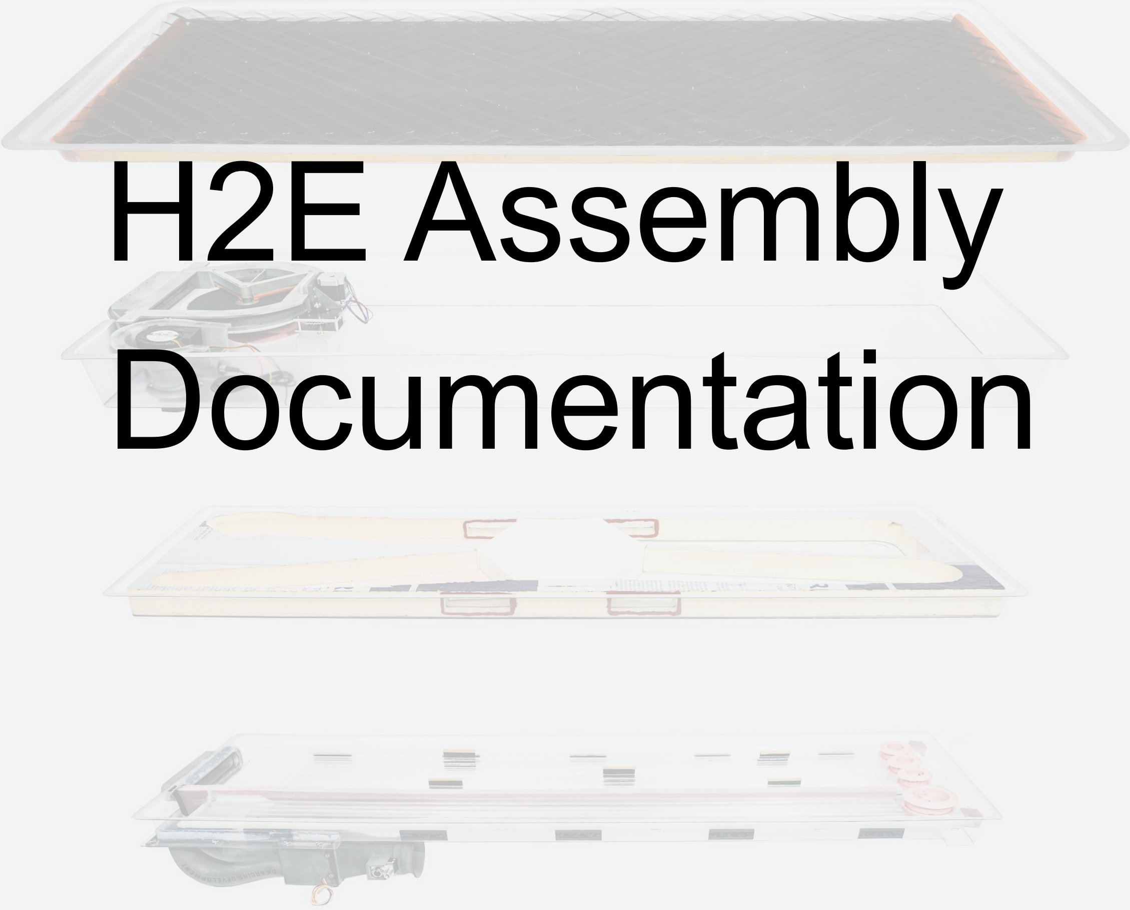
H2E Assembly Documentation



Summary / Index

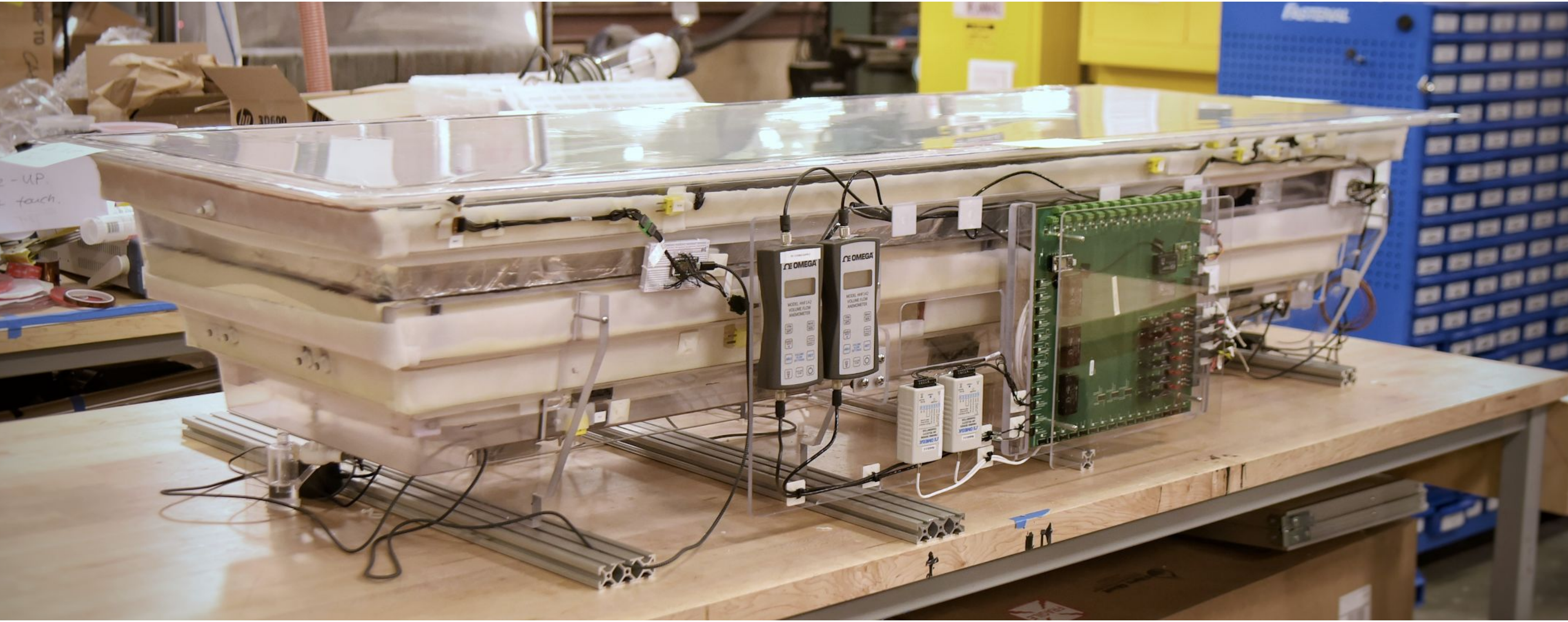
Introduction to this Assembly Documentation

This document captures raw images and notes around the assembly process of the "Proto4" version of our experimental Atmospheric Water Harvesting (AWH) device, the design of which is documented by the accompanying CAD files. This design was designed for and built by hand. It was very much stepping stone and a work in progress, but was the last fully assembled prototype before the COVID19 lockdowns hit; therefore we are sharing here how far we got, with the intent of enabling those who would like to continue on this or similar paths.

This device harvest sun heat with a frontal area of $\sim 1\ m^2$. In the limited outdoor testing time we had during pandemic lockdowns, this device peaked at $\sim$150mL/h/m^2 of water harvesting, exactly on target for this version, and with a $\sim$3x improvement potential we estimate as left on the table for devices of this type.

It is strictly a device for engineering experimentation, and not to drink water from. While it is straightforward to limit adhesives and other materials to those safe for food contact, this was not a goal of this version. Also, unlike a product-intent prototype, this device was designed to be disassemblable and modifiable, which comes at a steep cost in parts (e.g. "grommets"), complexity and thickness. Further, we were very selective in what parts we made in fabrication methods relevant for later mass manufacturing (e.g. all large components by vacuum forming). Many other parts were intentionally left as 3D printed or rubber seal assemblies, to enable fast design iteration and experimentation, fully knowing that those would not scale well to manufacturing as is. In several cases, designs of varying maturity were created, where functions here accomplished by 3D printed or cast parts, would be ultimately incorporated into the design of the vacuum formed shells.

1. Overview of Unit



Assembled View of Unit

Overarching Goals of prototype

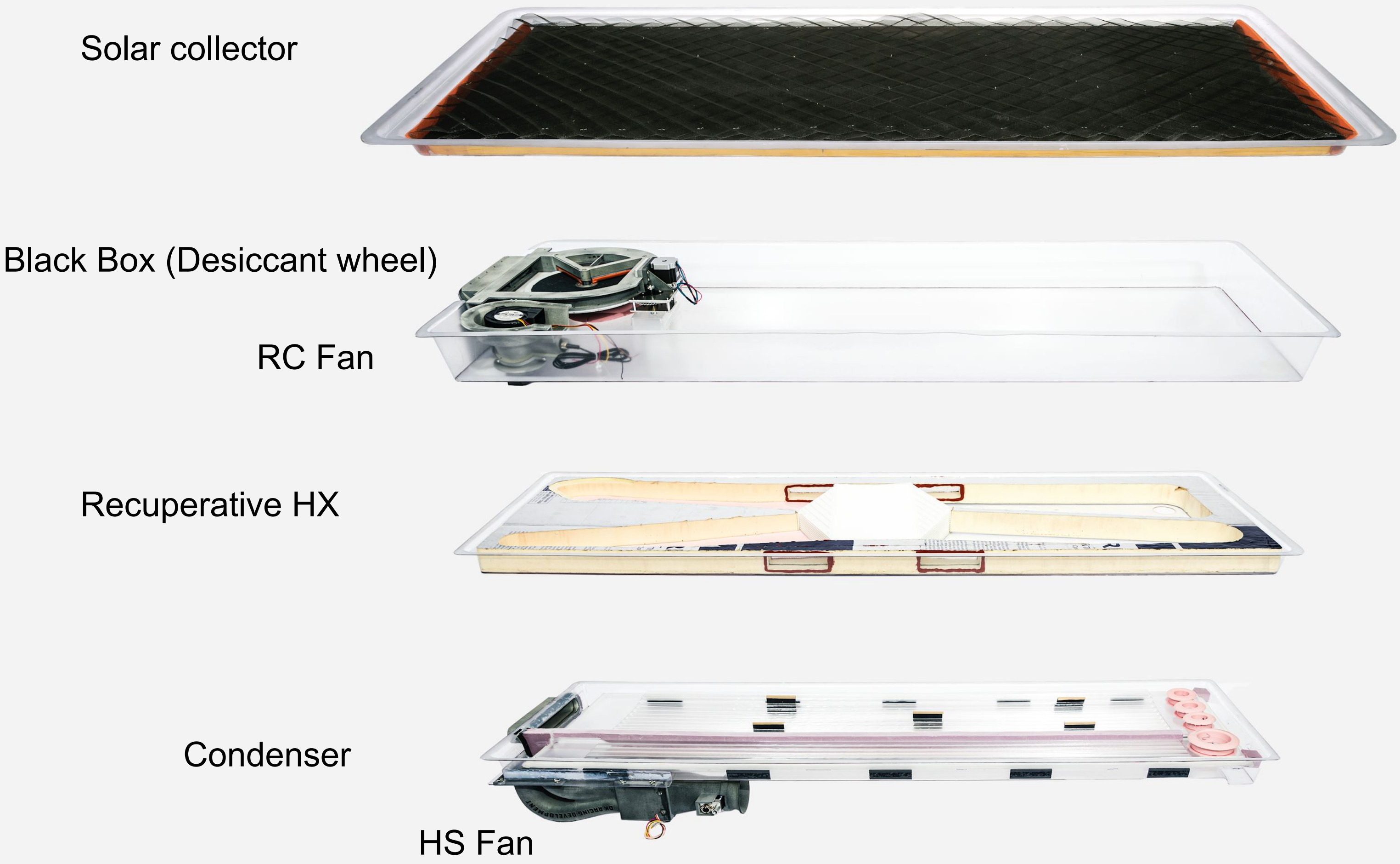
1. To be a vehicle for learning and testing to better understand and improve the performance of atmospheric water generator technology in general.
2. To increase our max water output from 44 $ml/hr/m^2$ to a milestone target of +150 $ml/hr/m^2$.
3. Be largely composed of thin vacuum-formed plastic parts in order to be an example of a 'low-cost manufacturing design language' and to help us learn how to design and fabricate with those materials.
4. To be well-sealed (low leak), and yet easily disassembled and reassembled without causing major damage or delays. (Ex: silicone grommet ports, gaskets, removable adhesives, access to cut layers away with a razor blade, etc). This comes at a high overhead in parts, cost, etc that would not be present in a later product.
5. To be fully instrumented with many sensors and highly automated in fan and motor controls to allow for running 100s to 1000s of experiments and gathering ample data to understand how to optimize performance amidst tradeoffs. This comes at a high overhead in parts, cost, etc that would not be present in a later product.

Overarching Goals of prototype (continued)

6. Incorporate the learning (and higher performing designs) from our component-level experimentation into one integrated device. Including:
    a. Solar Collector: multi-layers of ETFE films, solkoted mylar bottom surface, with multiple layers of solkoted Al mesh for turbulence and surface area to heat the air.
    b. Desiccant Wheel module (aka “Black Box”): minimizing pressure drop of Humidity Stream(HS) while improving uniformity (perpendicular flow input), using deformable foam seals on both sides of the wheel to adjust for variations, using silica-gel desiccant material, minimizing humidity stream leakage while prioritizing recirculating stream sealing first and foremost.
    c. Fans and Motors: using a stepper motor for greater control of speed (especially being able to go very slow), using fans that allow for high back pressure (~1000-2000 Pa) with higher flow rates (~80 m3/hr for RS, and ~250 m3/hr for HS), that can also be set to provide low flow rates as well. This comes at a high overhead in parts, cost, etc that would not be present in a later product.
    d. Recuperative Heat Exchanger: counter-flow. For expediency, using the CORE HX unit as it offers high performance out of the box(~85% efficiency), instead of the initial vacuum formed designs, which we assume can reach the same, but would start out at ~25% before optimization.
    e. Condenser: larger surface area, counter-flow (for experimental reasons of limiting droplet adhesion and measurement lag, internal surfaces coated with hydrophobic silicone oil + carnauba wax.)
    f. Extra focus on sealing: reducing number of seams/parts, all static seams siliconed or double-sealed, desiccant wheel lip seals made of FEP-coated foam on both sides of the wheel.

Exploded View of Unit

Exploded View of Unit



Exploded View of Unit

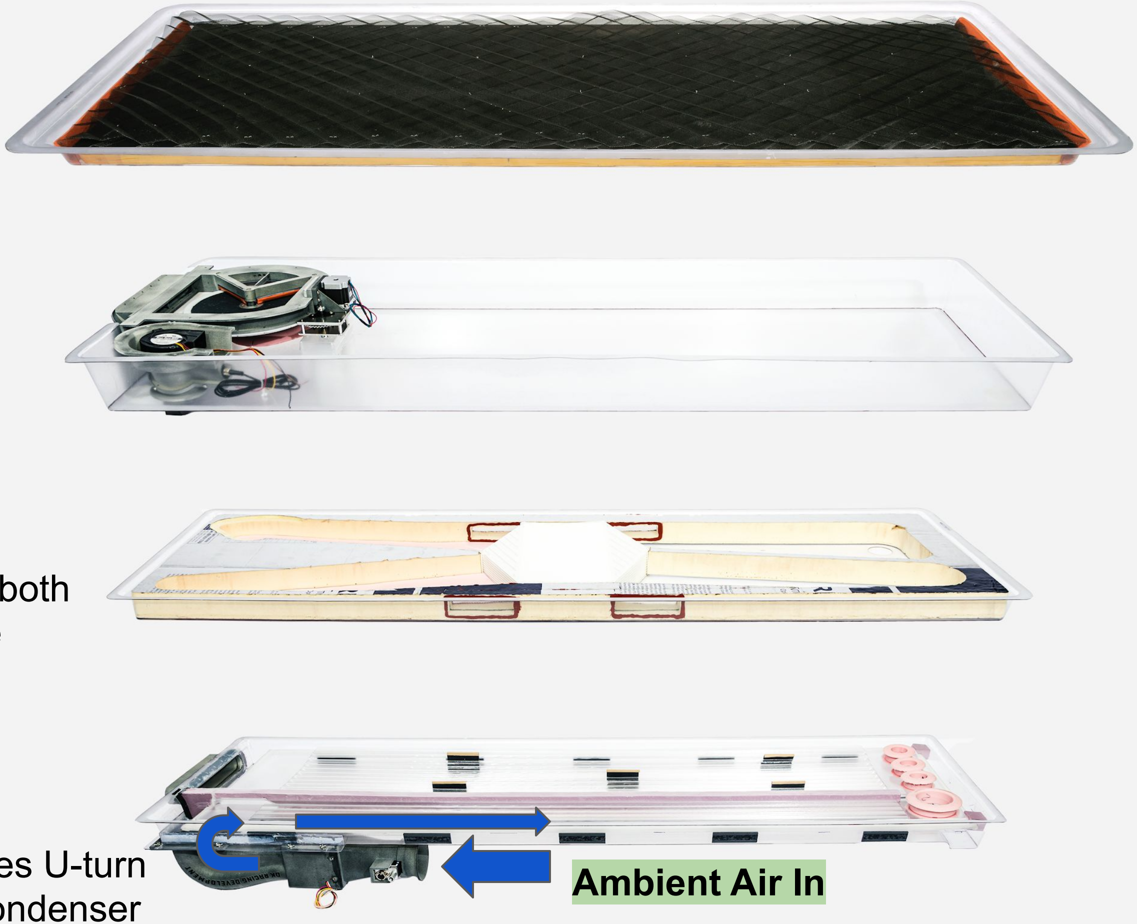
Air-Flow Path: HUMIDITY SUPPLY

Ambient Air In

HS Fan pulls air in

Step 1

Air-Flow Path: HUMIDITY SUPPLY



HS air flows outside (both above and below) the clamshell, providing cooling to the RC air inside

Air does U-turn into condenser

Step 2

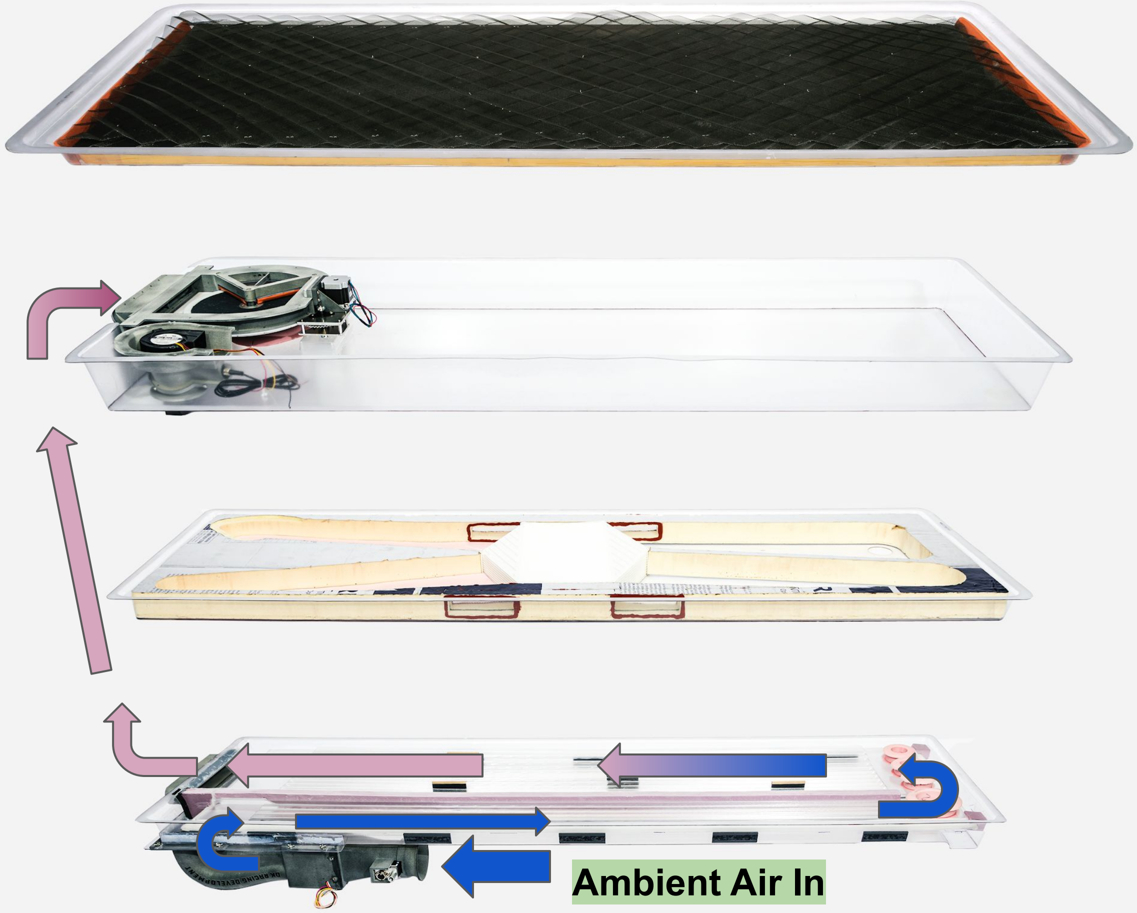
Air-Flow Path: HUMIDITY SUPPLY

HS air flows outside (both above and below) the clamshell, providing cooling to the RC air inside

Air does U-turn into wide-section of condenser

Step 3

Air-Flow Path: HUMIDITY SUPPLY

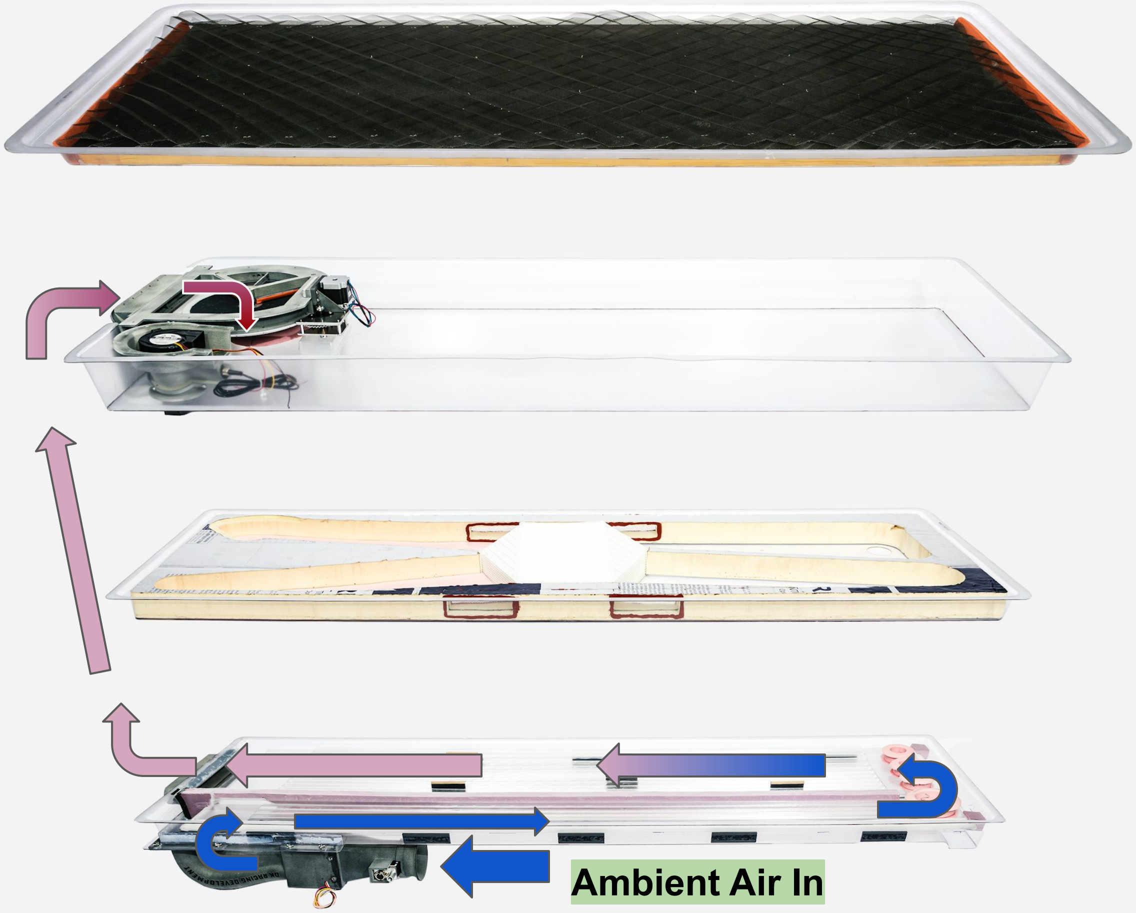


HS air leaves the condenser through an external duct called “the snorkel”

Step 4

Air-Flow Path: HUMIDITY SUPPLY

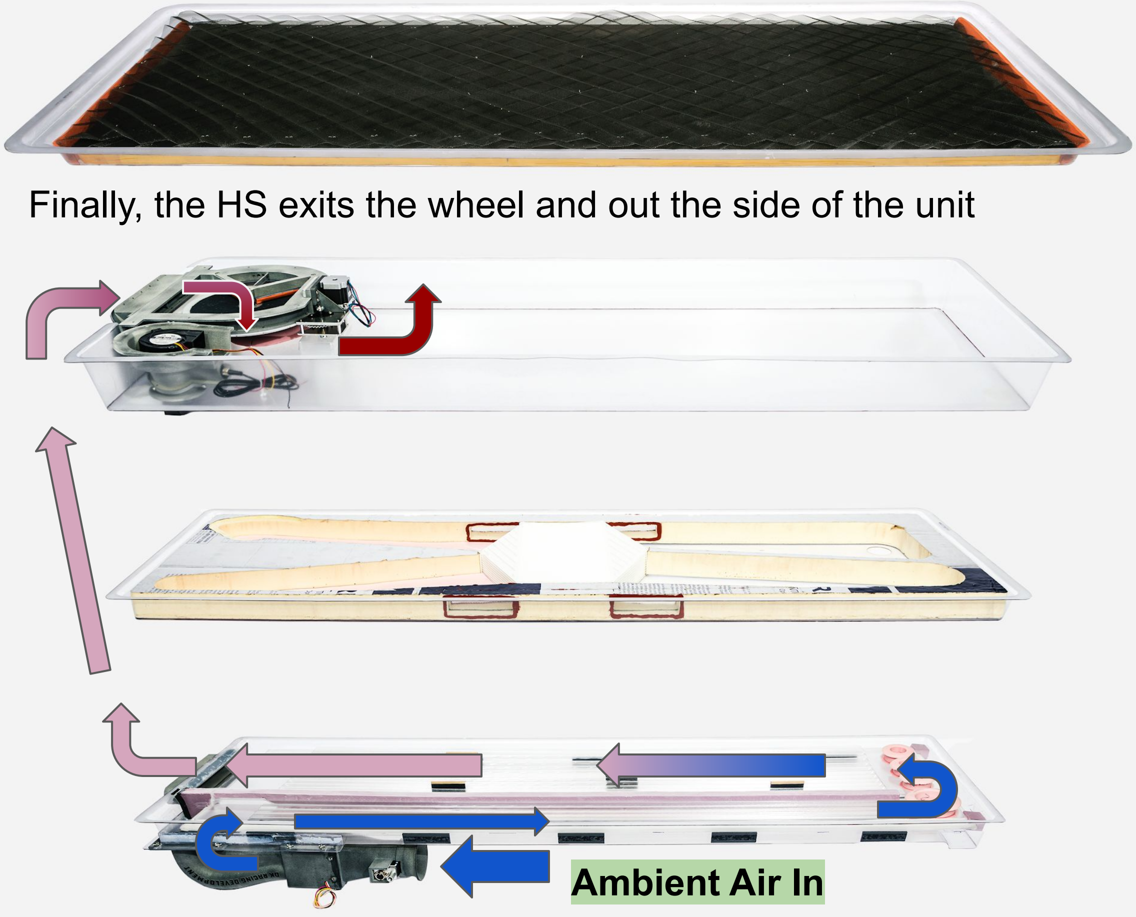
And then enters the desiccant wheel, called the "Black Box", to rehumidify ¾ of the wheel.



Step 5

Air-Flow Path: HUMIDITY SUPPLY

Finally, the HS exits the wheel and out the side of the unit



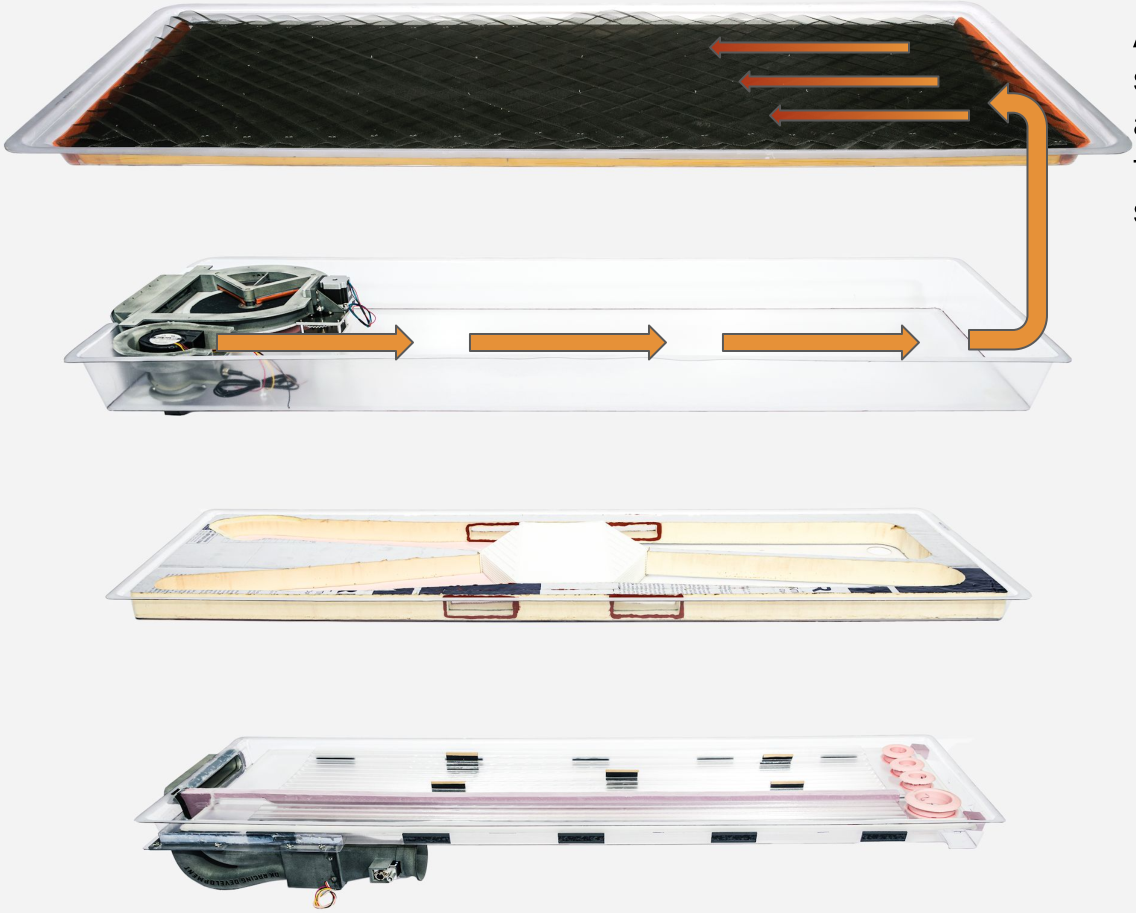
Step 6

Air-Flow Path: RECIRCULATED STREAM

RS Fan pushes air down a channel under the solar collector

Step 1

Air-Flow Path: RECIRCULATED STREAM



Air u-turns into the solar collector area, and spreads out over the sun-heated surfaces

Step 2

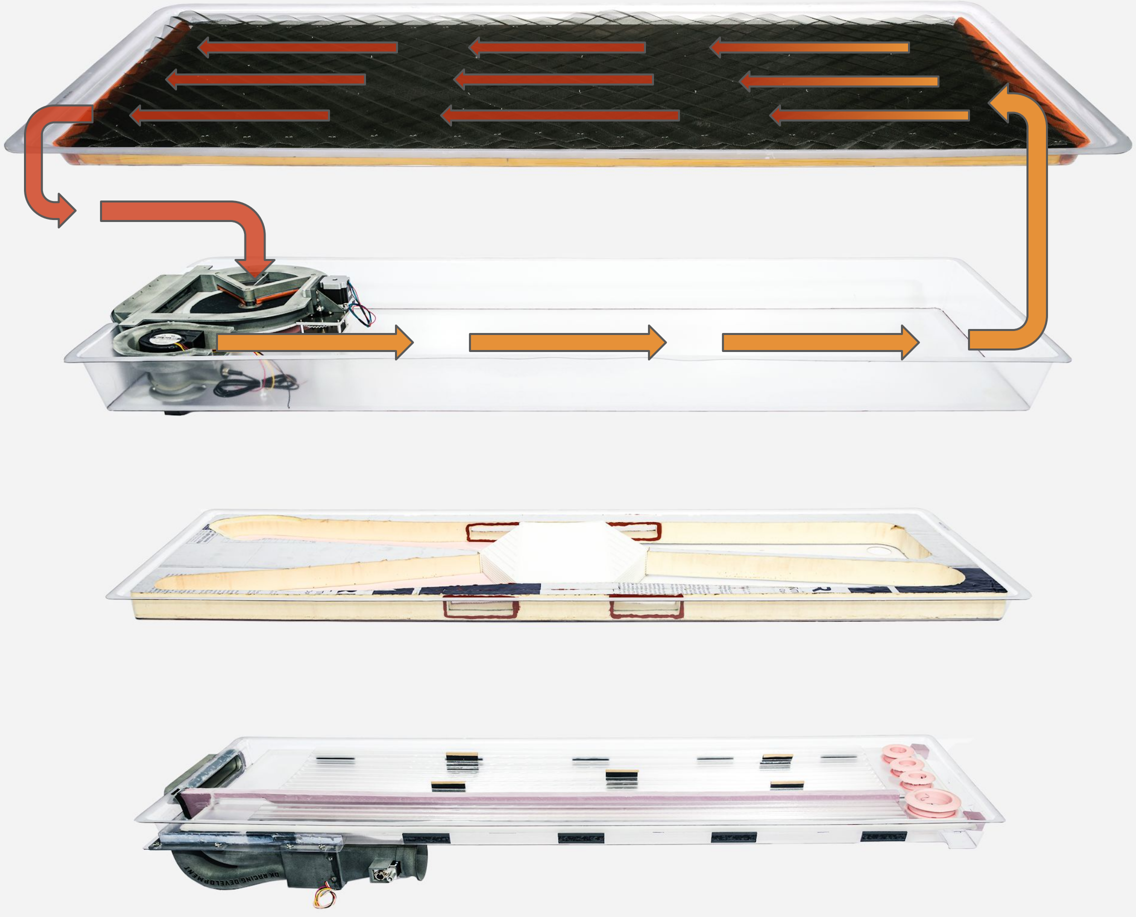
Air-Flow Path: RECIRCULATED STREAM

RS air becomes hot and %RH drops

Step 3

Air-Flow Path: RECIRCULATED STREAM

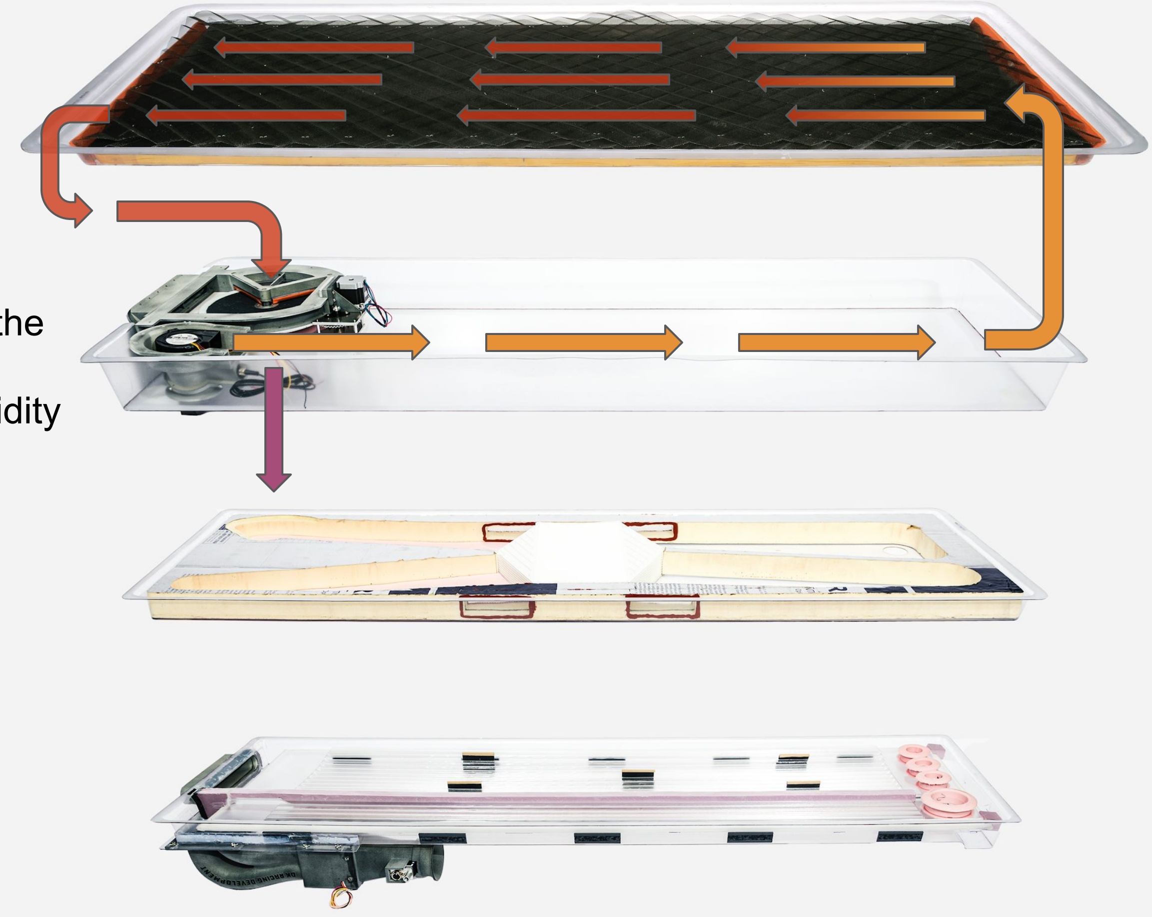
The hot, ‘dry’ RS air u-turns under the solar collector and enters the ¼ desiccant wheel



Step 4

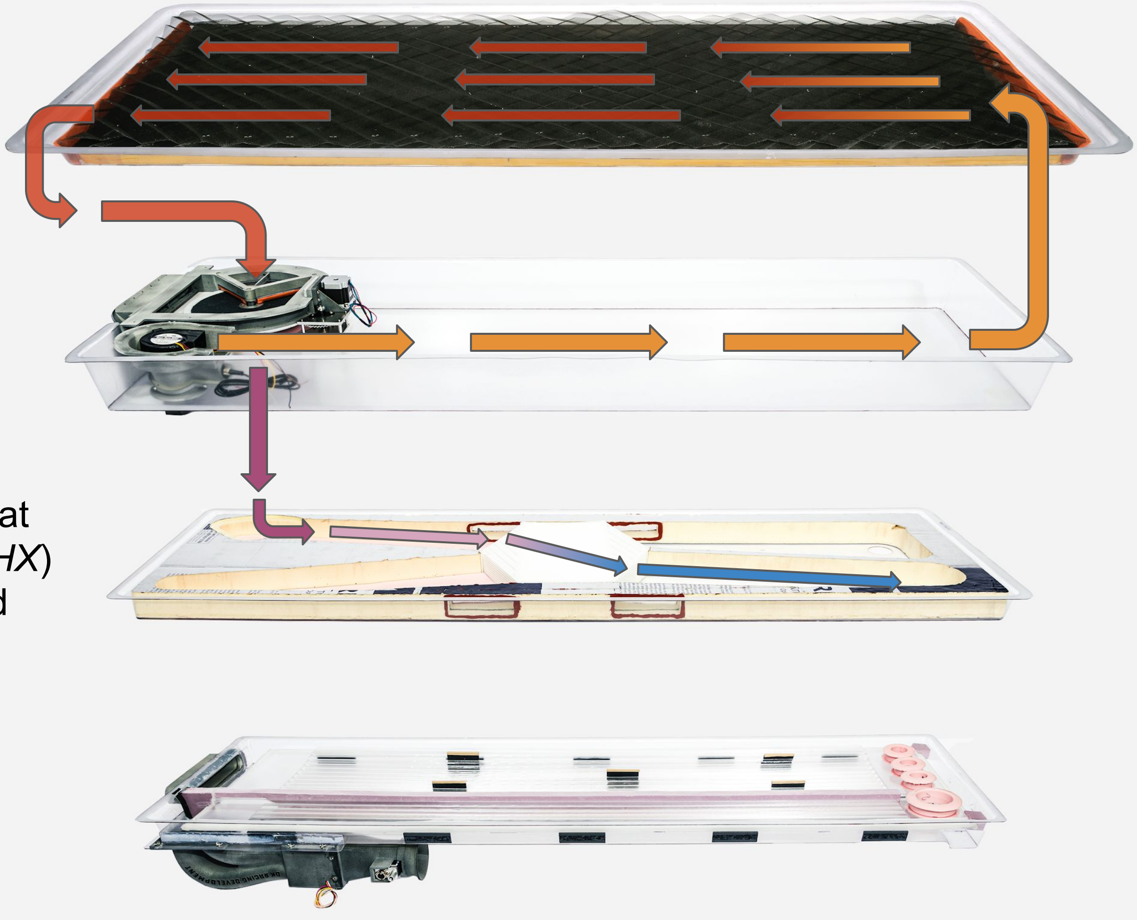
Air-Flow Path: RECIRCULATED STREAM

The RS pulls moisture out of the desiccant, increasing Humidity and slightly reducing Temp



Step 5

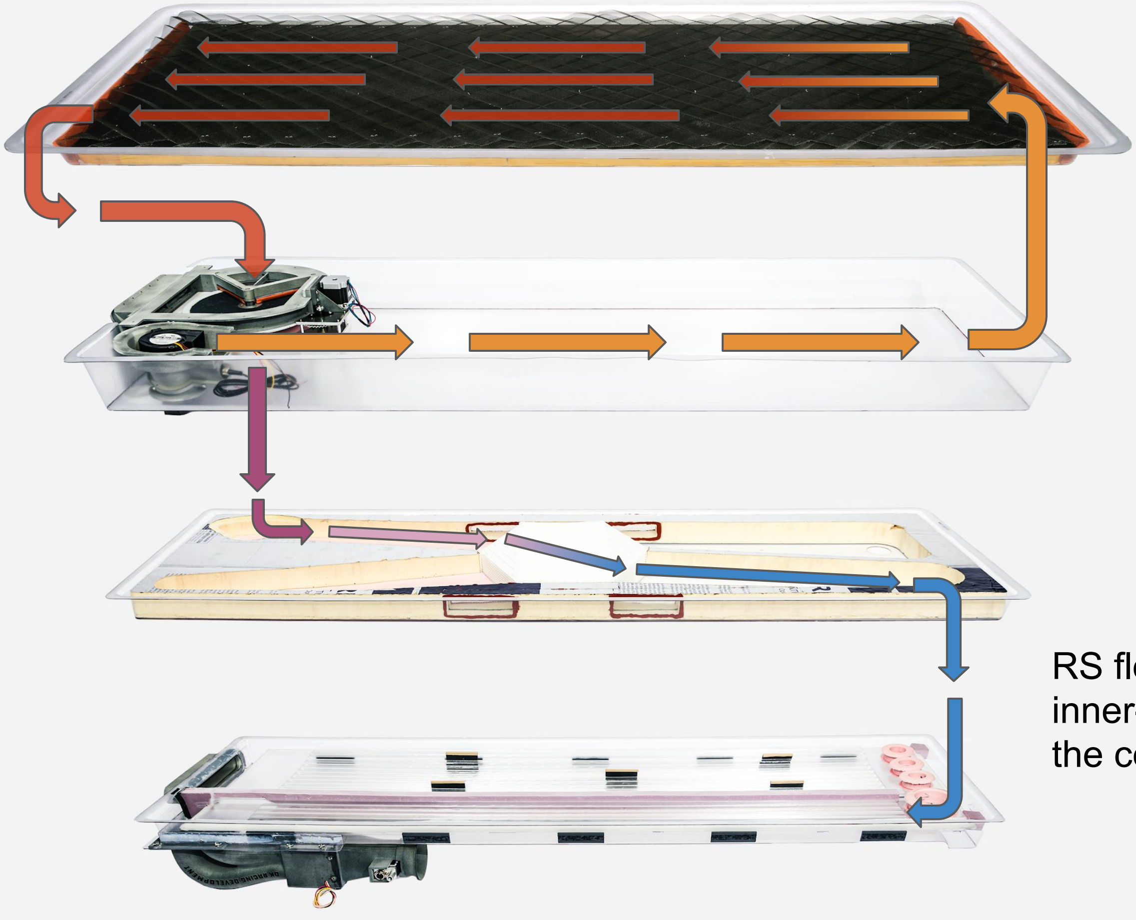
Air-Flow Path: RECIRCULATED STREAM



RS flows into the Recuperative Heat Exchanger (*RC-HX*) where it is cooled down

Step 6

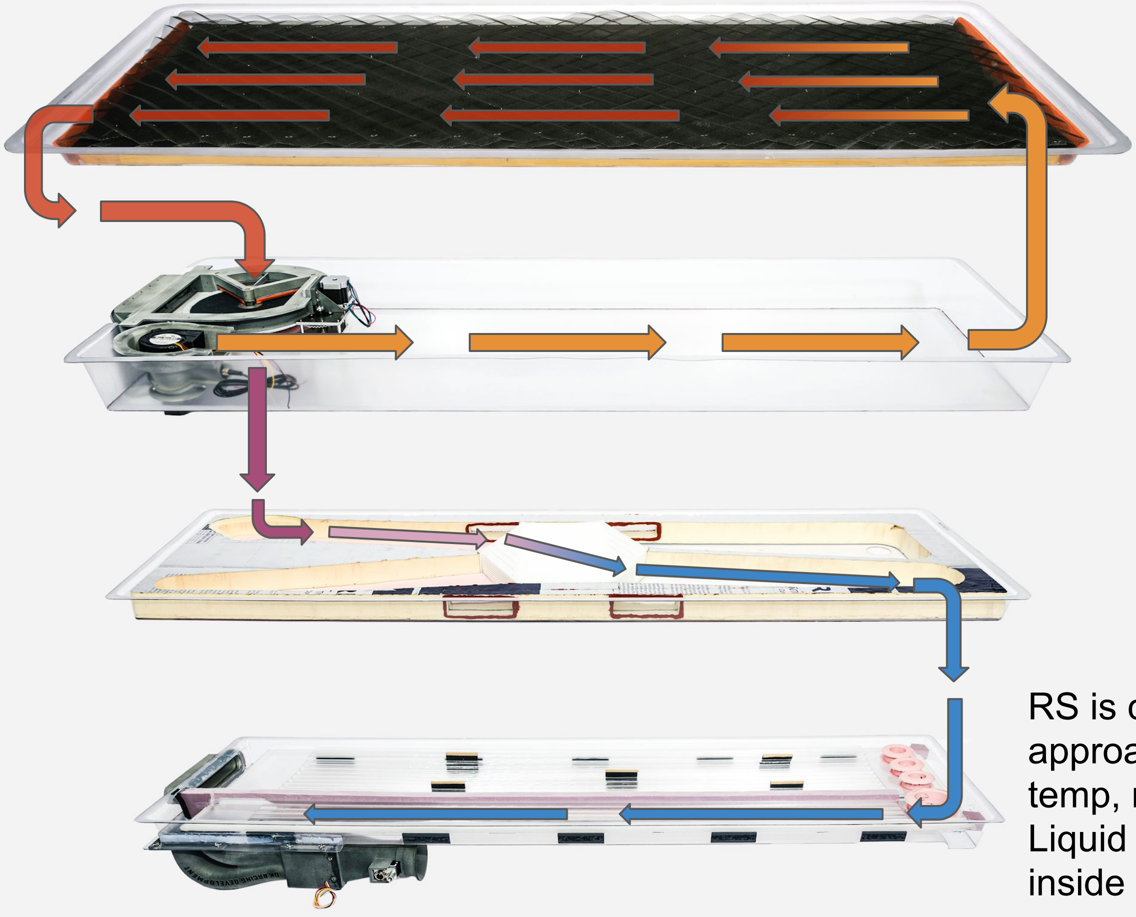
Air-Flow Path: RECIRCULATED STREAM



RS flows into the
inner-clamshell of
the condenser

Step 7

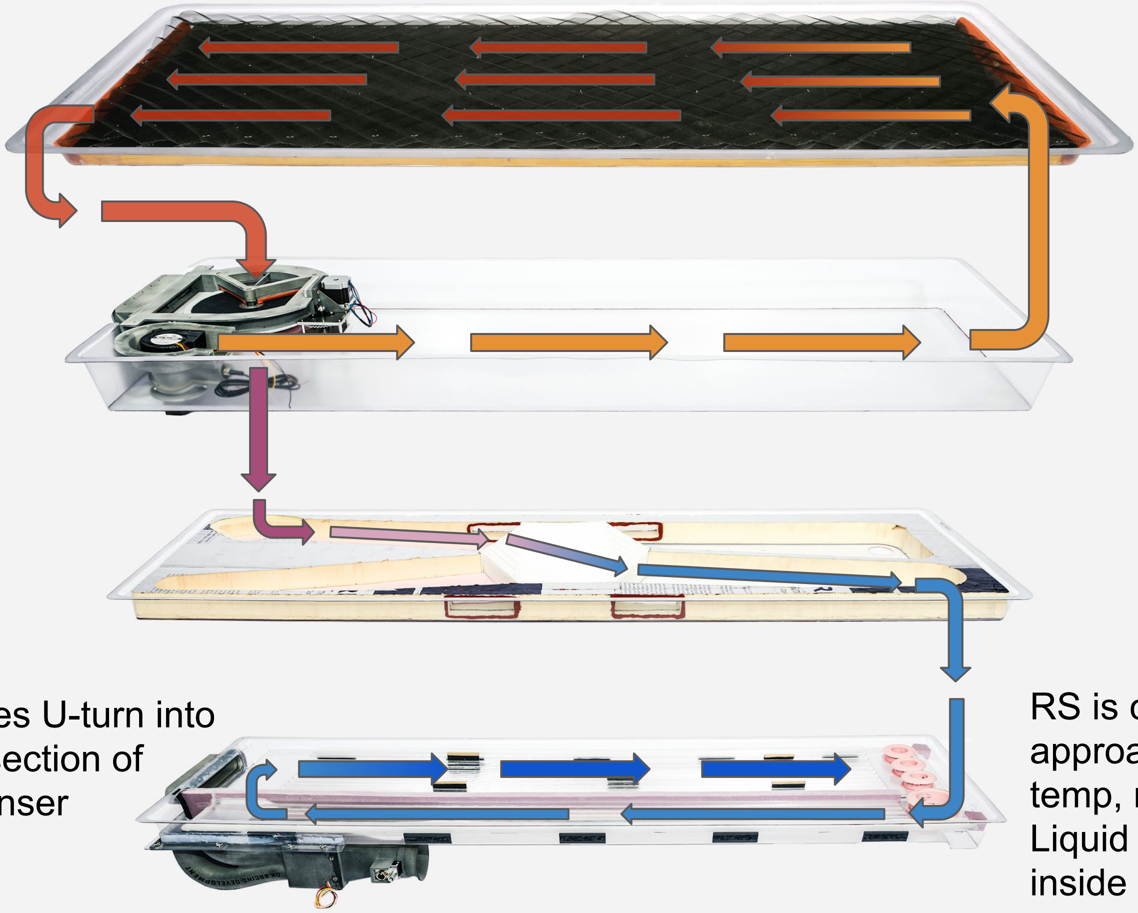
Air-Flow Path: RECIRCULATED STREAM



RS is cooled by the HS and approaches ambient air temp, reaching 100%RH. Liquid water condenses inside the clamshell

Step 8

Air-Flow Path: RECIRCULATED STREAM

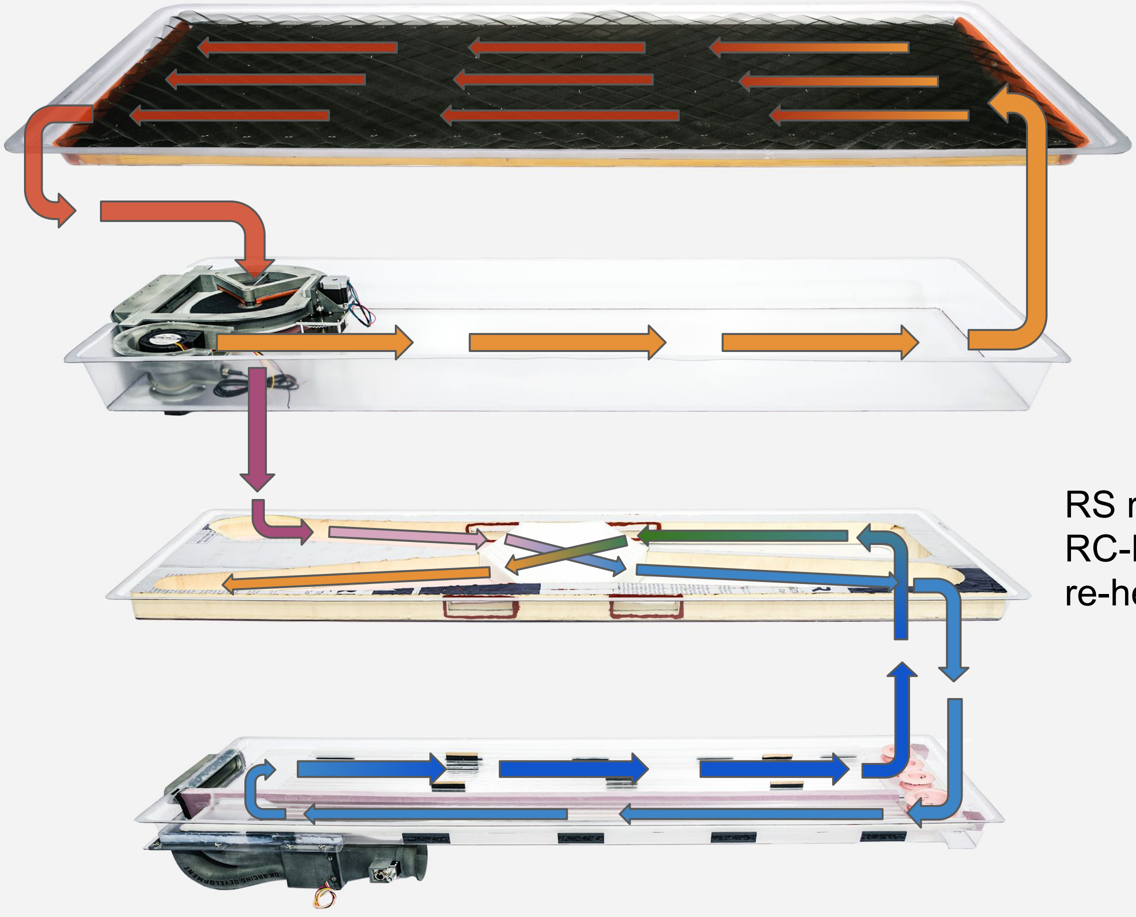


Air does U-turn into
wide-section of
condenser

RS is cooled by the HS and
approaches ambient air
temp, reaching 100%RH.
Liquid water condenses
inside the clamshell

Step 9

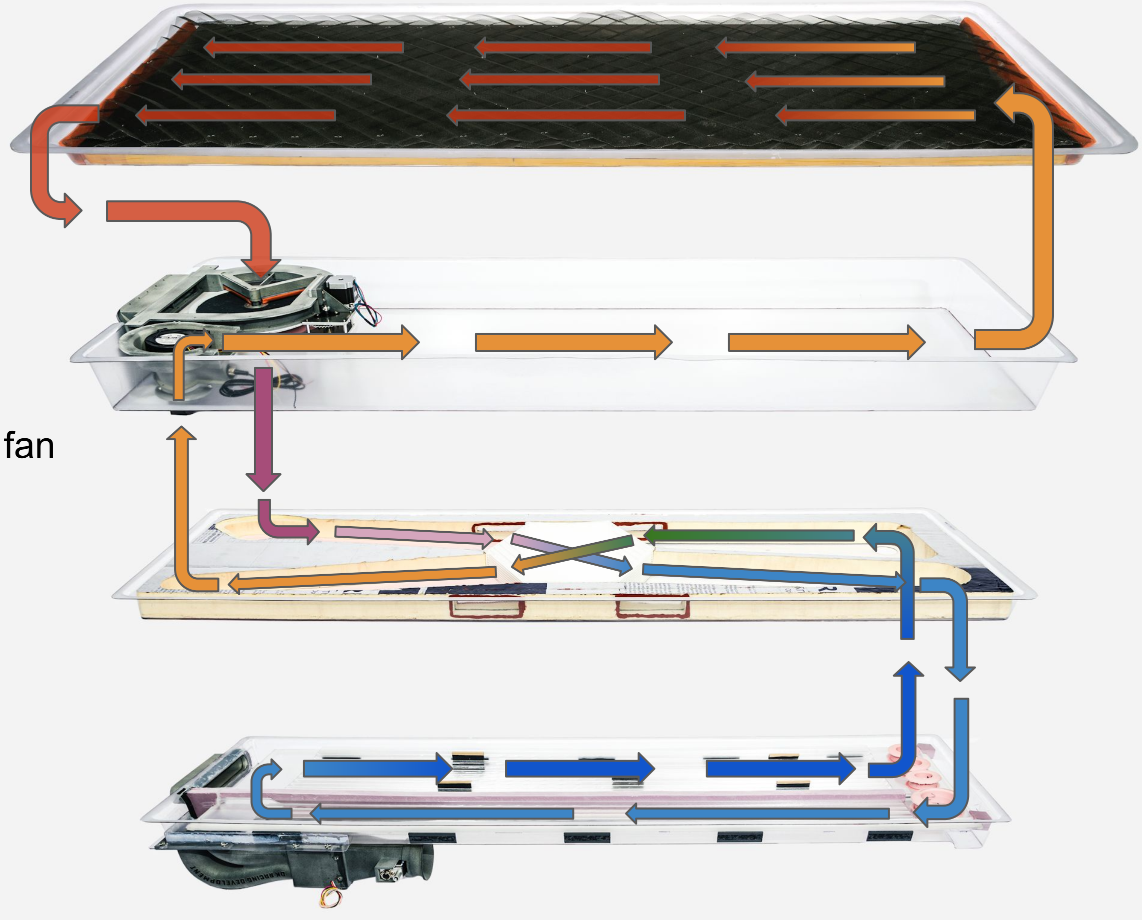
Air-Flow Path: RECIRCULATED STREAM



RS returns to the RC-HX to be re-heated

Step 10

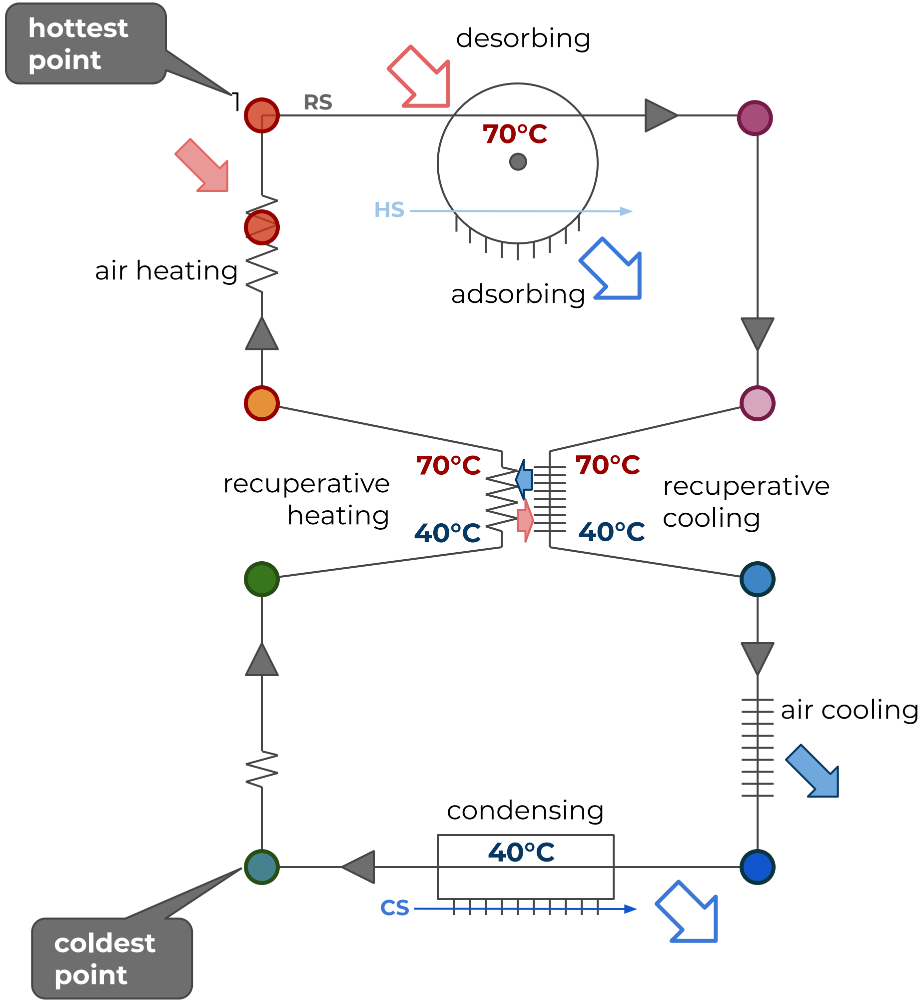
Air-Flow Path: RECIRCULATED STREAM

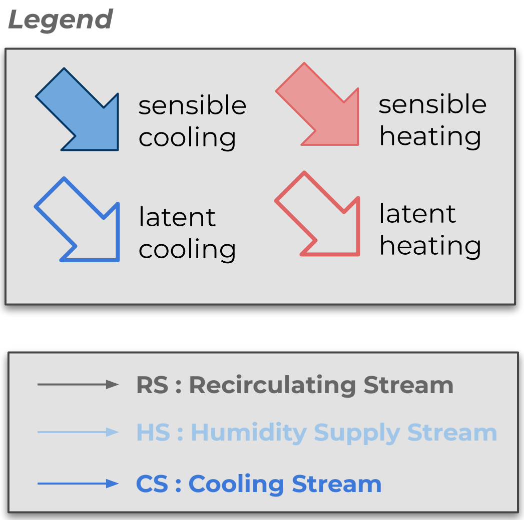


RS returns to fan

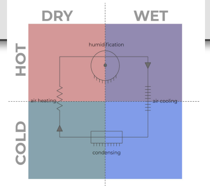
And the cycle continues...

Step 11



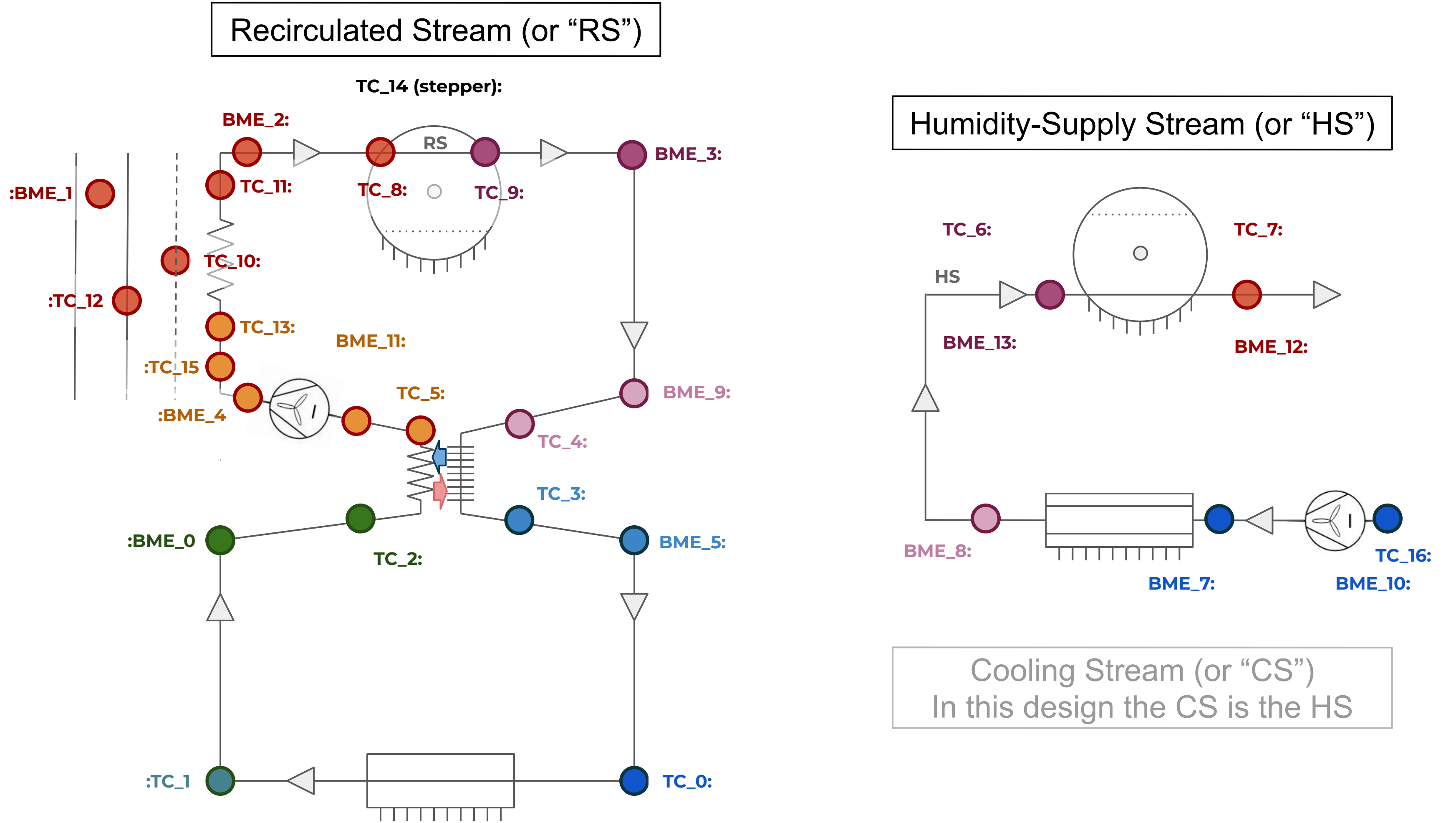


Try graph scheme with color family by quadrant. Reds, purples, blues, greens.
This should clearly show the recuperator on both sides as the "color jump"



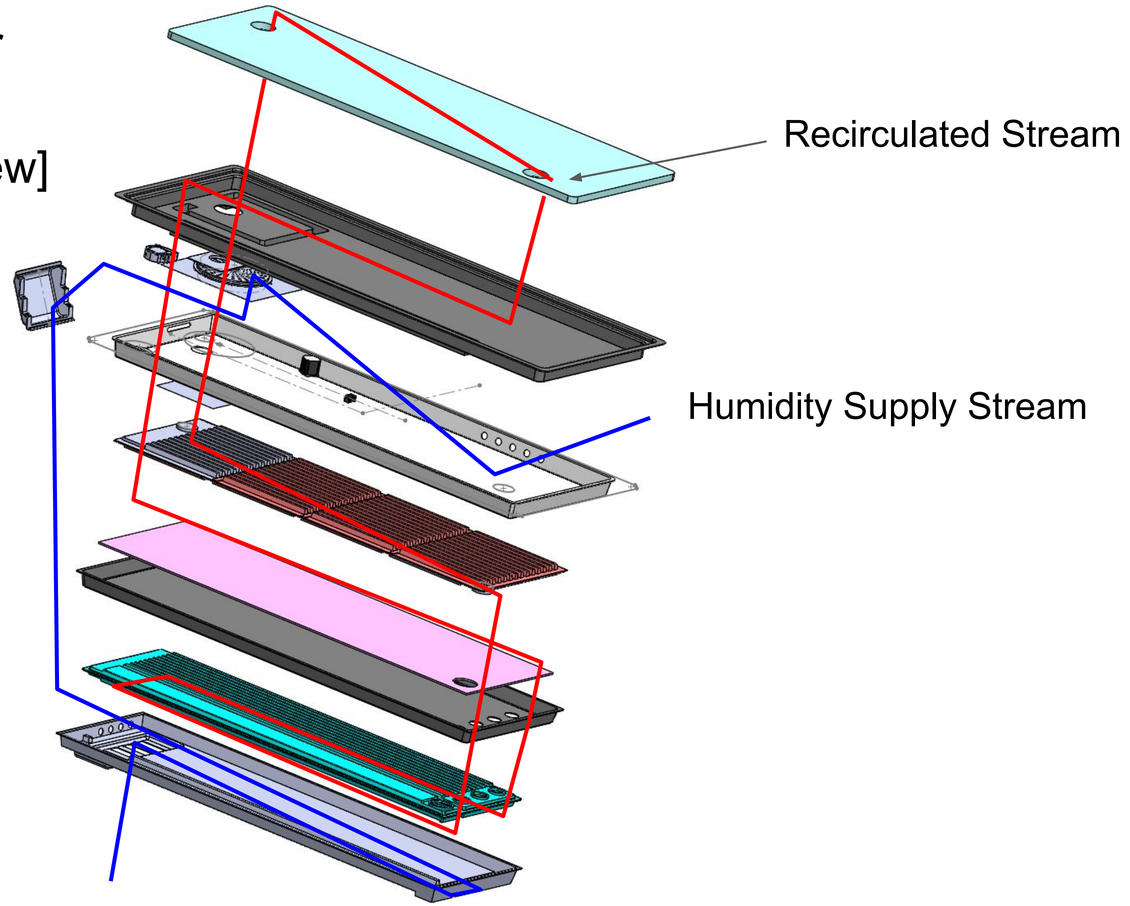
Schematic of Unit, with Sensor Location

(Note: same color coding as flow diagrams above)



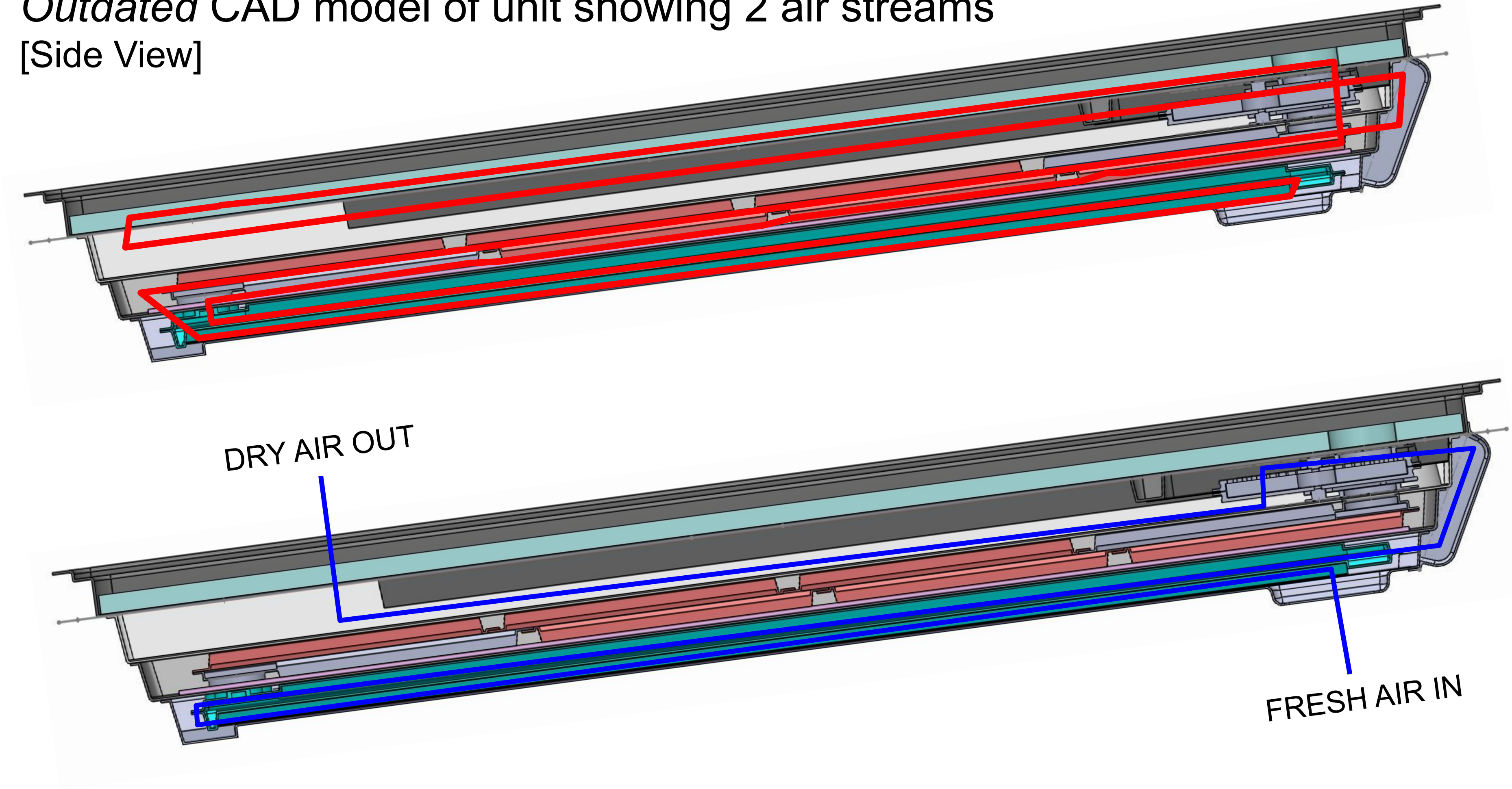
Outdated CAD model of unit showing 2 air streams

[Isometric Exploded View]



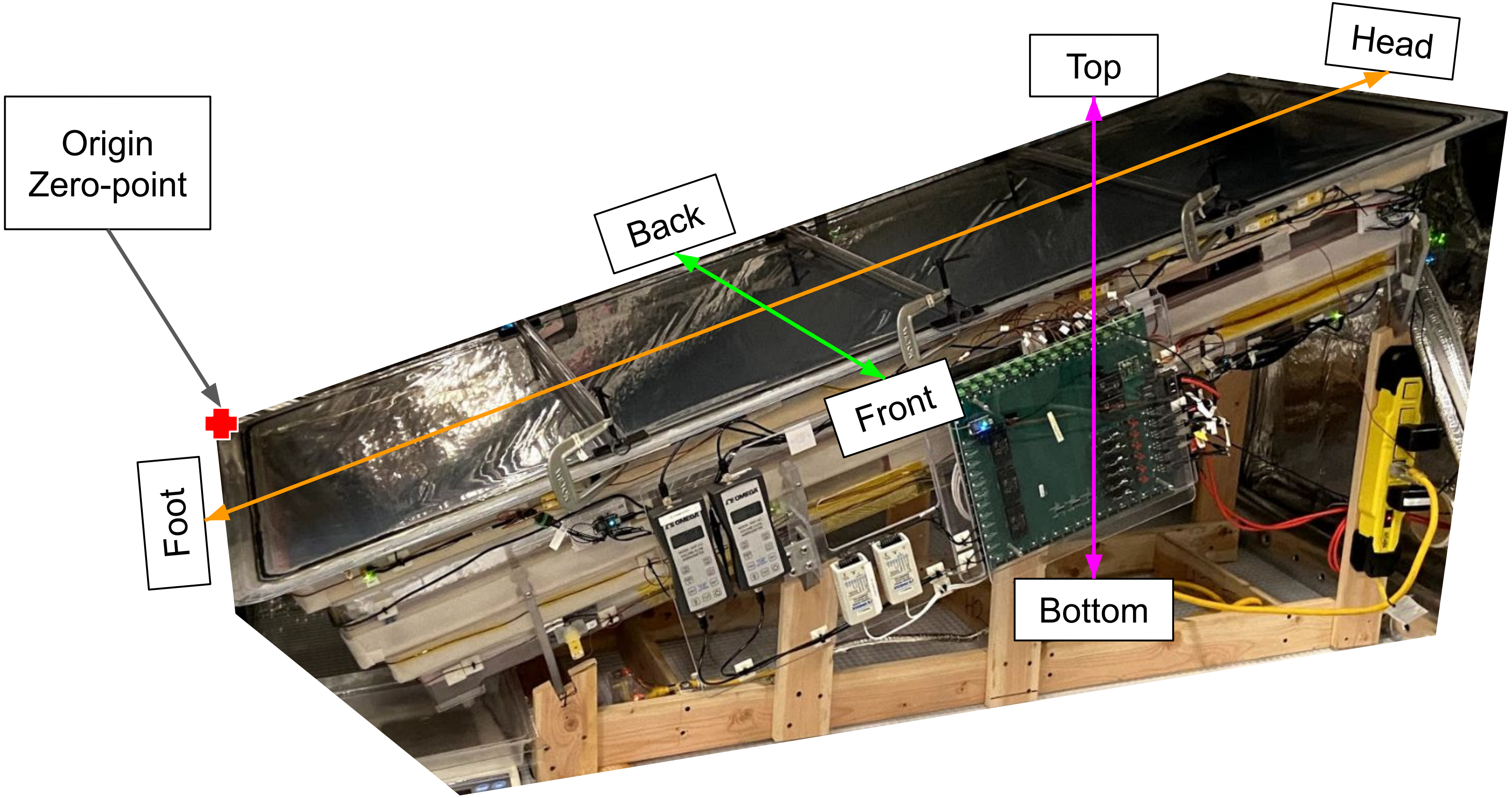
Outdated CAD model of unit showing 2 air streams

[Side View]



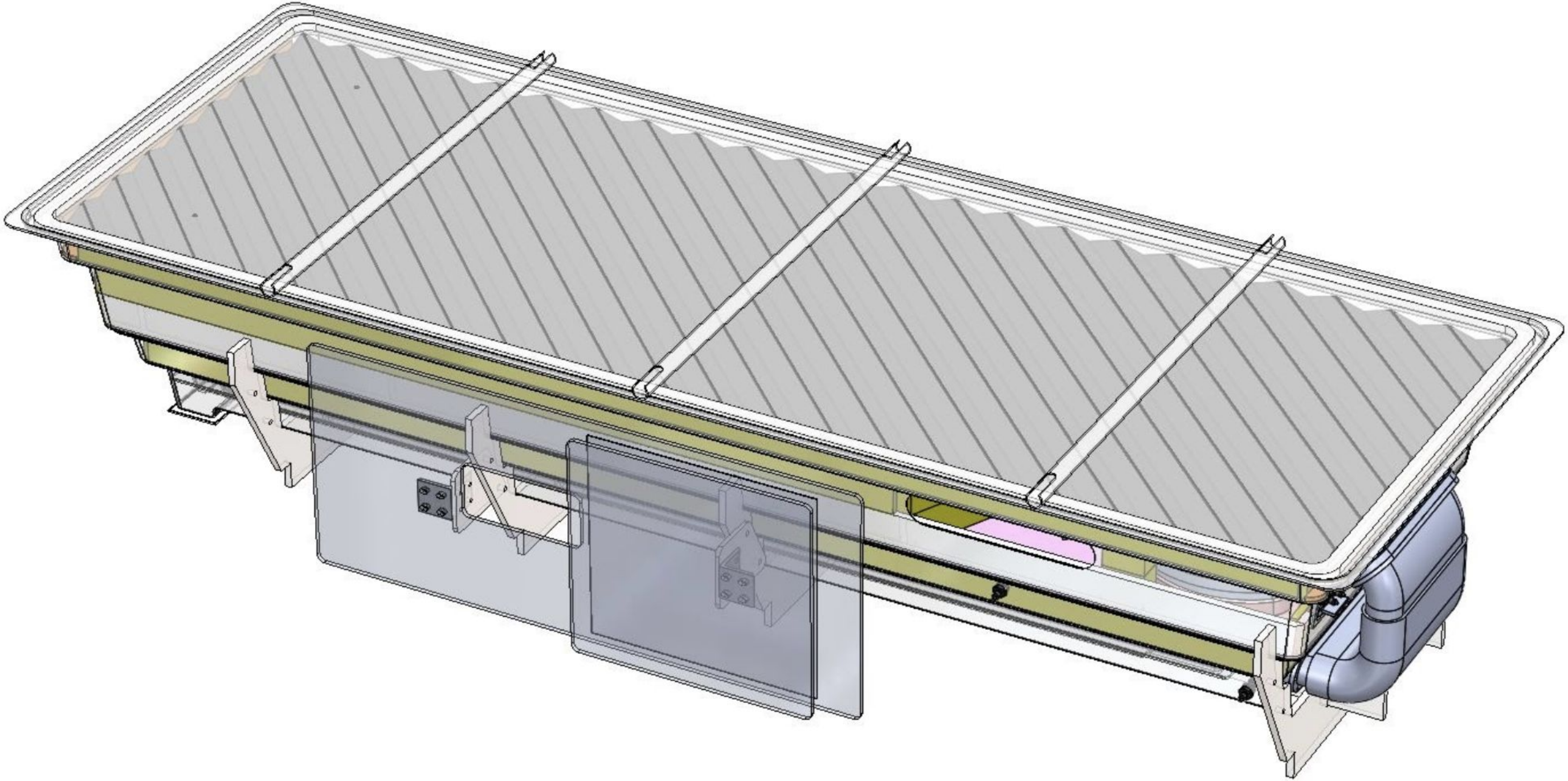
Prototype installed in old Sun-Climate Chamber

Nomenclature and Position Standard

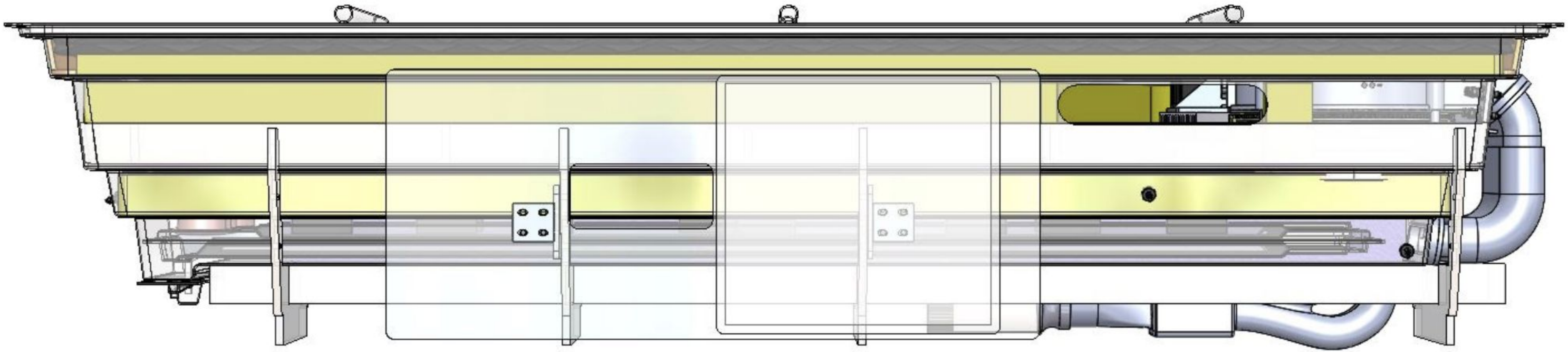


Note: CAD origin is in the center of the model, bottom of the solar tray.

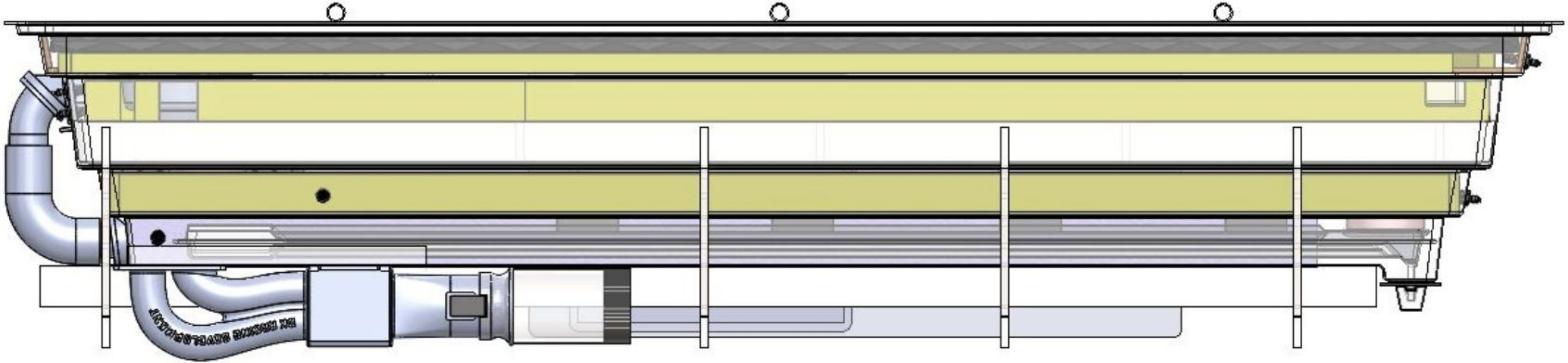
CAD of Unit   Isometric View



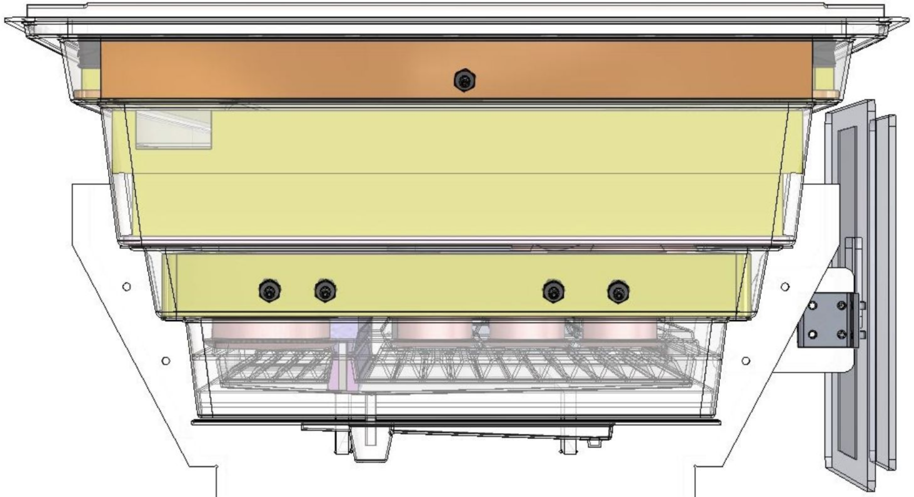
Front Side View



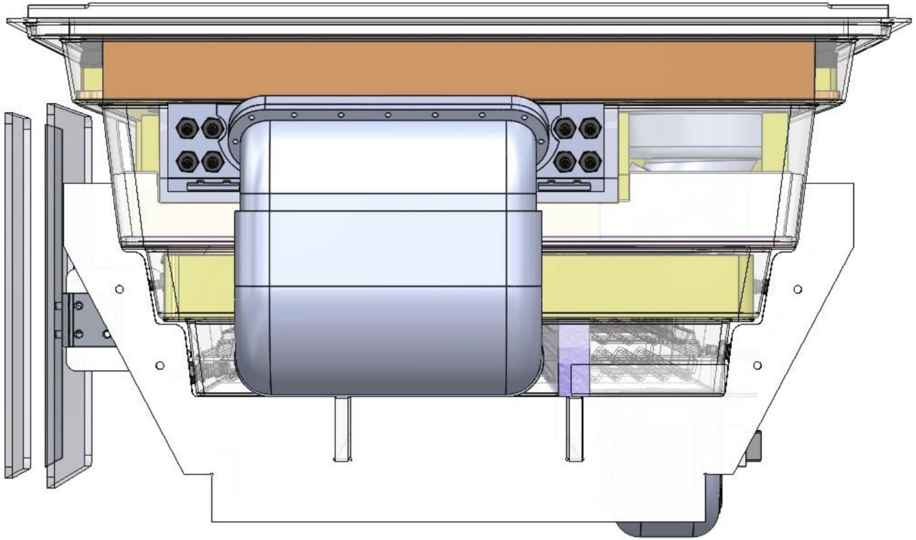
Back Side View



Foot Side View



Head Side View



Bottom View

¾ Side View: Front/Head Corner

2. Vacuum forming and trimming of shells

Vacuum Forming

1. Why vacuum forming? It is one example of a low-cost fabrication paradigm that we think will be necessary to meet our goals of a low-cost AWG for low and middle income users.
2. This common mass manufacturing technique uses heat to soften a plastic film, and vacuum or pressure to form it over a mould or buck, where it cools and then holds that new shape.
3. Often, this is done in a roll-to-roll process for high volume production.
4. For example: take-away food containers.
5. It can also be used to create large format parts, and with creative designing of ribs, even very thin materials can form rigid bodies.
6. We think we can stretch this technique to meet our needs, while maintaining the advantages.
7. This is just one of many potential low-mass and low-cost manufacturing paradigms we could employ for a final product, however it seemed like the best fit for a design that we felt confident we could execute on, so we started with vacuum-forming.
8. We decided to focus the design approach for our next prototype on vacuum forming in order to learn how to work with those materials and fabrication methods.

General Notes

- These are coming in as raw formed plastic that need edge trimming, holes drilled, etc. ABS, PETG, Polycarbonate.
- Thinnest formable Polycarbonate was 1/16 inch. The Petg and ABS was down to .06”   Test shells made in ABS were the easiest to form.
- Polycarbonate had the most difficulty as it has the highest GTT (glass transition temperature -- the temp when the material gets soft and formable), meaning it had to be heated higher and longer, and often there was less time to form it. PC also has the issue of moisture sorption over time causing bubbling in the part, so sheet stock should be oven preheated for many hours to drive off moisture before a pull.

Process for producing vacuum formed shells

1. Conceptual design and hand sketches
2. Rough CAD model for all major components, including lining up all ports and mating points.
3. Detailed CAD for all vacuum formed, grommet, seal, and other major components of the unit.
4. Use the CAD for the vacuum formed parts to make CAD for bucks.
5. Use the buck CAD to make tool path plan
6. Order the materials for bucks (Renshape and MDF base)
7. Rough-cut the blocks of material into the general shape, and/or laminate sheets together for thicker parts.
8. Adhere the blocks to the tool bed and CNC machine the buck to shape. Check that part is within tolerance.
9. Remove the buck from the tool bed and clean up
10. Use a router to cut a vacuum air-path into the back side of the buck. There are 2 central vacuum pulling points located under the buck that need to be connected to and distributed out to the edges of the buck.
11. Use an aircraft drill (~3/32”, long bit) to drill vacuum pulling holes spaced about 2” apart in all low points or internal corners.
12. Rough-cut MDF base to shape (we tried to use the same size base so that swapping bucks out would be faster for the vendor). Then glue and screw the MDF to the bottom of the buck. Hole-saw a large hole in 2 places in the MDF where the vacuum will be drawn underneath the buck.
13. Ship to the vendor
14. Vendor vacuum forms the parts, starting with 4’x8’ flat sheet stock. Bucks are placed in the machine and centered, plastic sheet is clamped into a metal frame and slid into the radiant heating oven until they are soft, then the film+frame are slid back over the buck, the buck is raised up pneumatically into the soft film, vacuum is applied to pull the plastic into shape, and is let to cool and soldify. The edges are roughly trimmed to ~3” away and the parts are packed and shipped back to us at RLS.
15. We receive the parts and do a final trimming, hole-cutting, and deburring of edges.
16. Then the part is ready for the next phase of assembly.

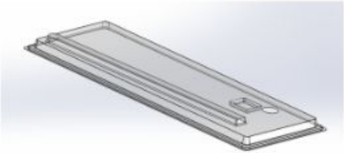
7 Bucks Designed in CAD

After the CAD of the entire unit was completed, we made CAD for a buck for each of the 7 key component shapes (used to make 8 key parts).

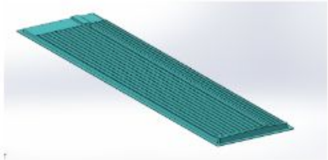
(The Recuperative HX layer buck was intended to be used to make a top and bottom part, each with differently located holes. However we used a CORE HX unit instead for Proto 4 Rev 1 build.)

Once the CAD files were completed, we developed the CNC toolpath plans, and then machined the bucks on a large-bed tool.

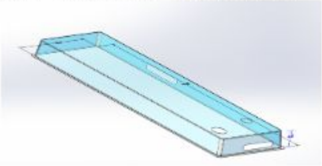
Layer 1 (Collector) Qt 2 Polycarbonate 1/16"



Condenser A top Qt. 2 x PETG 0.060"

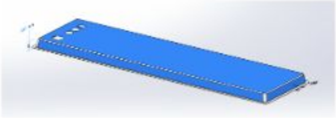


Layer 2 Black box layer Qt. 2 - Petg .060"



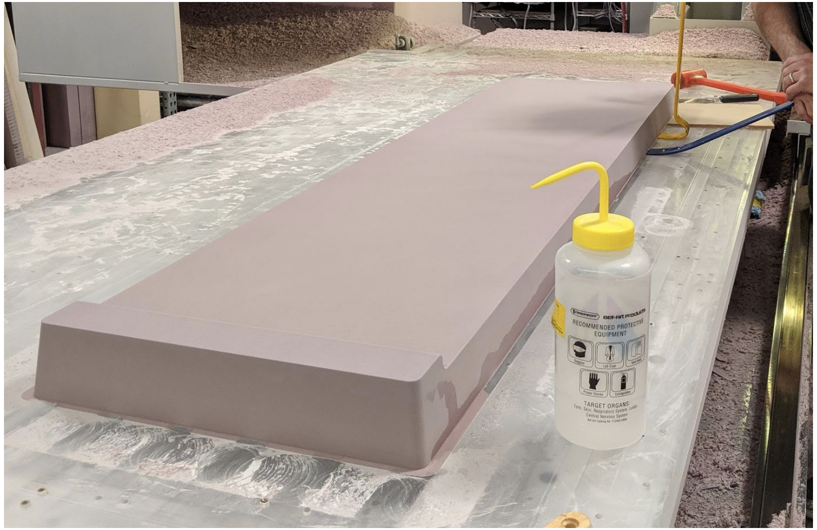
Condenser B bottom Qt. 2 x PETG 0.060"

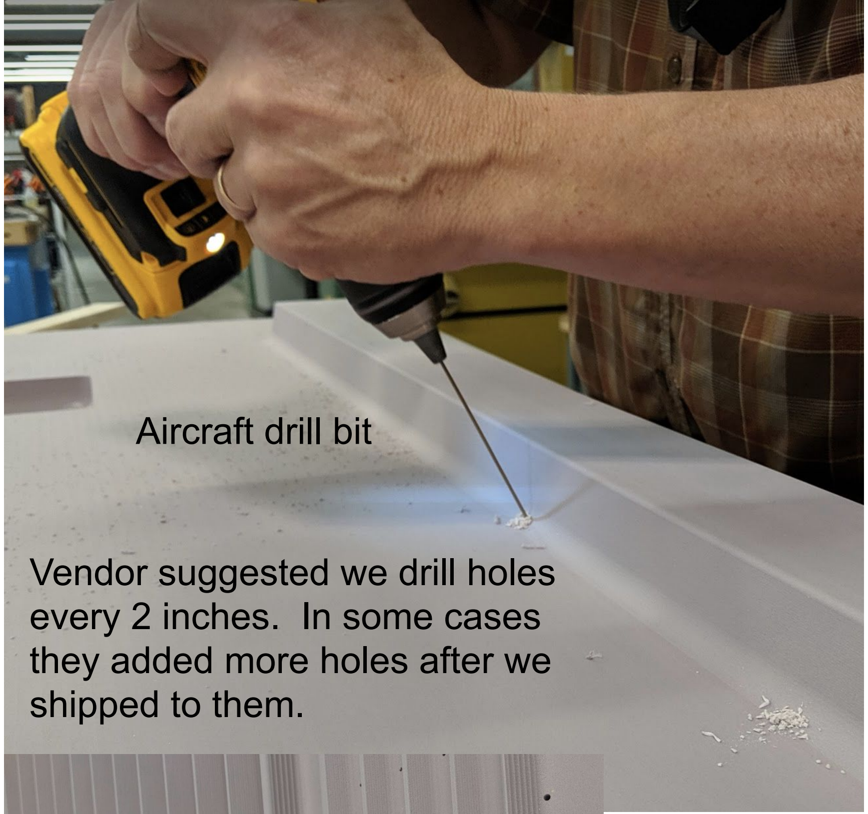
Layer 3 2.25" tall- Qt. 2 x Petg .060"



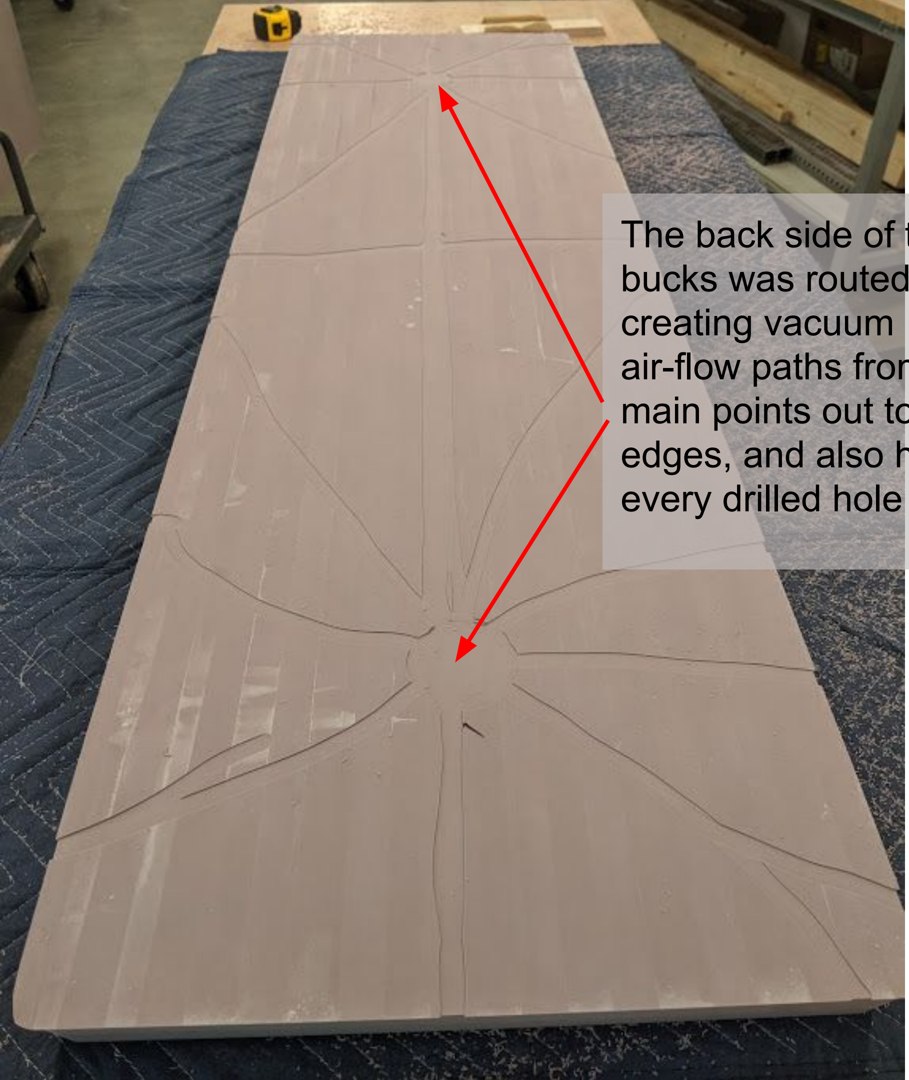
Recuperative HX Core Qt.1 x PolyCarb 1/16" Qt. 2 x ABS 0.060"

Layer 4 (Condenser tray) Qt. 2 x petg .060"

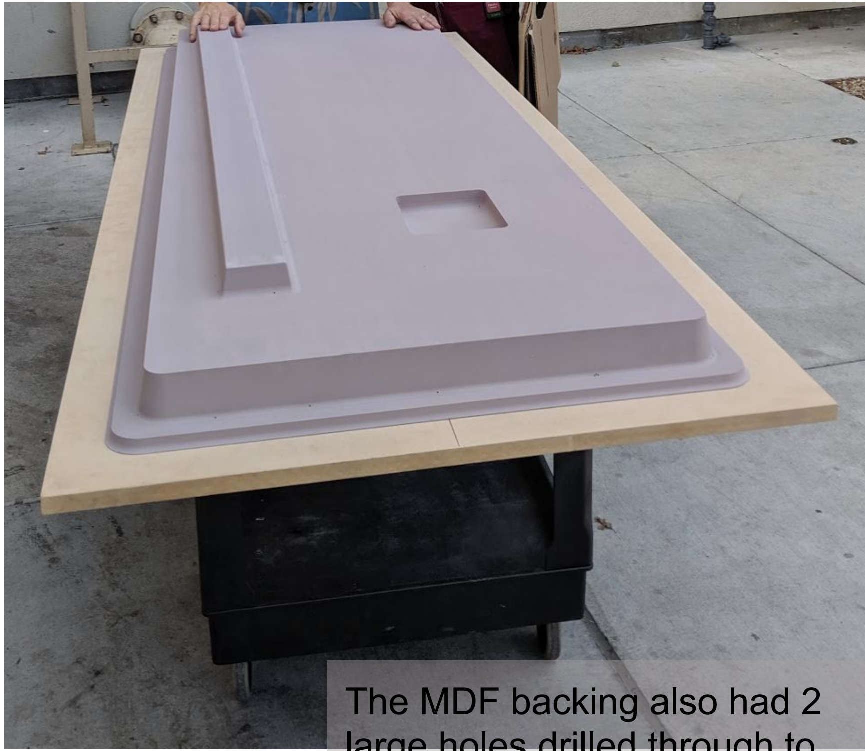




Double-sided sticky tape was used to adhere ("clamp") the renshape onto the platform of the mill tool. We then used IPA and held pressure (lifting with crow bar) to the finished buck to get the adhesive to release.

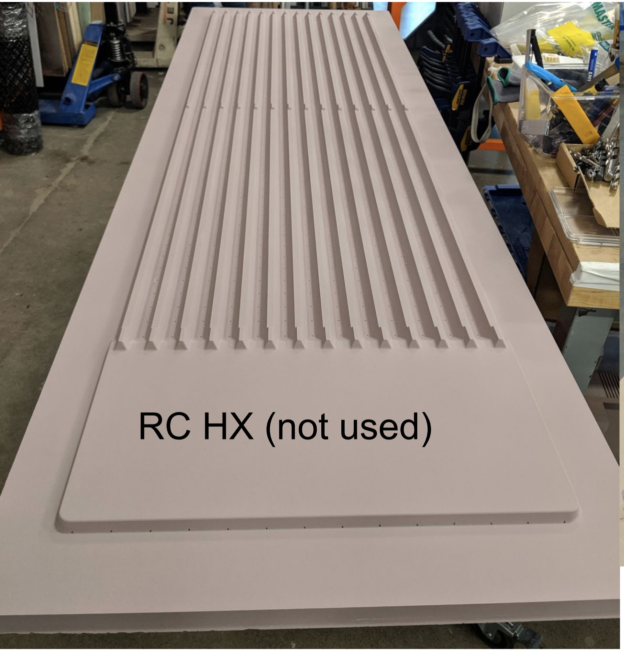


The back side of the bucks was routed out, creating vacuum air-flow paths from two main points out to the edges, and also hitting every drilled hole

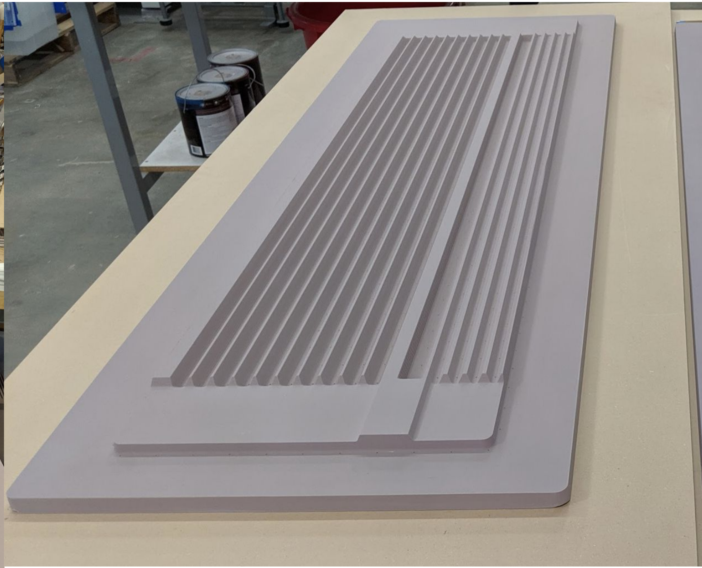


The MDF backing also had 2 large holes drilled through to line up with the vacuum ports. The MDF was then glued to the bottom of the Renshape.

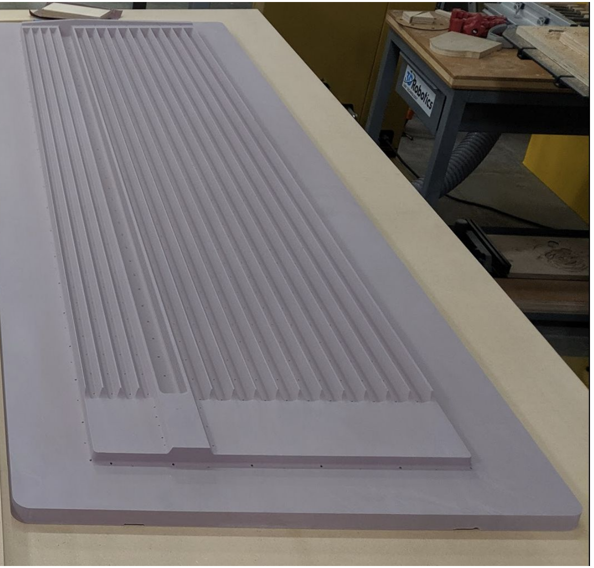
Images of finished Bucks



RC HX (not used)

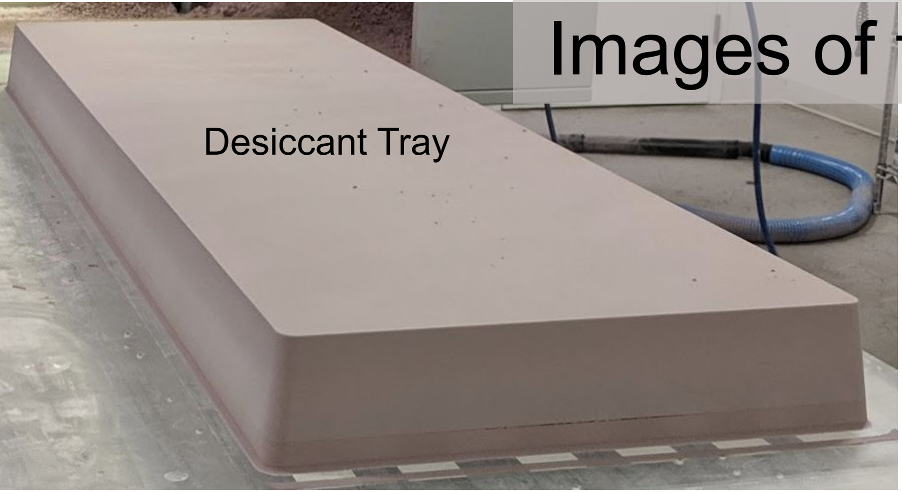


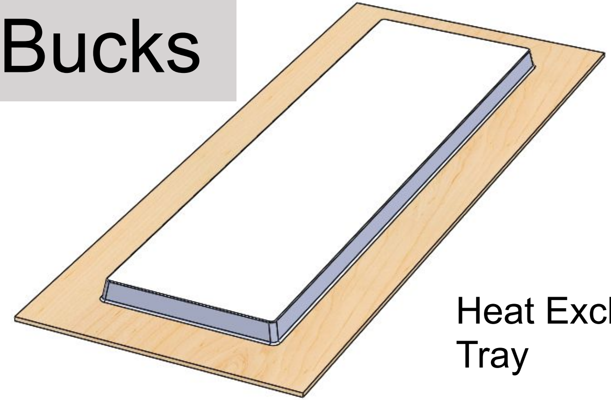
Condenser
Clamshell Top



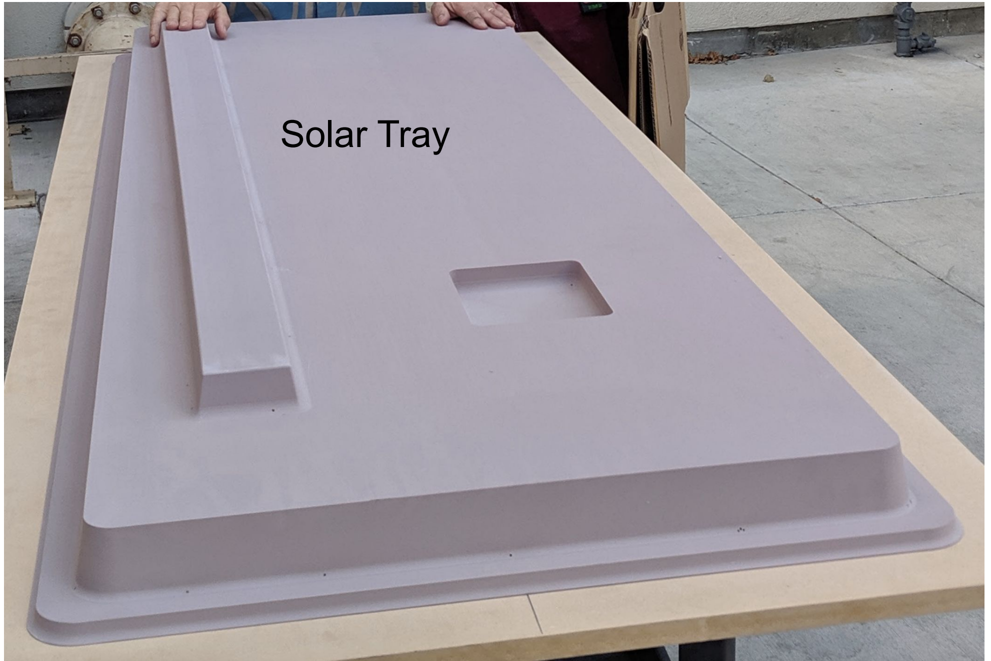
Condenser
Clamshell Bottom

Images of finished Bucks





Heat Exchanger
Tray

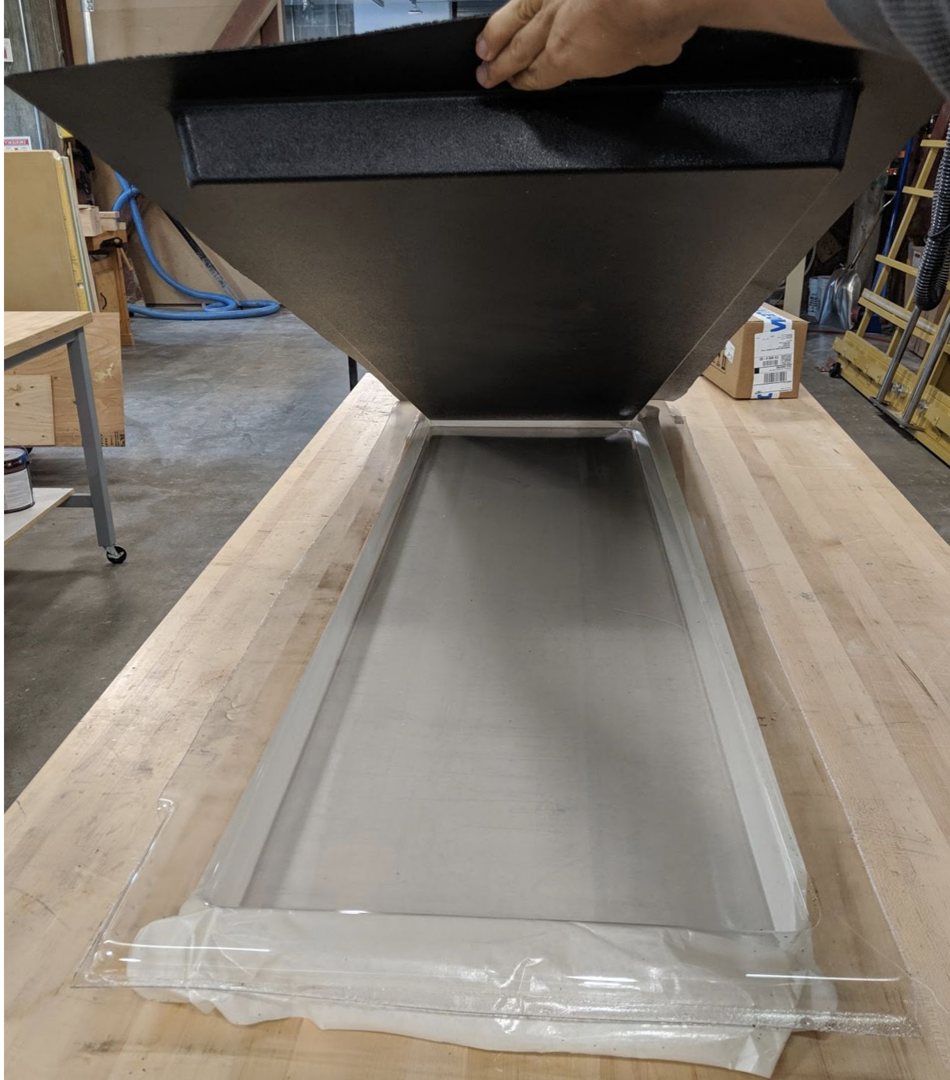


Parts back from vendor

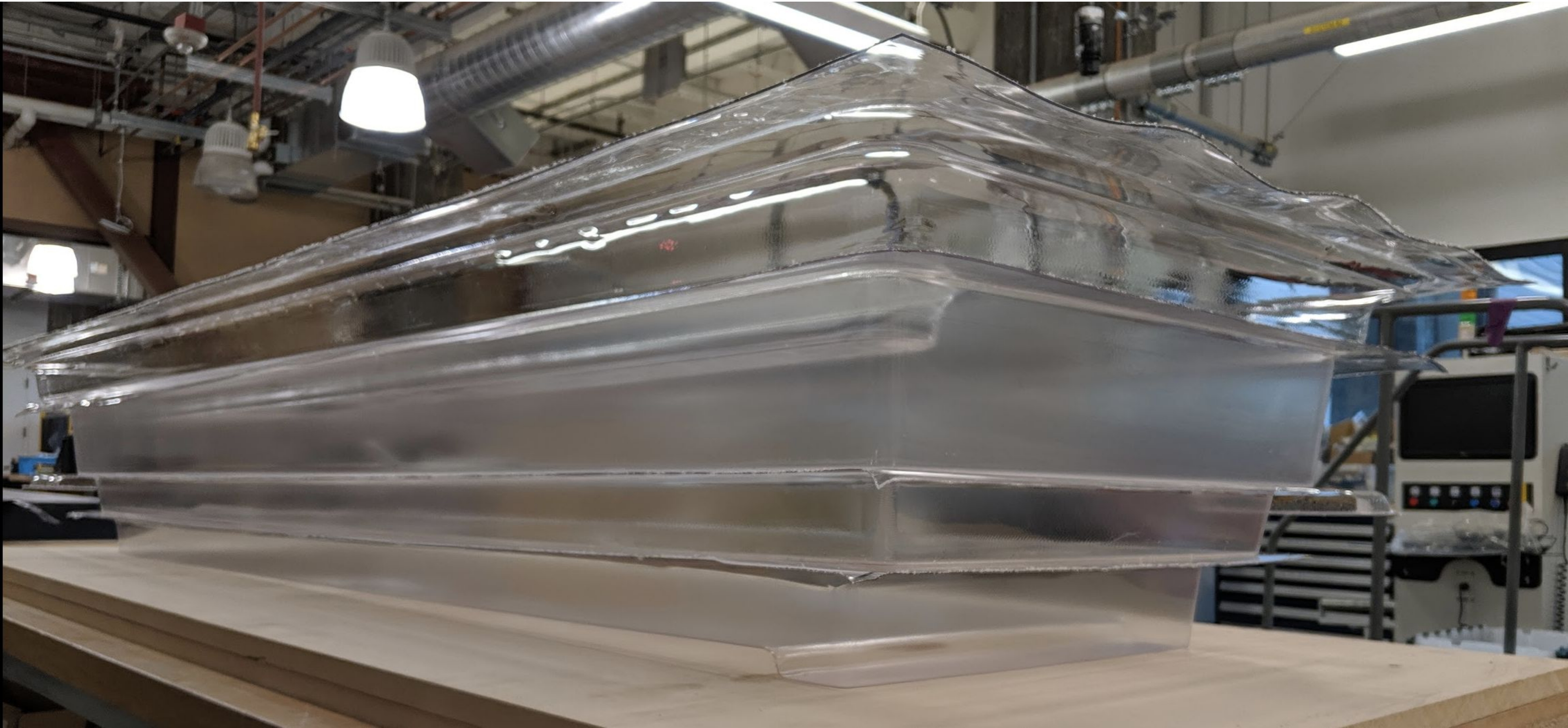
They had been rough-cut likely using a hand-held jig saw.

A protective plastic film had been applied after forming to prevent the parts from getting scratched during handling and transit. We removed those protective films.

Many of the parts were able to nest (upside-down order), making handling, shipping, and storage easier.
→ (This caused us to think about shipping the shells nested, and having the customer or local CM complete the assembly?)

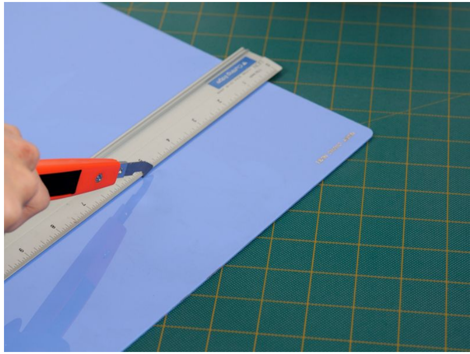


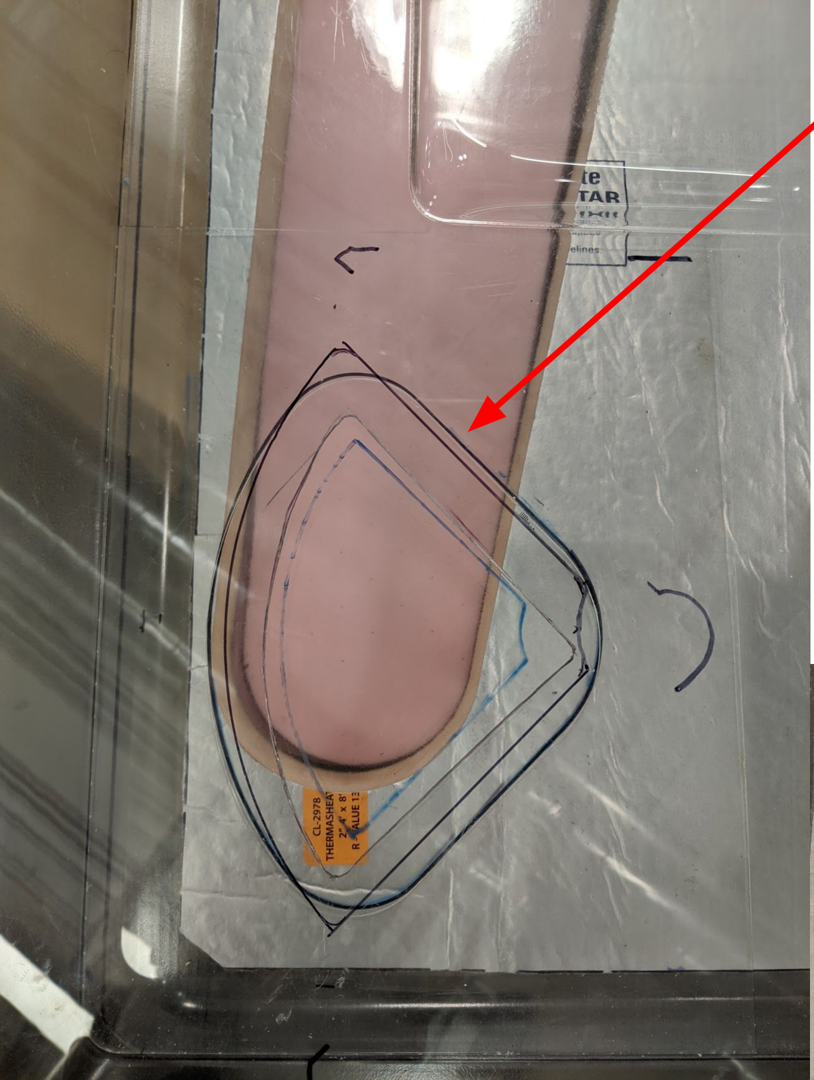
Preliminary Stack of all layers (PC and PETG materials)



Trimming of Vacuum Formed Shells

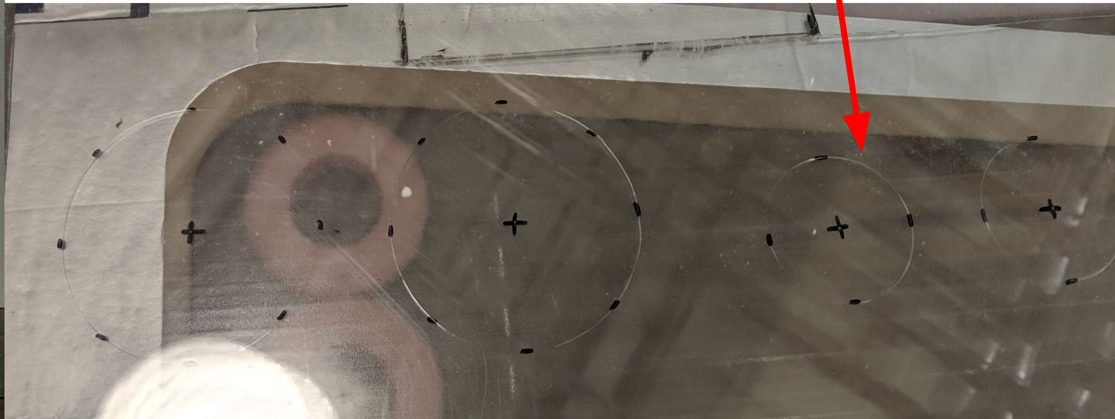
- The initial rough trimming was performed by using a pneumatic cut-off tool and small abrasive disk. This worked relatively well, and sort of melted the plastic at the cut, likely relieving stress and minimizing cracking.
  - However this was mostly not precise enough, and additional trimming was needed. Also the abrasive disk / melting left a burr that was difficult to remove. A razor blade seemed to be best for burr removal.
- Score-and-snap method of cutting worked well for PETG and Styrene parts. But we had to be careful not to let the blade wander and score into the area we wanted to keep! (ex: Condenser clamshell).
- Length of parts made it difficult to score straight lines, and cutting neatly radiused corners was tricky
  - A cutting stencil or guide of some kind of other tooling could make this easier and more reliable
  - For straight lines, we found that using a metal ruler to define the edge, and then a box-cutter to repeatedly score the line worked well. Even some round radiuses could be scored by hand this way
- Round holes were cut into PETG sheets mainly with a fly-cutting tool and hand-held drill, with a piece of scrap wood underneath the plastic sheet for full support. The photo on the right is a similar tool to what we used.
- Other holes that were not round, such as the pie-wedge hole in the solar tray and desiccant wheel tray were best cut by first drilling a hole with a zero-rake bit at the ‘corners’, and then using a box cutter to score the rest of the line.
  - For non-linear lines, we did not score and break. Instead we continued scoring until we fully penetrated through the plastic to the wood or table underneath. This was done out of extra caution since we only had 1 vacuum formed part in many cases.





Positioning of holes was done manually with the actual parts assembled. Sharpie was used to mark the holes after all measurements were triple checked.

We tried multiple hole cutting methods on multiple materials, including hand-scoring, hole-saw drilling, manual hole-saw turning, and fly cutting. Fly cutting was cleanest.



3. Adhesives

Adhesives Overview

For experimental use, the main challenge was to find adhesives that satisfied conflicting criteria:

- Allowed for reliable air-tight sealing that would not leak, even after being exposed to high temperature, mechanical wear, vibration, and significant force in the form of pressure.
- But could also be easily removed from substrates during disassembly, to allow for a clean re-assembly.
- Able to bond to materials of various surface energies, such as ETFE, and also to higher surface energy plastics like PC, PETG, Nylon, etc.

To achieve this, we employed various adhesive materials and approaches including:

- Using qualitative (feel / pull) and quantitative (air leak rate) testing of adhesives on all materials.
- Separating mechanical bonding (tape) and air-tight-sealing (silicone) into different adhesives.
- Using multiple lines of sealing, such as 2x silicone seals, or a silicone line backed by a tape seal.
- Layering up adhesives, such as 2 types of tape, or 2 types of silicone on top of each other.

In the future, the need for disassembly will disappear, simplifying adhesive choice. However we will add the new constraints of:

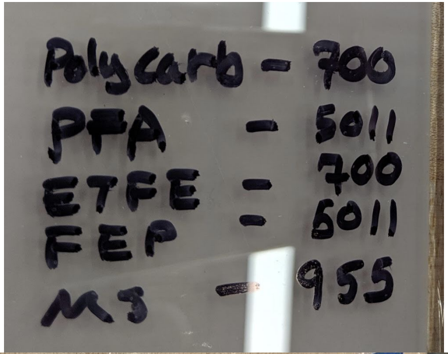
- needing to be food-safe
- and able to last 3+ years

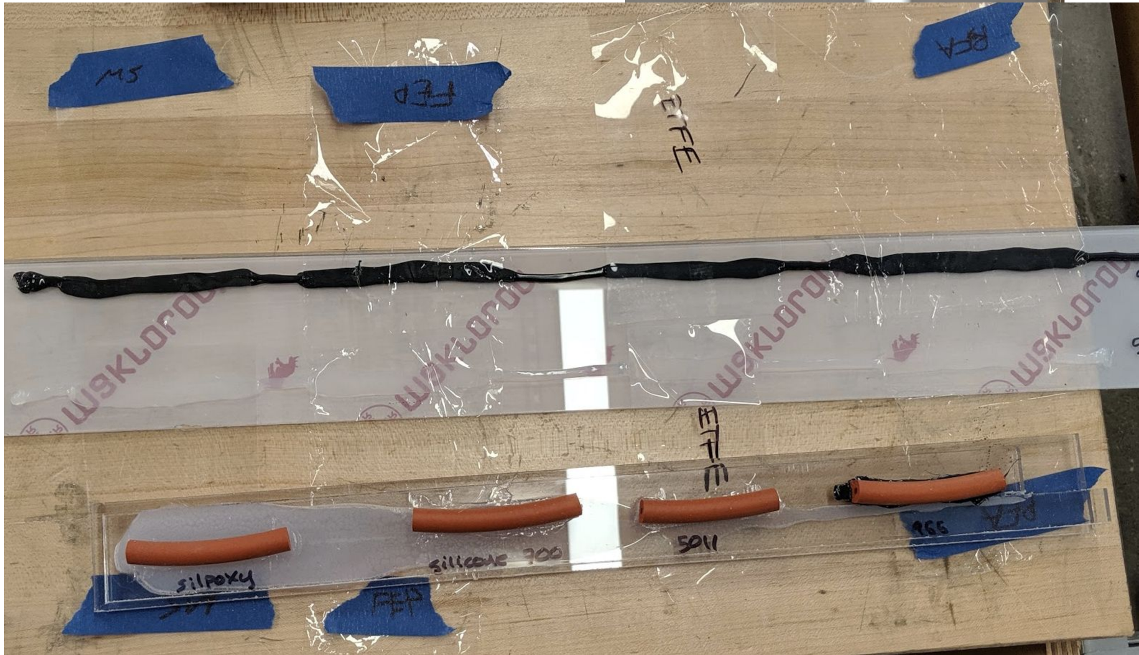
Sheet detailing Adhesive Testing:

Description	Material A	Material B	Operating Temp [C]	Air-tight Seal	Mechanical Strength	Peel-off with ease	Notes	Number	Adhesive to Test	Operating Temp [C]	Air-tight Seal	Mechanical Strength	Peel-off with ease	Notes	**Recommended Best Option**
Back of solkoted Mylar glued to Polycarb sheet. Solar air heater	Polycarb, 1.5mm	Mylar film	150	-	Yes	-		1	Epoxy (1 ?)						
								2	Epoxy (2 ?)						
								3	Silpoxy						
								4	3M glue tape						
								5	(silicone) Dowsil 700						
ETFE glazing bonded to Polycarb shell (2 layers)	Polycarb, 1.5mm	ETFE film, 0.005"	120	Yes	Yes	Yes		**1**	**(Silicone) Dowsil 700, and VHB + 3M glue-tape**						
								2	(Silicone) Dowsil 700						
								3	(Silicone) Dowsil 995						
								4	(Silicone) Dowsil HVAC/B						
								5	(Silicone) Loctite SI 5011						
								6	(Silicone) Loctite SI 596						
								7	Silpoxy						
								8	E6000						
								9	(Silicone) GE 100%						
Polyiso foam insulation adhered to polycarbonate shell in the solar heater, directing air-flow where we want it	Metalized paper (on Polyiso)	Polycarbonate	120	Yes	-	Yes		1	(Silicone) GE 100%						
								2	(Silicone) Dowsil 700						
								3	3M glue tape						
								4							
MJF printed parts (black box) glued onto polycarb trays (solar heater), and polycarb parts (seal-backers)	Polycarb	MJF (sintered Nylon)	120	Yes	Yes	Yes		1	(Silicone) GE 100%						
								2	(Silicone) Dowsil 700						
								3	(Silicone) Loctite SI 596						
								4	**(Silicone) Dowsil 995**						
PETG parts glued to polycarb parts, such as solar heater tray onto lower trays.	Polycarb, 1.5mm	PETG, 1mm	100	Yes	Yes	Yes		1	(Silicone) GE 100%						
								2	(Silicone) Dowsil 700						
								3	Weld-on 4						
								4							
PETG glued to PETG, such as the condenser trays	PETG, 1mm	PETG, 1mm	100	Yes	Yes	Yes		1	(Silicone) GE 100%					Long cure time for burried interfaces	
								2	(Silicone) Dowsil 995						
								3	3M Extreme Sealing Tape 4412N, Translucent, 3 in x 18 yd	149				Most ideal for seams	
								4	Stanley Dualmelt						
								5	Loctite 4310 (UV Curable)					Fast cure time for burried interfaces	

Initial Film onto PC adhesive testing

Initial Qualitative testing was done on how to bond various films to PC.

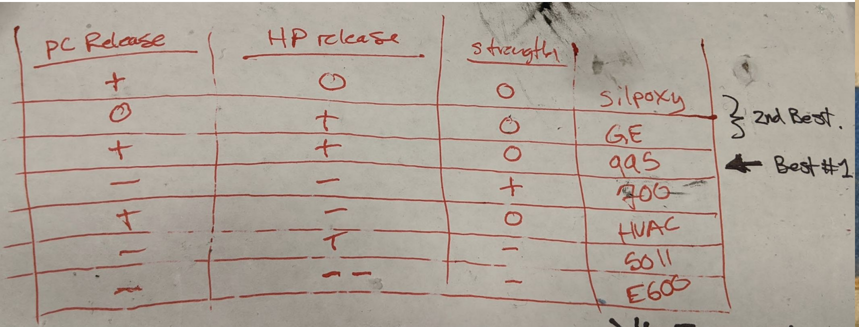


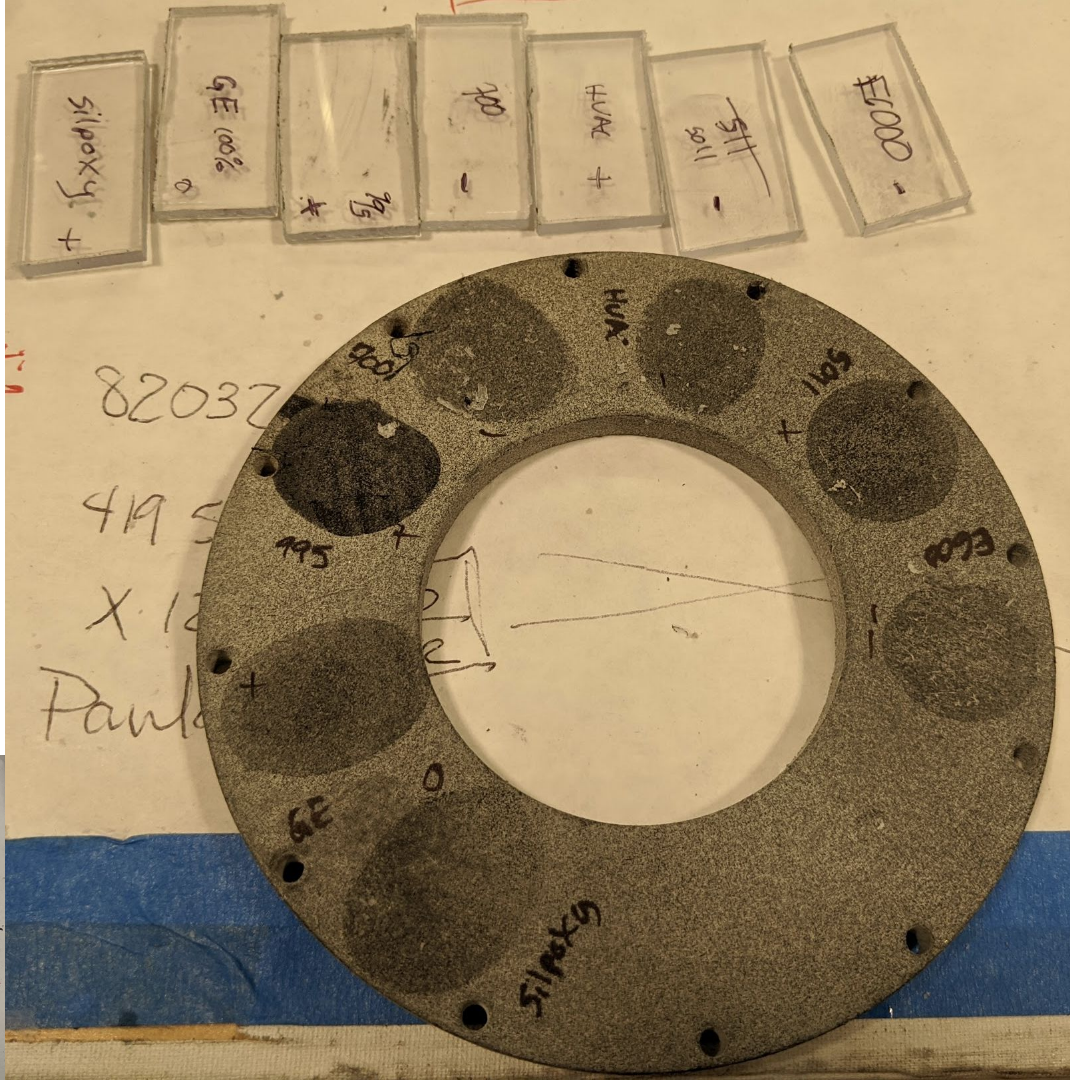


HP to PC bonding

Simple glue-up and manual pull-apart tests were used to determine “strength” and “release” performance. Note that this was with ~12-24 hr glue time, and the core of the Silicones had not fully cured.

Dowsil 995 was ‘best’ overall, with GE100% and Silpoxy as close 2nds.





3M Extreme Sealing Tape

This proved to be a valuable asset for quick bonding of various materials, and with care could create air-tight seals even over irregular shapes and joints. In P4 it was used as a final seal on the outside of all bonded trays.

However this elastic material can creep, especially over time and if it has load on it, and/or heat. Here it de-bonded from our Mule Black Box test setup, skewing data.

Comes in:

- 1” wide rolls
- 3” wide rolls

Quantitative Testing of Adhesives -- the leak test chamber

Protocol:

1) Apply adhesive to base material
2) Adhere solid circle
3) Measure leakage with leak tester

		Testing Results					
Number	Adhesive to Test	Operating Temp [C]	Air-tight Seal	Mechanical Strength	Peel-off with ease	Notes	**Recommended Best Option**
1	(Silicone) GE 100%					Long cure time for burried interfaces	
2	(Silicone) Dowsil 995						
3	3M Extreme Sealing Tape 4412N, Translucent, 3 in x 18 yd	149				Most ideal for seams	
4	Stanley Dualmelt						
5	Loctite 4310 (UV Curable)					Fast cure time for burried interfaces	

ETFE films

Bonding to ETFE was our biggest challenge. In the end we used:

Leak Seal:
Dowsill 995 had the best bonding for air-tight seal. GE100 was also used in some places, though it delaminates easier.

Mechanical Bonding:
3M glue tape to bond to the ETFE film + clear VHB to bond the glue tape to the PC substrate.

4. Condenser sub-assembly

Condenser General Notes (part 1 of 2)

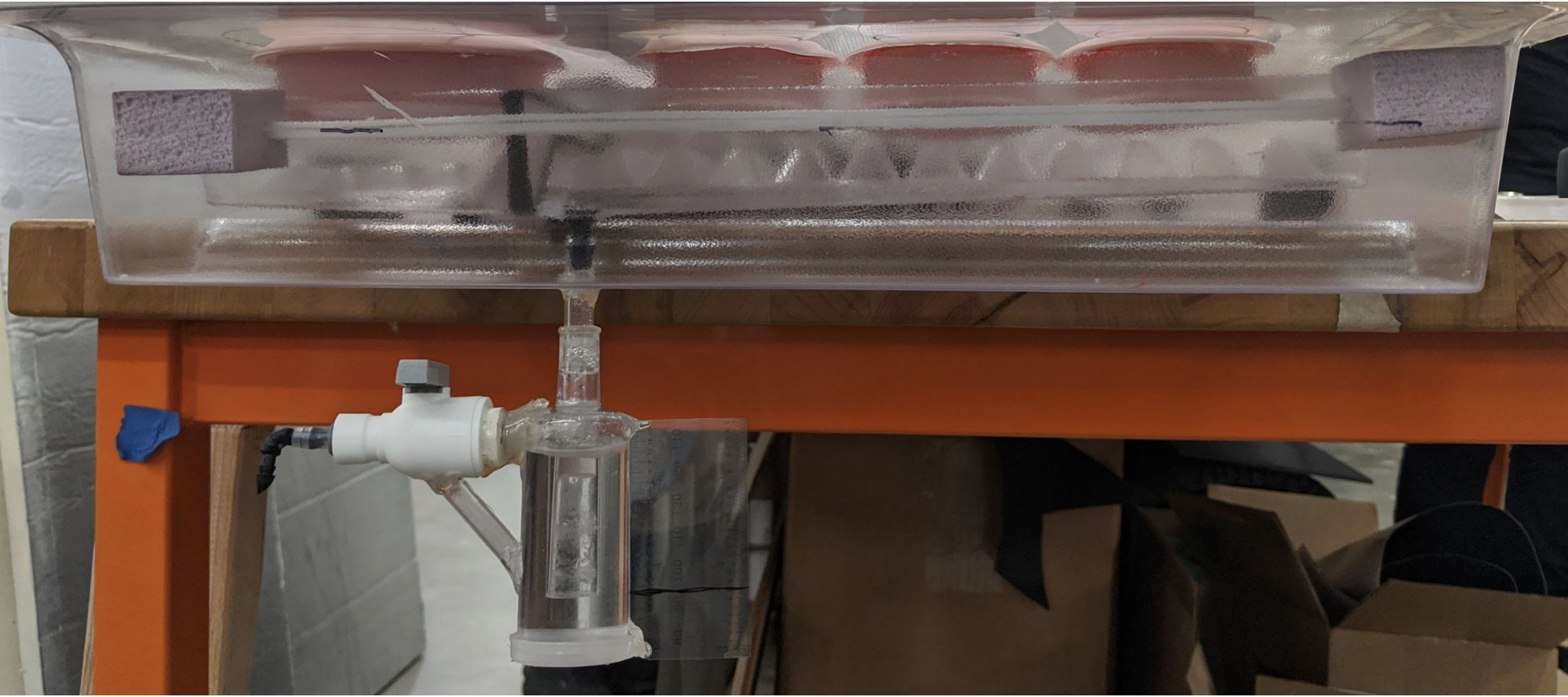
The Condenser was designed with the following features in mind:

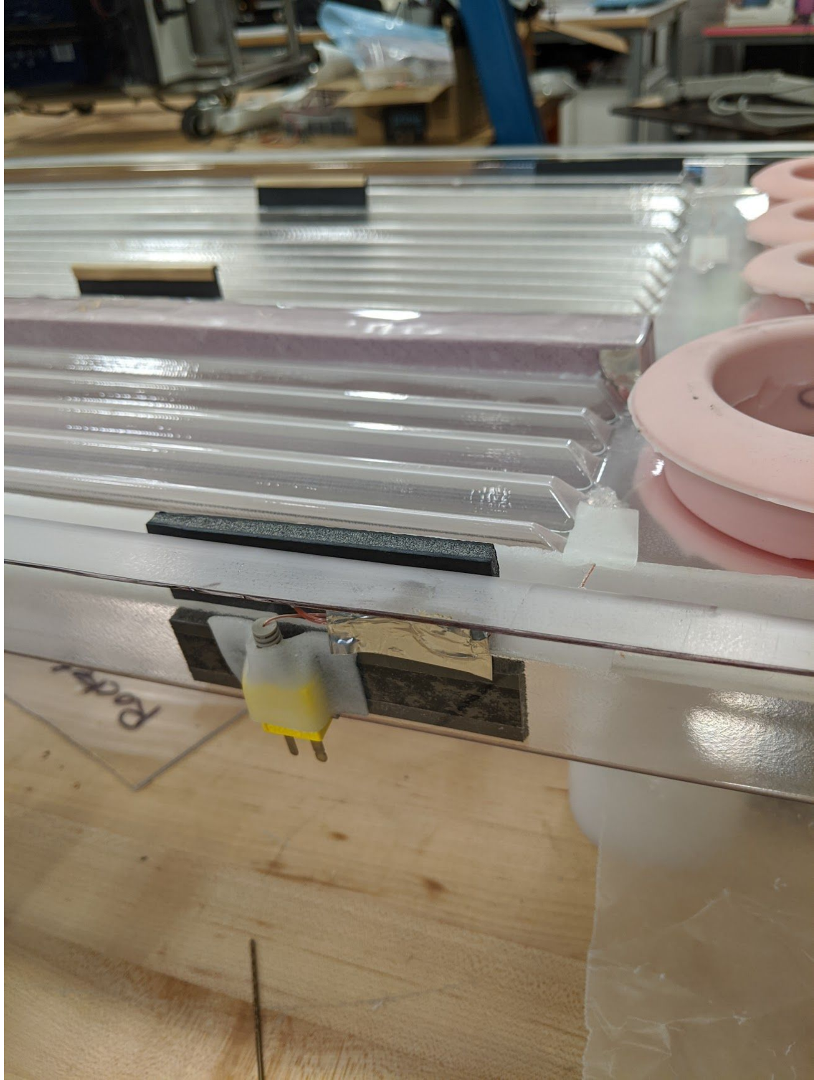
- Counter-flow design of the Humidity Stream (HS) and Recirculating Stream (RS) air paths.
- But the RS inlet and outlet to the condenser needed to be on the same side of the unit (the foot side), so we decided to use a “U”-turn in the RS flow. Thus the HS flow also had a “U-turn”, which helped to keep its output near the BB inlet, and also keep the HS fan inlet away from the ground. All good things. Except this U-turn adds pressure drop, and creates a portion of the device where RS airflow fights against the gravity pulling on water droplets.
- Try to maximize surface area for heat transfer and for condensation to collect on, while not creating major pressure drop, and while staying within the footprint of the unit. Hence we used ribbing on the clamshell to roughly double the effective surface area, and a clamshell design with flow on both sides to double it again.
- Try to use the RS airflow to help sweep water droplets towards the outlet, and use a slanted angle (gravity) to be the primary driving force.
- HS and CS would be the same to begin with, but have the option to use a different fan for each (snorkel is a convenient break point)
- Prioritize sealing of the RS stream in the Condenser -- it is a critical area where leaking with HS is likely.
- Purple foam inserts were used outside the clamshell to force the HS to be counterflow instead of short-cutting from entrance (fan) directly to the exit (snorkel). This had to be bonded to the clamshell, and also to the bottom and top of the surrounding trays. Similarly an acrylic part was cut and VHB+siliconed in place inside the clamshell to prevent shortcutting.
- Also, that acrylic wall had a small gap near the bottom to allow water to flow from the narrow part of the Condenser to the wider part, so that all water drained to 1 main drain tube and water trap. That small gap has a small ‘wall’ of silicone next to it about 4mm tall, forming a miniature water trap, preventing air from shortcutting through that small gap / hole.

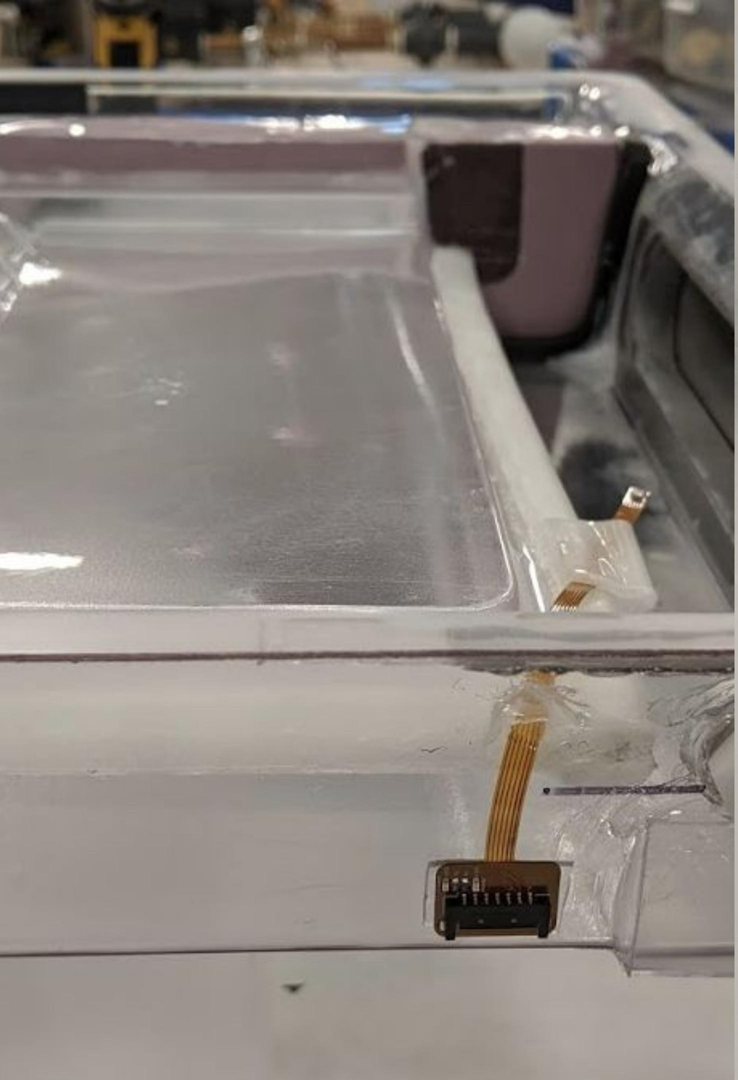
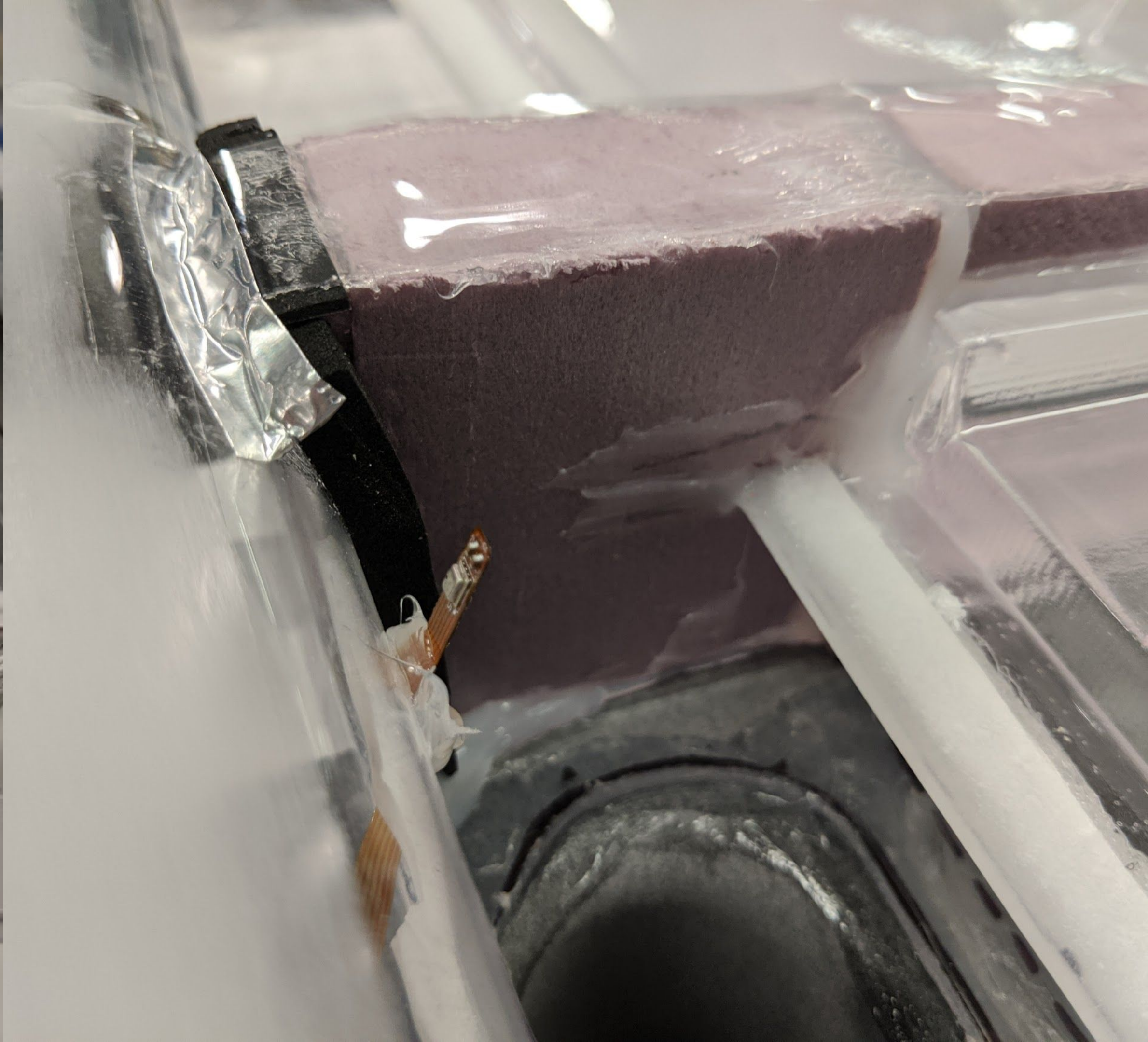
Condenser General Notes (part 2 of 2)

Tricks we used, problems we encountered:

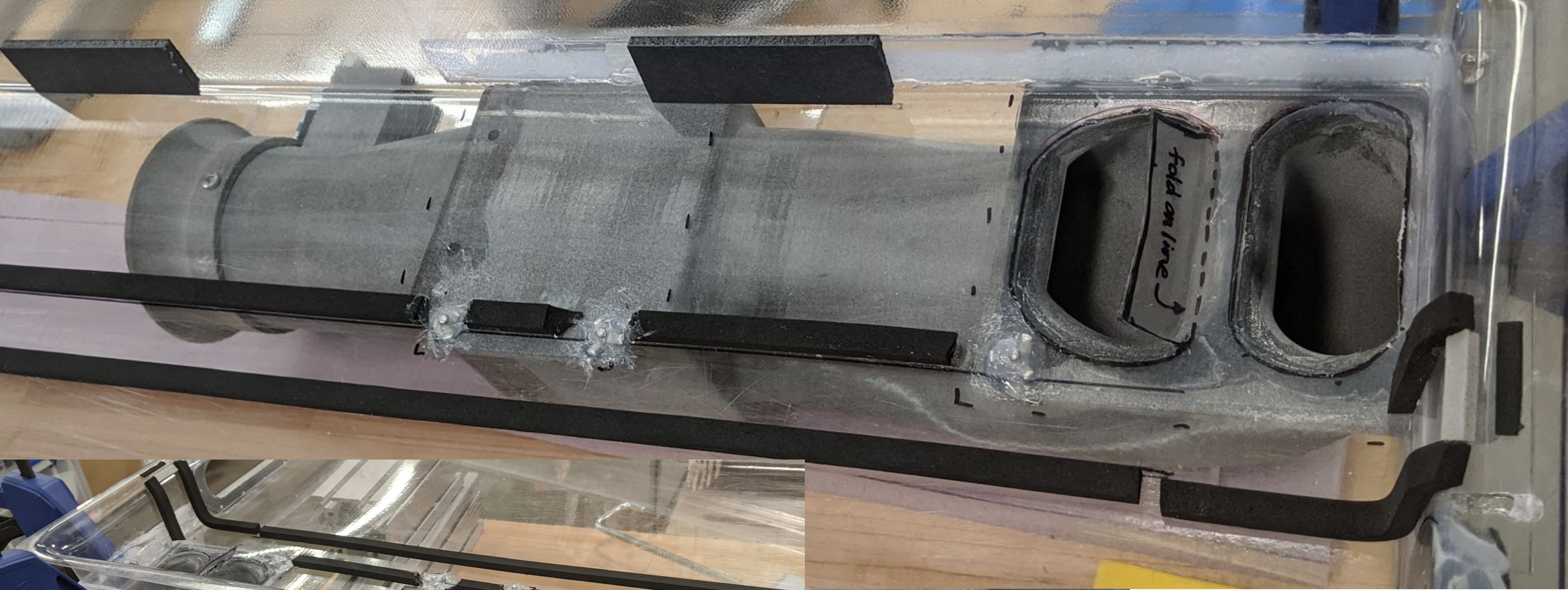
- Condenser clamshell needed extra foam bits to prevent sagging inside the tray
- The condenser sagging under its own weight and the walls of the tray flexing outward when unsupported contributed to the foam support needs
- It was difficult to to trim both halves of the insert to the same outer dimensions. The flimsy plastic flexes so straight lines are hard to cut.
- The clamshell top and bottom were hard to align well during glue-up
- The unpredictable radii on vacu-formed parts prevented us from making some tools and templates ahead of time or from CAD models, but if those are dialed in we can make better tooling for trim etc. In this case we had to hand-carve each piece to fit.
- We tried some low-temp, removable hot glue for prototyping, but it accidentally deformed the PETG in places, so we stopped that and used either glue-tape for gatorboard bonding, 3M sealing tape for the edges, or silicone.
- In order to keep HS airflow roughly even on top and bottom of the clamshell, we used gatorboard inserts + the purple foam air-dam to help hold the clamshell in the middle of the height of the condenser tray. We also used a divided and directed output from the HS fan: half of the flow aimed above the clamshell and half aimed below it.
- The gatorboard inserts (the 5 inside the clamshell) were also used to minimize the collapse of the clamshell due to HS pressure.
- Silicone would likely not pull cleanly off the purple foam, so to protect the top part of purple foam from damage during a potential disassembly, we first laid down a strip of mylar siliconed to the foam, and let that cure. Then the mylar was GE100 siliconed up to the tray above, creating a cleaner, easier separation layer for disassembly.
- The condenser tray was dropped and cracked ~3 times during assembly. Go slow to move fast! We patched holes by first mechanically repairing with CA glue and/or a shim glued to the outside, and then sealed with a thin silicone layer on the inside.

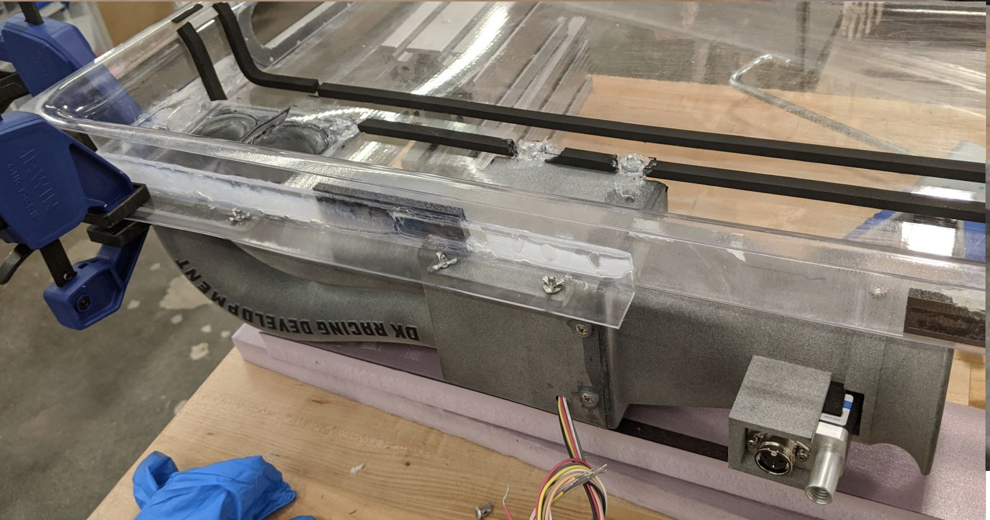





fold on line


fold on line


DK RACING DEVELOPMENT

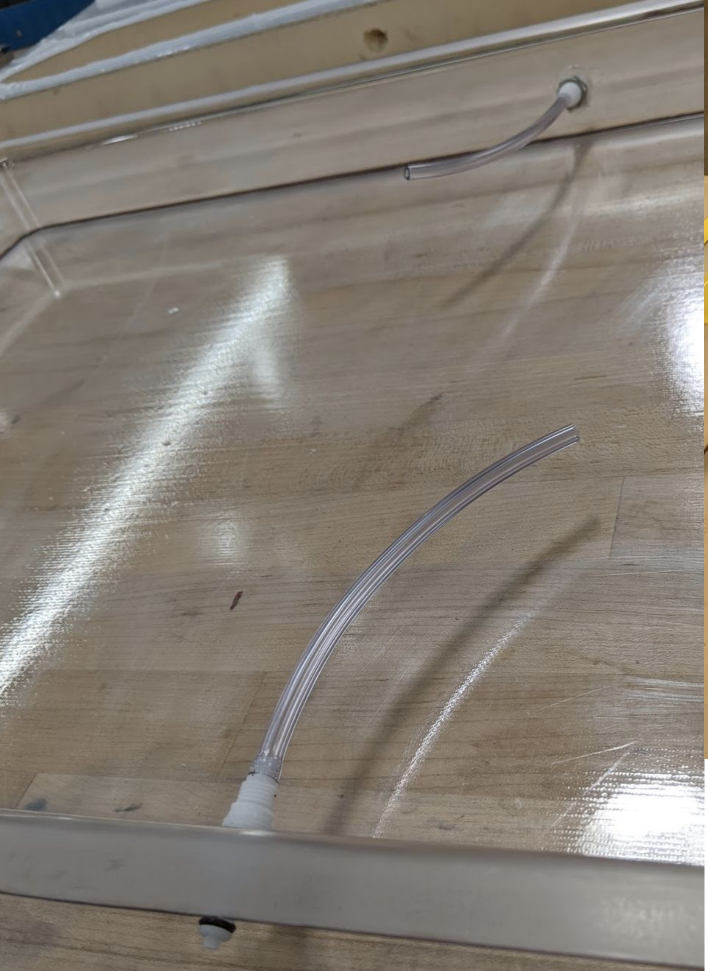

IRWIN
GAFFER


DEWALT

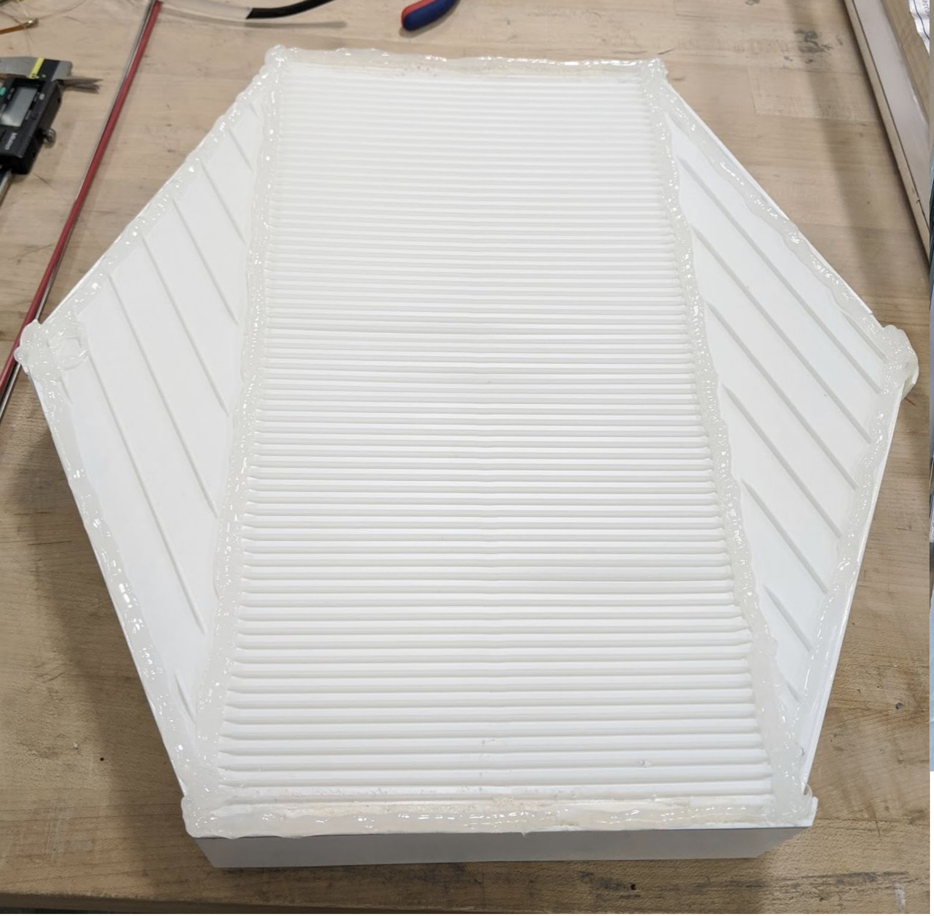
5. Heat Exchanger sub-assembly

- Cartridge-style heat exchanger was simple to install, but delicate to cut to size and required lots of hand cut foam to channel the air
- The polyiso foam gets dusty when cut, which can make tape or glue fail unexpectedly
- Determining the internal height of the tray was a little tricky with the flex of the side walls, but it was important to keep foam assemblies flush with the top edge, neither proud nor shy

Foam channels to direct HS flows
pre and post condenser

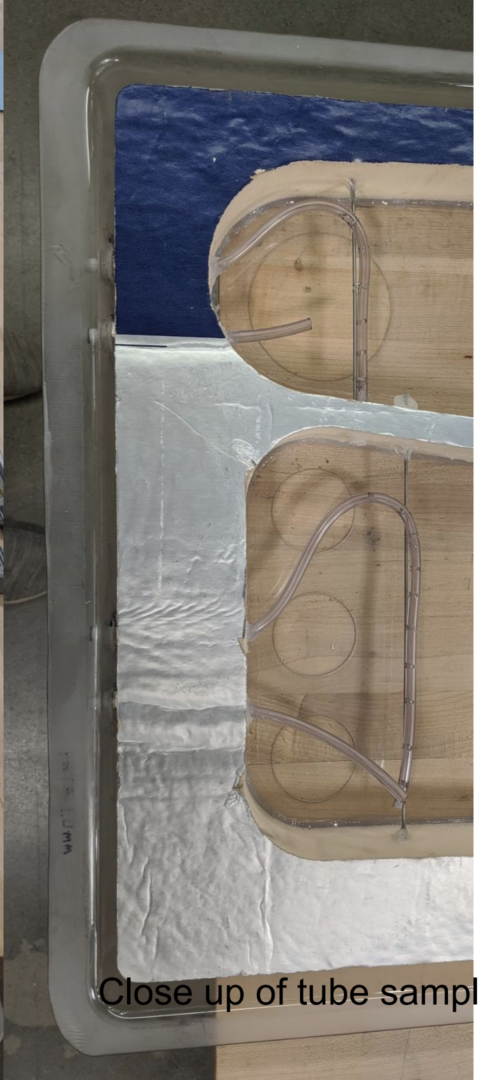


Installation of tube sampling ports for temperature and humidity measurement

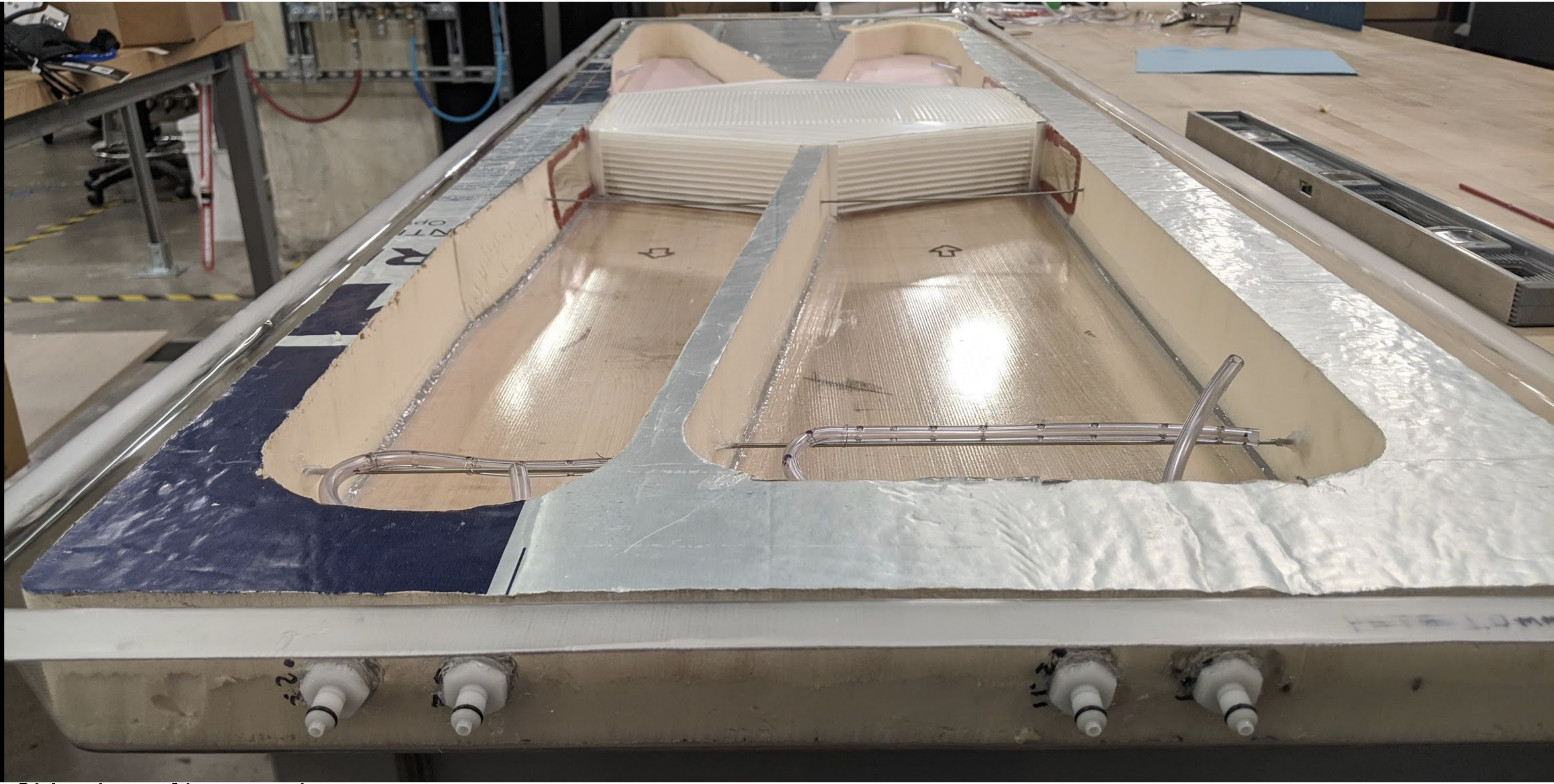



Heat exchanger (left) and location within foam cut outs (right)

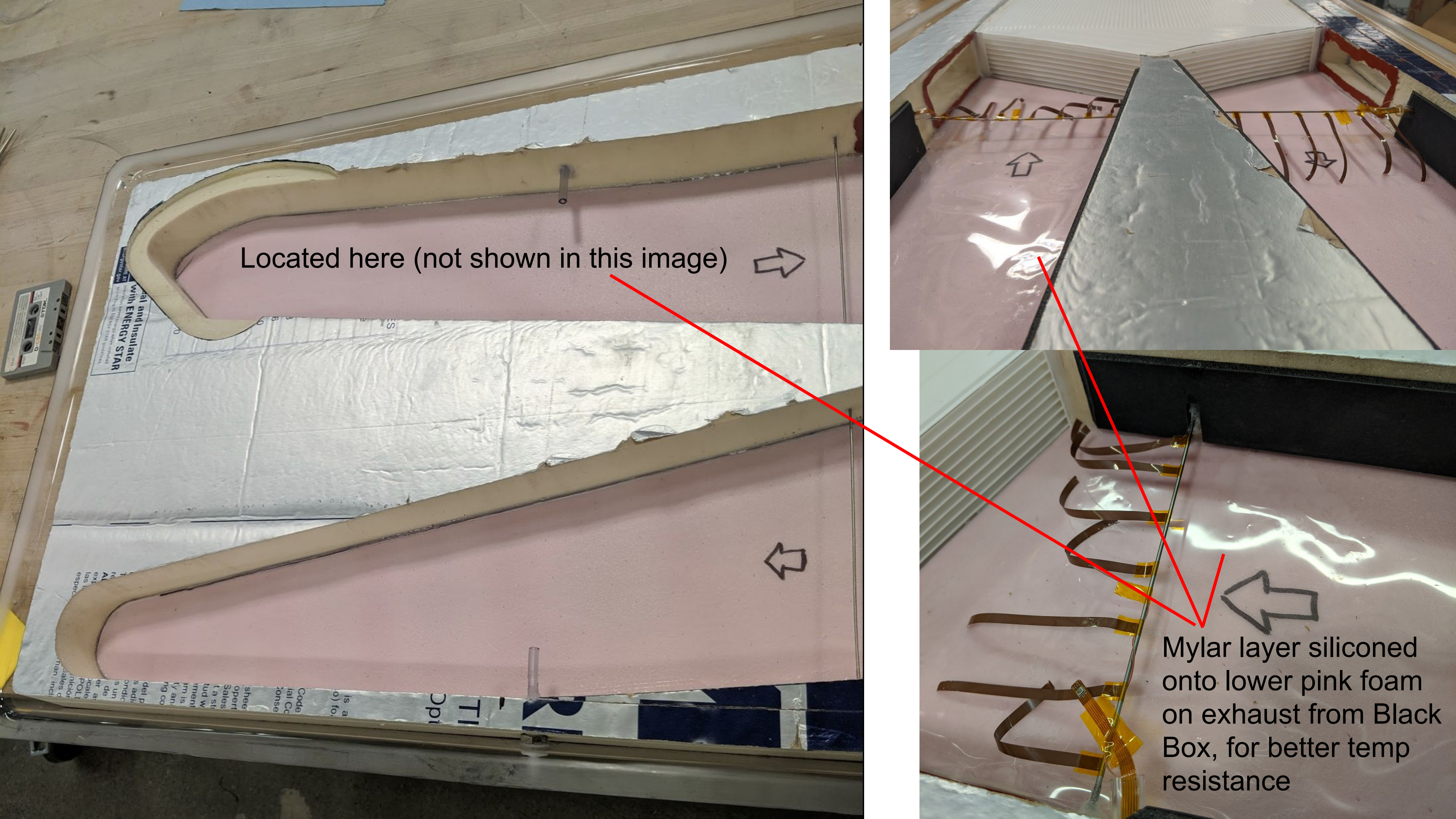
Heat exchanger installed with foam and pink insulation

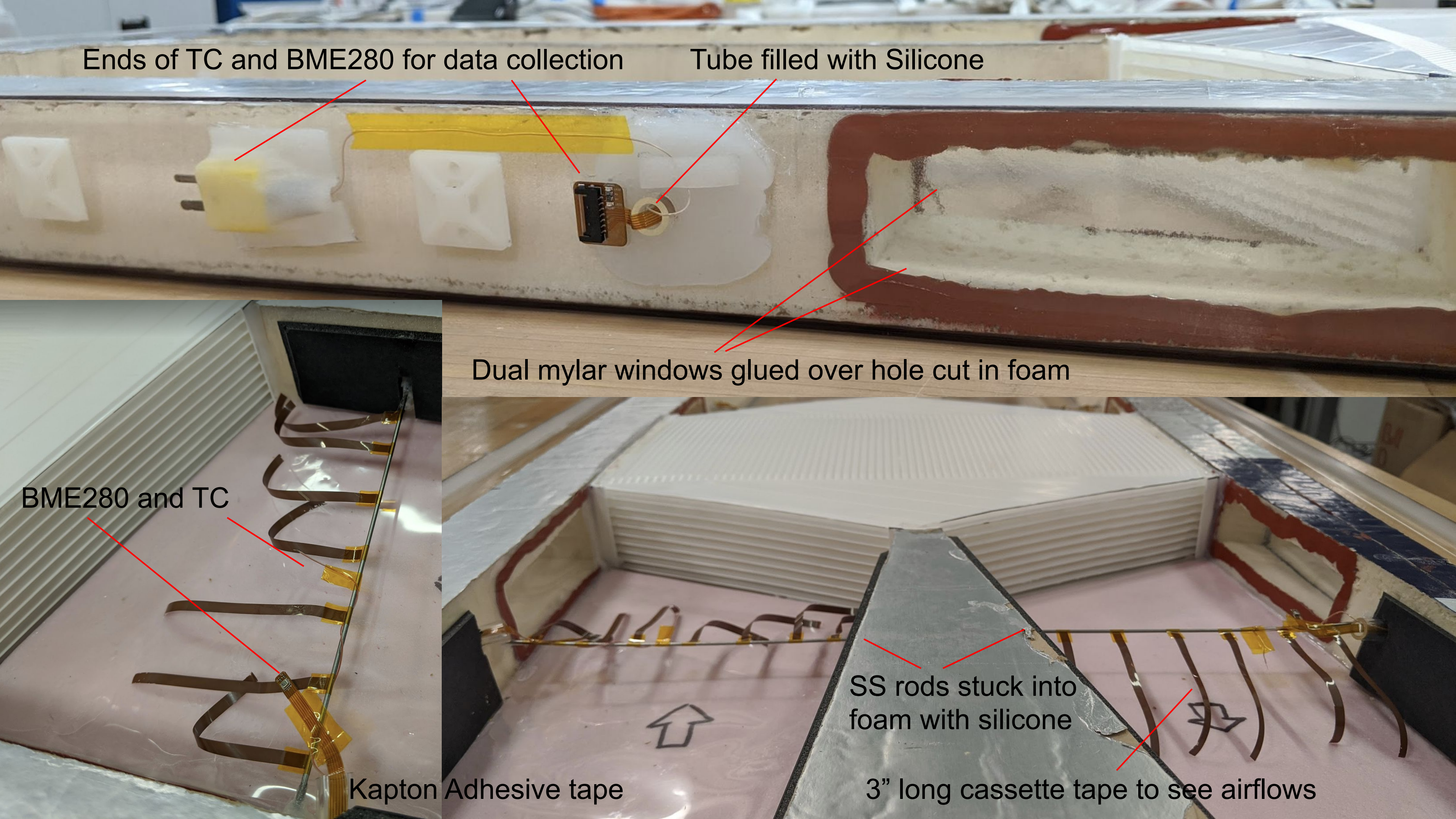


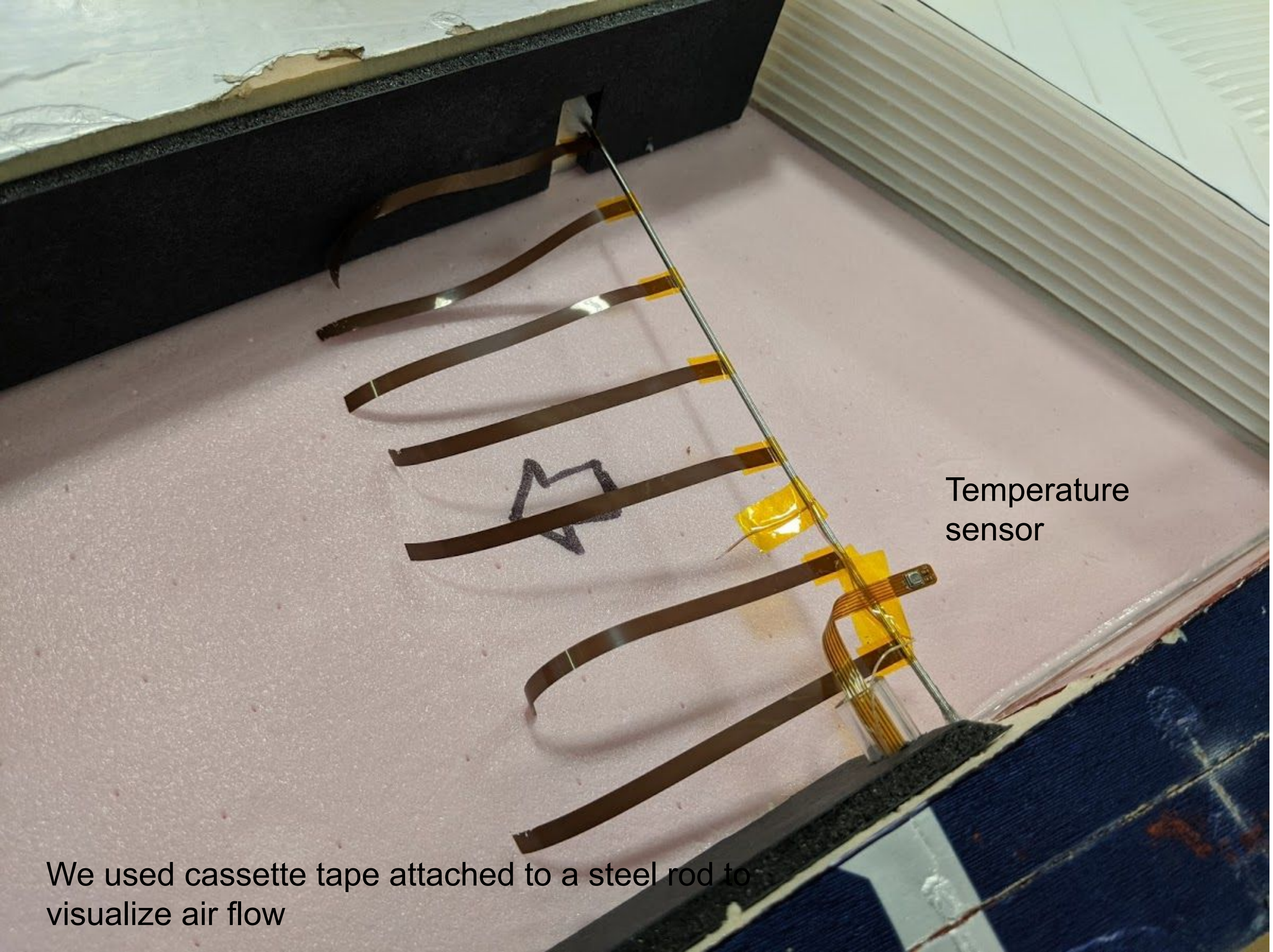
Close up of tube sampling ports



Side view of heat exchanger


Located here (not shown in this image)
Mylar layer siliconed onto lower pink foam on exhaust from Black Box, for better temp resistance

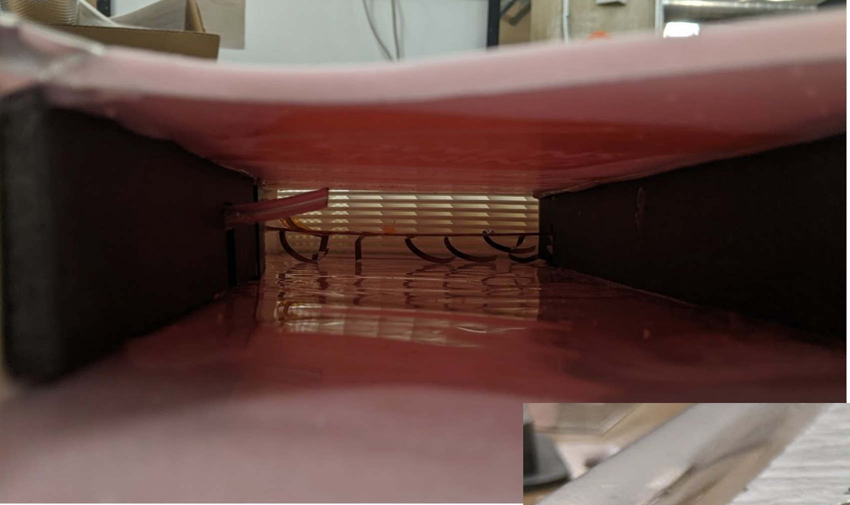

Ends of TC and BME280 for data collection
Tube filled with Silicone
Dual mylar windows glued over hole cut in foam
BME280 and TC
SS rods stuck into
foam with silicone
Kapton Adhesive tape
3” long cassette tape to see airflows



We used cassette tape attached to a steel rod to visualize air flow

Additional foam insulation added (black and pink)

Pink foam added to seal airflow and insulate



End view of air channel entering heat exchanger

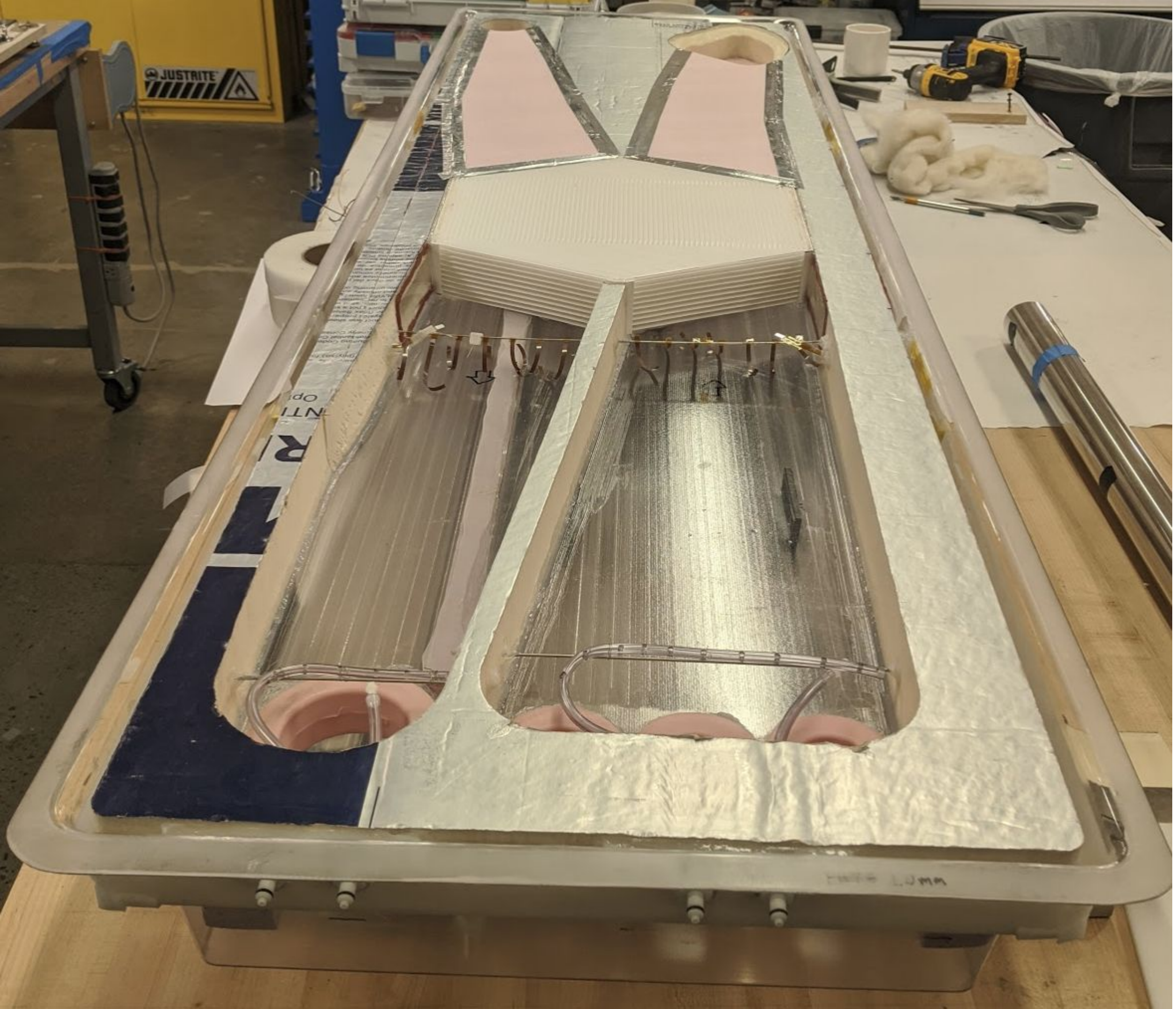


Image of Final Part Before Assembly: HX Layer

Not yet shown: Mylar film layer siliconed and glued down to this surface prior to assembly of the desiccant wheel tray on top of the Mylar.

6. Desiccant Wheel and Tray sub-assembly

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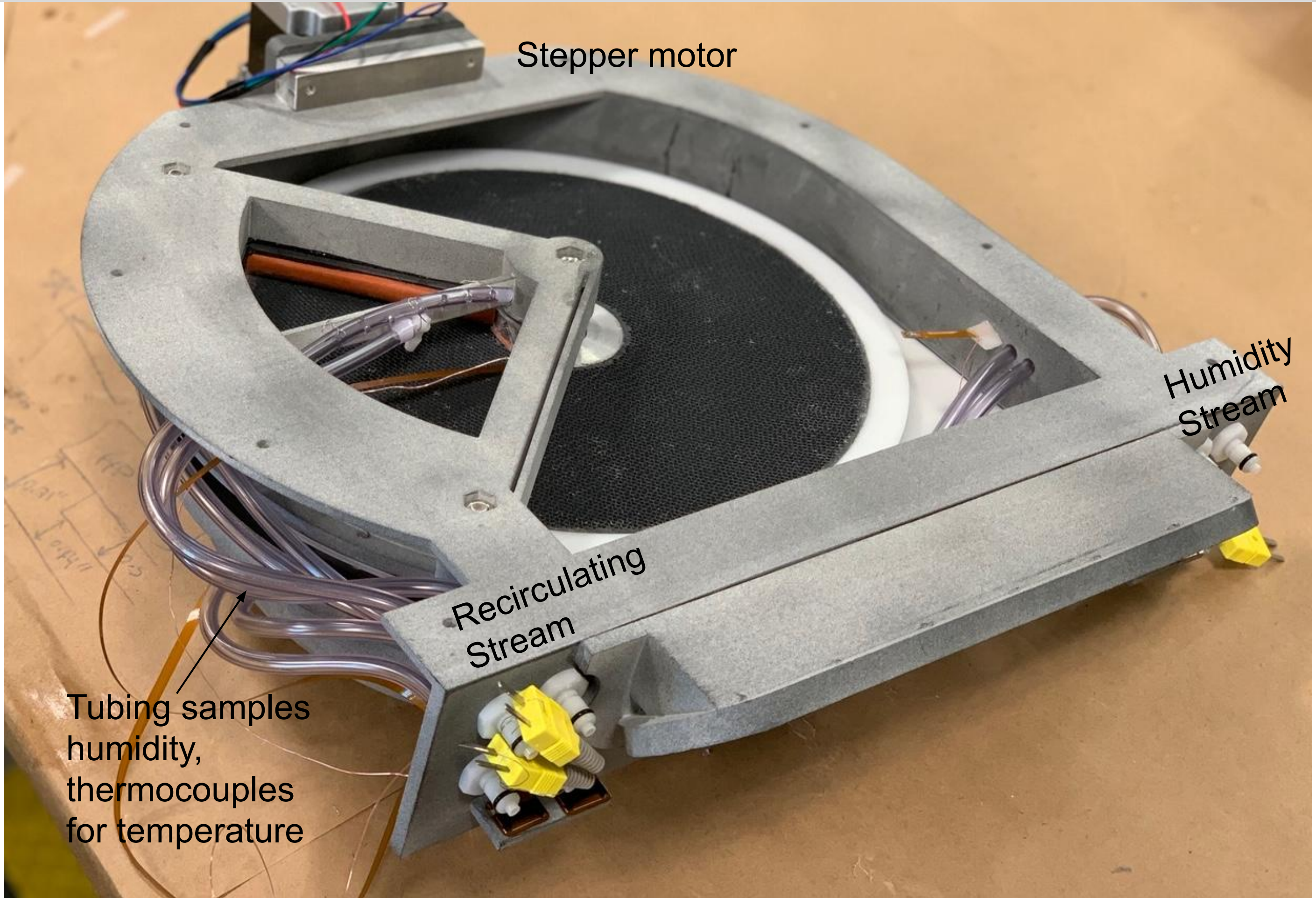
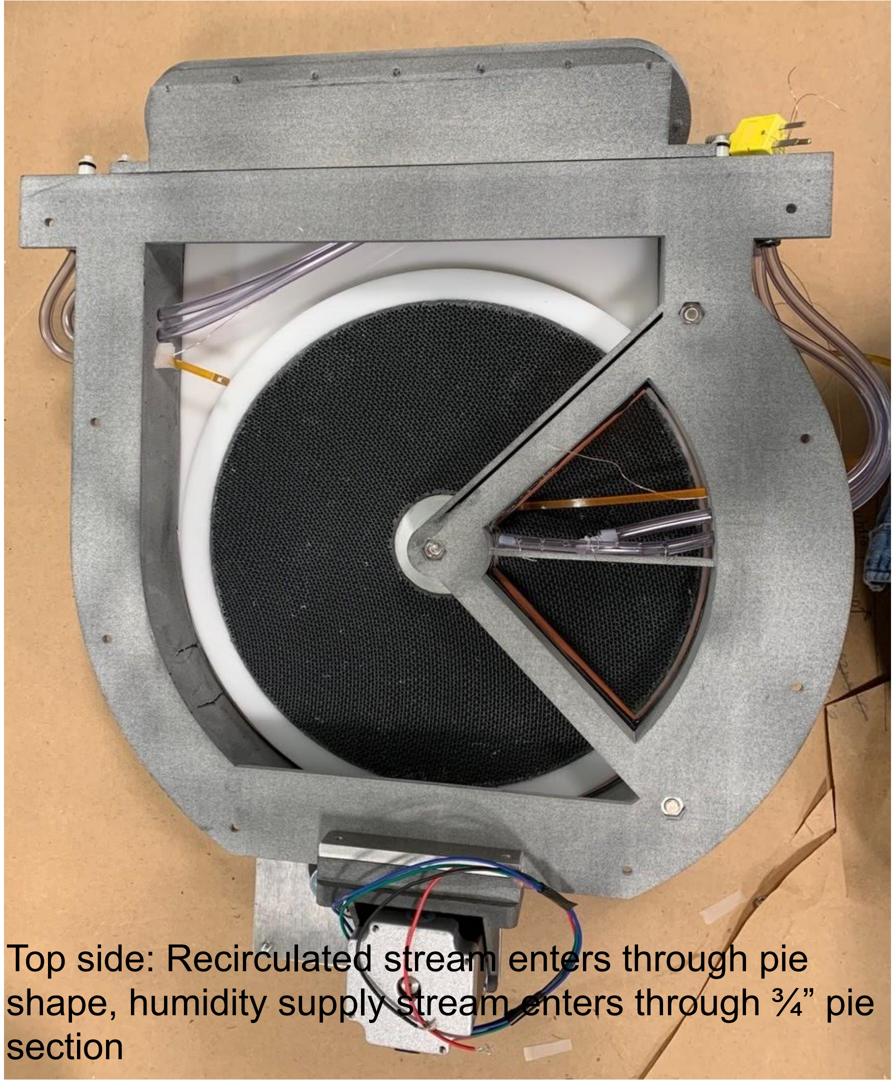
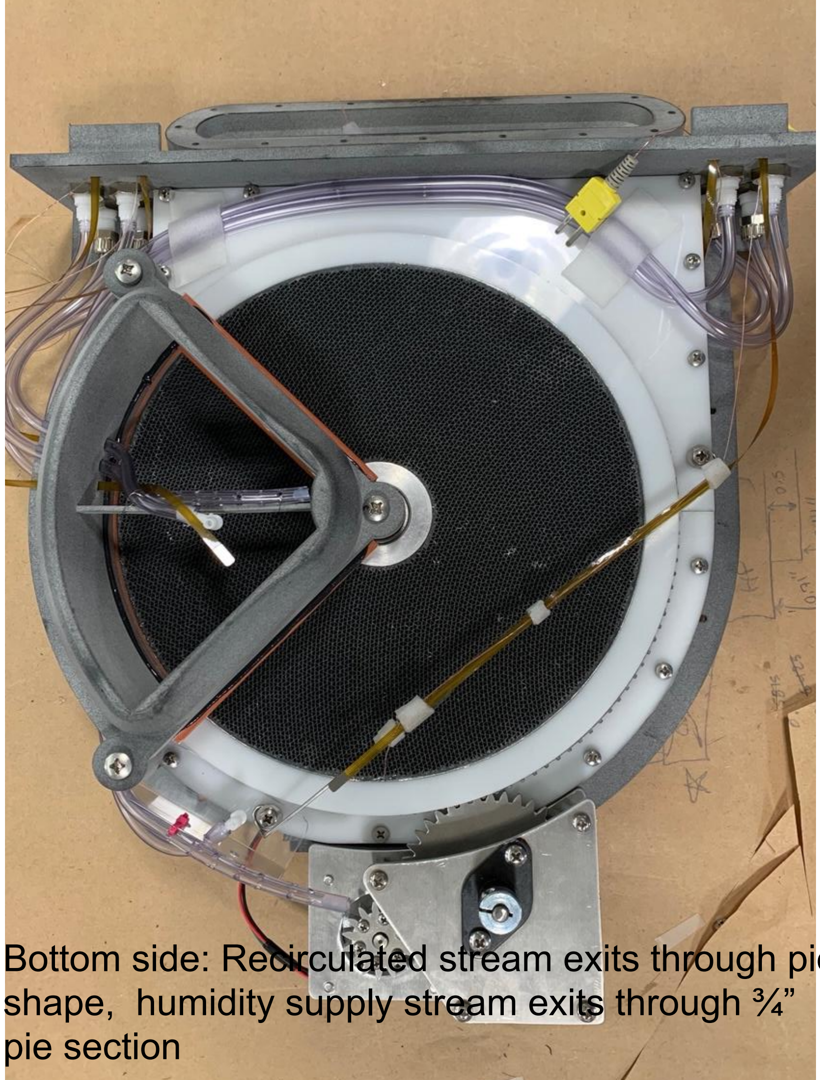
Desiccant Wheel Assembly
(aka Black Box).

This could be entirely integrated in the vacuum forming structure (and we have designs for that), but for experimental reasons we chose to make this a highly overspec'ed 3D printed assembly, with lots of accommodations to help experimentation



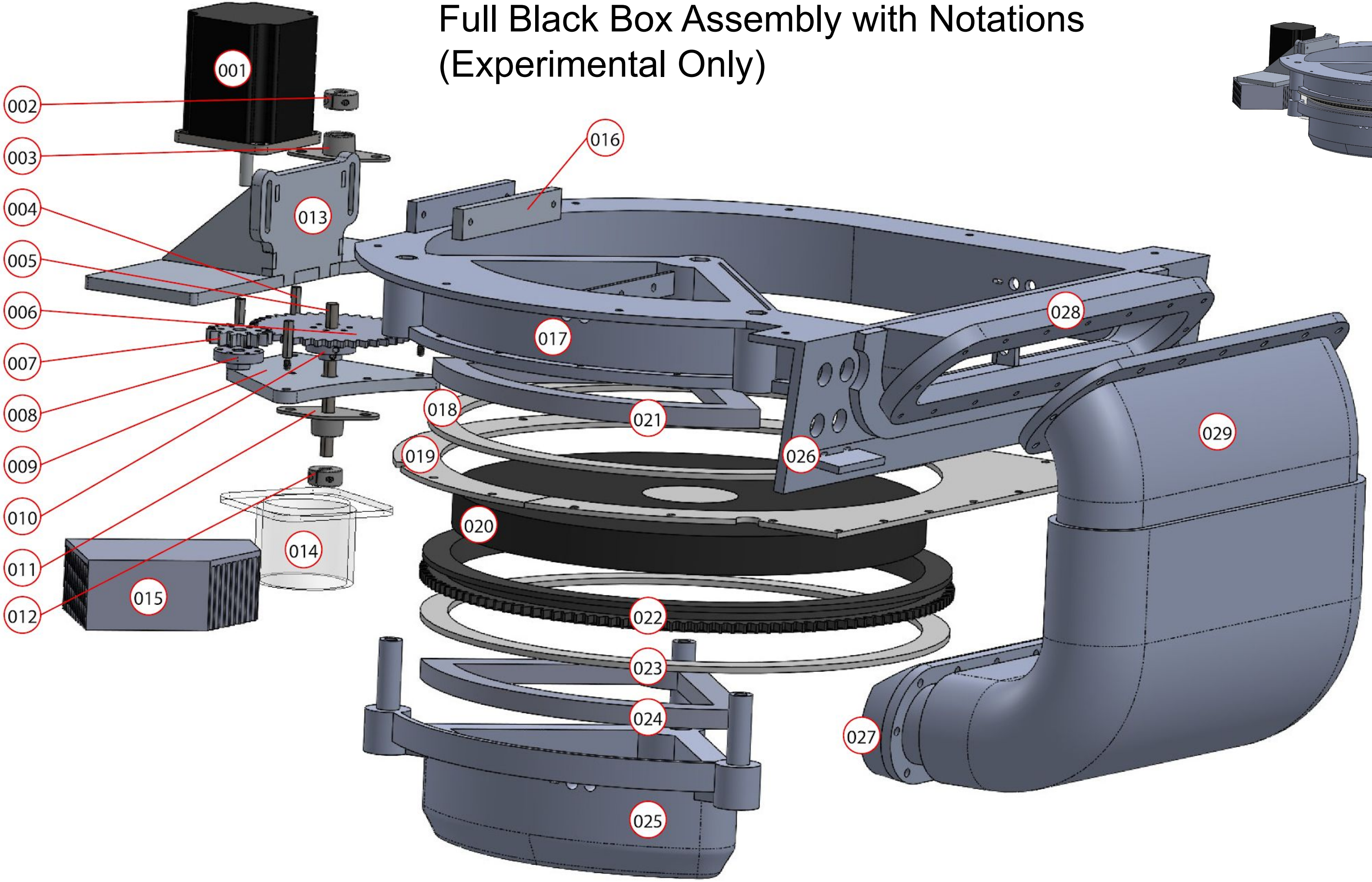


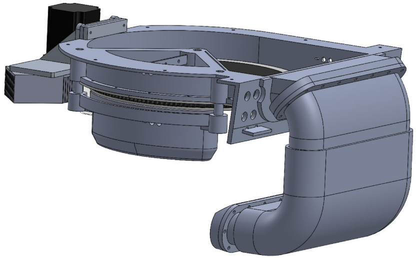
Top side: Recirculated stream enters through pie shape, humidity supply stream enters through ¾” pie section



Bottom side: Recirculated stream exits through pie shape, humidity supply stream exits through ¾” pie section

Full Black Box Assembly with Notations (Experimental Only)





01	Nema 23 200 S/Rev, 57×76mm, 8.6V, 1 A/P	stepper motor Pololu 1477 link
02 & 12	Shaft collar	McMaster 6435K120
03 & 11	Mounted Roller Bearings	McMaster 1434K430
04	6-32 Standoffs 1 of 4	
05	D-Profile Rotary Shaft	McMaster 8632T132
06	Gear - 40 teeth, M2, 20 deg angle with Oil-Embedded Thrust Bronze Bearing (not shown)	Waterjet 1/8” AL McMaster
07	Gear - 15 teeth, M2, 20 deg angle	Waterjet 1/4” AL
08 & 10	Mounting Hub for 1/4″ Shaft	Pololu 1993 link
09	Bottom Gearbox Plate	Waterjet 1/4” AL

13	Mounting Bracket	Waterjet 1/4” AL and tig welded
14	Gearbox Support Column	Plastic tube and base
15	Aluminum Heat Sink	
16	Mounting Bracket backing	Waterjet 1/4” A
17	Black Box Chamber	HP MJF Print Design in CAD file
18 & 23	Upper & Lower Wheel Riding Surface	Waterjet 1/8” Acedal
19	Bottom of Black Box Chamber	Waterjet 1/8” Acedal
20	Desiccant Wheel	
21 & 24	Upper and Lower Seal Platforms With Seals (not shown)	Waterjet Polycarbonate, 3/16” Silicone foam (McM 8785K17) & FEP film (McM 7562A18)

22	Wheel Rim with integrated gear - 135 teeth, M2, 20 deg angle	HP MJF Print Design in CAD file
25	Lower Recirculating Air Channel aka Pie Sweep	HP MJF Print Design in CAD file
26	Mounting holes for Licor ports and platforms for BME 280 sensors	
27	Flange attached to lower tray	HP MJF Print Design in CAD file
28	Connecting port for duct to lower tray, aka Snorkel	HP MJF Print Design in CAD file printed separately from chamber
29	Duct for recirculating air supply, aka Snorkel	HP MJF Print Design in CAD file three parts telescope for best fit and are fixed with adhesive.

Box Housing

The housing has several purposes -

- To hold the rotational center of the desiccant wheel firmly in place so that the seals of the recirculating air stream can make firm and constant contact with the wheel’s surface.
    - Note: the seals must be held parallel to the wheel and at just the right amount of compression on the thin foam to create good seal performance. This height adjustment and parallel orientation is also part of the BB housing design and purpose.
- To evenly direct the humidifying airstream through the desiccant wheel, preventing the passage of air around the desiccant wheel
- To provide an attachment point for the mechanical components used for turning the wheel around its center axis
- To provide an attachment for the ducting and connections that transport the two air streams: RS, HS.
- To anchor the connectors and input points for data acquisition sensors (TCs, BME280s) and LICOR tubing ports (can also be used for differential pressure sensing).

Design considerations, the housing must -

- Not add unnecessary height to the device
- Not add restriction to the airflow, or otherwise cause the fans to be inefficient
- Withstand a temperature of 120C
- Have some adjustability to allow for design changes to seals, sensors, and other components
- Be securely attached to the device while still allowing access to its insides for maintenance or design changes

Mounting in Trays
Due to the weight of the housing, gearbox and wheel attachment to the top tray with adhesive alone was not enough. We attached the Box to the top tray mechanically with rivets and supported the gearbox further with a plastic column that reaches to the bottom of tray 2. At the top attachment, silicone sealant aids the rivets with mechanical fastening and also provides an airtight seal. A pie-slice-shaped hole in the top tray lines up with the inlet of the recirculating air stream (RS) channel and a hole in the bottom of tray 2 holds the pie wedge shaped grommet (aka gromzillapie) that seals around the base of the RS channel.

Disassembling

Reasons to disassemble

- The components of the box, such as RS seals and sensors may need adjustment or replacement
- The shape of the interior of the black box may benefit from inserts to change the airflow of the HS upstream of the wheel for better wheel hydration
- The type of desiccant wheel used may be changed

How to disassemble

1. Once the seam between tray 1 and tray 2 is opened, and the adhesive holding the RS fan component is cut, the trays can be separated. The Box housing will stay connected to tray 1 and the base of the RS channel will easily come apart from the lower grommet. (Note, there are also 2 screws attaching the snorkel flange to the tray sidewall)
2. The three screws that hold on the lower RS channel section can be unscrewed and the channel section removed.
3. The screws holding on the floor of the black box chamber can be removed and then this floor will come off in two parts
4. Next the wheel with its rim can be removed. At this point the box is completely open and all components can be accessed.

Lessons learned in development

- The location of the recirculating air stream (RS) channel within the black box is a compromise. There is a tradeoff between the length of air travel in the heating cycle of tray 1 and optimum location of the RS channel from a wheel hydration viewpoint. From a wheel hydration viewpoint the pie wedge shape would be at the end of the housing opposite to the inlet and would make the housing symmetrical to incoming air. This would, however, shorten the flow of the air in the heating cycle, so a compromise was made to put the RS channel on the side of the housing.
- In order to even the hydration airstream (HS) entering the desiccant wheel we tested a triple pass model that channeled air through the wheel three times before the air exit. While this did evenly distribute air through the wheel, the air moved very slowly due to a back pressure which was too high for the HS fans to overcome. The result was a significantly lower overall HS mass flow rate, leading to a sorption-limited process, and a lower over water output. We decided to prioritize higher HS flow rates over HS flow uniformity through the wheel, in order to target better water production rates.
- The stepper motor control is important to get right. For a smoother operation, target using fewer steps such as 1/16th, 1/32nd, …. 1/256th step, etc. These are the settings we used on the microcontroller on the prototype: 480 steps per second using the 1/16 mode:
  - 1rpm for the max speed for the rotor,
  - There are 135 teeth on the wheel rim, and 15 on the spur gear, so each time the wheel goes around 1 time the spur gear goes around 9 times, 9 rpms max.
  - The motor is a 200 step and we are running it at 1/16 of a step, so 3,200 steps per revolution.

Next Steps

- The interior shape of the housing on the humidifying stream input side can do more to channel the air evenly through the desiccant wheel in order to fully hydrate the wheel.
- The housing structure may be built into the tray forms to save on cost and weight
- More sensor supports could be integrated into the housing so that data accusation is as even as possible across prototypes

Air Streams and Their Seals

Overview

In the Box housing the airstreams act on the desiccant wheel - the humidifying stream (HS) depositing water and the recirculating stream (RS) removing water. Both airstreams need to be put through the wheel as evenly as possible. Both airstreams need to be sealed off from each other and from the outside air.

Recirculating Stream (RS)

The dry RS air travels from the heating upper tray, gets hydrated in the wheel, and then goes to tray 3 for cooling on its way to evaporation. As it travels through the wheel it passes the humidifying airstream (HS) and it is important to keep these two airstreams separate. We achieve this with seals that run on the surface of the desiccant wheel, the inner aluminum hub, and the outer white delrin rims.

<u>Design and Construction</u>

The seals are constructed from high temperature silicone foam topped with an FEP teflon film. The foam is attached to polycarbonate platforms which are then adhered to the pie-piece shaped RS air channels. The sides of the foam and film topper are wrapped around the platform to prevent their edges from catching on the rough fiberglass surface of the wheel. Because the wheel surface is abrasive and hard to seal we run the inner and outer circular sections of the seal on the inside hub of the wheel and on the smooth acetal wheel rim surface respectively. The pressure put between the seal and the wheel is carefully dialed in, too little pressure will keep the seal from sealing, and too much will make it function as a break, preventing the wheel from rotating. On the top surface this balance was achieved by selecting the right height of shims added between the seal platform and the box housing. On the bottom of the wheel this balance comes from just the right number of washers to set the distance between the posts of the lower pie wedge and their mating surfaces in the housing.

Lessons learned in Development

In designing the current seals we designed, built, and tested many sealing surfaces. Our investigations showed that in almost all cases the trade off is between sealing and friction, with the best sealing designs creating friction that was too high, and most of the worst sealing surfaces sliding smoothly. There were also materials that provided both high friction and low sealing, but those were quickly dismissed. Some of the materials tested were cast silicone, felt, comercial wipers, contoured foams, and many others. The design and materials that we arrived at gave a good compromise between sealing and friction.

Humidifying Stream (HS)

The HS enters the housing through the snorkel. It then travels through the desiccant wheel and past the motor heat sink on its way to the exit at the side of the device.

Design and Construction

The top of the housing is well sealed to the tray above, so air in the chamber can only go through the desiccant wheel, around the desiccant wheel, or into the recirculating airstream (RS) channel. Because some minimal leakage of the HS around the wheel is not significantly detrimental to water production rate we chose to make a smooth running low friction connection between the wheel and the box housing. This saves our friction budget for the more important RS seal (where even a small leak would greatly reduce water production rate). We have made a seal that is low friction by smoothing and waxing the grove of the wheel rim and having it rub against the smooth acetal material that makes up the floor of the housing . The HS is kept from the RS both upstream and downstream of the wheel by the pie piece shaped seals that travel on the desiccant wheel. To aid in sealing we balance the pressures across the RS seals. We have designed the device so that air travels the same direction in both streams, and this allows the pressures across the RS seals to be as similar as possible.

Lessons Learned in Development

Earlier designs aimed to put all the HS air through the wheel by sealing around the wheel with a rubber riding surface attached to the chamber floor. This seal pressed against the top of the slot on the wheel rim. The seal produced too much friction, even after a smooth FEP film top was added to the foam. The friction was too great for the motor that turns the wheel and was removed.

Ducting and Connections

Two air moving components of note are the HS upstream (of the wheel) “snorkel” and the RS downstream (again, of the wheel) “grommet”. The HS downstream and RS upstream air is moved through simple holes in the trays.

Snorkel

The snorkel extends from the lower tray HS exit port to the HS entry port on the Box housing. The exact location of these ports relative to each other could not have been known before the whole device was assembled. To account for this unknown we designed the snorkel in 3 parts. The center part with the 90deg bend allows the upper section to move in the z axis while the lower section can move in the x axis. Once fit to the completed device the parts were affixed and sealed to each other using silicone. The snorkel attaches to the HS entry port at a 45deg angle. This is to allow it to remain close to the body of the prototype so that it can fit into the testing chamber. Note that in order to print the box chamber in the 280mmx380mm HP MJF printer the inlet port for the HS was printed separately and then attached with adhesive.

Next Steps

Because the snorkel folds down tightly it makes accessing 5 of the 16 mounting holes on both sides the top and bottom flanges impossible. We used silicone to seal the flanges to the flange platforms, and tightened them together with screws where possible. I do not think that the snorkel on the current P4 will come off or leak, but still it would be good to find an attachment method that will work better with the shape of the snorkel.

Grommet

The grommet is made to accept the RS downstream channel with great fitting flexibility in the x, y and z directions. The grommet seats into tray 2 with wide mounting surfaces on both top and bottom of the mounting hole. The top mating surface is curved and provides a spring force into the plastic. The bottom mating surface is thick and provides backpressure for the spring. The face of the bottom surface has two ridges (“double lipped”) to concentrate sealing pressure. The width of these surfaces allows the grommet to be moved approximately half an inch in the x and y directions while still maintaining a seal. The inside of the grommet’s through hole has teeth shaped ridges along its length. These ridges are designed to deform against the outside of the RS channel, providing multiple continuous seals around the channel. The channel has approximately a full inch of travel in the z direction before its seal is compromised. The designed in sealing capabilities of this grommet were enhanced in installation with silicone sealant inside the horizontal mounting grove, and dow vacuum grease in the vertical through hole. Details of the grommet casting are in section 9.

Desiccant Wheel

Overview

The inside section of the desiccant wheel is a waffled honeycomb structure made of fiberglass and embedded with desiccant material. Its purpose is to collect water from the HS and release water to the RS.

Specifications

The wheel is ~240 mm in diameter and ~20 mm tall. It has an aluminum hub in the center into which is press fit a rotational bearing. The bearing’s center is 12 mm in diameter. The outside is encircled with a thin stainless-steel ring that is siliconed and riveted into place.

Rim and Riding Surfaces

Overview

We mount the raw desiccant wheel into a rim. (Note, usually the term desiccant wheel refers to the assembled wheel including the rim and riding surfaces). This rim has a center section of HP MJF nylon and upper and lower layers cut from white Acetal. The rim has useful features -

- gear teeth by which the wheel is rotated (135 teeth).
- a smoothed channel to hold the wheel in the housing and to provide a sealing surface for the HS stream.
- Two smooth acetal disks on which the RS channel's seals partially run, silpoxied down to the HP material.

Design Considerations

The RS seals run partially on the fiberglass surface, and partially on the smooth outer section of the rim. To make the seals as effective as possible we have been very careful when constructing the wheel/rim structure to keep the height of the rim and wheel consistent and to fill and smooth any gaps and cracks.

Construction

1. The first step is to grind down the rivets that secure the metal band around the raw desiccant wheel. Removing these rivets does not compromise the strength of the wheel because the wheel is glued to the band and because we will soon be surrounding the wheel with a securely adhered rim.
2. The trickiest part of attaching the rim to the raw wheel is that the wheel, as it comes from the manufacturer, varies by about 2mm in diameter and 1mm in height. The MJF printed center rim part is flexible and can accommodate this variation. The gear teeth on the rim are deep enough that they can accommodate being out of round. The riding grove in the rim has enough clearance to the edges of the hold in the housing floor to prevent binding. The smooth running toppers, however, need to be cut to the largest diameter of the particular wheel they will be mounted on. If they are cut too large a wide gap will exist between the metal sheath of the wheel and the inner surface of the smooth topper. This gap is a prime leak spot and can prevent the RS stream from sealing. If the topper is too tight it will deform into a cone shape, and that will also spoil the seal.

3. Once the acetal smooth toppers are waterjet to the correct size, their inner facing surfaces are roughened with sandpaper so that they can be glued.
4. In preparation for glueing a smooth working surface is cleaned and covered with wax paper.
5. The bottom riding surface is placed on the wax paper, smooth side down, then silpoxy is applied to its up-facing roughened surface and to an end of the MJF print [n22] (it is fine to start with either the grove side or the gear side). These two parts are pressed together so that their inner diameters line up.
6. Next the inside upper section of the MJF rim and the lower section of the wheel's metal band are also coated with a thin layer of silpoxy. Quickly, before the glue dries, the wheel is pressed into the rim and riding surface and all parts are pressed flat into the wax paper. It is important that the wheel and riding topper are on the same plane.
7. After this is allowed to dry overnight any extra glue is trimmed off. The other topper is put flat with its rough side up onto the wax paper. A thick layer of silpoly is applied to its rough surface. A thin layer of silpoxy is applied to the metal rim of the raw wheel. Then the wheel is pressed into the riding surface until both are firmly against the wax paper. There should be a half mm gap between the MJF center rim and the smooth acetal riding surface. This gap will account for any differences in raw wheel height. The thicker layer of adhesive will fill this gap and if any squishes out around the edge it can be trimmed after drying.

Next Steps

The wheel surface is very difficult to seal to. It is also quite rough and punishing to the RS seals, causing them to have a short life. There is the possibility that the wheel could be covered with a smoother perforated surface that would have 2, 4 or 8 seating locations for the RS seals. The wheel could then be indexed between these locations. While this would increase sealing capacity and seal life, it would also send pressure waves through the device to unknown results. Furthermore it would require more sophisticated gearing or an electronic control mechanism adding unwanted expense to a final project. This surface covering would also add some thermal mass to the rotor, increasing that parasitic load.

Data Collection

Overview

Using LICOR, thermocouples, and BME280s we monitor the pressure, temperature, and humidity of the HS and RS airstreams upstream and downstream of the desiccant wheel. More the specifications for these sensors can be found in the sensor section of this report. I will in this section address the specific locations and labeling used for the sensors in the Box Housing.

Sensor Connection Port Locations

The connections points for the Box sensors are all on the face of the housing.

Left Side

The connectors on the left side all monitor the RS, with the top LICOR ports monitoring the air upstream from the wheel and those on the bottom monitoring the downstream. For both the left most port is the Supply air and the right is the Return air. The BME and thermocouple connectors on the left side of the housing also monitor the RS with the left going to the upstream and the right to the downstream.

Right Side

Sensors connections on the right side of the Box face monitor the HS, again with upper LICOR connection points servicing upstream sensors and lower connection points those that are downstream. The BME and thermocouple connectors on the right side of the housing also monitor the HS with the left going to the upstream and the right to the downstream.

Sensor Tip Mounting, Locations and Considerations

Supporting Sensors

Each sensing location requires a support structure. The RS is carried in a MJF nylon printed channel, and it was a simple matter to print the support structure into these channels. Similarly the HS upstream of the wheel is run through a MJF nylon printed duct (the snorkel n29) and so the support structure is printed into that structure. The HS downstream of the wheel dumps into the relatively open area of tray 2 without any extension of the housing providing structure. For these sensors we added a metal bar that holds the LICOR, BME and Thermocouple about 1” off the surface of the wheel in a location between the center of the wheel and the exit port of tray 2. We judged this to be a location that would get a representative air stream.

LICOR

The LICOR samples are continuously collected by small .25” OD tubes, analized, and then sent back into the airstream from whence they came. To evenly collect across the airstream we sealed the end of the sampling tube and perforated its last inch of length. After analysis the return air is sent back into the airstream. To do this without creating pressure we connected a barbed 90deg fixture to the tube’s end and aimed the open end of that fixture downstream of the air flow. All sampling tubes were mechanically secured in place with SS wire.

BME and Thermocouple

We placed the sensing ends of the BME and thermocouples into the streams of air at point we judge to be representative of the general airstream. We were careful to hover the sensor ends over their support surfaces and keep them away from any heat-sinking solids.

Mechanicals

Overview

The desiccant wheel is turned at a rate of approximately 1 revolution per a minute. We are driving the 135 tooth wheel rim with a gear box, consisting of a driving gear, 15 teeth, and intermediary gear of 40 teeth. For each revolution of the wheel the driving gear turns 9 times. The motor we are using is a 200 step stepper motor. We have programmed its driver to run it at 1/16th of a step, or 3,200 programmed-steps per revolution, 480 programmed-steps per second.

Lessons Learned in Development

Due to the friction of the seals the torque needed to turn the wheel is significant for the motor in this design. It would be desirable for product-intent designs to avoid this tradeoff systematically. For our experimental prototype, we chose to use a stepper motor over a servo because of its high torque at low speeds. Even with the right motor type we had to change from a Nema 23 x 56 to a Nema 23 x 76 to for more power. It was still not enough. Because we did not have the height needed to use the Nema 23 with integrated gear reduction, we built in a gear reduction of our own by making the pinion gear smaller and using a larger intermediary gear to reach the teeth of the wheel rim. In earlier designs the gear shafts were held on one side, but the torque in the gear train was causing them to splay. To fix this we added a second plate at the bottom of the gear assembly to hold the shafts true.

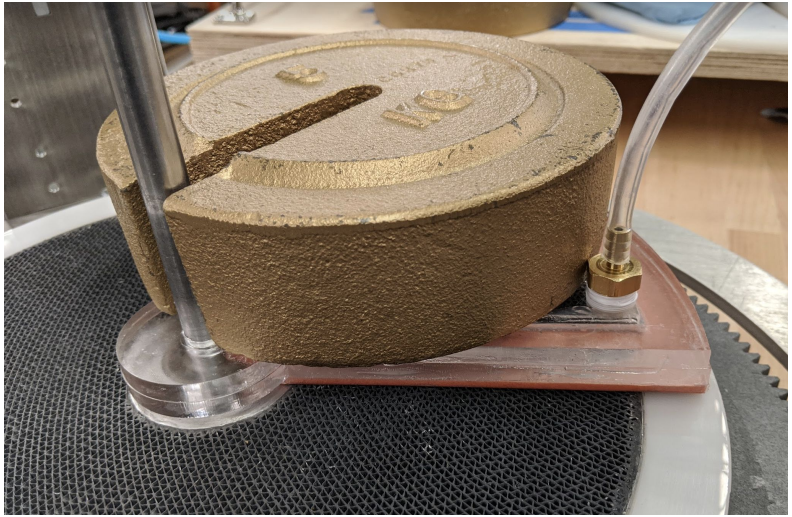
The added weight of the more powerful motor and the extra gearing and supports required that the mounting bracket for the gear assembly be made of aluminum rather than MJF printed nylon. To cool the motor we used the material of the mounting bracket to our advantage, additionally adding a heat sink onto the motor housing and placing it squarely in the HS air as it exits passes through the wheel on its way to the exit. The weight of the gear assembly is partially supported by the column that reaches to the floor of tray 2. The motor is rated to only 50C, whereas the top of the motor is almost flush with the bottom of the solkoted mylar layer in the solar collector, which may reach >100C. We have concerns about overheated and damaging the motor, and so are using this Al heat sink in the HS to try to remove heat from the motor and Al gear assembly, and also have a TC placed on top of the moto
interlock safety control.

Next Steps

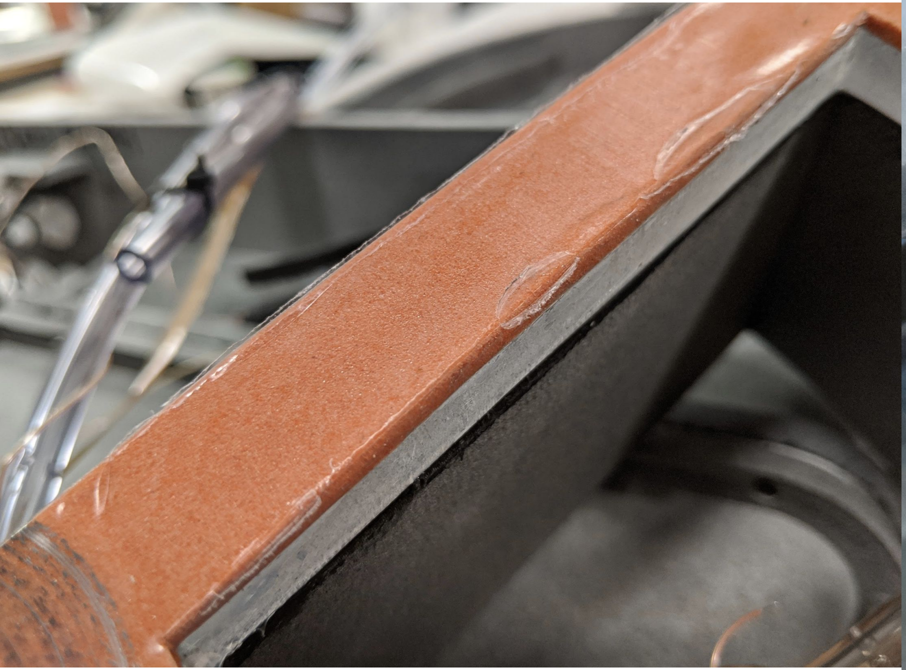
As long as the motor does not overheat it should rotate the desiccant wheel as expected. The only way to reduce the load on the motor assembly would be to design the seals to work with less friction.

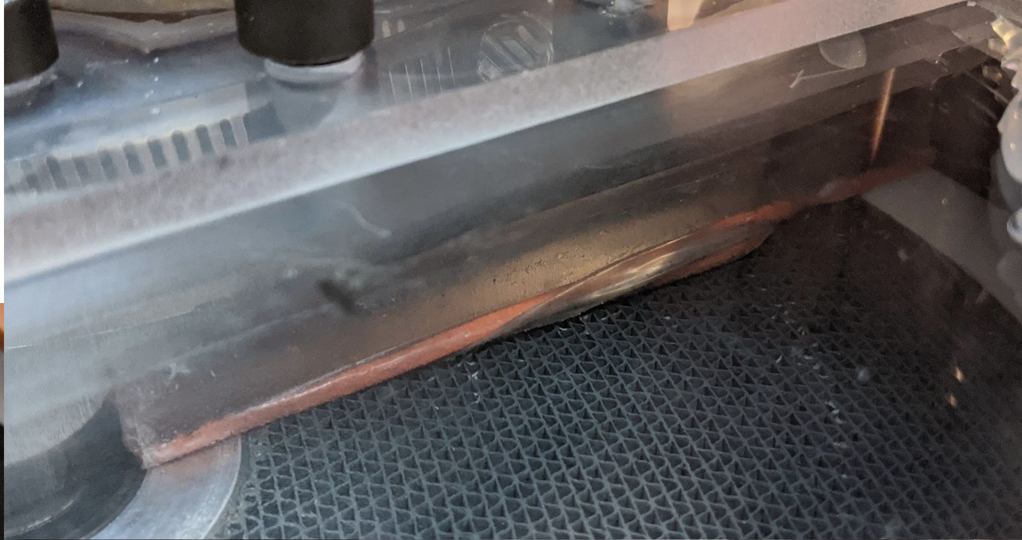
For experiments like this, we recommend considering an interlock on the temperature of the stepper motor: if it reaches 45C, the motor power shuts off, and the RC fan speed increases. If the temperature reaches 50C, the lights in the chamber are turned off.

Testing the rotary seal with a weight (left).

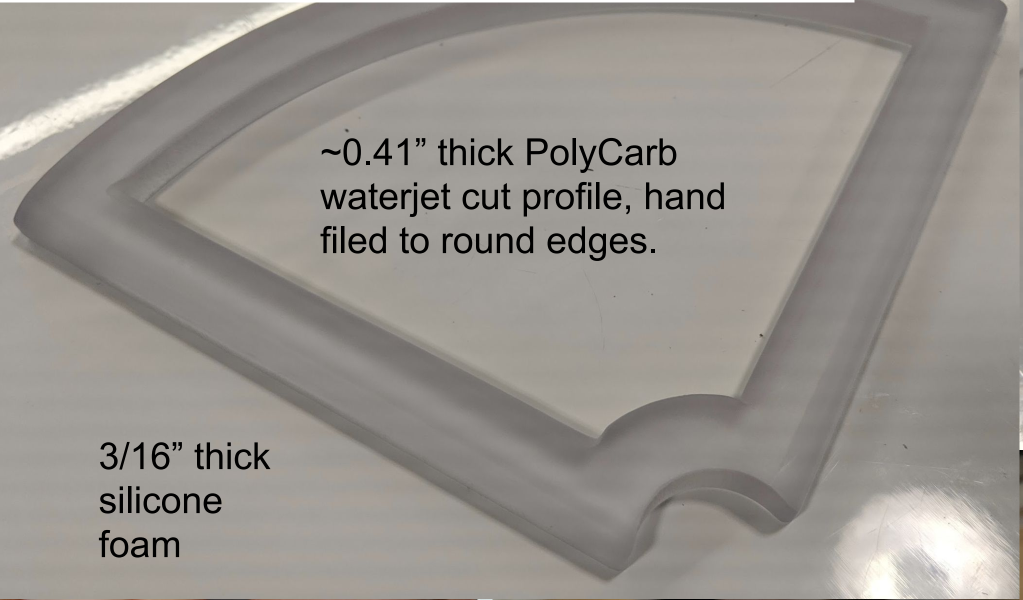


Testing the rotary seal page 2. The flat profile created high wear spots (photo below) on the ETFE film, causing failure of the seal (right).



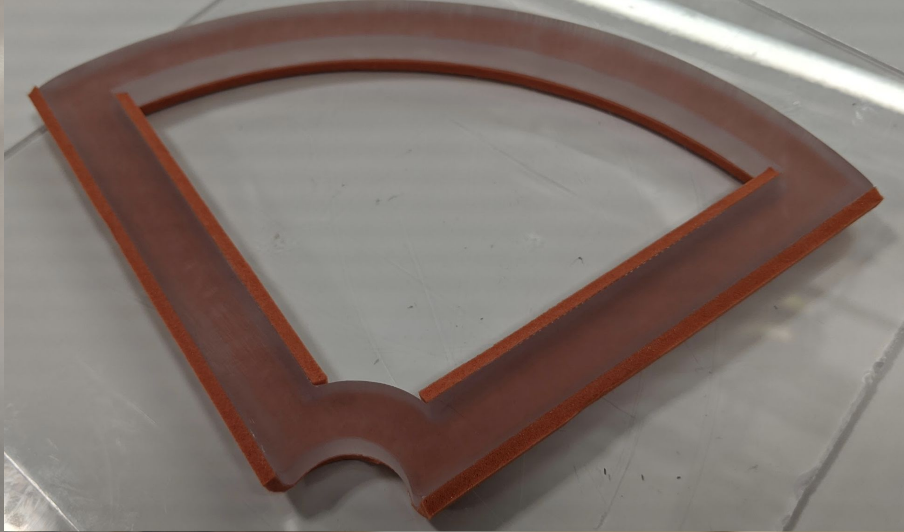


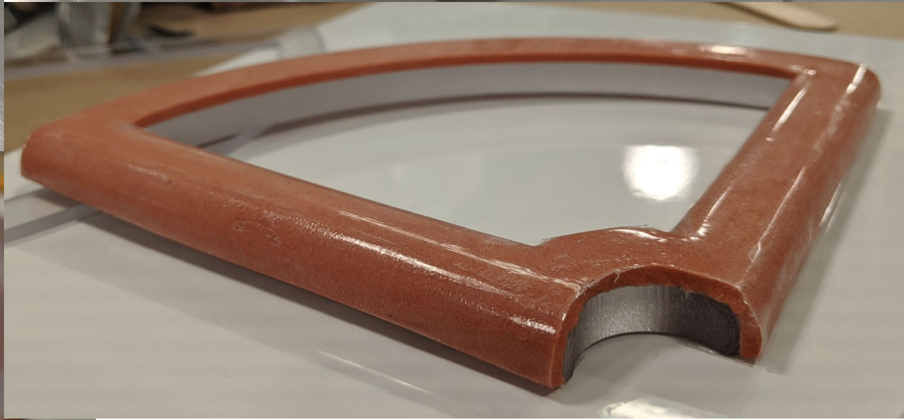
Redesigned seals using a rounded edge profile

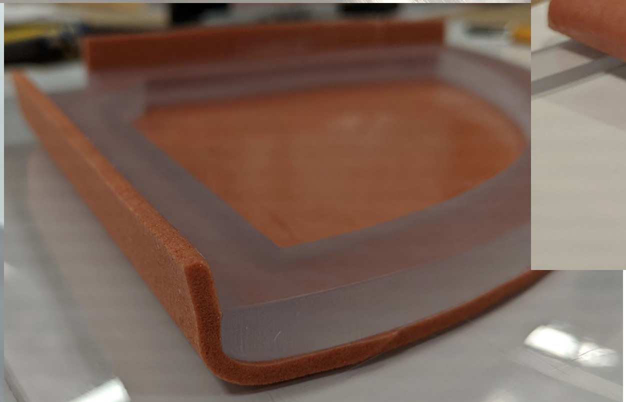


~0.41” thick PolyCarb waterjet cut profile, hand filed to round edges.

3/16” thick silicone foam







2 layers of FEP film, lower one adhered with Silpoxy to the foam

Seal designs tested in rotary test chamber

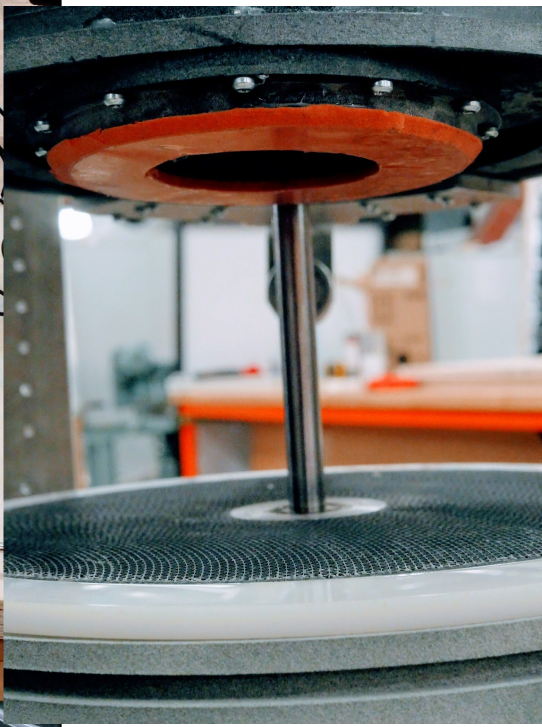
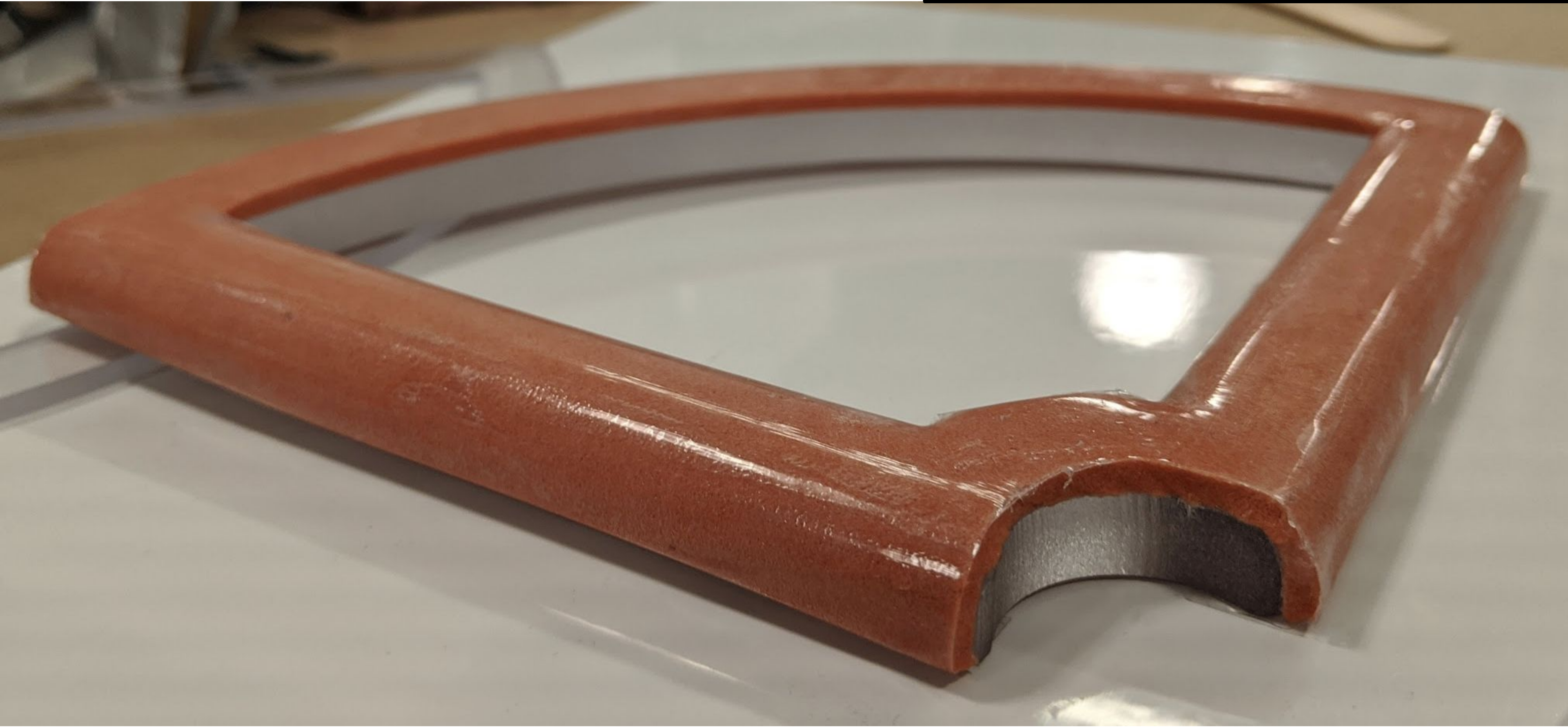


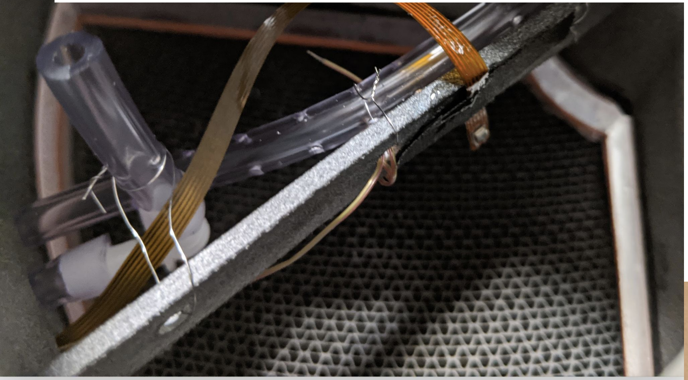
Image of Final Part Before Assembly: Rotary Seals

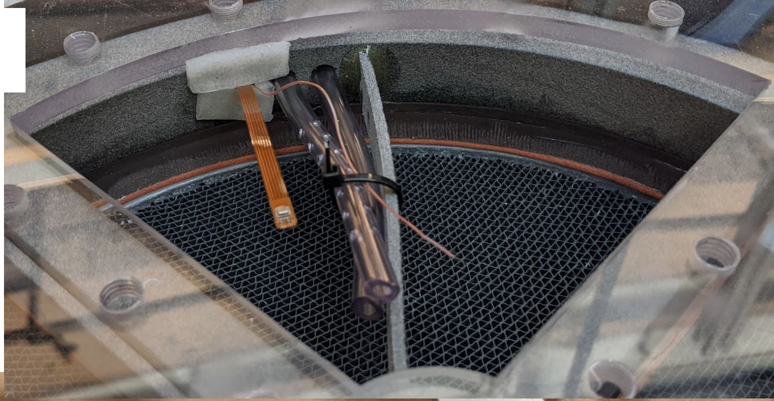
Total gap should be ~0.55” that the seal insert should fill. PC fly-cut to 0.41” thick, then Silicone 0.1875” thick, compressed down to ~0.140”, nets the 0.55” gap filled. (Note, small thickness for black silicone, silpoxy, and 2 FEP skin layers

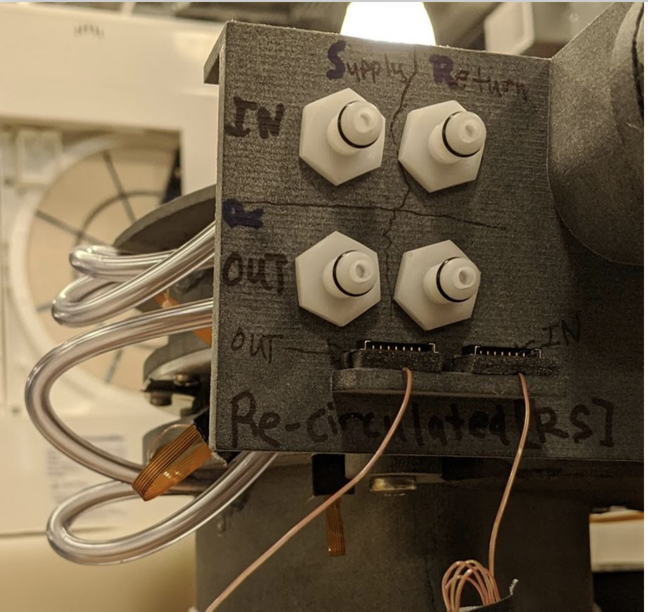


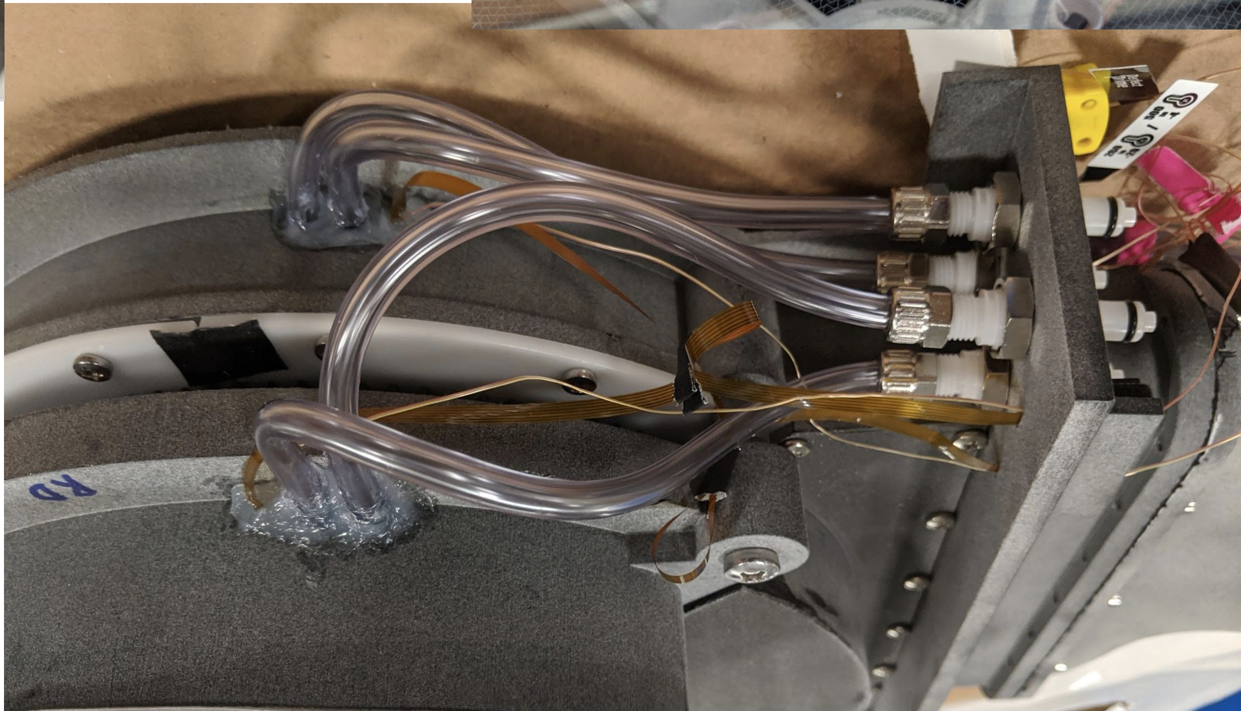
Close up views of air sampling setup in desiccant wheel housing

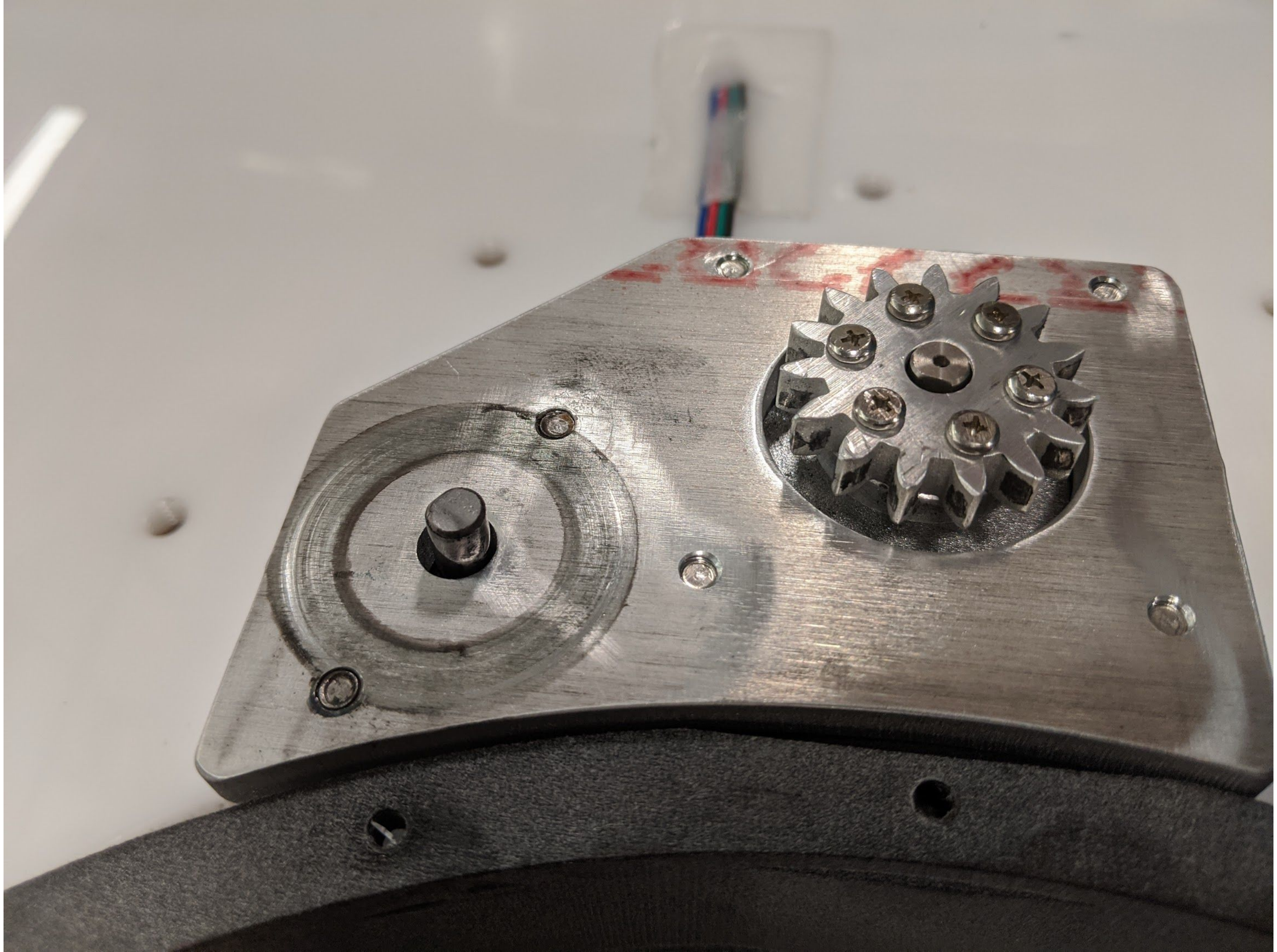
Close up views of air sampling setup in desiccant wheel housing



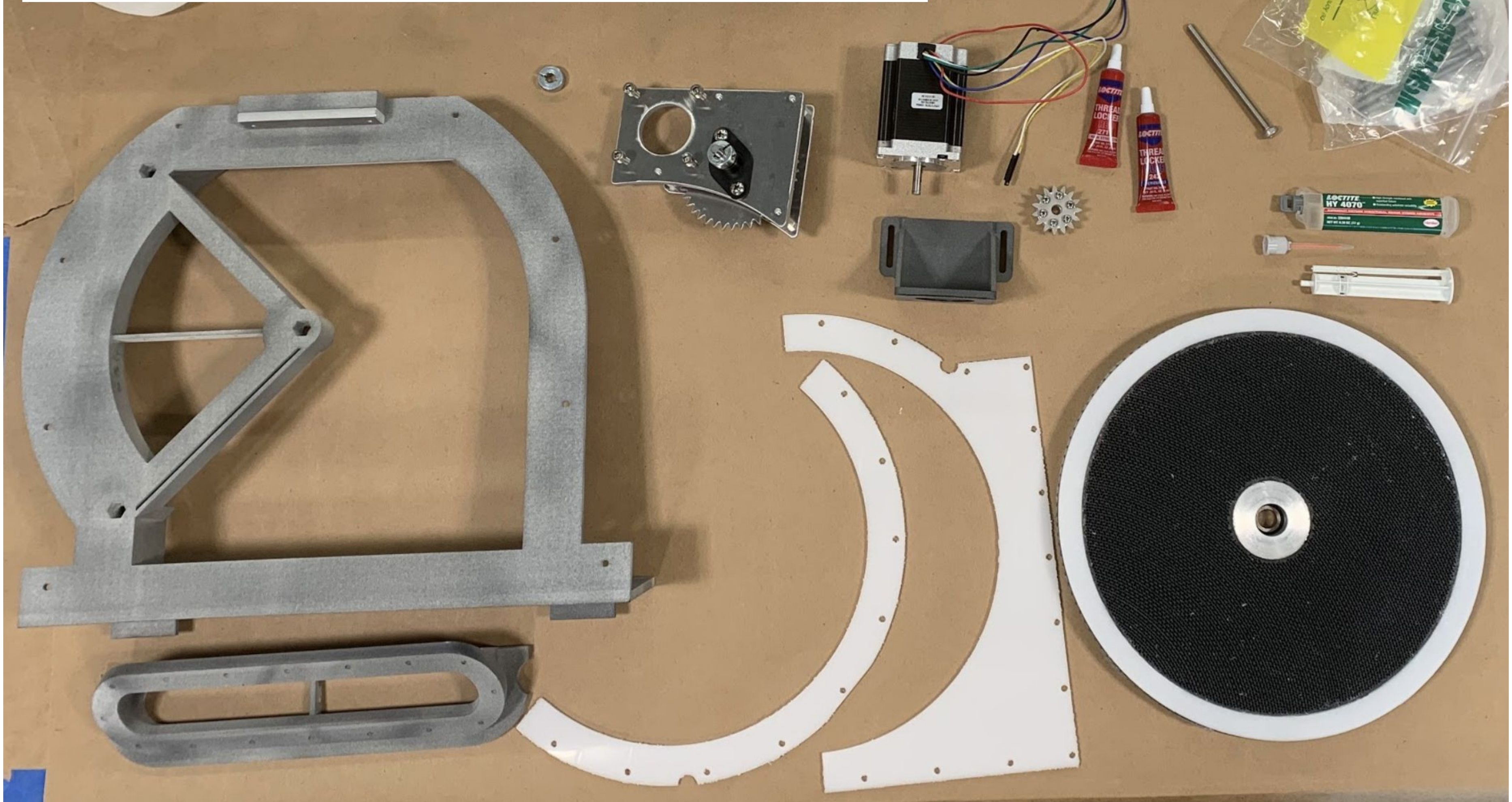






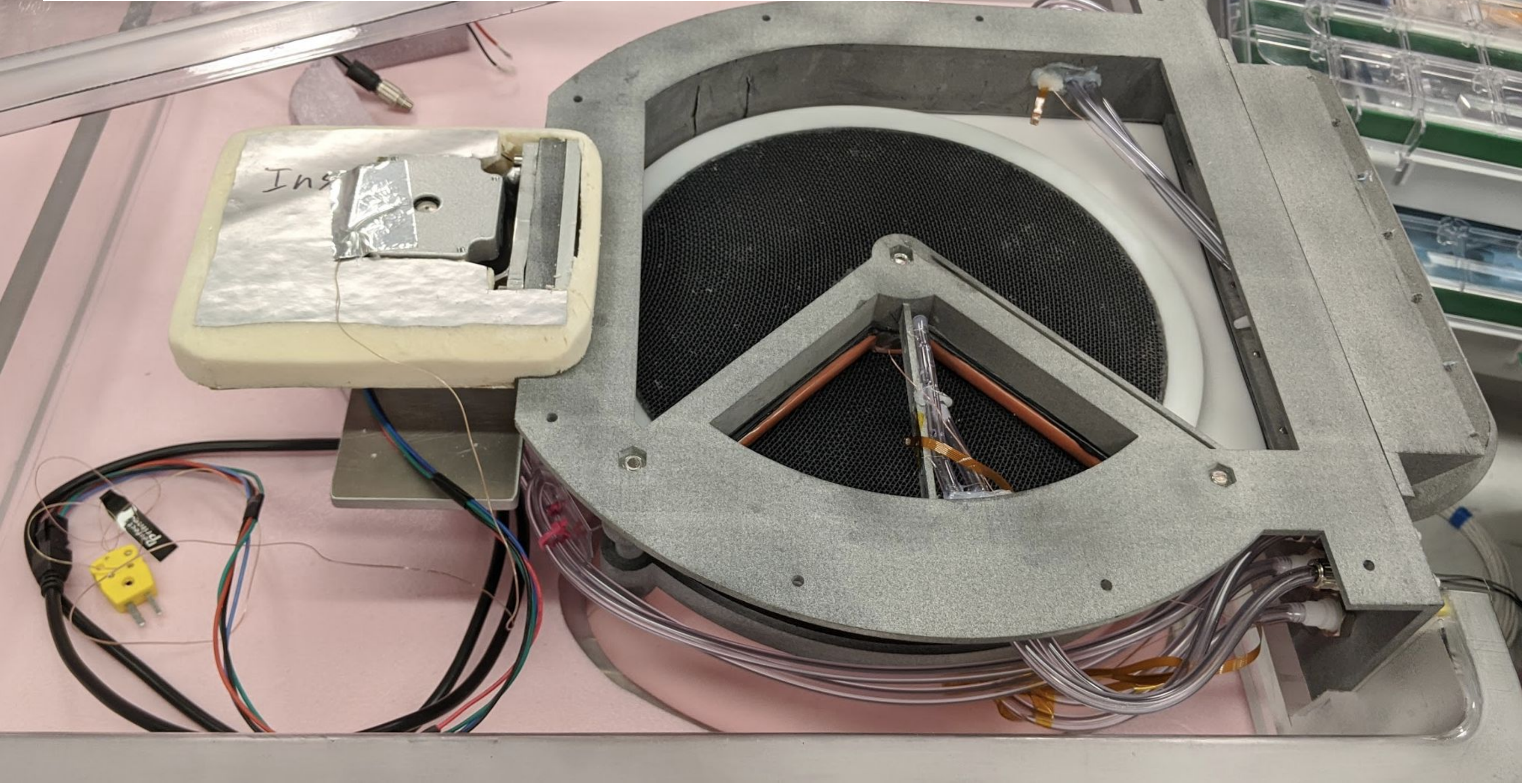


Disassembled desiccant wheel setup

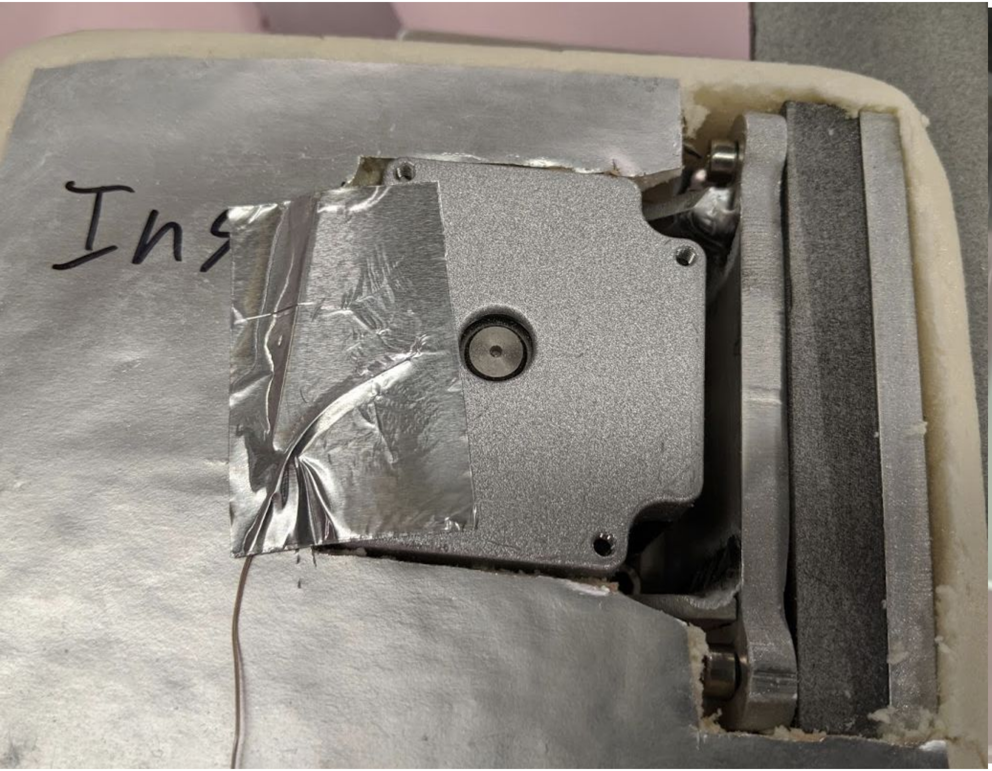


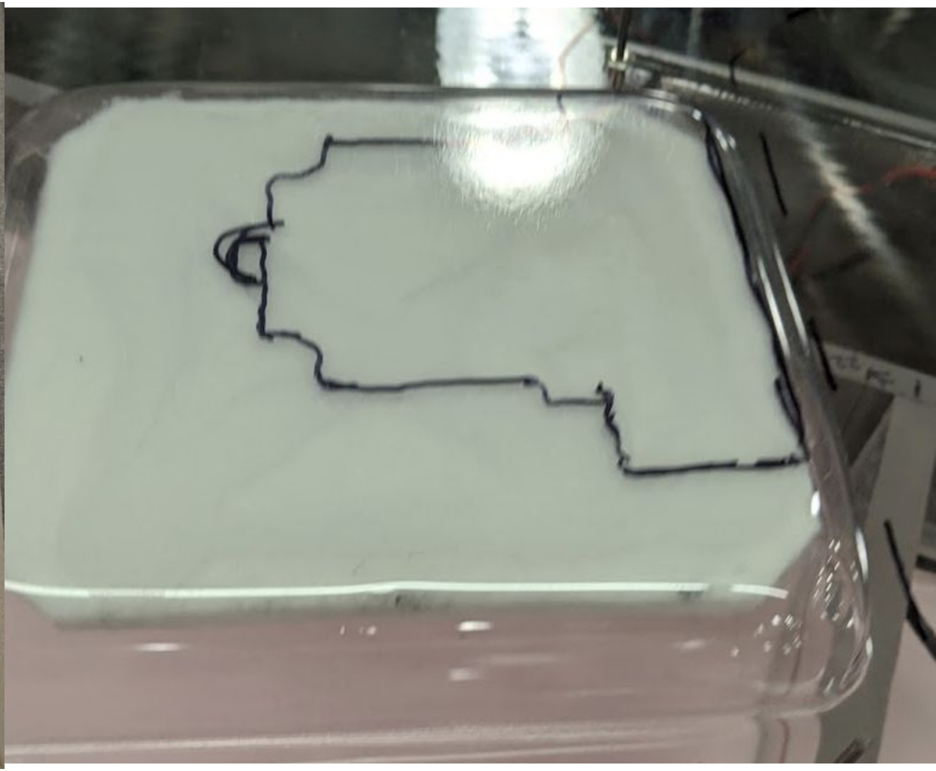
Focus on desiccant wheel seal assembly

Assembled desiccant wheel with stepper motor

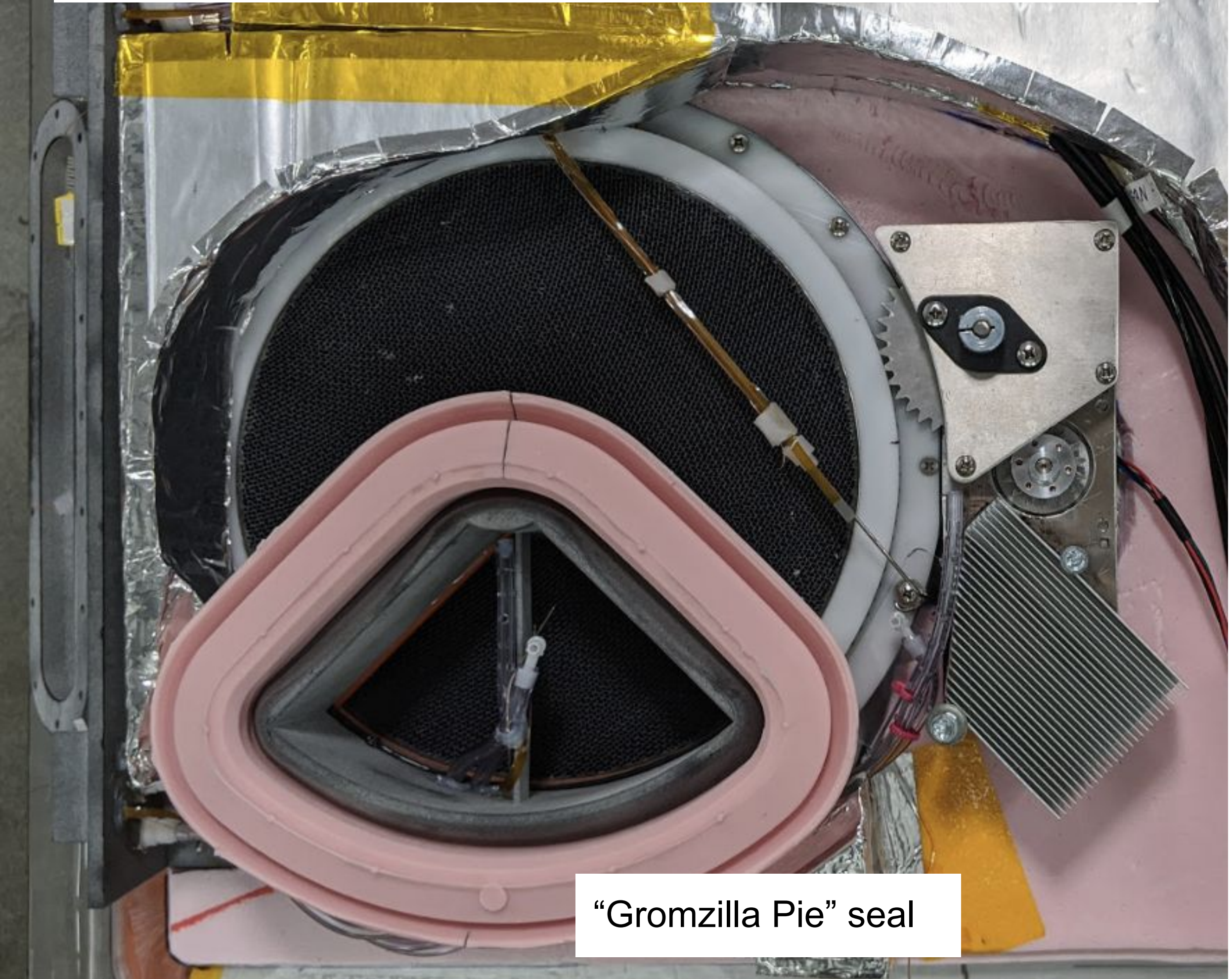


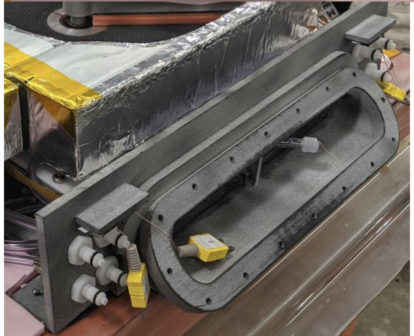
Orienting the motor and wheel assembly on the tray



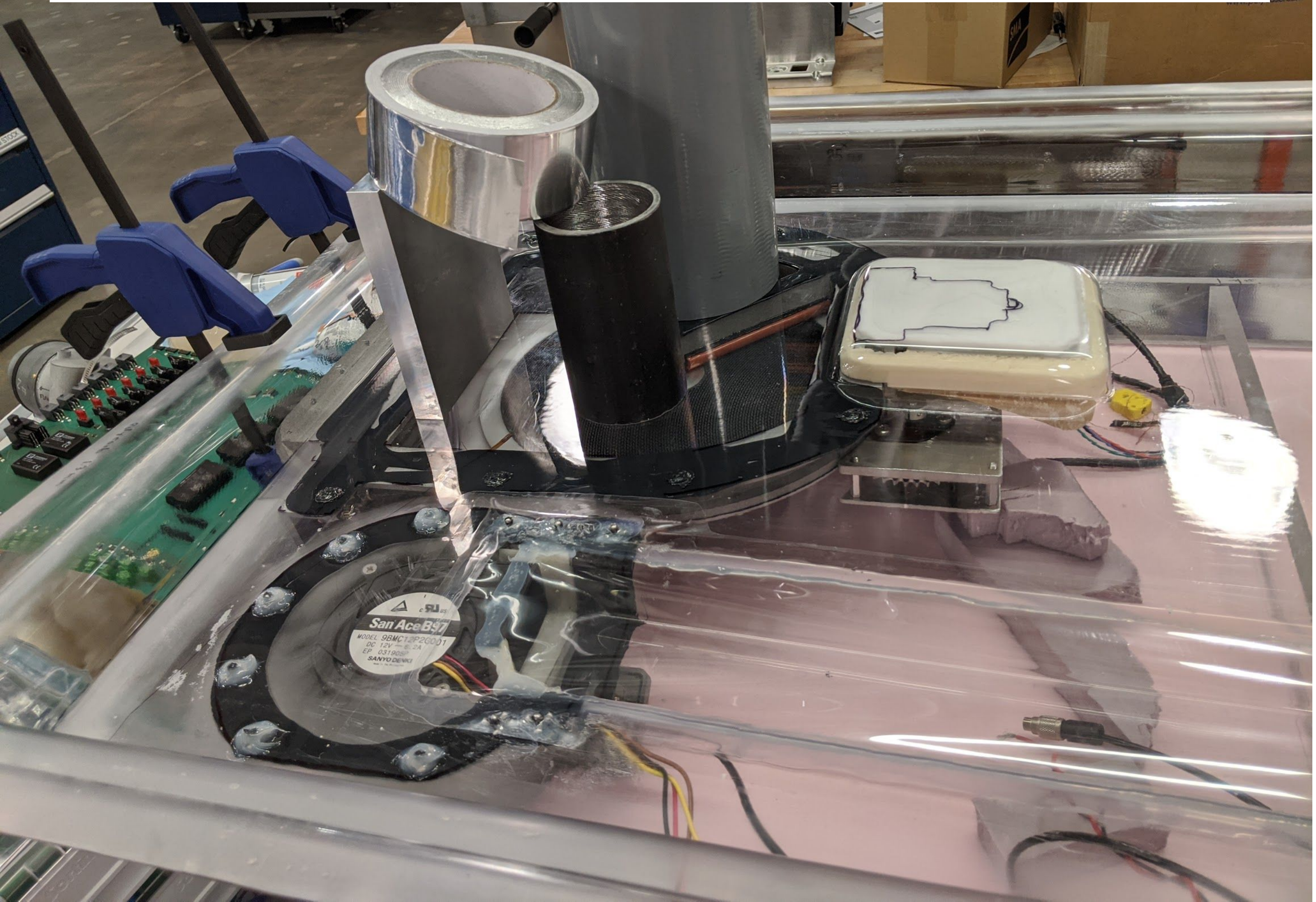


Desiccant wheel installed in device





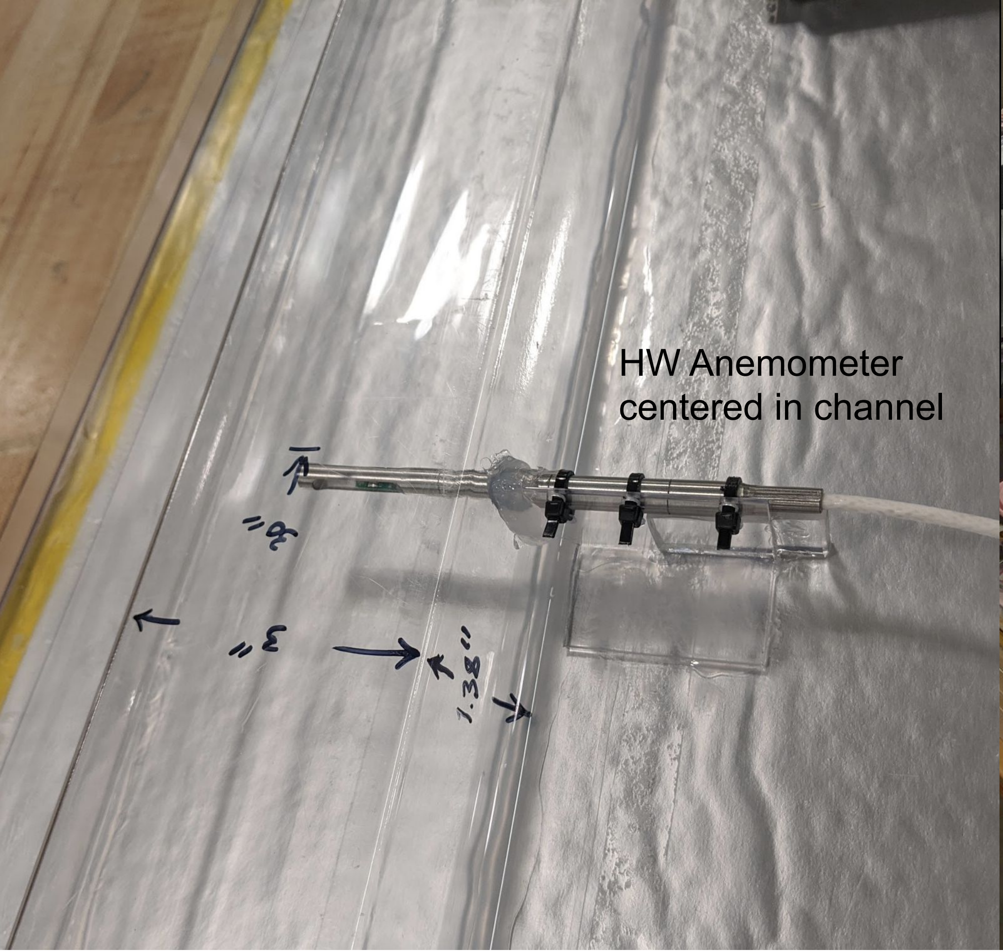
Assembly of device: using found objects to hold down tray for assembly

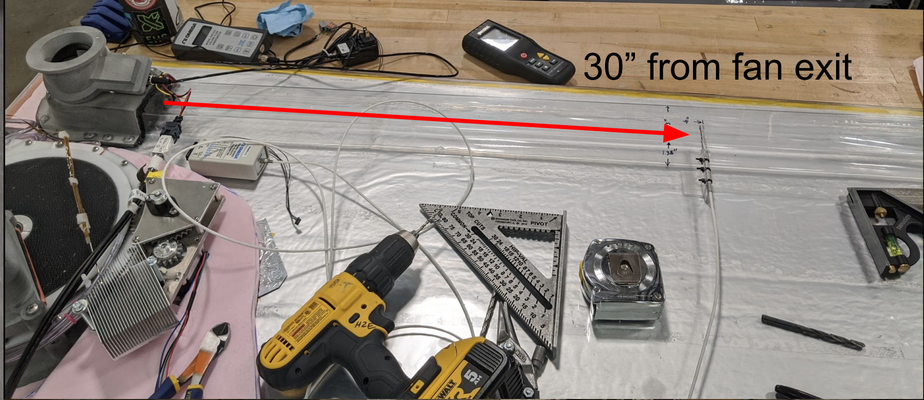


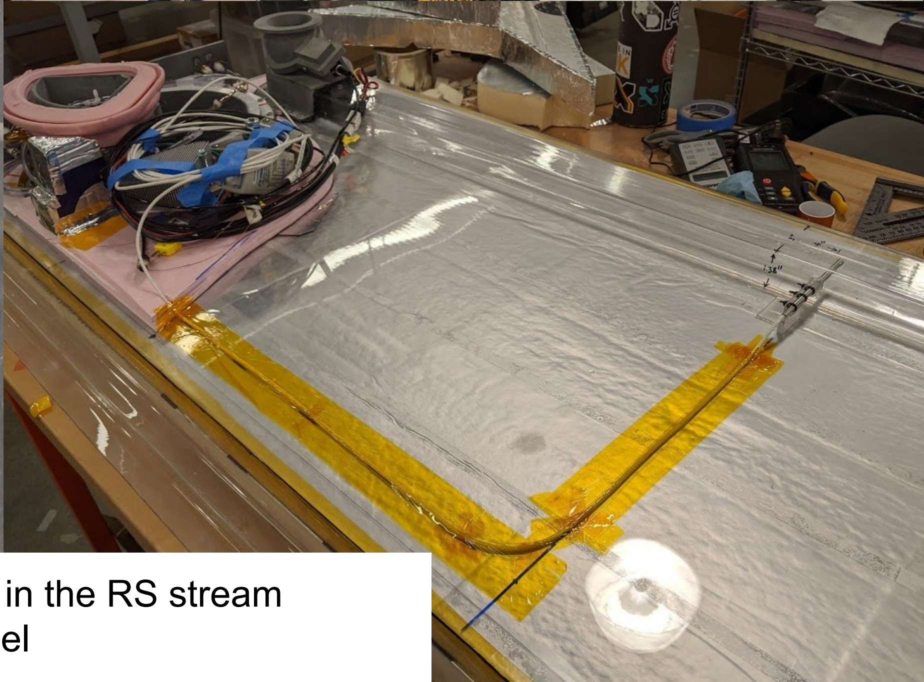
Close up views of desiccant wheel tray seals and rivet holes

Close up views of desiccant wheel tray seals and rivet holes

Cutting foam insulation to surround desiccant wheel

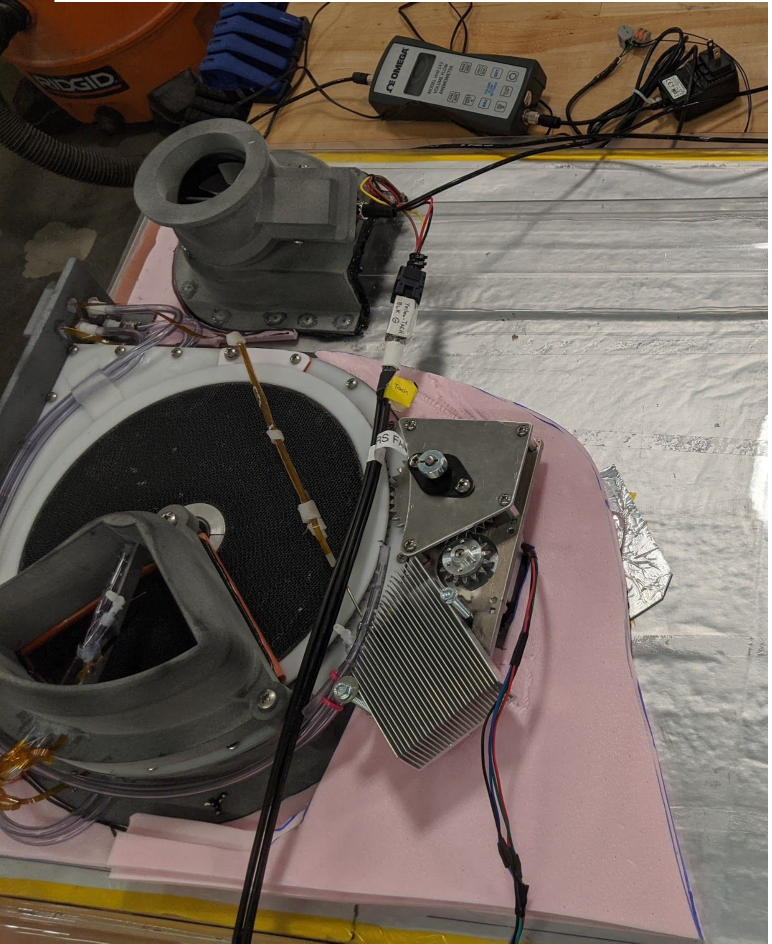




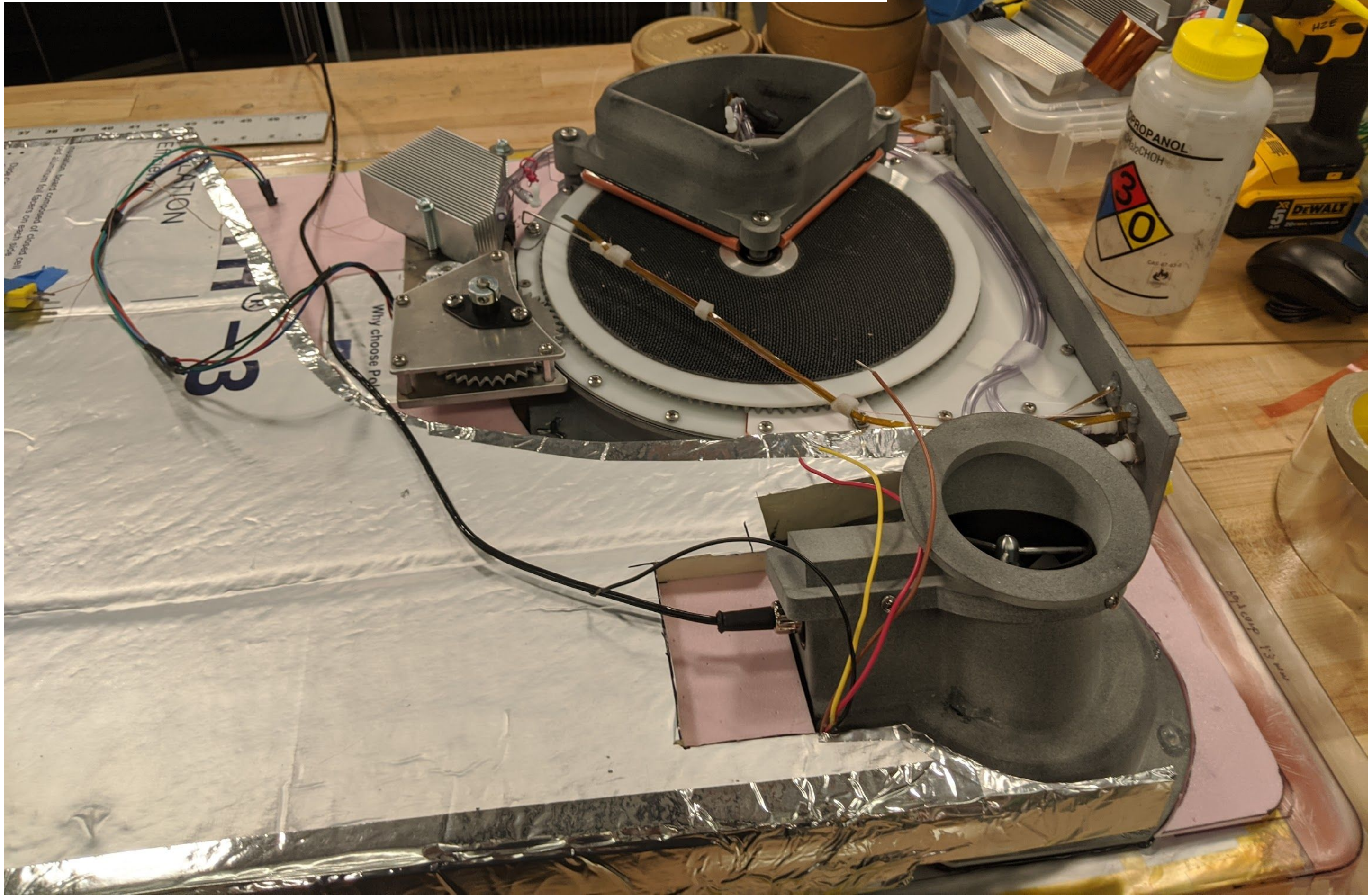


Prior to attaching foam we installed a hot wire anemometer in the RS stream channel (top tray layer) to measure air velocity in the channel

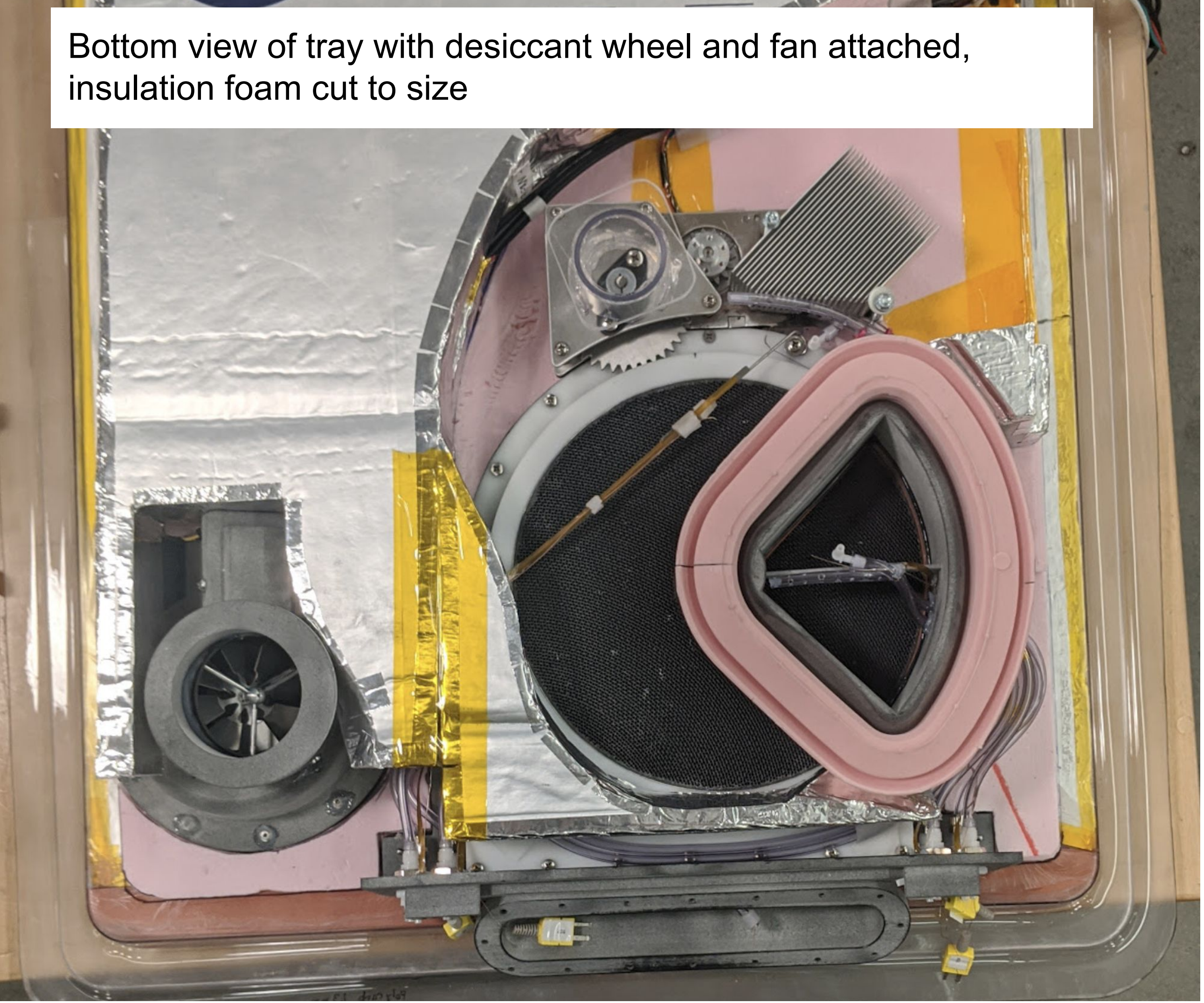
Bottom view of tray with desiccant wheel and fan attached, insulation foam cut to size



Bottom view of tray with desiccant wheel and fan attached, insulation foam cut to size

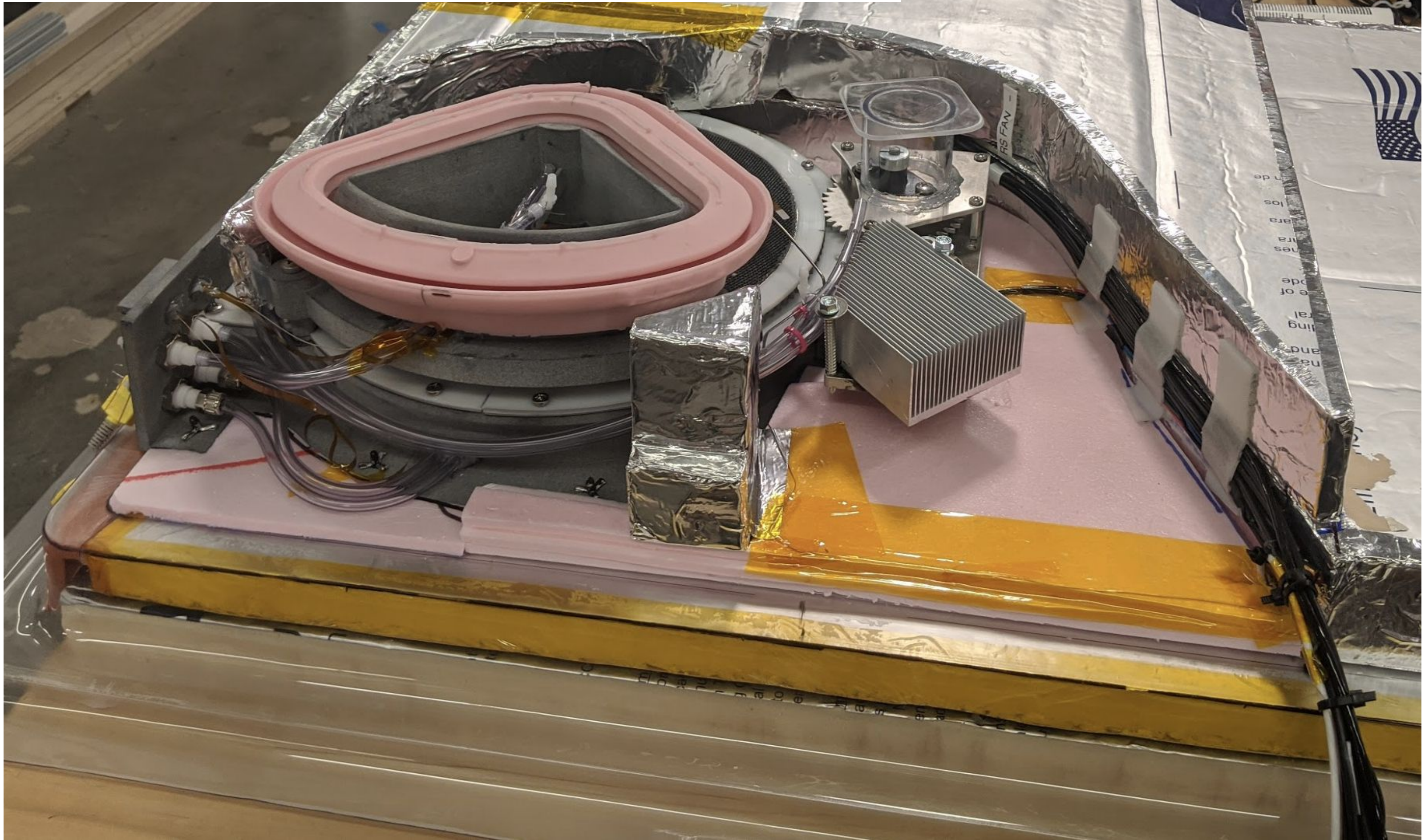


Bottom view of tray with desiccant wheel and fan attached, insulation foam cut to size



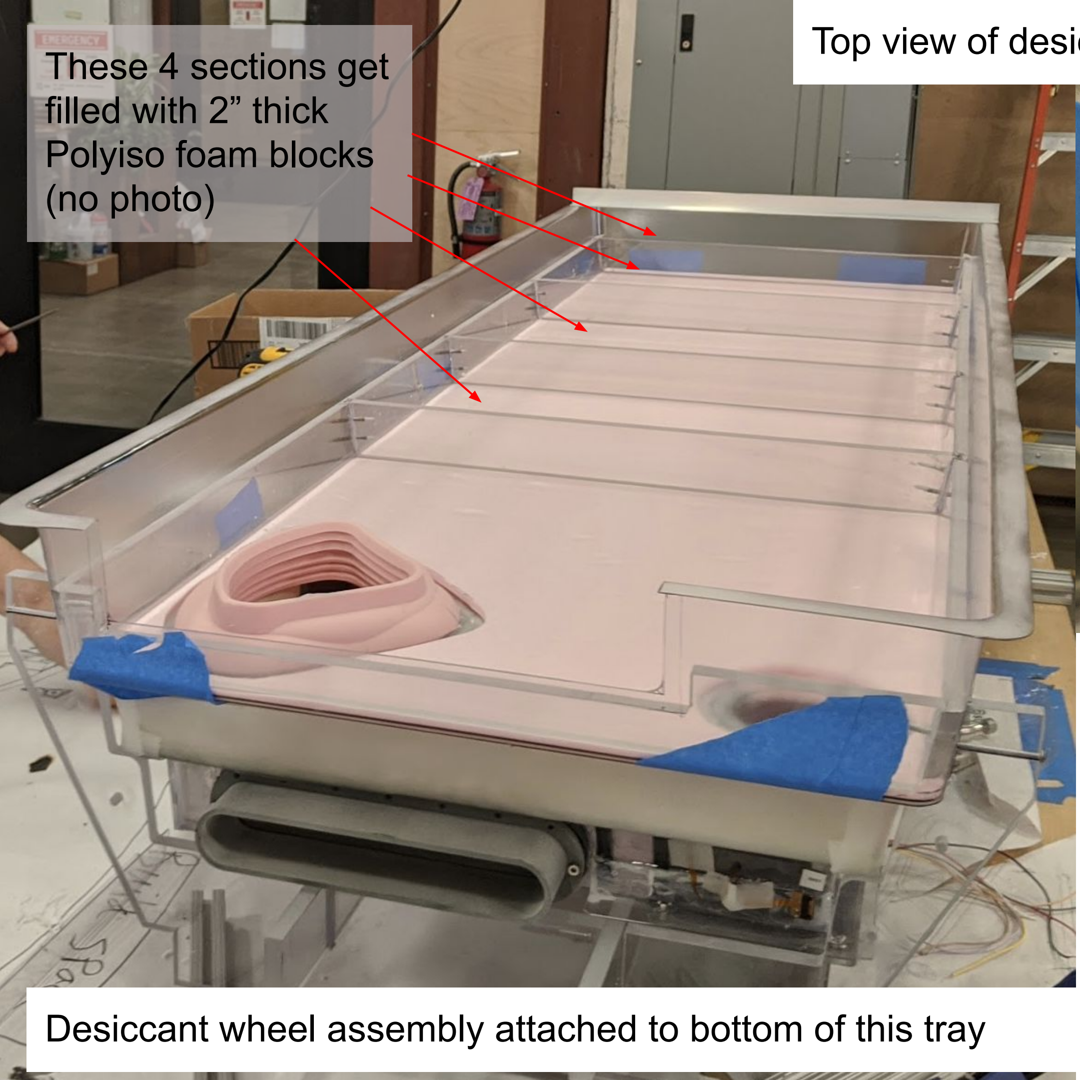
Bottom view of tray with desiccant wheel and fan attached, insulation foam cut to size

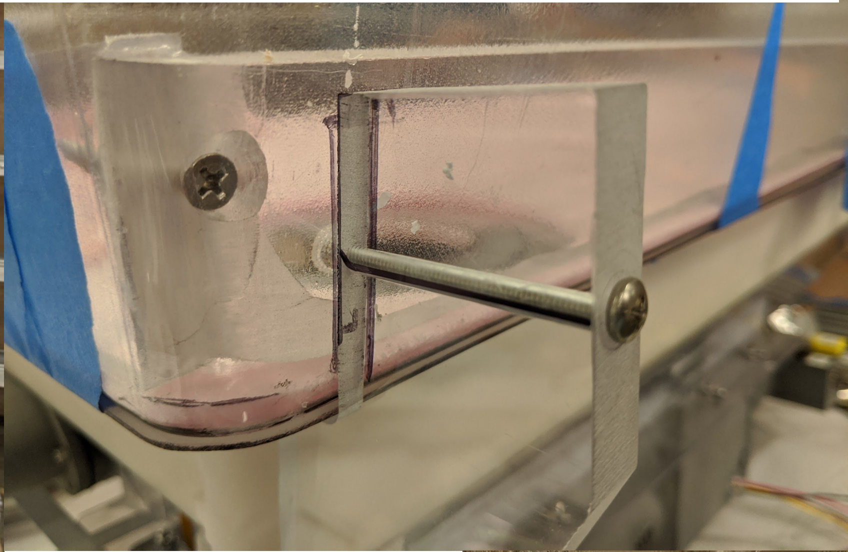
Bottom view of tray with desiccant wheel and fan attached, insulation foam cut to size

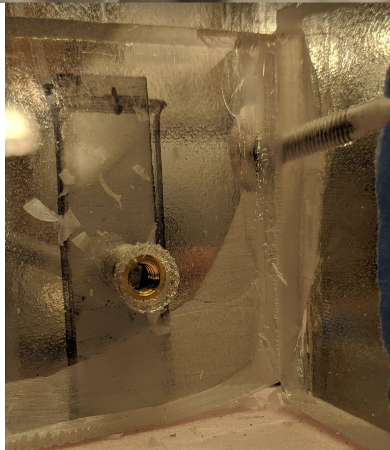


Top view of desiccant wheel tray

These 4 sections get filled with 2” thick Polyiso foam blocks (no photo)



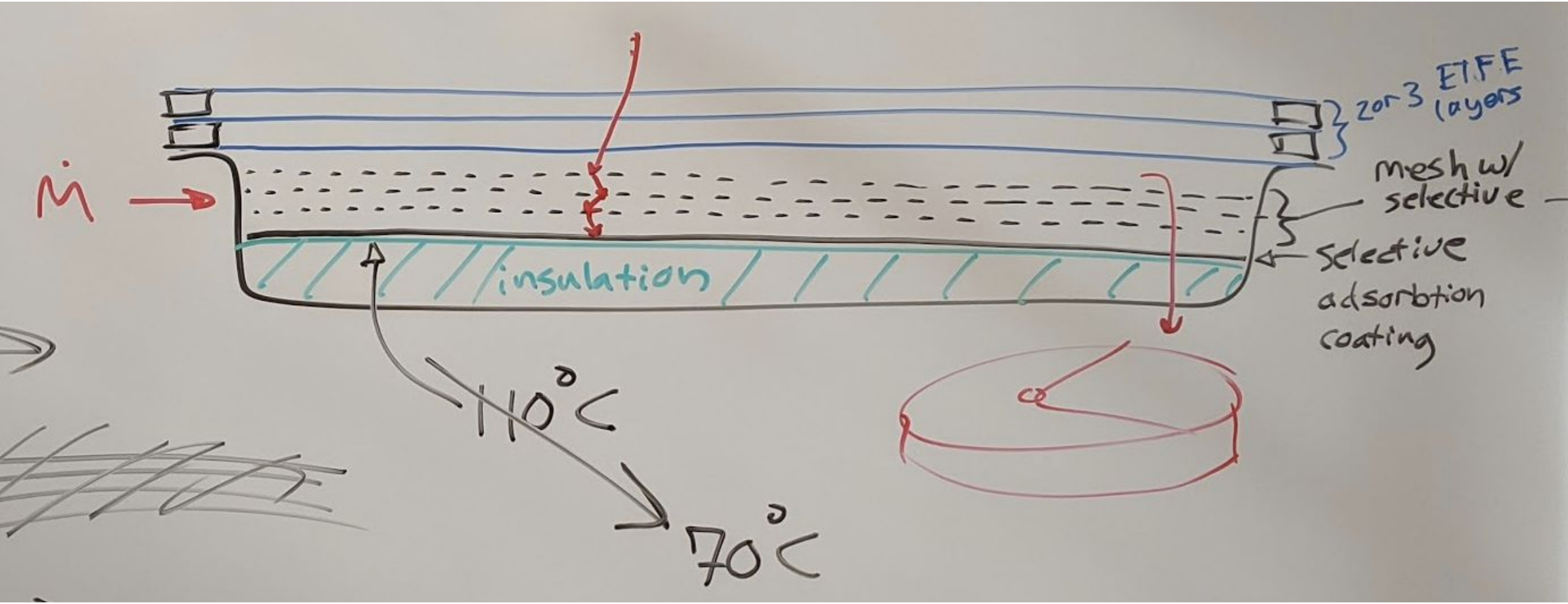




Desiccant wheel assembly attached to bottom of this tray

Image of
Final Part Before
Assembly: Desiccant
Tray Layer

7. Solar collector sub-assembly

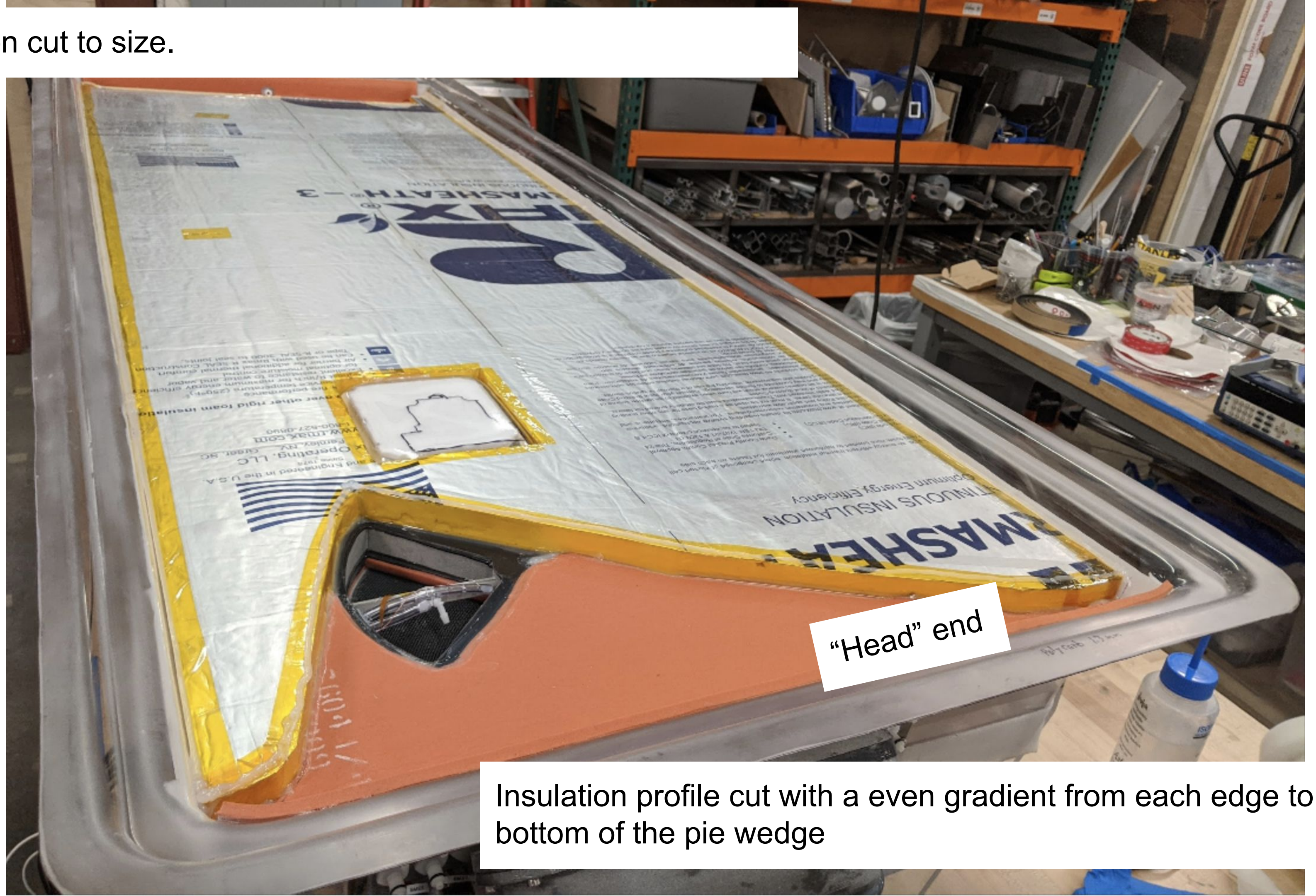


Overview

- The solar collector sub-assembly has two components (from bottom to top:)
  - Insulation: Used to separate the hot air created by the mesh/mylar section from the ambient temperature of the level down. The ends of the insulation are cut into specific profiles to even the flow as it transitions direction
  - Solar absorber: Quilted mesh over solkot mylar to absorb solar irradiation and convert to heat. The design of the mesh directs the airflow evenly across the the plane of the mylar to reduce hotspots

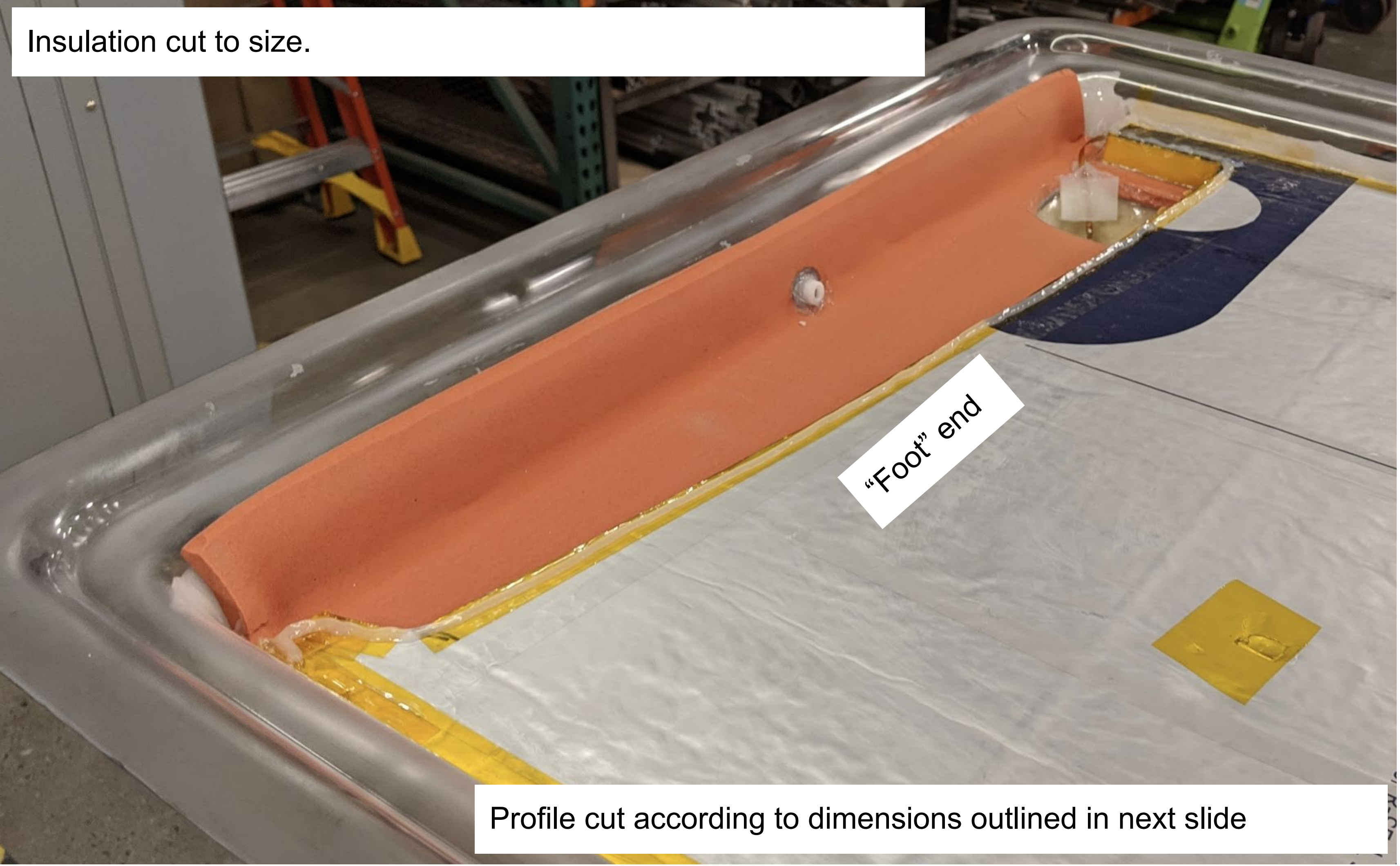
Solar collector component 1:
Insulation (cutting and installation)

Insulation cut to size.



Insulation profile cut with a even gradient from each edge to the bottom of the pie wedge

Insulation cut to size.



Profile cut according to dimensions outlined in next slide

Determining the end shape of the insulation

To determine the shape of the insulation (pink block in the base setup image), we measured the airflow using a hot wire anemometer. Initial ideas were made in mockups using clay and the most promising ones were re-done with a sheet stock model, shown to the right.

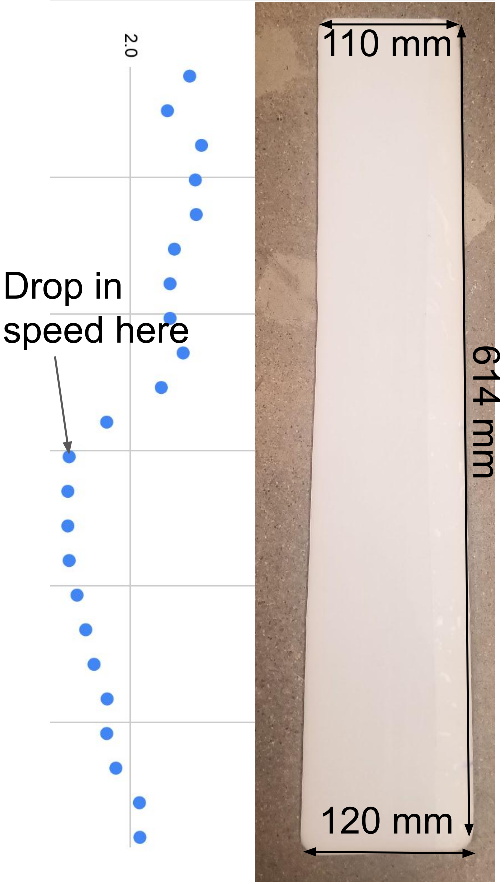
The goal of this work was to evenly spread airflow from inlet around the insulation, and back over the top.

Test 1: Test 1 used a even slant from 110 on the short side to 120mm on long. The test results showed a low spot in airflow 39.5 cm down from the short edge. Therefore the profile was reshaped in Test 2 to even out the flow

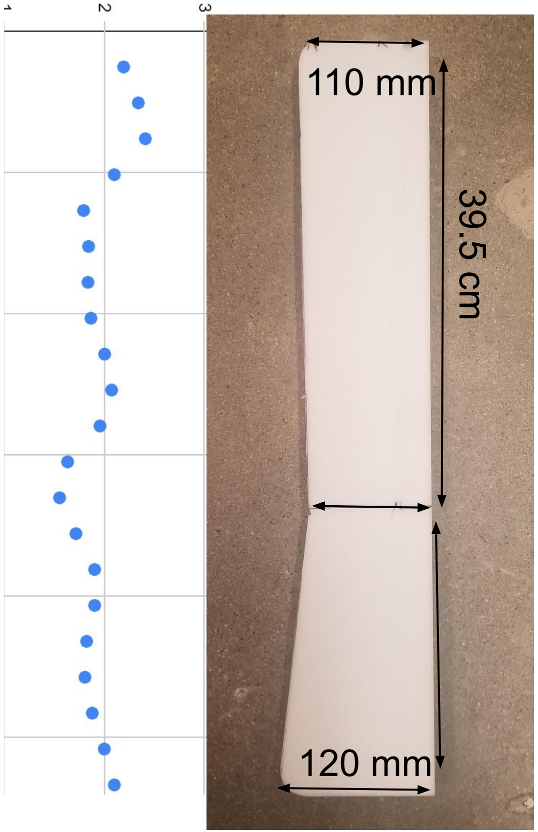
Test 2: Final design selected due to low airflow variation along profile

Base setup

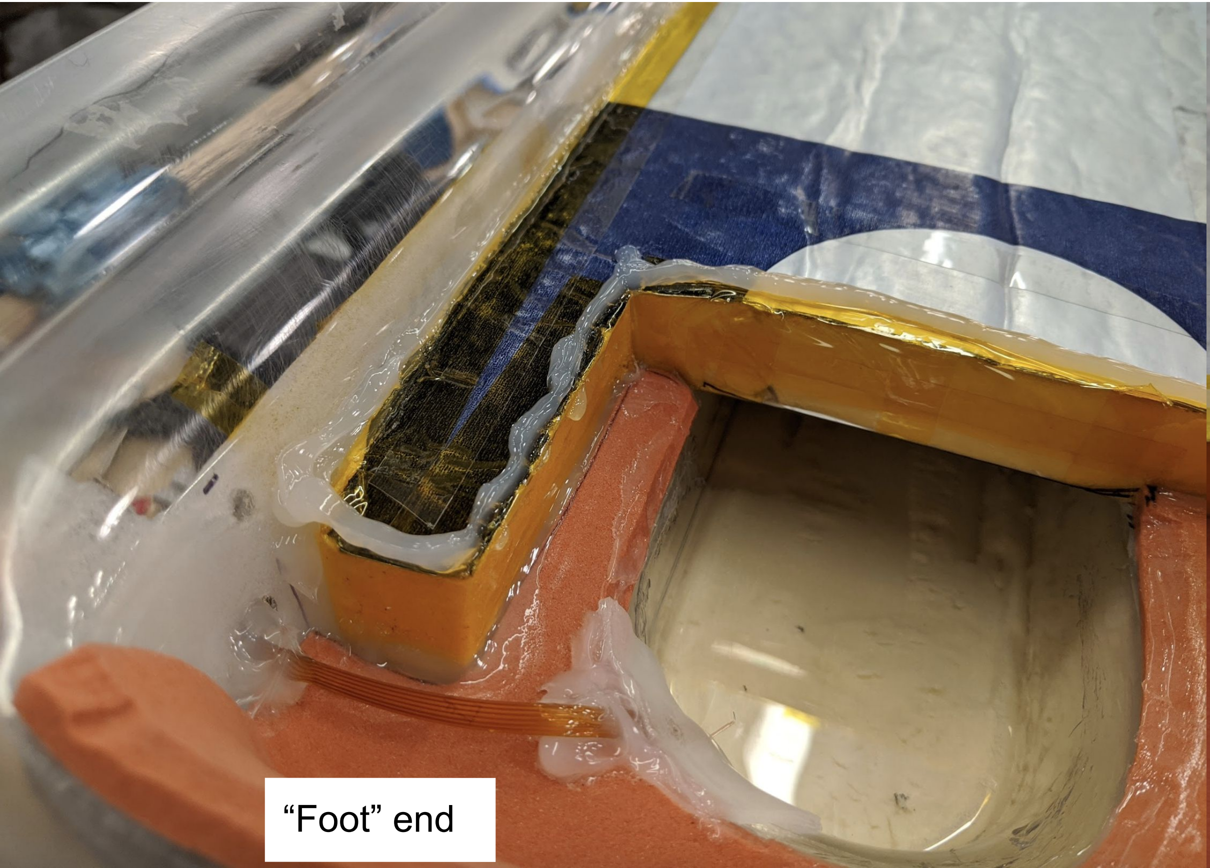
Test 1

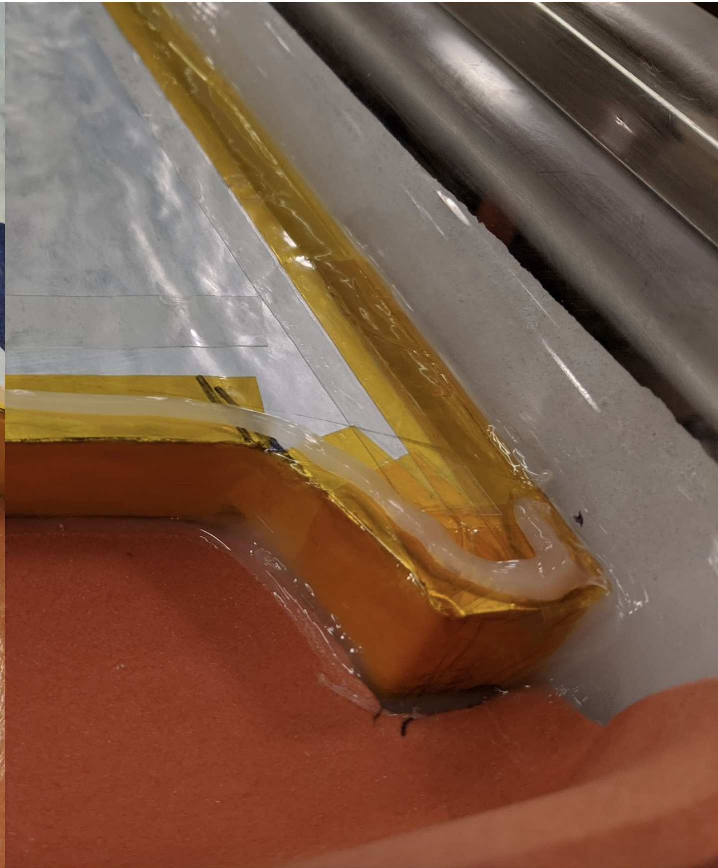


Test 2

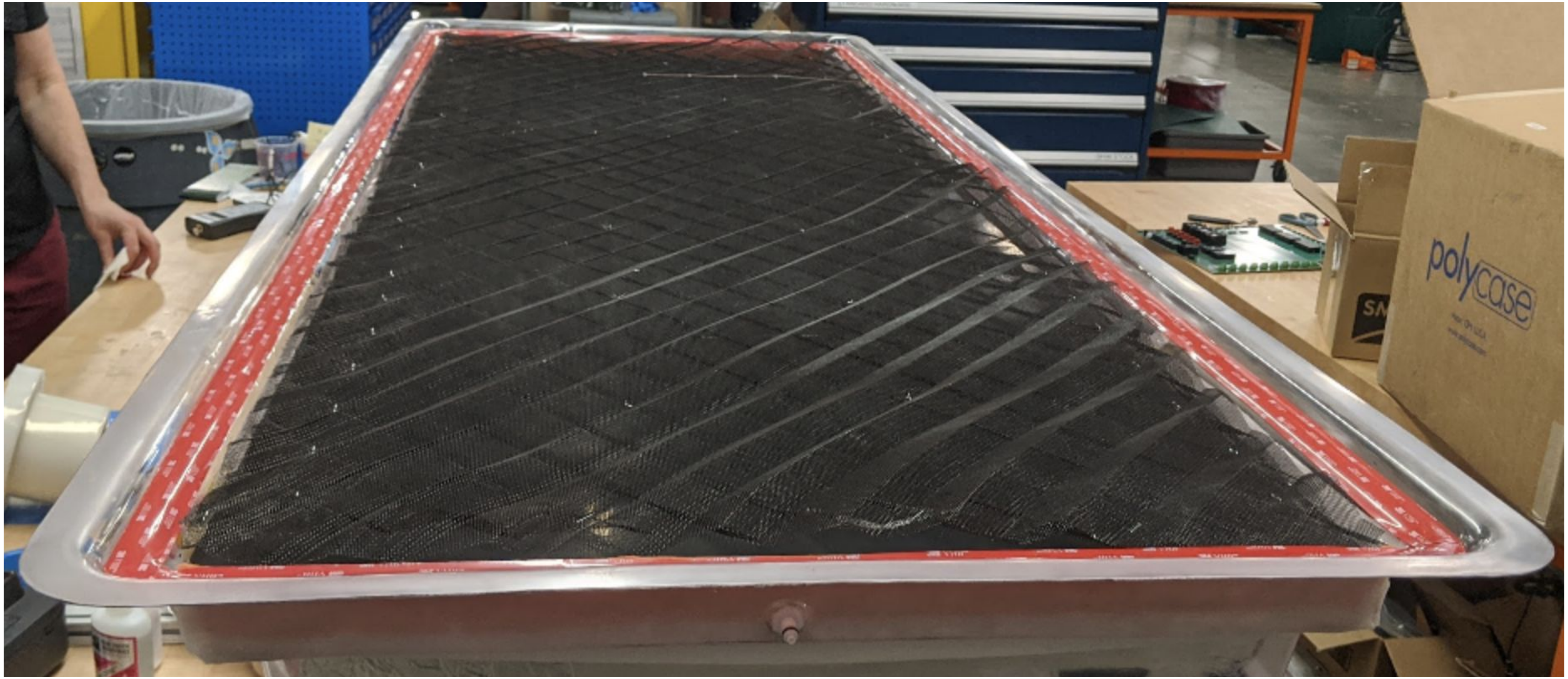


Preparing to bond on the PC sheet with Solkoted Mylar





Solar collector component 2: 2 Layers of Solkoted Mesh and Solkot mylar sheet



Step 1: Making the Solkot mylar sheet (sits under mesh quilt)

Coating the solar absorber and mesh:

The Solar Absorber used a Solkote spray coating on a polycarbonate sheet, the quilted mesh used Solkote on aluminum screening

The choice of the quilted mesh was driven by our findings on airflow uniformity

Specifications:

Specifications:
Substrates / Parts:
Flat sheet stock, about 52cm wide x 102cm tall. Thickness: ~1 - 2 mm thick.
Material: Aluminum. QTY = 2 pcs. (likely 6061 alloy, brushed finish)
Material: Plastic. QTY = 2 pcs. (likely polycarbonate, smooth finish, however we make it a brushed finish if that's helpful)

Coating:
"Solkote" black paint made by SOLEC.
Technical details: https://www.solec.org/solkote/solkote-technical-specifications/

Job Summary:
QTY = 2 pcs aluminum sheet, 1 pc polycarbonate sheet to be coated.
Coating only on 1 side of each sheet.
Fixturing: anywhere on the outer 1 cm of edge of the sheets can be used to fixture. As well as the entire back side.
Coating thickness: Target of 1.0 mil coating thickness. +/- 0.25 mil variation would be good. (If this is not possible, we can discuss opening up this spec or range).

Coating the solar absorber and mesh:

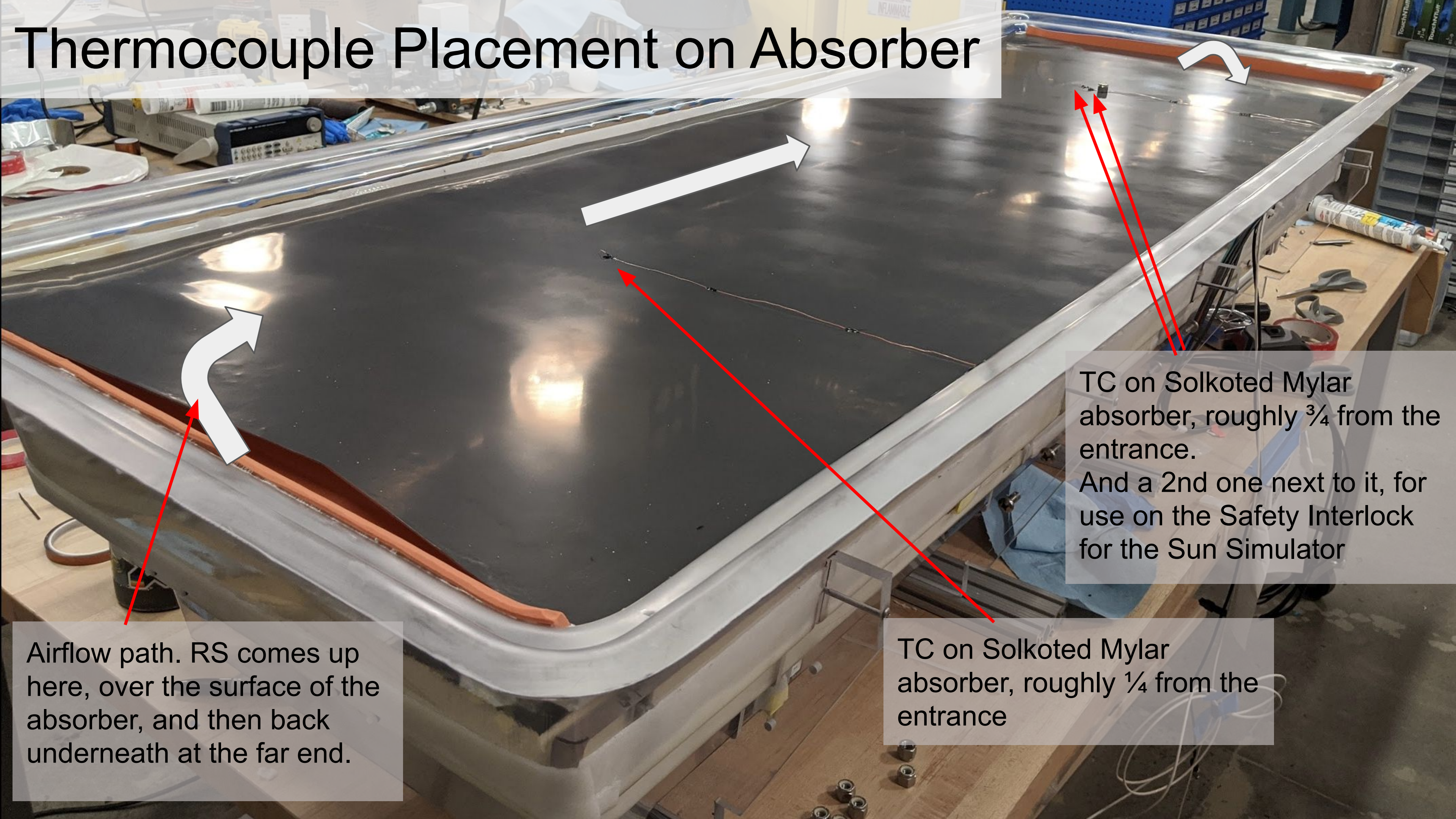
Solkote spray-on selective absorber paint: https://www.solec.org/solkote/solkote-technical-specifications/

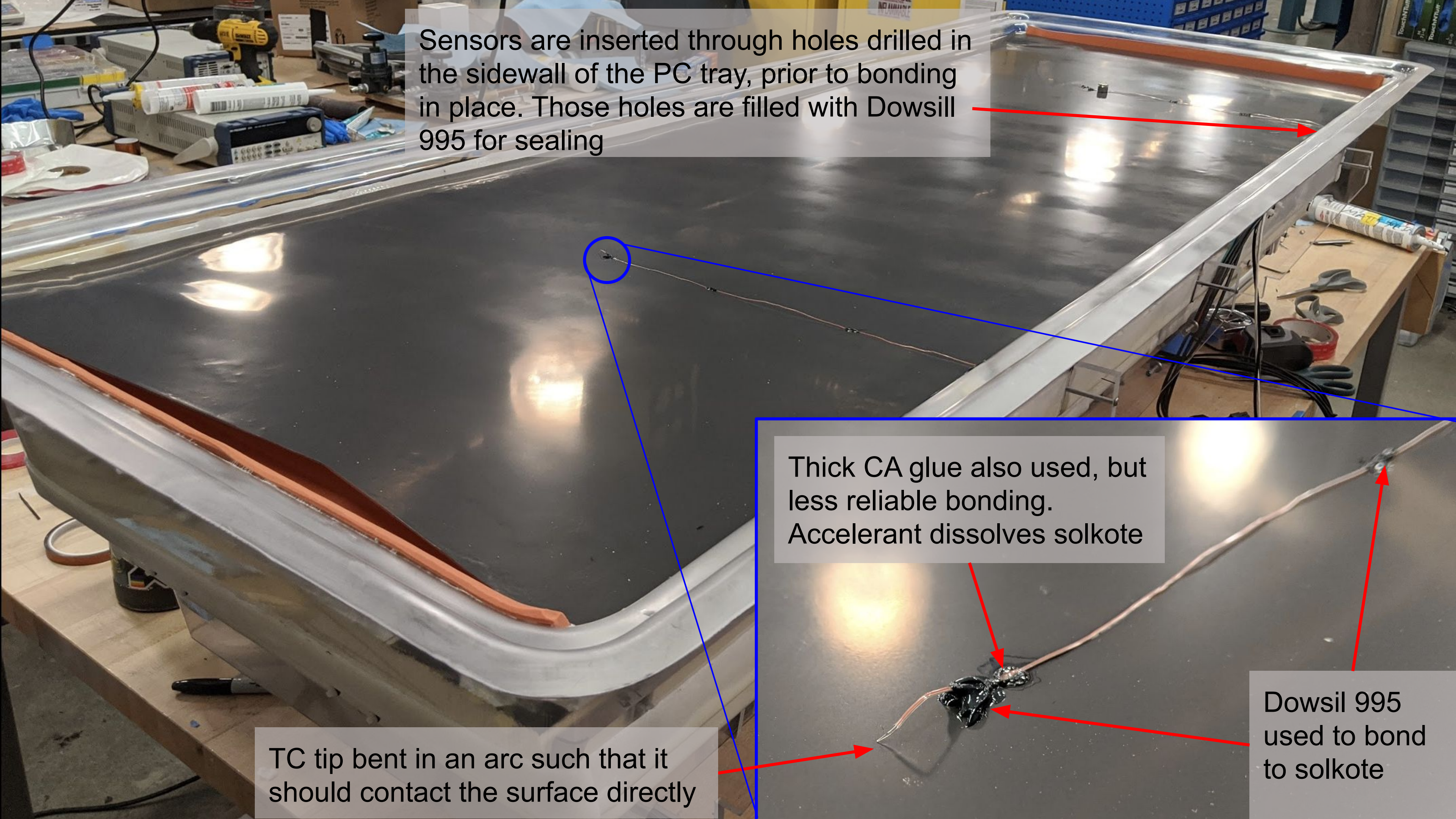
- We prepared the Mylar substrate by attaching it to a foam-core sheet, and then wrapping with protective clean paper
- We then spray painted the film, trying to keep the paint layer as thin as possible while still getting coverage. After drying, it was packaged in paper

The PC sheet is 1/16” thick and was cut to size to fit ~0.75” back from the ends of the orange silicone foam to give air

Solar Absorber Installed

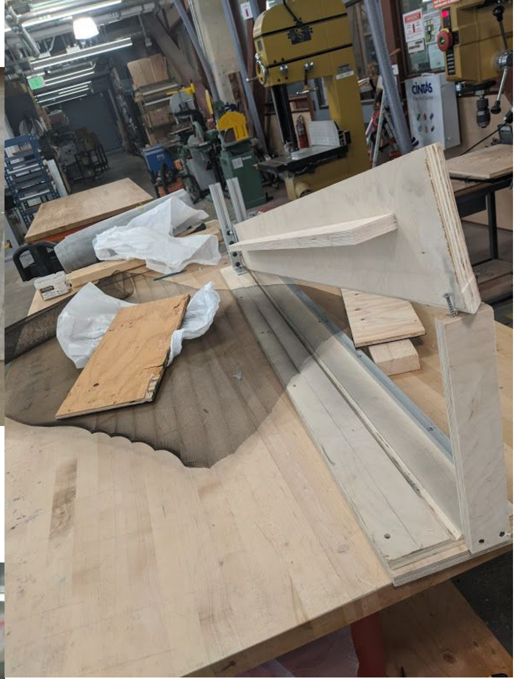
Thermocouple Placement on Absorber



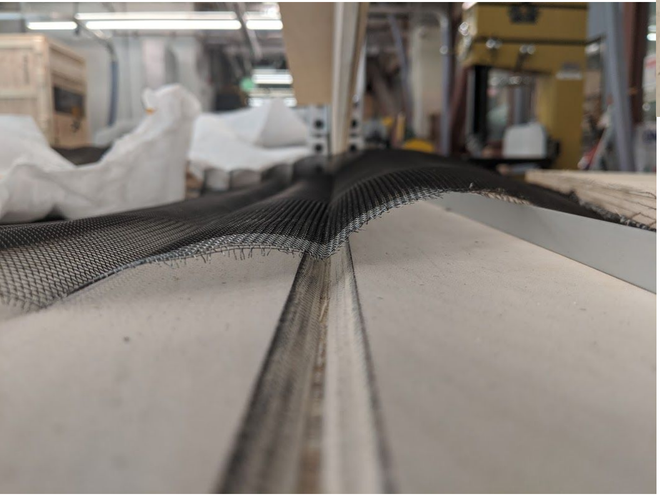

Sensors are inserted through holes drilled in the sidewall of the PC tray, prior to bonding in place. Those holes are filled with Dowsill 995 for sealing
Thick CA glue also used, but less reliable bonding. Accelerant dissolves solkote
Dowsil 995 used to bond to solkote
TC tip bent in an arc such that it should contact the surface directly

Step 2: Making the quilted mesh to sit on top of solar absorber

Bending the Solkoted Mesh



Wooden “Press Brake” makes bend in screen every 2” aprox. One complete side of screen has all bends done in first pass. Second pass done on reverse side making bends halfway between first set of bends. This makes a “Z” pattern in the mesh

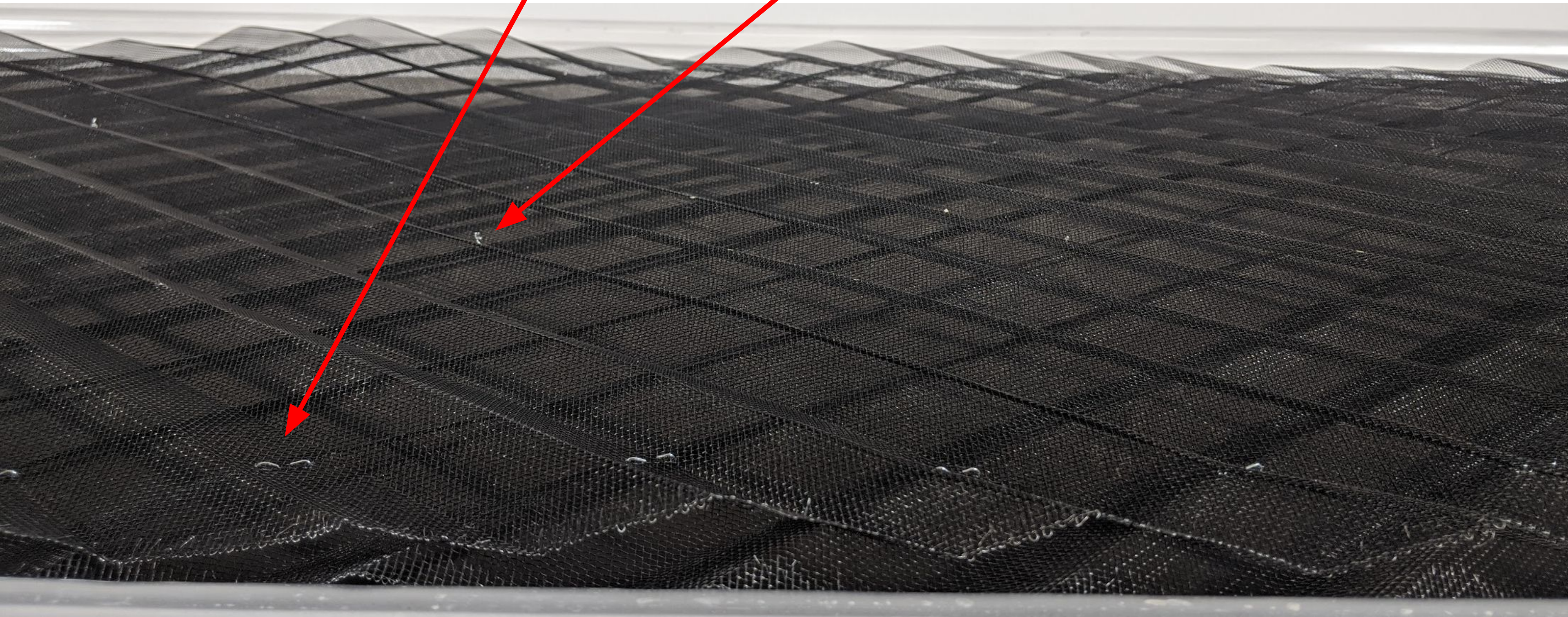


The sharpest angle possible (given brake length) was used so that the air would be only partially diverted to the side.

Then a second mesh sheet was made in the same manor.

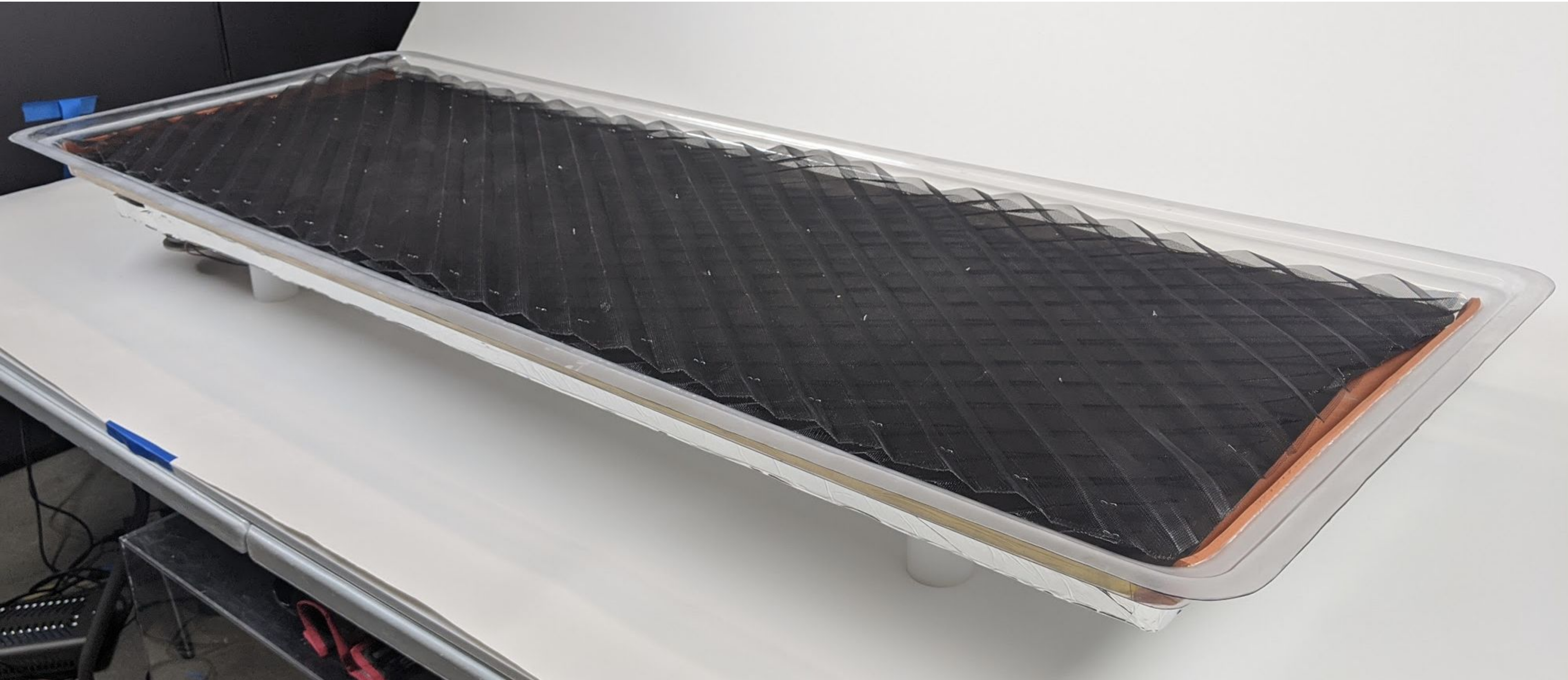
Solkoted Mesh Insert

The 2 layers of solkoted mesh, now bent, were then stacked on top of each other such that they made a criss-cross pattern. Then staples and twisted wire were used to bind these 2 layers to each other at meeting apex points.



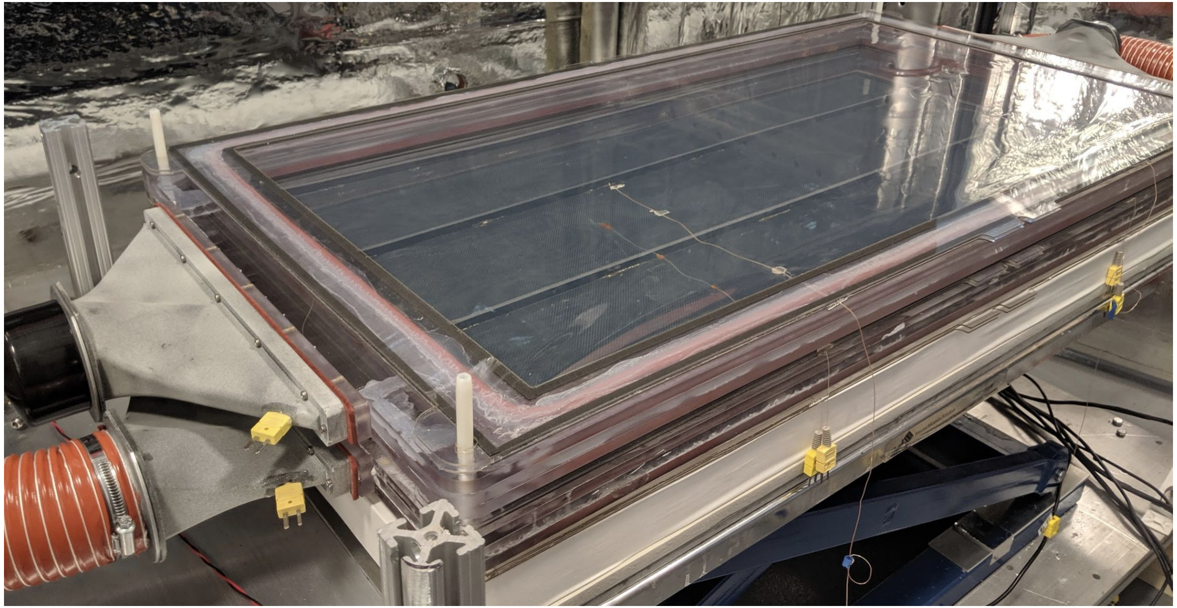
Solkoted Mesh Insert

The insert was then trimmed to size (slightly too wide, and too long) using scissors, and then the insert was ready to be placed inside the tray over the solkoted mylar layer. Mesh is not glued down.



Airflow uniformity testing: focus on mesh insert

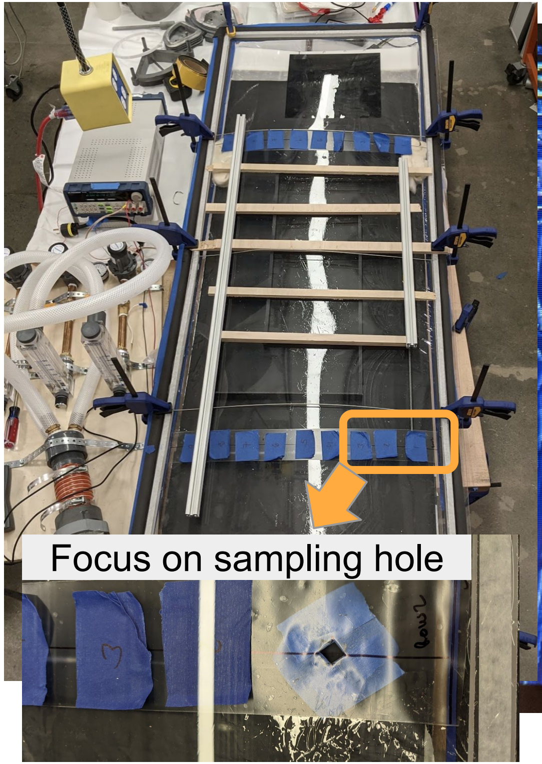
This is a picture of our testing set up for the mesh insert, which was a prototype of our eventual quilted design. Through our testing, we found this design to effectively spread air evenly across the surface of the Solar Absorber, preventing hotspots.



Flow Uniformity

General Notes and Procedures:

- The goal of this work was to even out flow of the humidity supply stream across the solar collector section in order to maximize the heat transferred to the air and ensure there weren't any hotspots that were at risk to being damaged due to overheating.
- Air is blown into the solar collector from an opening in the top head section. It runs through a channel along the back side toward the foot, where it exits the channel into the solar collector tray. The air then flows from the foot to the head and exits into the desiccant rotor through a cut out in the front head section
- Flow uniformity was influenced by two major factors: 1) the shape of the foam insulation on the foot side and 2) having material (e.g. Solcoat mesh) in the path of the flow.
- We measured the flow in two way 1) by running hot air through the layer and using the FLIR camera to see heat distribution and 2) by using the hot wire anemometer to measure the air speed



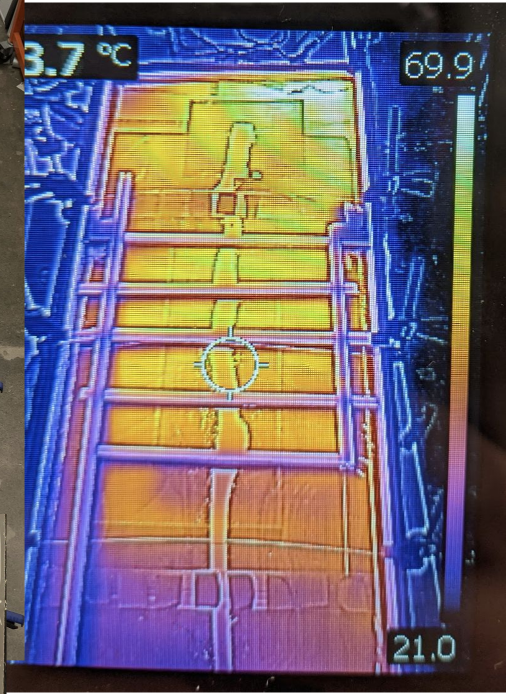


Photo on left: sampling ports cut into to film to insert hot wire anemometer
Photo on right: FLIR image showing heat distribution across surface

Airflow uniformity testing

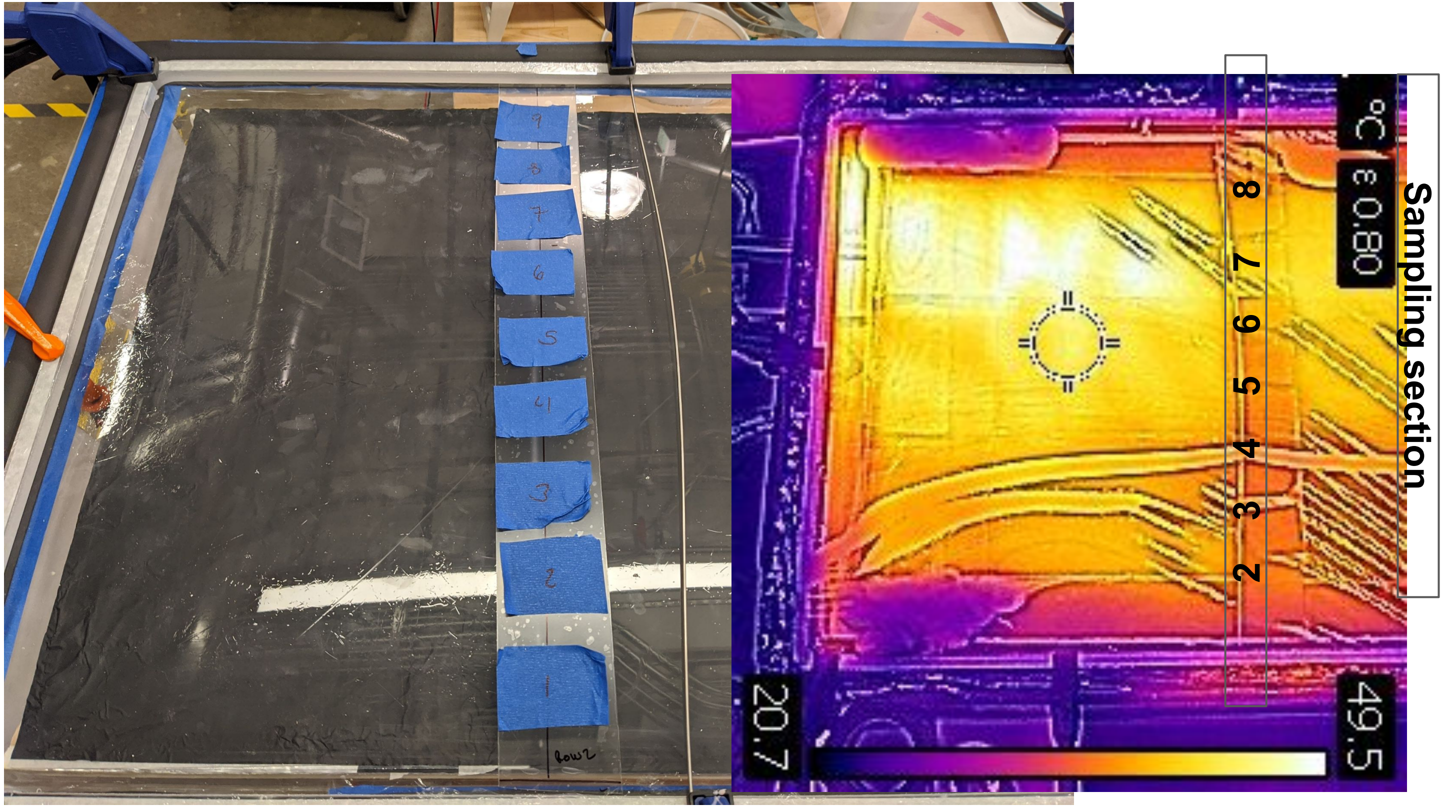
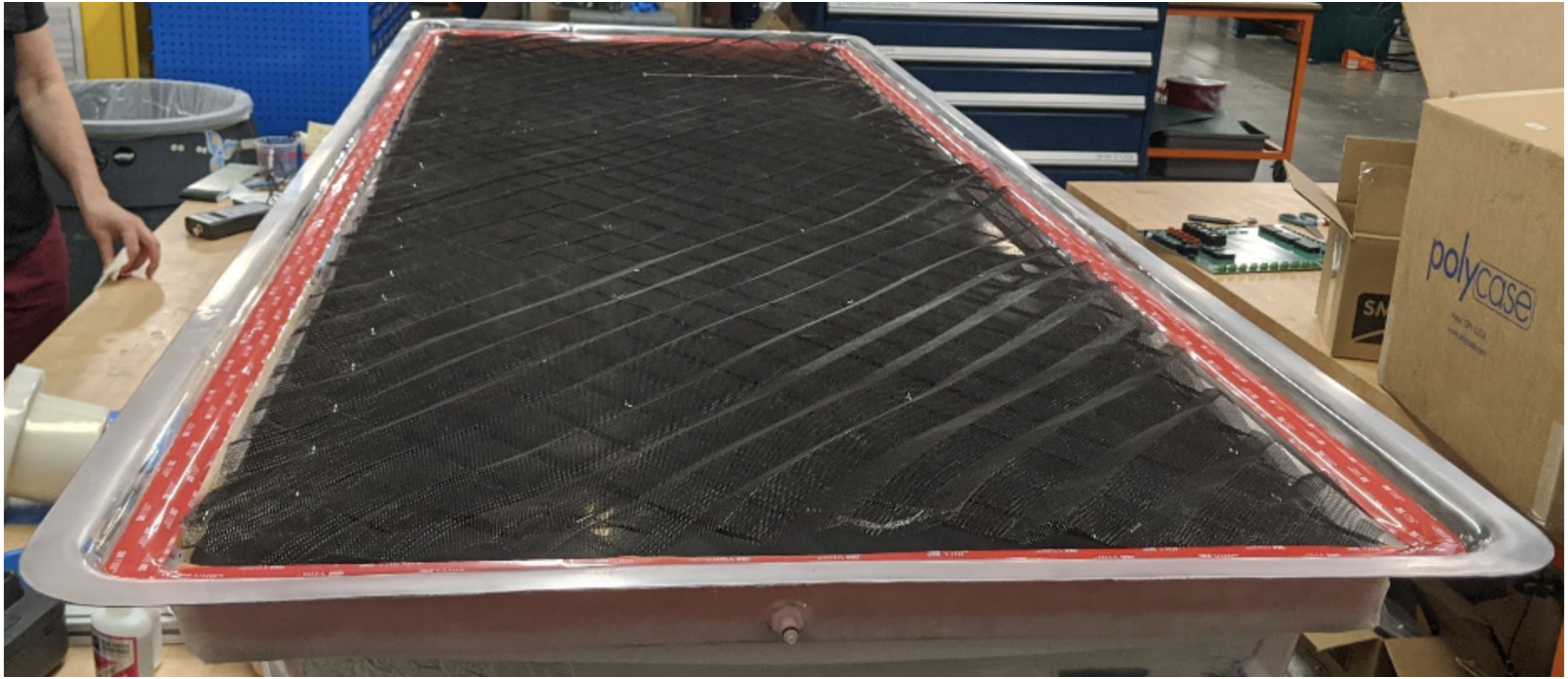


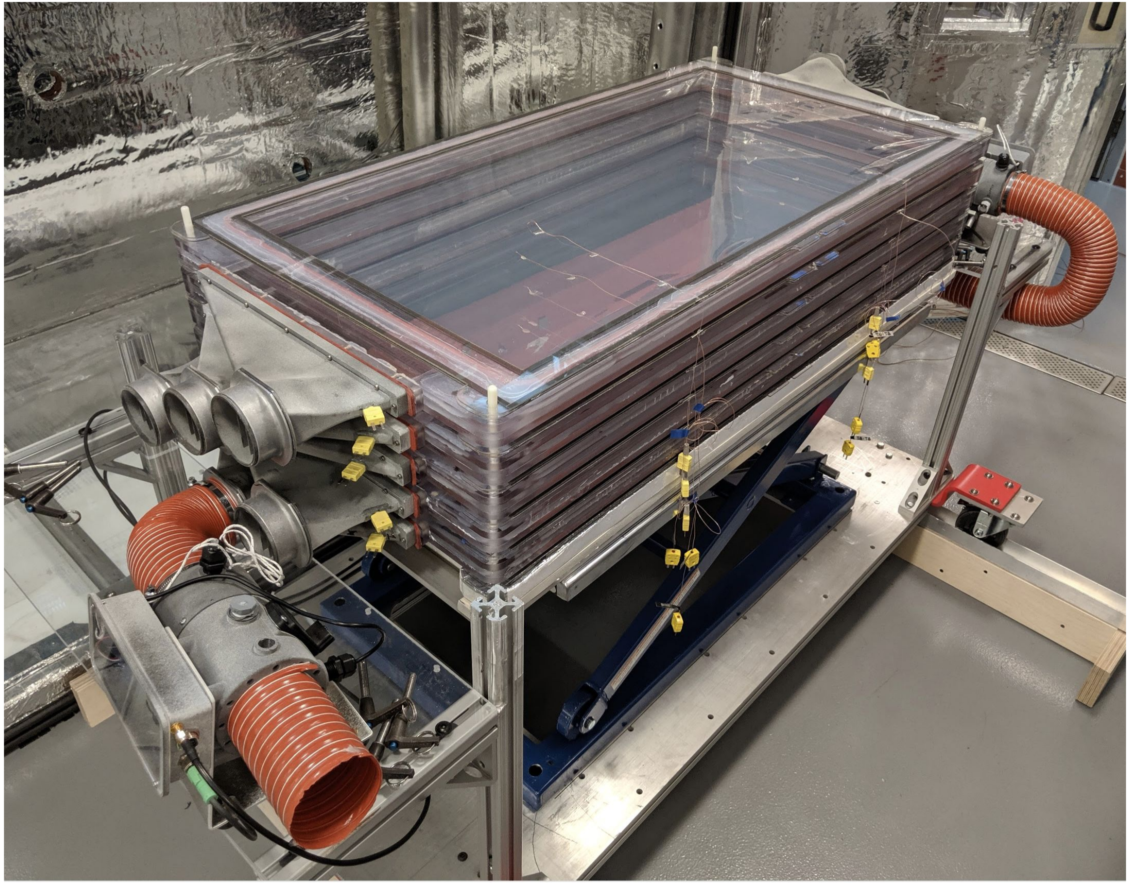
Image of
Final Part Before
Assembly: Solar
Collector Layer



Stack-N-Bake (SnB)

The SnB setup was a prototyping set up outside of our main device which allowed us to do significant testing of Heat Exchanger and Solar Collector sub-assemblies. That knowledge was then incorporated into the design of Proto 4. For example:

- Use of VHB+glue-tape for mechanical bonding, and Silicone for air-tight sealing of ETFE
- Solkoted mylar (aluminized side) performed best as the absorber layer.
- Multiple (2) layers of solkoted Al wire mesh above the absorber to increase watt transfer to the air, and decrease radiative losses from a hotter bottom absorber.
- ETFE films as the generally best materials to use.
- Multiple layers or ETFE (3-4 seemed optimal) on top for best performance. We used 2 for Proto4, with the option to add more on top.
- Avoiding the “snake” airflow design as it reduced flow rate, and thus reduced watts.



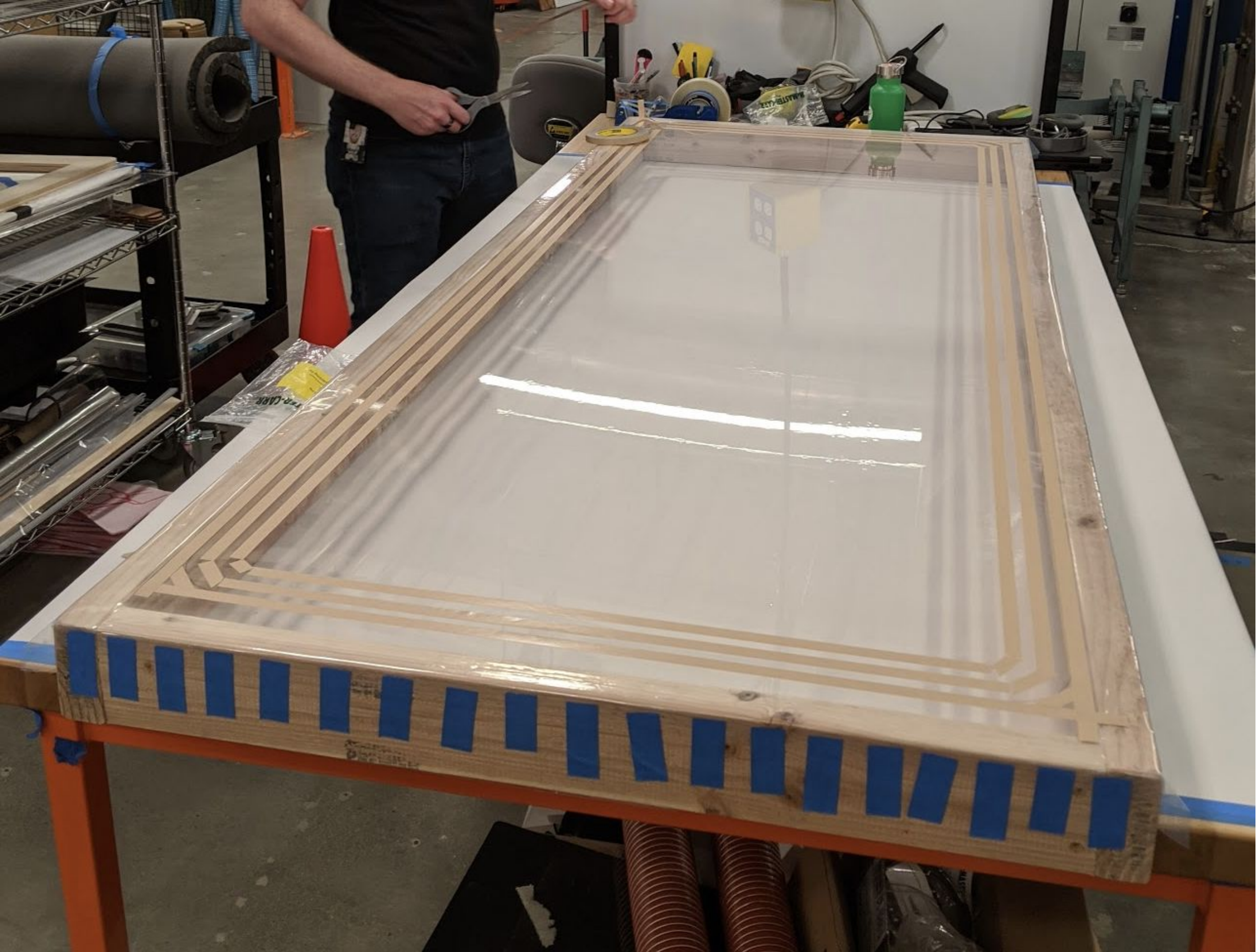
8. Film and Frame sub-assembly

Films are adhered to the top of the solar collector tray to create a greenhouse effect, heating the air inside.

Film mounting in frames

General Notes and Procedures:

- Films are slippery! Even with a combination of adhesives we had a small de-bond almost immediately
- Wood is a good material for pre-stretching frames, but typical lumber will warp over time allowing the frame to change shape. The plywood frame was more dimensionally stable
- Pre-finished plywood worked pretty well, since the smooth finish was a good surface for the tape
- Dust was the biggest impediment to taping films taught. Any dust on the tape would compromise its ability to hold under the tension of the film
- We used blue painter's tape since it didn't seem to harm the film and was easy to release and reposition if necessary. The adhesive comes off on hands easily, so minimizing handling helps ensure the tape will have the strength to hold the film
- In some cases, we used packing tape over wood to create a surface to better adhere the blue tape (the 2x4s were too rough).
- Film gets stretched like canvas, start in middle of long edges and place each piece of tape directly opposite of the last piece. With the long edges in place, repeat from the middle of the short edges, then work from long side to long side, short side to short side, all the way around
- We taped all the edges of the polyiso foam to prevent the foil from delaminating and allowing air around. Nice side effect of reducing dust shed from cut edges. This taping was done using Kapton electrical tape because it is very thin and rated to high temperature. McMaster part, 2" wide tape.

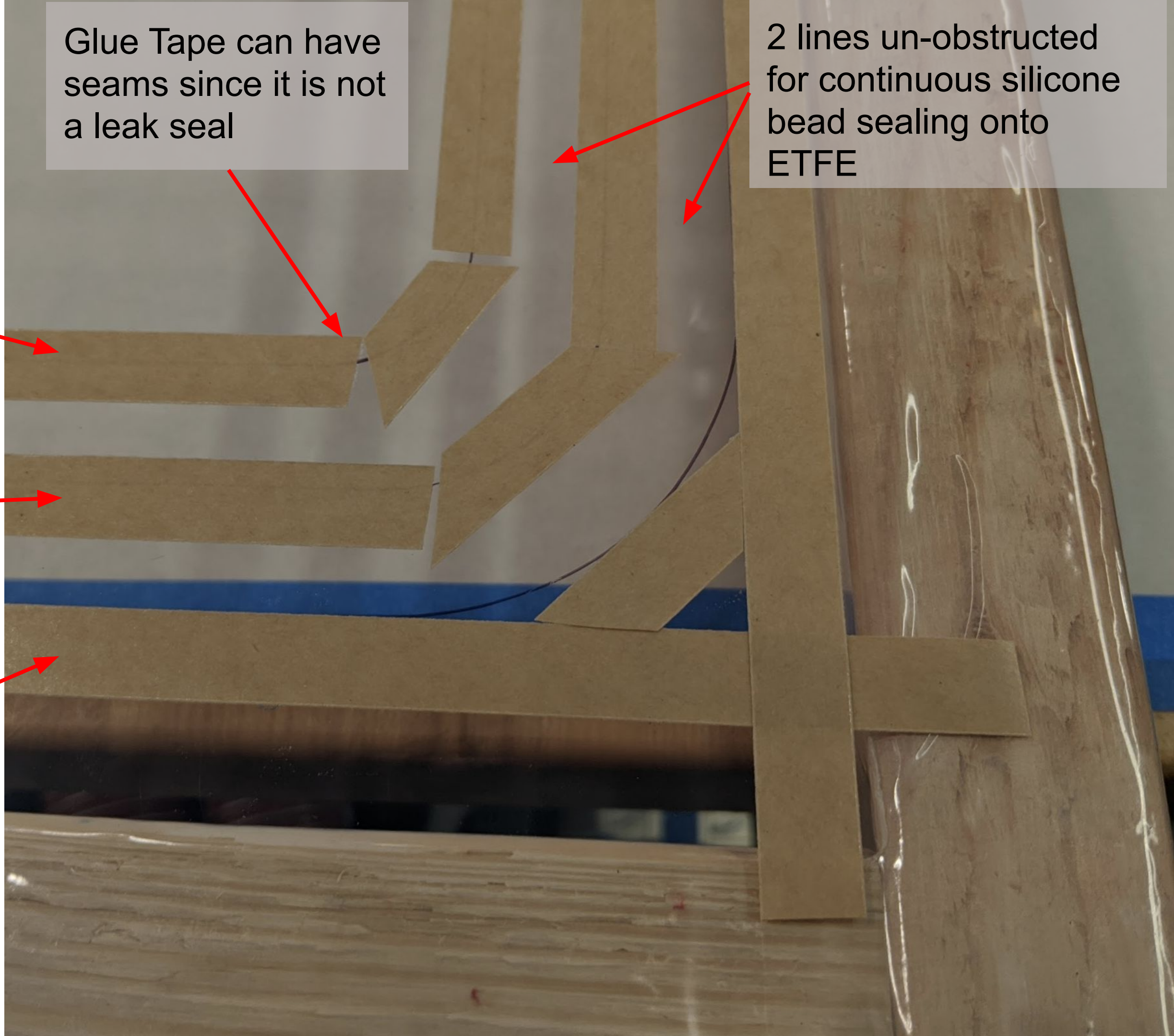


Glue-Tape on top ETFE film

Inner-most glue tape line for inner-most VHB: ⅛” wide clear, on the PC film-frame

Middle glue tape line for middle VHB: ⅛” wide black, on the PC film-frame

Outer glue tape line for outer VHB: 1” wide clear, on the PC solar tray outer flange (half on top, half underneath the flange)



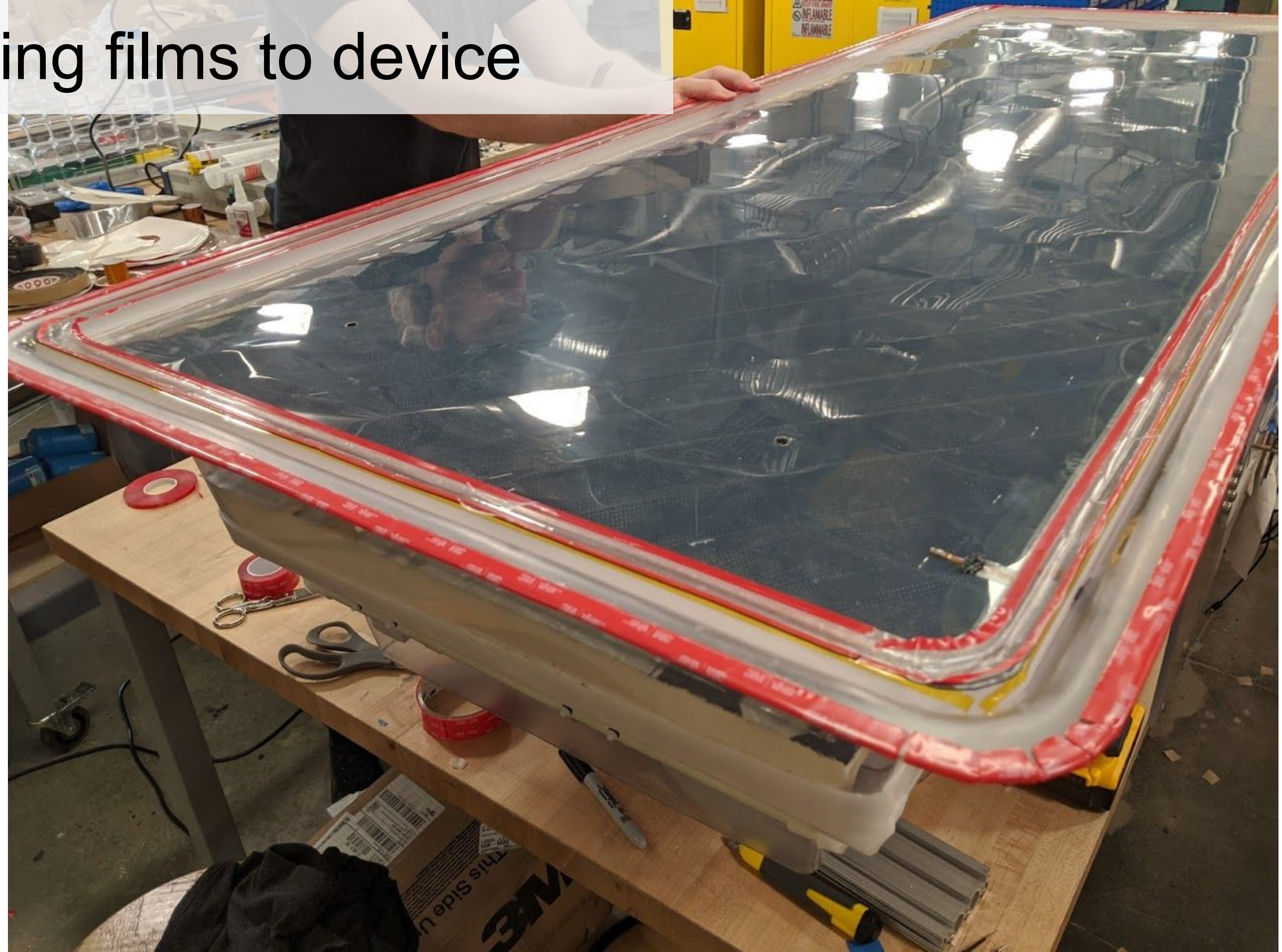
Glue Tape can have seams since it is not a leak seal

2 lines un-obstructed for continuous silicone bead sealing onto ETFE

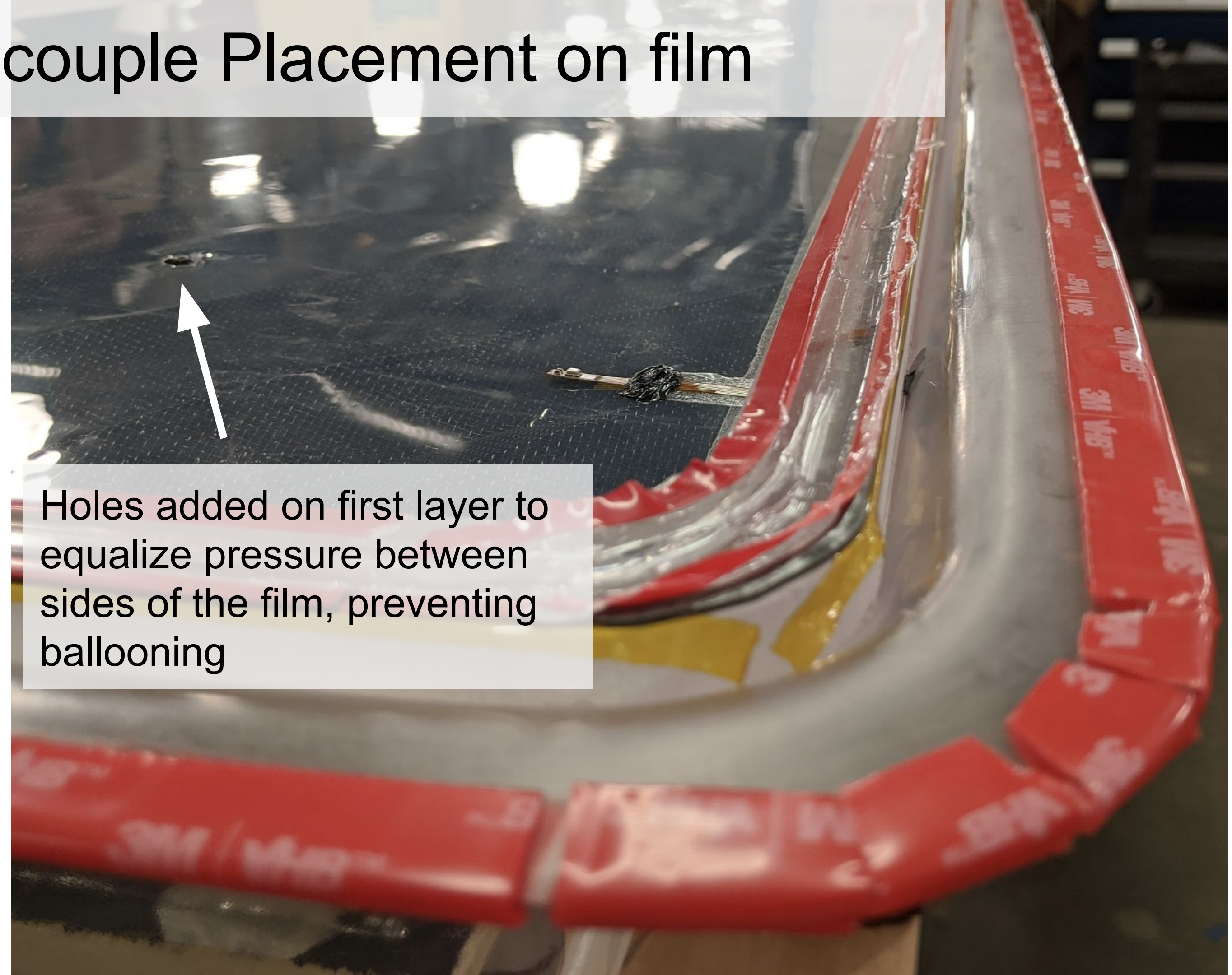
The Glue-Tape we used is a 3M product bought from McMaster: Glue-on-a-roll. Meant to bond to ETFE

Image of Final Part Before Assembly: Films

Attaching films to device

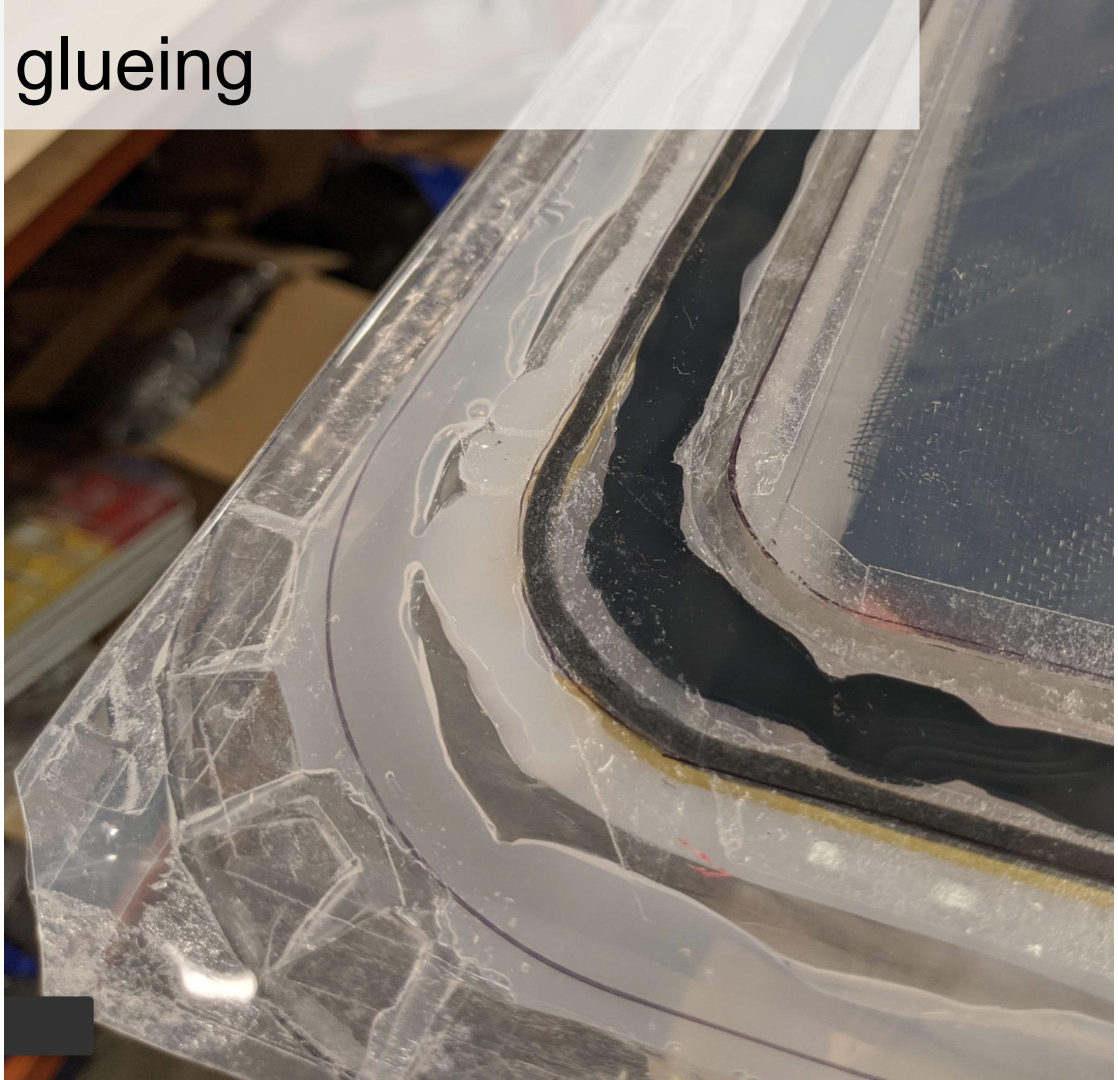


Thermocouple Placement on film



Holes added on first layer to equalize pressure between sides of the film, preventing ballooning

Close up of glueing



9. Grommets & Moulds, Lip-Seals

There were a number of places where we needed to make joins between parts airtight, but also allow for assembly/disassembly. (We were designing the prototype for testing and iteration, and therefore wanted swappable components. We used cast elastomeric components (aka “grommets”) for many of these interfaces. These would not likely be in a final design, where durability and cost effectiveness are prime drivers.)

This section documents the design and casting of these parts.

Parts were designed in CAD and then subsequently a mold was designed around it. Molds were 3D printed and the parts were cast in them using Smooth-Sil™ 940

Casting using 3D printed molds

Standpipe hot glued around inlets, using pressure head of silicone to force air out of moulds

Vent holes allow air out, and when silicone extrudes out it is a sign the mould is full

Grommet Casting

Mold Making and Preparation

The mold was printed in sintered nylon using HP's MJF. Sealing surfaces (indicated on drawing) were sanded until smooth and then waxed. All surfaces were coated with a wax and mold release. Sealing surfaces were then wiped smooth.The mold was fit together and pins were used to hold the outer parts together.

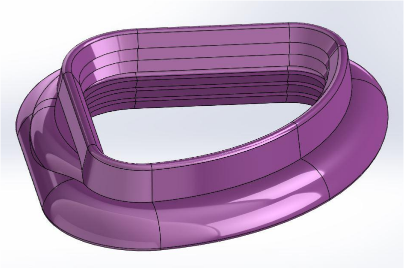
CAD files can be found in "P4-Grommets" subfolder in the CAD folder.

Part Casting

1. Smooth-Sil™ 940. was measured according to instructions
2. The two parts were mixed until no color streaks remained
3. The mixture was debubbled using a vacuum chamber
4. This mixture was then poured in a thin stream from a height of approx 18" into a standpipe, location indicated on drawing
5. After sitting overnight, 4 holes (approx locations indicated) were drilled into the mold into which bolts were screwed so that the parts of the mold were forced apart in a slow and deliberate fashion. In the next rev these holes should be in added in CAD.

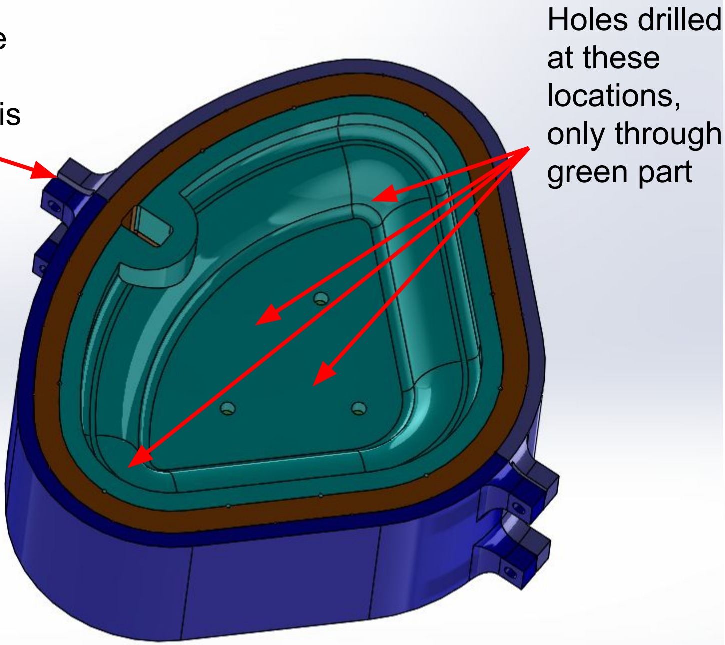
Moulds for Grommets - “Pie” Gromzilla

Pie Shaped Grommet

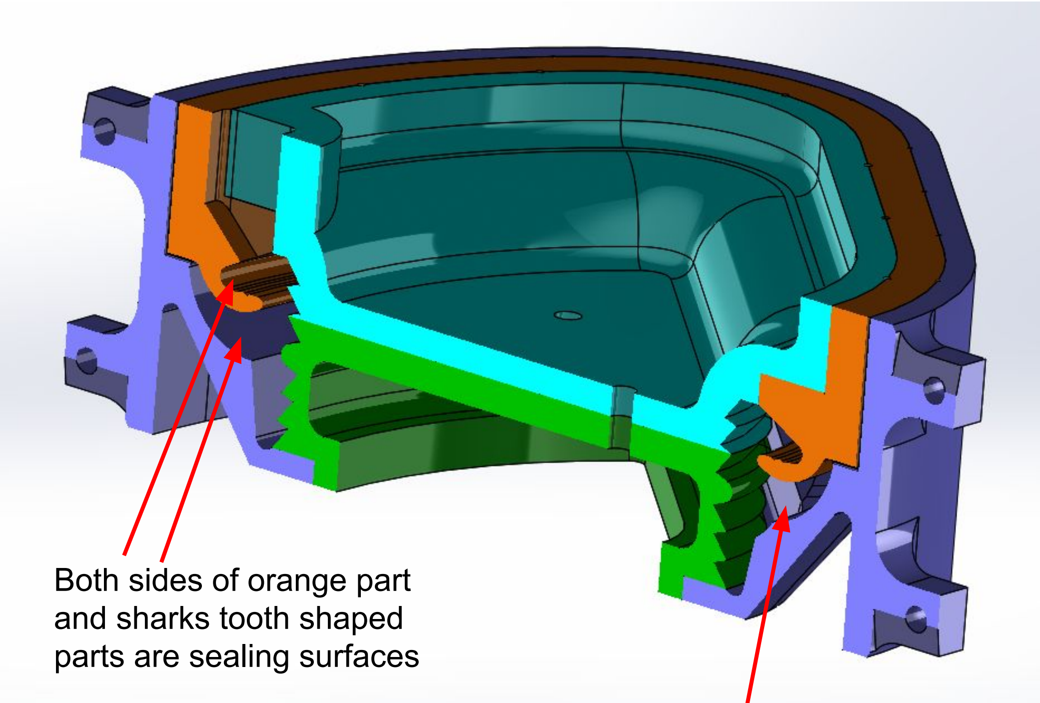


Located at the RS outlet from the Black Box, on the inlet to the HX tray

Standpipe hot glued around this inlet



Holes drilled at these locations, only through green part



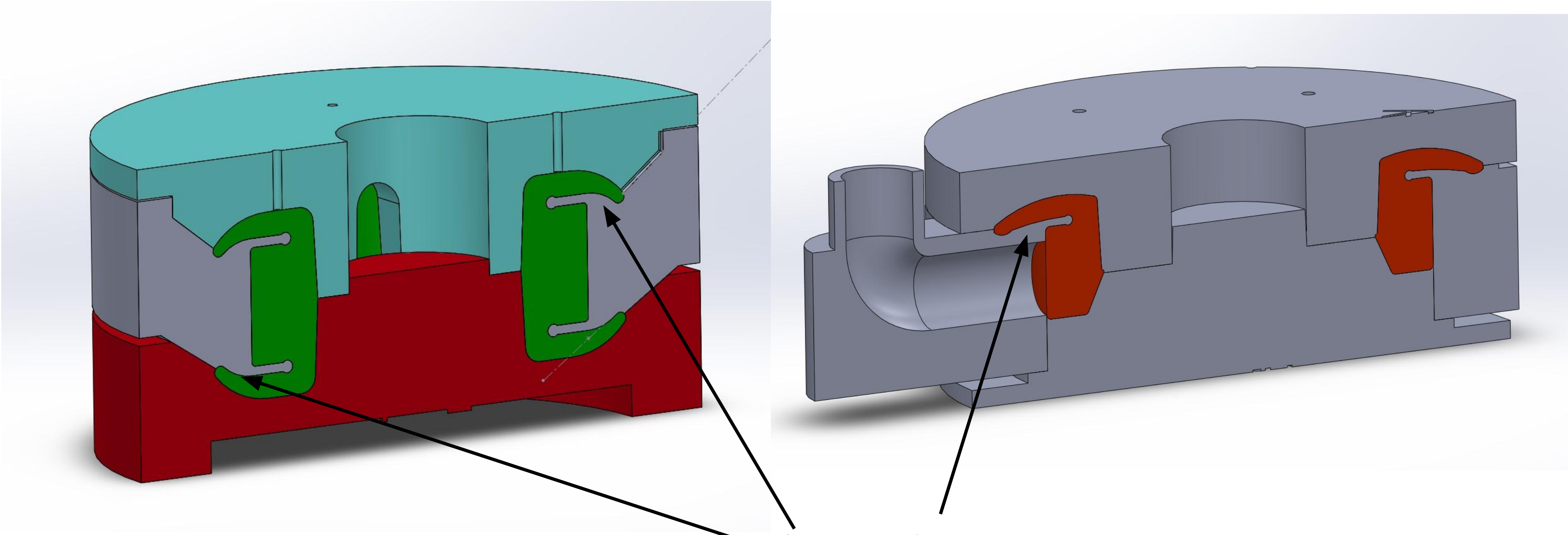
Both sides of orange part and sharks tooth shaped parts are sealing surfaces

Actual Final Part not shown here

Moulds for Grommets - Round Shapes

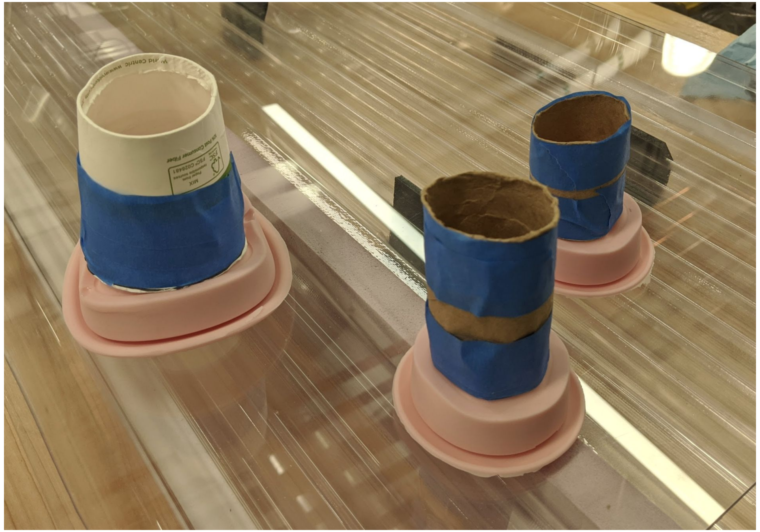
Circular Condenser Tray grommet
(Note: there is a large and small size of this design)

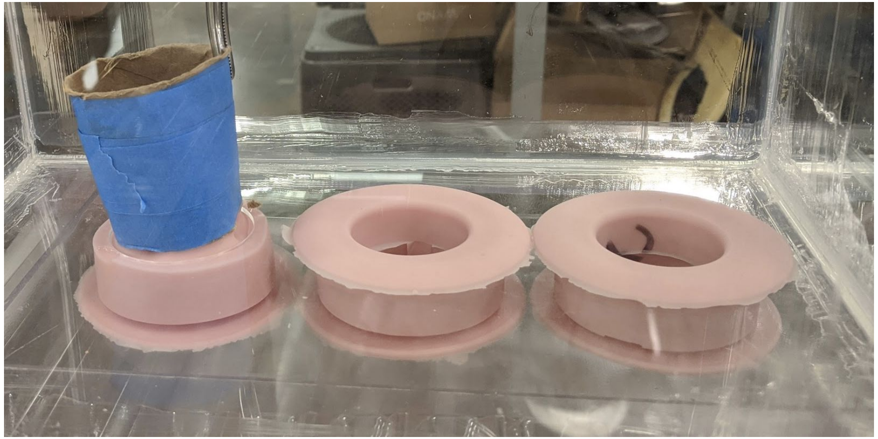
Large Tray 2 fan grommet
(Note: not used in first P4)



Sealing surfaces on round grommets were sanded and polished on the lathe

Some final cast parts





Desiccant wheel installed in device

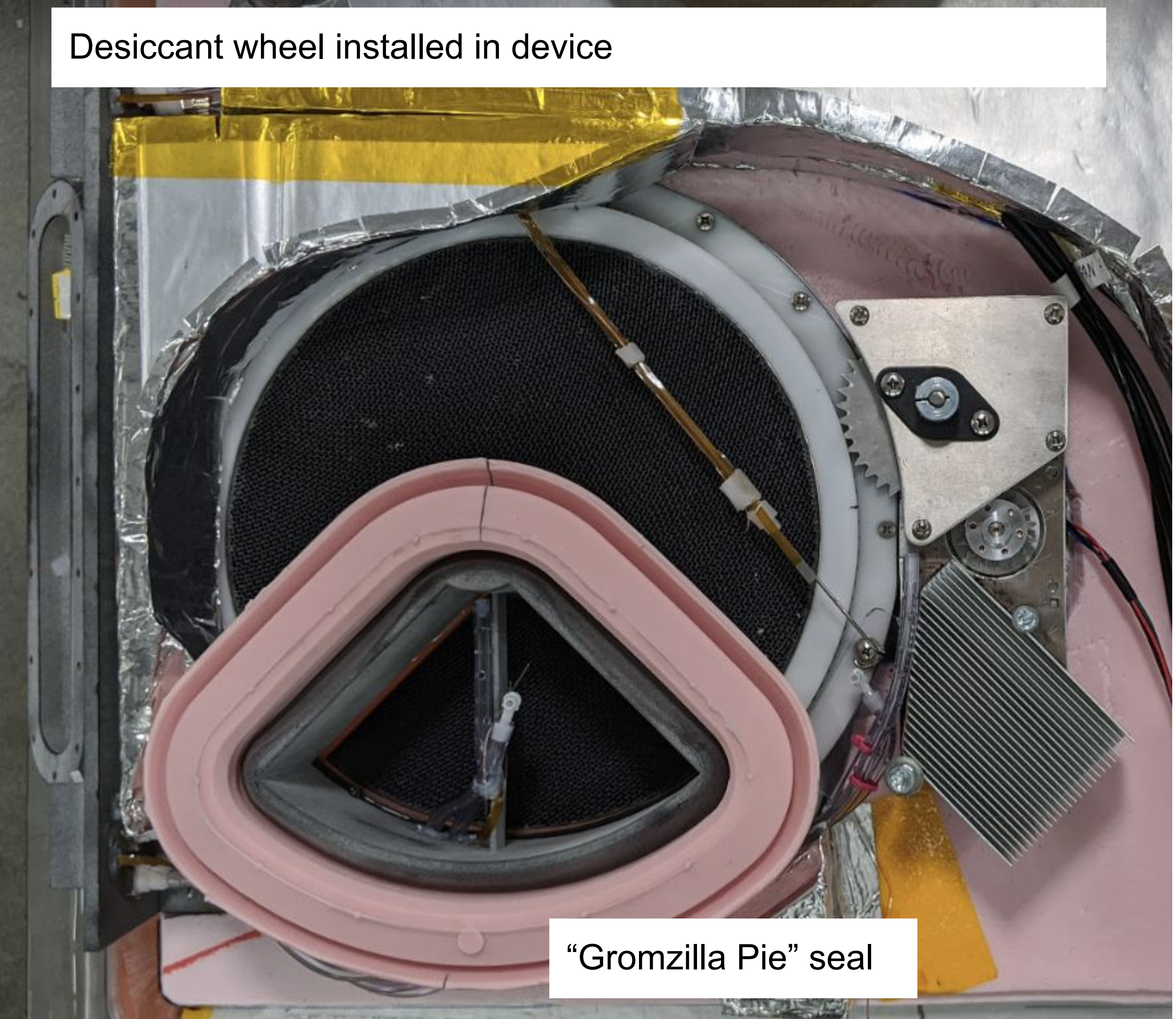
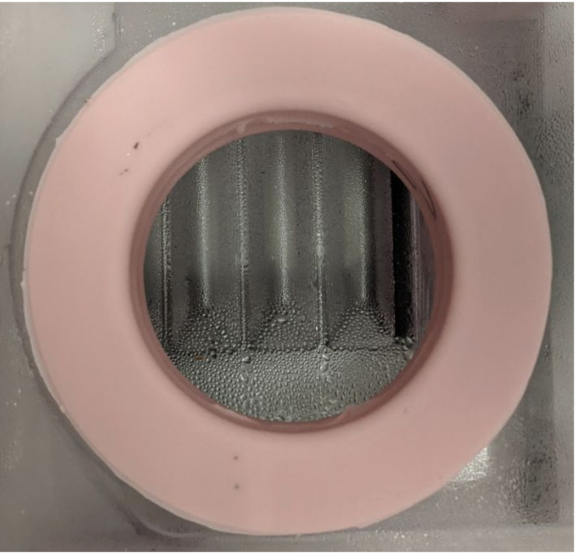
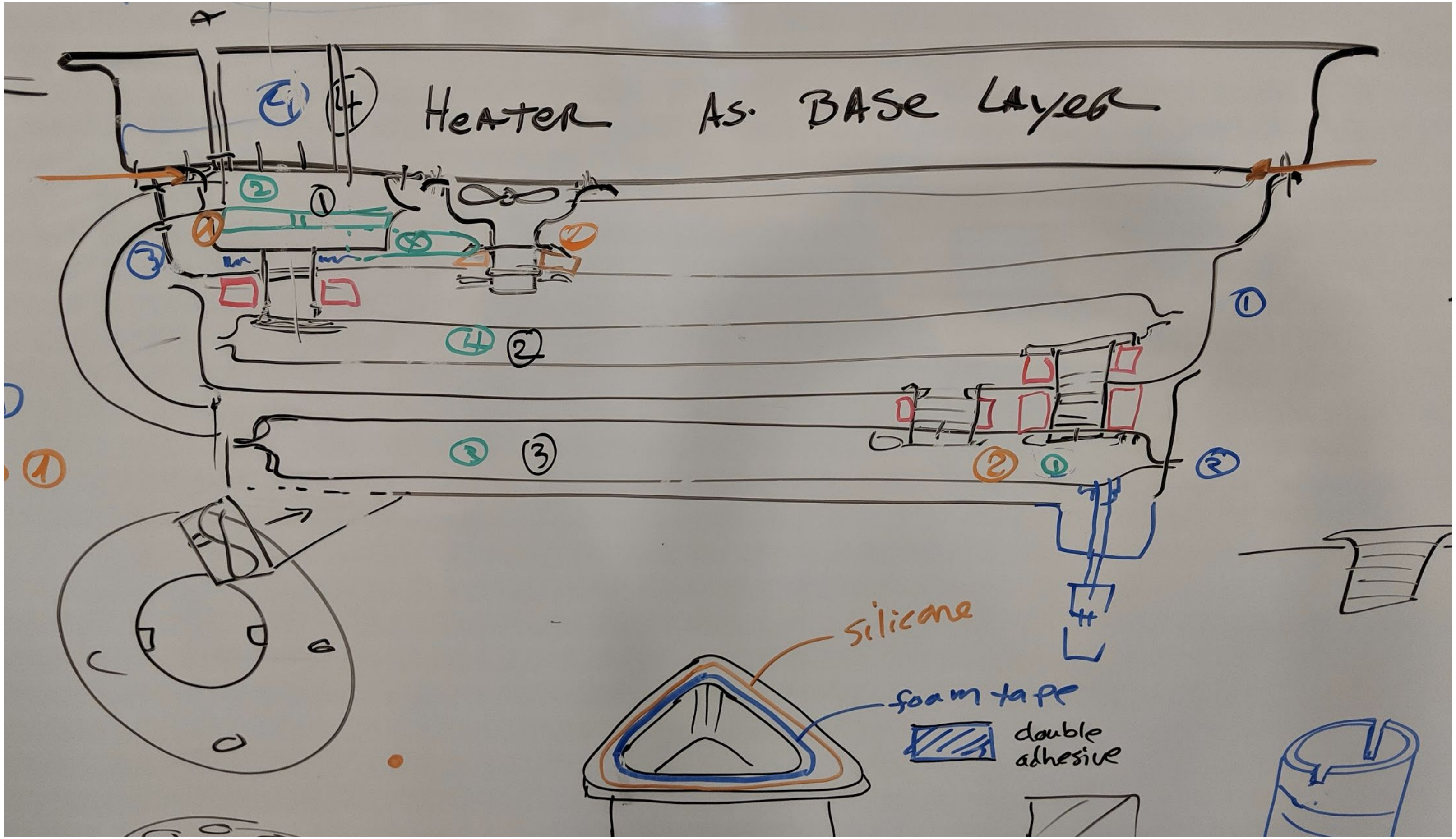


Image of
Final Part Before
Assembly: Grommets



10. Overall Assembly process



Assembly Order and Process: (1 of 5)

Condenser + Recuperative HX Trays:

1. Double check that all sub-assemblies are complete and ready: condenser, RC HX, desiccant black box + fan tray, solar collector, films, and prepare all sensors.
2. Place the condenser on 80/20 blocking so that it is supported flat above a table top and the HS fan and water outlet are not bearing weight.
3. Silicone down a strip of Mylar to the top of the purple foam, to allow for easier separation via wire-cutting, and let cure.
4. Clean the 4 grommet ports with IPA, then apply a liberal coating of vacuum grease around openings on both sides of PETG clamshell sheet, apply grease inside the lip of the 4 grommets, and pop them into place on the condenser. Rotate to help seal.
5. Use a cardboard tube or tape to prepare the top lip of the grommet so that it will easily slide into the holes in the HX tray. Coat the HX tray 4 holes with vac grease top and bottom.
6. Clean all surfaces with IPA, then apply a continuous bead of GE100 silicone all around the top flange of the condenser, and down the mylar-coated purple foam.
7. Then place the RC-HX layer on top of the silicone-coated flange by first aligning the 4 grommets (cardboard tubes) with the holes, then slowly lowering down with all corners aligned, being careful not to lift up or cause any bubbles or holes. Press down with minimal force to ensure silicone sealing and inspect visually.
8. Gently pull up on the 4 cardboard tubes, releasing the grommets to pop into place on the HX bottom tray. Rotate to help seal.
9. Using 3” wide extreme sealing tape, run a strip down all 4 sides of the siliconed seam. Work quickly since there is <10min initial setup time for the silicone. First apply the tape to the underside of the lower tray, then pull up on it while sticking to the sidewall of the HX tray in one spot. Then repeat as you work your way from the center out to one end, and then from the center out to the other end.
10. Trim overhanging tape before applying the next edge of tape, so that the corners make an air-tight seal.
11. Trim any tape away from sensors or windows on the RC HX tray side walls.

Assembly Order and Process: (2 of 5)

Recuperative HX + Desiccant Trays:

1. Wipe down the top of the RCHX foam and HX with IPA. Prepare a roll of Mylar that is wide and long enough to cover with a couple inches of overhang. The Mylar creates an easier separation layer during disassembly, just like the strip placed on the purple foam on the condenser layer.
2. Apply a continuous bead of Dowsil700 silicone all around the edges and seams of the foam, the HX, and the ports on the top surface of the assembly. (Optionally, also use the Loctite E90-FL to create an adhesive coating in between the silicone for a flatter bonding surface.
3. Align the mylar film, and slowly lower down, first touching at one end of the assembly, and then using a round PVC pipe to apply downward pressure on the film, walk the contact front down to the other end of the assembly so that air has a way to be pushed out. Then gently press where needed to ensure a seal is made with the silicone, but not too much pressure that would cause squeeze-out or air bubble ingress. Inspect for captured air volumes that cause bulging and pierce the film with a scalpel and squeeze out the air, then fill the hole with silicone.
4. Place a large, thick flat sheet on top to apply uniform pressure (we used ½” thick PC cut to size - a drop from frame cutting). Place extra weight on top as needed and let cure for 12+ hours.
5. Remove the weights and use razor blade to trim away excess mylar from the edges. Inspect the seal for continuity.
6. Cut away the mylar at the location of the 2 ports that connect to the layer above.
7. Wipe down the flange edges of the HX and desiccant trays, and the area around the holes in the mylar film and the holes in the bottom of the desiccant tray with IPA.
8. Apply a continuous bead of GE100 silicone all around the top flange of the HX tray and the holes in the mylar.
9. Then place the desiccant tray on top of the silicone-coated flange, slowly lowering down with all corners aligned, being careful not to lift up or cause any bubbles or holes. Press down with minimal force to ensure silicone sealing and inspect visually.
10. Using 3” wide extreme sealing tape, run a strip down all 4 sides of the siliconed seam. Work quickly since there is <10min initial setup time for the silicone. First apply the tape to the underside of the lower tray, then pull up on it while sticking to the sidewall of the HX tray in one spot. Then repeat as you work your way from the center out to one end, and then from the center out to the other end. Trim overhanging tape before applying the next edge of tape, so that the corners make an air-tight seal.
11. Install the snorkel: the output flange port should be installed onto the HS outlet from the condenser section, using a neoprene gasket. Match up the rest of the snorkel parts with the BB inlet for a dry-fit. Then apply a liberal bean of GE100 silicone all around the mating surfaces of the 3 snorkel parts, and also on the flange of the inlet to the BB. Use SS screws to attach the snorkel parts onto the BB flange, noting that the screws on the bottom will be hard to reach, so use a shortened allen key to get the ones near the edges and skip the inaccessible ones in the middle. Check that there is a continuous bead of silicone all around each of the 3 joints.

Assembly Order and Process: (3 of 5)

Desiccant + Solar Collector Trays:

1. Install a layer of ¼” pink foam of the bottom of the desiccant tray, cutting holes for the ports with ~0.75” extra radius of gap all around for later siliconing or sealing to the upper layer.
2. Install the ½” thick, 2” tall PC ribs into the tray, first installing roughly and radiusing any edges to fit to the vacuum-formed tray. (Note, the piece near the end needed to be notched to fit around the flange of the black box). Once everything is properly fit and squared, mark up with sharpie. Place wax paper inside the tray under each of the 10 joints. Then pull out 1 piece at a time and use #16 fast set acrylic glue to bond the ribs in place. Repeat until all glued. Long clamps were used to keep contact and pressure on the middle 3 ribs as the tray bows out slightly. Let cure for >1 hour. Measure and cut HS exhaust hole in tray wall.
3. Pull out the rib assembly, and add metal bolts for shear strength, 2 per joint. First pre-drill the hole through both pieces. Then counter-sink the top to ensure the bolt head will be flush or below the surface, then tap the hole, and install the bolt. (x 20)
4. Re-install the PC rib frame into the tray. Now align the outer ribs into their places and mark with pen (offset from inner ribs). Drill hole through the outer rib and then through the inner rib for all joints. Remove over ribs and install thermal insets from inside the tray. Then do final installation of outer ribs with bolts from the outside, and use #16 glue to fix the long runner ribs in place, and let cure. Now the unit should be fully supported by the rib assembly.
5. Measure and cut 2” thick Polyiso foam blocks to fill all the spaces between the ribs except leave the area open where the desiccant wheel will eventually be. Push the foam into place, no adhesive needed.
6. Install the ‘Gromzilla’ grommet into the pie-wedge hole. Clean all parts and surfaces with IPA. Apply a liberal coating of vac grease to both sides of the tray around the hole, and inside the lip of the grommet. Then pop into place and move around to ensure good sealing with the grease.
7. Clean the tray flanges with IPA, and the Black Box and Fan HP printed parts where they will be sealing to the tray (round hole for fan), and gromzilla.
8. Vac-grease the inner lips of the Gromzilla, and the outer surface of the HP-printed pie outlet tube.
9. Apply a continuous bead of GE100 silicone all around the top flange of the desiccant tray, including on the inner surface around the cut-out for the black box / snorkel. And around the round hole in the tray where the fan inlet meets.
10. Then place the solar collector tray on top (3 people needed). First position tray up-side-down to the side of the assembly and snake all the wires (fan, motor, sensor) from the solar tray through the HS exhaust hole. Then flip the tray into position over the assembly. Align the gromzilla, then slowly lower down with all corners aligned and seal silicone, same procedure as before.
11. Use 2 self-tapping screws to clamp the PETG tray onto the back flange of the BlackBox.
12. Install 3” wide extreme sealing tape, same procedure as previous trays.

Assembly Order and Process: (4 of 5)

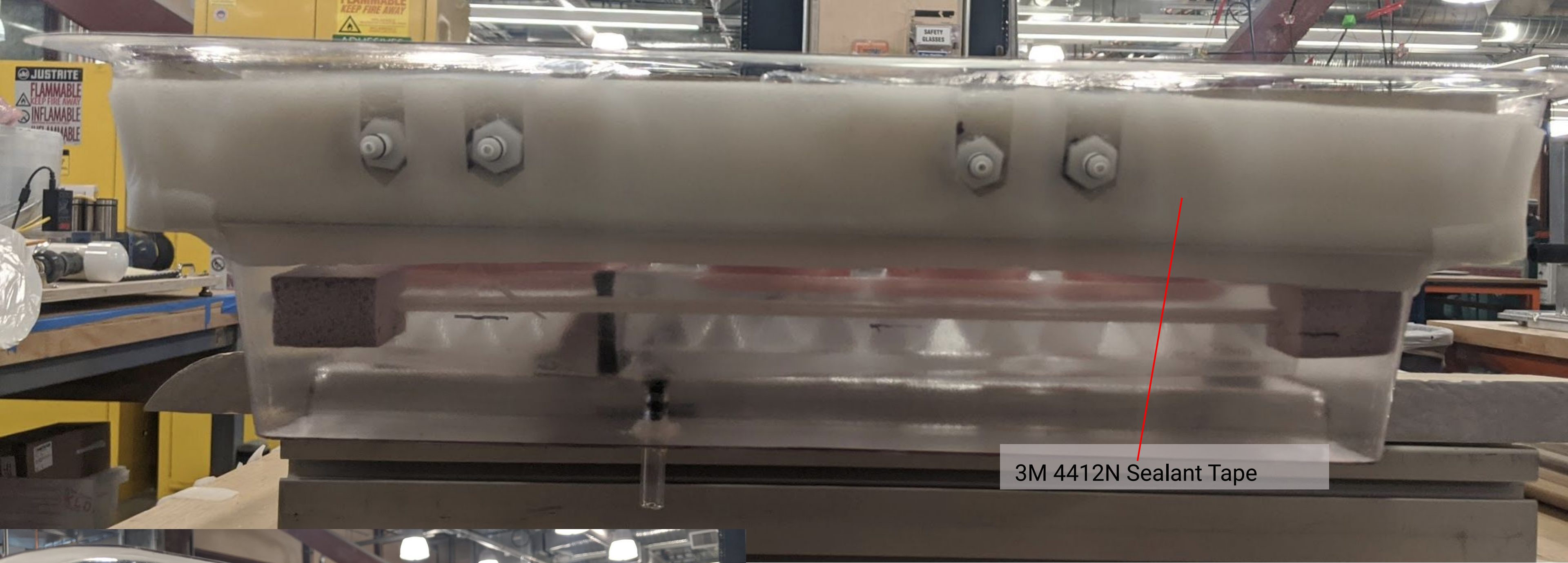
Solar tray + Films:

1. Prepare the films for installation. Perform stretching operation using blue tape to adhere the ETFE film to the wooden frames so that it is taught, flat, and smooth. Do for both the lower film (plywood frame) and upper film (2x4 frame). Punch 2 small holes in the bottom film for pressure equalization, using hole-punch set, punch + hammer.
2. Apply glue-tape to the films aligned where VHB tape will contact it. The lower film has 2 lines, and the upper film has 3 lines of glue tape.
3. Prepare the ½” thick PC film-frame. On one side apply ⅛” wide VHB tape continuously in a line all the way around the inner edge of the frame, and a second line all around the outer edge of the frame. This is to provide mechanical bonding to the film. The air-tight sealing will be with silicone...
4. In-between the two lines of VHB, apply a very thin continuous film of GE100 silicone onto the PC. It should be smooth and always below the top of the VHB, leaving room for a thicker bead of silicone during final assembly. Let fully cure >12 hrs. (This is to allow for good release of silicone from the PC frame in case it is reused after a disassembly).
5. Install the final sensors on the solar collector: TCs on the solkote and the solkote mesh. Use Dowsil995 silicone to bond the TC to the solkoted mylar, and thick CA glue + accelerator to bond the TC to the mesh (don’t glue the measurement tip! Hook it on the mesh).
6. Make sure the mesh is fully installed and not overhanging onto the bonding edges.
7. Clean all surfaces with IPA. Then apply 1” wide clear VHB tape to the lower flange. This is to mechanically bond to the ETFE film, no air-tight seal at this time.
8. Then install the lower film by aligning the plywood frame, and slowly lowering into place, starting from one end. Press down to ensure good bonding, then use clamps to hold in place for >1 hr to allow for film bonding. Once ‘cured’, use scalpel to cut away the ETFE at the bottom edge of the plywood, and lift off that frame, leaving the film bonded to the unit.
9. Install the BME280 near the foot of the unit, and the TC on top the film near the head of the unit above the mesh TC, using 995 silicone to bond it to the ETFE. Start by drilling holes through the side wall of the PC tray, then insert the sensors, 995 silicone holes to seal.
10. Apply ½” wide clear VHB tape to the bottom side of the PC film-frame. Then install it on top of the ETFE film, starting at one end and curling it down toward the other end, ensuring good alignment of the frame onto the tray and film edge. (This is a mechanical bond only)
11. Apply 1” wide clear VHB onto the top / outer edge of the PC tray such that ½” of the tape width is on top, and ½” is on bottom.
12. Apply Dowsil700 silicone in the gap between the PC tray and PC film-frame, filling that gap to create an air-tight seal. Then apply a second bead on the upper flange of the PC tray just inside the VHB tape. Apply Dowsil995 in a continuous bead on the PC film-frame between the thin VHB lines. Work quickly since there is <10 min silicone skinning set up time.
13. Install the upper ETFE film. Using 3-5 people, remove the glue tape and VHB paper covers, then align the film above the unit, and slowly bring it down starting at one end, and slowly working your way to the other end, aligning the film with all the VHB and silicone lines on both edges. Once in place, use pressure and rubbing to bond the glue tape to the VHB. Do not press down on the Silicone but do ensure it is sealed continuously.
14. Use a scalpel to cut away the ETFE from the 2x4 frame, leaving ~2-3” extra width of material to wrap under the flange. Remove the 2x4 frame. Then pull on the ETFE to keep it taught and bond it to the VHB under the flange. Rub it in to get good bonding.

Assembly Order and Process: (5 of 5)

WB board, wiring, and sensors, installing in KL:

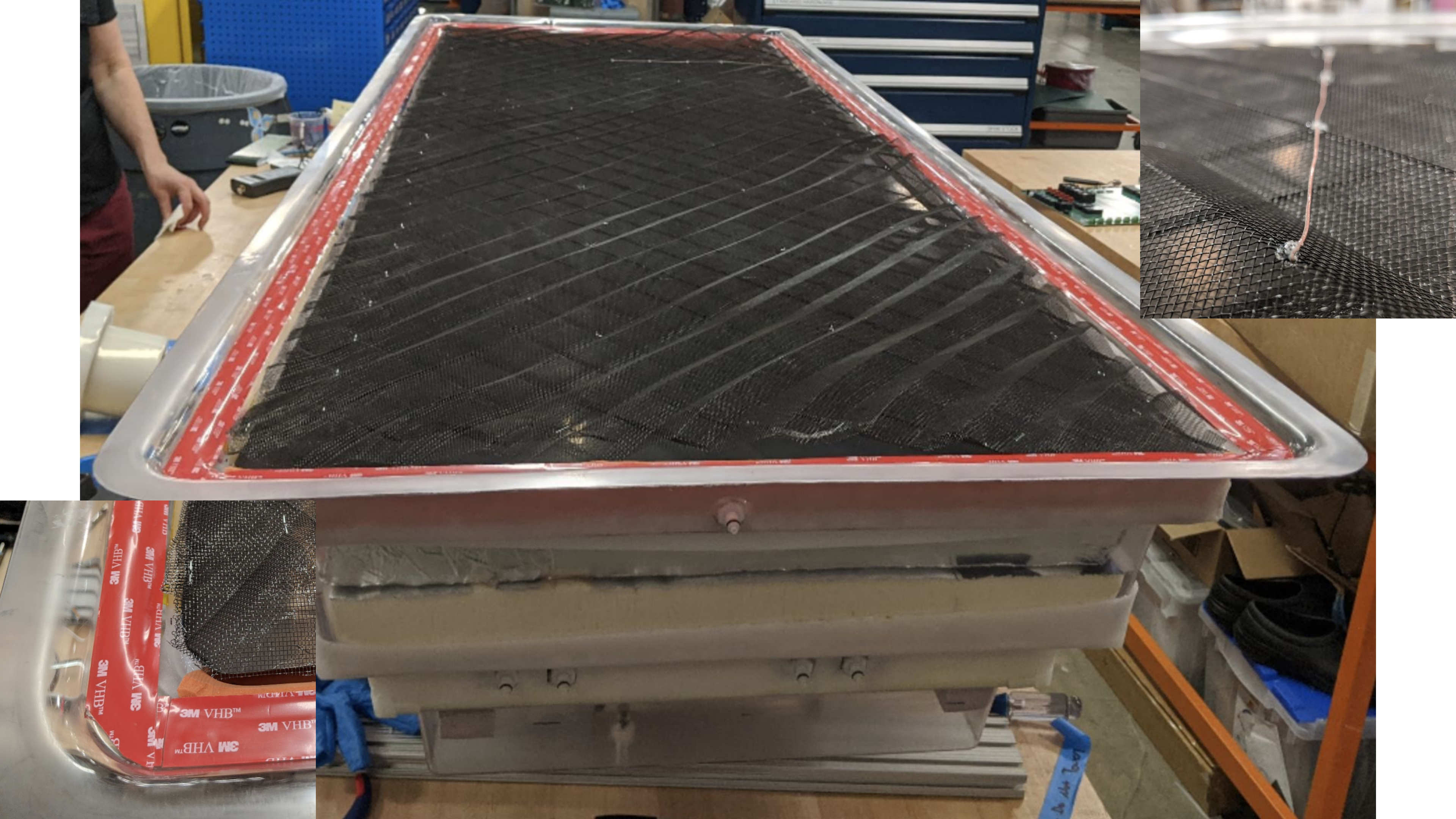
1. Install the PC sheet that holds the WB board onto the external ribs of the unit using 80/20 hardware. Mount the WB board onto the PC with standoffs, and place a protective PC cover over the board with standoffs.
2. Mount the 4 anemometer sensors to the PC sheet, and route wires to the left side of the board. Using VHB for mounting. Use strain relief and zip ties on all cables and connection points.
3. Add strain relief and plug in the main power supply cable, 3 fan power cables, stepper motor to the right side of the WB board.
4. The BME280s need to be read and powered by separate particles + breadboards, so install these on the outside of the unit and connect to the BMEs with the shortest extension possible, usually 2 BMEs per particle, totalling 7 particle boards. Route USB cables to provide 5vDC power to each particle. Use strain relief and zip ties.
5. Use the Type-K TC extension cables to connect each TC to the WB board on the top edge. Cut each TC cable to length, strip the wires, and install directly into the screw terminals. Use strain relief on the TC ends, and kapton tape to route the TC wires along the walls of the unit. Aim to keep the TC routing specific to each layer or tray they originate on in order to make disassembly easier.
6. [Modification] Install 3 Acrylic 1” diameter tubes on the top of the solar collector to hold the upper ETFE film down, so that it does not strain the bonding and seals, and minimizes its stretching.
7. Lift the completed unit and place it on the wooden angled frame (ideally placed on a cart for ease of moving).
8. Install the water trap onto the condenser. (either original version, or the modification: vacuum-formed low profile water trap).
9. Set up the water measurement system, such as a scale + water tray with lid, or other unit.


3M 4412N Sealant Tape
JUSTRITE
FLAMMABLE
KEEP FIRE AWAY
INFLAMABLE
SAFETY GLASSES


GE100 Silicone around all edges for sealing
Loctite U-09Lv - filling all flat areas for mylar film adhesion

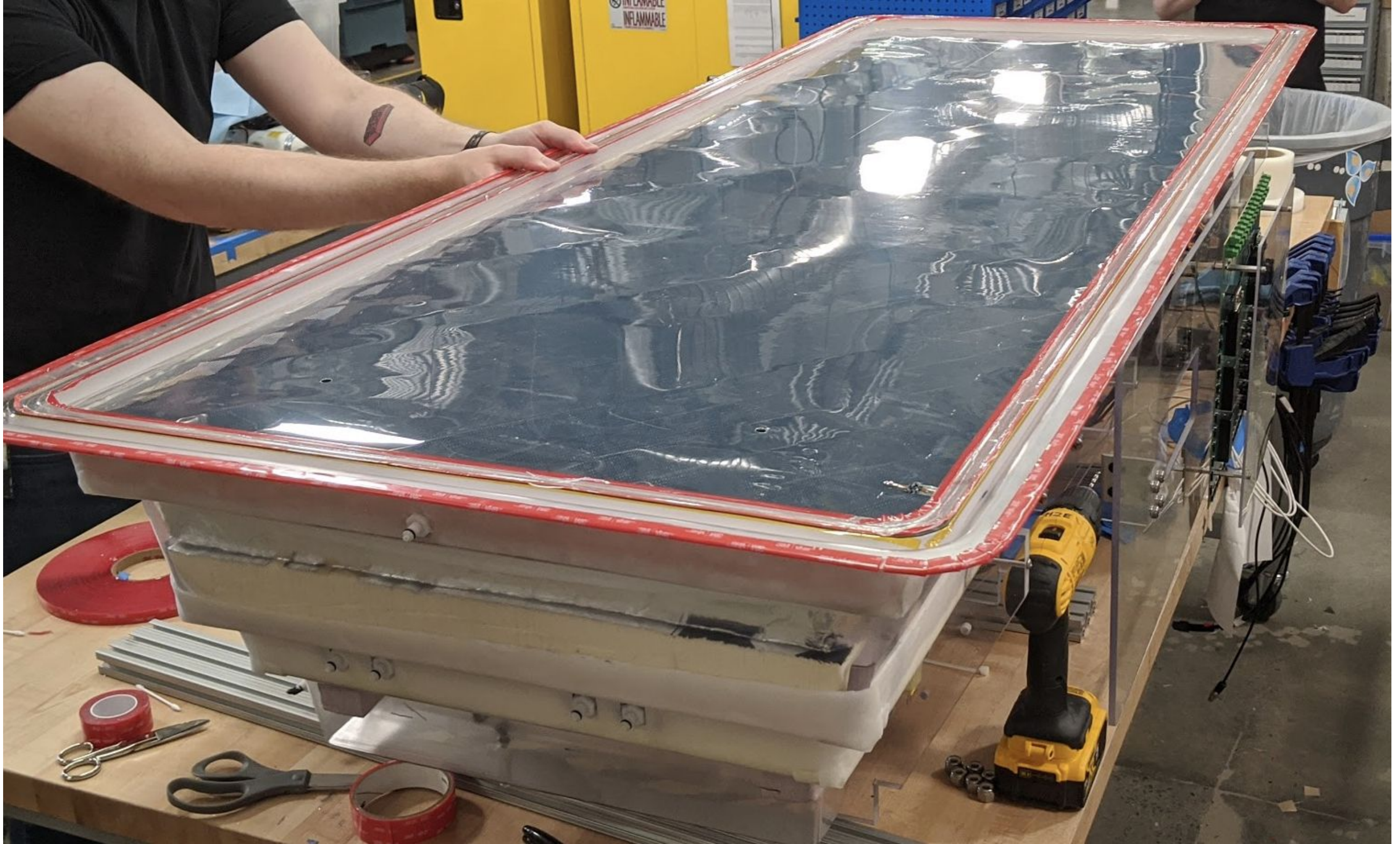

JUSTRITE
Project

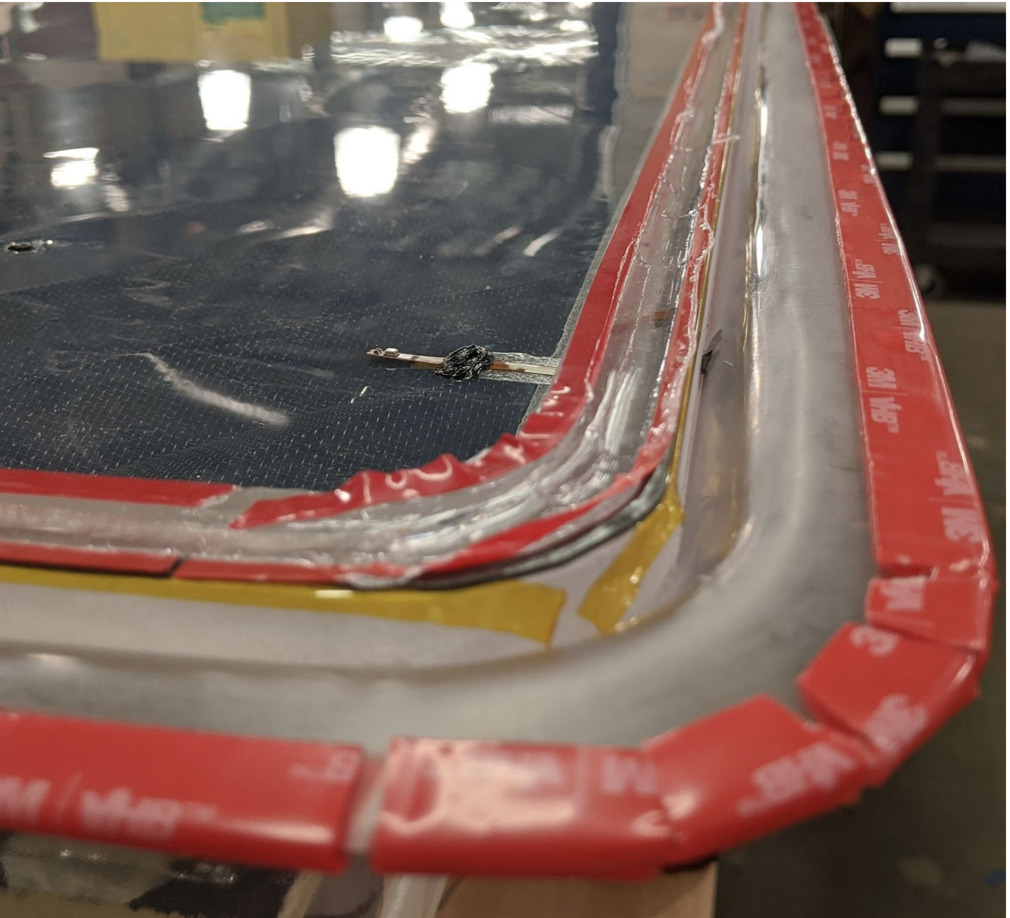

BME8

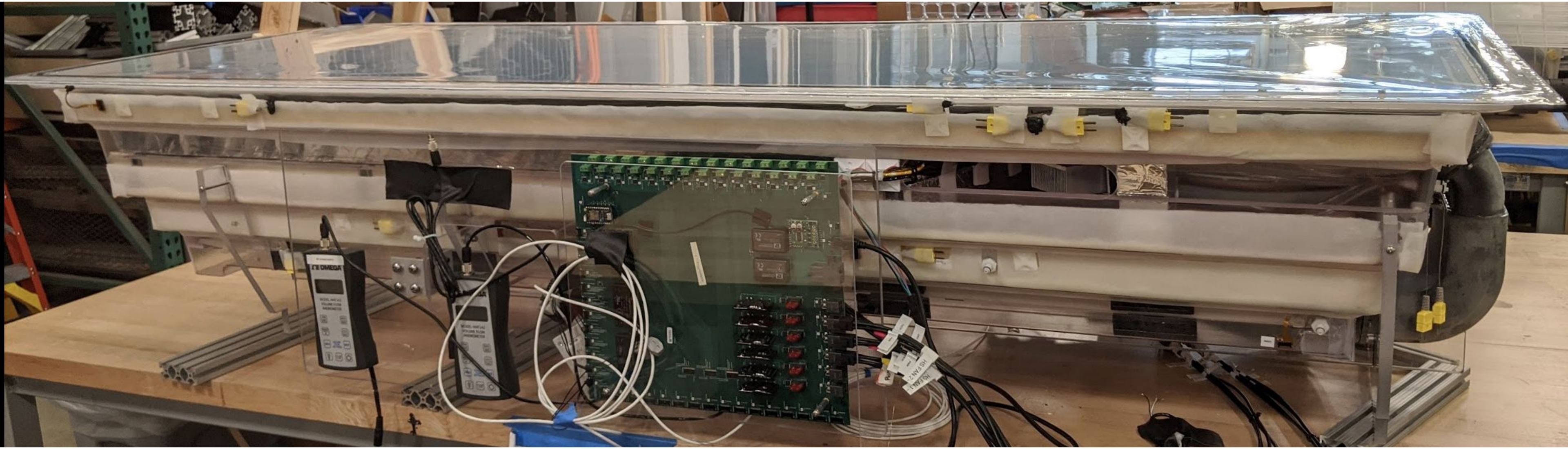

3M VHB™


FASTENAL
JUSTRITE
FLAMMABLE
INFLAMABLE
SAFETY GLASSES
IRWIN
QUICK-GRIP


JUSTRITE
FLAMMABLE
KEEP FIRE AWAY
INFLAMMABLE
INFLAMMABLE
METRIC HARDWARE
1A9

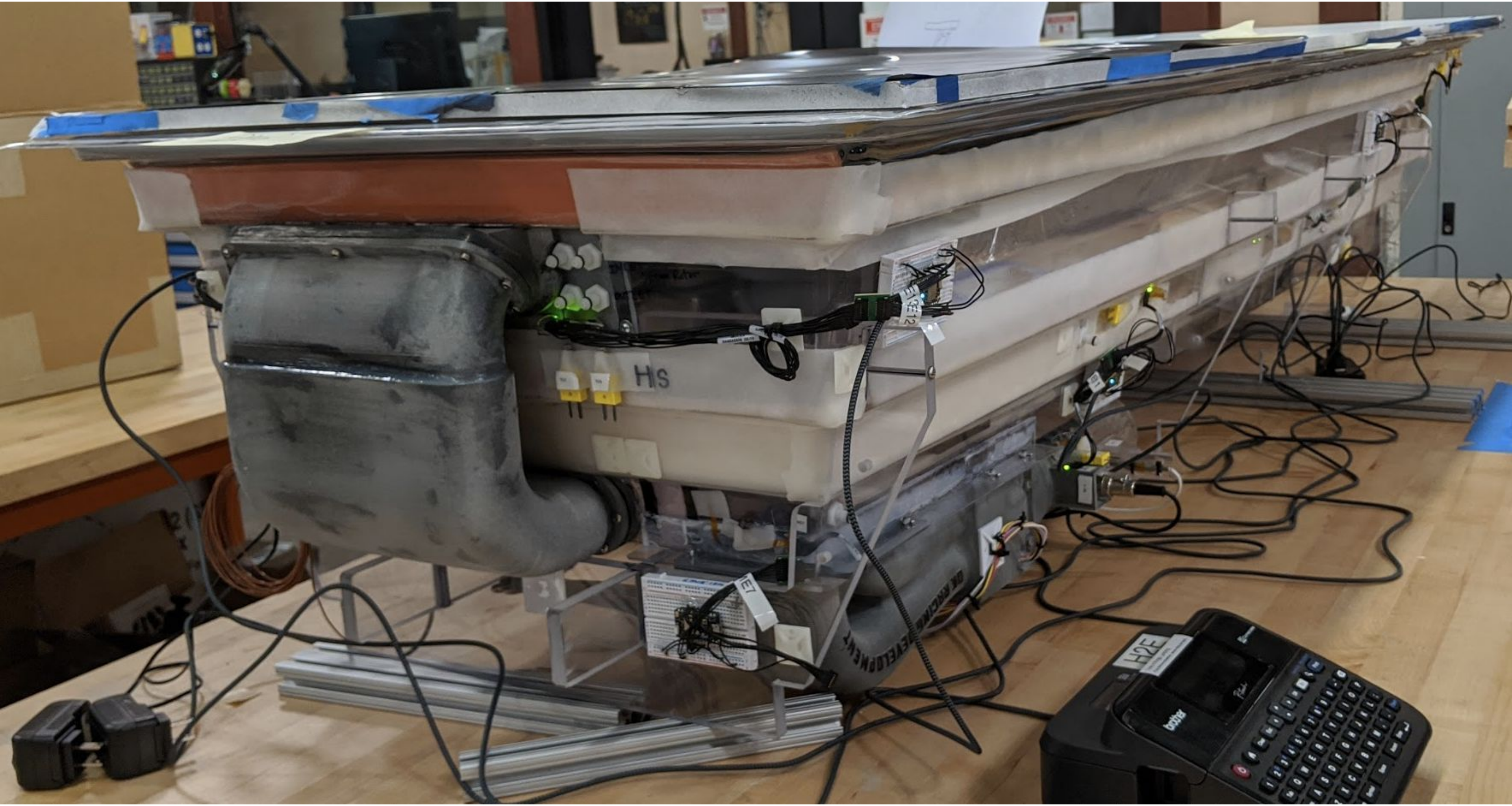

INFLAMMABLE

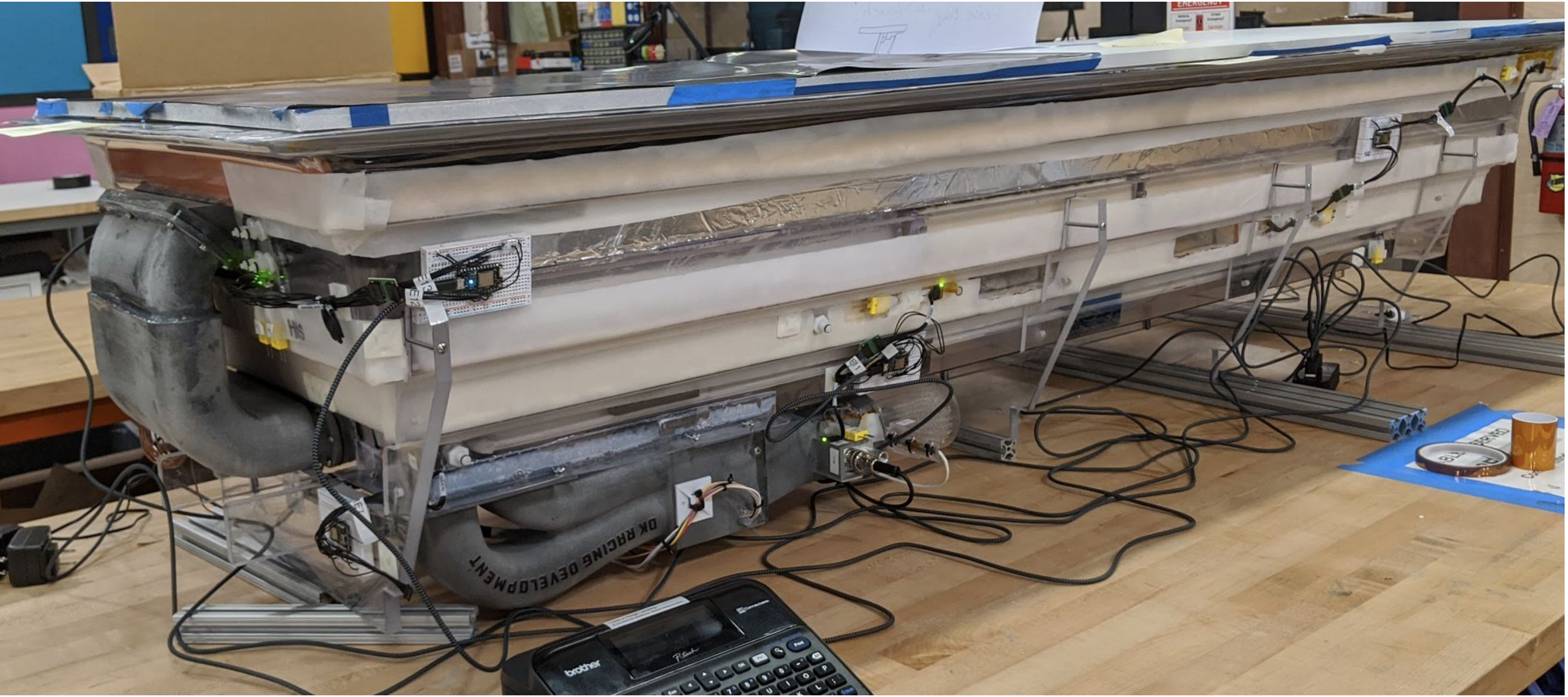

3M VHB


OMEGA


ABLE RESERVED
H2E Proje

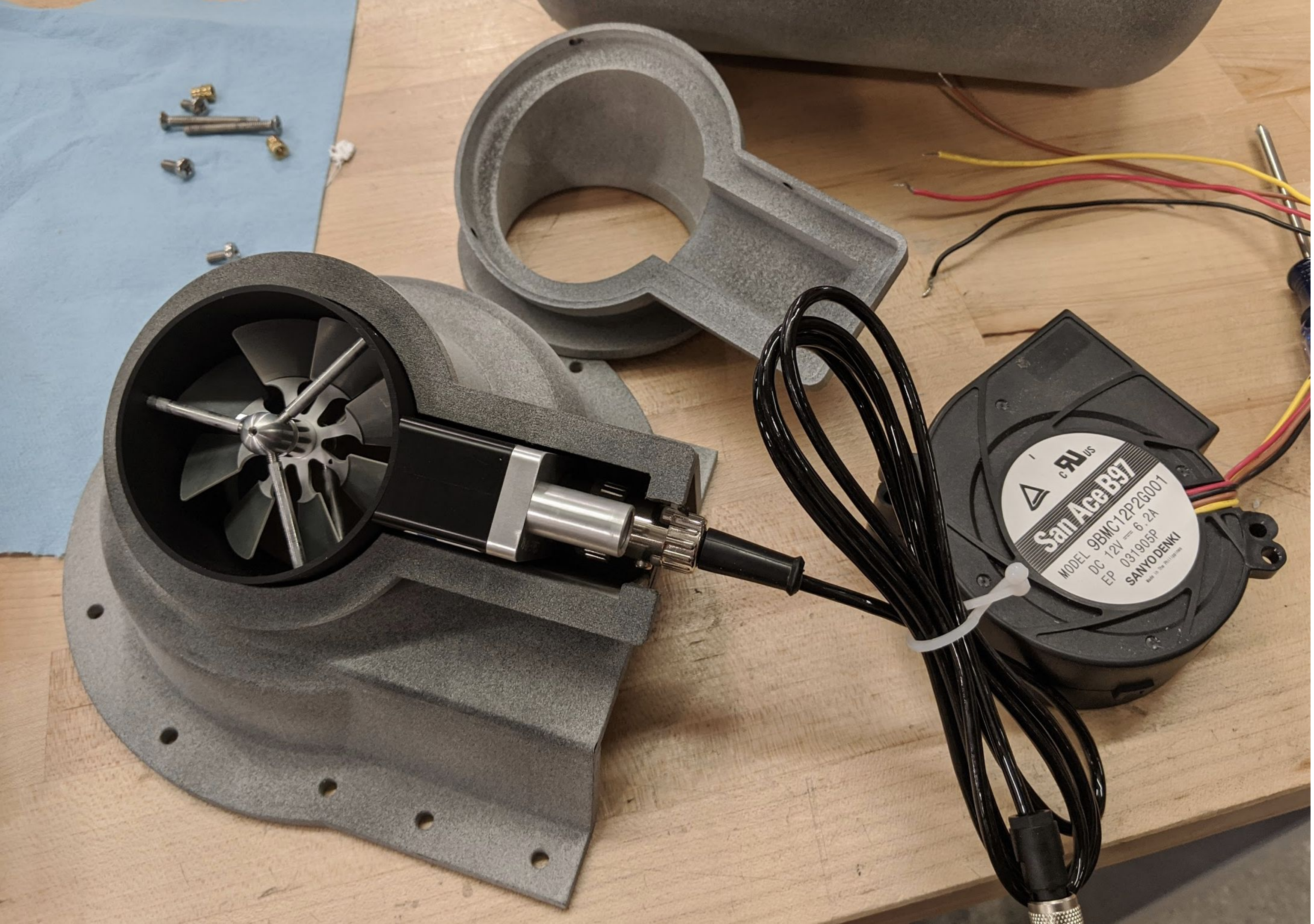

RS
HS
from Rotor


HIS
E7
H2E
brother


DK RACING DEVELOPMENT
brother
EMERGENCY

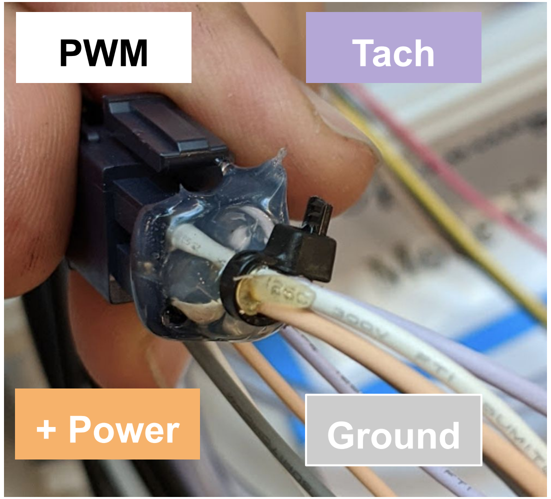

OMEGA
OMEGA
MODEL HHF142
VOLUME FLOW
ANEMOMETER
MODEL HHF142
VOLUME FLOW
ANEMOMETER
Project

10. Fans, Motor, Flow sensor calibration


San Ace B97
MODEL 9BMC12P2G001
DC 12V ⎓ 6.2A
EP 031905P
SANYO DENKI

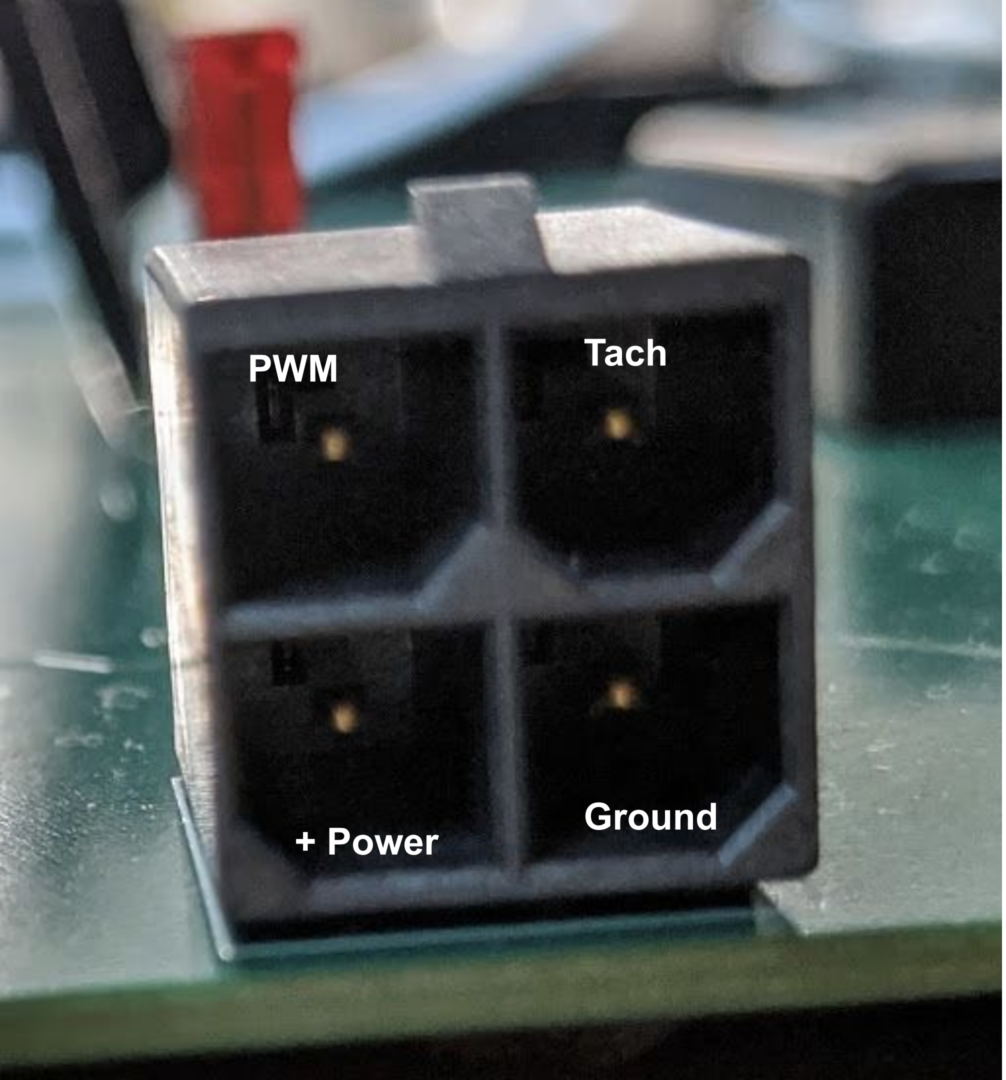
HS: Dual Axial Fan: SanAce 9CRA0912P0G001

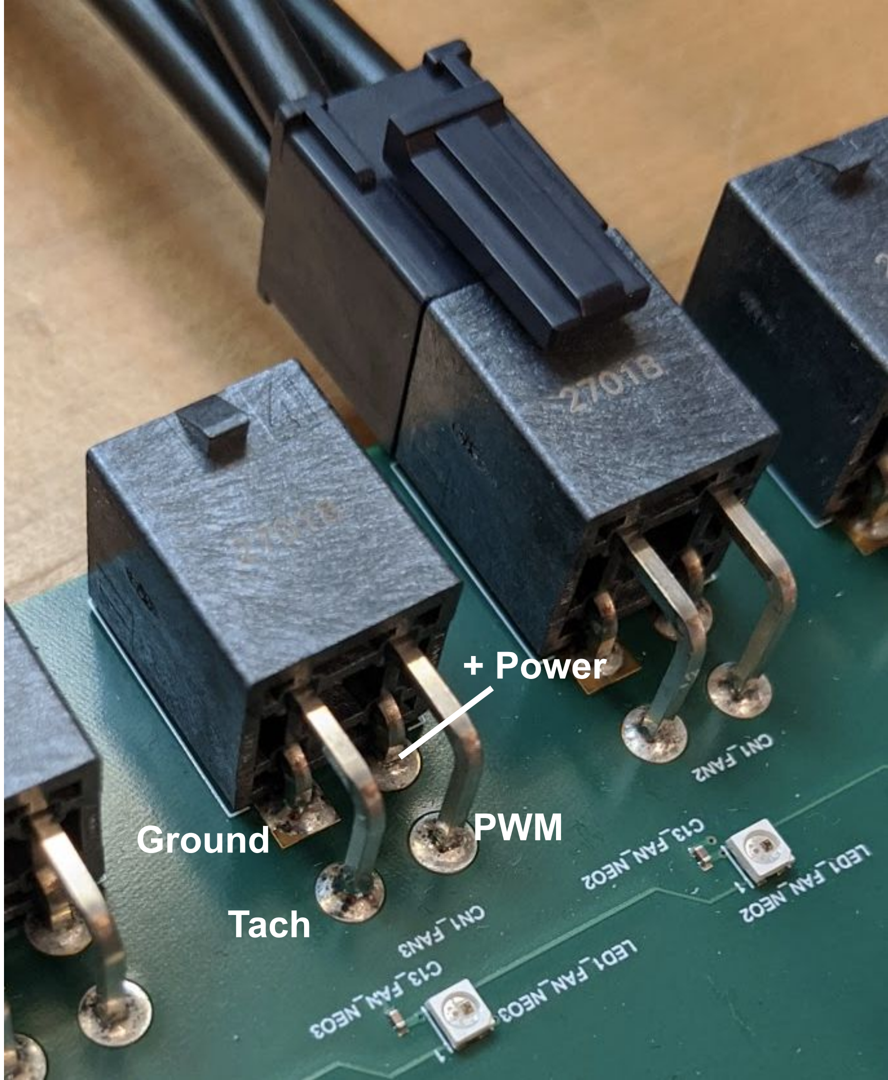
· Lead wire .... Inlet ⊕Red ⊖Black [Sensor] Yellow [Control] Brown
Outlet ⊕Orange ⊖Gray [Sensor] Purple [Control] White



RS: Blower fan: SanAce **9BMC12P2G001**

⊕Red ⊖Black [Sensor] Yellow [Control] Brown


PWM
Tach
+ Power
Ground


27018
+ Power
Ground
PWM
Tach

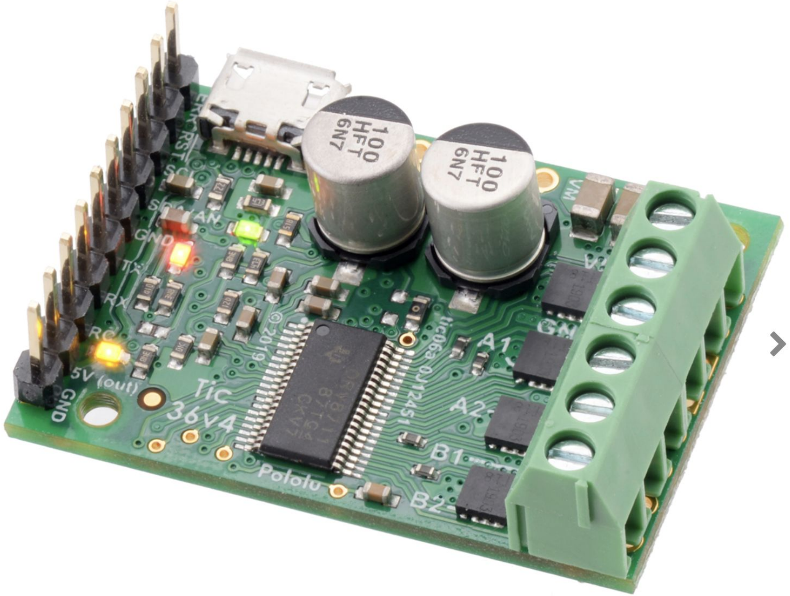
Stepper Motor

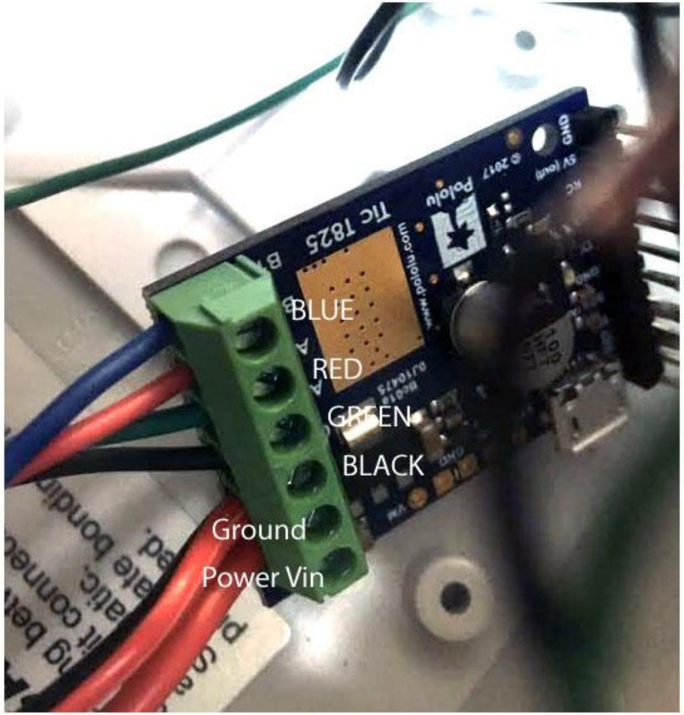
2.5V = 0rpm

5v = 1 rpm CCW if looking down on the wheel

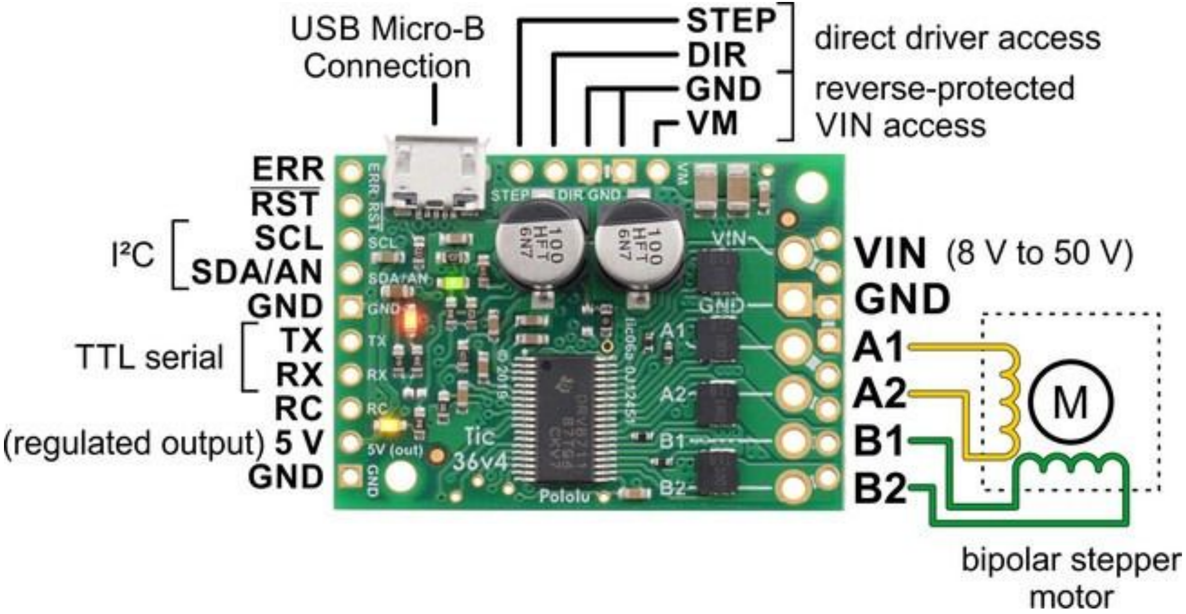
0V = 1 rpm CW if looking down on the wheel.

We only want to rotate CW for Proto 4, hence control should be between: 0V to 2.35V (no rotation observed until ~2.35V).





BLUE
RED
GREEN
BLACK
Ground
Power Vin



USB Micro-B
Connection
STEP
DIR
GND
VM
direct driver access
reverse-protected
VIN access
ERR
RST
I²C
SCL
SDA/AN
GND
TTL serial
TX
RX
RC
(regulated output) 5 V
GND
VIN (8 V to 50 V)
GND
A1
A2
B1
B2
M
bipolar stepper
motor

Stepper Motor

- Size: 56.4 mm square × 56 mm, not including the shaft (NEMA 23)
- Weight: 0.7 kg (25 oz)
- Shaft diameter: 6.35 mm (0.25″) “D”
- Steps per revolution: 200
- Current rating: 2.8 A per coil
- Voltage rating: 2.5 V
- Holding torque: 13 kg-cm (180 oz-in)

CW motor =
CW wheel

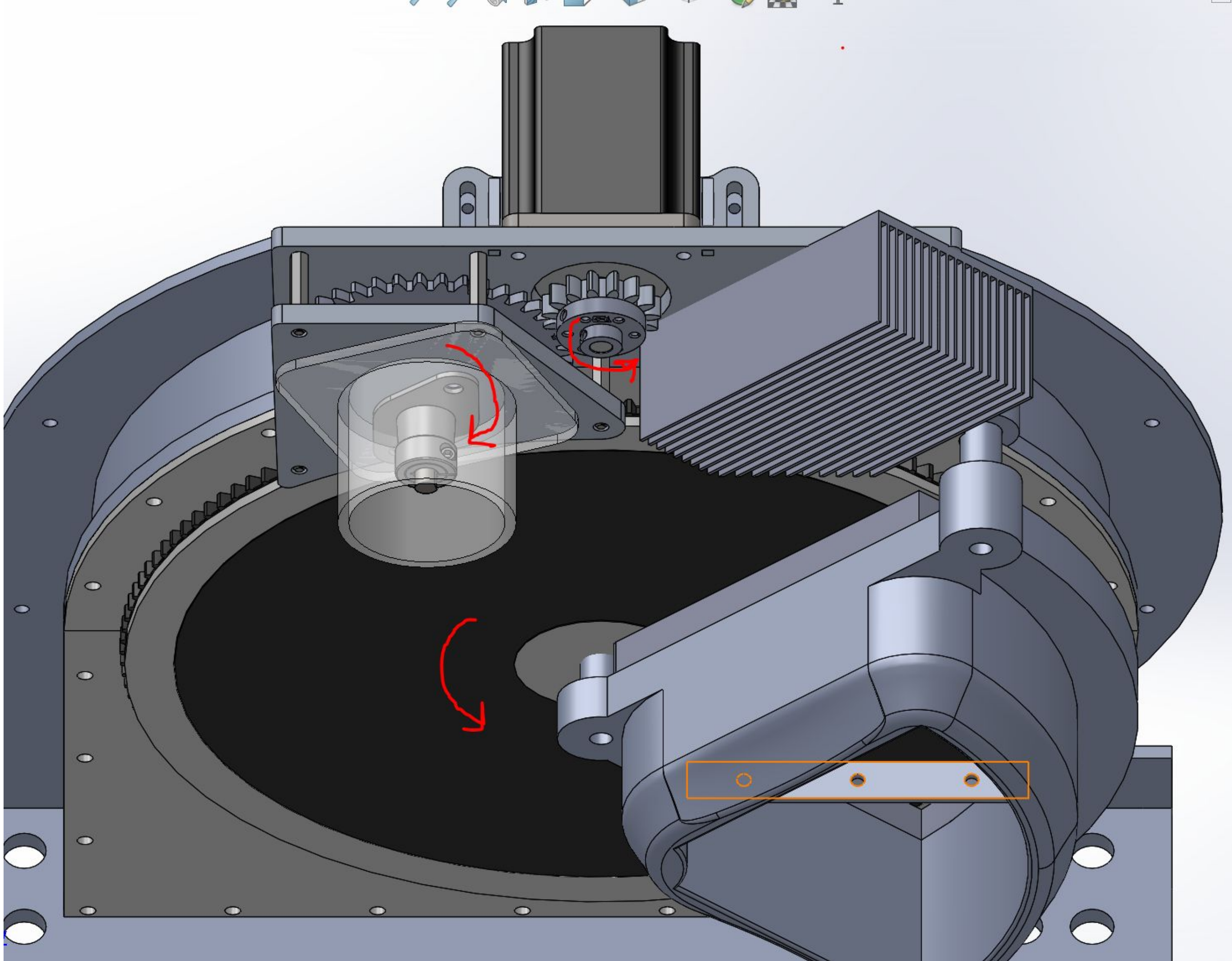
Speed: The stepper shaft goes 9 times for every 1 time of the wheel, so expect it to rotate 1 time every 6.67 seconds when the wheel is going 1rpm.

- 15 teeth on motor shaft

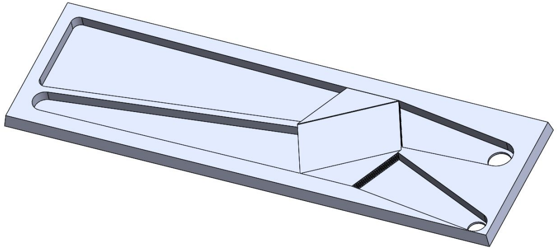
- 40 teeth on transfer gear (no impact on ratio)

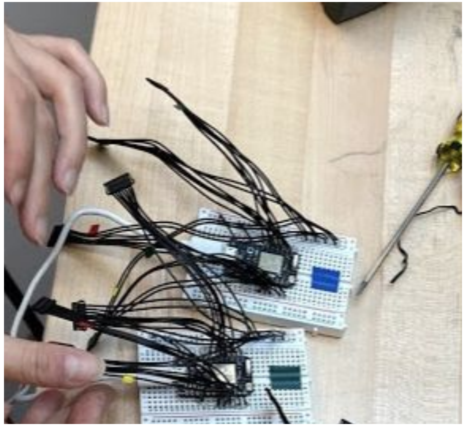
- 135 teeth on desiccant wheel

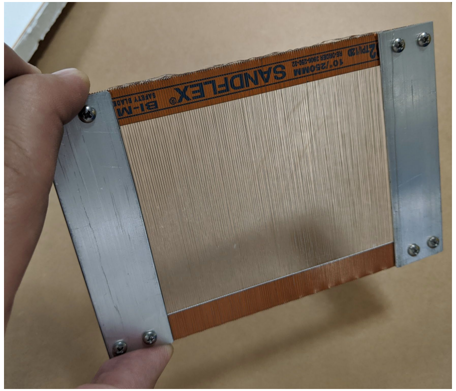
Direction: If the motor is going CCW as seen with it's shaft up the wheel will go CW as seen from the top. See attached image.

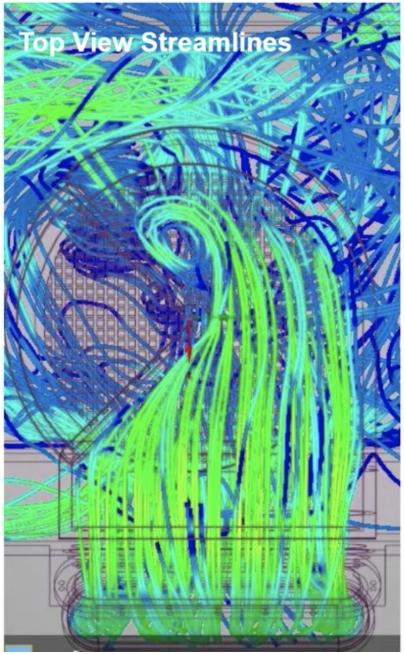


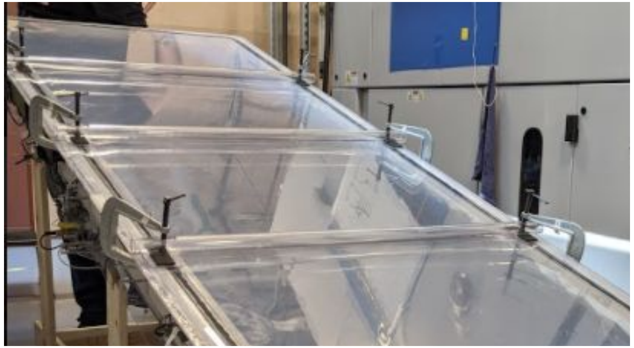
11. Modifications, Recommendations for next time

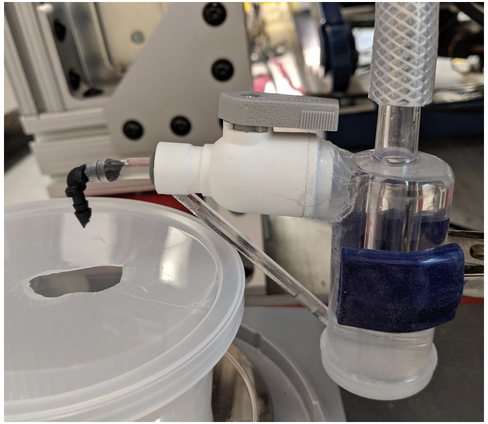




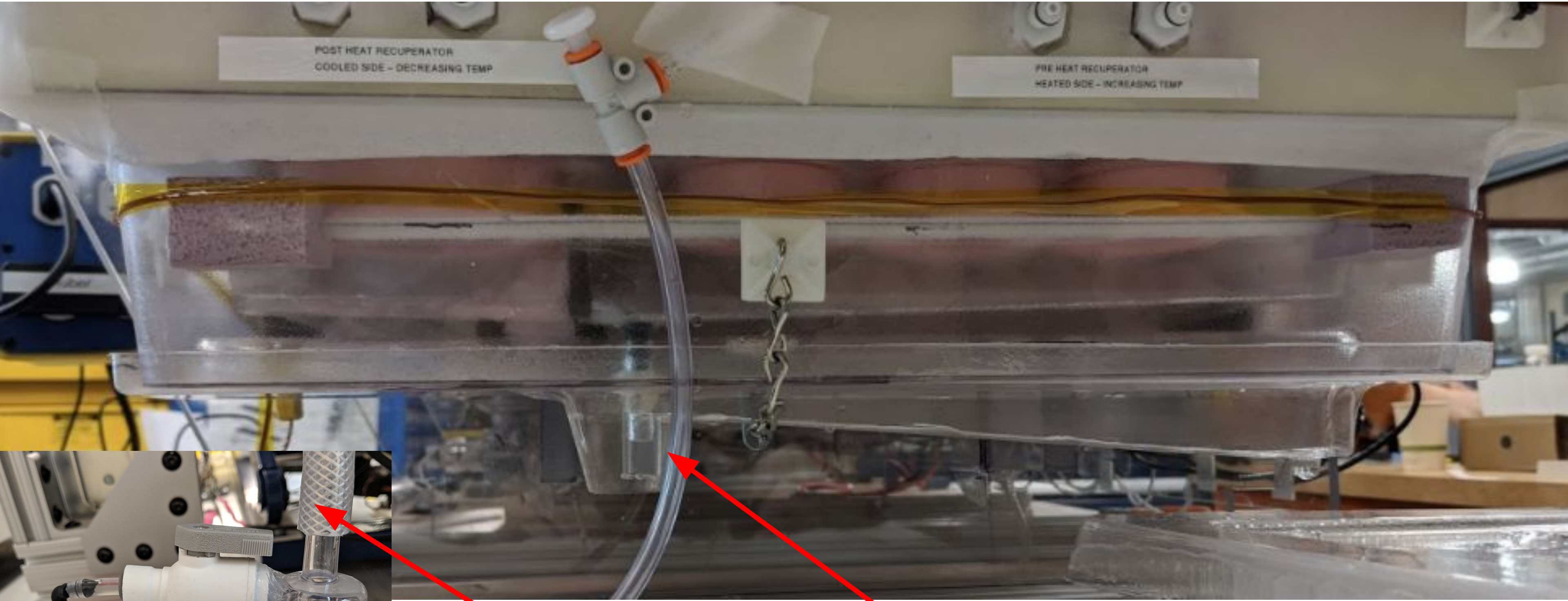


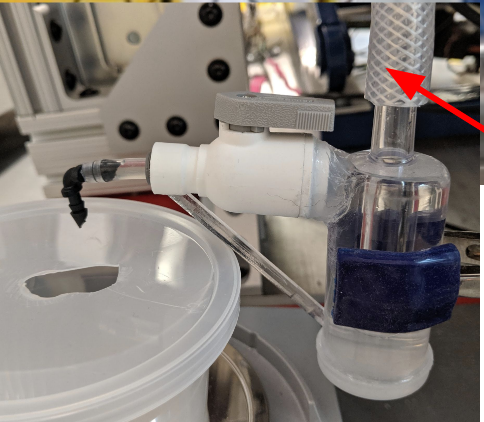






Water Trap change -- reducing height to fit in the test box

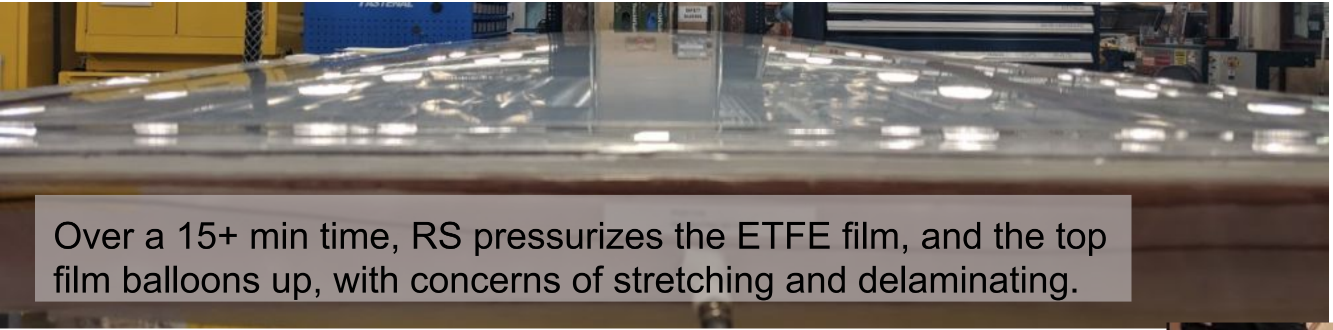




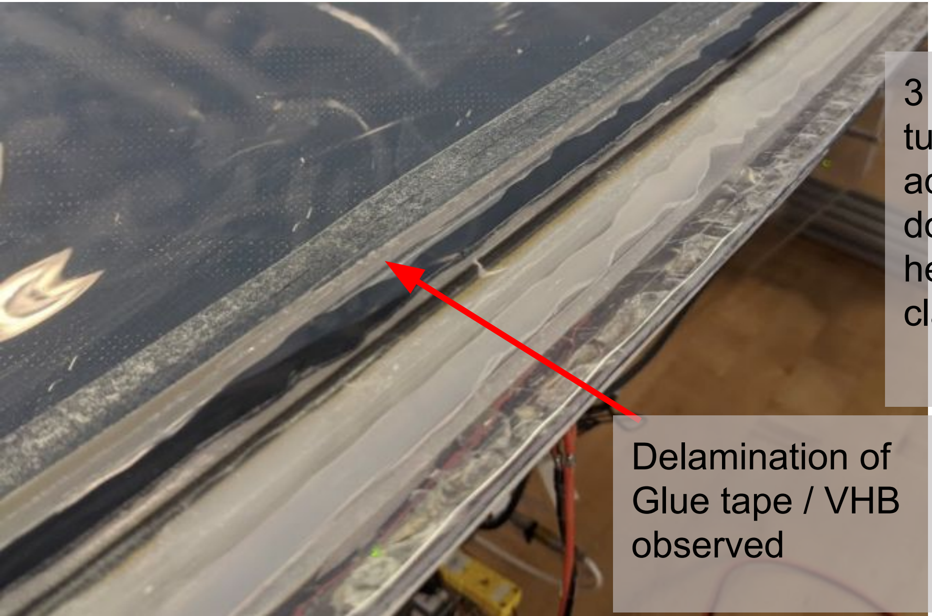
Old design: customized brewers airlock. ~4” total height.

New design retains roughly 1” of water column height.
~1.5” total height

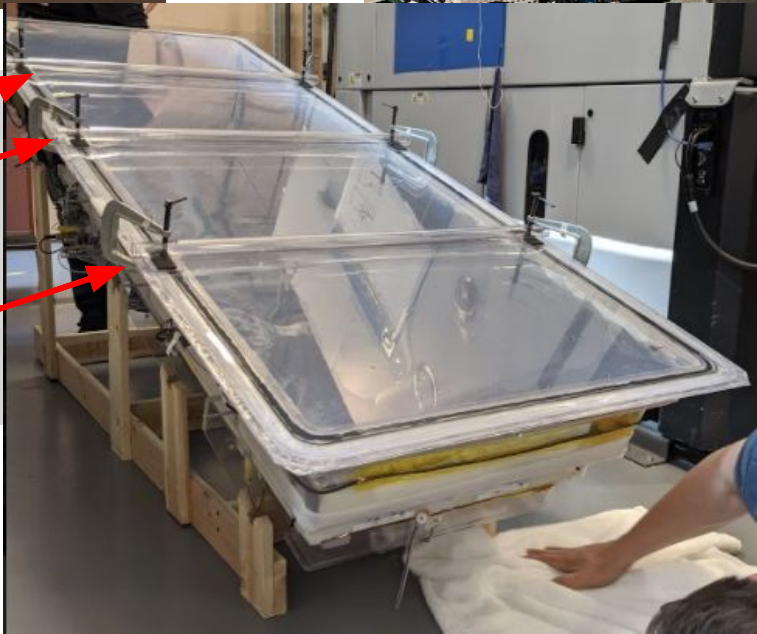
Adding Acrylic Tubes over ETFE film



Over a 15+ min time, RS pressurizes the ETFE film, and the top film balloons up, with concerns of stretching and delaminating.



Delamination of Glue tape / VHB observed



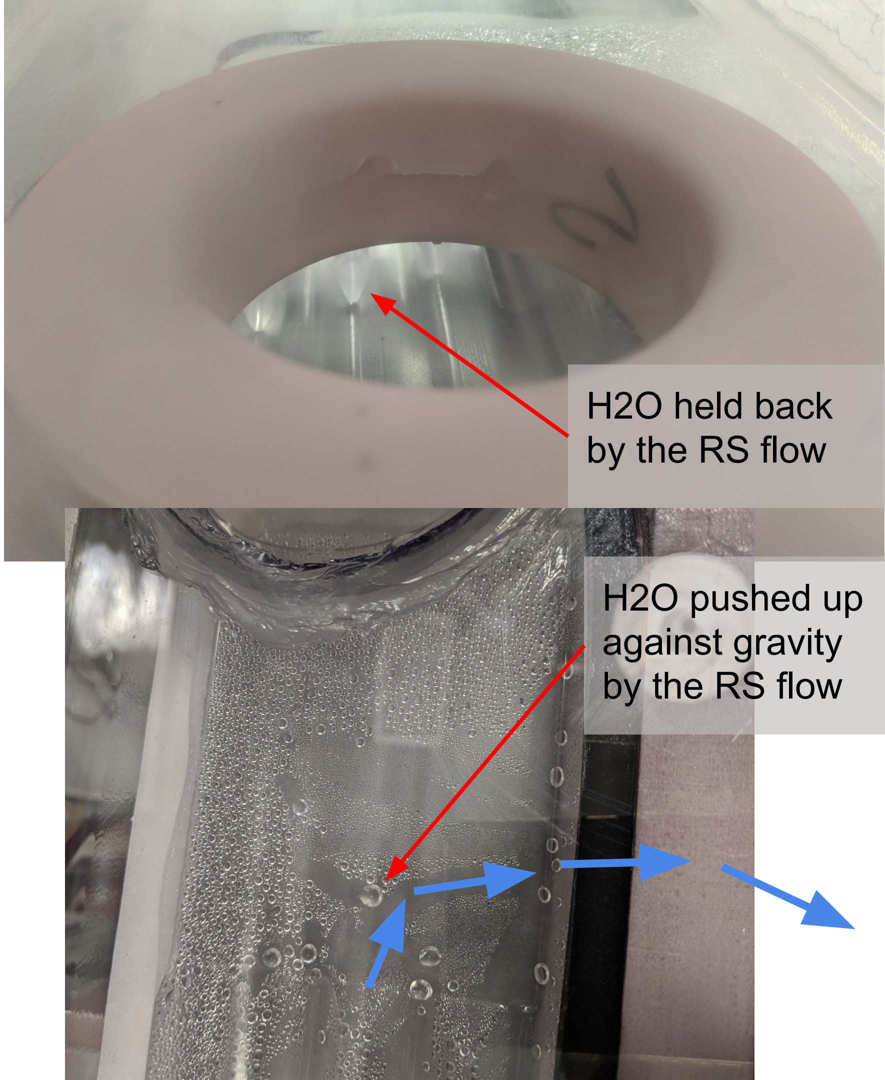
3 Acrylic 1” tubes were added to hold down the film, held on with clamps

General Recommendations for Next Time

1. Water lock for tubing and trap: try to integrate into vacuum formed shells
2. Black Box HS flow optimization for uniformity and lower pressure drop
   - Consider orienting in-line with flow like all commercial desiccant units, instead of orthogonal?
3. Bowing of large, flat plastic surfaces: anticipate, and try to use shell ribbing to address.
4. Replace hand-cut foam blocks (for strength and insulation) and PC ribs (for bowing resistance) with more complex vacuum-forming and ribbing.
5. Better hydrophobic condenser coating (experiment only): silicone oil draining into water trap
6. Make sure the vendor makes multiple parts off the first run, so we don't end up with only having 1 part to work with!
7. If vacuum forming again, consider using Aluminum bucks that can be pre-heated, to help the plastic flow better. This may also allow for thinner shells.
8. *"Go slow to move fast!"* The condenser tray was dropped and cracked ~3 times during assembly -- luckily we were able to patch it each time. It pays dividends to be extra careful and set up a clean and organized work area.
9. Explore other desiccant wheel materials

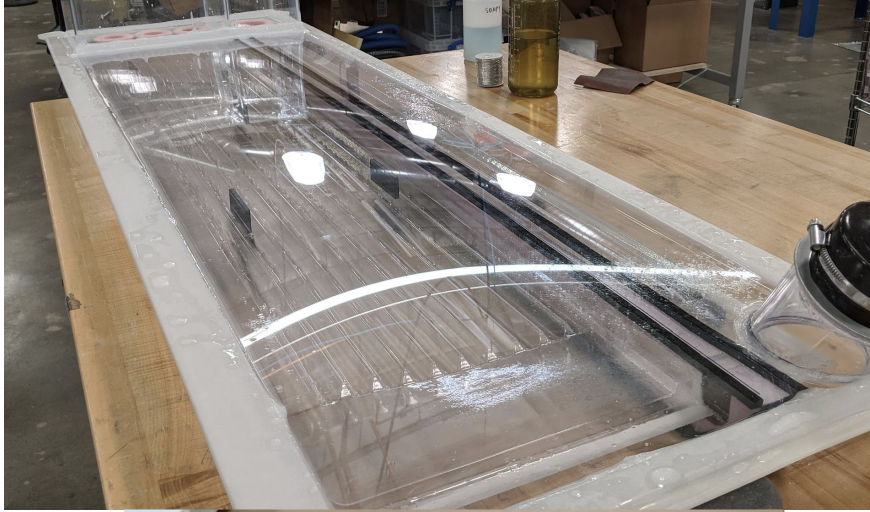
Condenser Recommendations (1/2)

- Try to simplify the airflow geometry, such that U-turns are avoided (pressure drop).
- Try to have the flow of air and gravity working together 100% of the time for droplet collection.
- Ribbing turned out to not have great HX efficiency performance, consider CORE type unit or turbulator designs.
- Consider a different hydrophobic coating that won't drain out with the water.
- Orient the condenser air/water path as vertical as possible. (Perhaps a cross-flow design?)
- Try to eliminate the snorkel and integrate that air-path into vacuum formed shells.
- Keeping it clear plastic where possible is great.
- Eliminate foam and gatorboard with more ribbing and bumps in vacuum forming.



Condenser Recommendations (2/2)

- Consider more ribbing in the vacuum formed shells or other design approach (tubes?) to eliminate the bowing and the need for external ribbing.
- Consider a dew harp or other design that could capture micro-droplets of water in the RS flow exiting the condenser. Initial studies pointed to **~40-80%** of the water we were condensing may have been exiting the condenser and being re-evaporated. If that was the case, it would be a large watt load that should be reduced, but needs more study to root cause
- Integrate the water trap into the condenser tray or clamshell?
- Use a double-seal approach on the condenser, not just the 3M sealing tape, as we did in Rev1. (+Silicone)



The End