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Apollo-19 Ventilator Project

Comparisons, Grading and Alternatives

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4/27/2020

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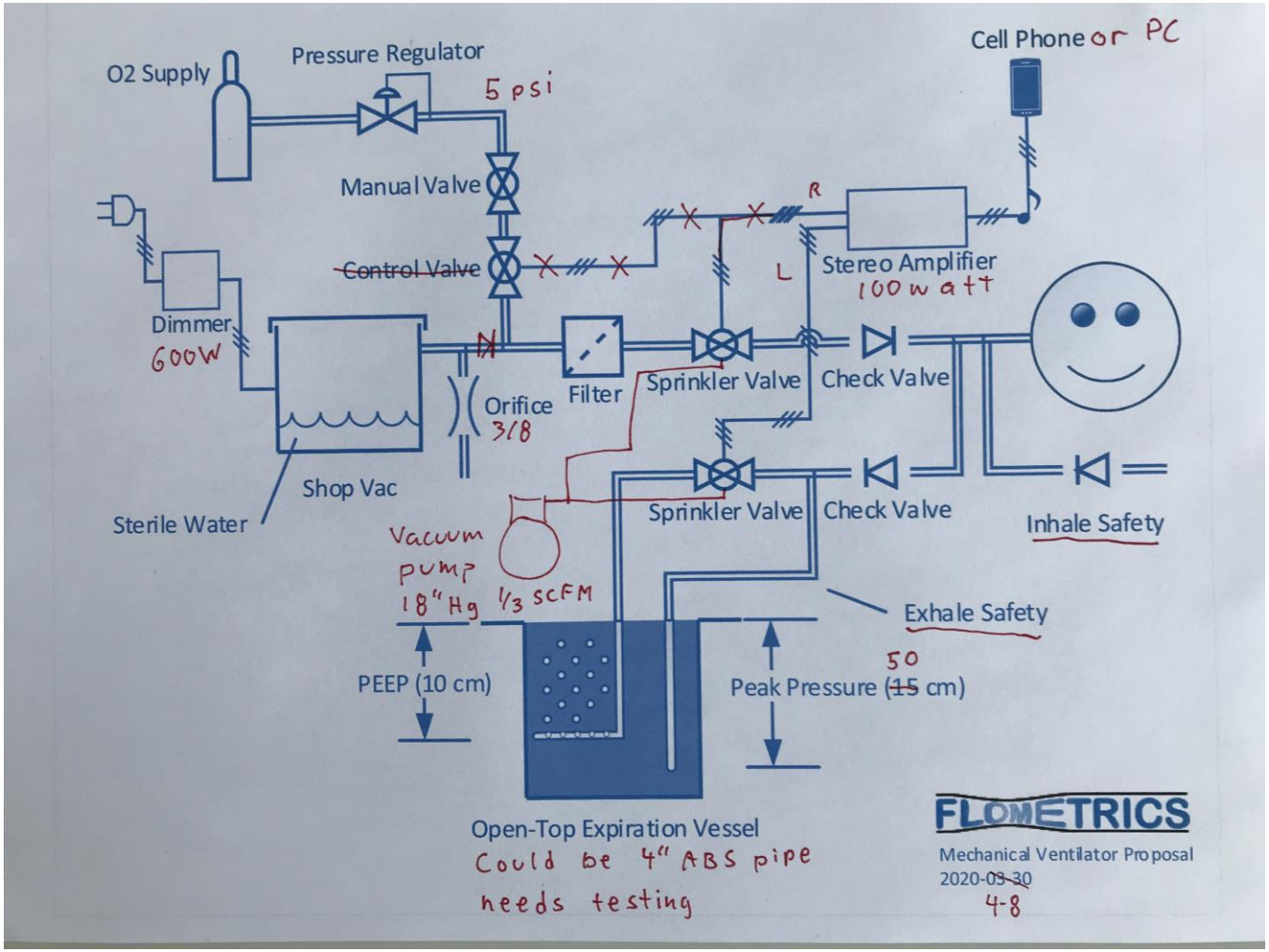
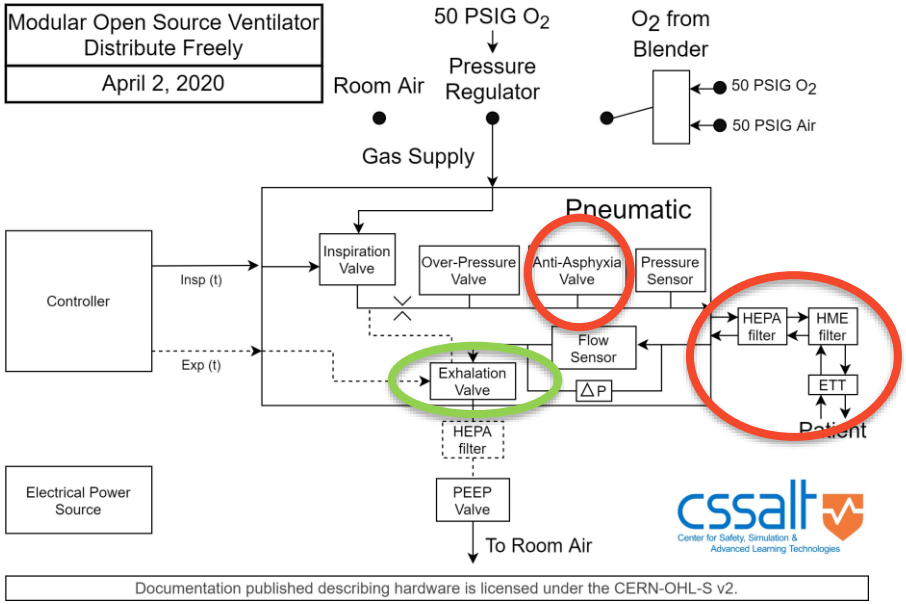
Outline

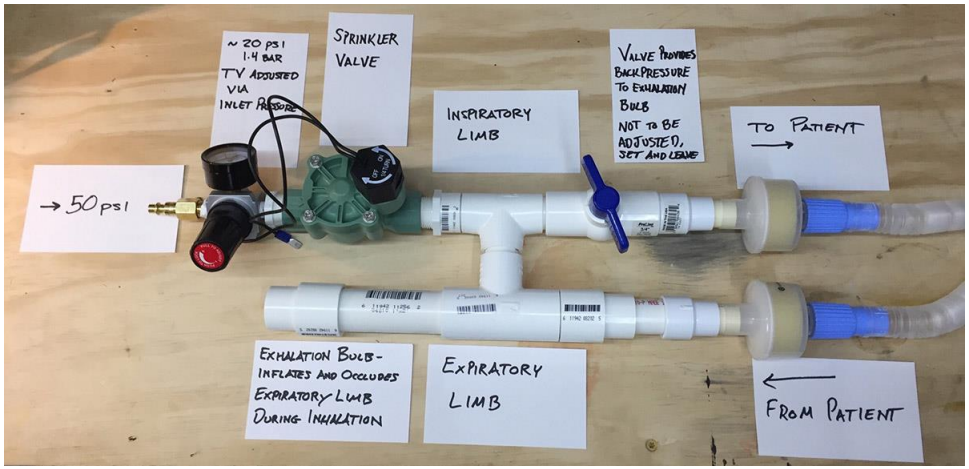
- System Comparisons – Major Differences
  - Flometrics (Steve Harrington) Mechanical Ventilator Proposal, dated 4/8/20
  - University of Florida Health (UFH) Modular Open Source Ventilator, v 1.2
- Grading Matrix
- Component-level alternatives
  - Control valves
  - Check valves
  - Pressure Relief/Regulation
  - Instrumentation
  - Flow throttling (Flometrics)
  - Vacuum Pump (Flometrics)

Flometrics (Steve Harrington) Mechanical Ventilator Proposal, 4-8-2020

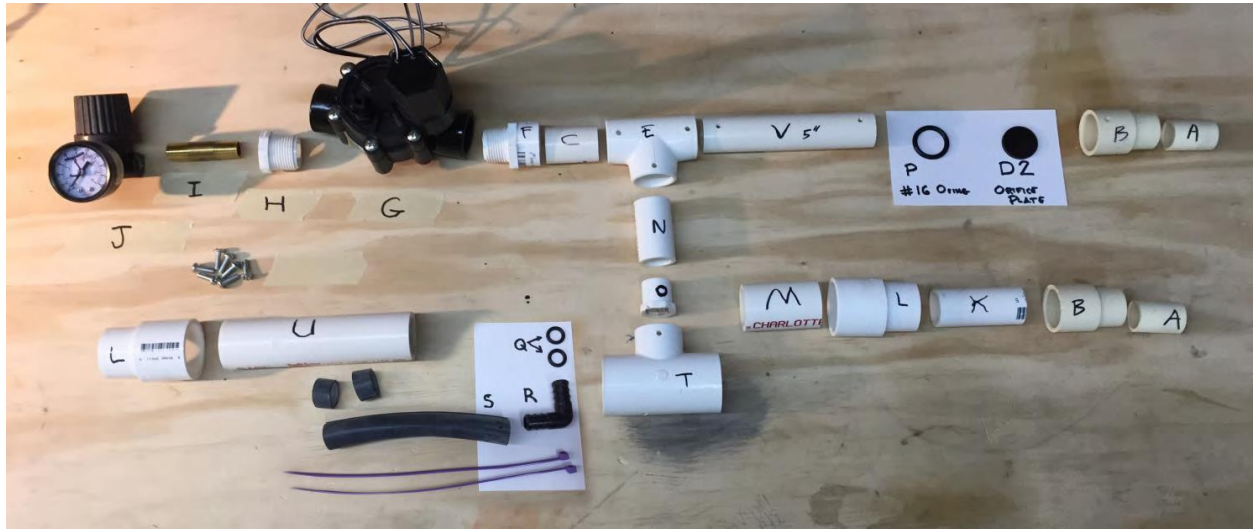


University of Florida's Health Modular Open Source Ventilator v1.2





Passive valve made by a bladder that blocks the expiratory limb during inhale



System Comparisons – Air Supply

	UFH	Flometrics
Type	Pressurized air/O_2 (could be hospital bedside air, compressor, air tank)	Shop vacuum
Pros	- Known reliability - Can serve multiple systems/patients with single compressor - More adaptable (can use variety of pressure sources without changing system operation)	- Does not need air supply infrastructure/modularity - can be used in non-hospital setting (only needs power)
Cons	- Requires separate air supply infrastructure (bedside air, compressor, etc.) - Pressure may require regulation depending on system needs	- System requires use of vacuum pump to provide sufficient deltaP for sprinkler valve operation - One shop vac per system/patient - Less adaptable - Reliability testing done by ShopVac indicates consumer units will not survive 2 week continuous runtime (commercial grade units recommended)

System Comparisons – Control Valves

	UFH	Flometrics
Inspiratory	Sprinkler valve	Sprinkler valve with vacuum assist
Expiratory	Custom passive bladder valve	Sprinkler valve with vacuum assist
Pros	- Requires one sprinkler valve (procurement, reliability advantages)	- Active control over expiratory valve timing
Cons	- No active control over expiratory valve timing - Build variability in passive bladder valve - Highly dependent on inner tube selection and assembly	- Requires two sprinkler valves - Modifications required to valve (build variability - Vacuum system required

System Comparisons – Control Systems

	UFH	Flometrics
User Interface	2x16 LCD Display with potentiometer knob and push button	Cell Phone or PC
Controller/Driver	Arduino	Stereo Amplifier
Pros	- Robust user interface - Sensor integration options	- Can potentially adjust additional settings
Cons	- Cannot easily adjust additional settings	- Dependent on additional device (phone/PC) - Sensor Integration

*Neither control system was tested at LANL. A custom system was developed to meet our operating and testing needs.

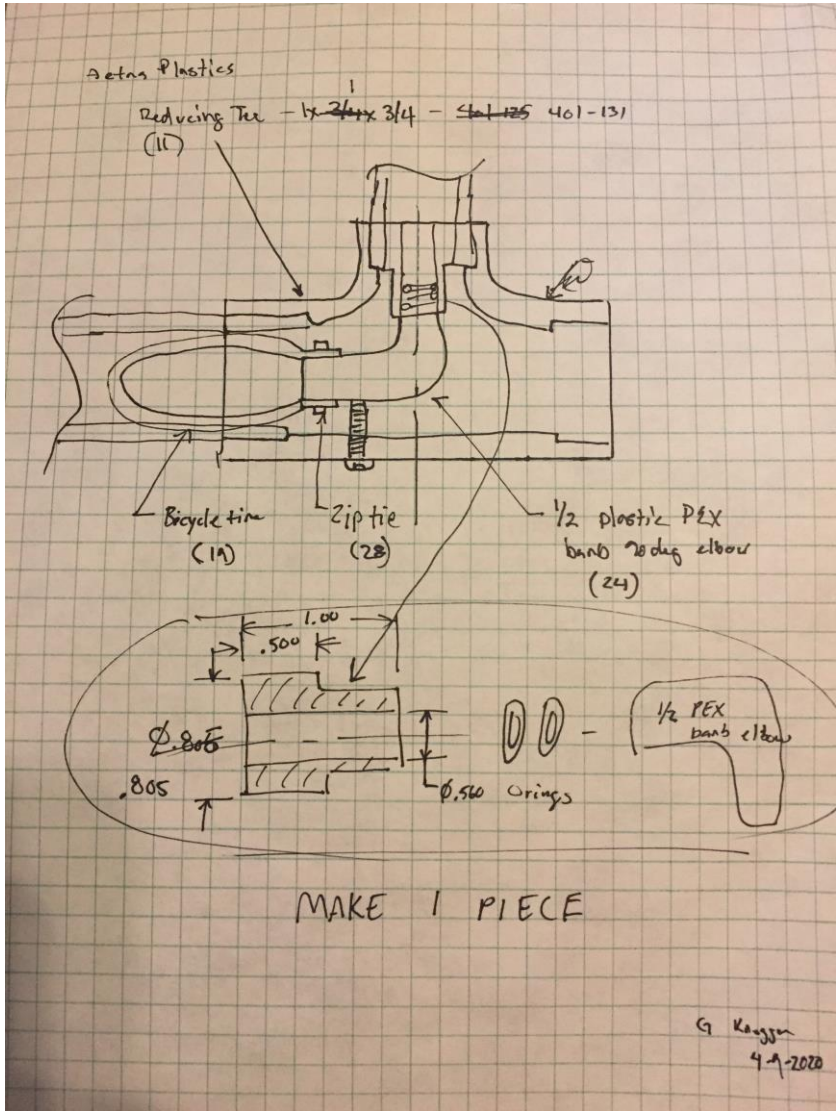
Grading Matrix

Criteria	Flometrics (Steve Harrington) Ventilator, 4/8/2020	University of Florida Health (UFH) Modular Open Source Ventilator, v1.2	Comments
	Baseline		
Does it function	0	0	Both function well at steady state conditions.
Can it sustain continuous operation for 400 hours	0	0	More long term testing on UFH, Preliminary function testing at LANL shows no major concerns
Amount of routine maintenance for continuous running	0	-1	UFH design does not allow for on the fly adjustments. Orifice plate must be switched out.
Component/System reliability	0	0	Limited cyclic testing cannot validate either. Recommend swapping for intended use components
Ease of procurement (assume 500-2000 systems needed)	0	1	Shop vacs and vacuum pumps may be harder to procure.
Number of components	0	1	
Amount of off the shelf component modification needed	0	1	Sprinkler valve modification can be challenging (one destroyed during build). UFH requires lathe for one part, AM could replace this.
Ease of assembly	0	0	After modifications, assembly fairly straight forward.
Ease of operation	0	0	Depends on final complexity of control system
Is the system adaptable to meet a patients needs, adjustments requi	0	-1	More control over active exhaust valve, adjustments require orifice plate swap.
Is the system adaptable to serve multiple patients	0	1	Higher pressure and flow line may be more capable of supporting multiple patients
Component materials safe for human ventilator use	0	0	Unknown components and chemicals used in sprinkler valves.
Safety systems present (anti-asphyxiation valve, exhale over-pressure valve)	0	-1	Original UFH design does not include but could be added in easily
Sensors, real-time monitoring and alarms	0	1	microcontroller offers more options for integration with digital sensors than speaker amplifier
Can the components be sterilized (outside or inside/outside if internal systems cannot be isolated)	0	0	Unknown
Certified components (UL, ASTM, etc.)	0	0	No clear specifications on sprinkler valves
General Pressure Safety	0	-1	UFH system operates at higher pressure but reasonably low risk
Total	**0**	**1**	

Component Level Alternatives – Control Valve

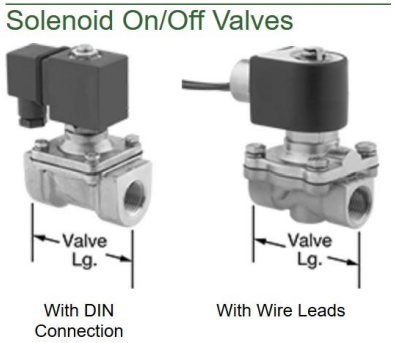
- AM part for improving UFH bladder valve design
- Improves UFH bladder valve
  - Original design made of three parts:
    1. ½ in. PEX barb 90-Degree elbow
    2. (2) O-rings
    3. Schedule 40 1/2 in. Spigot x 1/2 in. Dia. Slip PVC Plug, ***modified using lathe***
  - Replaces all three parts
  - No lathe required!
  - Simplifies assembly
  - New part can be easily 3-d printed, estimate 5-7 days for required quantities (~1000 parts) using W-11/E div printers

Prototype AM part



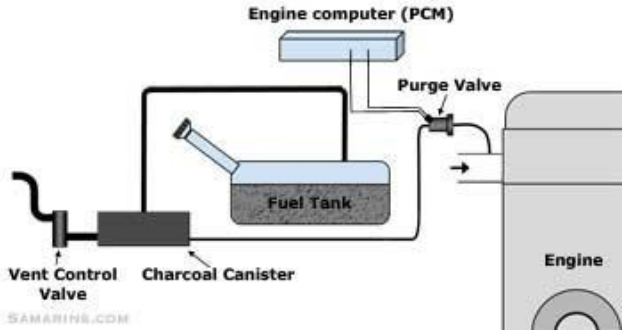
Component Level Alternatives – Control Valve

- Pneumatic Solenoid Valve
  - Replaces sprinkler control or UFH bladder valve
    - Readily available from McMaster (1000 within a week)
    - Solenoid-driven, 24 VDC or VAC
    - Engineered for pneumatic systems, not liquid (operating under intended use)
    - Certified
    - $80



Pneumatic solenoid valve

- Automotive Canister Purge Valve
  - Replaces sprinkler control or UFH bladder valve
    - Part of the vehicle Evaporative Emission Control (EVAP) system
    - Solenoid-driven, 12 VDC
    - Can be partially opened
    - Operating flow rates/pressures unknown
    - Assumed to be widely available in large quantities
    - $25-$50



Canister purge valve

Component Level Alternatives – Control Valve

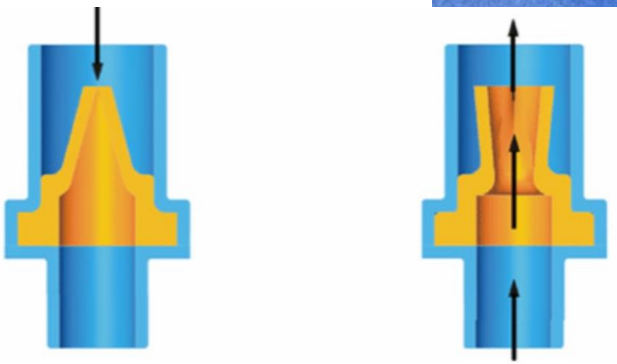
- DC solenoid sprinkler valve
  - Replaces 24 VAC sprinkler valve (additional complexity of controlling AC solenoid)
    - DIG In-line sprinkler valve with DC solenoid
      - 6-12 VDC latching solenoid
      - ¾ in. NPT
      - 10 - 150 psi
      - $42, availability unknown
    - Hunter 9 VDC solenoid for battery powered systems
      - Designed to be swapped into Hunter sprinkler valves
      - $20, availability unknown

DIG sprinkler valve

Hunter 9 VDC solenoid

Component Level Alternatives – Check valves

- Philips Respironics Universal Inline Pressure Valve (PN 302418)
  - Is a medical device
  - Availability TBD
- Duck Bill Valve
  - Low pressure to operate
  - Basic Design
  - Readily Available
  - Easy Material Validation (Rubber/elastomer)
- Exhalation valve
  - Low pressure to operate
  - Basic Design
  - Availability questionable with high mask production
  - Easy material validation



Component Level Alternatives - Instrumentation

- Pressure
  - Standard Gauges (Analog)
    - Readily available
    - Requires user monitoring
  - Manometer
    - Can be built using simple parts
    - Requires user monitoring
  - Digital pressure sensor (integrates with control system)
    - Readily available
    - More accurate tracking, can be linked to controller alarm system
- Flow
  - Venturi Meter
    - Can be built using simple parts
    - Requires user monitoring
  - Ultrasonic Sensor for microcontroller
    - Validation concerns
  - Pneumatic inline flow meters
    - Readily available

Component Level Alternatives – Flow Throttling

- Shop vacuum flow throttling
  - Replaces dimmer switch/variac throttling of shop vac motor (shop vac runs at full power)
    - Use manual flow control valve after shop vac outlet
    - Could be 3-D printed
    - Will require shop vac to run at full power – may affect motor life

Component Level Alternatives – Vacuum Pump

- Vacuum pump for Flometrics system (need 1/3 SCFM)
  - Replaces Home Depot Stark 3 CFM Vacuum Pump
    - Fixed Flow Air-powered vacuum pump (Venturi Pump)
      - 0.5 - 28 CFM
      - 25 – 28 in of Hg max vacuum
      - Requires 75 - 80 psi compressed air to operate
      - No moving parts
      - Readily available from McMaster (1000 within a week)
      - $73 - $370
    - Small DC Pump*
      - 12V
      - 12W
      - 0-16 in of HG vacuum
      - Total availability unknown

Stark >

1/4 HP 3 CFM Rotary Air Vacuum Pump HVAC A/C Refrigerant

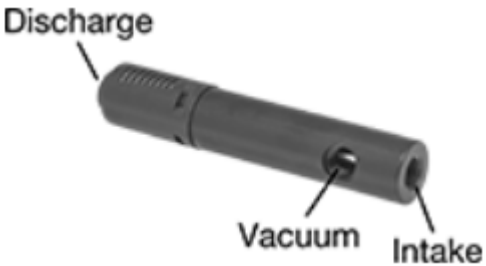
★★★★½ (13) Write a Review Questions & Answers (5)

- Eliminates all moisture from conditioning systems in little time
- Built to be highly durable and cost efficient
- Self diagnostic tool for A/C repair and HVAC refrigerant recovery

$65.98

Home Depot Vacuum Pump

DC Pump



Venturi Pump

*Some system testing has led to overheating.

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