DIY VENTILATOR DESIGN CHALLENGE

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GOAL

*To create a safe, automated ventilation system for an **Ambu-Bag**, while minimizing cost and complexity—and maximizing **efficiency** and **patient health**.*

DESIGN PHILOSOPHY
Priorities

Accessibility

- Option to use cheap, household goods
- Low cost

Simple Assembly

- Intuitive bag-press system via motor rotation
- Minimal required tools for assembly

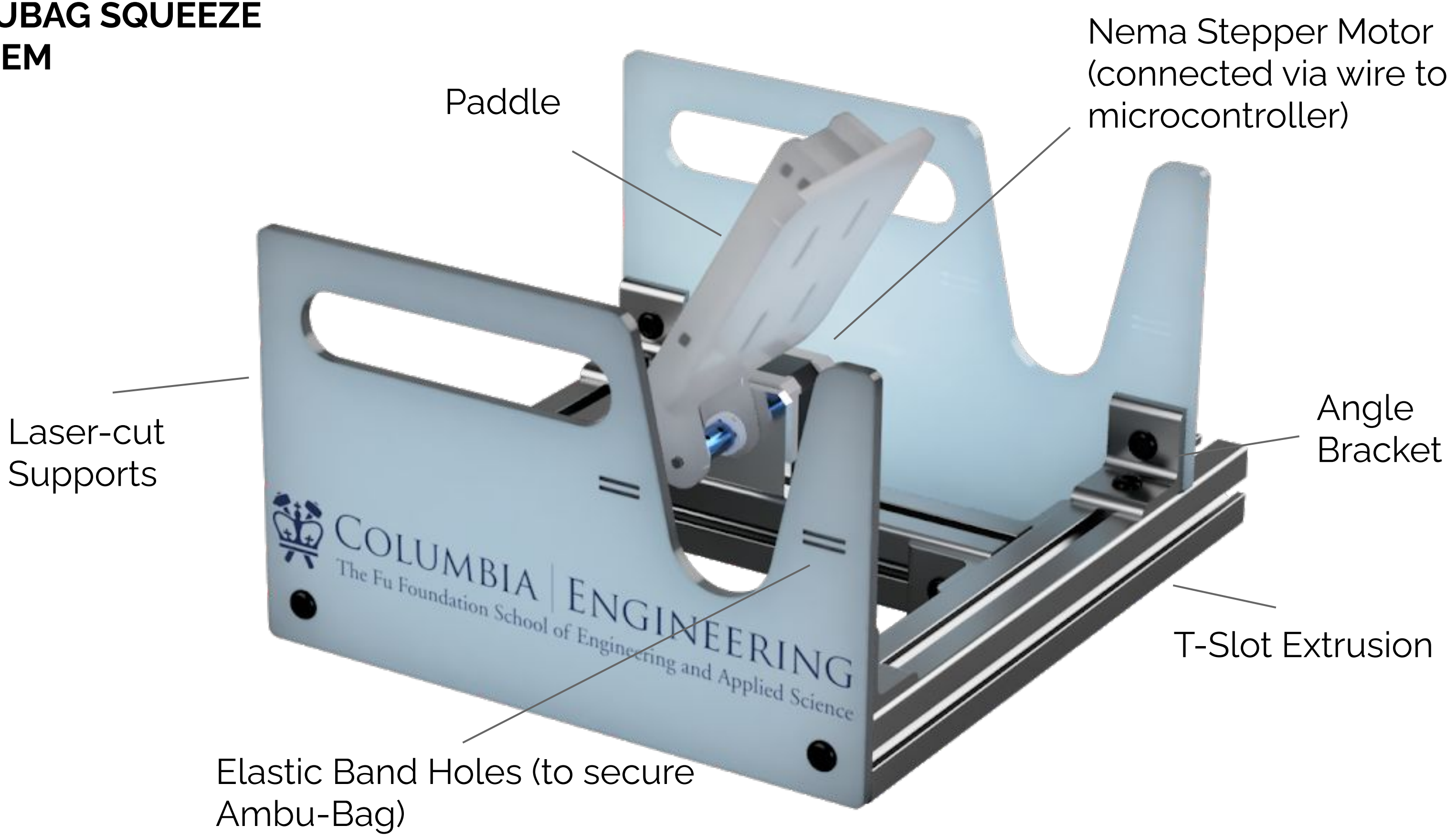
General efficacy

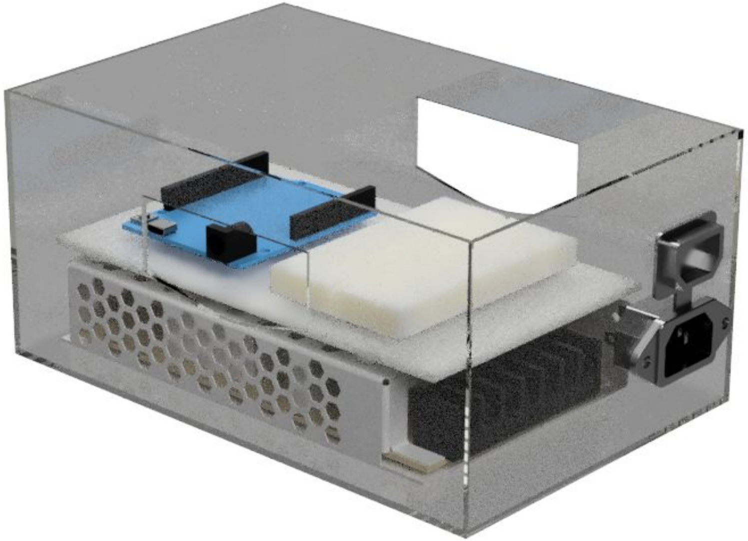
- Use of CPAP grade pressure sensor for accurate readings
- Clear UI to regulate pressure and rate
- Safety nets

SYNOPSIS

Our approach revolves around having a straightforward, some-assembly-required kit structure to be easily shipped to remote areas of the world with relatively low production costs. The concept of DIY is embodied in its use of open-source components and affordability. Even if the kit is not acquired, others should still be able to make it at home.

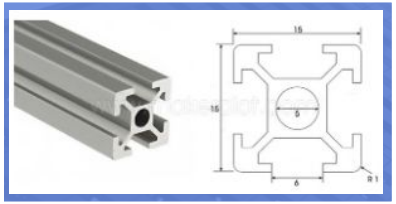
AMBUBAG SQUEEZE SYSTEM





Note: Any box with the same dimensions can be used to house the electronics (i.e. shoebox)

DECISION
Motor Driven Actuation



Motor-driven actuation method was chosen due to ease of access and convenience.

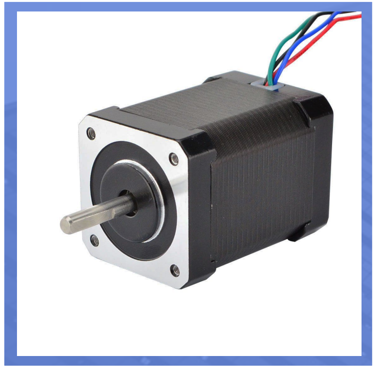
Overheating should be less of an issue due to low RPMs.

Stepper motor with built-in encoders used to time rotations accurately without use of separate encoder parts.

Motor drives some sort of “arm” component - arm can easily be substituted with whatever materials are on hand - to rotate and press down on Ambu-Bag.

Ambu-Bag is held in a T-slot extrusion frame. T-slot extrusion is easy to find and easily adjustable compared to machined frames. Extremely quick assembly and easily-understandable instructions.

MOTOR SPECIFICATIONS



High Torque Nema 17 Bipolar Stepper Motor

- Assuming 12 breaths/min, 12 x 1440 x 7 = **120,690 cycles per week**
- Stepper driver strain could add significant heat to the system in the long run, but can be combated with appropriate cooling
- Maximum force achieved by the motor on the bag would be approximately **2.682 N**, which is equivalent to approximately **0.274 kg** in weight.
- Capable of achieving a maximum of 2.5 **squeezes/second.**
- Max stroke length is **indefinite** and min is **2 seconds/cycle.**

MANUFACTURED PRESSURE SENSOR CONNECTOR

In order to address the issue of measuring pressure sensitivity, we had to design our own pressure interface in the form of a connecter which goes between the tracheal tube and the Ambu-Bag patient input.

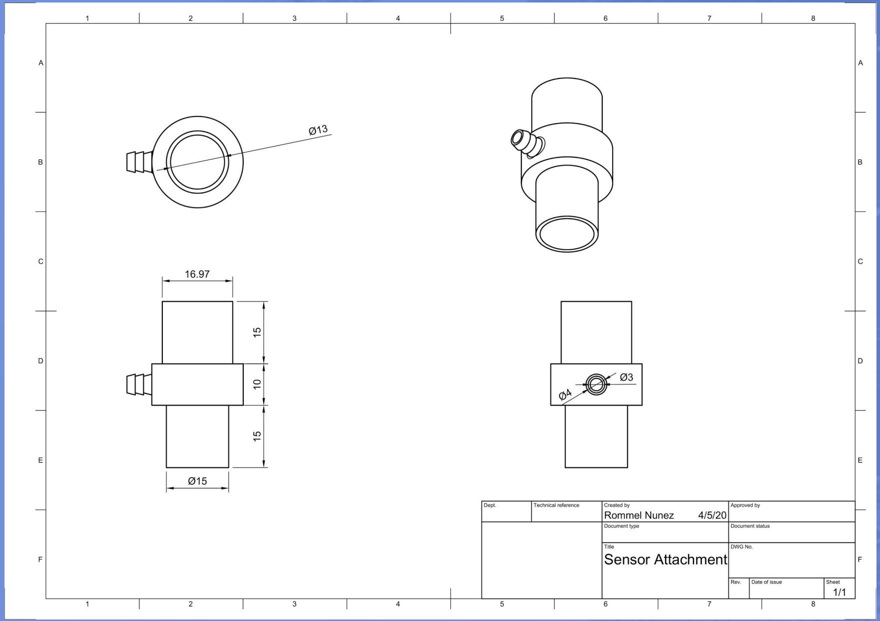
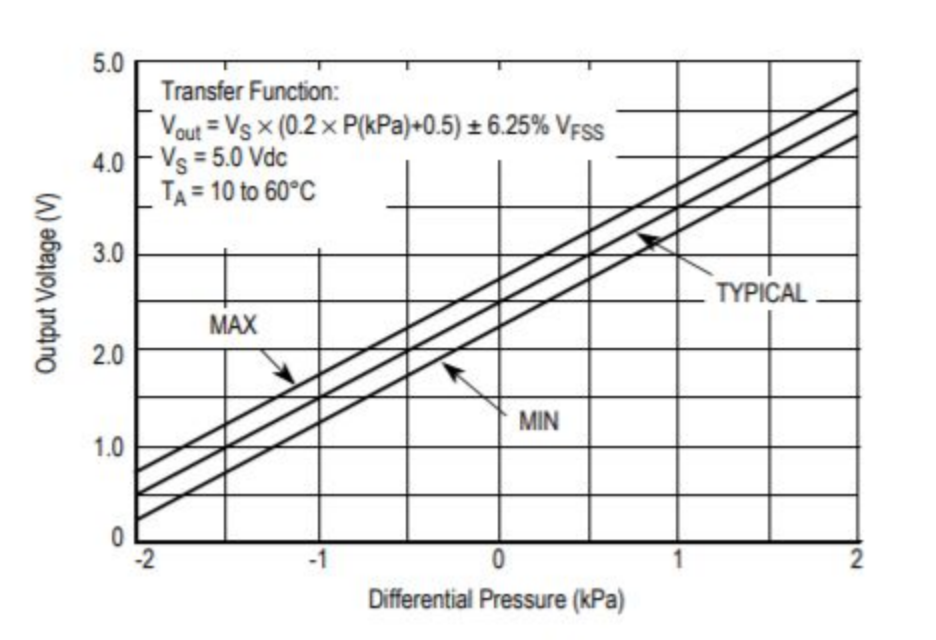


Fig. 1

PRESSURE SENSOR CHOICE (MPXV7002)

This monolithic pressure sensor has one part in the system and the other exposed to ambient air. **It reads pressures between -0.3 and 0.3 PSI (approx. -210 to 210 mmH20** (fits neatly in the patient's range of 5-45 mmH20)).

Using the manufacturer's transfer function, **the 0-5V reading from the machine to the Arduino can be translated into a reading onto the LED screen**.



Voltage Output vs. Pressure Differential

SENSOR INTEGRATION

The strength of this prototype lies in its ability to **adapt to a unique patient profile.**

The feedback from the electronic pressure manometer is used to ensure a minimum amount of positive pressure in the Ambu-Bag during discharge of air into the patient. If the pressure value drops too low, the system most likely has a leak, and an alarm will sound to indicate its dysfunctionality. **This is a critical safety mechanism.**

Moving beyond this, the pressure manometer will also be able to detect a negative pressure. Spontaneous breathing of a patient will cause a negative pressure on the Ambu-Bag system upon inhalation if the frequency of breath administration is not in sync with the patient. To accommodate the changing profile of the patient's breathing, the system will immediately switch to discharging air upon detecting a negative pressure, so that it will align with the breathing time and pattern of the patient. An alarm will also sound to indicate the system's recognition of the spontaneous breathing of the patient. This function is crucial for adapting to the changing **needs** and **reliability** of the patient on the DIY ventilator.

SUMMARY: PRESSURE REGULATION

The key to our pressure regulation system is the use of a pressure sensor. **The pressure sensor used (MPXV7002)** is able read pressures between the range of around 5 to 100 mmH20, and has been used in DIY CPAP monitors.

The sensor can be connected by a manufactured piece (*Fig. 1)* or via a standard Y connector that will keep the link to the connector to the tracheal tube or face mask while providing access to the pressure sensor via pneumatic tubing. **The pressure sensor will either have to be replaced or removed and deep-cleaned between uses.**

The cost to replace the pressure sensor, however, is relatively cheap when compared to the benefits of being able to directly detect the pressure in the AmbuBag-patient system. The readings from the pressure sensor will be read by the microcontroller and translated into mmH20 that will be projected onto the user interface. Through an algorithm that we devise, we will be able to actively control the volume of air delivered to the patient.

SUMMARY: SQUEEZING MECHANISM

In this part of our design, we simulate the "squeezing" of the Ambu-Bag. The main action is done by pressing the bag, which is held in place by two sliding supports, elastic band, and velcro (to allow for varying sizes of bag).

The sliders consist of t-slot extrusions, and can be put together with the use of screws, nuts, and screwdrivers. The supports themselves can be cut from plexiglass or taken from a household container, similar to a laundry basket. The bag is pressed by a paddle attached to a stepper motor that can also be slid back and forth to increase/decrease pressure on the bag. The stepper motor regulates how quickly and firmly the bag is pressed, affecting both rate and pressure.

This system is simple to put together, made with accessible parts, and will simulate the squeezing of the bag by the hand of a health provider.

SUMMARY: ELECTRONICS/ USER INTERFACE

All electronics will be centralized in a box. This box can be any box as long as it fits all of the components. The set will consist of a microcontroller that incorporates a motor controller, an LCD interface that comes with a potentiometer knob and button, a power supply, and connects out to the motor and the pressure sensor.

The user will be able to see the current pressure and rate on the screen. Using the potentiometer/button the user will be able to toggle between controlling the rate and the pressure and adjust according to the patient's needs. The microcontroller can be connected to the computer via USB adapter and programmed using the Arduino IDE.

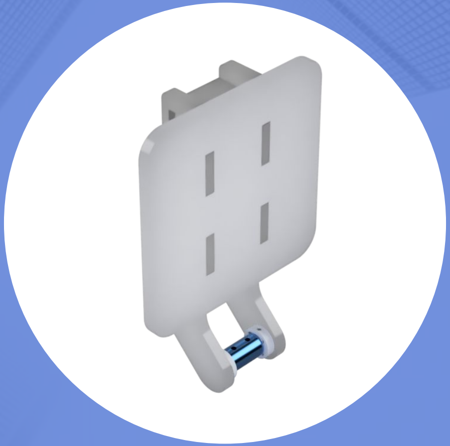
IDEAL SCENARIO: *DIY "KIT"*

We believe the the best-case scenario would be to mass consolidate inclusive "kits" to create our design that can then be shipped and assembled with no additional tools. However, the next slides propose alternatives for parts if individuals only have instructions and no access to the "kit", 3D printers, or laser cutters.

ALTERNATIVES A:

CUT PADDLE
vs.
PING PONG PADDLE

Cut Paddle



- Would require access to a cutter/be manufactured
- Will allow for modifications to allow easy connection to motor

Ping Pong Paddle

- Cheap and easy to buy
- Would still require modification or 3D printed part for attachment

ALTERNATIVES B:

MANUFACTURED VS. Y-CONNECTOR

Manufactured Connector

- Would require access to a 3D printer/be mass manufactured
- Ideal access to pressure sensor while maintaining airway

Y-connector

- Readily available for purchase
- Will need more parts to connect to pneumatic tubing

ALTERNATIVES C:

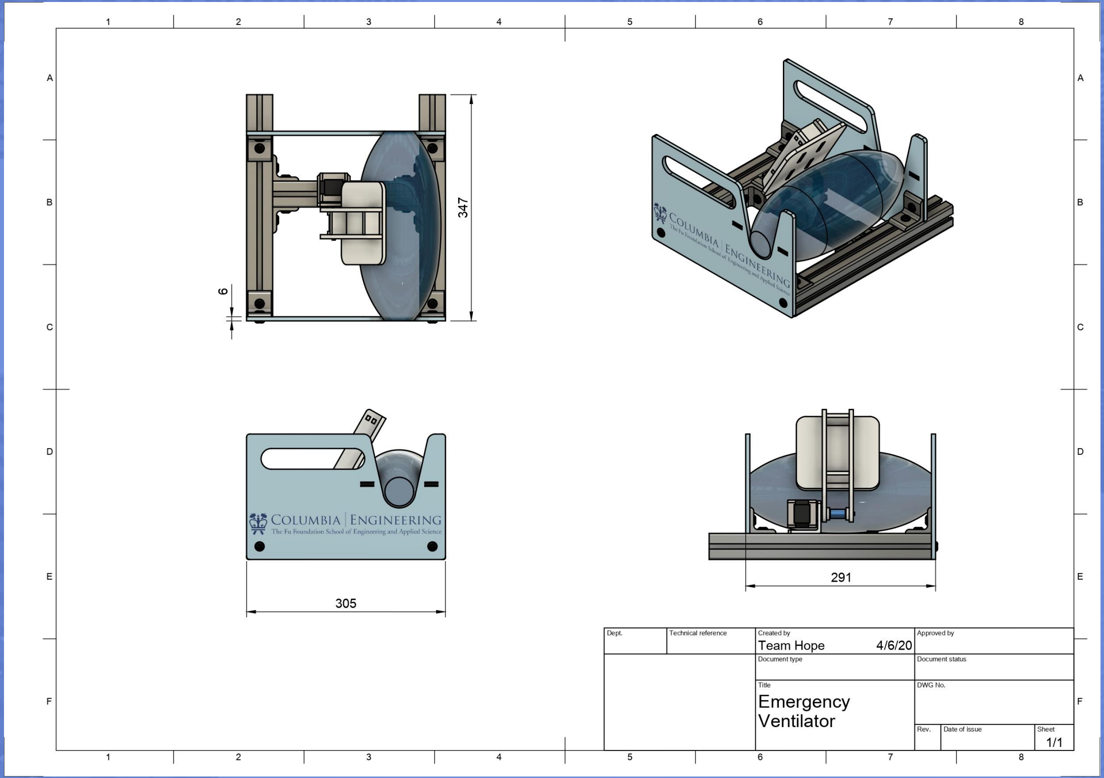
PLEXIGLASS/WOOD SUPPORTS VS. LAUNDRY BASKET

Plexiglass/Wood

- Would require access to a 3D printer/be mass manufactured
- Smoothly connects into design and holds the Ambu-Bag in place

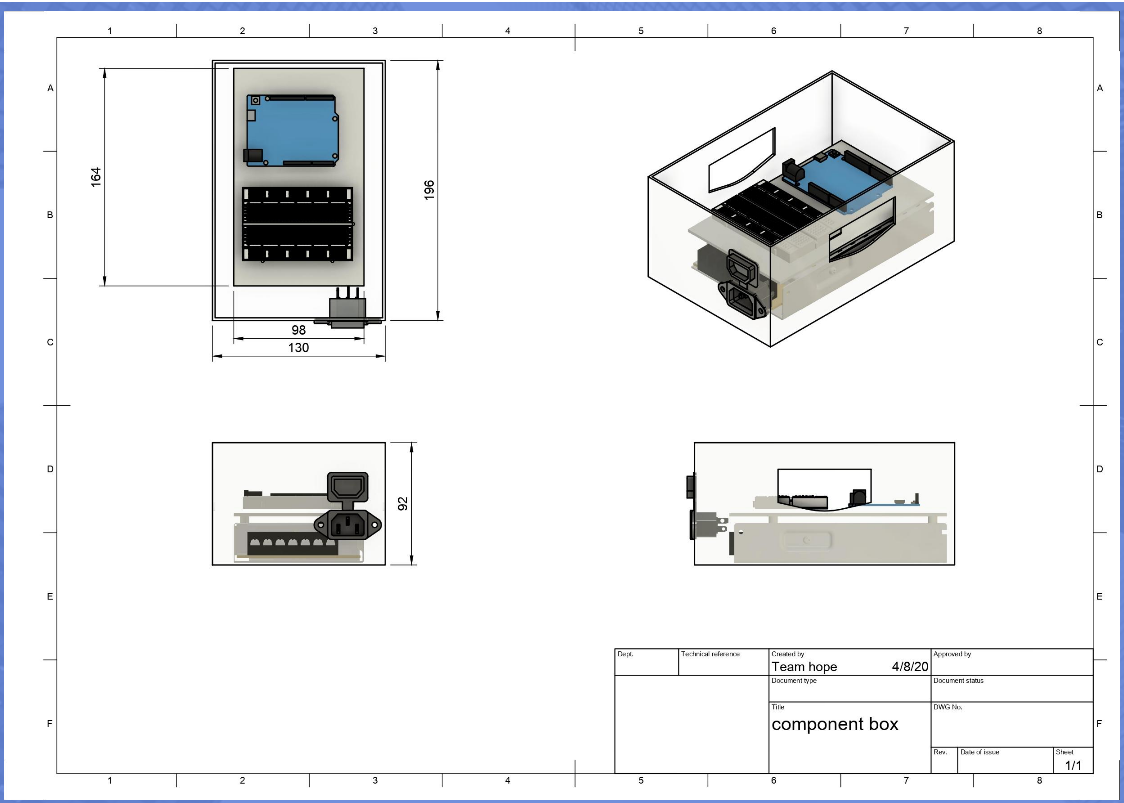
Laundry Basket

- Cheap, no tools besides scissors to modify
- Will still need to be attached to the system
- Less sturdy
- Can be incorporated with plexiglass as a “casing”



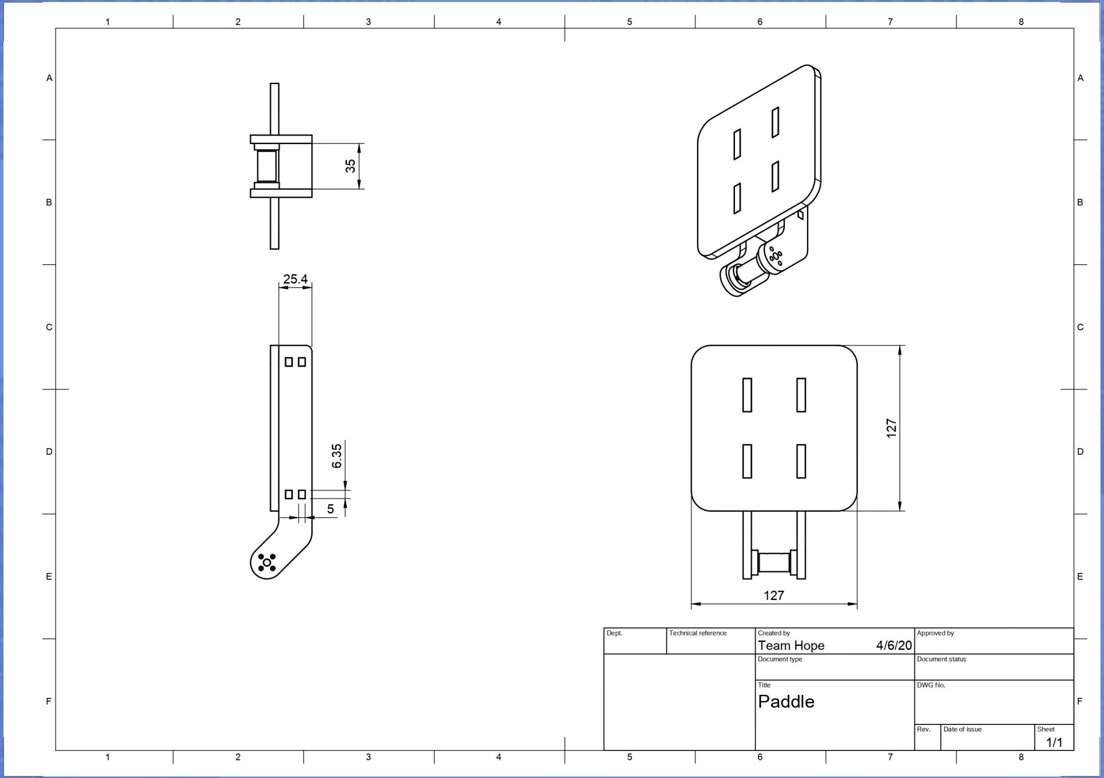
All units in mm

CAD Models A



All units in mm

CAD Models B



All units in mm

CAD Models C

EXAMPLE USE CASE 1 (NON-KIT):

Scenario 1: *A healthcare provider is looking for a way to effectively provide temporary ventilation to a patient for minimized resources.* ***After minimal online research, our design is found.*** *Access to all software is available via public Github repository, links to all parts are accessible, and detailed instructions are provided. All parts are obtained by the provider within a few weeks, and* ***with the help of a friend with basic engineering skills and a standard 3D printer, they are able to re-create the ventilation system within a few days.***

EXAMPLE USE CASE 2 (KIT) - *IDEAL:*

Scenario 2: *Healthcare providers have already expressed need for simple temporary ventilation systems.* ***All parts, instructions, and tools to create our design are sent out in masses of cost-effective DIY kits****. Volunteers and staff with minimal engineering can build several of these machines every day. Having everything in one kit, pulled together from parts easily accessible in the United States, makes it much easier for the device to be constructed in less developed regions.*

CAVEATS

- Does not calculate volume of the system
- Modification of pressure is both manually (slider) and digitally (UX) controlled
- Some soldering, printing, or cutting of parts may be required at this stage of design
- Pressure sensor must be replaced or deep-cleaned. However, price of sensor goes down significantly at scale.
- This model, like most other AmbuBag-centered designs, MUST be used on sedated patients to avoid barotrauma and other forms of respiratory injury

ADVANTAGES

- Relatively cheaper alternative to current ventilators
- Simple construction - minimal tools required
- Many parts can be replaced with low-demand alternatives (paddle, laundry basket)
- Many parts (microcontroller, t-slots) readily available
- Includes digital pressure readings for monitoring patient
- LED Screen based UX
- Potentially be contained in DIY IKEA-style "kits"
- Can be manufactured at scale
- **Adaptive to the changing needs and reliability of the patient on the ventilator.**

FUTURE PLANS

STREAMLINE DESIGN / FORMULATE KITS + INSTRUCTIONS

- Modify materials used
- Order materials
- Create detailed diagrams of circuits and mechanisms

CREATE PROTOTYPE / TEST

- Manufactured vs. Alternative Parts
- Efficiency of Pressure Sensors
- Motor Movement vs. Pressure

RESEARCH

- Gain expert information/collaboration on pressure/volume regulation
- Look into integration of inspiratory valve
- Assess and apply feedback

PART LIST
Electronics

PART	LINK	$ (not per unit)	DETAILS
LCD Screen	link	13.99	Shows Pressure/Rate Details, allows user to toggle controls via attached knob
Arduino Uno	link	22.00	Controls all electronics, very simple connection to drivers and LCD
Motor Drivers	link	8.99	Translates motor voltage. Two per unit
Power supply	link	8.16	12V
Wall cable to power supply	link	3.99	Cable
Inlet module	link	7.99	Control power
Terminal kit	link	29.99	For interfacing to inlet module
Cable (power supply to Arduino)	link	10.98	Allows for access to power, 10ft

PART LIST

Electronics (continued)

PART	LINK	$ (not per unit)	DETAILS
Solid Core Wire	link	15.99	Wire
Pin terminals	link	7.99	Simple terminals

PART LIST
Mechanics

PART	LINK	$ (not per unit)	DETAILS
Pressure Sensor	link	16.90	Gives electronic feedback
Color Sensor	link	4.88	Potential cheaper option than pressure sensor
Claw, Ping Pong Paddle	link	2.39	Easily accessible squeezing mechanism
Nema 17	link	12.36	Higher torque alternative
Mounting Hub for Nema 17	link	7.49	Secures the paddle to the axle

**Note: not all parts listed are necessarily used in every version of the design. This list includes alternative parts.*

PART LIST
Mechanics, continued

PART	LINK	$ (not per unit)	DETAILS
Y connector	link	2.00	Alternative to manufactured piece
Metal extrusions	link	40.00	10 ft
Metal extrusion connectors	link	2.69	4/pack
Polycarbonate	link	92.00	4ft x 3ft
Angle brackets	link	6.58	x6

**Note: not all parts listed are necessarily used in every version of the design. This list includes alternative parts.*

UNIT BREAKDOWN

cost per unit: approx $140 without mass manufacturing (Lowest price estimate <$100)

construction time per unit (given all parts): less than 2 hours

tools to construct kit unit:
Hex tool for frame, motor
solder kit

tools to construct from scratch:

Laser-cutter
3D printer
Hex tool
Solder kit
Drill
Chop-saw

We are requesting

$2,000

in funds for the production and testing of several prototypes.

The following resources will also be used for the project:

3D Printer, Laser Cutter, Soldering Irons

REFERENCES

[Pressured-controlled ventilators]

[Stepper motor interface with arduino]

[MIT E-vent]

[Inspiratory valve]

[Ambu bag instructional]

[Breathing circuits for manual and mechanical ventilation]

CONTACT INFORMATION

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