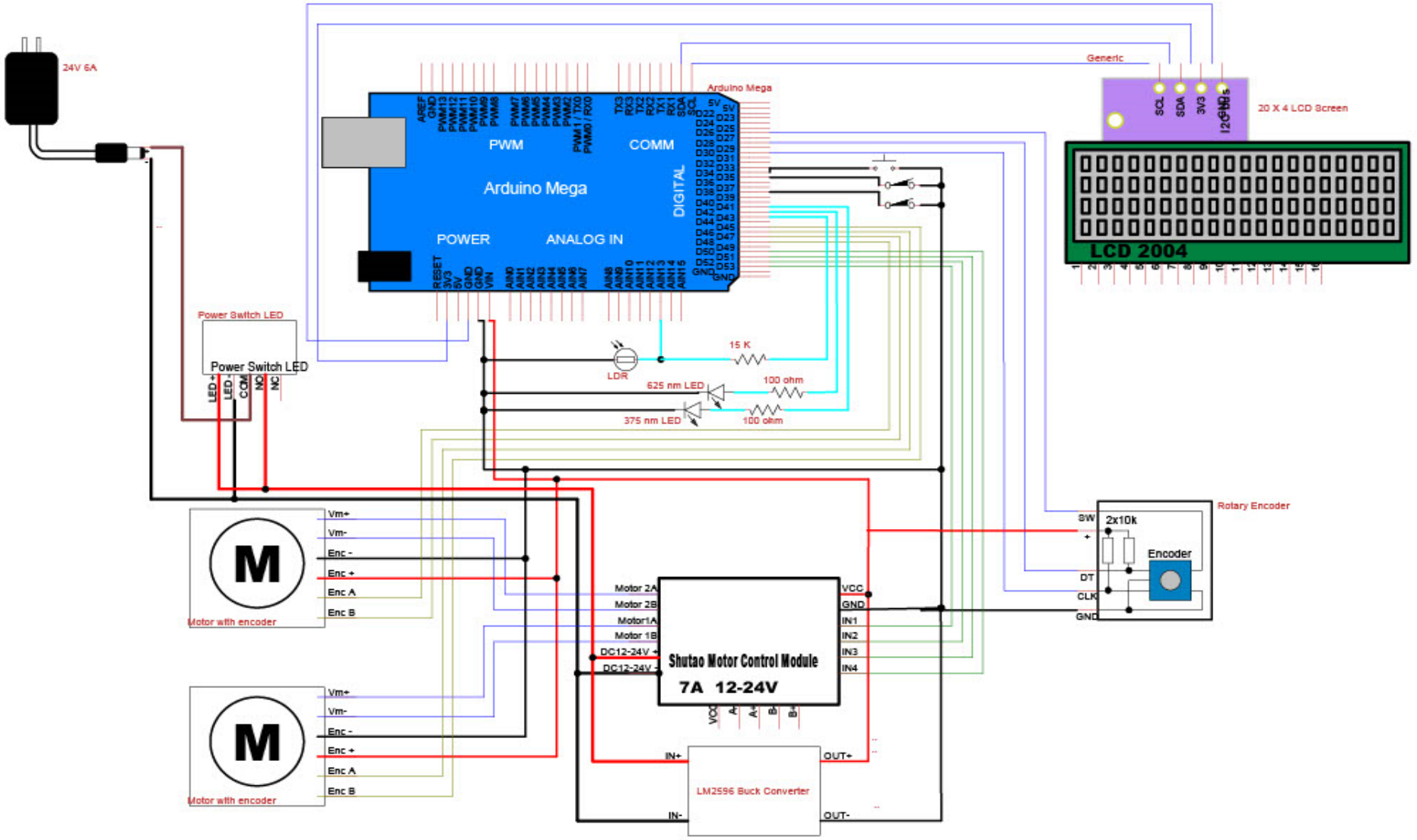
$$y = 2r\sqrt{\sin(f\theta)\cos(f\theta)}\sin(f\theta)$$



Key Features: Control Box and Interface

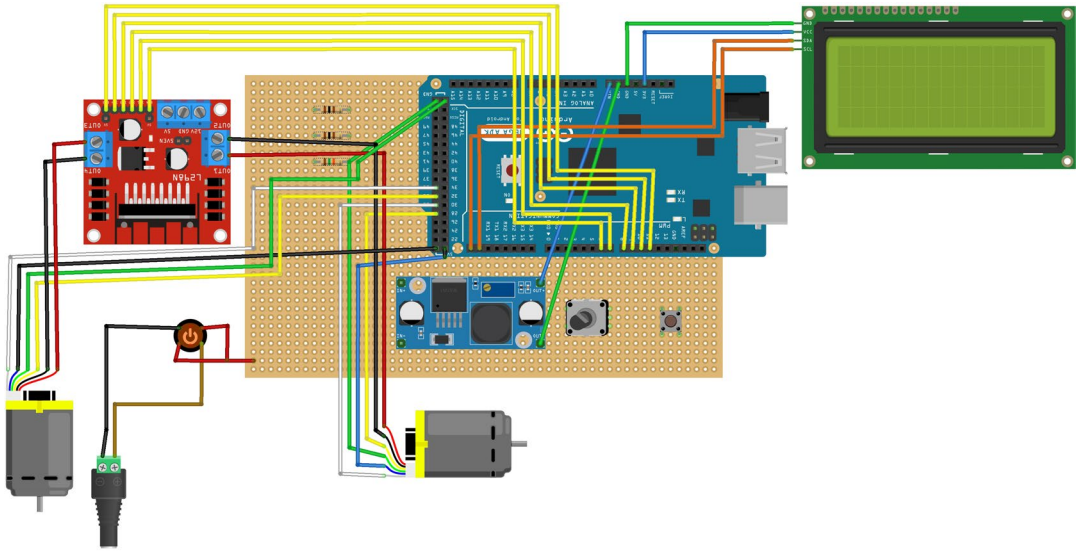
- PLA printed control box to house electronic components
- User interface with a 20x4 LCD Display
  - On/Off Indicator
  - Mode of Function (shake pattern, shake speed, elapsed shake duration, shake time remaining)
- Clickable Rotary Encoder
- Pause/Resume Button
- Power Switch (Emergency Shut-Off)
- Mountable and Detachable Back Panel
- Outputs ODFI readings

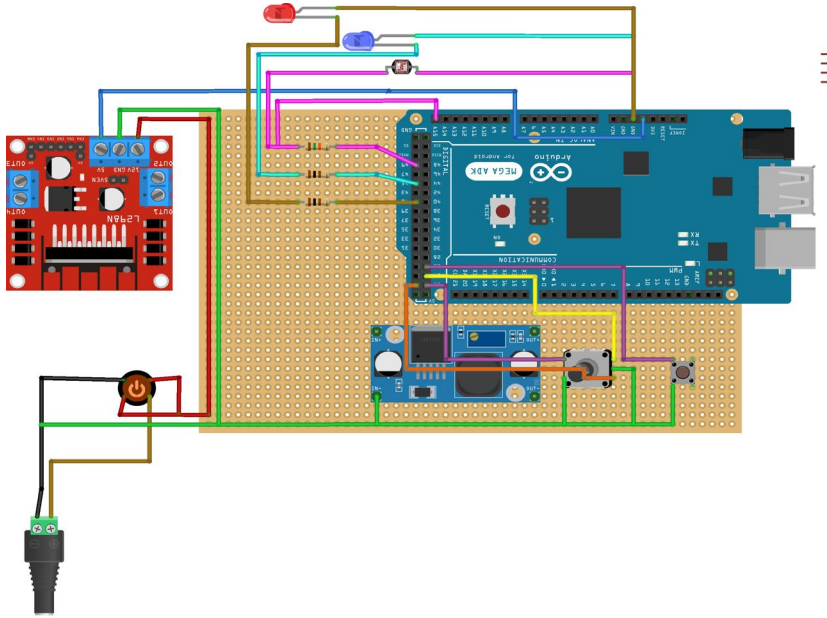
Key Features: Control Box and Interface



Key Features: Electronics

Jumped Connections

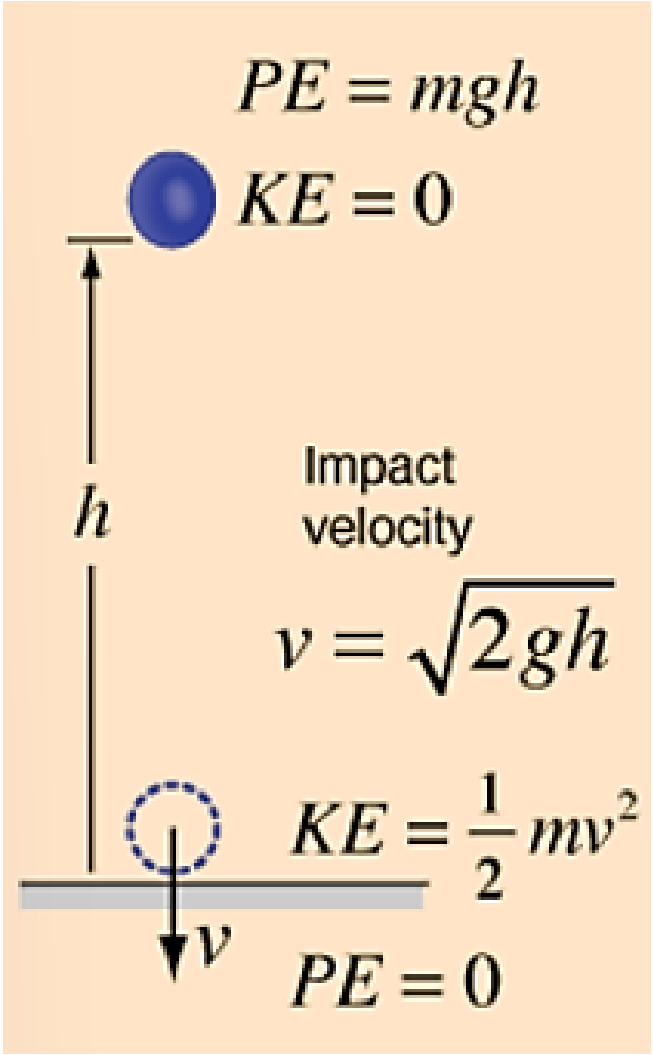




Soldered Connections

Key Features: Enclosure and Corner Posts

- Our shaker table is built to be rugged and survive a fall
- A blunt external force from a fall based on drop height, energy conservation and work-energy principle was determined.
- v_f is the final velocity of the shaker table before impact, h is the height of the table that the shaker table falls from, g is gravity, δ is the elastic deformation in the table, and m is the mass of the table
- $v_f = \sqrt{2gh}; K.E = \frac{1}{2}mv_f^2; F_{avg} = \frac{\delta}{\Delta K.E.}$



Key Features: Enclosure and Corner Posts

- The enclosure undergoes a bending stress ($\sigma_{bending}$) assuming blunt force occurs at the top of the enclosure in the worst-case scenario
- M_{avg} is the average moment exerted on the enclosure, where h is the height of the enclosure and F_{avg} is the average blunt force
- $M_{avg} = h \times F_{avg}$
- Where y is the distance from the center axis of the enclosure wall to the outside of the wall, and I is the second moment of area of the enclosure wall.
- $\sigma_{bending} = \frac{M_{avg} y}{I}$
- This calculated bending stress was divided from yield stress of aluminum 6061 to get factor of safety
- From these calculations, our shaker table can theoretically withstand a drop from 10 meters with as F.O.S of 2.184

Key Features: Waterproof Fabric Sleeve

- To waterproof the enclosure to prevent water damage to internal parts, a polyester fabric with PVC backing is over the top of the enclosure.
- The fabric is held in place by a square bracket and the plate tie down bracket translated by the belts.
- The fabric is left enough slack to allow full range of motion, much like a stick shift.

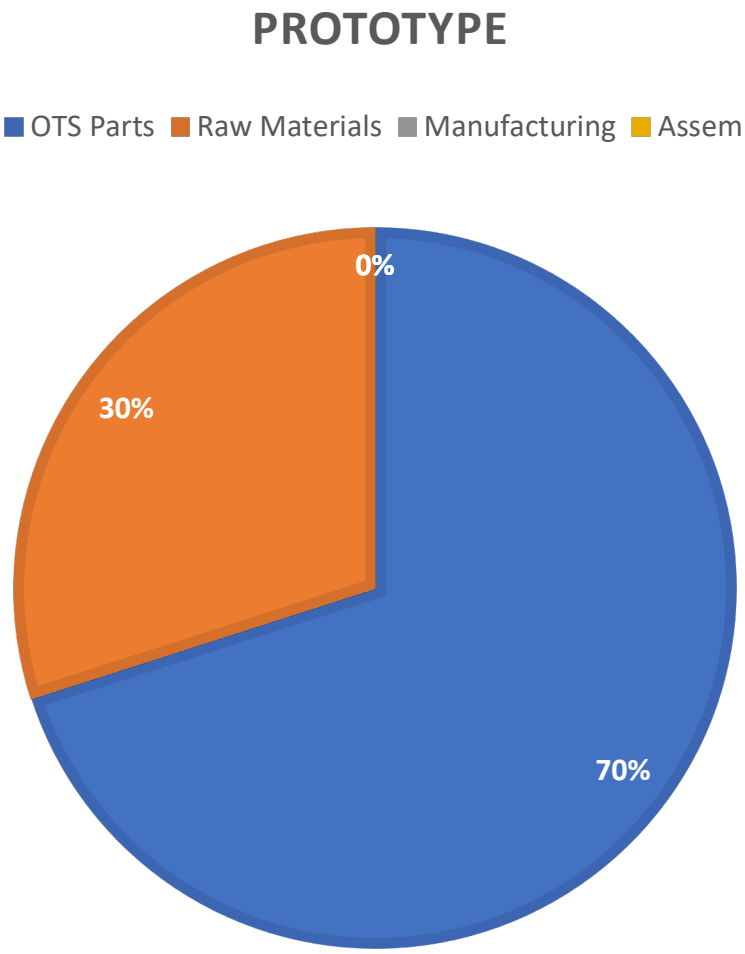
Cost Table Summary (Prototype)

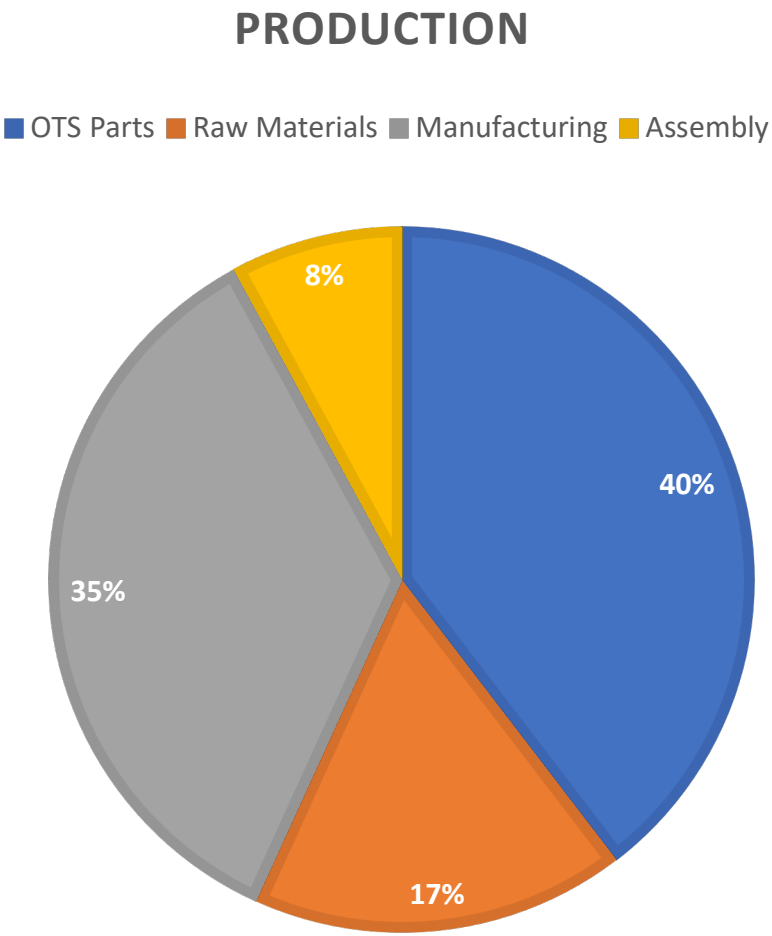
Action	Cost	Justification
OTS Parts	$484	Vendor Pricing
Raw Materials	$207	Vendor Pricing
Manufacturing	$0	In House
Assembly	$0	In House
Total	$691	

Cost Table Summary (Production)

Action	Cost	Justification
OTS Parts	$327	Vendor Pricing
Raw Materials	$142	Vendor Pricing
Manufacturing	$291.60	Bureau of Labor Statistics
Assembly	$65.24	Bureau of Labor Statistics
Total	$825.84	

Cost Percentage Comparison





Conclusion

- Proven ODFI effectiveness
- Use of DC motors means more precise movement at faster speeds
- Robust design to survive a fall off a table
  - Support pillars on corners
- Suction cups to adhere table in place semi-permanently
- Waterproof sleeve to ensure that no water seeps into the electronics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