Printing Under Pressure (P.U.P.)

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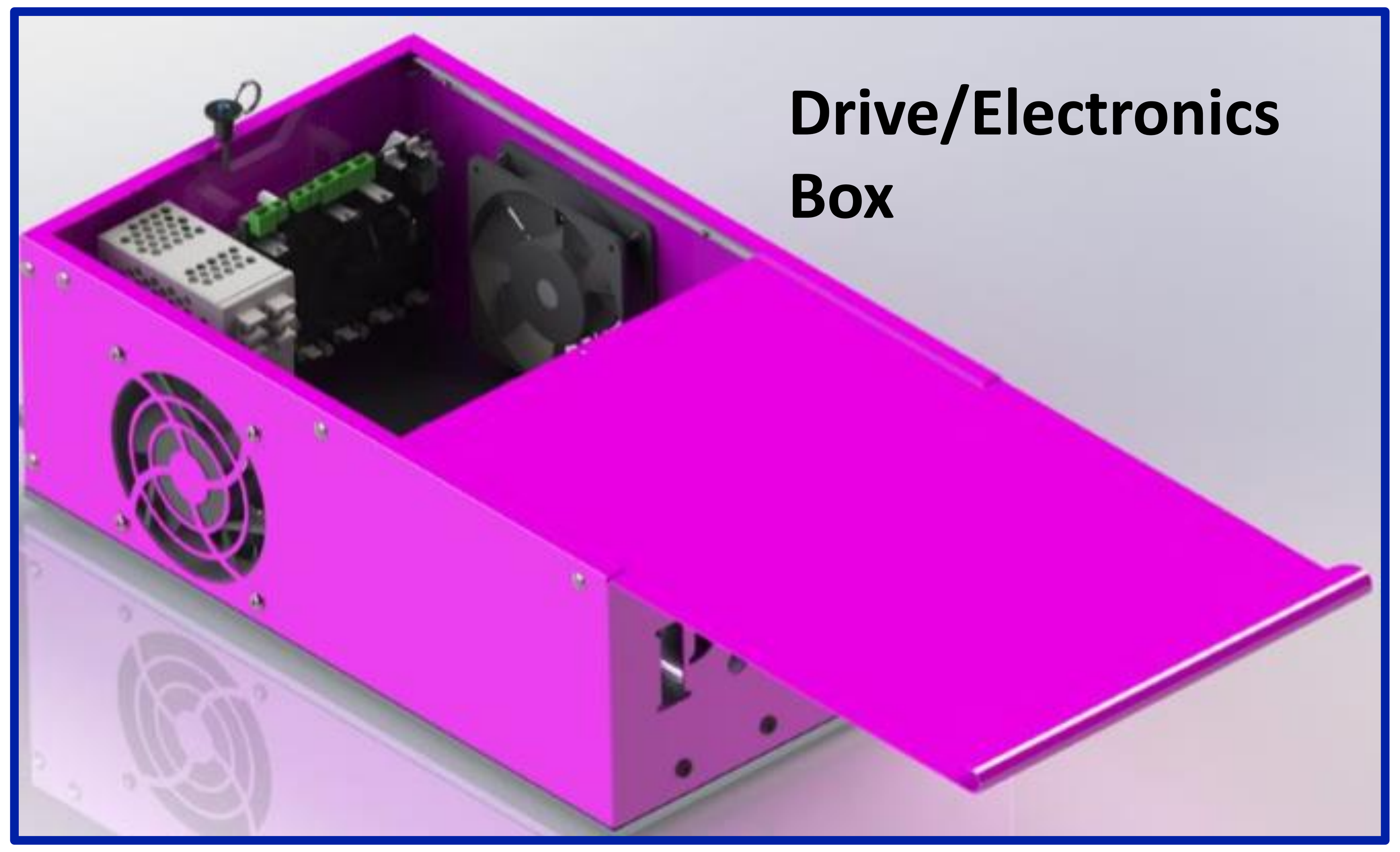
Group 7: *Ryan Garcia, Chris Magnus, William Meldrum-Thush, Amir Mettawa, Duc Nguyen, Jack Ruskell*

Abstract

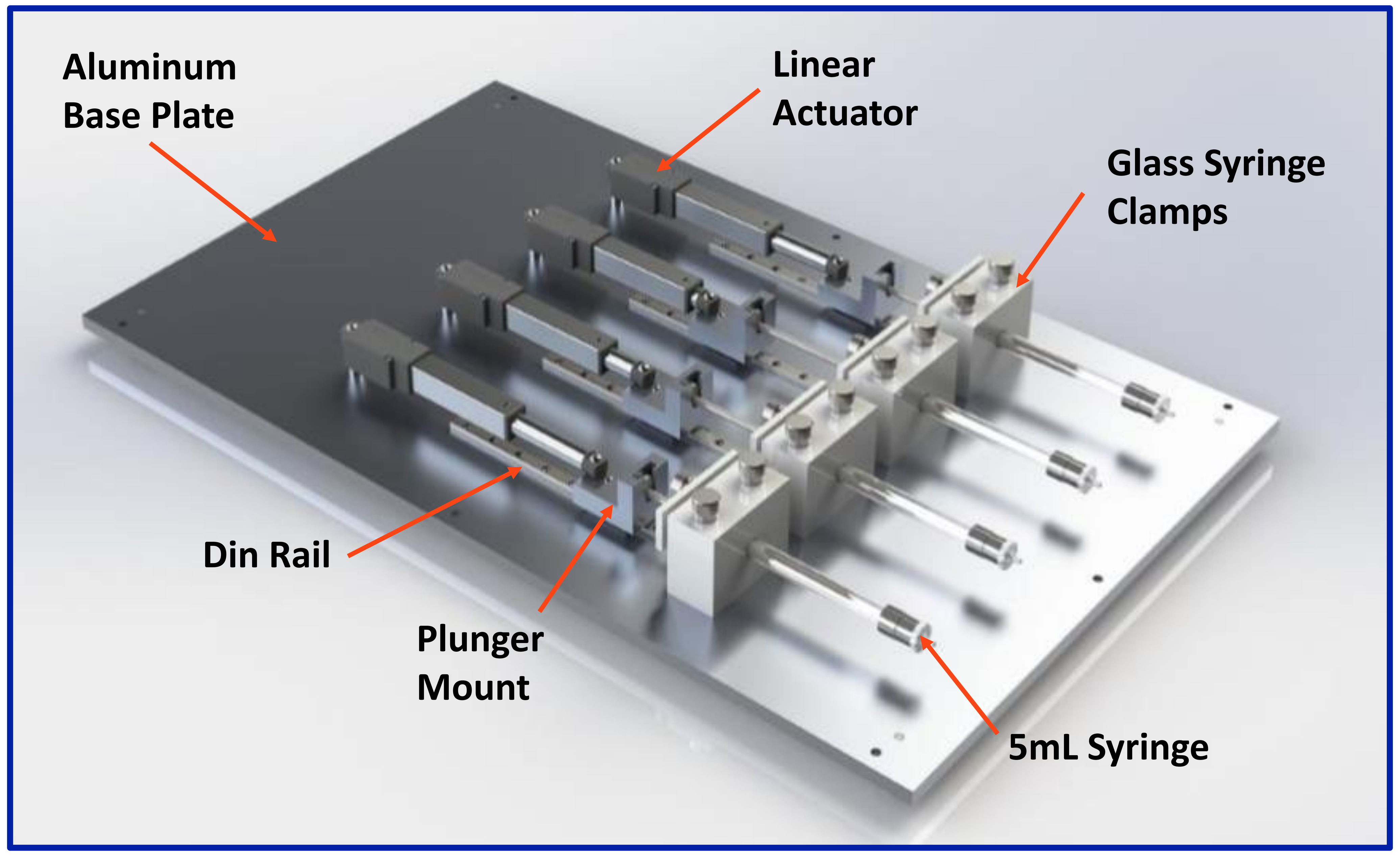
3D bioprinters are becoming common in many research and development laboratories around the world. Unfortunately, many of the existing bio-printers on the market are expensive and cannot be mounted to existing microscopes found in many labs. Our PUP is a cost effective and simple and has the capability to be mounted to a microscope.

- It uses many commercial off-the-shelf components which simplifies part replacement.
- Motion is obtained with a hydraulic linear actuation system which precisely positions the dispensing tip in the required location with precision of as little as one cell diameter.
- Our printer's design allows for simple and rapid changes between cell types for experiments.
- The actuators are all located off-site in a control box to avoid vibrational effects.

As such, our PUP printer allows for an affordable, reliable, innovative, and simplistic solution to this otherwise complex challenge.



Case and electronics removed



Expense Type	Cost (USD)
OTS parts	$1909.33
Customized parts	$579.56
Raw Material	$284.44
Manufacturing Labor	$426.67
Energy Consumption	$0.1309/kW-hr
Assembly Labor	$160/hr
Total	$3360.13

Summary of Product Functionality

The dispensing tip utilizes a similar hydraulic system to dispense and retrieve small amounts of bio-oil substance. The printing head has three columns instead of four for translation along the z-axis. The arrangement allows for the printer to be precisely aligned with the piston and condenser adapter. The drive system is held off-site in an aluminum sheet metal box with internal fans for cooling for the Smoothie board and power box. The heat transfer calculated for the system in the box does not exceed 95 degrees Fahrenheit. The drive system is composed of four 5 mL glass syringes acting as the fluid storage of the hydraulic system. The initial motion of the hydraulics is started by the linear actuators attached to the syringes which is transferred to the three piston bodies on the printer head. The XYZ motion system is controlled by the three piston which drive the translation of the carriages in each axis along guide rails. The rails have bushings to allow for smooth translation. C-clamps were added at the end of the rails to hold the rails in place and act as stops. One syringe contains the bio-oil to directly feed the cells to the needle tip for printing; this is the dispensing system. The needle tip is held in by a barb mount to allow for the connection of the hose to the printer head. The printer head is connected to the microscope via a customized condenser adapter. The adapter was heavily customized with fillets and extruded cuts to meet the weight limit of 200g.

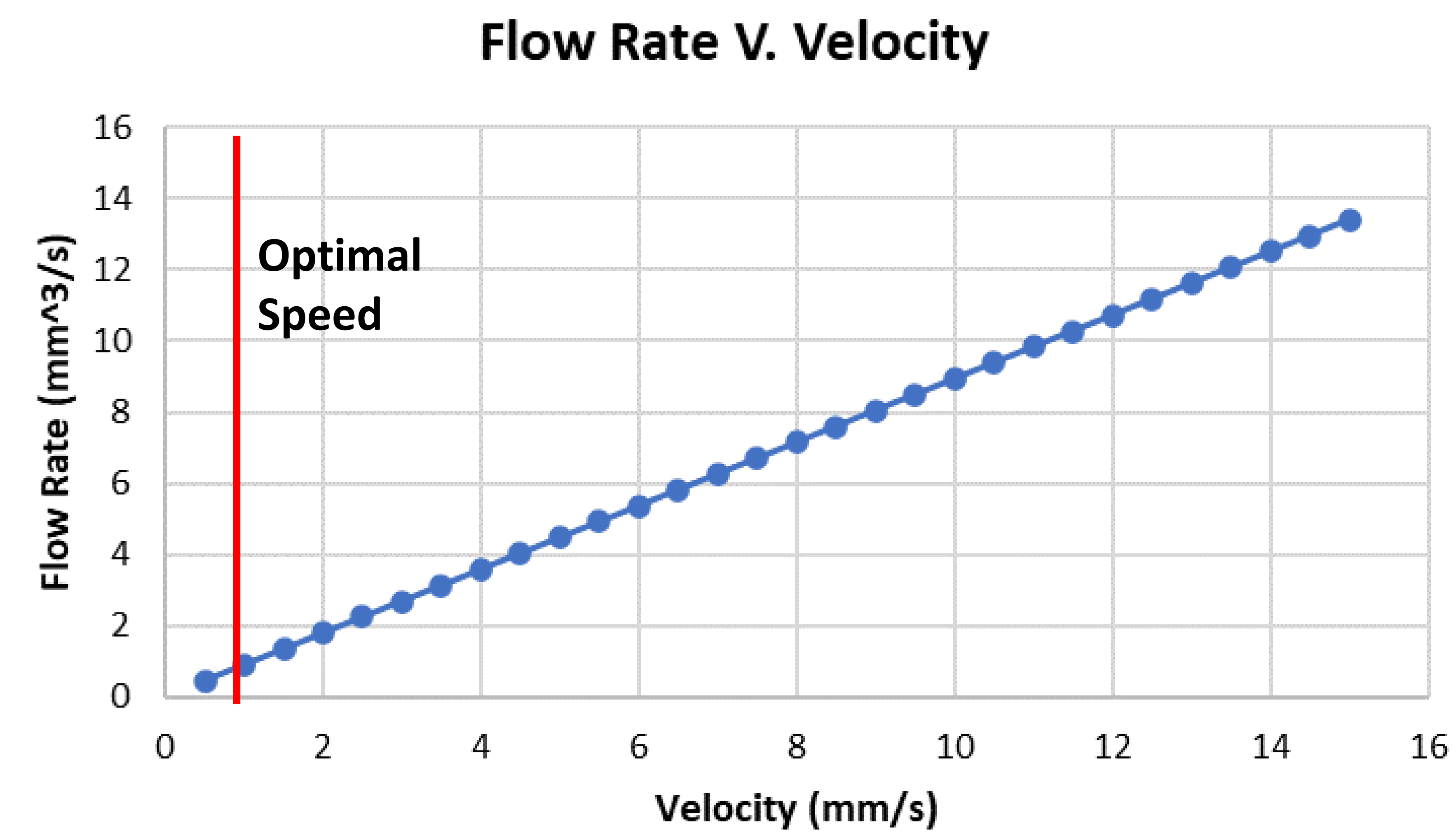


Fig 1. Flow Rate V. Velocity. This is a graph to reference when printing to avoid an excessive flow rate. This will keep the biostructure from being destroyed. The linear actuator can go up to 25mm/s


Subsystems
Dispensing Mechanism
Motor/Driving System
Turret Mount
XY Motion
Z Motion
Mounts to Nikon Eclipse Ti microscope turret
Number of methods to mount concept must be >=1
Only one method of mounting print head to turret mount.
Primary structure must fit within 100 mm cube
Size of print structure must be less than 100 mm on each side
Print structure is 84x79x92 mm.
200 g maximum weight
Device weight must be less than 200 g
Device weight must be less than 200 g, lighter is better
Linear accuracy <= 1 cell diameter
Positional accuracy must be less than 15 μm
Positional accuracy must be less than 15 μm, smaller is better
Speed of ~1 μm/s, slower is better
Print speed must be ~1 μm/s
Print head travel speed is between 1.544 mm/sec.
Print extents of single well on 96 well plate
XY motion must have a 100 mm² travel area
XY motion travel area is 306 mm².
Motion transmitted to printer from remote source
Young's modulus of component connected to the motor must be ~1.8 Gpa
Motors are located far away from print head and microscope turret mount.
Capable of printing experimentally relevant feature sizes
Inner diameter of printing tip >=2.693 mm (10 gauge needle)
Inner diameter of printing tip is 1.067 mm (17-gauge needle).
Maximum sale price of $4,000
Keep BOM total cost under $4000
Total cost of bio-printer is $3200.
5-year life with 8 hours of usage per workday
Life cycle of at least 10,400 hours for all printer components
Life cycle of all components allows for at least five years of operation.
Minimum flowrate capable of printing experimentally relevant features
Device must print 160 μL/sec at 400 μm feature diameter
Device prints 1 μL/sec at a feature diameter of 332 μm.
In center of travel, X and Y travel directions must be aligned with optical axis and constrain needle within 1° of horizontal
Mounting to microscope must be perpendicular to vertical within ±1° and mounting to microscope must be within ±0.5° of XY motion
Because of simplicity of print head and relatively small tolerances on components, these angular tolerances were achieved.
Printer must deposit and extract material
Time to switch from extracting to depositing fluid should be >1 min
Switch from deposition to extraction only requires a different voltage to be supplied to the linear actuators.
Must print fluid with viscosity of water and shear stress of 10 Pa
Yield stress of fluid extraction tip must be >40 Pa
304 stainless steel has a yield stress of 215 Mpa.
Tip must be disposable or reliably sterilized
Steps to replace or clean fluid extraction tip should be <=4
Fluid extraction tip can be pulled out of holder and replaced.
Can't generate bio-reactive or metallic debris
Motors rated ISO 85731 class 1/3 oil free/dry, filtered at 1 μm
Motors are dry, oil free, and enclosed to prevent debris.
Sterilization with common laboratory methods
Components must withstand at least 3 lab cleaning chemicals
All bio-printer components can be cleaned with propylene, ethanol, and autoclave devices
System assembly/disassembly by lab technician
Percent complex parts in device must be less than 50%
Less than 8% of components are complex.
Operation in BSL-1 clean-room environment
Printer should meet all 8 BSL-1 requirements
Printer will not generate large debris particles as linear actuator motors are enclosed, and material selection prevents significant wear of materials.
Holding/dispensing fluid will not kill cells
Dispensing mechanism can not change fluid temperature >1°C
Bio-fluid is contained only in end of dispensing mechanism line far away from components which generate heat.
Device to be controlled via Smoothieboard 5x
Bio-printer must have 5 or less motors to be controlled
Bio-printer has four linear actuators to control all functions.