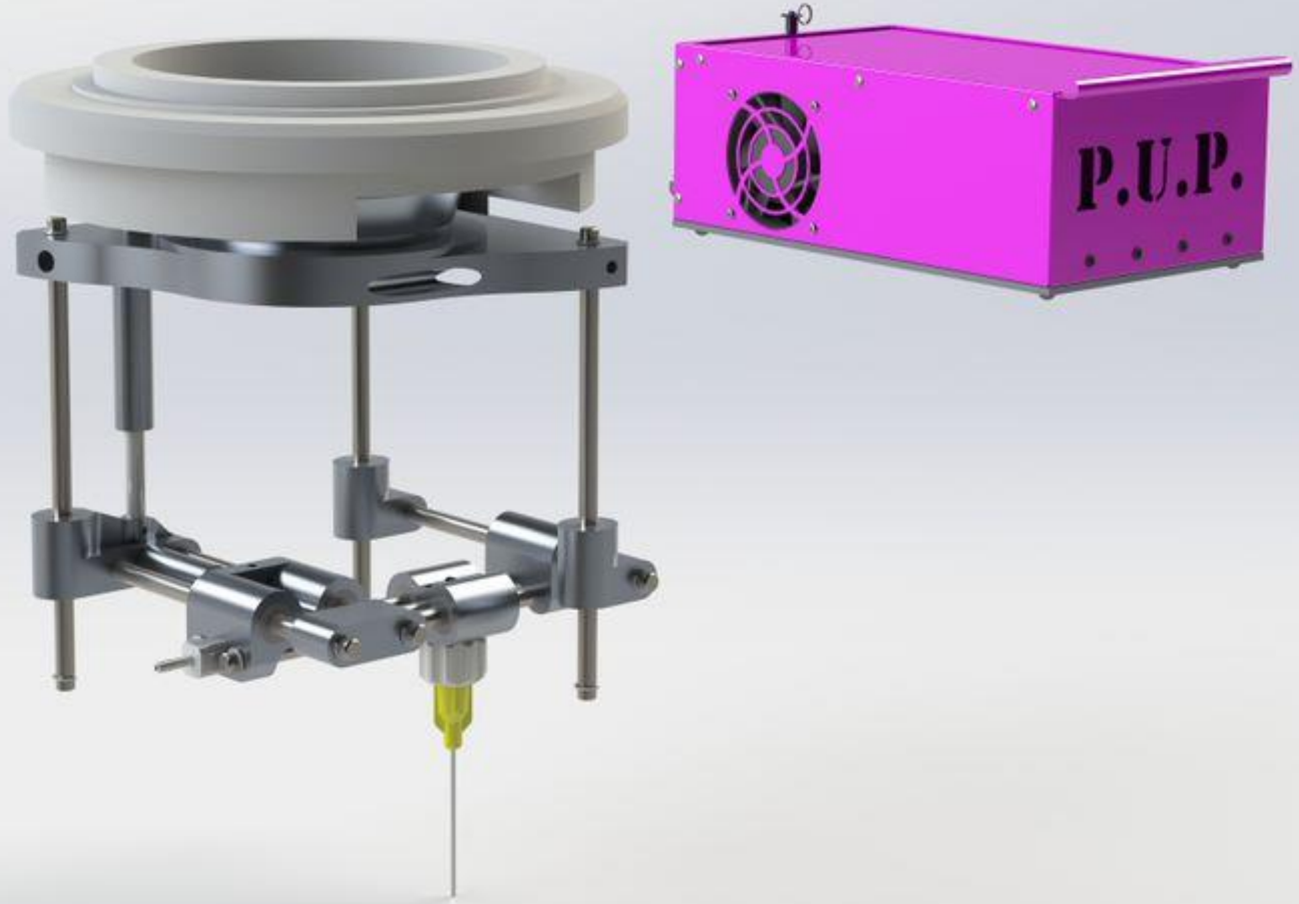
PUP Printer



GROUP 7

The Team

William Meldrum-Thush

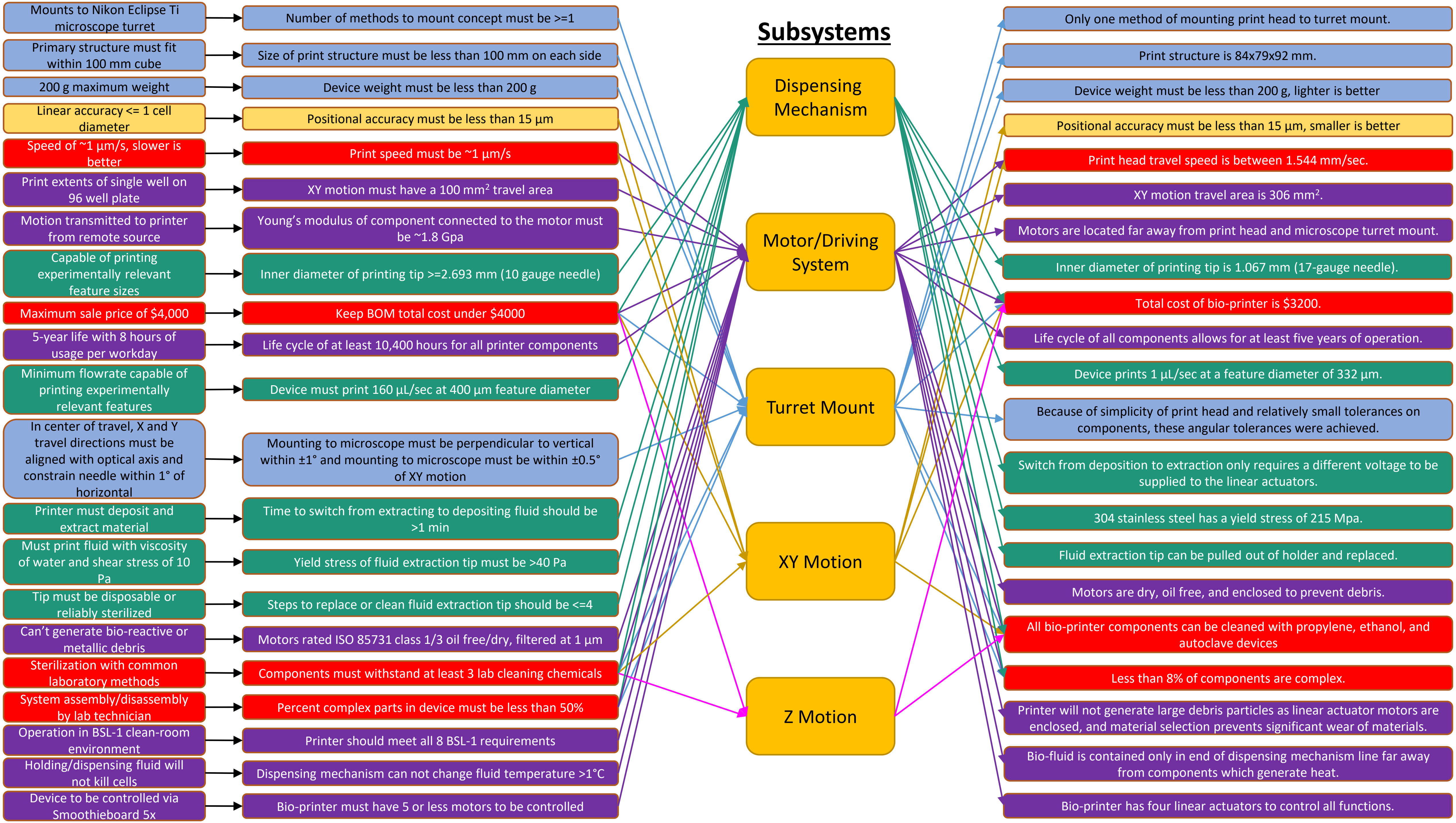
Chris Magnus

Jack Ruskell

Amir Mettawa

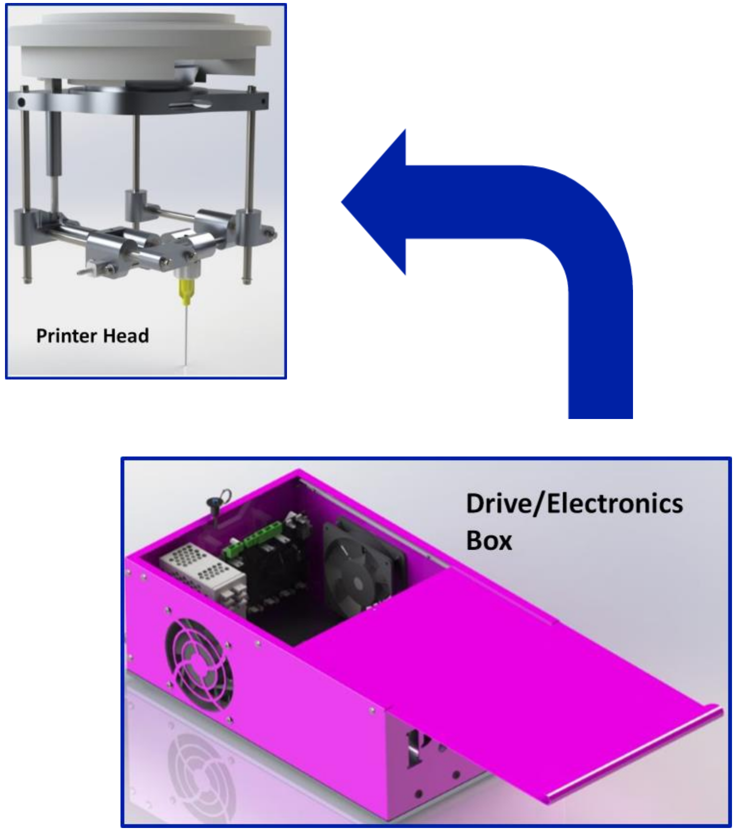
Duc Nguyen

Ryan Garcia


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

Product overview/design philosophy

- 3D bioprinters are becoming commonplace around the world.
  - Many research and development laboratories have them
- Unfortunately, 3D bioprinters mounted to microscopes are little and expensive!
- The team’s hedgehog concept:
  - cost effective and simple!



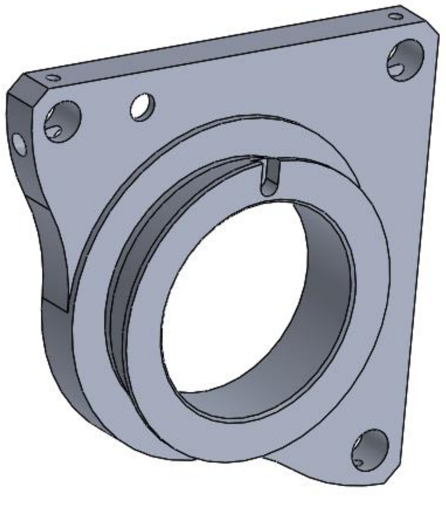
Design Overview: Print head

Highlights

- Modified OTS mounting solution
- Simple linear guide rails with polymer bushings
- Center Driving Pistons

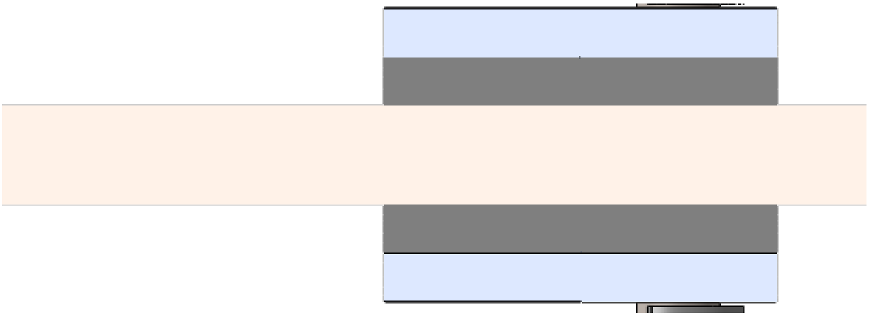
Modified OTS Mounting

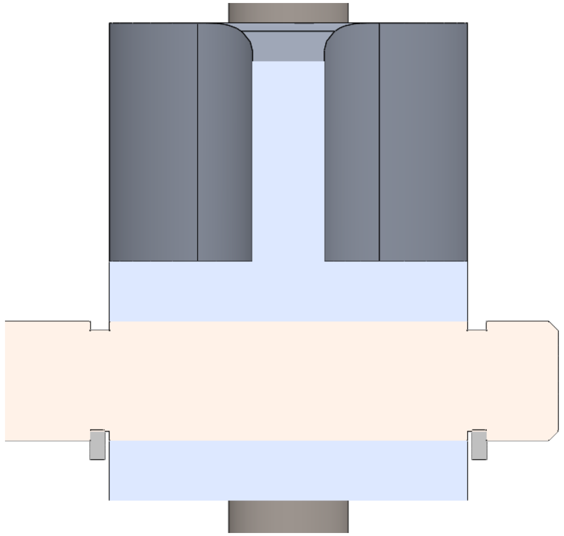
- To simplify manufacturing, an OTS condenser port adapter is modified to hold the dispencing structure
    - Weight reduced from 181.6g to 37.6g
- Features for functional surfaces will be controlled, reducing risk from supplier



Guide rails

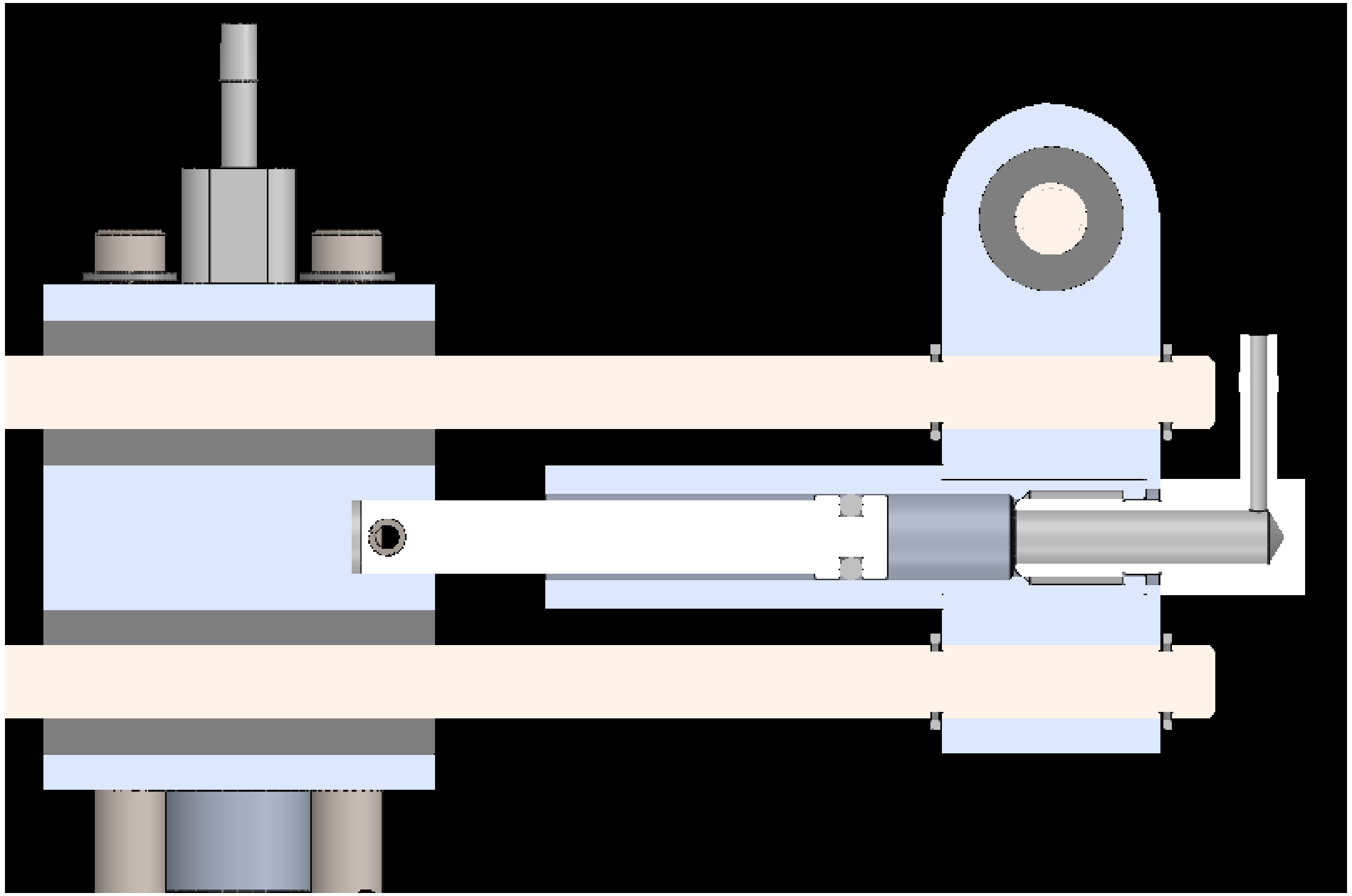
- Acetal co-polymer bushing
  - Low coeficent of friction
  - Low wear
  - Good machinability
  - Initally considered PTFE
- 1/8 " Stainless Supprt rails
  - Line fit to light press
  - C-Clips to constrain axial movement



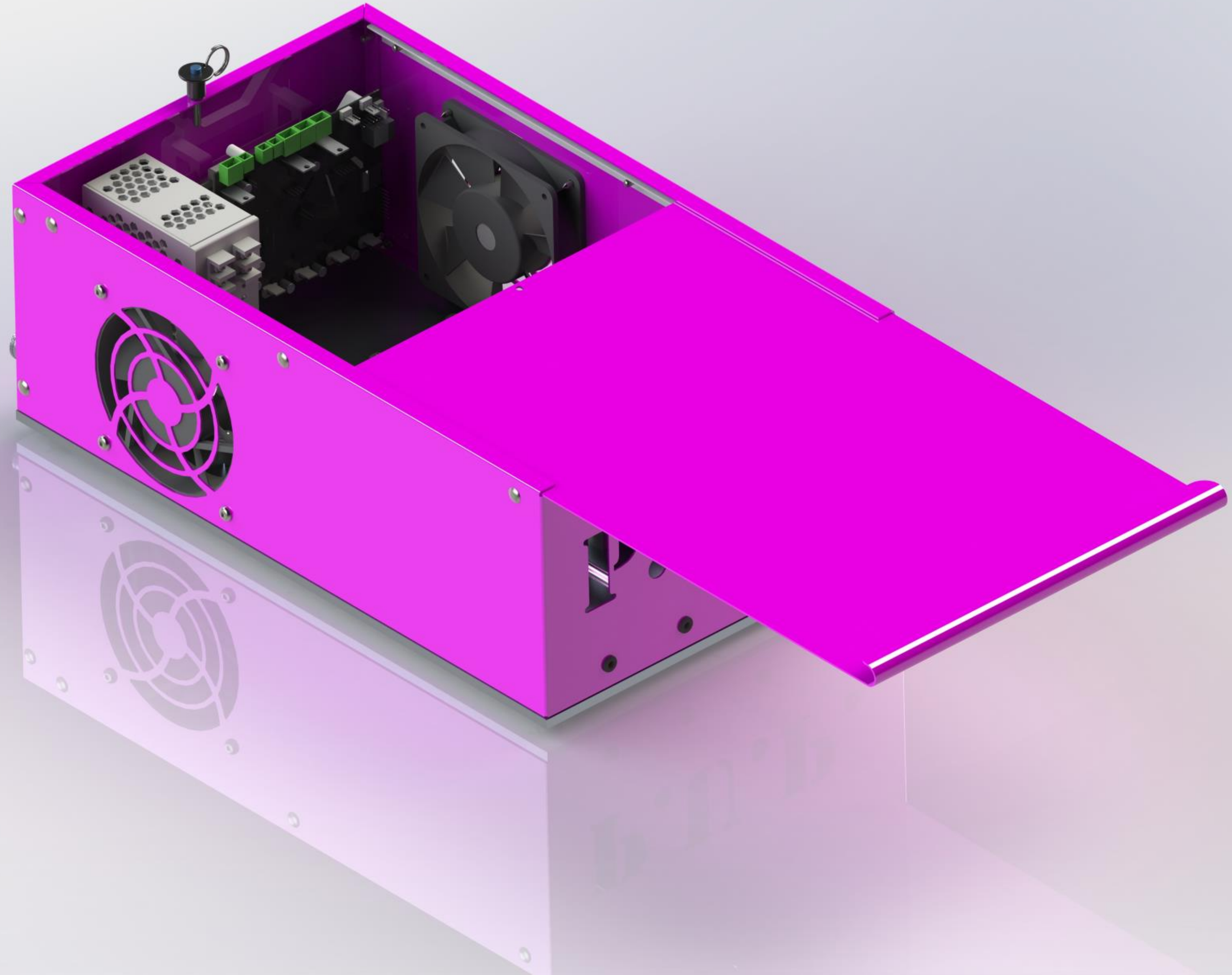


Center Driving Pistons

- Driving Piston for XY located between linear rails
  - balance any induced moment
  - Reduces risk of "racking"



Design Overview: Driving/Dispensing

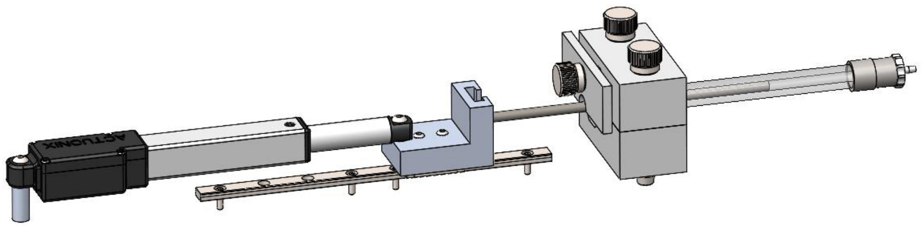


Highlights

- Modular piston system
- Smoothie board mount
- Driving System Enclosure

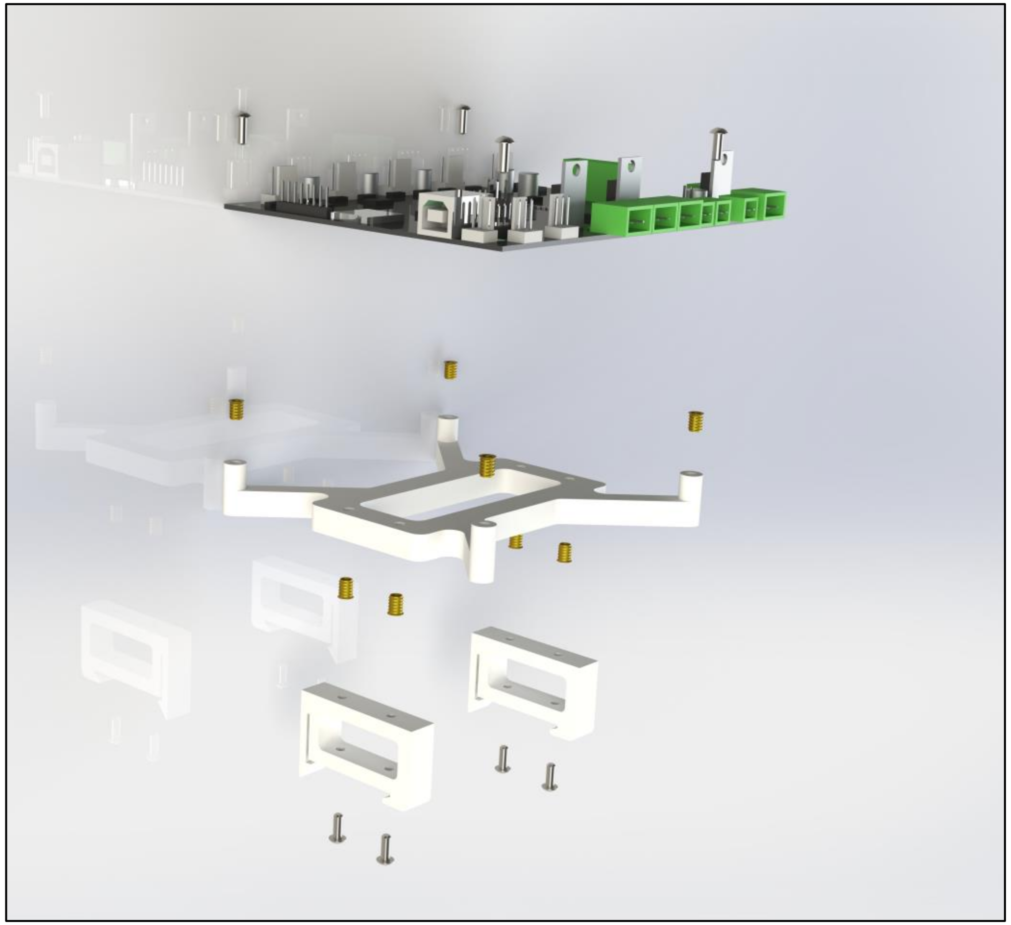
Modular Piston Assembly

- Assembly is modular which allows for the quick replacement of syringe
- Actuators to drive piston
  - Low Cost
  - Good Controllability
  - Limited Assembly needed



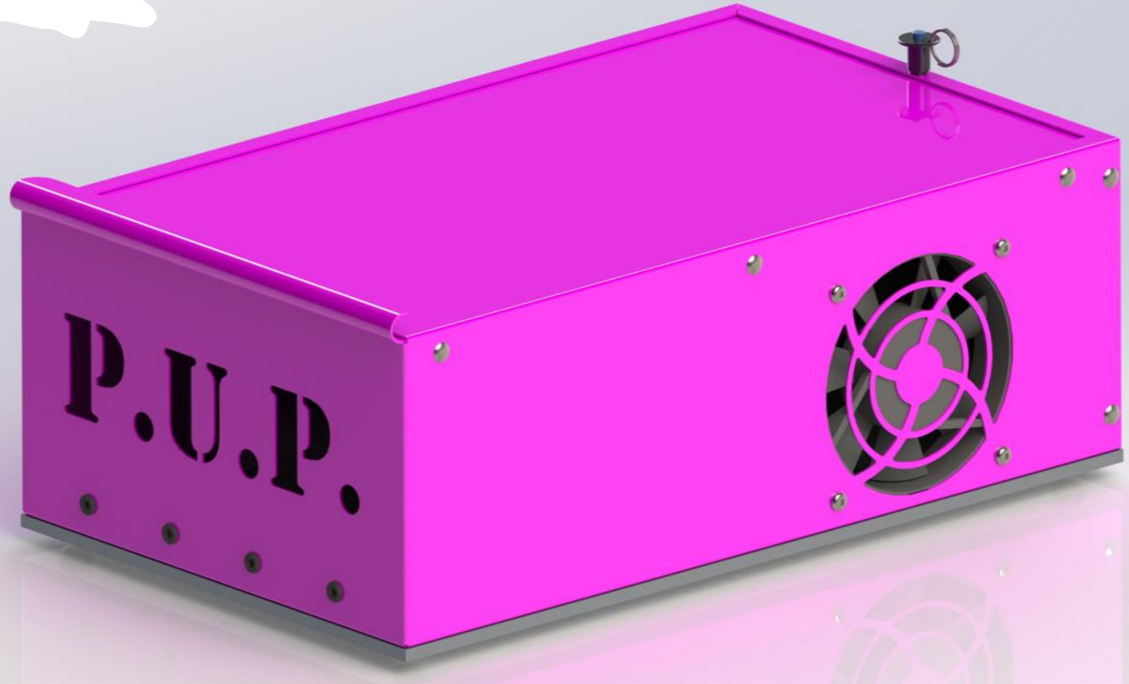
Smoothieboard Mount

- Designed for 3D printing in ABS
- Custom designed to mount to DIN rail
- Threaded inserts to aid in assembly



Driving System Enclosure

- Sheet metal enclosure designed for ease of manufacturing
- Enclosure provides professional appearance



Sub-system Analyses

Dispensing:

- Dispensing force for desired flow rate determined by Bernoulli equation
  - Pressure at needle outlet and fluid velocity in syringe barrel were neglected

$$P_1 = \frac{1}{2}\rho {V_2}^2 + \rho \Delta z$$

- Variables:
  - ρ - density of print fluid
  - Δz - height difference between syringe barrel and dispensing tip
- Volumetric flow rate: $Q = V_2 A_2$
  - A_2 - dispensing tip cross sectional area
- Pressure applied by actuator: $P_1 = \mathrm{F} A_1$
- Solving for F:

$$F_{req} = \frac{\rho A_1 Q^2 + 2\rho A_1 {A_2}^2 \Delta z}{2{A_2}^2}$$

Motion:

- Printable feature size d from (O'Bryan 2017):

$$d = \sqrt{\frac{4\,Q}{\pi\, v_n}}$$

- The maximum actuator velocity is 25 mm/sec under no load
  - Maximum velocity under load assumed to be 15 mm/sec
- Print head speed can be determined: $v_1 A_1 = v_2 A_2$
  - A_1 - syringe piston area
  - A_2 - motion piston area

$$v_2 = \frac{A_1}{A_2} v_1$$

$$v_{2,max} = \frac{0.161\, mm^2}{0.172\, mm^2} \cdot 15\, \frac{mm}{s} = 14.5\, \frac{mm}{s}$$

- Projected feature size of $d = 0.3\, mm$ when $Q = 1\, \mu L/s$.

Sub-system Analyses Con't

Control Box:

- Actuator and fan thermal efficiencies of 0.75
- Power supply surface area used as heat dissipation area, conservative approximation
- Volumetric flow:
  - No flow rate loss due to large PUP cutout on front face
- Q - total heat being dissipated
  - Four actuators, two case fans, and Smoothieboard control
- Dimensionless numbers – Reynold's, Prandtl, Nusselt
- Results:
  - 100°F
  - 38°C
  - 16°C above ambient temperature

ht_for_control_box.m

```
clc; clear;

%Define Variables:
qactuator = 3.45*(1-0.75);  %Watts
qcontrol = 2.5;  %Watts
qfan = 1.2*(1-0.75);  %Watts
l = 0.1;  %meters
w = 0.050;  %meters
h = 0.121;  %meters
vol = 0.068;  %meters^3/sec
tinf = 22.22+273;  %Kelvin
k = 0.0262;  %Watts/(meters^2*K)
nuair = 1.48*10^-5;  %meter^2/sec
rho = 1.225;  %kg/meters^3
hbox = 0.154;   %meters
wbox = 0.277;   %meters


%Calcs:
q = (4*qactuator)+qcontrol+(2*qfan);  %Watts
surfarea = (2*l*h)+(l*w);  %meters^2
boxarea = hbox*wbox;   %meters^2
vel = vol/boxarea;  %meter/sec
Re = ((vel*l)/(nuair));  %unitless
alpha = ((k)/(rho*1000));  %meter^2/sec
Pr = nuair/alpha;  %unitless
Nu = 0.037*(Re)^(4/5)*(Pr)^(1/3);  %unitless
h = ((Nu*k)/(l));  %Watt/meter^2*Kelvin
t_calc_celcius = tinf+((q)/(surfarea*h))-273  %Celsius
t_calc_fahrenheight = (9/5)*t_calc_celcius+32  %Fahrenheight
```

Command Window

```
t_calc_celcius =

   37.7746


t_calc_fahrenheight =

   99.9943
```

Cost and Parts Sourcing

OTS Parts	Raw Material	Manufactuirng Cost	Assembly Cost
$1,909.33	$284.44	$1,006.23	$320
		Total:	$3,520

- OTS parts make up the majority of printer components
- Raw material consisting of plate, rod, and rectangular stock were sourced for every custom part
- Manufactuirng cost was determined using a feature-based quoting system that considers tolerances and required operations
- Assembly labor was quoted at $80/hour and requires two people for two hours

Why PUP?

BEST BANG FOR YOUR BUCK

MINIMAL ASSEMBLY TOOLS

DESIGNED FOR FAST MANUFACTURING

MANY REPEATED PARTS

HIGH % OTS

Thank you!

Thank you, Northrop-Grumman and Cummins, for your continued support of the Capstone program and for helping make our program one of the best in the country!