<- Navigation document

Have concerns? Please read and contribute to "Red teaming": ~~ AJP (Admin)
https://docs.google.com/document/d/1RDihfZIOEYs60kPEIVDe7gmsxdYgUosF9sr45mgFxY8/edit#heading=h.bwhv35yauezw

Open Source Ventilator

Contact us
Google drive: Ventilator
Slack channel: #hardware-ventilator
Portugal specific: #hardware-ventilator-portugal
👍 Upvote this document on Sourceful

For a specific approach based on automating a bag valve mask, head to #hardware-ambu-bag
The list of other ongoing hardware project is here : Hardware Projects (Google drive)

Description

In Italy, each ventilator is like gold. The US, which has an above average medical system, is likely also going to run out of ventilators, let alone countries in the developing world.

The goal of this project is to design an open source, scalable, safe, and easy to use DIY ventilator for use in hospitals.

Contents

Have deleted. Use "View" > "Show document outline" (on desktop). Can click links on there to change url to shareable links.

Necessary specs :

UK:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/876167/RMVS001_v3.1.pdf

Spanish:
https://foro.coronavirusmakers.org/index.php?p=/discussion/78/resumen-del-dia-2-especificaciones-clinicas-y-render-de-prototipo-rees#latest

Ventilator derived parameter :

The basics of respiratory mechanics: ventilator-derived parameters :
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6212352/

Safety concern:

Respiratory support for patients with COVID-19 infection

*"**Jonathan Chun-Hei Cheung and colleagues do not recommend use of a high-flow nasal cannula or non-invasive ventilation until the patient has viral clearance**. Supporting the recommendation of the authors, I would like to add some points in relation to the use of high-flow nasal oxygen therapy and non-invasive ventilation in patients with COVID-19 infection:*

***First, although exhaled air dispersion during high-flow nasal oxygen therapy and non-invasive ventilation via different interfaces is restricted, provided that there is a good mask interface fitting, not all hospitals around the world have access to such interfaces or enough personal-protective equipment of sufficiently high quality** (ie, considered fit-tested particulate respirators, N95 or equivalent, or higher level of protection) for aerosol-generating procedures, and several hospitals do not have a negative pressure isolation room.*
...
*Second, the fundamental pathophysiology of severe viral pneumonia is acute respiratory distress syndrome (ARDS). **Non-invasive ventilation is not recommended for patients with viral infections complicated by pneumonia because, although non-invasive ventilation temporarily improves oxygenation and reduces the work of breathing in these patients, this method does not necessarily change the natural disease course**."*
(https://www.thelancet.com/.../PIIS2213-2600(20.../fulltext)

That being said, professionals often use NIV to "limp" a patient along until a ventilator is available.
Legal :

[FDA] Coronavirus Disease 2019 (COVID-19) Emergency Use Authorizations

This is an authorization for Personal Protective Equipment (PPE), saying that nonstandard N95 masks and the like can be used in medical settings.

Red Teaming

Meta: a red team is a team in an organization that goes around trying to show people ways their ideas are flawed, hardening the production process. Ideas that survive the red team have grappled with the ways that they are insufficient, providing a larger context around the idea and allowing for a better picture of the costs/benefits.

Is shortage of ventilators likely to be a limiting step?

Italian doctors referred to them as gold. So yes I think shortage is a problem. China shipped another 1000 to Italy. Why do that if you had enough for your staffing levels? DEFINITELY AN ISSUE< NEED MORE VENTS we are planning to share vents the way we would for a trauma shortage (see articles published around the time of las vegas shooting if you want more details) but may be an issue because of infectious origin rather than trauma

What are the patient need distributions, which cases can we address?

From https://www.ncbi.nlm.nih.gov/books/NBK554776/# - Features, Evaluation and Treatment Coronavirus (COVID-19)

- Mild disease: non-pneumonia and mild pneumonia; this occurred in 81% of cases.
- Severe disease: dyspnea, respiratory frequency ≥ 30/min, blood oxygen saturation (SpO2) ≤ 93%, PaO2/FiO2 ratio [the ratio between the blood pressure of the oxygen (partial pressure of oxygen, PaO2) and the percentage of oxygen supplied (fraction of inspired oxygen, FiO2)] < 300, and/or lung infiltrates > 50% within 24 to 48 hours; this occurred in 14% of cases.
- Critical disease: respiratory failure, septic shock, and/or multiple organ dysfunction (MOD) or failure (MOF); this occurred in 5% of cases.

I would argue that the Severe cases above are the places we can contribute the most. Designing a system for the Mild or Critical cases will have less impact.

Is it wise to spread designs that require skill to make and operate?

Summary - Don't make it easy to be unsafe

If they cause harm they'll never be used.

Perhaps but there are docs off record saying they would try using them if it was that or patient dying. If they don't have them they can't use them.

You're about to say HFOV, CPAP etc. What does that mean?

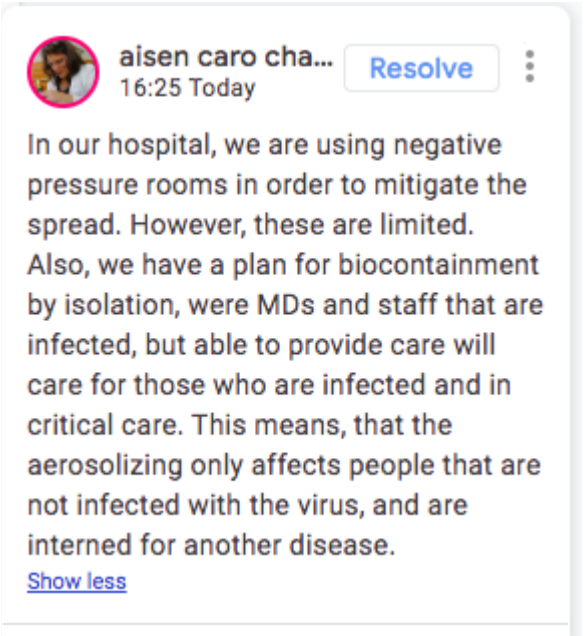
Look further down the document, you'll find some explanations

Ok but what ventilator? HFOV needs sedation, intubation, bloods, etc Very labour intensive to maintain support for these patients. Staff will be shortage.

Yep. Not going to be an HFOV but could be a NIV like CPAP or BIPAP or Cuirass

But NIV, CPAP, BIPAP produce aerosols so they won't be used in a formal medical setting or where there is a risk to staff and other patients. See interview here.

Not true and now have reports of doctors who are infected but still functioning treating patients using these machines.



Fine so hospitals might use NIV if the doctor already infected but they're

not going to use a DIY machine.

Please see "If they cause harm they'll never be used." above.

Do we need strict guidelines regarding aerosolization and the use of NIV ?

Based on a small chat I had with a nurse on facebook (here) aerosolization is occurring both in invasive (Intubation) and non-invasive (NIV) setup. Here is a review of what have been said:

"For the record, arisolatization only occurs when the patient is on a mask. Most of our BiPap/CPAP machines in a hospital setting are also ventilators. My hospital uses V60s for example, and they're all 3.

Intubation itself causes aerosolization, which is why our doctors have been instructed to use glidescopes during the procedure, but once a patient is intubated the risk of it is minimal. BiPAP and CPAP are technically just ventilation settings. Somebody can be intubated and placed on CPAP mode, for instance.

The issue is really with "noninvasive ventilation." If somebody is being ventilated WITH A MASK, then the particulates are more likely to be aerosolized because there's no tube to contain them "

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>This patient is intubated. His respiratory secretions are contained.</td><td>This patient is on a BiPap. His secretions are not.</td></tr>
<tr><td colspan="2">BOTH of these patients are being ventilated with a V60. That's the computer looking thing the tubes lead to.</td></tr>
</table>

At the same time having a HEPA filter on the outtake is not solving everything, as the seal around the face "leaks". "The air leaking from around the seal is expelled by the force of the machine, which shoots virus-laden droplets everywhere."

It seems that There's a machine called a Trilogy that a lot of BiPAP or CPAP users have at home. If you were to look into machines to be modified for use with ET tubes, you should start there.

Regarding oxygen nasal cannula :

Most patients are requiring nasal cannula for oxygen support. This does not cause aerosolization, but the patient can still spread droplets when they cough.

80% of people are mildly affected and can treat themselves at home. 10% need a hospital stay and oxygen through a nasal cannula. 10% require ventilators of some kind.

If two or several patients are already infected can we share one ventilator between them ?

COVID-19 How to Use One Ventilator to Save Multiple Lives
A Single Ventilator for Multiple Simulated Patients to Meet Disaster Surge

How do we tackle and ensure the reusability of our tools (sensors stacks) and ventilator, as well as maintaining everything safe and sterile ?

Ambu-bag or pipes are normally single use (depending on the use cases). How do we deal with that ? ***How do we ensure a proper sanitization of it and reusability according to hospital standards?***

As most people will do, sensors will be used, how do we make sure to have an accurate measure but also avoid cross-contamination ? **If the sensor stack got in contact with contaminated air (or assumed so) how do we ensure cleaning and reusability of it**.

A point to keep in mind is cost and simplicity. Health professionals won't be able to recalibrate sensors (if needed) or rewire everything when they are on the fire. On the other hand, changing the sensor stack everytime is going to be too expensive (even more if we speak about pressure sensors and anémometer).

What about the ventilator who got used and touched contaminated air ? Do we need to have labeling on it ? Color coding maybe ?

How easy is the ventilator to build ? How about durability and repairability?

Advanced tools might not be accessible quickly (laser cutter, 3D printer,...), thus we need to think of the design in order for the ventilator to be easily fixable with "low tech style" material.

TO DO: break out other statements/ questions to make it easier to process this Red Team feedback

If they are non-invasive ventilators, then the patients with COVID-19 spew viruses everywhere. Interviews with doctors here indicate that the risk of aerosolizing the virus with CPAP, BIPAP or high

flow oxygen is inadvisable.
Ref for claim aerosol is serious concern in formal healthcare setting:

- https://www.apsf.org/wp-content/uploads/news-updates/2020/apsf-coronavirus-airway-management-infographic.pdf
- https://www.ncbi.nlm.nih.gov/pubmed/32102726

From what I have seen, there isn't a lot of benefit of the NIV systems in COVID when invasive ventilation is available. Most people deteriorate quickly and won't be "turned around" with a brief period on a BiPap (as would a patient with a CHF exacerbation, etc)

Additionally, It seems to me that ventilators are pretty difficult to build. The Rice ambu bag approach seems to resolve these problems slightly, but doctors I've talked to have indicated that ventilator management is a difficult task. A given respiratory therapist can only manage approximately 6 ventilators at a given time, and those are fully fledged not-DIY ventilators. Given that the DIY ventilators are going to have only a small amount of modes, I don't see why people expect that these 3 simple modes will provide ventilation that will *actually help* patients with COVID, instead of just pushing air in and out of their lungs in a way that causes ventilator-induced lung injury.

Before we go and build a ventilator, we need to answer questions like "will this even help a patient instead of hurting them?"

In case of shortage, a poor ventilator should still be better than no ventilator at all. Non-invasive ventilators, despite that for COVID-19 they could indeed cause further viral spreading, can be used for non-COVID cases, so that more resources would be available to epidemic cases.

Priorities

1. We need contacts with medical personnel (respiratory, ICU, anesthetists), not only to assess the construction dilemmas, but also to assess their most critical needs (how many devices of what kind are needed, case studies)
2. or guidance from ventilator companies
3. Government / public health bodies supporting the project… so that it can be deployed into regions where it is supported and people have used the open source designs to make the machines.
4. What ventilators do we need to deal with Covid-19? Can we use NIV for beginning and recovery?
5. Designs that meet these criteria
6. The device should be non-invasive for rapid deployment. This would allow for an institutional IRB (Internal Review Board) to review a study for said device and issue an IDE (Investigational Device Exemption). The IDE would allow for a non-FDA approved device to be used as part of a study, it's a temporary pre-approval.
7. A study should be planned, approved, and deployed for the clinical trial of a device, this requires a PI (Principal Investigator) to direct the study. The study can then be cross-institutional, enrolling many investigational hospitals but with one governing body, the PI's base institution.

This study will require patients to enroll in said study in order to use these devices.

Design philosophy

Safety is the priority for both patients and medical staff in the design of a novel a quick-deployment medical ventilator. This is why having medical institutional oversight is critically important.

Questions to ask medical staff

There is a general doctor questionnaire that experienced doctors could be asked to complete

Maybe we can ask / clean answers from here: https://coronavirustechhandbook.com/doctors

There was a lengthy discussion with an MD about this in the facebook group:
https://www.facebook.com/groups/670932227050506/permalink/672522666891462/

According to your best knowledge:

what is the most used mode:
Assist / Control ventilation (A / C) -One East Coast American Doctor said this is most common for COVID-19 Patients
Pressure Support Ventilation (PSV)-Same East Coast American Doctor said this is also common for COVID-19 Patients
Synchronized Intermittent Mandatory Ventilation (SIMV)

> This will vary by institution, region, SICU vs MICU. Though volume or Pressure A/C are common. Agree and if we are going to split vents between patients it's best done with volume control

Which equipment is most at risk of being in short supply in the event of an epidemic?

> As of now it seems PPE equipment is of concern. Though in Italy the report is a lack of ventilators. Both PPE and ventilators. We also have a severe shortage of surgical gowns because they predominantly came from China.

Which settings commonly adjust for each patient?

> Not a simple answer as we utilize many to achieve adequate ventilation, including TV (Tidal Volume), FiO2, PEEP, Insp Pressure, Insp Time, etc. If you're trying to simplify it for desperation i think volume for size of patient, PEEP and FiO2

What security systems are available on the equipment?

What are the common problems they encounter in the use of the equipment that should be foreseen in this project?

There is some issue with generators, when we had a bad hurricaine with a generator out they worry because you don't want any lag time for the vent sorry don't know much about it, additionally a leak in the system would be an issue

What is the average duration of continuous use by a patient?

Unclear as ARDS patients can be on for weeks.

What would be most useful in a triage situation where only say family are available to assist?

Not sure what you are asking here.

Why won't manual ventilators work if nothing else is available?

Concern is man power, and manual ventilator leaves someone with continued exposure. Using a bag valve mask may increase aerosolization of virus. Reemphasizing we are not supposed to even bag mask before intubation (which is a pretty standard practice) because of aerosolizing

Would one ventilator between 3 patients be too much of an infection risk?

Each patient has different requirements, needs different tidal volumes, etc. The physiology of each is too varied to share, then there is the infection risk. We use 1 ventilator for 2 patients in a trauma situation. They have to be same size patient (need similar tidal volumes) and we do it on volume control. It is less than ideal but works. We are discussing do this for covid but 2 forseable issues - 1) requirements on a vent are more delica re rete in an infectious process than trauma, 2) patients are going to be infected with multiple things (pneumonia in addition to covid) which will breed antibiotic resistant strains etc etc etc so really need to make sure the air isnt circulating between patients. Need a quick way to split them on to separate ventilators if one of the patient arrests and needs resusitation ideally without transition to bag mask again because of aerosolization

This report from a doctor in Italy may give some insight

Introduction to Ventilators

The standard of care of patients with ARDS: ventilatory settings and rescue therapies for refractory hypoxemia

Infographic for Principles of Airway Management in COVID-19

Practical procedures oxygen therapy

Equipment in Anaesthesia and Critical Care (Chapter 4 - Ventilators)

The Standard Application Procedure for the Approval of Air-Purifying Filtering Facepiece Respirators Under 42 CFR Part 84

Intro Videos

Mechanical Ventilation Explained Clearly - Ventilator Settings &i Modes (Remastered)
Mechanical Ventilation Explained Clearly by MedCram.com | 2 of 5
Mechanical Ventilation Explained Clearly by MedCram.com | 3 of 5
Mechanical Ventilation Explained Clearly by MedCram.com | 4 of 5
Mechanical Ventilation Explained Clearly of MedCram.com | 5 of 5

Ventilator simulator

Hamilton T1 Simulator (Requires Flash)

NIV (Non-Invasive Ventilation)

CPAP

Continuous positive airway pressure/power (CPAP) is a form of positive airway pressure ventilator, which applies mild air pressure on a continuous basis. It keeps the airways continuously open in people who are able to breathe spontaneously on their own, but need help keeping their airway unobstructed. It is an alternative to positive end-expiratory pressure (PEEP).
CPAP (Continuous positive airway pressure)
There is a 3dprinted fan based on a CPAP fan

BiPAP

(Bi-level Positive Airway Pressure) machines are commonly used at home to treat sleep apnea and lung diseases. "Modern BiPAP machines are tabletop devices fitted with tubing and a mask. You simply put the mask over your nose and/or mouth to receive two levels of pressurized air. One pressure level is delivered when you inhale, and a lower pressure is delivered when you exhale."[1] In short, BiPAPs decrease the effort of breathing.

Hospital NIV (non-invasive ventilation) machines are fairly similar to home-use BiPAP machines. One doctor (Thomas Kwa's father) estimates that 30% of patients normally put on a ventilator could be put on a BiPAP machine. However, patients with acute respiratory distress are not put on NIV as often. According to the WHO, NIV is not the preferred treatment for severe acute respiratory infection due to risk of complications[2], but "NIV [non-invasive ventilation] can be used in select patients with mild ARDS [acute respiratory distress syndrome]." In addition, older BiPAPs with poor interface fitting generate viral

[1] https://www.healthline.com/health/copd/bipap-for-copd
[2] See lecture 9 of the free OpenWHO course on severe acute respiratory infection.

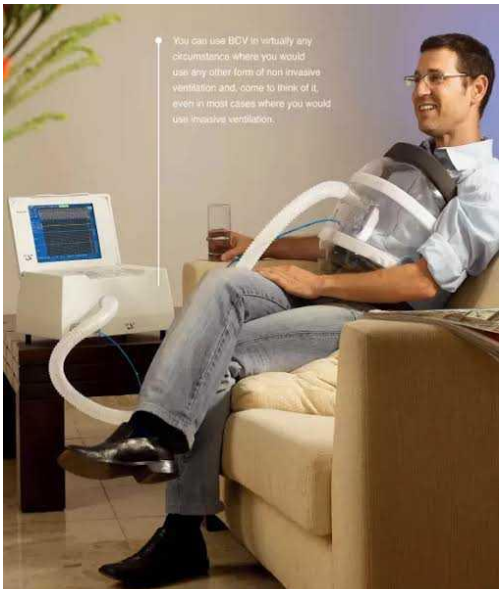
aerosol that requires healthcare workers to wear full-body protective suits. Manual and internal parts photos of older BiPAP in link below
https://www.hmebc.com/wp-content/uploads/Respironics-Synchrony-Bipap-Machine.pdf

Negative pressure ventilation (AKA Iron lung/ Cuirass)

Iron Lung/ Both respirator

An old technology, not as effective as modern ventilation but the machines are easily produced and non-invasive. May not have the same aerosol problems as other approaches. More info here: Negative pressure respirator may be useful when combined with an Oxygen concentrator?

Cuirass



An anesthetist from Perth expressed interest in this [in the Slack channel]

Table 2 Stratification of treatment failures and fatalities by underlying disease and causes leading to coma

Disease	*No. of patients*	*No. of treatment failures*	*No. of deaths*
Underlying disease*			
COPD (alone)	81	24 (30%)	19 (23%)
COPD associated with other systemic diseases	37	11 (30%)	9 (24%)
Chest wall diseases	9	3 (33%)	2 (22%)
Sequelae of pulmonary tuberculosis	16	6 (37%)	5 (31%)
Other	7	1 (14%)	1 (14%)
Causes leading to coma**			
Exacerbation of chronic disease	74	19 (26%)	14 (19%)
Pneumonia	41	16 (39%)	14 (14%)
Sedative agents	23	3 (13%)	2 (9%)

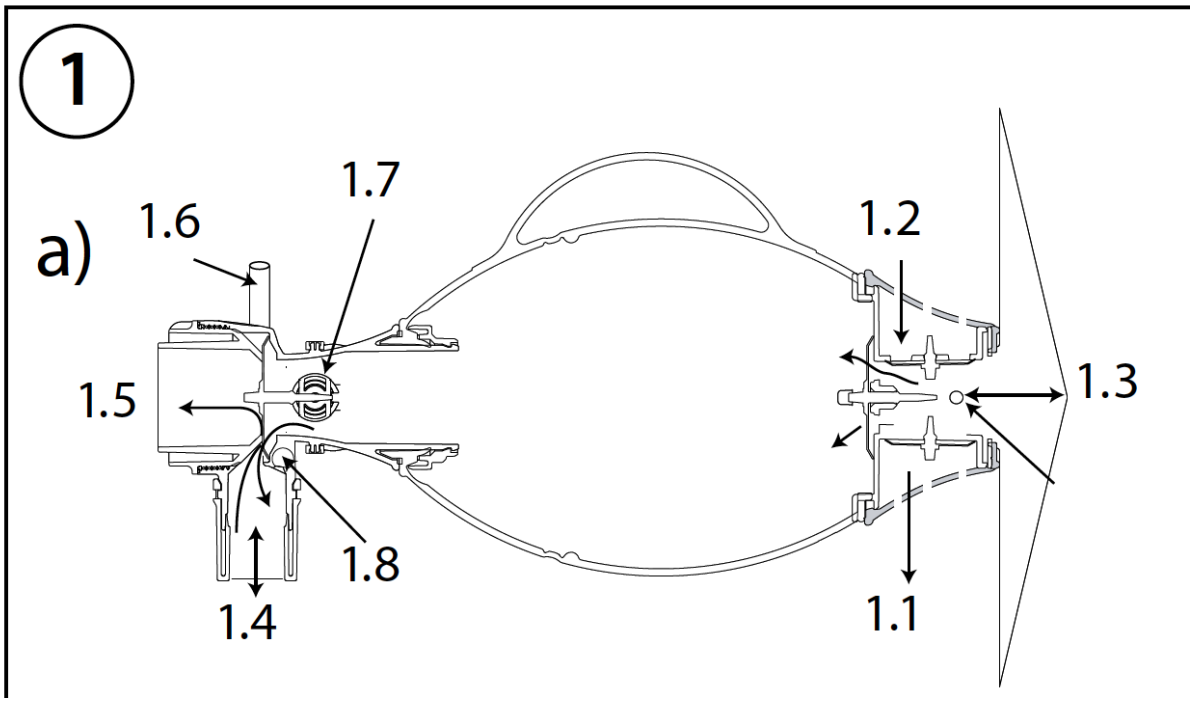
Above is a section of this paper:
[Intermittent negative pressure ventilation in the treatment of hypoxic hypercapnic coma]

Ambu-bag

See the [Slack channel #project-ambu-bag]

The low-cost ventilator consists of the sort of cheap manual pump that is ubiquitous even in rudimentary first-aid kits, connected to a battery and motor, exhaust system and PEEP valve. A set of dials on the exterior of the box control the volume and breath cycles, while a gauge monitors pressure flow and prevents over-pressurizing of the lungs,

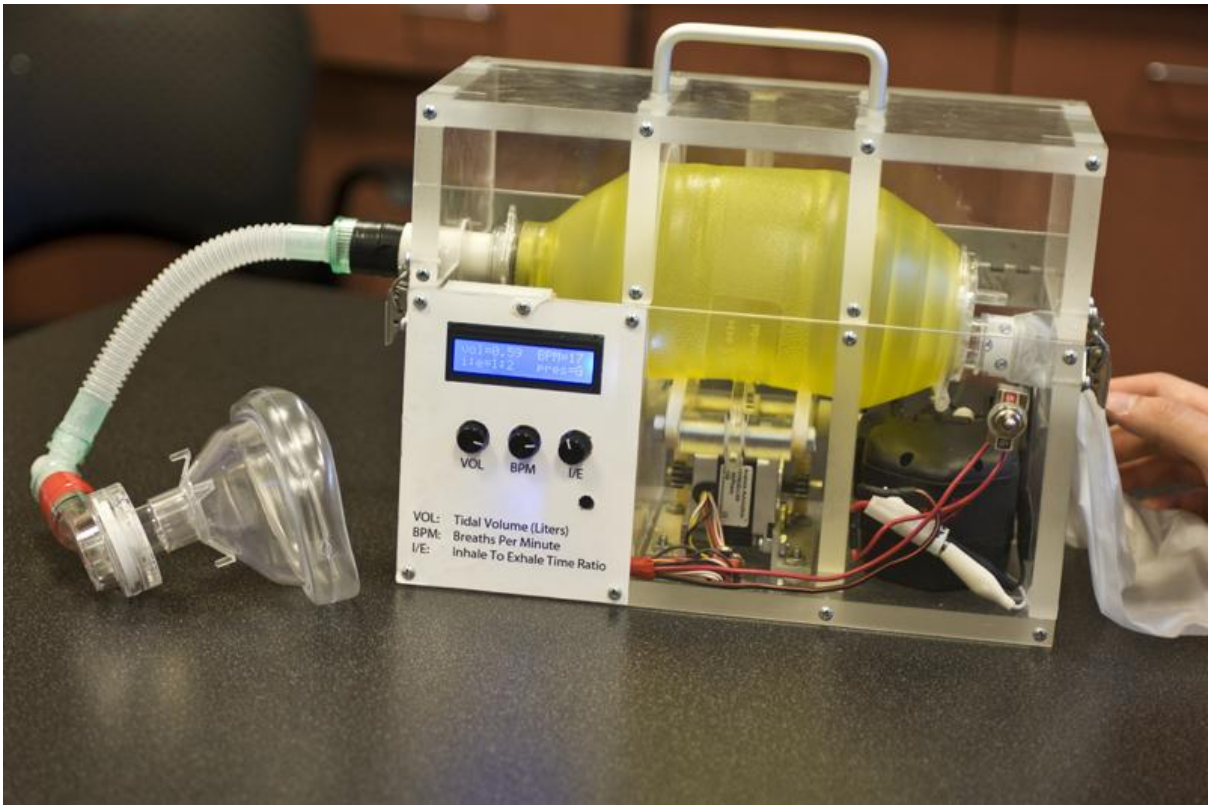
A [PEEP] fitting is [available for these bags] which seems important in treating covid



Above image from [this document]

Take note of [this caution on Ambu bag approach]
Ambu-bags may work for patients that can't breath on their own but will **not work** for lungs under distress from Covid-19. These patients need higher pressures and flow.

Existing Ambu bag designs



MIT design

MIT paper

MIT Github (code in ServoTimer1-fixedv13.zip)

Pro: Code is available now

Con: if the approach is not fully valid , maybe at least the controller code could be reused?

Rice design

Team of Rice bio and mechanical engineers worked to create an automated bag valve mask device

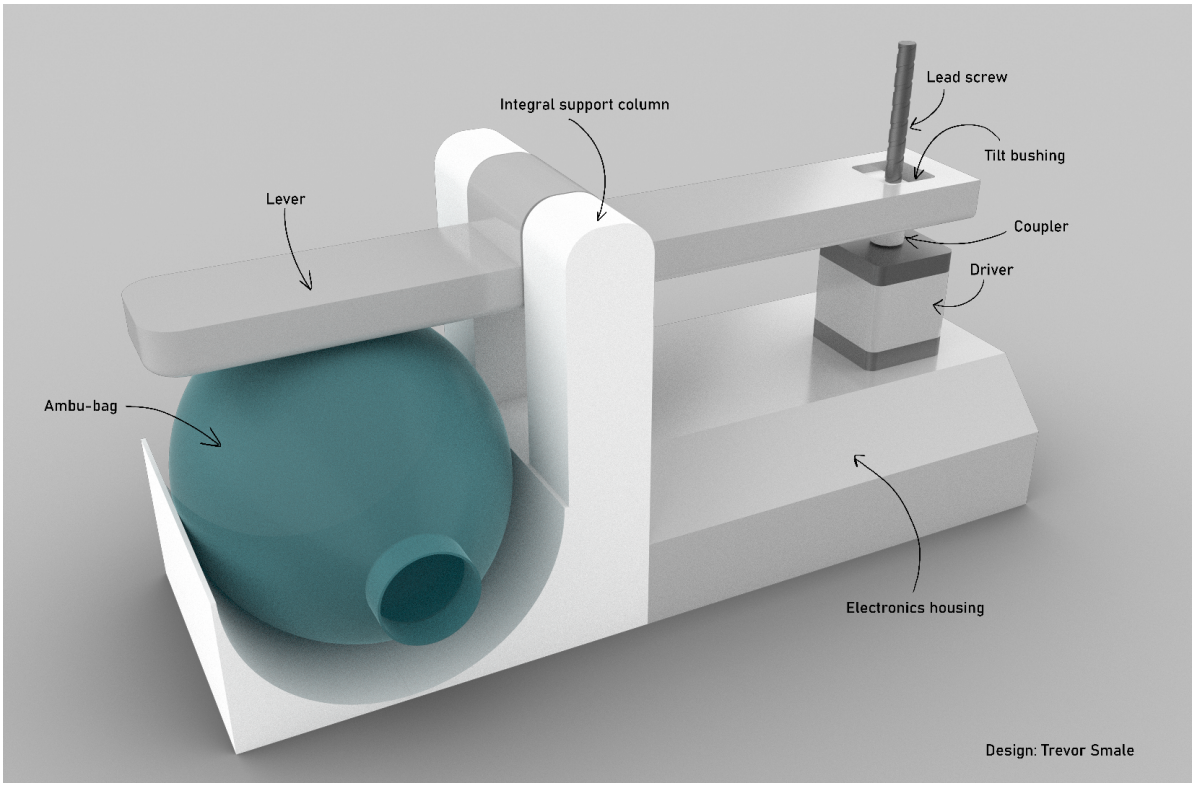
that fits around a normal Bag Valve Mask (BVM), allowing for fully autonomous compression at different speeds varying by patient size (baby, child, adult). The device works using a dual rack and pinion design with a servo motor that continuously opens and closes, squeezing the bag a certain amount to supply air to the patient. The design was set to be cheap and easy to make in low resource settings.
https://www.youtube.com/watch?v=NiMcbdYNMMI (Team video)
https://www.youtube.com/watch?v=1t2t8d8xtD0 (Rice video)
https://www.facebook.com/groups/670932227050506/permalink/672160093594386/ (Facebook post)
https://www.dropbox.com/sh/slesaaiwuweis5i/AAB8et6P9QJbhl3L8airvpdBa?dl=0&fbclid=IwAR3-v4KhINmIfEAGxiBJysaH8iEp6KXL5X-CUocq5nWurMohtq8MJ8j04jY (File archive)

Final Paper :
https://docs.google.com/document/d/1-DRXnVkJOlDCmvTzh-DgWDxeLSrZTiBYyH0ypzv8tNA/edit?usp=sharing

Code:
https://drive.google.com/a/rice.edu/file/d/1GlypT3hOTxqrytrGpGkJgi-HeJiGzdOm/view?usp=sharing

Pro: Natalie one of the developers is active and engaged in this project
Con: Servo motor failed after ~11hr in current design. CO2 accumulation.
Comment for discussion: If the servo motor failed, couldn't be just a weak part of this design? May be with a more robust motor/slight different mechanics it survive...

Decision to be made: Hendrik van Rensburg has CAD and results files that he could share if Rice would allow it- which they do not want to do for now - in the channel we are discussing if launching a petition on change.org or something like that ?



Low

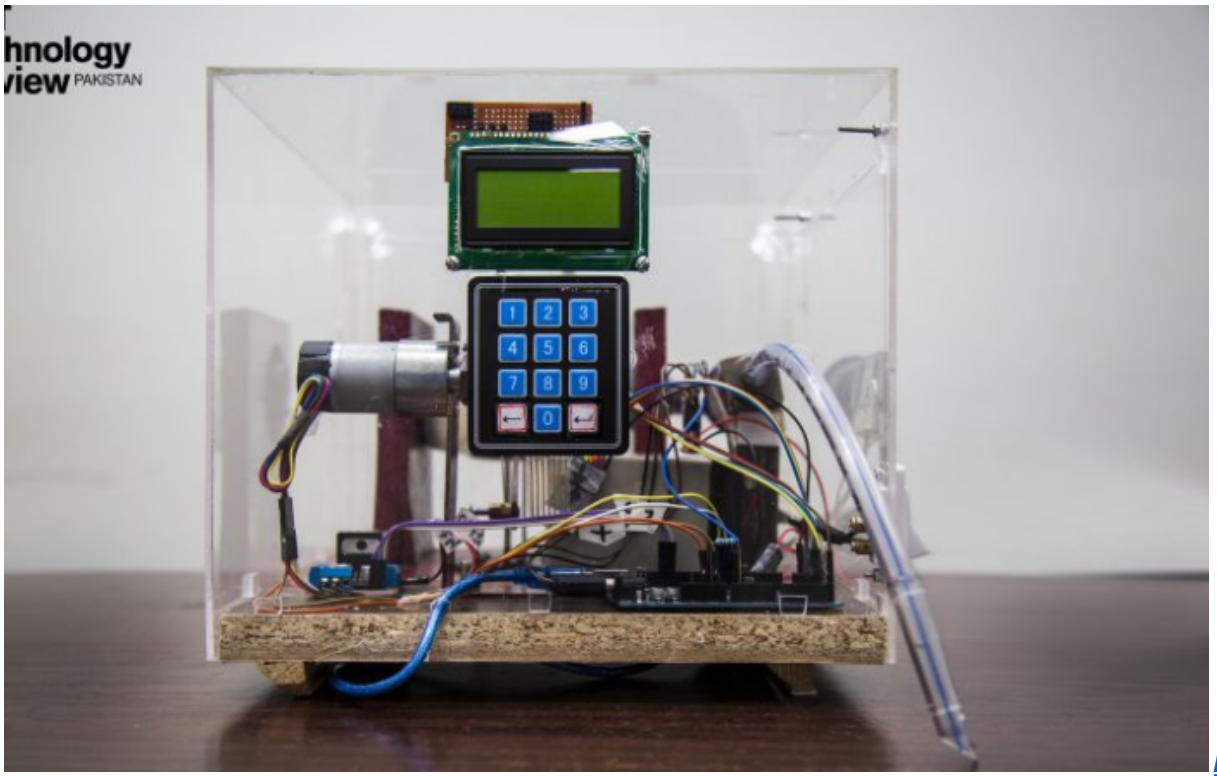
resource Ambi-bag ventilator design

This project was jump started by the COVID-19 global pandemic as a result of community discussion on a facebook group called Open Source COVID19. It builds on two projects The first from an MIT research group. The second device from a Rice University Mechanical Engineering student group. This project seeks to combine and improve the efforts of these two projects into a more simple and reliable device that consists mostly of 3D printed parts.

Features and issues found in previous designs

- Great features found in the Rice Design - Easy to use 3 button adjustment scheme (Tidal volume + -), High low pressure alerting, mostly NC fabrication methods, Compact and light.
- Issues found with the Rice Design - Multi Material (Complex construction), Seemingly fragile components, Unventilated/cooled electronics, low humidity tolerance, No proper open source files.
- Great features found in the MIT Design - Ultra reliable cam actuation mechanism, simple/repeatable motor diver circuit, Similar Easy to use 3 button schema, Hermetically sealed.
- Issues found with the MIT Design - Multi Material (Complex construction), Overtly robust/substantial, Some specialty parts.

Pro: To do
Con: Quite a lot of plastic/ slow to produce/costly on 3d



Dr. Mujeeb ur Rahman design

A motor, that regulates the flow rate and the tidal volume of the ambu bag. Both these two parameters can be monitored via sensors connected at both ends, the motor and the ambu bag. These sensors not only help in ensuring that the correct parameters are being delivered,

Pro: Includes some sensors
Con: No public code, author not (yet) responded to email

Umbulizer design

looks patent encumbered but Dr. Rahman claims that this is just a plagiarized copy of his earlier design (see above)
Pro: had undergone some clinical trial
Con: Patent encumbered, not open source

Untested Ambubag ideas

Reciprocal motion

Pro: No reversal of motor which may have led to failure in Rice design. Miicrocontroller, code, complexity may not be required
Con: todo

3D-Printer compressing an Ambu-bag

Just an idea by @Luke Tospace for now.
What if we could use 3D printers with minimal modification to compress ambu-bags directly between the build plate and the extruder system?

Pro:

- seems easier than building a completely new machine
- communication with pc is already established

Con:

- Printer can't be used for printing
- Seems quite expensive and wasteful

Intubation

See risks mentioned here

PEEP (Positive End-Expiratory Pressure)

Positive end-expiratory pressure (PEEP) is the pressure in the lungs (alveolar pressure) above atmospheric pressure (the pressure outside of the body) that exists at the end of expiration.[1] The two types of PEEP are extrinsic PEEP (PEEP applied by a ventilator) and intrinsic PEEP (PEEP caused by an incomplete exhalation). Pressure that is applied or increased during an inspiration is termed pressure support.

HFOV (High Frequency Oscillatory Ventilators)

An HFOV (High Frequency Oscillatory Ventilator) is an advanced ventilator design that is sometimes used in ARDS (Acute Respiratory Distress Syndrome) patients when a conventional ventilator will no

longer provide adequate ventilation. Using a HFOV is considered a “lung sparing” technique.
https://panvent.blogspot.com/2009/09/high-frequency-oscillatory-ventilator.html

List of device vendors

List of device vendors spreadsheet

List of ventilator projects to work through and add to the relevant sections above

Let's see what we can / should build…
List of ventilators

Another list of ventilators projects
    but warning from https://panvent.blogspot.com/2020/02/im-back.html saying "Be very cautious with the article from Mechanical Engineering Group at MIT"
A High Frequency Oscillatory Ventilator Design
https://litfl.com/high-frequency-oscillation-ventilation/
https://www.ncbi.nlm.nih.gov/pubmed/2066132

Another list, please merge with this one:
https://forum.awesystems.info/t/project-list/1230/6
Notify LukeTospace on slack, when done

Challenges with using ventilators

There are multiple problems with using ventilators. They cause a lot of lung damage so the current method calls for:
1: sedate people
2: partially paralyze them (this is to stop them from breathing on their own because they'll fight the timing of the machine)
3: turn them on their stomach for at least half the day (prone positioning)
ref: https://www.youtube.com/watch?v=okg7uq_HrhQ

Tips for avoiding 10 common CPAP problems

https://www.mayoclinic.org/diseases-conditions/sleep-apnea/in-depth/cpap/art-20044164

Technical Description

Todo: Block Diagram (feel free to add)

Operating Modes

Assist Control
Pressure Control
Pressure Support

Parameters

List of parameters which need to be measured and/or controlled:

Name	**Unit**	**Expected Measurement Range**	**Required Accuracy**		**Comments**
Temperature (T)	[C]	30-45			
Volume (V)	[m^3]				
Oxygen (PO2)					
Carbon Dioxide (PCO2)					
Pressure (P)	[Pa]				
Humidity					
Flow Rate	[m^3/s]				
Rate	[Breath/min]	10-18			

Relevant Formulas

$Lung\ Compliance$: $c = \Delta V / \Delta P$

Components

Sensors

A lot of these comments are copied from
https://www.reddit.com/r/Coronavirus/comments/fgmima/need_help_diy_3d_printed_ventilator_using_a_bag/

Pressure and Sensing Pressure

For sensing pressure, we can use the sensor BME280 from Bosch. There are breakout boards available. They are cheap.
https://www.amazon.de/dp/B07FS95JXT/ref=sr_1_3?keywords=BME280&qid=1584103782&sr=8-3

Digital communication / control

I wouldn't rely on an ESP8266 or ESP32. They're notoriously unreliable in high wireless traffic situations.

Better to just go with a simple 2 wire RS485 setup. Rock solid, easily expandable and unlikely to fail.

You don't want your patients to get brain damage because the alarm signal never reached HQ from someone downloading a movie over the wifi.

Sensing CO2

Adafruit has a plug in CO2 sensor for $20. It has to be calibrated, and it will max out at 0.8%. Is that too low?
https://www.adafruit.com/product/3566?gclid=EAIaIQobChMI17CbwsmR6AIVDL7ACh28vgz1EAQYAiABEgIZUvD_BwE
This sensor from Adafruit is not reliable because it measures also other gases. NDIR sensors are better. Like the MH-Z19B

Actors

Housing

Exhaust

The air coming out of the system will need to be filtered to prevent infection.
I am suggesting a simple 3D printed adapter from the pipe to a face-mask.

Design documents

[pVp Pressure Vent Design]

Mechanical Basis of Design (BoD)

Automated Ambu Bag - Draft

As provided to me (Ben du) HVAC ME, Mechanical Engineer, in an email from a Medical Doctor, MD (Jeffrey Ebin) regarding this project. Please correct errors and add input.
Good bag to use as a prototype, 1 month lead time
https://www.amazon.com/Simple-Breathing-Tool-Adult-Oxygen/dp/B082NK2H5R/ref=sr_1_7?dchild=1&keywords=ambu+bag+adult&qid=1584051104&sr=8-7

Without over complicating there are three controls we need for the device. Control the respiratory rate, the tidal volume, and the PEEP. This device wont be as advanced as a modern day ventilator machine but with these 3 controls it will be able to keep patients alive. Here's an explanation for each control:

1. Respiratory Rate = This is how many breaths are delivered per minute. It's usually is around 15 but the number should be adjustable between 5 and 40. Essentially this is how many times in a minute the device contracts the bag.
    a. Mechanical translation → Rate bag is squeezed

2. Tidal Volume= the amount of air that passes to the lungs with each breath. It's typically around 500cc but should be adjustable. For example, there are many situations (kids, elderly, pathology) when you want only 200cc of air and other times you want more.
    a. Mechanical translation → Amount bag is squeezed

3. PEEP= Positive End Expiratory Pressure= This is the pressure that remains in the lungs after exhalation. This one will likely be the most difficult to control but is necessary. It usually ranges around 15 mmHG (0.2 Millibar) and should be adjustable.
    a. Mechanical translation → ??????? Possibly a pressure sensor on the tube that feeds into the lungs. The controller maintains a min and max pressure in that tube. Does this need to be constantly adjusted, it seems like it can be set once manually and then left https://www.youtube.com/watch?v=ErZVwdxWevc

Regarding masks and methods of connecting it to the patient that shouldn't be an issue. When someone is on a ventilator they usually have a tube in their throat to direct the air into the lungs. If there are any unclear parts of areas you want to know more detail about dont hesitate to ask

End Mechanical Bod

Template letters

Invitation to ICU / respiratory / anesthetist to collaborate

Dear Dr _____,

I am working on an open source project to develop ventilator designs using off the shelf parts and just-in-time manufacturing techniques. I was hoping that you would be available to assist us in understanding both the needs of the medical community and the requirements of ventilation devices.

Our goal is to mitigate the mortality of the disease burden in extraordinary circumstances. These devices would only be utilized in cases where the risk of no treatment is greater than the risk of an unproven medical device. Unfortunately, the experiences of hospitals in Italy suggest this may be a regular occurence.

I certainly understand this may be a time of tremendous load on you personally, as well as the hospitals you are involved with. There is no need to reply if you are unable to assist. I wish you health, safety, and rest.

Yours sincerely and in haste,
AJP

Link to project
Link to google doc (no designs there yet)
Link to slack channel

==========END==========