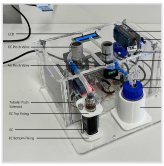

May 13, 2021

ECAM: A low-cost vaping device for collection of electronic cigarette condensate and in vitro studies

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 dx.doi.org/10.17504/protocols.io.bswunfew

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ABSTRACT

The use of electronic cigarettes (ECs) has become widespread despite many unknowns around their long-term health impact. ECs work by vapourising a liquid, known as an e-liquid, typically consisting of propylene glycol, glycerol, flavourings and nicotine. The chemical constituents and resultant impact on cells and tissue are dependent on several factors, including the flavourings used, the vaping topography/use pattern, and the device used. ECAM (Electronic Cigarette Aerosol Machine) is an open source, portable device for creating EC aerosol – for condensate collection and *in vitro* studies - using a controlled methodology. ECAM was developed as a low cost, automated, and customisable alternative to commercial devices. ECAM consists of a micro diaphragm gas pump to draw air/EC aerosol through the system. The device is automated using an Arduino and solenoid pinch values are used to alternate between air and EC vapour. Condensate is collected in a vial within a cold-water bath. Each ECAM unit uses a temperature/humidity sensor to measure ambient air conditions and a differential pressure sensor to determine the pressure within the system. ECAM is programmed to adhere to International Standards Organisation 20768:2018. The design files, source code, and build instructions for this device can be found at https://osf.io/3ngu4/.

DOI

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PROTOCOL CITATION

Rosa T Campbell, Kelly Burrowes, Vinod Suresh 2021. ECAM: A low-cost vaping device for collection of electronic cigarette condensate and in vitro studies. **protocols.io**
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KEYWORDS

electronic cigarette, vape, aerosol, machine, condensate, machine, automated

CREATED

Mar 02, 2021

LAST MODIFIED

May 14, 2021

PROTOCOL INTEGER ID

47796

MATERIALS TEXT

All the required materials are listed in the bill of materials that can be downloaded from https://osf.io/jdfge/?pid=3ngu4.

SAFETY WARNINGS

When using the soldering iron:

- Never touch the element of the soldering iron.
- Hold wires to be heated with tweezers or clamps.
- Keep the cleaning sponge wet during use.
- Always return the soldering iron to its stand when not in use. Never put it down on the workbench.
- Turn unit off and unplug when not in use.

When using the drill, hole saw and dremel rotary tool:

- Wear eye protection (safety glasses or goggles).
- Tuck in loose clothing, tie back long hair, and remove dangling jewelry.
- Make sure the drill bit is seated correctly in the chuck jaws when tightening and remove the chuck key before using the drill.

When handling needles:

- DO NOT uncover or unwrap the sharp object until it is time to use it.
- Keep the object pointed away from yourself and other people at all times.

DISCLAIMER:

BEFORE STARTING

Please refer to the bill of materials that can be downloaded from https://osf.io/jdfge/?pid=3ngu4.

Case Construction

1 The Structure holds all electrical, mechanical and pneumatic components of ECAM. The parts required are:

- **A1** Acrylic Sheets
- **A2** M6 Threaded Rod
- **A3** 4xM6 Hex Nuts
- **A4** 4xM6 Washers
- **A12** M8 x100 mm Bolts

Consumables

- **X5** Electronic Cigarette

Recommended Tools

- **Z1** M3 Tap
- **Z2** M3 Tap Wrench
- **Z3** M8 Tap
- **Z4** M8 Tap Wrench
- **Z5** Hacksaw
- **Z14** Spanner

2 Download the 3D Printing STL files from https://osf.io/sc7eb/ and using an FDM 3D printer, print with settings:

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- Infill: 20%
- Wall line count: 3
- Layer Height: 0.1 mm

When the print is finished, remove supports and sand down the rough edges.

3 Laser cutting

3.1 Download the laser cutting files from https://osf.io/chvne/

The laser cut components have been laid out in two template drawings of maximum dimensions 400x600 mm, the size of the acrylic sheets (**A1**)
- ECAM_011, 012 v1.SLDDRW
- ECAM_013, 014, 015, 016 v1.SLDDRW.

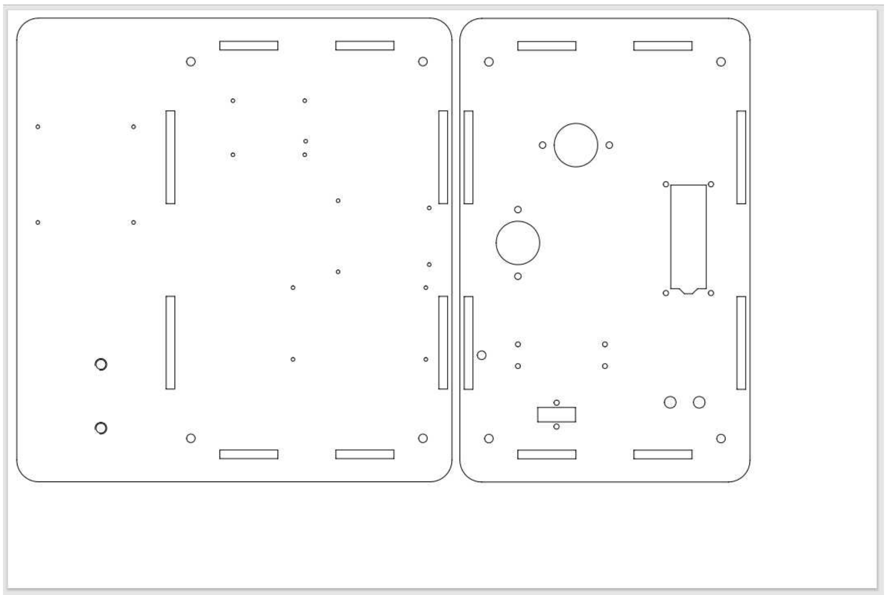

Image of the base and top acrylic components on one acrylic sheet

3.2 Tap the holes indicated in the drawing files below, located in the 'Laser Cutting Files" folder https://osf.io/chvne/. Holes marked with M3 should be tapped using the M3 tap (**Z1**) and the M3 tap wrench (**Z2**). Holes marked with M8 should be tapped using M8 tap (**Z3**) and M8 tap wrench (**Z4**).
- TappedHolesECAM_011 v1 AcrylicBase6mm
- TappedHolesECAM_013 v1 AcrylicLeftWall6mm
- TappedHolesECAM_014 v1 AcrylicRightWall6mm

Holes not marked are through holes and have been laser cut to specification.

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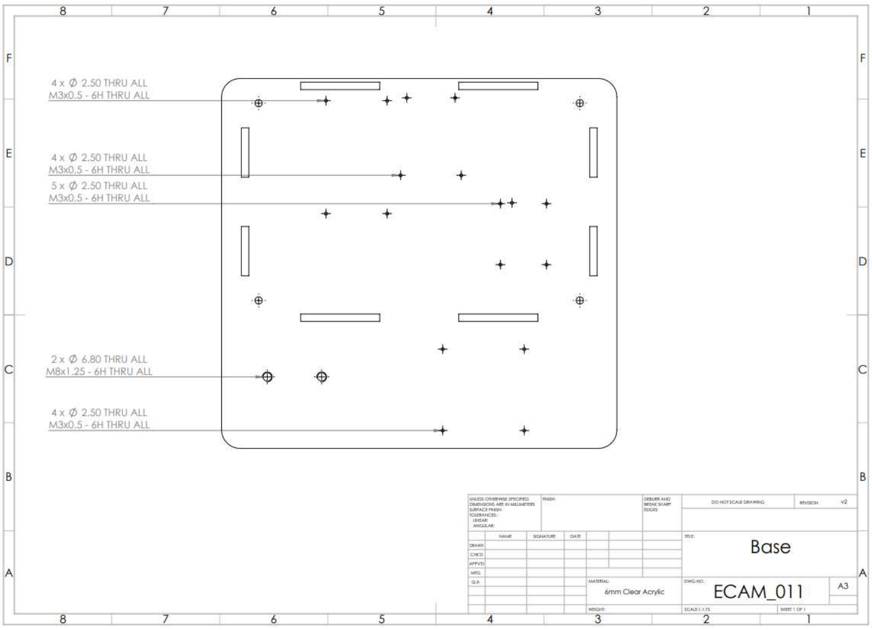
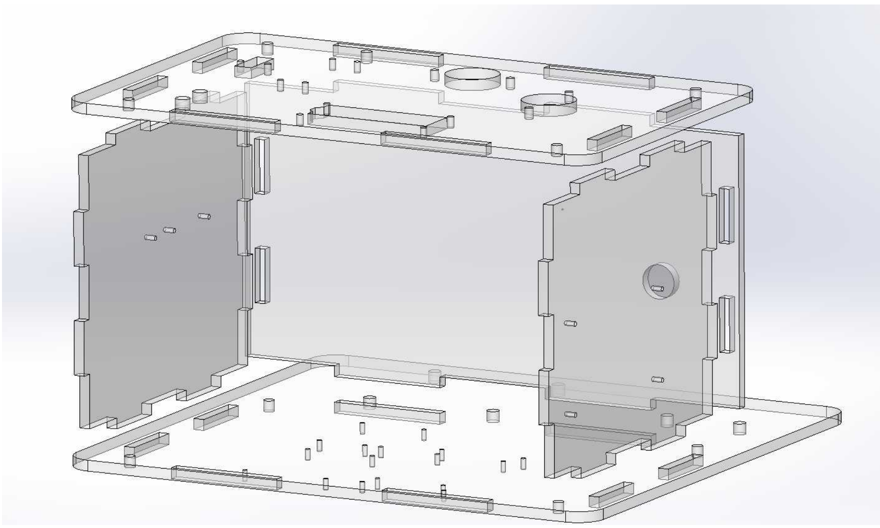


Example drawing of the 21xM3 holes and 2M8 holes to tap in the base.

3.3 Slot the left (ECAM_013), right (ECAM_014), and front (ECAM_015) walls into the base (ECAM_011). Then slot the top (ECAM_012) onto these walls.



Exploded view of the acrylic assembly base, top, left, right and front walls.

4 Prepare the threaded rod (**A2**)

4.1 Cut the 1m threaded rod (**A2**) to 4 pieces, each 170 mm long using a hack saw (**Z5**).

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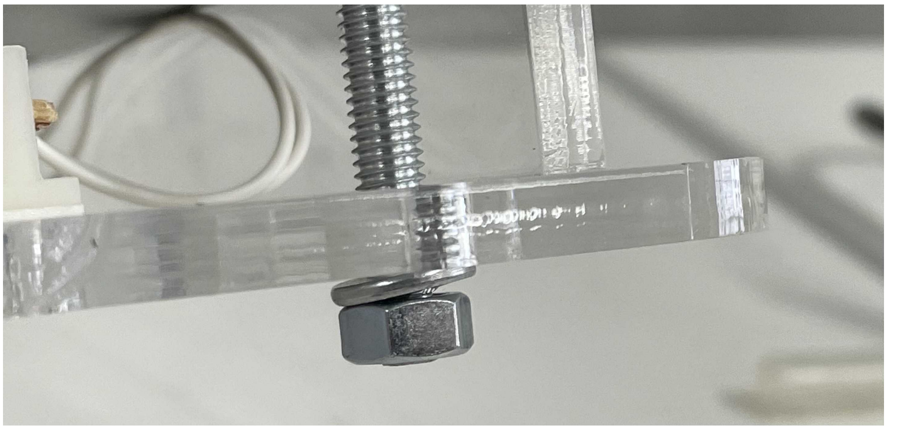
4.2 Place each rod through the clearance holes in the corners of the top (ECAM_012) and base (ECAM_011).

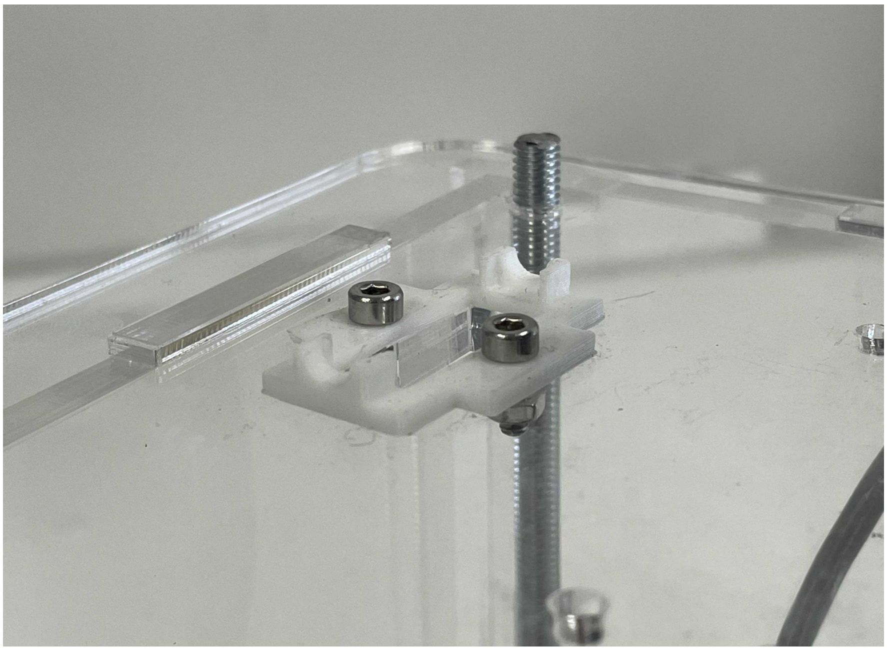
Rendered view showing threaded rod in place.

4.3 For each of the four rods, place 4 spring washers (**A4**) over the four threaded rods against the base from the underside and fasten with an M6 hex nut (**A3**) and tighten using the adjustable spanner (**Z14**).

Leave the top of the threaded rods resting in the holes in the top (ECAM_012).



5 Using a size 2.5 Hex Key (**Z9**) use two M3 x8 screws (**A6**) and two M3 nuts (**A10**) to screw the 3D printed flow sensor fixing (ECAM_152) into the top (ECAM_012).



3D Printed flow sensor fixing (ECAM_152) screwed into the top (ECAM_012).

6 Place the EC (**X5**) into the base fixing (ECAM_212) then the top fixing (ECAM_213) over the cartridge of the EC. Place the bolts (**A12**) through the clearance holes in the sides of the top and base fixing and screw into the tapped M8 holes in the base (ECAM_011)

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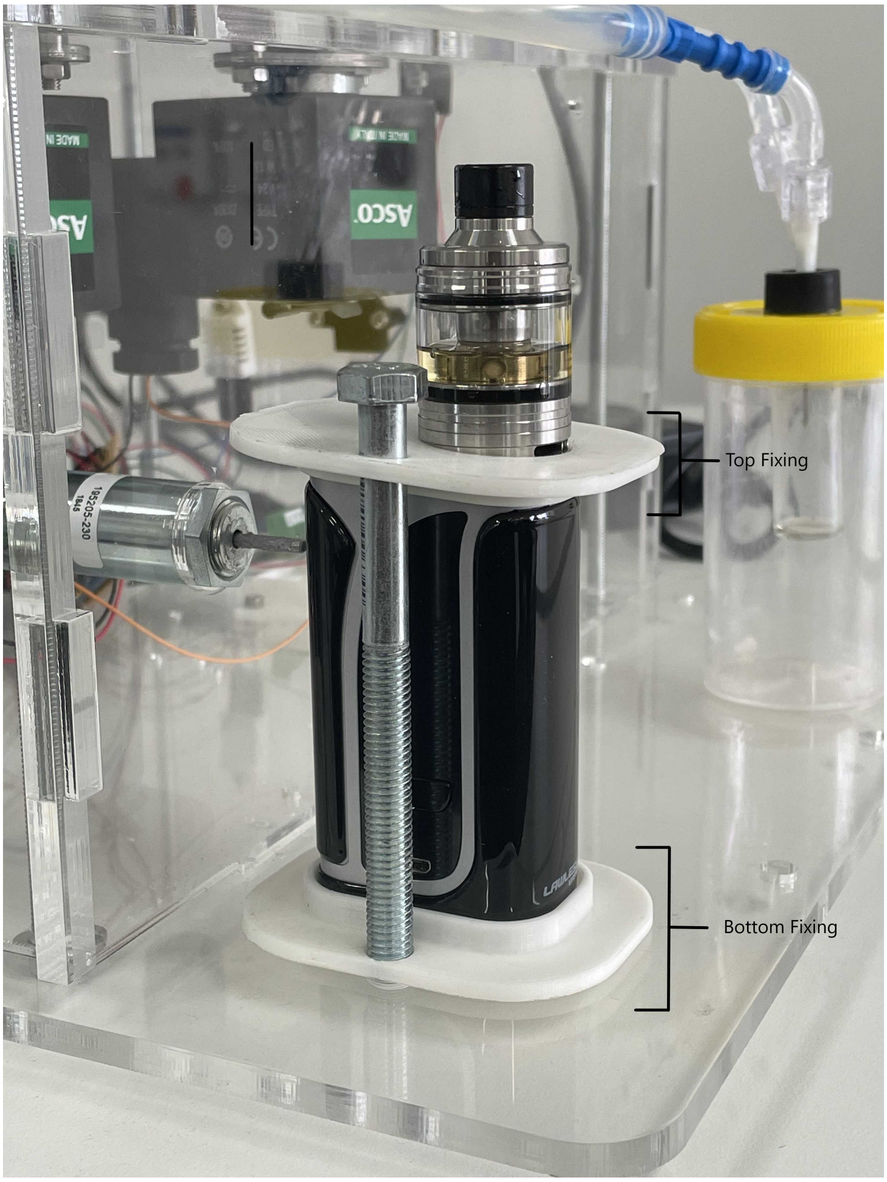

Firmware

7 Arduino Programming requires components:

- **A.E1** Arduino UNO
- **A.E2** USB A/B Cable

7.1 If you don't already have the open-source Arduino IDE installed you can download it from the website https://www.arduino.cc/en/software

7.2 Open ECAMSystemControl014.ino in the Arduino IDE

Install the DAC, LCD and Temperature/Humidity Sensor libraries:
Tools > Manage Libraries > Search: *"MCP4725" > INSTALL*
Tools > Manage Libraries > Search: *"liquid crystal I2C" > INSTALL*
Tools > Manage Libraries > Search: *"DHT" > INSTALL DHT sensor library by Adafruit*

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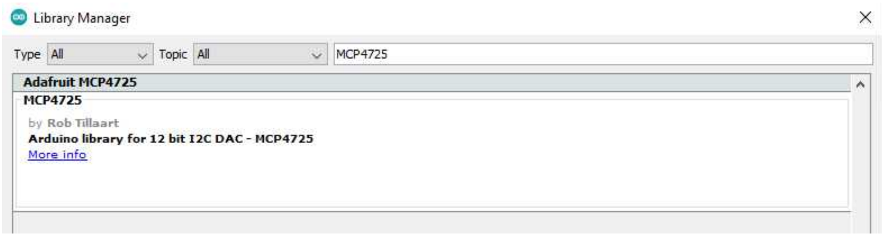
When the dialog opens asking if you would also like to install additional required libraries click *Install All*
To check that the library has been successfully installed navigate to C:/Documents/Arduino/libraries

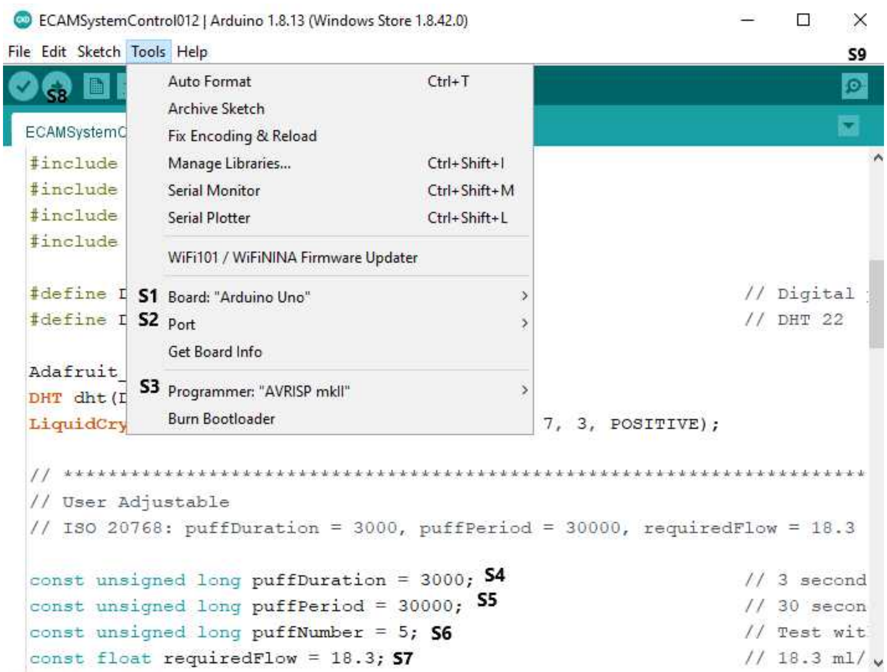


7.3 Plug the Arduino (**A.E1**) into your computer using the USB cable (**A.E2**). Under the *Tools* tab check that the:

- **S1** *Board* selected is the *Arduino UNO.*
- **S2** *Port* selected is the COM port associated with your Arduino. This will vary depending on your computer however it could look like *Port: COM 3 (Arduino UNO)*
- **S3** *Programmer* selected is *Arduino ISP*

Click the tick in the top left-hand corner of the Arduino IDE. This will verify that the code compiles and will complete if all required libraries are installed.

Click the upload arrow **S8** to deploy the firmware on the Arduino UNO. Wait a few seconds for the onboard LED to flash. Then you can unplug the Arduino UNO.



Screenshot of Arduino development environment.

Electronics

8 Prepare the custom jumper cables and wire electrical components
The parts required are:

- **A.S1** 2 Solenoid Pinch Valves

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- **A.S2** 1 Tubular Push Solenoid
- **A.S3** 2 DIN connectors
- **A.P2** Pump Microcontroller
- **A.PW2** DC Plug
- **A.PW3** DC Socket
- **A.PW5** 24V-12V DCDC Converter
- **A.E1** Arduino
- **A.E2** USB cable
- **A.E3** Relay Module
- **A.E4** 4 Diodes
- **A.E5** LCD
- **A.E6** I2C expander for LCD
- **A.E7** Flow meter
- **A.E8** Temp/Humidity Sensor
- **A.E9** Pressure Sensor
- **A.E10** DAC
- **A.E11** Vero Strip board
- **A.E12** Pin Crimp contact
- **A.E13** Socket Crimp contact
- **A.E14** 1 6-way housing
- **A.E15** 2 3-way housings
- **A.E16** 3 4-way housings
- **A.E17** 3 2-way housings
- **A.E18** Red Wire
- **A.E19** Green Wire
- **A.E20** Black Wire
- **A.E21** Blue Wire
- **A.E22** Yellow Wire
- **A.E23** White Wire
- **A.E24** Purple Wire
- **A.E25** Orange Wire

Recommended Tools
- **Z6** Wire Stripper
- **Z7** Crimping Tool
- **Z8** Screwdriver
- **Z16** Soldering Iron
- **Z17** Solder Wire

8.1 Cut wire to length (dimensions in mm)
- 14 Red wires (**A.E18**): 4x 150, 7x 100, 3x 50
- 11 Black wires (**A.E20**): 4x 150, 4x 100, 3x 50
- 6 Green wires (**A.E19**): 2x 150, 4x 100
- 4 Blue wires (**A.E21**): 1x 200, 1x 150, 2x 100
- 4 Yellow wire (**A.E22**): 3x 100, 1x 150
- 2 White wire (**A.E23**): 1x 150, 1x 100
- 3 Purple wire (**A.E24**): 1x 150, 2x 100
- 3 Orange wire (**A.E25**): 1x 150, 2x 100

8.2 Strip 10 mm of insulation from both ends of each section of wire.

8.3 Crimp a socket crimp contact (**A.E13**) to one end and a pin crimp contact (**A.E12**) onto the other end of the wires below:
- 3 Blue: 1x 200, 1x 150, 1x 100
- 1 Purple: 1x 100

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- 1 Orange: 1x 100
- 1 Yellow: 1x 100

Crimping instructions:

- Cut the stripped wire to approximately 5 mm
- Place the wire in the crimp contact so the insulation will only be crimped by the insulation
- Use the 1.3 die on the crimp tool (**Z7**) to crimp the wire
- Do a light tug test to ensure the wire is fixed
- Use the 1.6 die on the crimp tool (**Z7**) to crimp the insulation.

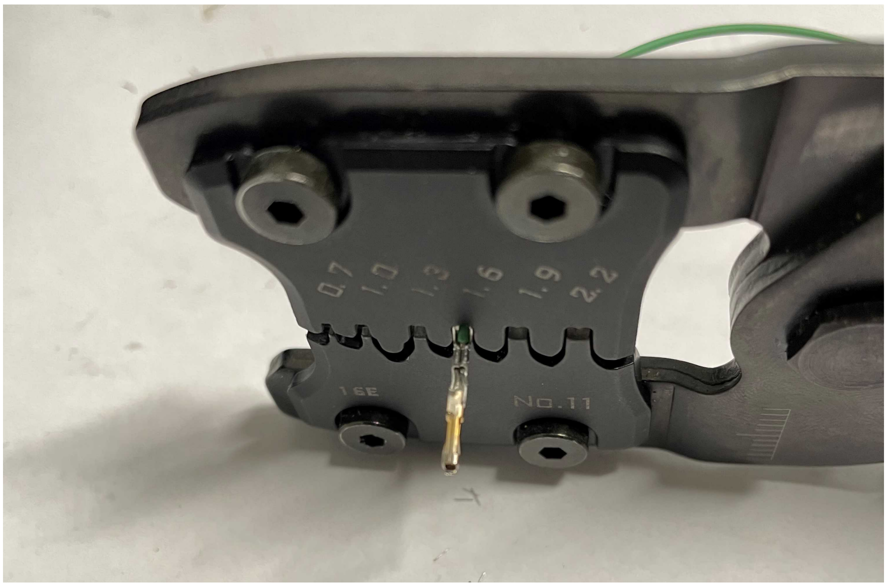

Image showing a crimp contact placed in the 1.6 die of the crimp tool to crimp insulation of a green wire. The wire has been crimped to socket crimp contact.

8.4 Crimp a socket crimp contact (**A.E13**) only to one end of the wires below, as per crimping instructions in 8.3 above.

- 5 Red: 2x 150, 3x 100
- 1 Black: 1x 100
- 5 Green: 2x 150, 3x 100
- 1 Blue: 1x 100
- 1 White: 1x 150
- 1 Yellow: 1x 150

8.5 Crimp a pin crimp contact (**A.E12**) only to one end of the wires below:

- 1 Red: 1x 100
- 1 White: 1x 100
- 1 White: 1x 100
- 1 Yellow: 1x 100

8.6 Push the crimp contacts into the connector housings.

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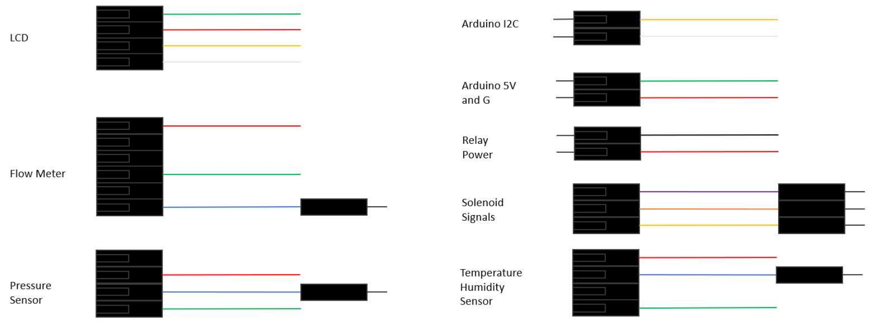

Visual of the crimp housing fabrication described below.

LCD 4-way housing (**A.E15**)
- 1: Green 250 with socket crimp only
- 2: Red 250 with socket crimp only
- 3: Yellow 250 with socket crimp only
- 4: White 250 with socket crimp only

Flow Meter 6-way housing (**A.E13**)
- 1: Red 200 with socket crimp only
- 4: Green 200 with socket crimp only
- 6: Blue 200 with socket crimp and pin crimp into 1x 1-way housing

1x 4-way housing (**A.E15**) for Pressure Sensor:
- 2: Red 150 with socket crimp only
- 3: Blue 150 with socket crimp and pin crimp into 1x 1-way housing
- 4: Green 150 with socket crimp only

Arduino I2C 2-way housing (**A.E16**)
- 1: Yellow 100 with pin crimp only
- 2: White 100 with pin crimp only

Arduino 5V and GND (**A.E16**)
- 1: Red 100 with pin crimp only
- 2: Green100 with pin crimp only

Relay Module 2-way housing (**A.E16**)
- 1: Red 100 with socket crimp only
- 2: Black 100 with socket crimp only

Solenoid Signals Arduino 3-way housing (**A.E14**)
- 1: Purple 100 with pin crimp and socket crimp into 1 of Relay 3-way housing
- 2: Orange 100 with pin and socket crimp into 1 of Relay 3-way housing
- 3: Yellow 100 with pin crimp and socket crimp into 1 of Relay 3-way housing

Temp/Humidity Sensor 4-way housing (**A.E15**):
- 1: Red 150 with socket crimp only
- 2: Blue 150 with socket crimp and pin crimp into 1x 1-way housing
- 4: Green 150 with socket crimp only

9 Solder components together using the soldering iron (**Z16**) and solder wire (**Z17**) following the instructions below. You may wish to refer to the electrical circuit diagram below.

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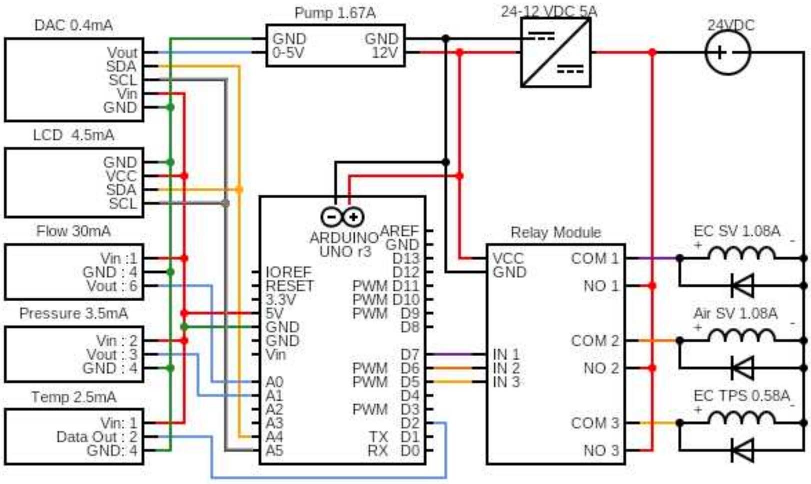
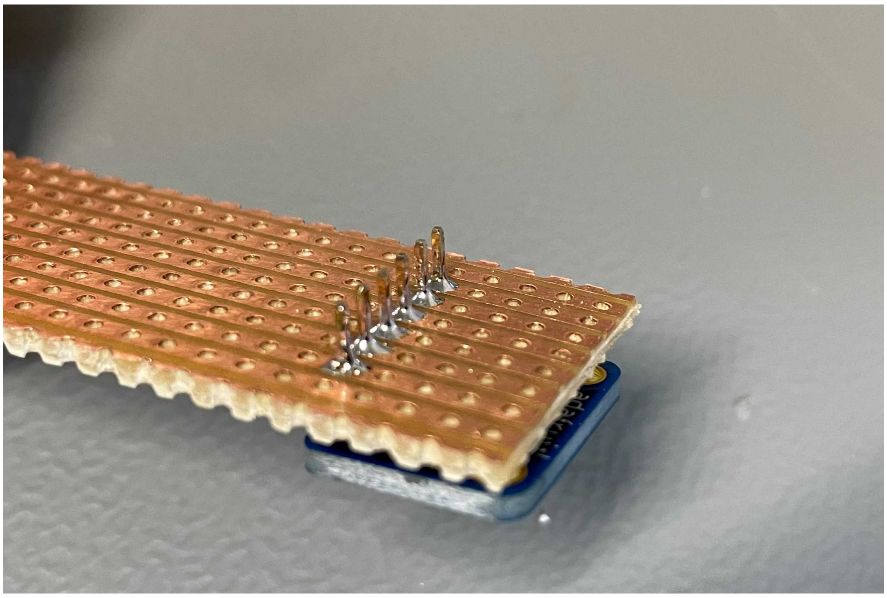


9.1 Solder a 6 Position Terminal Block Header to the DAC (**A.E10**). Cut a piece of Vero strip board (**A.E11**) at least 6 columns and 16 rows. Solder the pins of the DAC (**A.E10**) to the Vero board (**A.E11**) making sure each pin is connected to a separate copper strip.



DAC pins soldered to Vero board.

9.2 Solder the LCD, pump, pressure sensor and temperature/humidity sensor wires to the Vero board connecting the 5V (Red), Ground (Green), SDA (Yellow) and SCL (White) wires to each strip.

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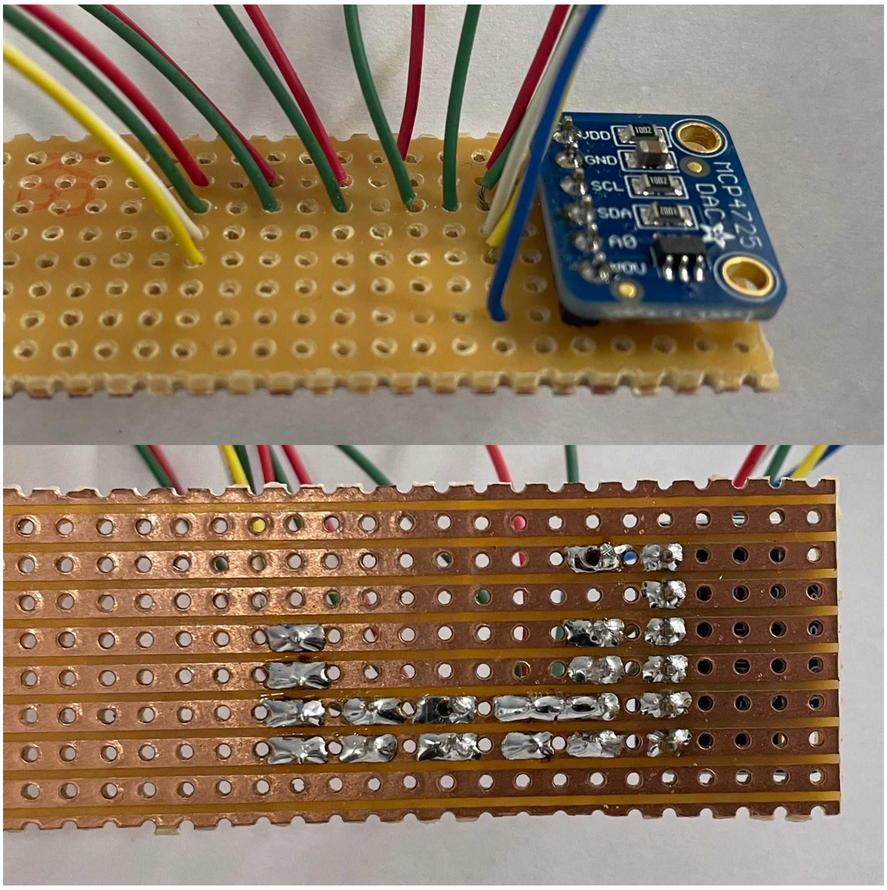

10
1. Cut a section of Vero board at least 4 strips wide and 10 holes long.
2. Solder a Red 150, and Black 150 wire to separate strips.
3. Solder the Red 100 from the 2-way socket housing to the same strip as the Red 100 and the Black 150 from the 2-way socket housing to the same strip as the Black 150.
4. Solder the Red 100 to the red strip and the Black 100 to the Black strip (pictured) we are using a DC power plug (**A.PW2**) with soldered wires however ECAM uses a DC power plug with screw terminals (**A.PW2**), screw the Red and Black 100 wires into the positive and negative terminals of the DC power plug (**A.PW2**) respectively.
5. Solder another Red 100 to the red strip and the Black 100 to the Black strip.

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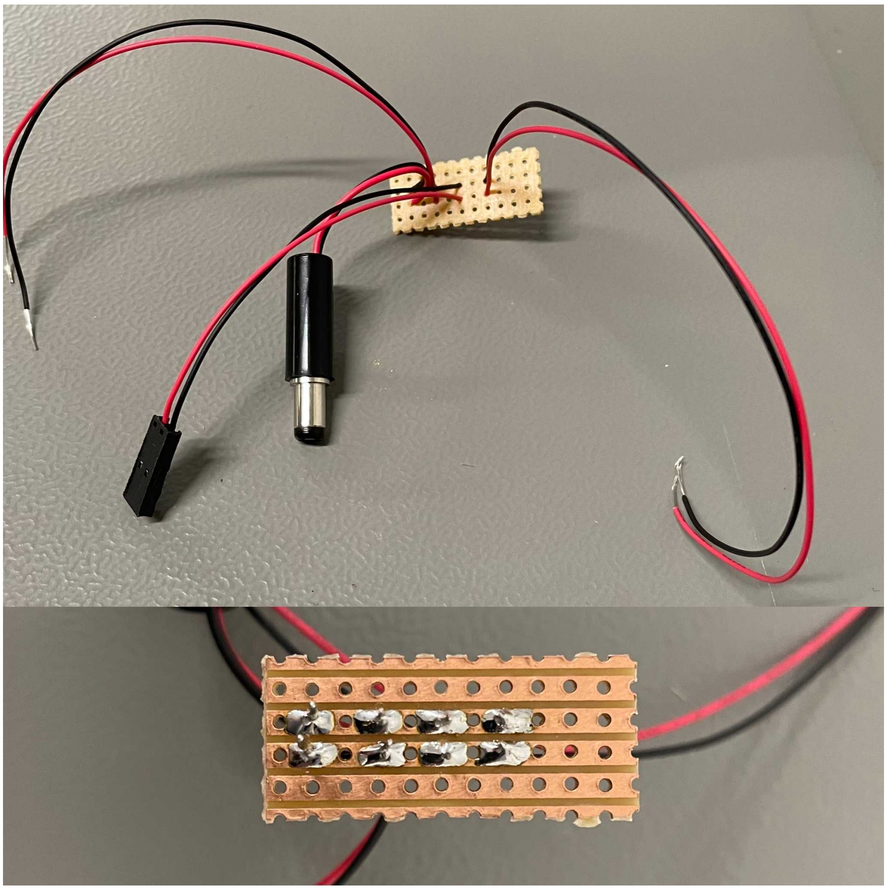

11 Wire the DIN plug (**A.S3**) for the pinch solenoid valves (**A.S1**).

11.1 Remove the screw terminal from the DIN plug housing by pushing the screw through the screw hole in the back, against the housing inside, the screw terminal should pop out the front.

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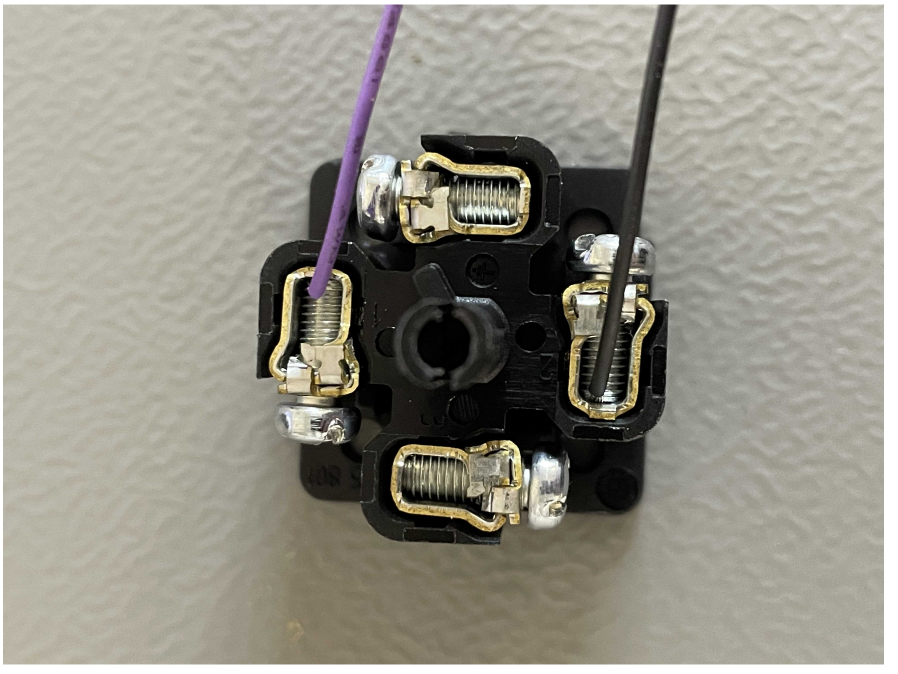
11.2 Screw the positive wire (Purple or Orange 150 with both ends only stripped) into terminal 1 and the negative wire (Black 150 with both ends only stripped) into pin 2.



11.3 Thread the wires through the DIN housing and push the terminal block into the housing ensuring the flat socket is in line with the wire opening.

11.4 Thread the gasket, washer and housing cap screw over the wires and screw tight.

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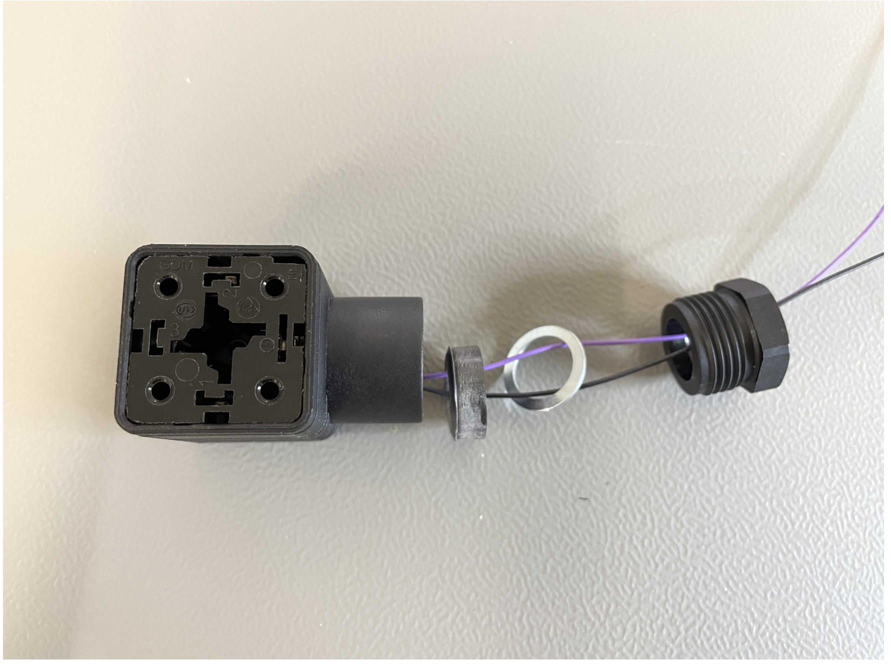
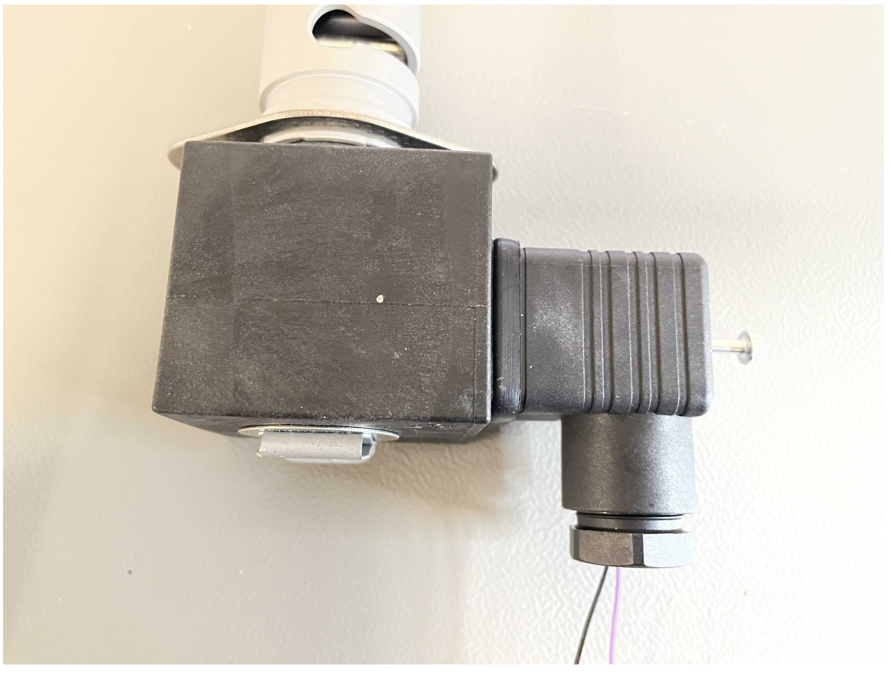


11.5 Plug and screw DIN connector into the Solenoid Pinch Valves



12 Wire the Solenoid electrical control components. Refer to the image below when following instructions in sub-steps below.

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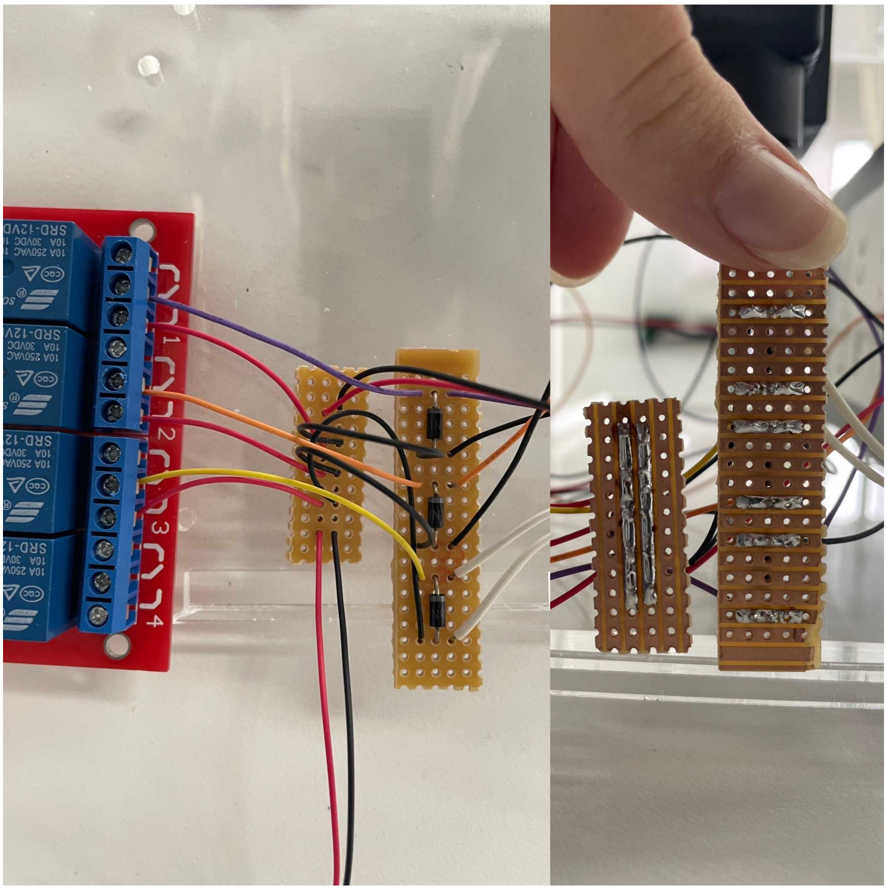

12.1 Solder the Solenoid Vero board

1. Cut a piece of Vero strip board (**A.E11**) to at least 20 rows, 5 holes long.
2. Solder three diodes (**A.E4**) in the middle of the Vero board making sure the positive and negative legs are soldered to separate copper strips.
3. Solder the positive wire (Purple 150) of the EC solenoid pinch valve (**A.S1**) to the same strip as the first diodes cathode (-) leg (the one closest to the grey stripe).
4. Solder the Purple 100 wire to the other side of the first diodes cathode leg on the same strip.
5. Solder the negative wire (Black) of the EC solenoid pinch valve (**A.S1**) to the same strip as the first diodes anode (+) leg.
6. Solder the Black 100 wire to the other side of the first diodes anode leg on the same strip.
7. Solder the positive wire (Orange) of the Air solenoid pinch valve (**A.S1**) to the same strip as the second diodes cathode (-) leg (the one closest to the grey stripe).
8. Solder the Orange 100 wire to the other side of the second diodes cathode leg on the same strip.
9. Solder the negative wire (Black) of the Air solenoid pinch valve (**A.S1**) to the same strip as the second diodes anode (+) leg.
10. Solder the Black 100 wire to the other side of the second diodes anode leg on the same strip.
11. Solder one wire (Either can be positive) of the tubular push solenoid (**A.S2**) to one to the same strip as the third diodes cathode (-) leg.
12. Solder the Yellow 100 wire to the other side of the third diodes cathode leg on the same strip.
13. Solder the other wire of the tubular push solenoid (**A.S2**) to one to the same strip as the third diodes anode (+) leg.
14. Solder the Black 100 wire to the other side of the third diodes anode leg on the same strip.

12.2 Solder the 24V Vero Board

1. Cut a piece of Vero strip board (**A.E11**) to at least 4 rows, 12 holes long.
2. Solder a Red 150, and Black 150 wire to separate strips.

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3. Solder the free end of the Black 100 from each of the diodes anode legs to the same strip as the Black 150 wire.
4. Solder three Red 50 wires to the same strip as the Red 150 wire.
5. Solder another Red 150 and Black 150 wire to the Red and Black strips respectively

12.3 Wire the relay module (**A.E3**)

1. Screw the free end of each Red 50 wire into the normally open terminal of relays 1, 2, and 3.
2. Screw the free end of the Purple 100 into the common terminal of relay 1.
3. Screw the free end of the Orange 100 into the common terminal of relay 2.
4. Screw the free end of the Yellow 100 into the common terminal of relay 3.

13 Connect the circuit

1. Screw the free Red and Black 150 wires from the 24V Vero board into the positive and negative terminals of the DC power socket (**A.P3**).
2. Screw the other free Red and Black 150 wires from the 24V Vero board into the positive (+Vin) and negative (-Vin) input terminals of the DCDC Converter (**A.PW5**).
3. Screw the free Red and Black 150 wires from the 12V Vero board to the positive (+Vout) and negative (-Vout) output terminals of the DCDC Converter (**A.PW5**).
4. Plug the 2-way socket from the 12V Vero board into the Relay Module (**A.E3**) power ensuring the Red wires socket plugs into the VCC pin and the black wire to the GND pin.
5. Screw the Red and Black 100 wires from the 12V Vero Board into the positive and negative input voltage terminals on the Pump Microcontroller (**A.P2**) respectively.
6. Plug the DC power plug (A.PW2) into the Arduino UNOs (**A.E1**) DC power socket.
7. Push the 4-way LCD socket into the LCD 12C port expender (**A.E6**) making sure the green wire lines up with the GND pin.
8. Push the 4-way Pressure socket housing into the Pressure sensor (**A.E9**) making sure the Red wire connects to pin 2.
9. Connect the blue pin from the pressure sensor (**A.E9**) to PIN A1 on the Arduino UNO (**A.E1**).
10. Push the 4-way Temperature/Humidity socket housing into the Temperature/Humidity sensor (**A.E8**) making sure the Red wire connects to Pin 1.
11. Connect the blue pin from the temperature/humidity sensor (**A.E8**) to PIN 2 on the Arduino UNO (**A.E1**).
12. Place the flow meter (**A.E7**) into the flow meter holder (ECAM_152) making sure P1 is facing the front and P2 facing the back as the sensor will only read flow in this direction.
13. Push the 6-way socket housing into the Flow Meter (**A.E7**) making sure that the red wire lines up with Vin.
14. Connect the blue pin from the flow meter (**A.E7**) to PIN A0 on the Arduino UNO (**A.E1**).
15. Push the 3-way pin housing into the Arduino UNO (**A.E1**) making sure that the purple wire lines up with PIN 7, Orange with PIN 6, and Yellow with PIN 5.
16. Push the 3-way socket housing on the other end into IN1, 2, and 3 on the Relay module (**A.E3**) ensuring the purple wire lines up with IN 1, Orange with IN 2 and yellow with IN 3.

Assembly

14 Fix all components into the acrylic case. Locations are indicated on the image below

You will need:

- ECAM_011 Base
- ECAM_012 Top
- ECAM_013 Left Wall
- ECAM_014 Right Wall
- ECAM_015 Front Wall
- ECAM_016 Back Wall
- ECAM_113 Pump Fixing
- ECAM_122 Relay Fixing
- ECAM_212 EC Base Fixing
- ECAM_213 EC Top Fixing
- ECAM_322 Condensing Fixing

Citation: Rosa T Campbell, Kelly Burrowes, Vinod Suresh (05/13/2021). ECAM: A low-cost vaping device for collection of electronic cigarette condensate and in vitro studies. https://dx.doi.org/10.17504/protocols.io.bswunfew

- **A5** 4 M4x12 screws
- **A6** 21 M3x8 screws
- **A7** 4 M3x12 screws
- **A8** 2 M3x16 screws
- **A9** 4 M4 nuts
- **A10** 4 M3 nuts
- **A11** 7 PCB edge supports
- **A.P1** Pump
- **A.P2** Pump Microcontroller
- **A.C2** 21G Needle
- **A.S1** Solenoid Pinch Valves
- **A.S2** Tubular Push Solenoid
- **A.S3** DIN Connector
- **A.PW2** DC Plug
- **A.PW3** DC Socket
- **A.PW5** DCDC Converter
- **A.E1** Arduino
- **A.E3** Relay Module
- **A.E5** LCD
- **A.E7** Flow Meter
- **A.E8** Temperature/humidity Sensor
- **A.E9** Pressure Sensor

Consumables
- **X4** Glue

Recommended Tools
- **Z9** M3 hex key
- **Z10** M4 hex key

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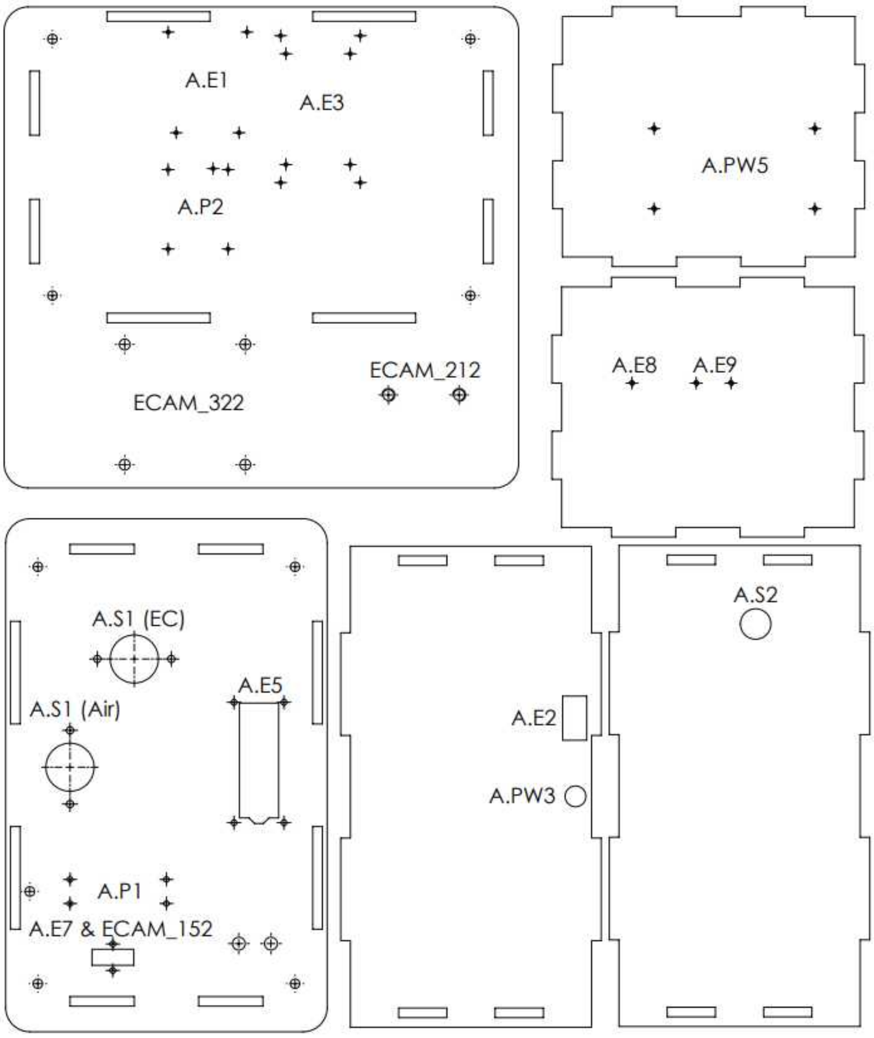


14.1 Place the three phase wires from the pump (**A.P1**) through the wire hole (to the left of the screw holes) and screw the pump into place on the top using four M3 x8 mm screws (**A6**)

Use the screw driver (**Z8**) to screw the 3 phase wires from the pump (**A.P1**) to the screw terminal on the pump micro controller (**A.P2**).

- X: Red
- Y: White
- Z: Black

Use the M3 hex key (**Z9**) to screw the pump fixing (ECAM_113) into place on the base (ECAM_011). Then sit the pump micro (**A.P2**) into its fixing.

14.2 Using the M4 hex key (**Z10**) screw the following into place:

- Air and EC Solenoid Pinch Valves (**A.S1**) with two M4 screws (**A5**) and two M4 nuts (**A9**) per valve.

Using the M3 hex key (**Z9**), screw: the following into place:

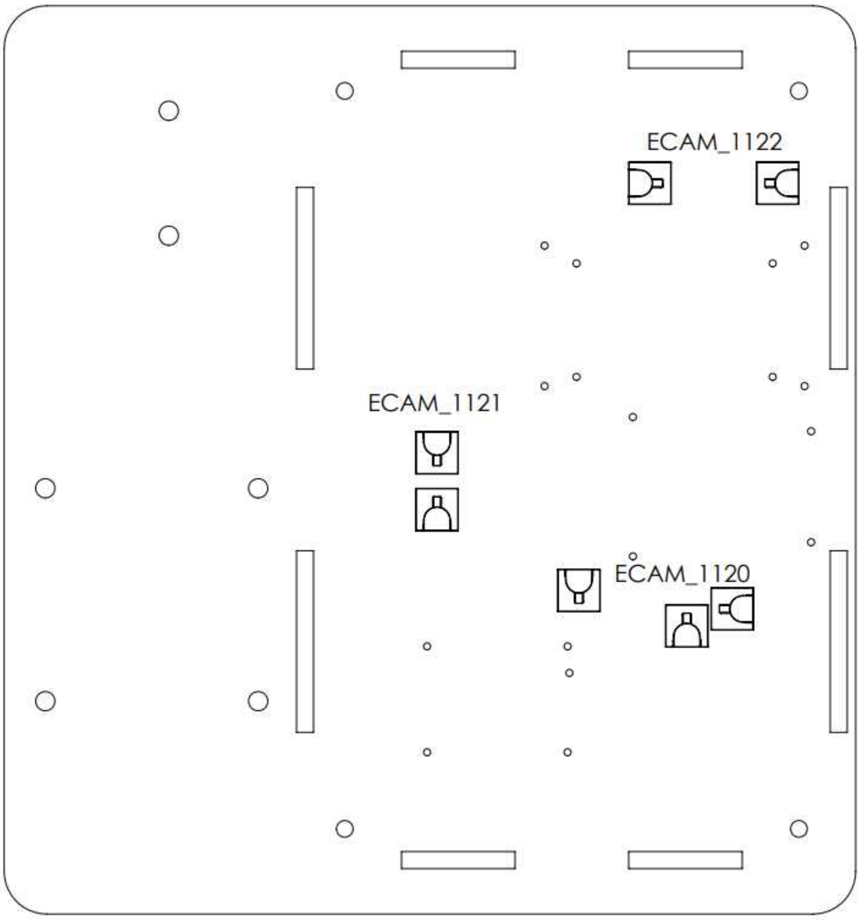
- Arduino Fixing (ECAM_132) with four M3 x8 screws (**A6**)
- Relay Module Fixing (ECAM_122) with four M3 x8 screws (**A6**)
- DCDC Converter (**A.PW5**) with four M3 x8 screws (**A6**)
- Temperature/Humidity Sensor (**A.E8**) with two M3 x8 screws (**A6**)
- Pressure Sensor (**A.E9**) with two M3 x16 screws (**A8**)

- LCD (**A.E5**) with four M3x12 screws (**A7**) and four M3 nuts (**A10**)

Then place the Arduino and relay module in their respective fixings.

15

Remove adhesive backing and stick the PCB Edge Supports (**A11**) in place following the layout diagram below. Then place the Vero boards in these mounts.



Drawing showing PCB edge supports locations.

16 Feed the type B end through the square hole in the back (ECAM_016) from the outside in. Then plug the Type B end of the USB cable (**A.E2**) into the Arduino (**A.E1**) leaving a short section of cable and the Type A end outside.

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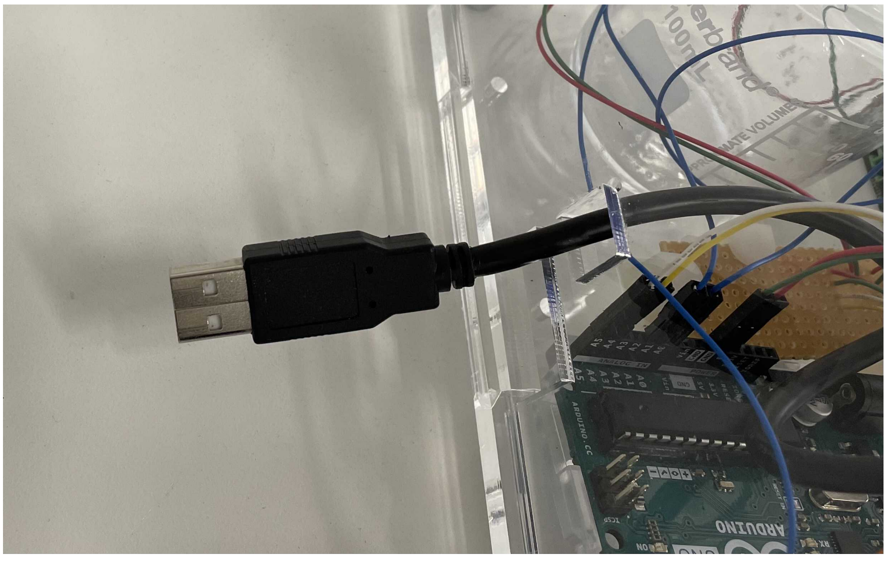
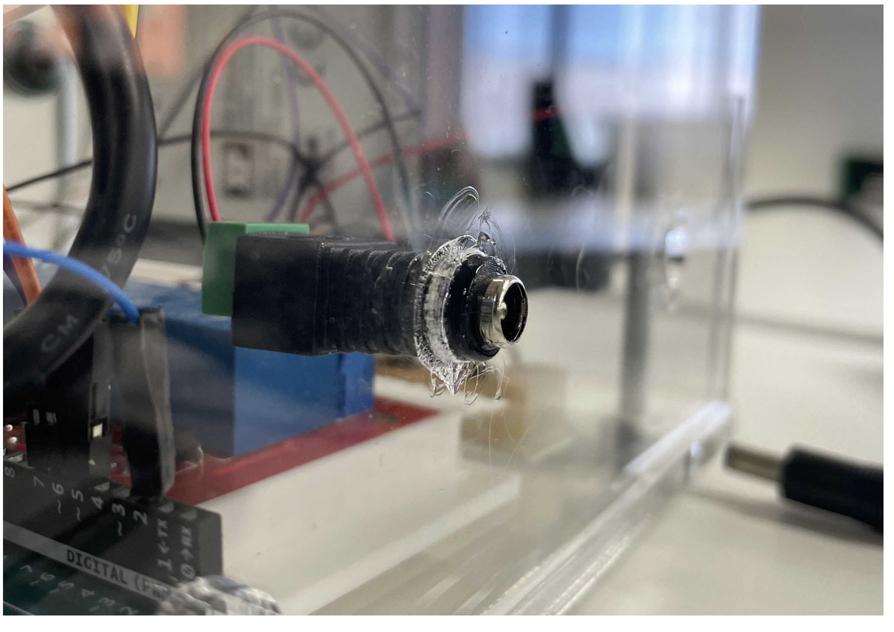


USB Cable Type A section in place.

17 Spread glue (**X4**) around the circular hole in the back (ECAM_016) and around the circular section of the DC power socket with screw terminals then push the socket through the back from the inside. Allow to dry for 24 hours before applying force to the joint.



DC Power socket with screw terminals glued in place.

Pneumatic Circuit

18 Set up tubes and connectors

You will need:

- **A3** M6 hex Nut
- **A4** M6 Washer
- **A.T1** 7.9 mm ID Tube

- **A.T2** 6.4 mm ID Tube
- **A.T3** 3.2 mm ID Tube
- **A.T4** Glass jar
- **A.T5** Y connector
- **A.T6** T connector
- **A.T7** Threaded hose connector
- **A.T8** Reducer
- **A.C2** 21 Gauge needles
- **A.C3** Luer to barb fitting

Consumables:
- **X1** Sample vial
- **X3** Thread Tape
- **X6** Isopropyl Alcohol

Recommended Tools:
- **Z3** M8 Tap
- **Z4** M8 Tap Wrench
- **Z11** Drill
- **Z12** 3mm Drill bit
- **Z13** 8mm Drill bit
- **Z14** Spanner
- **Z15** 19mm hole saw
- **Z19** Tube cutter

19 Fit hose connectors to glass buffer lids.

1. Mark two holes on two blue screw caps (**A.T4**) 13 mm apart.
2. Drill (**Z11**) a guide hole with a 3 mm drill bit (**Z12**) on each of the markings.
3. Drill (**Z11**) over the 3 mm holes with an 8 mm drill bit (**Z13**).
4. Tap the holes using the M8 Tap (**Z3**) and tap wrench (**Z4**).
5. Wrap thread seal tape (**X3**) around the threads of the 4 mm Male Threaded hose fittings (**A.T7**).
6. Screw the four hose fittings (**A.T7**) into the tapped holes in the lids and tighten with the spanner (**Z14**).

20 Screw on hose fitting (**A.T7**) into the pump inlet (the top hole).

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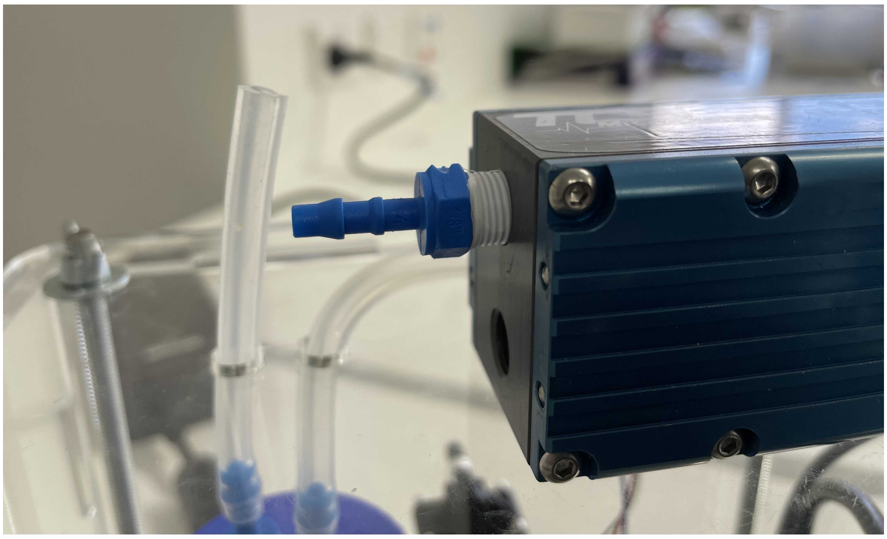


21 Drill a 19 mm hole in the centre of the third blue screw cap (**A.T4**) using the drill (**Z11**) and hole saw bit (**Z15**).

Left: Hole saw located in the centre of the lid (do not cut the hole with the lid on the glass beaker, the image above is for illustration purposes only). Right: Hole cut with sample vial inside the beaker.

22 Cut tubing to length using the tube cutter (**Z19**):

3.2 mm silicone tube (**A.T2**)
- 2x 85 mm (Pump to Buffer, Buffer to Flow Meter)
- 1x 120 (Flow Meter to Luer)
- 1x 35 (Luer to Y Connector)
- 1x 50 (Flow Meter to T Connector)
- 2x 100 mm (T Connector to Buffer, Buffer to Pressure Sensor)

6.2 mm silicone tube (**A.T3**)
- 80 mm (Y connector through Air Solenoid Pinch Valve)
- 160 mm (Y connector to reducer)

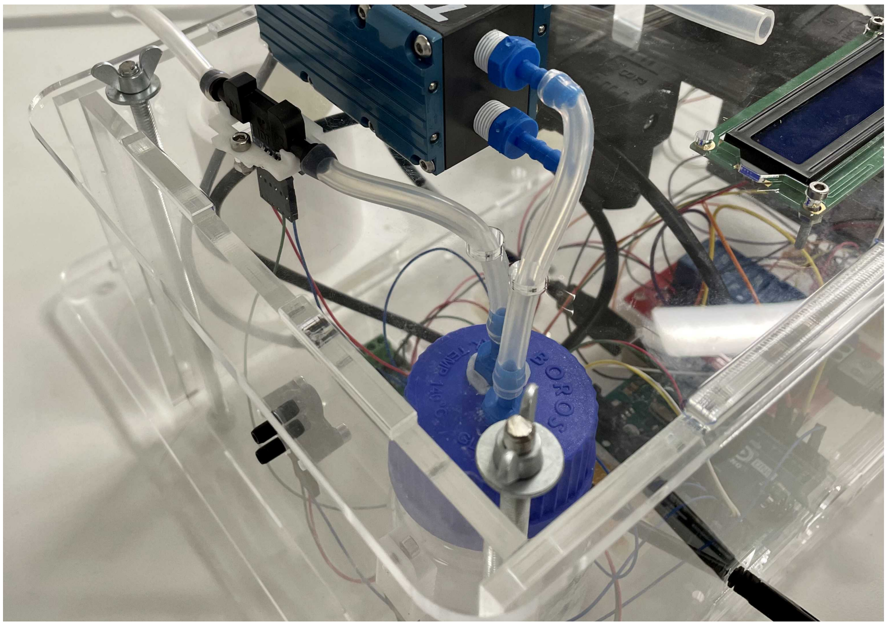
7.9 mm silicone tube (**A.T1**)
- 120 mm (Reducer to EC mouthpiece)

23 We recommend cleaning these components that are in contact with the aerosol and could contaminate samples before using the machine:
- All sections of tube, all sizes (**A.T1**, **A.T2**, **A.T3**)
- Glass jars (**A.T4**)
- Nylon hose connectors (**A.T5**, **A.T6**, **A.T7**, **A.T8**)
- Needles (**A.C2**)
- Luer fittings (**A.C3**)

This can be done by rinsing in warm, soapy water, allowing to dry then sterilise with Isopropyl alcohol (**X6**).

24 Put one lid with two hose fittings onto a glass jar and place this in the back right corner of the base. Connect one end of an 85 mm long 3.2 mm ID tube to the hose connector on the inlet of the pump, through the back tube hole and onto one hose connector on the glass jar lid.

Connect the other 85 mm long 3.2 mm ID tube to the other hose connector on that glass jars lid and through the front tube hole onto the outlet barb of the flow meter.



Pump, buffer volume and flow meter pipes connected to the hose barbs.

25 Connect the following:
- 120 mm long, 3.2 mm ID tube from the Flow Meter inlet barb (**A.E8**) to Luer barb (**A.C3**)

- 35 mm long, 3.2 mm ID tube from the Luer barb (**A.C3**) to the Y Connectors primary barb (**A.T5**)
- One 21 gauge needle (**A.C2**) to each Luer lock (**A.C3**)
- Insert both needles into the silicone self-sealing cap of the sample vial (**X1**)
- Place the sample vial into the 19mm hole in the blue cap of one glass jar
- 80 mm long, 6.4 mm ID silicone tube from the Y connectors right branch (**A.T5**) through the Air Solenoid Pinch Valve (**A.S1**)
- 160 mm long, 6.4 mm ID tube from the Y connectors left branch (**A.T5**) through the EC Solenoid Pinch Valve (**A.S1**) to the 6mm end of the reducer (**A.T8**)
- 120 mm long 7.9 mm ID tube from the 8 mm end of the reducer (**A.T8**) to the EC mouthpiece (**X5**)

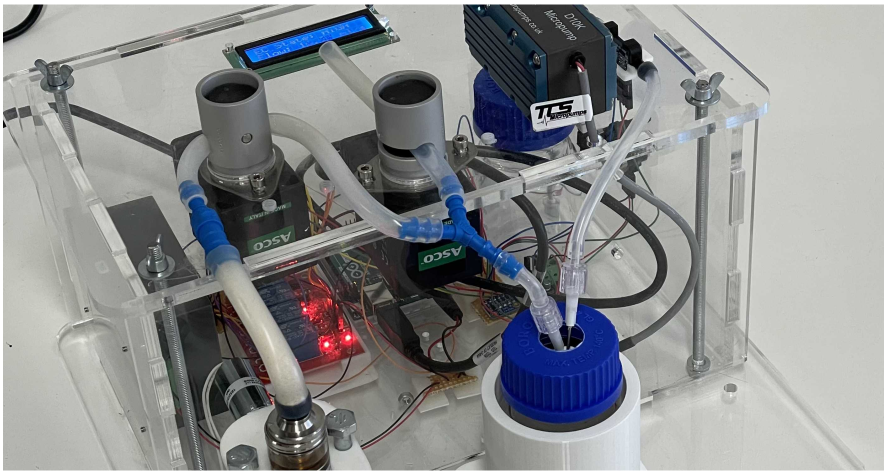
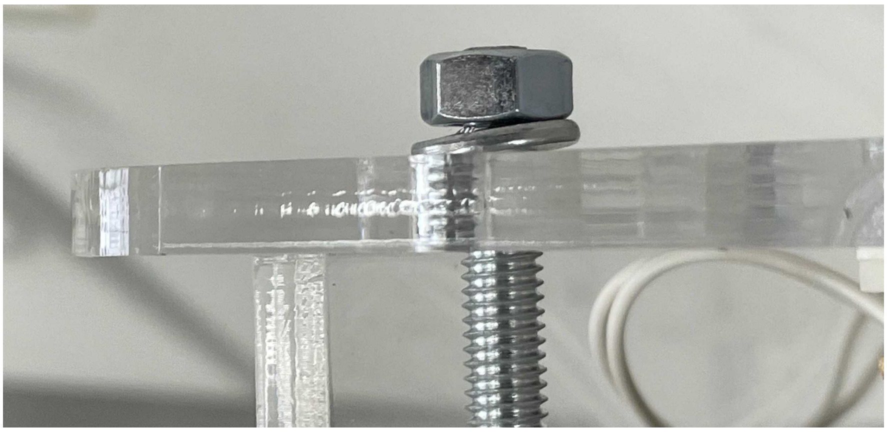


Image showing tubes and connectors of pneumatic circuit connected.

26 Lift up the top (ECAM_012) and slot the back tabs (ECAM_016) into the base slots (ECAM_011) and wall slots (ECAM_013, ECAM_014) into the back tabs. Then let the top down until the back tabs slot into the top slots. This might require some jiggling.

27 Place a spring washer (**A4**) over each of the four threaded rods coming out the top then fasten with an M6 hex nut (**A3**) using the adjustable spanner (**Z14**)



Washer and nut screwed onto the top of the threaded rod, holding the top and bottom acrylic sheets together and the walls in place.

Pressure Compensation Testing - Optional

28 If ECAM has been constructed following these Build Instructions exactly - the machine will meet ISO 20768: 2018

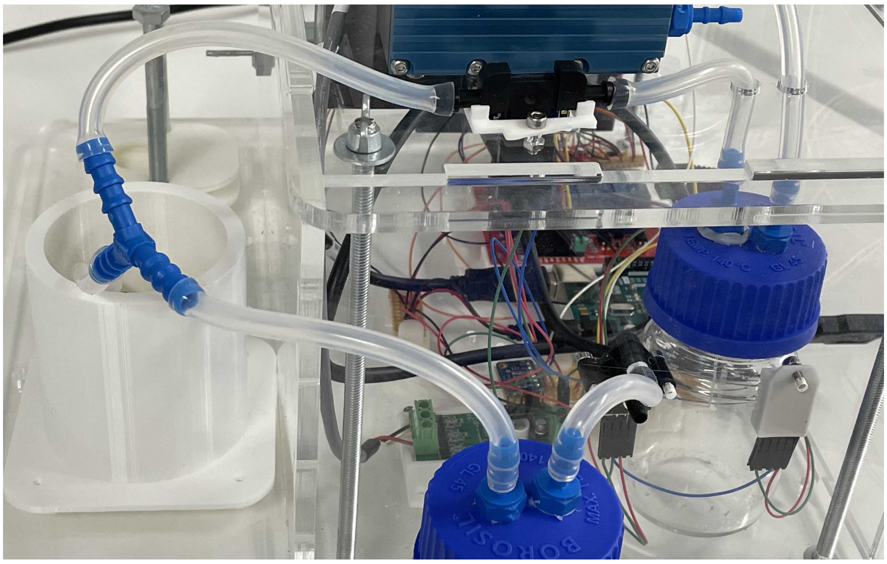
Citation: Rosa T Campbell, Kelly Burrowes, Vinod Suresh (05/13/2021). ECAM: A low-cost vaping device for collection of electronic cigarette condensate and in vitro studies. https://dx.doi.org/10.17504/protocols.io.bswunfew

requirements for the ability to compensate for a pressure drop of 3000 ± 50 Pa without a reduction of more than 3 ml from the puff volume.

If changes to any components (such as the pump) have been made, the following calibration step is recommended.

28.1

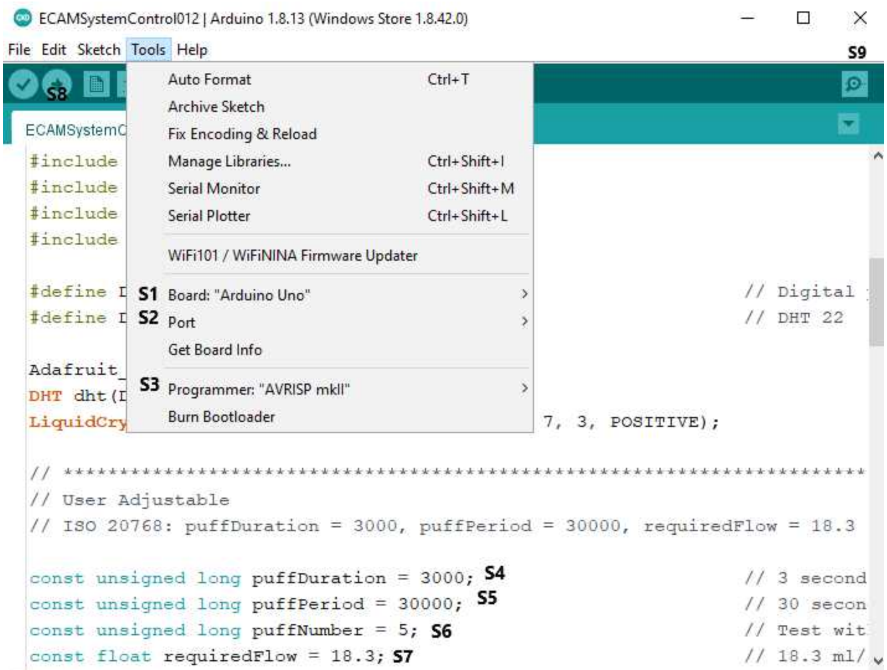
- Disconnect the 120 mm long, 3.2 mm ID tube from the flow meter (**A.E8**)
- Connect this free end to one straight barb of the T connector (**A.T6**)
- Connect the 50 mm long, 3.2 mm ID tube from the flow meter (**A.E8**) to the other straight barb of the T-connector (**A.T6**)
- Connect one 100 mm long 3.2 mm ID tube from the branched barb of the T-connector (**A.T6**) to the inlet barb on the lid of the other glass jar
- Connect the other 100 mm long, 3.2 mm ID tube from the outlet barb on the glass jar to the top barb of the pressure sensor (**A.E9**)



28.2 Cut the 16-gauge needles (**A.C1**) to 10 mm long using the Dremmel tool (**Z18**) with the 191 High Speed Cutter attachment. Then remove the 21-gauge needles from the silicone vial cap and the luer lock fittings. Replace with the short 16-gauge needles.

28.3 Section 6.3 Pressure Compensation Calibration outlines the protocol for determining if the ECAM is capable of sufficient compensation.

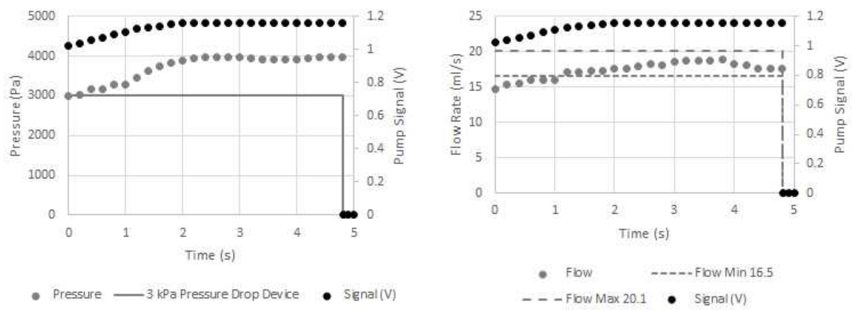
1. Plug the USB Cable Type A end into a computer.
2. Open the Arduino IDE
3. Open the serial monitor by clicking the magnifying glass icon in the top right corner (S9).
4. Plug the power cable (A.PW4) into the power supply (A.PW1) and a mains wall socket making sure the power is switched off at the wall socket.
5. Then switch the power on to let one test run.



28.4 Copy the serial data into an excel spreadsheet and make three plots;

1. Pressure versus time in the compensating phase
2. Flow versus time in the compensating phase
3. Flow versus time in the test phase

The pressure at the start (with the machine calibrated for test conditions 21-gauge needles) should be 3000 ± 50 Pa at 0 s. This will increase as the pump speed increases to maintain the flow.



Left: Pressure plotted against time during compensation stage. Right: Flow plotted against time during the compensation stage.

The puff should remain within the rectangular profile guidelines outlined in Section 5.2.2 of ISO 20768:2018.

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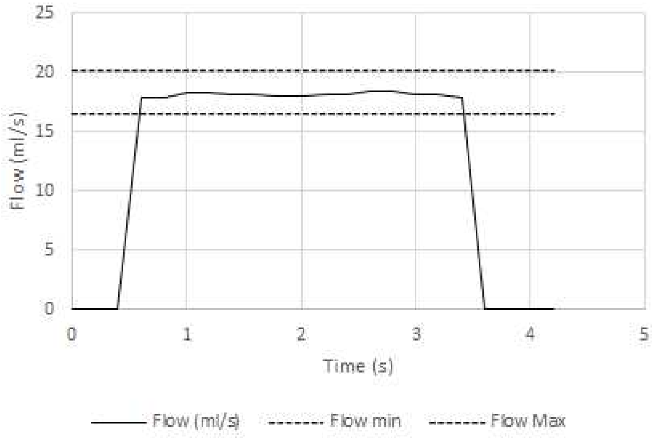

The puff profile during the test phase plotted as flow vs. time.

The area under the graph can be calculated using the formula:

$$Volume = \sum_{n=0}^{n=15} (f_{n+1} - f_n))(t_{n+1} - t_n)/2 + f_n(t_{n+1} - t_n)$$

The volume should be greater than 52 ml.

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