Loop PEEP Test Report 2020-04-12 v2

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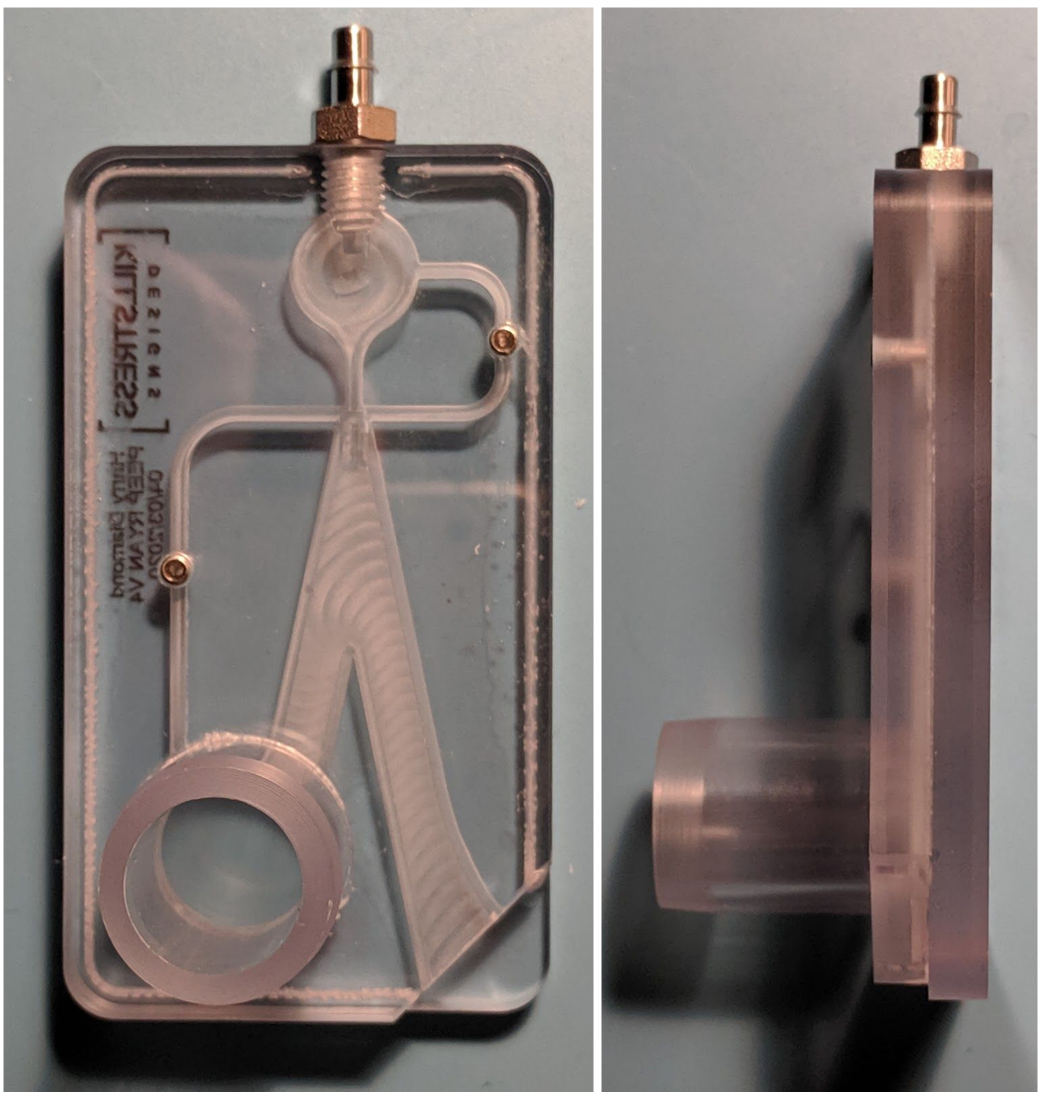
CAD files

https://github.com/MillionVentilators/ARMEE_Ventilator_1.0/raw/master/models/Harry_Diamond_PEEP_Ryan%20v5.f3d
https://github.com/MillionVentilators/ARMEE_Ventilator_1.0/raw/master/models/Harry_Diamond_PEEP_Ryan%20v5.step

Photos



(as-tested device made by Tyler Smutz)

Construction

The device is constructed from 1/4" polycarbonate sheet stock, McMaster-Carr 8574K172 or equivalent.

Mill the channels into the top piece to the depth and width shown in the CAD file +- 0.05mm. Channel cross section area is a critical dimension. Do NOT mill the face which will become a joint between the pieces: it should have the original smooth surface from the plastic sheet. Make sure the channel sides and bottom are smooth (surface finish ISO N6 or better).

Tap the adjustment screw holes using a M3x0.5 tap. Make sure that there are no burrs left, and the face which will be joined to the other piece is flat.

As tested: Tape the top and bottom pieces together to ensure proper alignment. Slowly inject a few ml of water-thin acrylic solvent cement, IPS Weld-On 3, SciGrip 3, McMaster-Carr 7528A13 or equivalent, into the "v" grooves that run around the periphery of the part. Watch the "v" grooves fill with solvent and stop filling as soon as the solvent reaches the end of the groove. Let sit for 30 minutes before removing tape. Inject the solvent using a Precision Needle-Tip Squeeze Bottle, McMaster-Carr 1902T111 or equivalent, to keep the fumes contained.

(Alternate method: Spread a thin, uniform layer of solvent cement on the cover; place the piece with the channels on top of it and clamp. Best method still a work in progress)

Tap the input fitting hole using a M6x1 tap.

Adjustment screws: Stainless Steel Flat-Tip Set Screw, M3 x 0.5 mm Thread, 6 mm Long
McMaster-Carr 92605A100

Input fitting: Stainless Steel Barbed Tube Fitting, 4mm Tube ID, M6 x 1 mm Male
McMaster-Carr 4406T772

Equipment

Ventilator analyzer: Fluke VT Plus HF gas flow analyzer; can substitute Fluke VT650/VT900A, TSI Certifier FA Plus 4080, IMT Analytics Citrex H3/H4/H5 or equivalent

Air source: Porter Cable C2002; or any other oil-free compressor capable of at least 2 scfm and 50psi; or medical air wall outlet

Flow adjustment valve: McMaster-Carr 46425K12 or equivalent

Test lungs: rigid volume, two 5.5 gallon glass carboys, detailed construction as described in "How To Make Your Own Accurate Test Lungs for Testing Emergency Ventilators"

Calibration

Connect the input of the device to a source of compressed air regulated to 50psi and with a precise flow adjustment valve at the output.

Connect the output of the device to the analyzer, and the output of the analyzer to the test lung with compliance 30 +-2 ml/cmH2O and resistance < 3 cmH2O/(liter/second).

Turn both adjustments screws so they are fully in. Do NOT overtighten as they can crack the joint between plastic pieces; just turn until they bottom out.

Close off the connection to the test lung, then open the input valve and adjust the flow to 38 +- 2 lpm.

Open the connection to the test lung.

Slowly open (turn counterclockwise) the output adjusting screw until tidal volume is 450 +- 50 ml. As this point the device should be cycling steadily, with PIP approx 25 cmH2O and PEEP at 0.

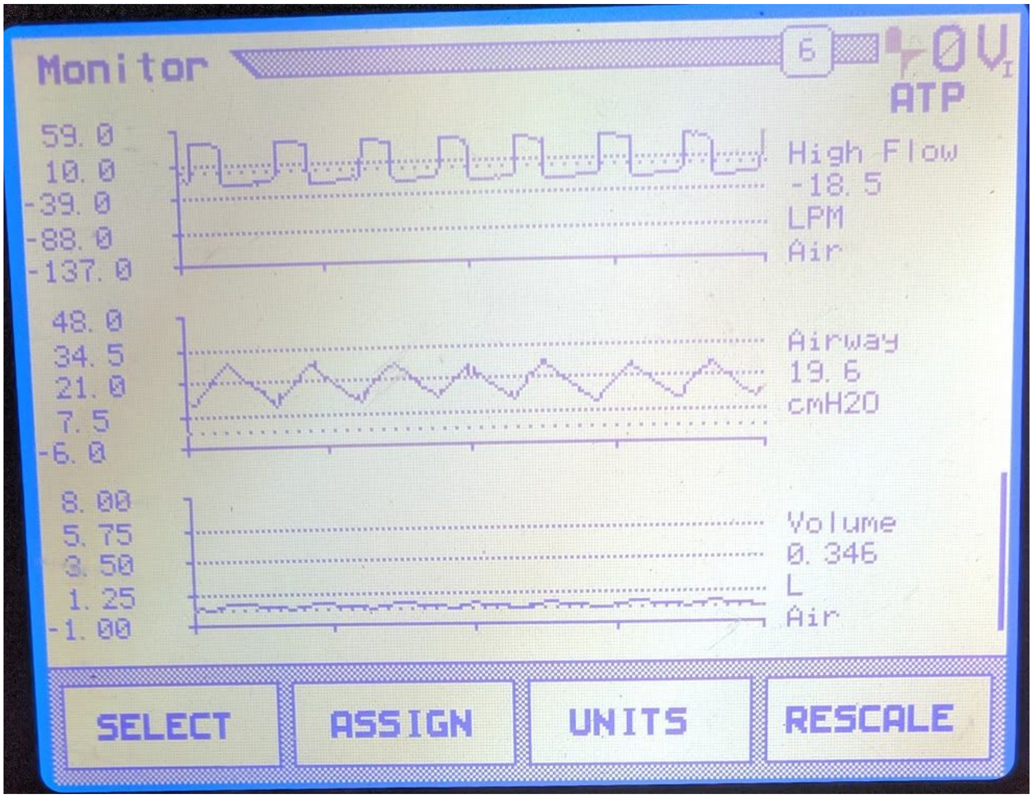
Slowly open (turn counterclockwise) the PEEP adjusting screw until PEEP is approx 10 cmH2O.

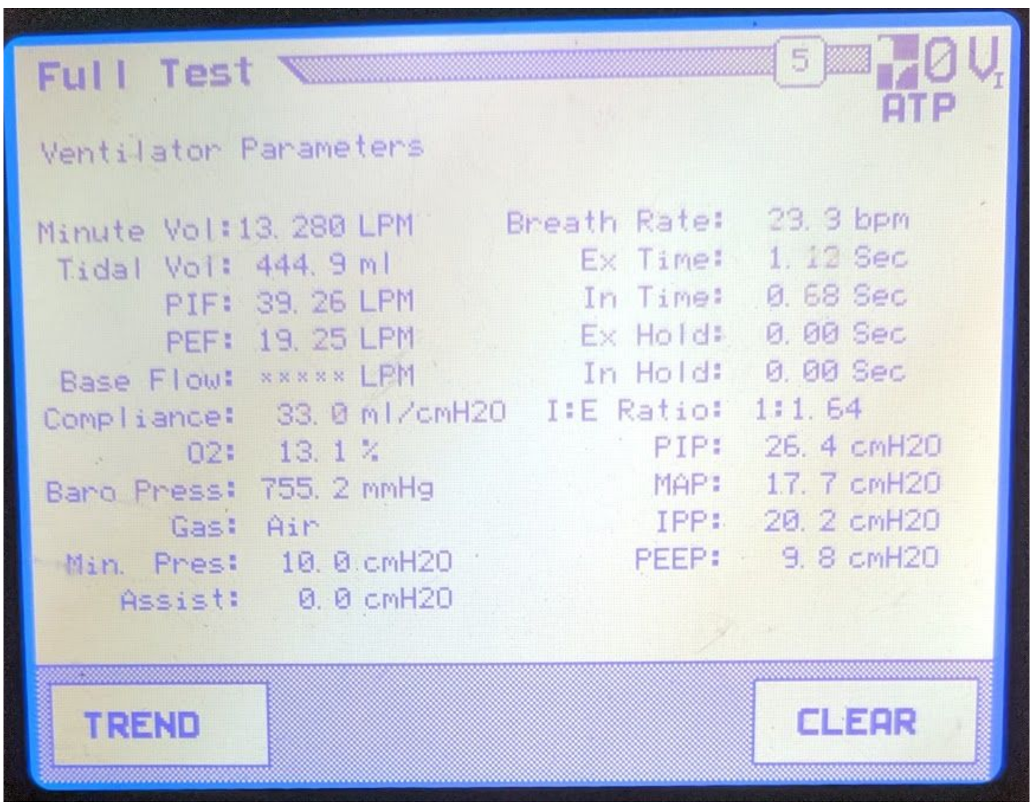
On this particular device, the output screw was open by 0.56 mm and PEEP screw by 0.14 mm.

Results

The operation of the device is stable and cycles between PIP 25-26 cmH2O and PEEP 9-10 cmH2O. Tidal volume is 450+-20 ml.

The flow rate and airway pressure appear well behaved; see screenshots from Fluke VT Plus analyzer below.


Monitor
6
ATP
59.0
10.0
-39.0
-88.0
-137.0
High Flow
-18.5
LPM
Air
48.0
34.5
21.0
7.5
-6.0
Airway
19.6
cmH20
8.00
5.75
3.50
1.25
-1.00
Volume
0.346
L
Air
SELECT
ASSIGN
UNITS
RESCALE


Full Test
5
ATP
Ventilator Parameters
Minute Vol:13.280 LPM
Tidal Vol: 444.9 ml
PIF: 39.26 LPM
PEF: 19.25 LPM
Base Flow: ***** LPM
Compliance: 33.0 ml/cmH20
02: 13.1 %
Baro Press: 755.2 mmHg
Gas: Air
Min. Pres: 10.0 cmH20
Assist: 0.0 cmH20
Breath Rate: 23.3 bpm
Ex Time: 1.12 Sec
In Time: 0.68 Sec
Ex Hold: 0.00 Sec
In Hold: 0.00 Sec
I:E Ratio: 1:1.64
PIP: 26.4 cmH20
MAP: 17.7 cmH20
IPP: 20.2 cmH20
PEEP: 9.8 cmH20
TREND
CLEAR

However, it was not possible to get a respiratory rate significantly less than 30 bpm with this device, unless the tidal volume was also much larger.

It appears that, for a given geometry, input flow rate, and lung compliance, the rate at which airway pressure rises and falls is relatively fixed, and is not affected by the PIP/PEEP adjustments. Thus, low (or zero) PEEP results in much lower respiratory rates.

If PEEP was non-zero (adjustment screw not fully in), there is a bit of switching noise (seen as pressure fluctuations) during both transitions. This is visible in the traces above; the magnitude appears to be 3-5 cmH_2O p-p. This corresponds to audible noise, probably as the flow oscillates rapidly between the two channels. Low input flow rates, and possibly some positions of the PEEP screw, can make this a lot more prominent, and it can last for much longer. This was the main reason the calibration was done at 38 lpm rather than the more typical for this design 30-34 lpm.

The operation does not appear to be affected by changes in resistance probably between R <2 and R >10.

Further work

- Modify design to eliminate pressure fluctuations during switching

- Test effect of different lung compliance and resistance values

- For a fixed calibration, draw curves of PIP/PEEP/RR/TV versus input flow

FAQ

Can I 3D print this?

Maybe! You're welcome to experiment (and let us know what you find).

There have been successful prints made, but we don't yet have a design we can recommend. Figuring out how to make this require less precise tolerances and a less smooth surface finish is a work in progress.

Can I mill this from materials other than polycarbonate?

Again, maybe! In general, it is the shape that matters, not the material.

A lot of our development work was done using milled aluminum pieces which were bolted together. This typically works fine. However, it is a lot harder to guarantee that the joint between the two pieces is sufficiently air-tight with metal. Also, aluminum is not recommended as a material to use in a pure oxygen atmosphere. That's why we don't recommend that style of construction outside of prototyping.

Acrylic should work equivalently to polycarbonate, but is less compatible with alcohol-based disinfectants.

Other plastics may also work, as long as the shape and tolerances can be guaranteed and the two pieces can be joined in an air-tight way. It may be possible to use another glue (not a solvent cement) or a gasket. However both may interfere with the flow channels, so we don't have a specific recommendation for a glue or gasket based build yet.

Disclaimer

This device described here is an engineering prototype. It is **not a medical device** and it is not intended for use in humans. We can't guarantee absolutely anything about it, including whether it is safe, whether it is suitable for any particular use, or whether it would work the same when you build it. The specific device tested (N=1) did exactly what is described in this report. That's all.

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