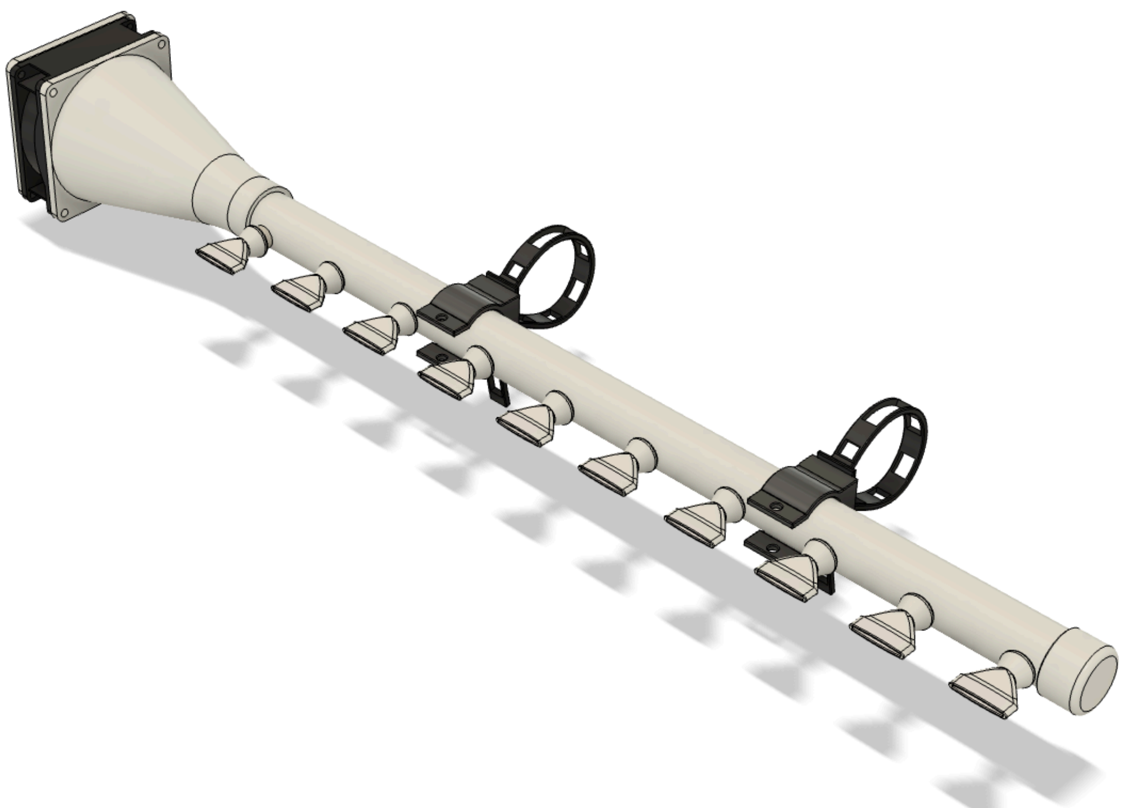
Emilio Alberto Ceballos, Andrew Joseph D'Onofrio, Ashley Demiana Padres, Anna-Sophie Macintosh Schaldenbrand, Hannah Margaret Sherman, Boluwatife Olusegun Sokan, Jamison Lee Taylor Jr. I



1. Executive Summary (15%)

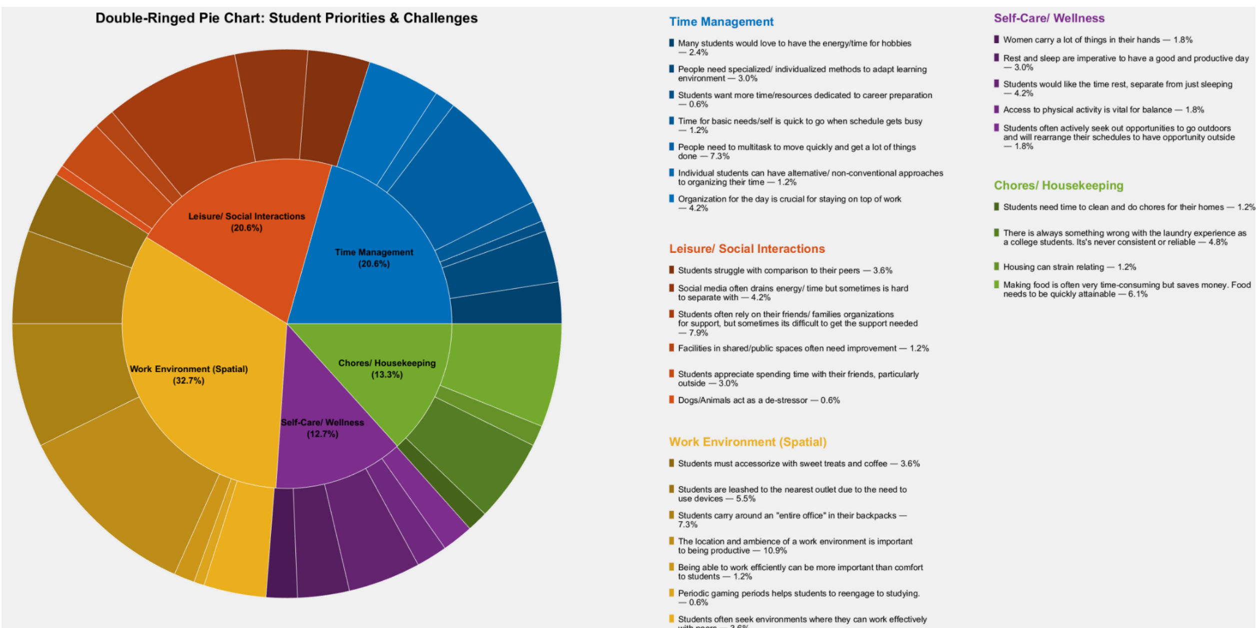
1.1 Team Name and Summary of Participants

- Team Name: Team 2
- Company: Apollotech
- Members: Emilio Alberto Ceballos, Andrew Joseph D'Onofrio, Ashley Demiana Padres, Anna-Sophie Macintosh Schaldenbrand, Hannah Margaret Sherman, Boluwatife Olusegun Sokan, Jamison Lee Taylor Jr.

1.2 Product Name

AeroDry

1.3 Problem you are solving



To identify the problem we wanted to solve, we conducted empathy fieldwork in and around Cornell University to better understand the college student experience. We collected over 150 empathy fieldwork data points that told us about the needs, insights, and surprises we encountered when observing and interviewing students going about their daily routines. We found that students' priorities can be categorized into the following five main categories:

1. Time Management
2. Chores/Housekeeping
3. Self Care/Wellness
4. Work Environment
5. Leisure/Social Interactions

AHP- Criteria Comparison Matrix

We then compared each category's importance relative to the others and found *chores/housekeeping* to be the most important category, and informed our decision to focus on a laundry product.

AHP-Criteria Comparison Matrix

	Chores/ Housekeeping	Self-Care/ Wellness	Time Management	Leisure/ Social Interaction	Work Environment
Chores/ Housekeeping	1	0.75	0.125	0.25	0.125
Self-Care/ Wellness	1.5	1	0.75	1	0.9
Time Management	3	3	1	3	1
Leisure/ Social Interaction	4	2	0.125	1	0.75
Work Environment	5	2	1	0.125	1
Sum	14.5	8.75	3	5.375	3.775

	Non-Dimensionalized					
	Chores/ Housekeeping	**Self-Care/ Wellness**	**Time Management**	**Leisure/ Social Interaction**	**Work Environment**	**Average**
Chores/ Housekeeping	0.06896551724	0.08571428571	0.04166666667	0.04651162791	0.03311258278	0.2759706803
Self-Care/ Wellness	0.1034482759	0.1142857143	0.25	0.1860465116	0.238410596	0.8921910978
Time Management	0.2068965517	0.3428571429	0.3333333333	0.5581395349	0.2649006623	1.706127225
Leisure/ Social Interaction	0.275862069	0.2285714286	0.04166666667	0.1860465116	0.1986754967	0.9308221725
Work Environment	0.3448275862	0.2285714286	0.3333333333	0.02325581395	0.2649006623	1.194888824
Sum	1	1	1	1	1	

Weighted Sum Vector	Priority Vector	
1.540446553	5.581921062	
4.591964651	5.1468398	
9.197967901	5.391138343	
4.928519611	5.294802548	
6.181604418	5.173372026	
Principal Eigenvalues (λ)	5.317614756	
Consistency Index (CI) (λ-n)/(n-1)	0.07940368898	
Consistency Index (λ-n)/(n-1)	0.07153485493	< 0.1
	Consistent	

Random Input values	
# criteria	*RI value*
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49
11	1.51

Description of the Problem:

AeroDry aims to address faulty clothes dryers, specifically when dryers do not dry clothes properly or thoroughly.

Impact of the Problem

College students and those in low-budget rental living situations often do not have the space, funds, or choice to afford their own dryers and must use housing accommodation-provided dryers or laundromats. These dryers often do not dry very well and leave clothes damp, with users forced to adapt.

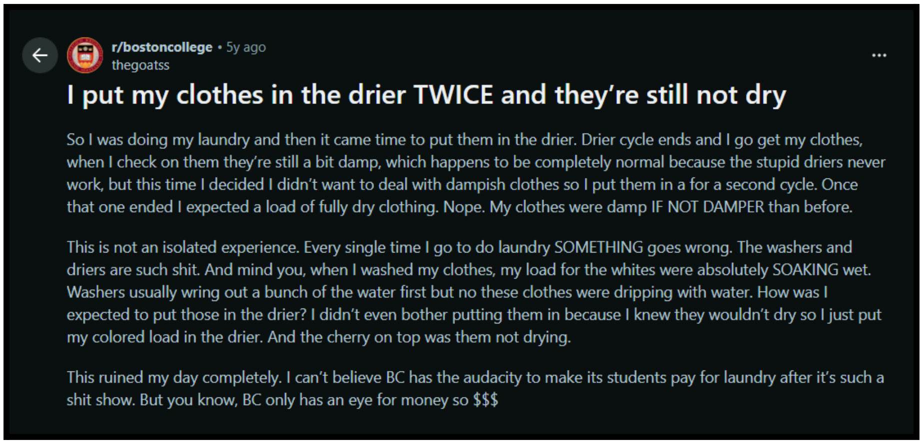
Goals and Objectives

To provide an affordable, easy solution to faulty dryers by creating an alternative clothes drying solution.

Constraints and acknowledgements

It is impossible to design a product that would be able to be installed in every person's clothing storage and/or closet because of the range of closets, as well as be able to perfectly dry every single type of clothing. Dryers themselves are not even used for every piece of clothing.

1.3.1 Reddit, Amazon Reviews, other evidence of problem


r/bostoncollege • 5y ago
thegoatss

I put my clothes in the drier TWICE and they're still not dry

So I was doing my laundry and then it came time to put them in the drier. Drier cycle ends and I go get my clothes, when I check on them they're still a bit damp, which happens to be completely normal because the stupid driers never work, but this time I decided I didn't want to deal with dampish clothes so I put them in a for a second cycle. Once that one ended I expected a load of fully dry clothing. Nope. My clothes were damp IF NOT DAMPER than before.

This is not an isolated experience. Every single time I go to do laundry SOMETHING goes wrong. The washers and driers are such shit. And mind you, when I washed my clothes, my load for the whites were absolutely SOAKING wet. Washers usually wring out a bunch of the water first but no these clothes were dripping with water. How was I expected to put those in the drier? I didn't even bother putting them in because I knew they wouldn't dry so I just put my colored load in the drier. And the cherry on top was them not drying.

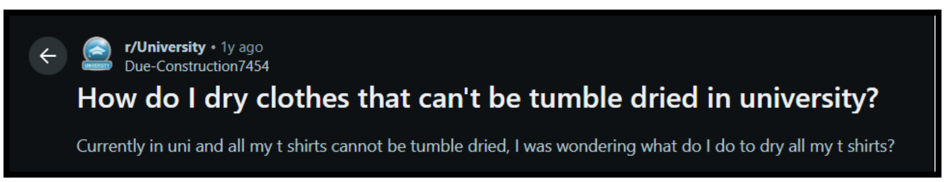
This ruined my day completely. I can't believe BC has the audacity to make its students pay for laundry after it's such a shit show. But you know, BC only has an eye for money so $$$


r/ucf • 3y ago
Careful-Session897

Dryer Problems

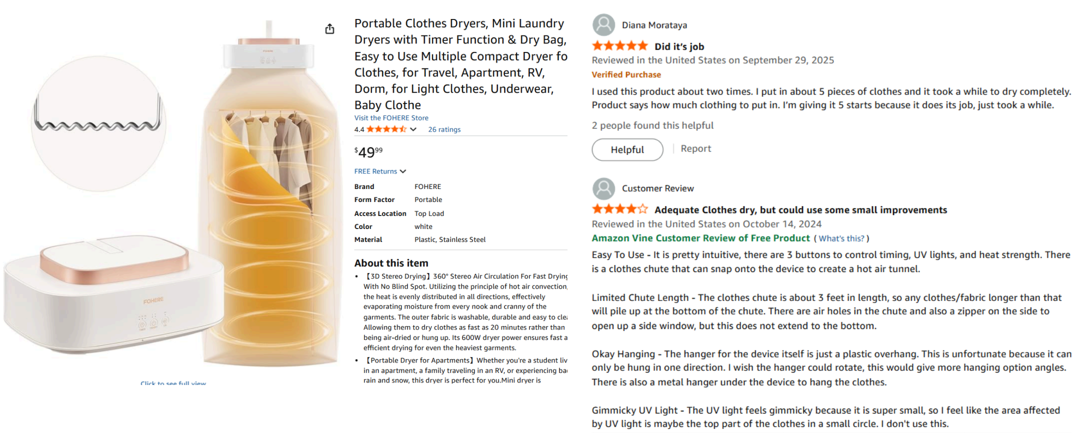
Housing Question

I live in a dorm and I've used the dryer a couple times now and each time my clothes haven't been fully dried. Any suggestions because it's very frustrating.


r/University • 1y ago
Due-Construction7454

How do I dry clothes that can't be tumble dried in university?

Currently in uni and all my t shirts cannot be tumble dried, I was wondering what do I do to dry all my t shirts?


Portable Clothes Dryers, Mini Laundry Dryers with Timer Function & Dry Bag, Easy to Use Multiple Compact Dryer fo Clothes, for Travel, Apartment, RV, Dorm, for Light Clothes, Underwear, Baby Clothe

Visit the FOHERE Store

4.4 ★★★★☆ 26 ratings

$49.99

FREE Returns

Brand	FOHERE
Form Factor	Portable
Access Location	Top Load
Color	white
Material	Plastic, Stainless Steel

About this item

- 【3D Stereo Drying】360° Stereo Air Circulation For Fast Drying With No Blind Spot. Utilizing the principle of hot air convection, the heat is evenly distributed in all directions, effectively evaporating moisture from every nook and cranny of the garments. The outer fabric is washable, durable and easy to clea Allowing them to dry clothes as fast as 20 minutes rather than being air-dried or hung up. Its 600W dryer power ensures fast a efficient drying for even the heaviest garments.
- 【Portable Dryer for Apartments】Whether you're a student liv in an apartment, a family traveling in an RV, or experiencing ba rain and snow, this dryer is perfect for you.Mini dryer is

Diana Morataya

★★★★★ Did it's job

Reviewed in the United States on September 29, 2025

Verified Purchase

I used this product about two times. I put in about 5 pieces of clothes and it took a while to dry completely. Product says how much clothing to put in. I'm giving it 5 starts because it does its job, just took a while.

2 people found this helpful

Helpful | Report

Customer Review

★★★★☆ Adequate Clothes dry, but could use some small improvements

Reviewed in the United States on October 14, 2024

Amazon Vine Customer Review of Free Product (What's this?)

Easy To Use - It is pretty intuitive, there are 3 buttons to control timing, UV lights, and heat strength. There is a clothes chute that can snap onto the device to create a hot air tunnel.

Limited Chute Length - The clothes chute is about 3 feet in length, so any clothes/fabric longer than that will pile up at the bottom of the chute. There are air holes in the chute and also a zipper on the side to open up a side window, but this does not extend to the bottom.

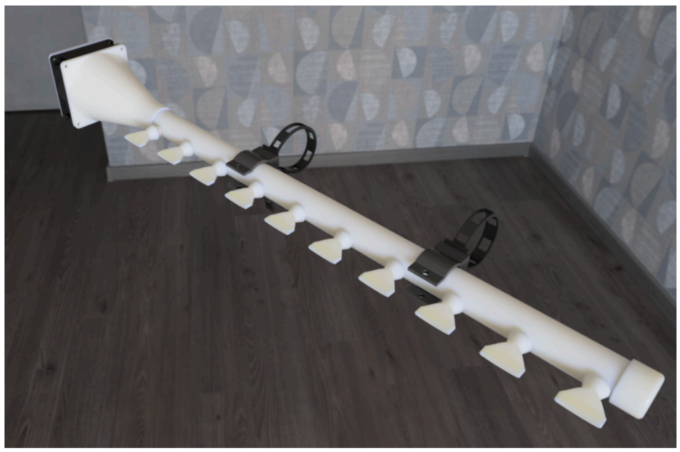
Okay Hanging - The hanger for the device itself is just a plastic overhang. This is unfortunate because it can only be hung in one direction. I wish the hanger could rotate, this would give more hanging option angles. There is also a metal hanger under the device to hang the clothes.

Gimmicky UV Light - The UV light feels gimmicky because it is super small, so I feel like the area affected by UV light is maybe the top part of the clothes in a small circle. I don't use this.

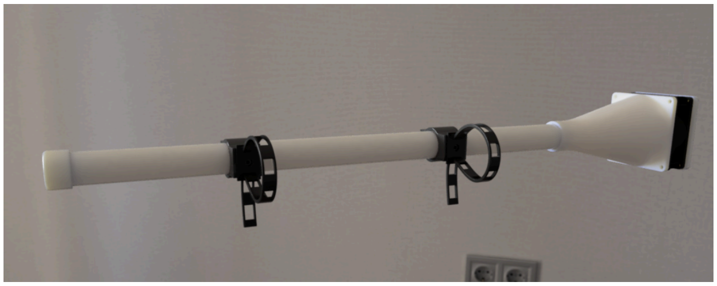
1.4 Product Hypothesis (Specific, Quantifiable, Actionable)

We believe that by developing an effective clothes dryer attachment that can be installed in most closets, it can address faulty dryers that do not dry clothes completely. This system will focus on being affordable, easy to install and use, compatible with most clothes, and save users by autonomously drying clothes. We expect that this innovation will make drying clothes less of a hassle for those with faulty dryers and lead to a 20x reduction in clothes drying time (10 hours to 30 minutes).

1.5 Picture of the highest level product refinement (CAD or physical)

Rendering One

Rendering Two

Rendering Three



1.6 Net Present Value of Opportunity

PROJECT NPV $ **632,676**

Set Base | Base NPV **10,000,000**

Changes from Base NPV

% of NPV	$ change
-93.7%	-9367324

MODEL VALUES

	first	last	base burn rate	adjusted burn rate	%Δ from base value	$Δ from base value	
Development	1	9	-1200	-1200	0.0%	0	-1
Testing	1	12	-1000	-1000	0.0%	0	-1
Tooling and Ramp-Up Costs	12	18	-1500	-1500	0.0%	0	-2
Market Introduction	9	24	-8000	-8000	0.0%	0	-8
Ongoing Marketing Costs	9	60	-2000	-2000	0.0%	0	-2
Unit Sales	9	60	1000	1000	0.0%	0	1
Unit Price	9	60	80	80.000	0.0%	0.00	80.000
Unit Production Cost	1	60	68	68.400	0.0%	0.00	68.400
Discount Rate (per time period)	10.00%						

Set input values in shaded cells.

2. Physical Description (35%)

2.1 List of Customer Requirements (C.R.'s)

Customer Requirements:

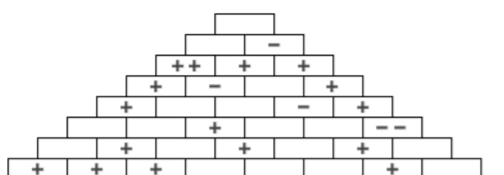
Quick to Dry	College-Student Budget	Clothing Compatibility	Renter Friendly
Energy Efficient	Easy to Install	Visual Aesthetics	Size Adjustability

2.2 List of Engineering Parameters (E.P.'s) of Concept

Engineering Requirements:

Time to dry 15 articles of clothing	ROI	Fan Lifetime	Exit Flow Rate of the Air	Selling Cost
Length Versatility		Tolerance	Sound Produced by Fan	Material Lifetime

2.3 House of Quality – CR's vs. EP's



		Engineering Requirements								
Improvement Direction		↓	↑	↑	↑	↑	↓	↓	↑	↓
Units		Mins	$$	Hours	Years	gpm	$$	Deci(dB)	m	m3
Customer Requirements	Importance Weight Factor	Time to dry 15 articles of clothing	ROI	Fan Lifetime	Material Lifetime	Exit flow rate of the air	Selling Cost	Sound produced by fan	Length Versatility	Tolerernce
Quick to Dry	4	9	3	3	0	9	3	9	3	0
College-Student Budget	5	3	9	9	9	0	9	0	0	0
Clothing Compatibility	5	3	3	0	0	0	9	0	9	3
Renter Friendly	4	0	0	0	3	1	0	3	3	0
Energy Efficient	1	9	0	1	0	3	9	3	0	1
Easy to install	3	0	0	0	0	0	9	0	3	3
Visual Aesthetics (UI)	3	0	9	9	9	3	9	9	9	1
Size Adjustability	2	0	9	0	9	0	9	0	9	9
Raw Score	861	75	117	85	102	52	183	78	123	46
Relative Weight %	100	8.71	13.59	9.87	11.85	6.04	21.25	9.06	14.29	5.34
Rank Order		7	3	5	4	8	1	6	2	9
Baseline		60	10	5	5	2	100	75	0.8 L	0.003
Benchmark (Room 6)		30	20	10	10	5	50	65	0.6 L	0.005
HOQ Priority %		8.71	13.59	9.87	11.85	6.04	21.25	9.06	14.29	5.34
Tech Difficulty (1-5)		5	2	4	1	5	3	4	3	2
Target		< 30 min	> 20 %	>10 years	>10 years	> 5 years	< $50	<65 dB	< 0.6 L	<.005 m
Rationale		Time it takes to dry a certain amount of clothes	The % of our selling costs over the production and material costs	How long the fan works without breaking	How long can the material last under the use conditions	Nozzle design with fast flowing air	The price we sell the product to make a profit	Quieter sound of the fan as it moves air	Moving the length of the product to fit different closets	Air tightness and precision designs

Customer Requirements	AERODRY-APOLLOTECH	ectric Clothes Dryer - Ufen	t Hanger Rod - Oceanstar	Smart Electric Dryer - LG	ble Drying Rack- Walmart	Foxdry Air -Foxdry	le Clothes Dryer - Wayfair	s Laundry Dryer - costway	less Laundry Dryer - Vevor	
Quick to Dry	3	4	1	5	1	4	5	3	3	
College-Student Budget	5	2	5	1	5	1	3	3	5	
Clothing Compatibility	4	3	3	5	3	3	4	3	3	Expecter
Renter Friendly	5	3	5	2	3	1	5	3	5	Comp. Adv.
Energy Efficient	3	2	5	2	5	3	3	2	3	
Easy to install	5	4	5	1	4	1	4	2	4	
Visual Aesthetics (UI)	2	3	2	3	2	1	4	3	2	Comp. Adv.
Size Adjustability	4	2	3	1	4	1	1	2	1	Comp. Adv.

2.3.1 What engineering contradiction(s) are you solving for?

Some of the major engineering contradictions our team aims to troubleshoot during the iteration process are balancing improved ROI from the product with ideal fan parameters, such as low sound production and the manufacturing efficiency for ensuring an airtight product for maximum outlet velocity. This includes sourcing low-cost fans with optimal efficiency and output for our specific use case, designing easily manufacturable components, and reducing assembly complexity to require less complex methods for bringing the individual components together. Additionally, ensuring maximal tolerance proves to be a major contradiction for the design process, as improved tolerance negatively impacts ROI and selling cost. This is primarily associated with the fact that higher tolerance manufacturing processes call for more expensive equipment.

2.4 Use of TRIZ throughout iterations

The TRIZ (Theory of Inventive Problem Solving) method is a problem-solving methodology used in product design that provides a systematic and creative approach to innovation by identifying and resolving contradictions.

Product 0 (Form Factor): This prototype was made to primarily test the fitting and aesthetic aspect of the product, constituting TRIZ engineering parameters associated with form. This specifically includes the weight of the stationary object, the length of the stationary object, and the volume of the stationary object. As such, our design initially included a telescoping component and was minimally sized. Our initial material, more specifically cardboard, was a good material to use because it was lightweight, but our team anticipated that this material would directly contradict later engineering parameters, such as ease of manufacturing, strength, and durability of stationary objects.

Relevant TRIZ Engineering Parameters

- 2 (Weight of Stationery)
- 4 (Length of Stationery
- 8 (Volume of Stationery)

Product 1: This prototype was made for functional and drying efficiency analysis, including all new fans, tubing equipment, and fixturing mechanisms. First, we bought a low-speed centrifugal fan from Amazon with a circular profile compatible with a ¾ inch diameter, and scheduled 40 PVC pipe. With this, we created a long tube body with 8 ¼ inch holes, and connected one end to the fan and capped the other end. One of the main contradictions to arise with this additional step in prototyping was the balance of length and volume of stationary objects with power and durability. These primary engineering parameters proved difficult to balance, and although the TRIZ solutions recommended changing parameters of the device's structure, our team was unable to determine an effective method for implementing these suggestions and opted to lower the importance of the length parameter.

Relevant TRIZ Engineering Parameters

- 4 (Length of Stationery)
- 8 (Volume of Stationery)
- 13 (Stability of Object)
- 14 (Strength)
- 16 (Durability of Stationery)

- 21 (Power)

Product 2: For the final prototype, our team aimed to further optimize the output of our device and validate the efficacy in a general use case. After finalizing the learnings from prototype 1, our team aimed to improve the volumetric flow rate from the fan, the direction of the air, and the durability of the design. Although major components remained similar to the previous design, the fan was boosted to a much higher CPM, and nozzles were added to the holes within the design.

Relevant TRIZ Engineering Parameters

- 14 (Strength)
- 16 (Durability of Stationary)
- 21 (Power)
- 22 (Loss of Energy)
- 23 (Ease of Operation)

2.4.1.1 Substance Field Analysis

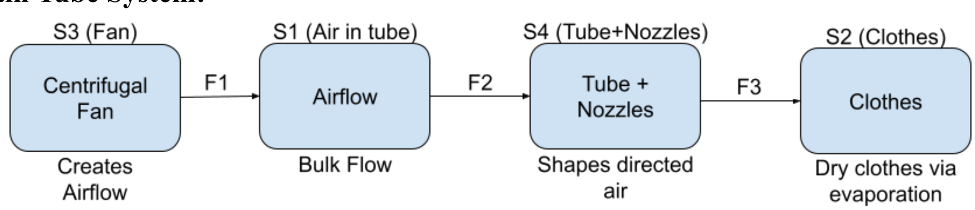
Substances (S):

- S3: Centrifugal fan (impeller + motor)
- S1: Air inlet, in tube, and jets)
- S4: Perforated tube with holes/nozzles
- S2: Clothes (damp)
- S5:Closet interior (walls/volume)
- S6 (optional improvement): Desiccant or moisture-absorbing element
- S7 (optional improvement): Humidity/temperature sensor
- S8 (optional improvement): Controller for fan

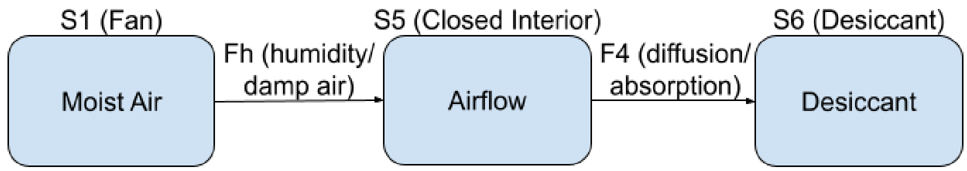
Fields (F):

- F1: Mechanical field (fan rotation → airflow/pressure)
- F2: Mechanical field (air guided, distributed, accelerated by tube/nozzles)
- F3: Mechanical + natural thermal field (air jets causing evaporation from clothes)
- Fh: Harmful humidity field (moist air increasing closet humidity)
- F4: Diffusion/adsorption field (moist air → desiccant, moisture capture)
- F5/F6/F7: Sensor and control fields (for optional smart control of fan)

Main Tube System:



Harmful System:



2.4.2 What are the historical solutions?

2.4.2.1 TRIZ solution

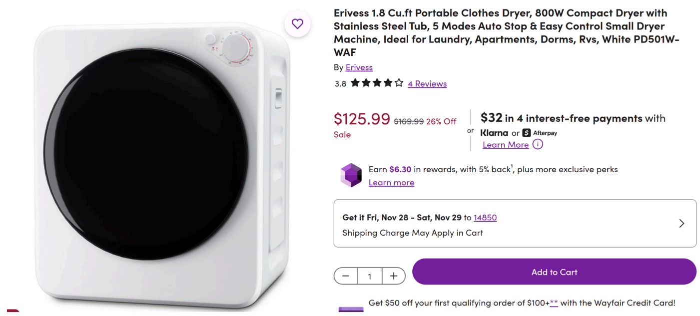
Prototype 0 Contradiction Solutions			
Improve (Right), Prevent Worsening (Below)	2 (Weight of Stationery)	4 (Length of Stationery)	8 (Volume of Stationery)
2 (Weight of Stationery)		Mechanics Substitution (28), Composite Materials (40)	Periodic Action (19), Parameter Changes (35)
4 (Length of Stationery)	Preliminary Action (10), Segmentation (1)		Parameter Changes (35), Anti-Weight (8)
8 (Volume of Stationery)	Merging (5), Spheroidality (14)	Parameter Changes (35), Anti-Weight (8)	

Prototype 1 Contradiction Solutions						
Improve (Right), Prevent Worsening (Below)	4 (Length of Stationary)	8 (Volume of Stationary)	13 (Stability of Object)	14 (Strength)	16 (Durability of Stationary)	21 (Power)
4 (Length of Stationary		Merging (5), Spheroidal, (14)	Thermal Expansion (37)	Dynamics (15), Sphereoidal. (14), Mechanics Substitution (28)	Segmentat. (1), Composite Materials (40)	N/A
8 (Volume of Stationary)	Parameter Changes (35), Anti-Weight (8)		Discarding/ Recovering (34), Mechanics Substitution (28)	Preliminary Anti-Action (9), Another Dimension (17), Dynamics (15)	Parameter Changes (35), Discarding/ Recovering (34)	Flexible Shells/ Thin Films (30), Universality (6)
13 (Stability of Object)	Inert Atmosphere (39)	Discarding/ Recovering (34), Composite Materials (40)		The Other Way Round (13), Another Dimension (17)	Inert Atmosphere (39), Local Quality (3), Feedback (23)	Parameter Changes (35), Color Changes (32), Dynamics (15)
14 (Strength)	Dynamics	Preliminary	Another		N/A	Copying (26),

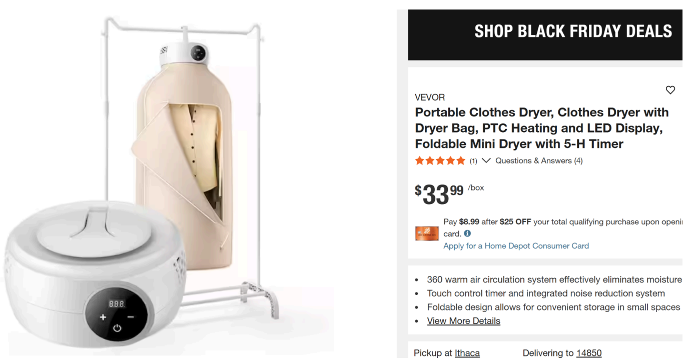
	(15), Mechanics Substitution (28)	Anti-Action (9), Another Dimension (17)	Dimension (17), Dynamics (15)			Preliminary Action (10), Mechanics Substitution (28)
16 (Durability of Stationary)	Segmentat. (1), Preliminary Action (10)	Parameter Changes (35), Discarding/ Recovering (34)	Inert Atmosphere (39), Local Quality (3), Feedback (23)	N/A		Partial/ Excessive Action (16)
21 (Power)	Equipotential (12), Anti-Weight (8)	Flexible Shells/ Thin Films (30), Universality (6)	Color Changes (32), Cheap short-living objects (27), Porous Materials (31)	Preliminary Action (10), Copying (26), Mechanics Substitution (28)	Partial/ Excessive Action (16)	

Prototype 2 Contradiction Solutions					
Improve (Right), Prevent Worsening (Below)	14 (Strength)	16 (Durability of Stationary)	21 (Power)	22 (Loss of Energy)	23 (Ease of Operation)
14 (Strength)		N/A	Copying (26), Preliminary Action (10), Mechanics Substitution (28)	Copying (26)	Preliminary Action (10), Parameter Changes (35)
16 (Durability of Stationary)	N/A		Partial/ Excessive Action (16)	N/A	Cheap Short-living Objects (27), Partial/ Excessive Action (16)
21 (Power)	Preliminary Action (10), Copying (26), Mechanics Substitution (28)	Partial/ Excessive Action (16)		Local Quality (3)	Cheap Short-living Objects (27), Partial/ Excessive Action (16)
22 (Loss of Energy)	Parameter Changes (35)	N/A	Preliminary Action (10), Parameter Changes (35)		Parameter Changes (35)
23 (Ease of Operation)	Parameter Changes (35), Mechanics Substitution (28)	Cheap Short-Living Objects (27), Partial/ Excessive Actions (16)	Mechanics Substitution (28)	Cheap Short-living Objects (27), Taking Out (2)	

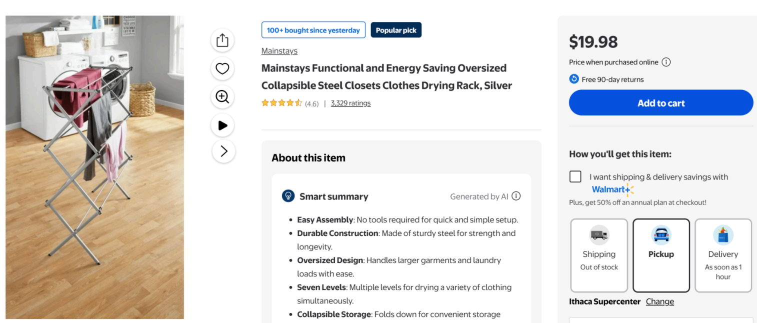
2.4.2.2 Competitor examples



[Wayfair- Erivess 1.8 Cu.ft Portable Clothes Dryer]: Our first competitor is a small portable dryer that lets users dry small batches of clothes anywhere there's an outlet. It's a convenient option for students because it can quickly dry items without needing constant oversight. However, the price is a bit high for many college budgets, and it's not a great replacement for a full-size dryer. If a student has a large load, whatever does not fit can stay damp and potentially develop mold if left unattended.



[Home Depot - VEVOR Portable Clothes Dryer]: Our second major competitor is a portable clothes-dryer bag. It's essentially an enclosed bag with hanging racks, and a fan at the top that blows air downward to dry clothes through convective heat transfer. This is a solid choice for students because it's affordable and has strong reviews, meaning it generally performs as expected. The downside is that it's bulky and takes up valuable dorm space, which is already limited for most students.



[Walmart - Mainstays Mainstays Functional and Energy Saving Oversized Collapsible Steel Closets Clothes Drying Rack] Our final competitor is a standard air-drying rack.

Users hang clothes on horizontal rods and rely on ambient convection to dry them. It's inexpensive, does not require power, and is very low maintenance. The trade-offs are that a full load of laundry may not fit on the rack, and drying times can be much longer compared to powered options.

2.4.3 What is your proposed solution?

In alignment with ApolloTech's priority of providing a solution that is compact, affordable, and compatible with the living situations of students, we chose to focus on making a simple, space-saving, affordable clothes drying product that could easily integrate into a student's residence. As a result, our proposed solution is called "AeroDry," a low-profile, modular clothes drying device that snaps onto any closet bar and can run in the background while students get on with their busy days.

2.4.3.1 How do you apply TRIZ solution to your specific problem

In order to get to this proposed solution, we utilized the TRIZ model to define the specific and relevant requirements for improving our design. After reviewing the product in the context of our core design necessities and isolating relevant TRIZ solutions, the following is the integration of the solutions towards our specific product stages:

1. **Prototype 0**: Create a Form Factor prioritizing Engineering Parameters 2, 4, & 8
    a. *Segmentation (TRIZ, 1*) - Modular assembly and disassembly played a crucial role in segmenting the body of the air chamber from the air-producing component and from the fixturing clamps
    b. *Preliminary Action (TRIZ, 10)* - All components are preinstalled/ preassembled, with the only control options being clamping the device into the closet and powering the fan by plugging into the wall
    c. *Periodic Action (TRIZ, 19)* - The fan will ideally be operated only during, dynamic components have been discussed, but would overly complicate the simplicity of the design for the device
    d. *Mechanic Substitution (TRIZ, 28)* - Replace the complex mechanisms of the fan with a simplified DC fan
    e. *Parameter Changes (TRIZ, 35)* - The major parameters involve a change in pressure, as the pressure generated from the fan into the air-tight chamber should be much higher to create high-velocity nozzle streams
2. **Prototype 1**: First iteration for functional, realistic prototype
    a. *Local Quality (TRIZ, 3)* - The open-hole method for the following prototype was inefficient for directing airflow, and as such, nozzles are needed to more specifically direct the output from the fan
    b. *Universality (TRIZ, 6)* - Improve the utility of the clamps to be more accessible for different size/ shaped clothing rods
    c. *Spheroidicity (TRIZ, 14)* - The design of the device needs to optimize smoothness to maintain better velocity profiles for air throughout the air, especially near the fan-pipe interface

d. *Partial/ Excessive Action (TRIZ, 16)* - Fan performance is far too low, and as such, excessive fan usage may be required to improve performance
e. *Mechanic Substitution (TRIZ, 28)* - Replace the DC fan system with a pneumatic system; however, this approach failed between prototype iterations, and our team returned to the DC fan system
f. *Flexible Shells/ Thin Films (30)* - For future iterations, reduce the thick schedule 40 pipe to a thinner plastic or transition towards sheet metal
g. *Parameter Changes (TRIZ, 35)* - Similar to the note for excessive action, with the fan's current low performance, the CFM needs to be boosted more

2.4.3.2 What specific technical innovation is solving your contradiction?

Four major technical innovations solve the contradiction and are related to the solutions recommended through the TRIZ method:

1. **Boosting Fan Performance**: One of the most persistent issues revolves around the fan's output performance. The device with the best fan performance was primarily the prototype V0, since the mechanism was lifted from a typical hairdryer. With future iterations, the primary technical solutions involved finding high-power, high-CFM output fans that were compatible with our general design requirements. Our greatest success was discovering a line of DC computer fans and conservatively scaling the output performance per iteration.
   Associated Design Solutions: Parameter Changes (35), Partial/ Excessive Action (16),
2. **Streamlining Outlet Airflow**: Beyond the fan output, the exit velocity of the airflow at the outlets for the device has provided two unique issues: wind intensity and focus. First, the hole diameters have proven to significantly impact the overall performance of the fan, and as such, nozzles of different diameters were produced during prototyping to determine the ideal outlet diameter. Additionally, with these nozzles, the air more directly impacts the quality of cloth-drying for individuals.
   Associated Design Solutions: Local Quality (3), Sphereoidicity (14), Parameter Changes (35)
3. **Improving Clamping Capabilities with Dynamic Fixtures:** After determining the range of closet types, our team determined that a more dynamic system was required for clamping the device onto the clothing rods. After parsing through different clamp types, from a linear clamp to a C-clamp, we settled on a zip-tie style clamp for all-purpose usage.
   Associated Design Solutions: Mechanic Substitution (28)
4. **Adaptable Sizing for Different Closets**: One of the last major concerns during customer discovery and prototyping involved creating a design adaptable in size to various closet types. As previously discussed above, this issue caused contradictions specifically between durability/power and volume/length.

Temporarily, our team designed the component to be as thin and small as possible to fit in numerous closet sizes, but we anticipate integrating telescoping capabilities to create an adaptable design for different environments.

Associated Design Solutions: Flexible Shells/ Thin Films (30), Mechanical Substitution (28)

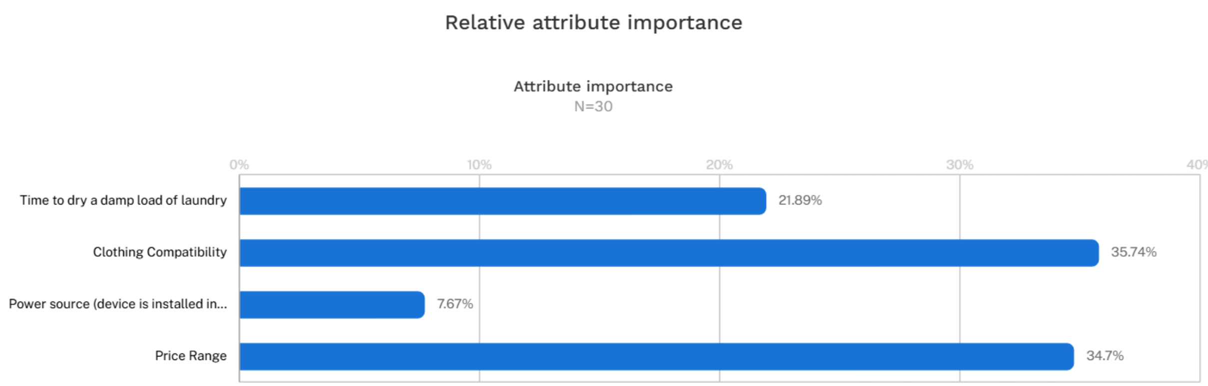
2.5 What is the embodiment of your solution?

2.5.1 Summary and analysis of Choice Based Conjoint results

To determine what features of the AeroDry product are most important to users, we conducted a Choice Based Conjoint (CBC) Analysis of the top four features of our product to determine which ones are the most important to our users. These attributes are:

1. Time to dry a damp load of laundry
2. Clothing compatibility (ie only clothes that hang on hangers, or other types of clothing items like socks and pants)
3. Power source (ie plug-in or battery powered)
4. Price

We collected 30 CBC survey responses and the results are shown here:



Time to dry a damp load of laundry

Level	Label	Utility N=30	Standard error
1	15	19.30	6.86
2	30 minutes	17.34	3.62
3	1-2 hours	-36.64	6.85

Clothing Compatibility

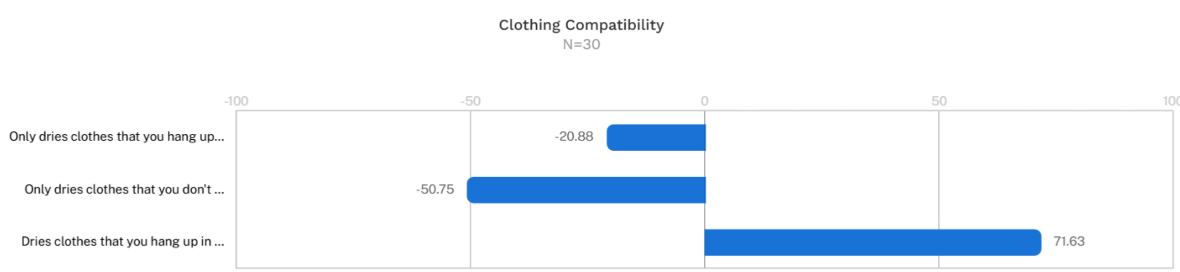
Level	Label	Utility N=30	Standard error
1	Only dries clothes that you hang up in your closet	-20.88	6.96
2	Only dries clothes that you don't hang up in your closet	-50.75	7.30
3	Dries clothes that you hang up in your closet AND clothes that you don't hang up in your closet	71.63	6.03

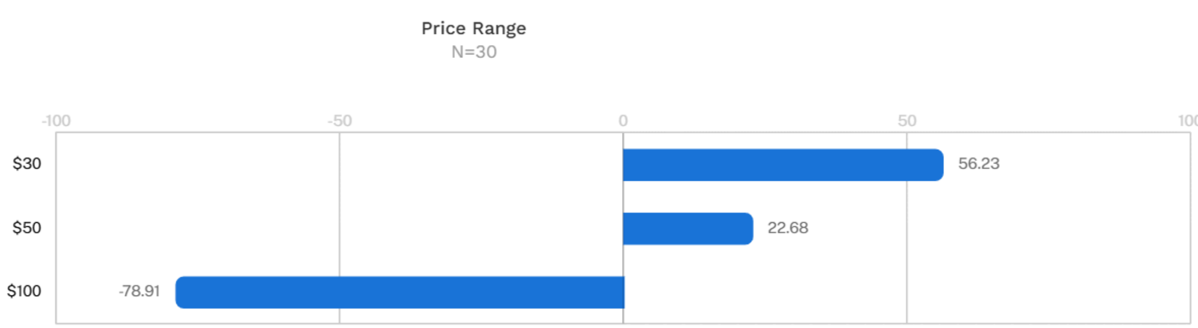
Power source (device is installed in your closet)

Level	Label	Utility N=30	Standard error
1	Battery powered (no cords)	3.79	3.14
2	Plug-in	-3.79	3.14

Price Range

Level	Label	Utility N=30	Standard error
1	$30	56.23	4.57
2	$50	22.68	4.50
3	$100	-78.91	5.61





2.5.1.1 What hypothesis was being tested?

Based on the results of the Choice Based Conjoint Analysis, we chose to make several design changes for our Design 2. First to address the customer need for the AeroDry's compatibility with clothes that you hang up in your closet and clothes that you do not traditionally hand in your closet (jeans, shorts, skirts, socks, underwear), we incorporated a hanging basket design that connect directly to the user's closet bar on which they can place non-hanging clothes and the airflow from AeroDry will still be directed toward those articles of clothing.

Although not the most important characteristic based on the Conjoint Analysis, the results also suggest that users prefer a battery-powered device rather than a wall-plug powered device. To test out the feasibility of a battery-powered option, we invested in a battery-powered air compressor that is expected to not only increase the drying performance of the device (by pressurizing the incoming airflow) but also provide a battery-powered option for the user.

2.5.1.1 Evolution of prototypes with explanations about the changes and what was being tested with each version

Product State Following Design Review 1

Following our first design review, one of the products we generated to better the lives of students was a drying rack that had the appearance of a traditional drying rack, but with a few key modifications. In our idea, the structure of the drying rack itself– the metal tubes– would be hollow, as many collapsible drying racks in the industry currently are. This hollow tubing would enable the flow of air through the drying rack's structure, and with regularly spaced holes in the metal tube frame, air could flow out along the span of the drying rack. The crux of this idea was that the active air flow built into this drying rack would accelerate the drying time of damp clothing.

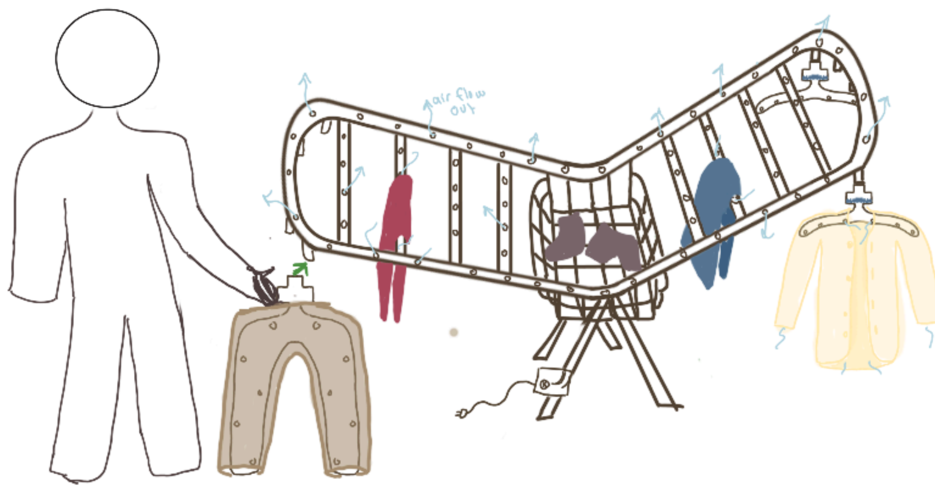


Figure 0. Concept sketch of clothes drying rack with an active air flow feature (to accelerate drying time) built into the structure of the drying rack.

Product State For Prototype 0

Given the positive feedback from our peers and from the industry advisors regarding this accelerated drying rack product, we spent additional time partaking in a more extensive idea generation process. The goal of this process was to enable us to further push what the solution we would pursue would look like, while still maintaining the key features and functionality we determined were critical to this product.

As a result of this intensive brainstorming, the design pivoted to tailor more toward our audience of students. This produced a new design concept that focused on being a simpler, space-saving, affordable product that could easily integrate into a student's residence. As seen in Figure 1, this new design concept is a tube that attaches to a closet's clothes-rod and blows air downward toward damp clothing that is hung from the clothes-rod, accelerating the drying process. The key features of this new concept involve:

- A hollow tube made of either lightweight aluminum, polyethylene, or PVC. This tube would have a telescoping feature that allows for net length adjustability and would have holes evenly dispersed along its length.
- A fan attached to one end of the tube blows air into the length of the tube. The fan will be attached to the tube via some type of custom adapter to adapt the fan's outlet geometry to the tube geometry through which the air is being directed. To direct the airflow outward and downward toward the clothes, the side of the tube not occupied by the fan would be capped, forcing the airflow out of the holes dispersed along the tube's length.
- A clamping feature that constrains the tube relative to a clothes rod of any reasonable size or shape. This component will hold the hollow drying tube component, such that the dispersed holes point downward to the clothing. Further, this clamp will mount the tube securely out of the way of regular use of the closet, by attaching the drying feature to the back side of the bar and above the hangars.

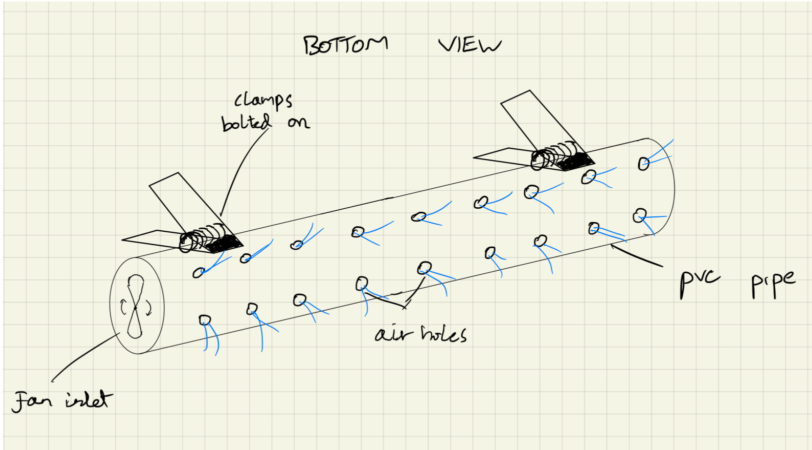


Figure 1. Initial concept sketch of simplified clothes drying tool that attaches to a closet bar.

After generating this idea, our next course of action was to begin prototyping our product in order to start identifying issues with our design. As a result, the first prototype we made– our "Prototype 0"– served mainly as a "looks like" prototype constructed from cardboard and supplies we readily had on hand, like a COTS torsion spring clamp. With these items, and with the ultimate goal of capturing the general size, shape, attachment method, and telescoping feature of our product, we generated the prototype seen below.

Figure 2. Cardboard prototype 0 - "looks like" prototype of clothes drying product.

With this prototype created, the next immediate course of action was to start testing this prototype with potential users, to get feedback regarding the basic features. Therefore, each of our group members sought out a variety of users to participate in a trial run of the product, generating a wide array of feedback stemming from the various users' personal living situations and their personal desires regarding the product, as demonstrated in Figure 3. This feedback was logged, grouped, and unpacked, informing us on the tensions that existed between our current prototype and the desired product features, exemplifying the areas needing improvement, as shown in Figure 4.

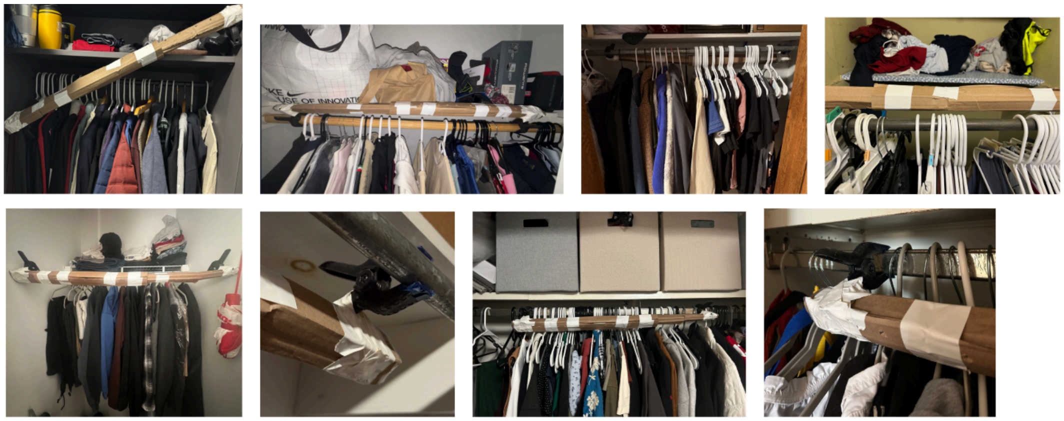


Figure 3. Subset of the images captured during prototype 0 user testing.

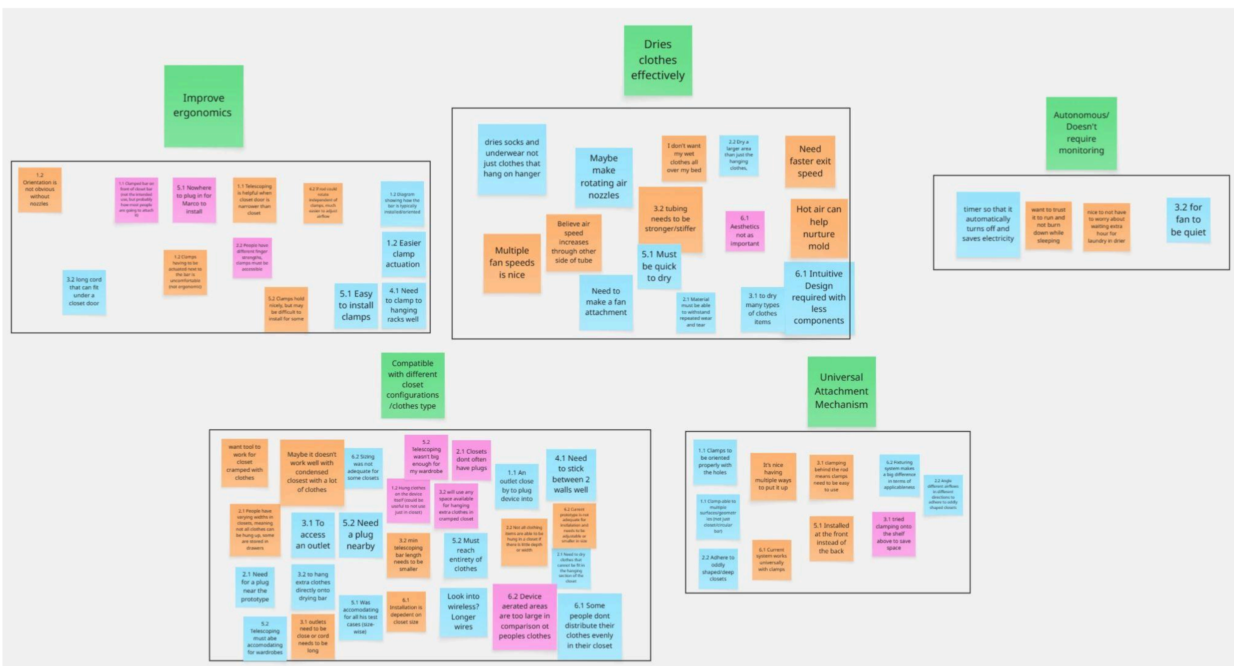


Figure 4. Prototype 0 user testing, unpacking, and modeling.

Product State For Prototype 1

Utilizing the feedback from our prototype 0, we came away with a few key features to focus on for prototype 1. In particular, the key pieces of feedback were:

- Users wanted the product to be mounted using an attachment mechanism that was universal, and could be easily adapted and installed to their particular closet clothes-rod.

- The ergonomics of the clamping mechanism of the product needed to be improved. The COTS torsion clamp already took a bit of force to open, and for the design use case of mounting the drying tube to the back of the clothes-rod (such that it remained out of the way of normal use), it turned out to be quite difficult to install, being an awkward mechanism to try to actuate without much space to maneuver and access the clamps (from the rear of the closet).
- Effective drying of their clothes was a priority; relative to the tool's ability to dry their clothes effectively, users cared less about how the product looked, considering that it was unobtrusively installed in the rear of their closet.

This user testing made it clear that, along with the smaller mounting configuration changes, it is of paramount importance to the users that the product is functional, leading us to decide to make prototype 1 as close to a "works like" prototype as possible. With our product's functional goal of accelerating drying time, this placed an emphasis on the airflow, which was dependent on the flow rate of the fan; the tube's inner diameter; the number, distribution, and size of the air-exit holes as well as the length of the rod. Additionally, to allow us to focus on implementing a working prototype, we tabled the telescoping functionality– with full intent of reimplementing it in a future prototype– to simplify our product for the time being, and give us the largest likelihood of producing a functioning device.

To narrow down the number of variables to be determined, we created prototype 1 around a COTS fan that we found, seen in figure 5, which is a centrifugal, outdoor barbecue fan that operates at 26 cfm. This helped lead us to the initial choice for the tube diameter, which we chose as a 3 ft long PVC pipe with an ID of 0.75'' and with an OD similar to that of the fan outlet.

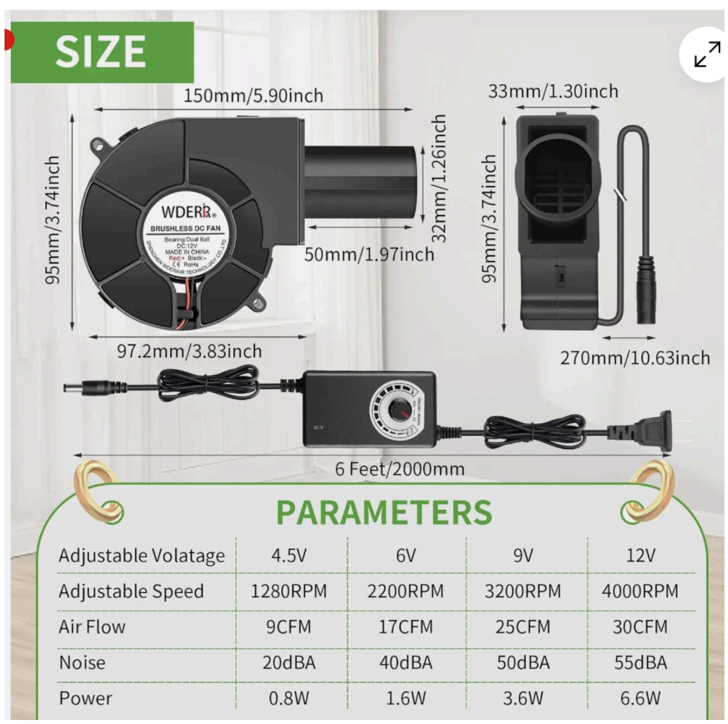


Figure 5. 12V Variable Speed Centrifugal Fan[10] designed for use for outdoor barbecues. Fan selected for use for prototype 1, purchased from Amazon.

Further, regarding choosing the air-exit hole distribution to maximize our fan's airflow and minimize any 'backflow' that would decrease our efficiency, we used a few different basic fluids equations to determine the size of each of our air exit holes along the tube's length, using principles of conservation of mass and momentum. By estimating the distribution of clothes, and with these quick calculations, we proceeded with creating 11x ¼" holes spaced out approximately every 3" of length along the tube.

With the core airflow functionality features flushed out, the next item of importance was to improve the mounting feature. For this, we chose to implement a custom 3D printed zip-tie mount with a snap-fit clamp, such that this clamp would be zip-tied to the clothes-bar, and then the PVC bar could be push-fit into the clamp. Altogether, the CAD model of the fan with the PVC pipe and the custom clamps. This model, and the associated prototype created, can be seen in Figures 6 and 7.

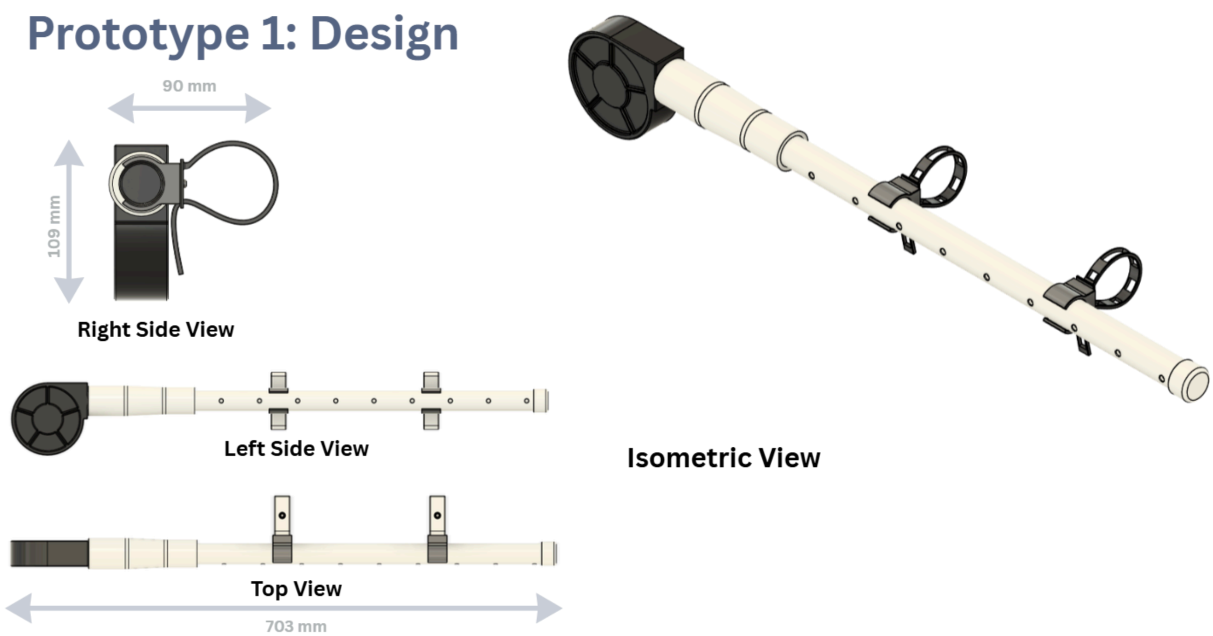


Figure 6. CAD rendering of prototype 1.

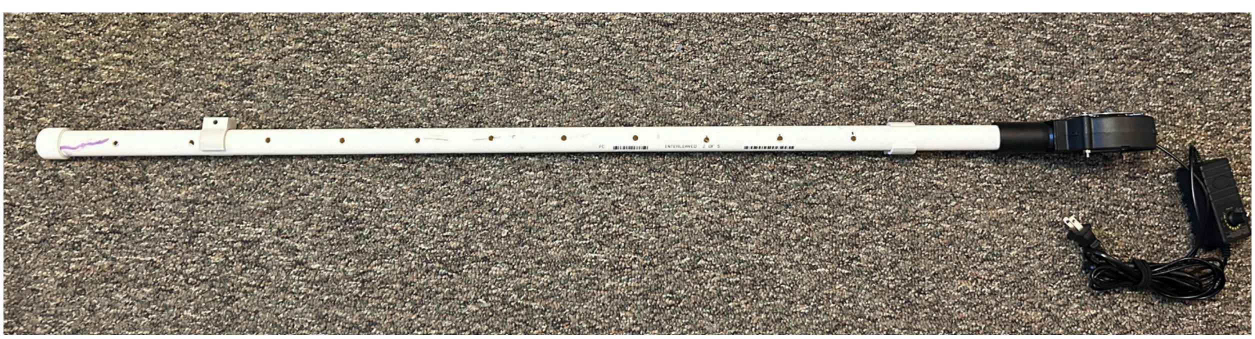


Figure 7. Photo of the physical version of prototype 1 created.

During initial testing of this prototype, we found that the outlet air through each of the air-exit holes was not particularly strong. In order to better understand the parameters that affected this outlet air speed, so that we could make more informed design changes proceeding this design, we made a 3D printed piece of test hardware. This test article is a 3D printed component that had an inlet diameter that matched the fan, meaning it could be easily integrated with the fan, and transitioned to a much smaller inner diameter for the section of tube with the air exit holes. The goal of this test article was to experimentally determine if the inner diameter of the tube had a significant impact on the velocity of the air exiting the tube. Proceeding this test, in which we compared, tactilely, the velocity of the air exiting the PVC pipe with a ¾" ID and the 3D printed test component, with a ¼" ID, we noticed no significant difference, leading us to the conclusion that changing the tube ID would have a limited impact on improving our air flow.

Regardless of the 'weak' airflow we were seeing with our PVC prototype 1, we wanted to still use the opportunity to test our working prototype and quantify initial time savings given our product. So, we proceeded with physical testing.

The PCB for the fan we initially chose broke during one of our build sessions, so we attached a hair dryer (~50-60 CFM) with a cold air setting to the PVC body of our product to mimic the performance of our original fan. We took several articles of damp clothing from a washing/drying cycle in a college town apartment and put our Design 1 to the test:

Figure 8. Test Setup of Design 1 using a Hair Dryer

The striped shirt on the far left of the image and the purple shirt on the far Right of the image are both 100% cotton T-shirts that were used as the baseline clothing item for determining the drying efficiency of AeroDry. The green sweater, flannel, and white sweater were added to the test to see the efficacy of

AeroDry on heavier-fabric clothing items. A control group of two 100% cotton T-shirts from the same washing/drying cycle as the test articles in Figure xx was hung up in the same room and left to dry with no active airflow:

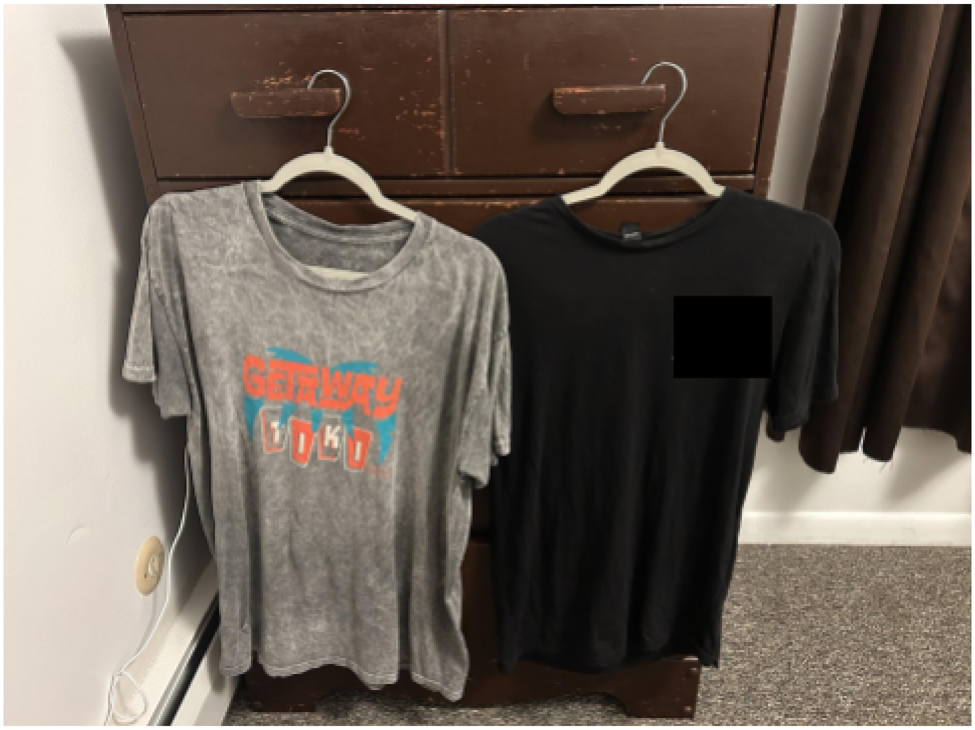


Figure 9. Control group of damp t-shirts hung to dry without AeroDry

The dampness of each article of clothing was documented for a device operating time of 1 hour:

Legend	
With AeroDry	Without AeroDry

Timestamp (hh:mm:ss)	Striped T-shirt	Purple T-shirt	Green Sweater	Flannel	White Sweater	Grey T-Shirt	Black T-Shirt
00:00:00	Damp everywhere	Damp everywhere	Damp everywhere	Damp everywhere	Damp everywhere	Damp everywhere	Damp everywhere
00:10:00	Dry to touch where there is direct air contact	Dry to touch where there is direct air contact	Less damp where there is direct air contact	Less damp where there is direct air contact	Less damp where there is direct air contact	Damp everywhere	Damp everywhere
00:15:00	Only underarm area damp	Only underarm area damp	Less damp where there is direct air contact	Less damp where there is direct air contact	Less damp where there is direct air contact	Collar & shoulders start feeling less damp	Collar & shoulders start feeling less damp

00:25:00	Completely dry	Completely dry	Bottom edges, side edges and underarm area still damp	Bottom edges, side edges and underarm area still damp	Bottom edges, side edges and underarm area still damp	Collar & shoulders start feeling less damp	Collar & shoulders start feeling less damp
00:30:00			Underarm and side edges still damp	Underarm and side edges still damp	Underarm and side edges still damp	Damp from underarms down	Damp from underarms down
00:45:00			Underarm area and arms are still damp	Underarm area still damp; rest almost completely dry	Underarm area and arms still damp	Damp from underarms down	Damp from underarms down
01:00:00			Completely dry (except underarm area)	Completely dry (except underarm area)	Completely dry (except underarm area and cuffs)	Damp from underarms down	Damp from underarms down
010:00:00						Completely dry	Completely dry

In the end, the dry time with the active airflow product was determined to be approximately 25 minutes for 100% cotton T-shirts, whereas the dry time just drying in stagnant air was approximately 10 hours. This is over a *20x decrease in drying time* with AeroDry.

There were also several interesting qualitative observations made during this testing session:

1. The orientation of the holes relative to the hanging clothes is important
    a. In this testing session, the hangers allowed the shirts/sweaters to lie in the plane of the exit holes from the device. Normal hangers do not allow this. Our next design should incorporate nozzles to efficiently direct the airflow to cover a maximum surface area over hanging articles of clothing.
2. The PVC pipe started to heat up significantly after 15 minutes of device operation.
    a. This is likely due to the highly frictional tape connection between the hair-dryer and the PVC body. In our actual and next design iteration, the fan will be attached to the PVC pipe with a well-toleranced plastic adapter that prevents motion between the fan and the PVC pipe, which we believe is the main source of the heat generation.
3. Direct airflow from the device could be felt by hand at the bottom edge of all the tested articles of clothing.
    a. This is an important feature to ensure that air is drying not just the top of the clothes, but down to the bottom edge. This result tells us that our final product should use a fan with a CFM equal to or greater than that of the hairdryer (> 60 CFM)

Product State For Prototype 2

The testing from prototype 1 was critical to our design phase. After testing, we determined that we had a few key improvements and changes to make:

1. The flow rate of our original fan was too low. Increasing the flow rate of our fan, either similar to or larger than the flow rate of the hair dryer we used for testing, would increase the success of the product in drying the clothes rapidly.
2. Directing the air more effectively at or toward the clothes could improve the product's ability to dry clothes more quickly.
3. The mounting mechanism was easy and convenient to use, but the fact that a key component– the zip tie– was not reusable was something left to be improved. Reusable mounting that could be easily adjusted and installed is an important feature to improve.

In regard to the first key improvement, we investigated different fans we could invest in. With an emphasis on improving airflow by increasing the flow rate of the fan, we ended up selecting a fan with quadruple the CFM of our first fan for prototype 2, increasing it from 30CFM to 132CFM.

Figure 10. Delta Electronics[9] 24V Axial Flow Fan used for prototype 2, purchased from Digikey.

To achieve the second improvement objective for prototype 2, we investigated the addition of nozzles to better direct the air toward the clothing. While we took the .stl of a nozzle available commercially on McMaster[11], we customized the nozzle attachment to allow it to attach to the pipe, and then we 3D printed the whole nozzle assembly. A key customization that proved to be useful in this phase of prototyping was how one component of the nozzle was permanently attached to the PVC tube, and the other portion (with the nozzle itself) was press fit, allowing us to quickly test different nozzle geometries.

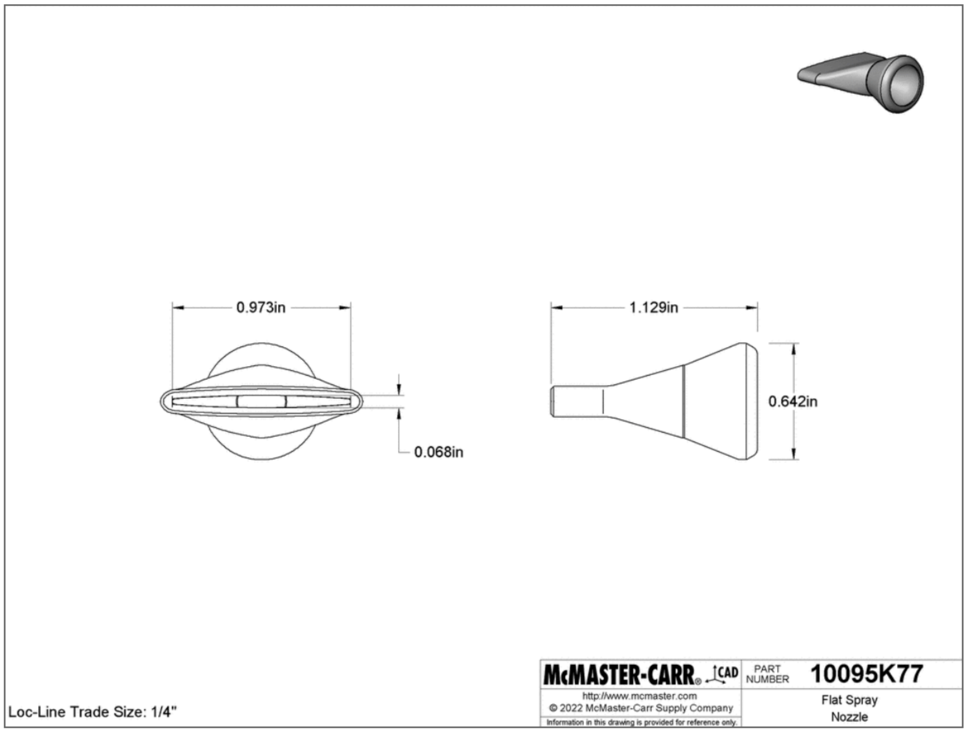


Figure 11. McMaster-Carr Nozzle Drawing, PN 10095K77 [11]

Figure 12. Isometric View of Nozzle Assembly (Nozzle rendered as transparent to show nozzle adapter geometry)

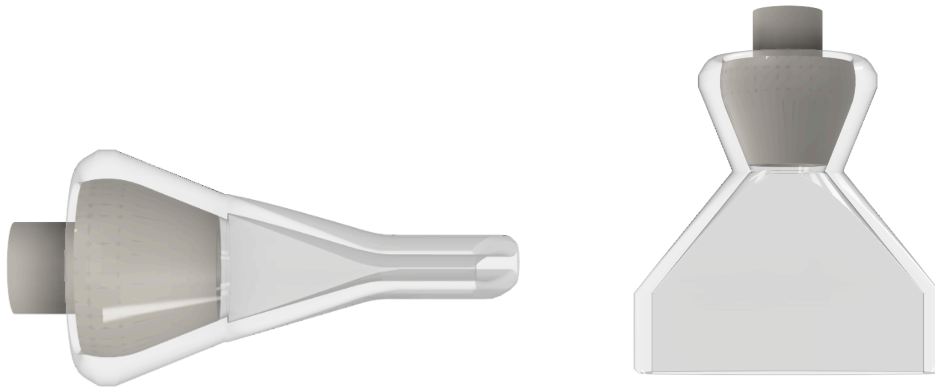


Figure 13. Custom nozzles adapted from COTS nozzles available on McMaster. Nozzles designed to be interchangeable for rapid testing capability. (Nozzle rendered as transparent to show nozzle adapter geometry)

For the third improvement goal, we explored different options for our next clamping mechanism (with the renderings seen in the figure below), as the *non-reusable* zip-ties key to the prototype 1 mounting mechanism seemed sub-optimal for the team. In the end, we decided to pursue working with *reusable* zip-ties, as seen in iteration #1, as the zip-tie feature had proved to be intuitive and quick to use in prototype 1, and was overall a lightweight solution.

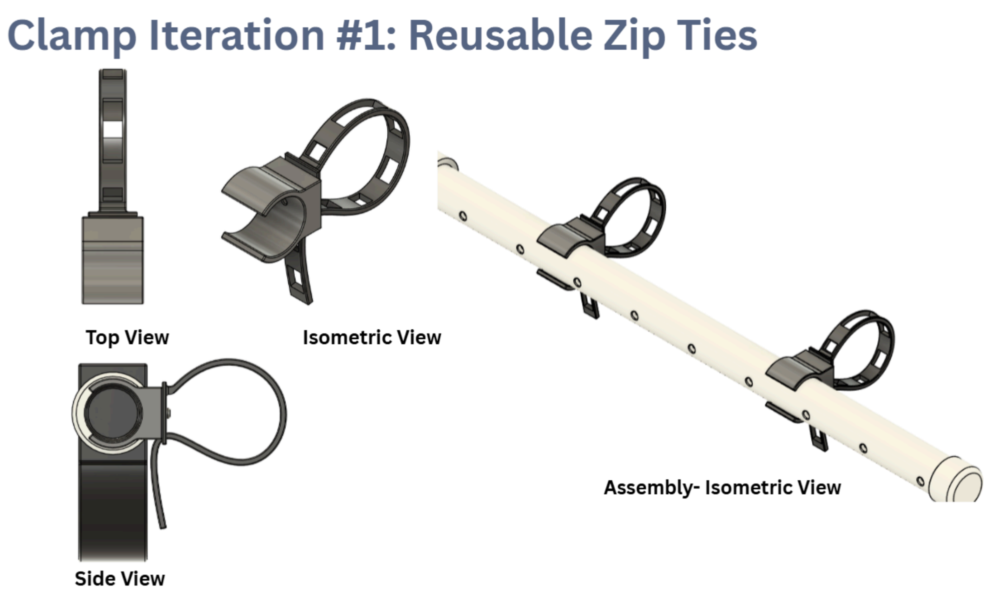


Figure 14. Renderings of clamp attachment mechanism option 1.

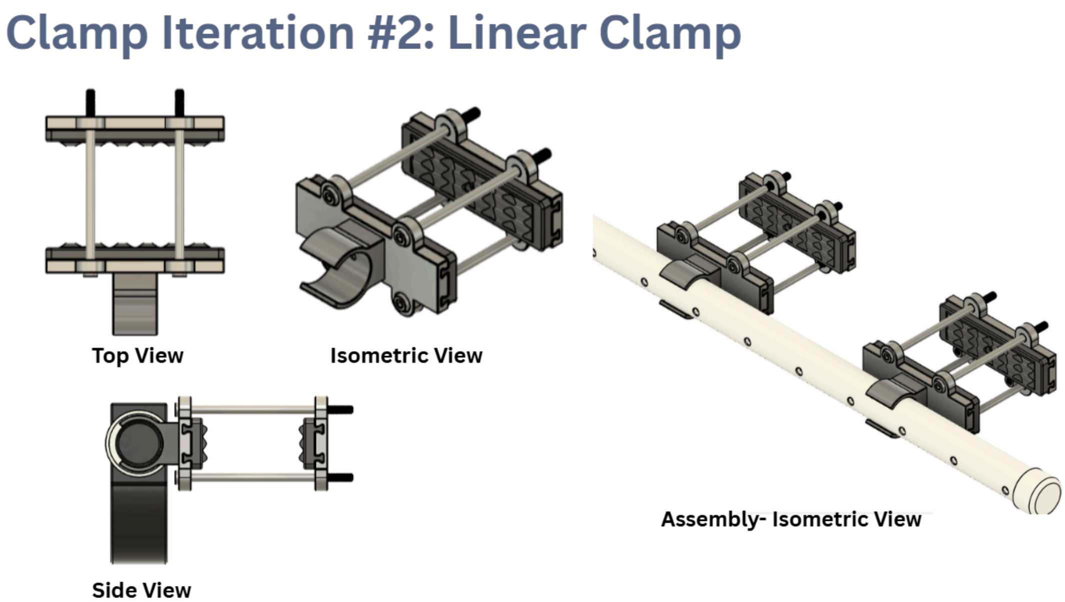


Figure 15. Renderings of clamp attachment mechanism option 2.

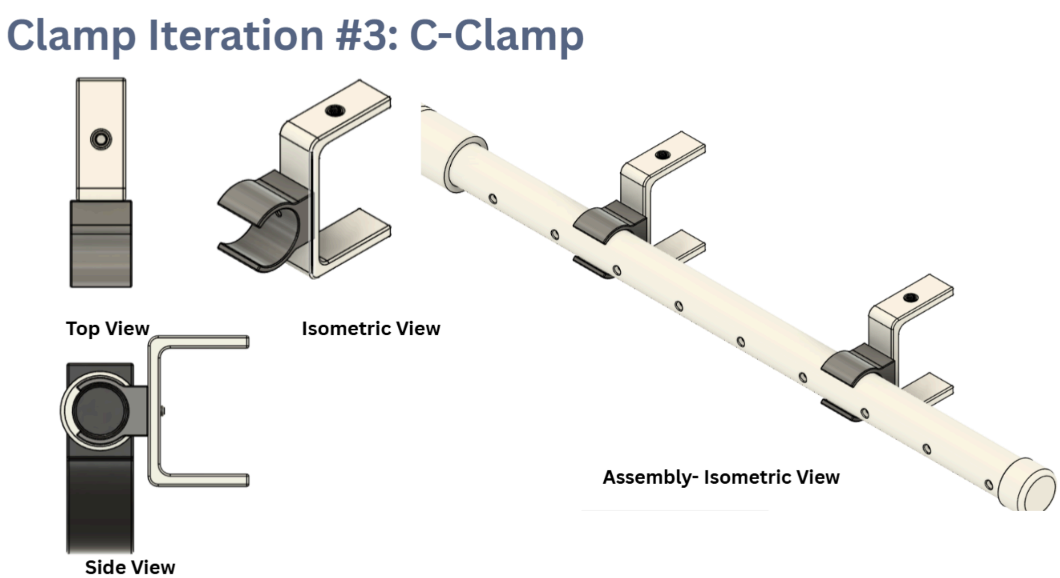


Figure 16. Renderings of clamp attachment mechanism, option 3.

Additionally, due to early user desire to have a device that could dry a variety of clothing types, we investigated the addition of a basket that could hang from the clothes-rod and could support clothing not traditionally hung, such as socks, pants, or delicate items not meant to be hung while drying. After some research, we quickly discovered that there are many affordable COTS components like the 'hanging basket' we had in mind, and so we purchased one (see figure 17 below) and tested the basket with the drying tube.

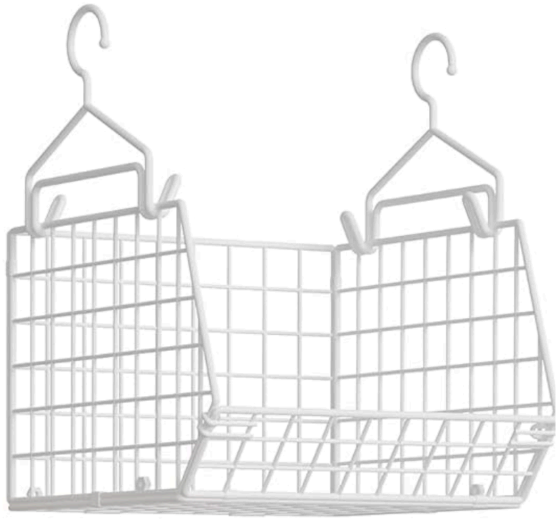


Figure 17. COTS hanging clothes basket.

In the end, prototype 2.5, with a few minor modifications from prototype 2, looked as follows:

Figure 18. Full assembly and mounted configuration of prototype 2.5.

2.6 Mechanical Analysis of Key Features

2.6.1 Analytical

Initial sizing for our prototype involved using conservation of mass to determine the appropriate hole size to ensure maximum flow through the device and minimize “backflow” due to pressure build-up in the main tube of the product. Initially, we noticed that if the air-holes were too small, pressure would build in the tube, causing air to flow back toward the fan, reducing the efficiency of the device. To mitigate this, we used the conservation of mass for a control volume:

$$\rho_1 U_1 A_1 = \sum_{i=1}^{N} \rho_i U_i A_i$$

Where *N* is the number of holes along the length of the tube. We assume here that the loss in pressure along the device is negligible.

We then developed a more refined MATLAB script to model the system with pressure losses along the length. The model predicts the pressure/velocity distribution along the length of the device to inform future iterations of the design, as well as the exit velocity through each hole, assuming a discharge coefficient of 0.5 per hole, for rough edges, which we assume for our PVC prototype. We wanted to determine how critical the losses along the length of the device are. Using the fan parameters (maximum pressure and maximum flow rate) for the fan implemented in our most recent design with 11 holes at 0.25” diameter.

The pressure of the fluid along the pipe is approximated using the Darcy-Weisbach friction factor, f_D, for pressure loss in a pipe, obtained using the Haaland equation where:

$$\frac{1}{\sqrt{f_{Di}}} = -1.8\, log\left[\left(\frac{(\varepsilon/D)_i}{3.7}\right)^{1.11} + \frac{6.9}{Re_i}\right]$$

For every hole along the length of the pipe, the loss factor f_D is recalculated and used to predict the pressure at the next hole, $p_{i+,1}$ assuming that there is negligible z-direction variation in the flow:

$$p_i + \frac{1}{2}\rho U_i^2 = \Delta B_i + p_{i+1} + \frac{1}{2}\rho U_{i+1}^2$$

$$\Delta B = \frac{1}{2}\frac{\rho U_i^2 L_i}{D} f_{Di}$$

Where L_i is the length of the pipe segment between hole *i* and hole *i+1.* The results of this analysis are shown below in Figure 20:

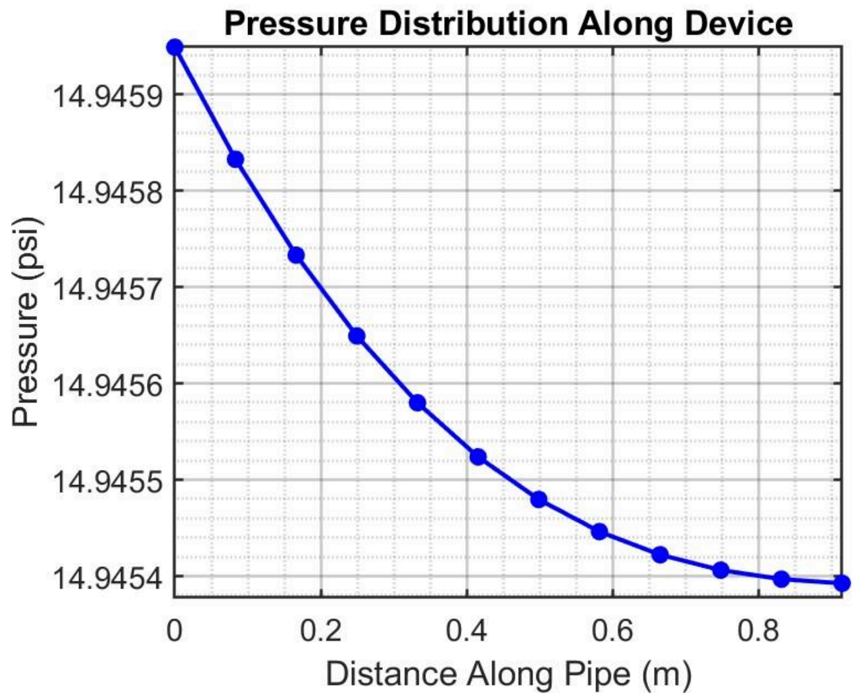


Figure 19. Pressure Distribution Along Device (Design 1 with Fan 2)

The velocity distribution of the flow and the exit velocity were approximated using an estimated discharge coefficient for each hole and accounting for the fluid loss after each hole along the length of the pipe. The pressure drop between the air in the pipe at a specific hole *i* and the ambient pressure outside the pipe is given as:

$$\Delta p = p_i - p_{atm}$$

The exit velocity of the fluid from a given hole *i* is therefore given by:

$$U_{exit} = C_d\sqrt{\frac{2\Delta P}{\rho}}$$

Where C_d is the discharge coefficient of the hole, which we assume to be constant for all the holes because they are the same size and material property. We assume a C_d value of 0.6, which is a common value for a rough-cut through a PVC pipe section [12]. The new flow rate in the pipe is found by subtracting the mass flow rate through hole *i* (calculated from the previously found exit velocity) from the total flow rate through the pipe. The results are summarized in the three figures below:

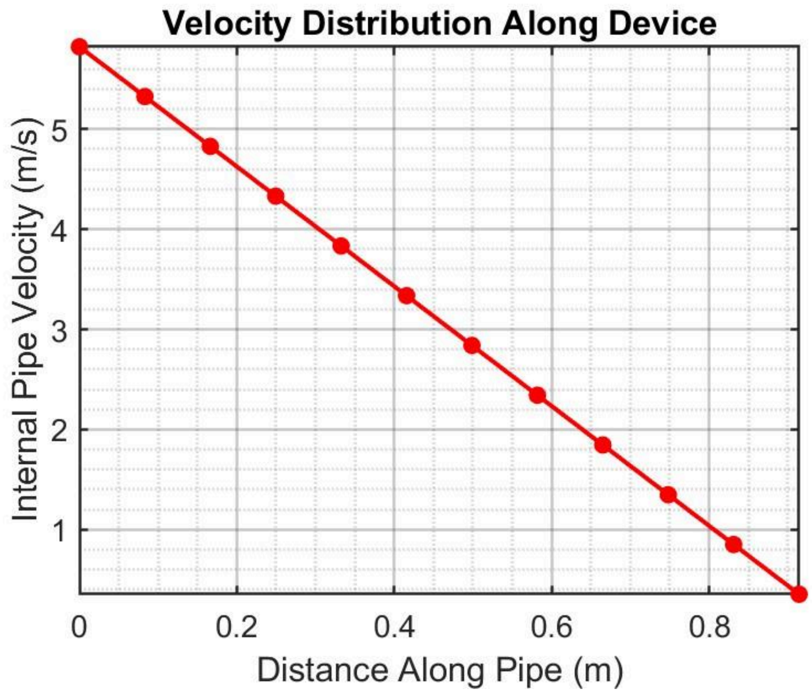


Figure 20. Velocity Distribution Along Device (Design 1 with Fan 2)

This velocity distribution makes sense because it shows that all the flow into the fan is lost through the holes, as seen by the internal fluid velocity at the end of the pipe being 0 m/s. This indicates that we properly sized our exit hole diameter to match the inlet flow rate of our fan.

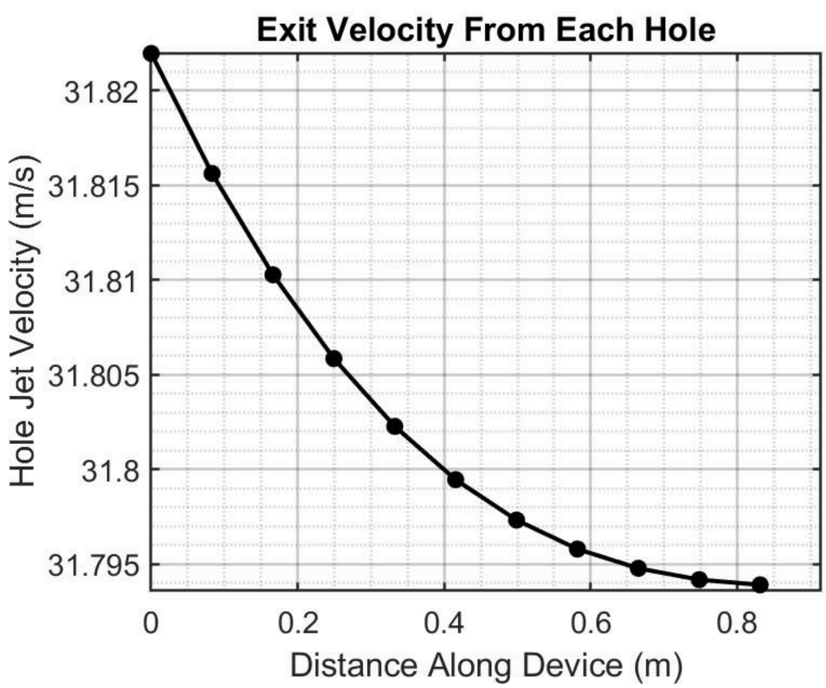


Figure 21. Hole Exit Velocity Along Device (Design 1 with Fan 2)

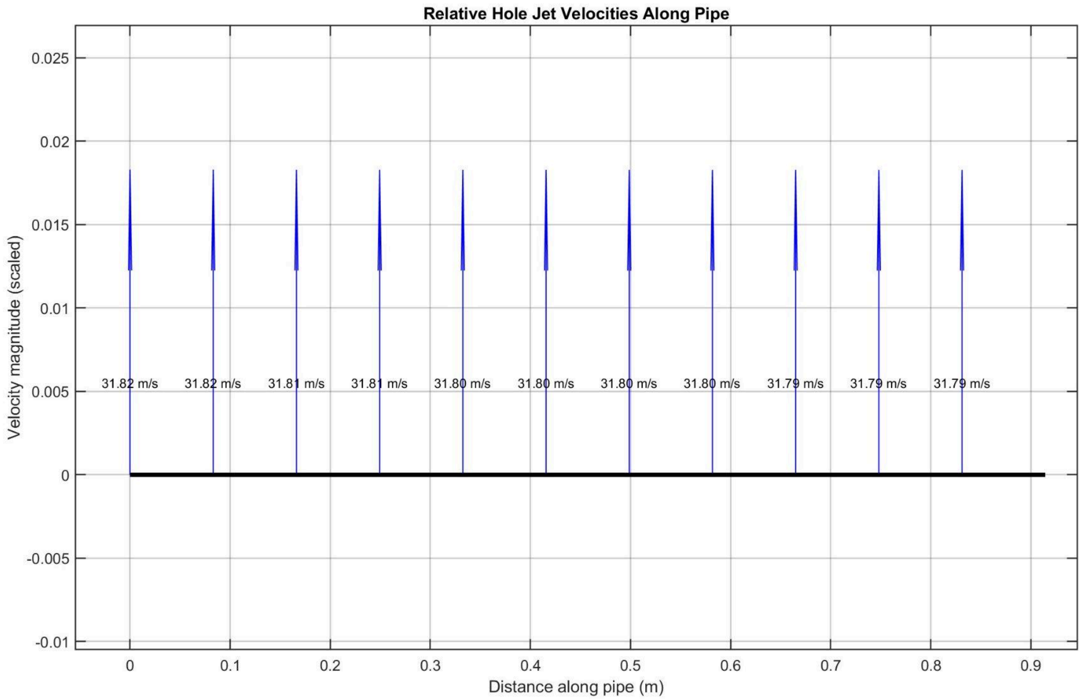


Figure 22. Visual of Hole Exit Velocity Along Device (Design 1 with Fan 2)

2.6.2 FEA

In addition to the previous MATLAB simulations, our team developed a rudimentary FEA fluid model demonstrating the profiles of air flow throughout the chamber of the device. With this, outlet velocity and streamlines within the chamber are visualized to determine preliminary efficacy and inform later design issues. Internal fluid geometry was developed in Fusion360 to model the internal area of prototype V2; boundary conditions were experimentally determined from the fan prototype V2 datasheet provided through DigiKey, and ANSYS Fluent computed the individual elements of the model. Here are the preset conditions for the model and the results of the ANSYS Fluent computation:

Geometry Details		Boundary Conditions		Air Parameters	
Hole Number	8	*Fan Volumetric (m^3/s)*	0.062	*Density (kg/m^3)*	1.225
Hole Diameter	0.25 inches	*Fan Area (mm^2)*	5026.548	*Viscosity (Pa*s)*	0.00001803
Spacing	2.75 inches	*Fan Area (m^2)*	0.00502655	*Reynolds Number*	15964.56262
Edge Space	1 inch	*Fan Velocity (m/s)*	12.33450378		*Turbulent*
Pipe Diameter	0.75 inch	*Inlet Pipe Velocity (m/s)*	12.33450378		
Pipe Area (in^2)	0.442				
Pipe Area (mm^2)	285.16				
Pipe Area (m^2)	0.000285				

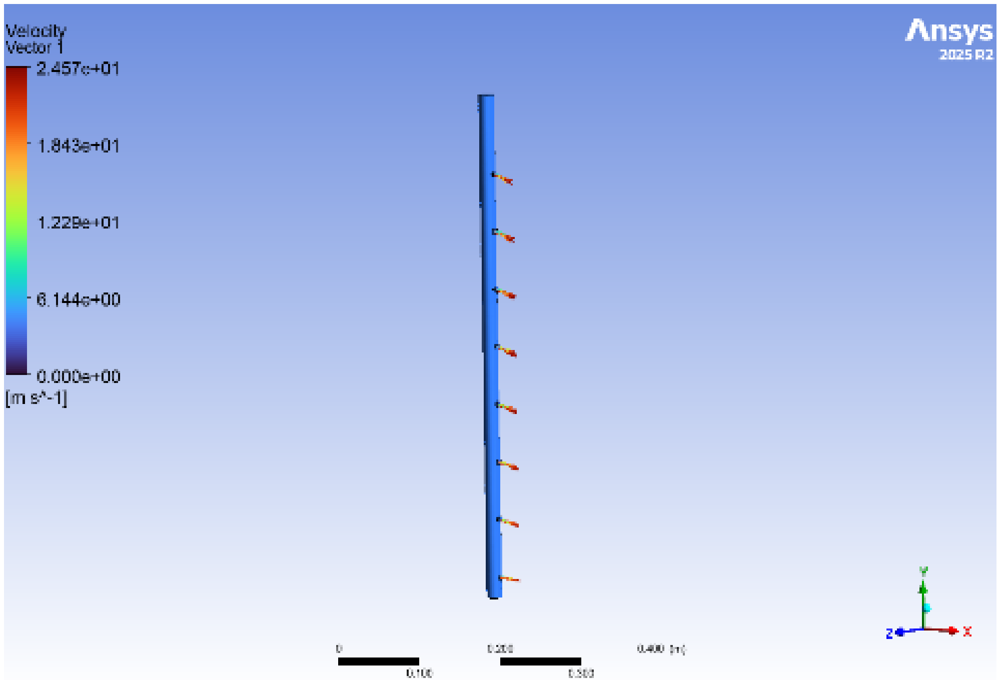


Figure 23. Outlet Velocity Vectors at the Holes of the AeroDry

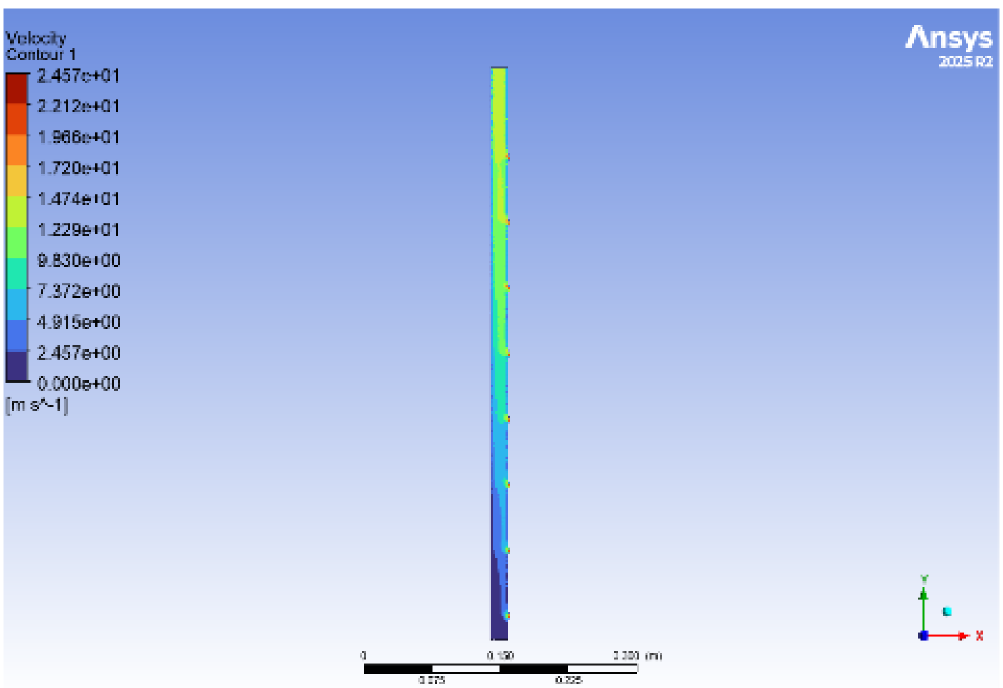


Figure 24. Outlet Velocity Contour at the Holes of the AeroDry

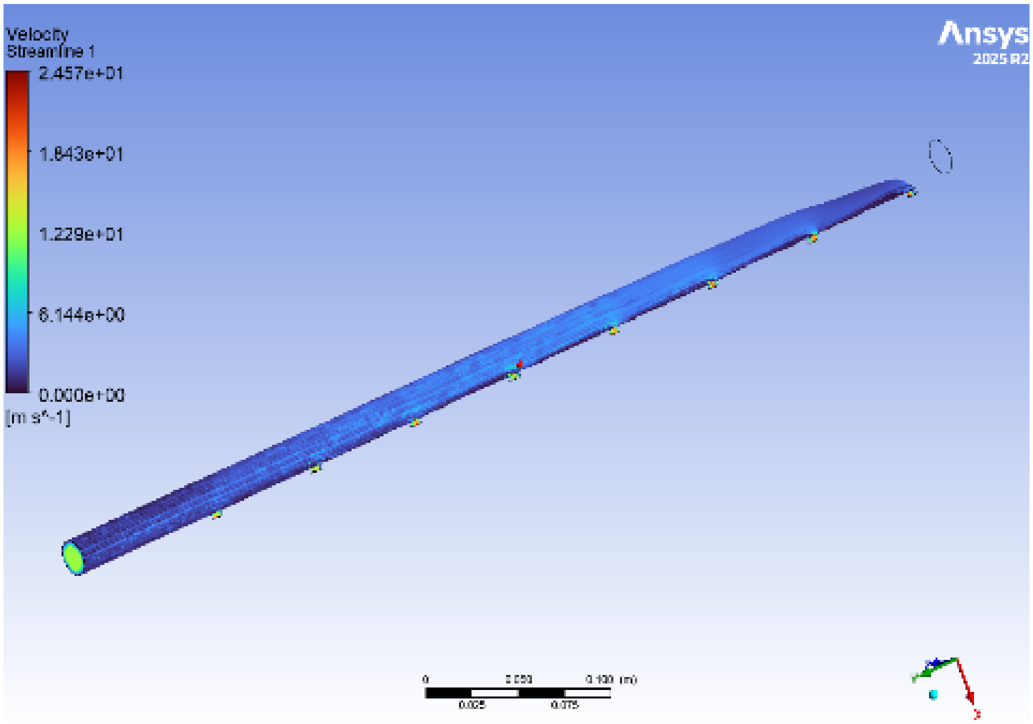


Figure 25. Velocity Streamlines of the Entire AeroDry Chamber

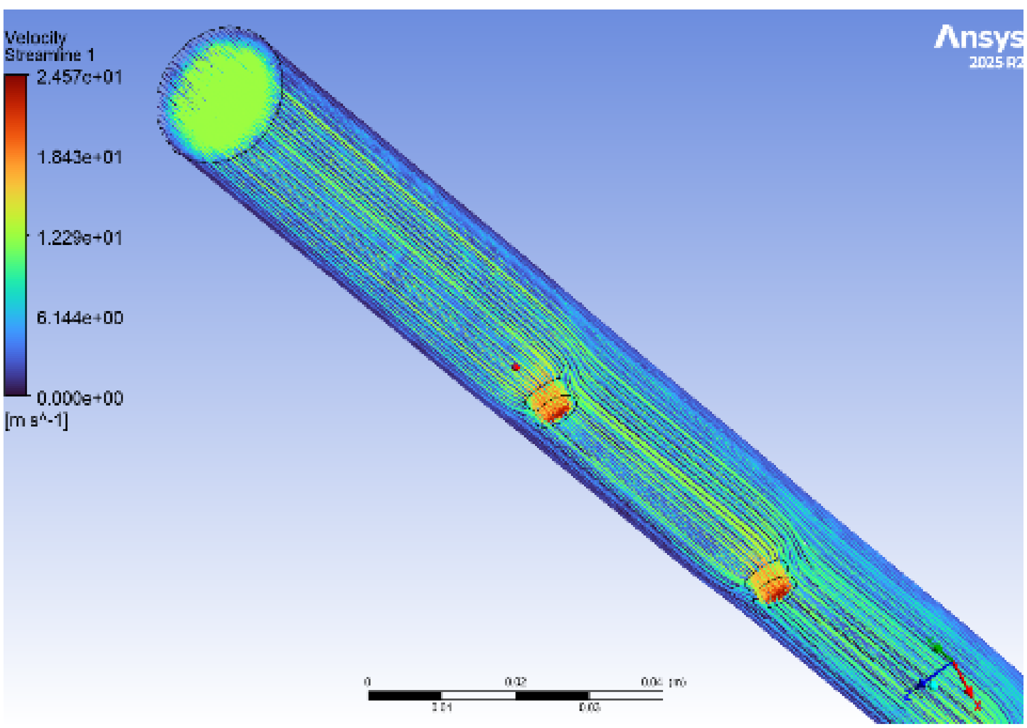


Figure *26. Velocity Streamlines for the Inlet and A Few Holes of the AeroDry*

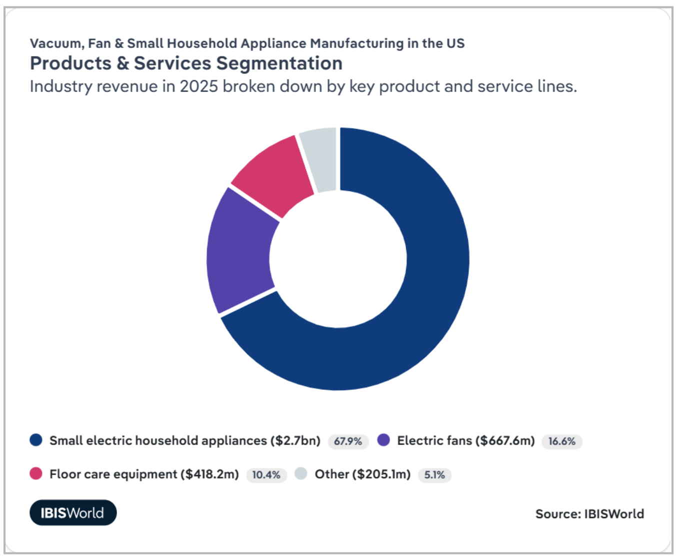
Current models have been reviewed with FEA-specialty faculty and TAs to confirm reliability. Although the outlet velocities appear on the higher end, the boundary conditions model the system based on only the maximum inlet velocity from the fan datasheet. Likely, the fan will experience a combination of lower output due to lower supply voltage (19 V vs. recommended 24 V), and low efficiency due to backflow and building static pressure in the chamber. The FEA model results for exit velocity through the holes match the order of magnitude that our analytical MATLAB model predicted, indicating agreement between our two methodologies.

3. Market Opportunity (35%)

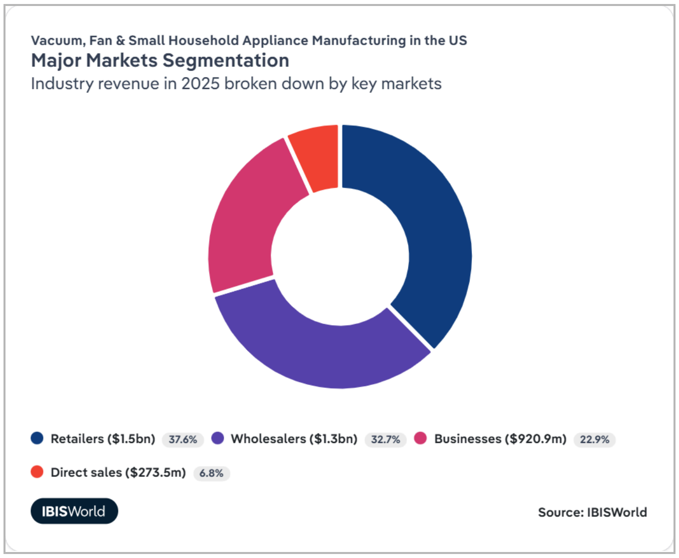
3.1 Target Market

3.1.1 Market Size – IBIS world/other market reports

AeroDry falls under the category of a "small home appliance," similarly defined as that in the Consumer Affairs Journal of Consumer Research. Although a clothes-drying device like AeroDry is not specifically mentioned in the description of "small home appliances," it is most akin to the category of "microwaves, refrigerators, vacuums, cookers or ovens and washing machines" [1]. In the United States, the market of small home appliances comprises around $4 billion annually, with an expected revenue growth of 0.1% over the next 5 years[2]. Of the category of small home appliances, "small electric household appliances" make up 67.9%, which is the exact category AeroDry falls under, which suggests that we are targeting the most popular category within all small household appliances.



The breakdown of small household appliances and their respective markets suggests that we should focus our business model on selling AeroDry to large retail stores and wholesale distributors like Costco, Sam's Club, and Amazon, in addition to selling our product through our personal website. Using this strategy, we target over 77% of the market for similar products [2].



It is noteworthy that this data speaks to the entire US market, not the subset of college students that our product is specifically targeted for. Therefore, we are additionally optimistic that our true customer base will produce more favorable numbers, considering that the problem that AeroDry solves is a specific pain point experienced by our customer base, as evidenced by our empathy field work data points and prototype testing results.

3.2 House of Quality – Competitive Analysis

	Customer Requirements	AeroDry-Apollotech	Portable Foldable Electric Clothes Dryer - Uten	Metal Portable Adjustable Closet Hanger Rod - Oceanstar	Smart Electric Dryer - LG	Collapsible Drying Rack-Walmart	Foxdry Air -Foxdry	Portable Clothes Dryer - Wayfair	Electric Portable Ventless Laundry Dryer - costway	Electric Portable Ventless Laundry Dryer - Vevor	
Relationship Matrix	Quick to Dry	**3**	**4**	**1**	**5**	**1**	**4**	**5**	**3**	**3**	
	College-Student Budget	**5**	**2**	**5**	**1**	**5**	**1**	**3**	**3**	**5**	
	Clothing Compatibility	**4**	**3**	**3**	**5**	**3**	**3**	**4**	**3**	**3**	**Expecter**
	Renter Friendly	**5**	**3**	**5**	**2**	**3**	**1**	**5**	**3**	**5**	**Competitive Advantage**
	Energy Efficient	3	**2**	5	2	**5**	3	3	2	3	

	Easy to install	5	4	5	1	4	1	4	2	4	
	Visual Aesthetics (UI)	2	3	2	3	2	1	4	3	2	Competitive Advantage
	Size Adjustability	4	2	3	1	4	1	1	2	1	Competitive Advantage

Our competitive analysis revealed that customers of laundry drying products expect complete clothing compatibility; their product should be able to dry all clothing types. It also revealed that this product could fill the following competitive advantages:

- Renter-friendly: the most effective products on the market require permanent installation or a long set-up time. AeroDry is designed to be a one-time, quick installation that can be removed by renters easily.
- Visual aesthetics: AeroDry has the potential to address a lack of visual aesthetics in its competitive advantage. It is designed to work sight unseen since it is installed inside your closet.
- Size adjustability: Most competitor products are one size and feature no size customization. Aerodry will feature telescoping to allow it to be adjusted to most closet widths.

3.3 Pricing Policy

3.3.1 Derived from Conjoint and other observations

The results of our conjoint analysis suggest that customers are willing to pay up to around $50 for AeroDry, given that it offers more desirable features like battery power and attachments for smaller clothing items. Considering that our ideal, final design of the product incorporates both a battery power source and a basket attachment for non-hanging clothing items, our pricing of $80 per unit, based on manufacturing costs, is consistent with our CBC price analysis range.

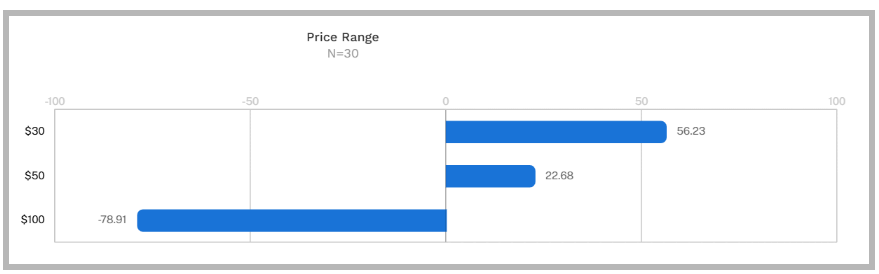


Figure 27. CBC Analysis Results for Product Price

3.4 Bass Model Forecasting to predict product demand

Historical data for similar household appliances/gadgets are not readily available based on our literature review, and since our product has not yet been introduced to the market, we do not have historical data to utilize in our Bass Model Forecasting. However, using a generative AI agent[12], we settled on the following inputs:

Parameter	Value	Value Justification
Coefficient of Innovation (p)	0.015	A typical value of p for clothes dryers is 0.017, and we are choosing a slightly lower value in our scenario to account for the fact that this is a new device/technology, so it will likely take longer to take hold [12].
Coefficient of Adoption (q)	0.35	A typical value of q for "consumer durables" is 0.35, which we are choosing as representative of our product. A value of 0.35 is on the lower end of typical q values for consumer products, so we are being conservative in this estimate [12].
Contact Rate	22/day	Del Valle, Sara & Hyman, James & Hethcote, Herbert & Eubank, SG, 2007 created a mathematical model to predict the average number of daily contacts made as a function of age group[8]. The age range of 18-30 years old is 22 people/day.
Population Size	50,000	Data published by the National Student Clearinghouse Research Center estimates that 18.4 million students were enrolled in undergraduate and graduate programs across the United States in the Spring of 2025[7]. The software enables up to 50,000 agents in the model, so we used this maximum value.

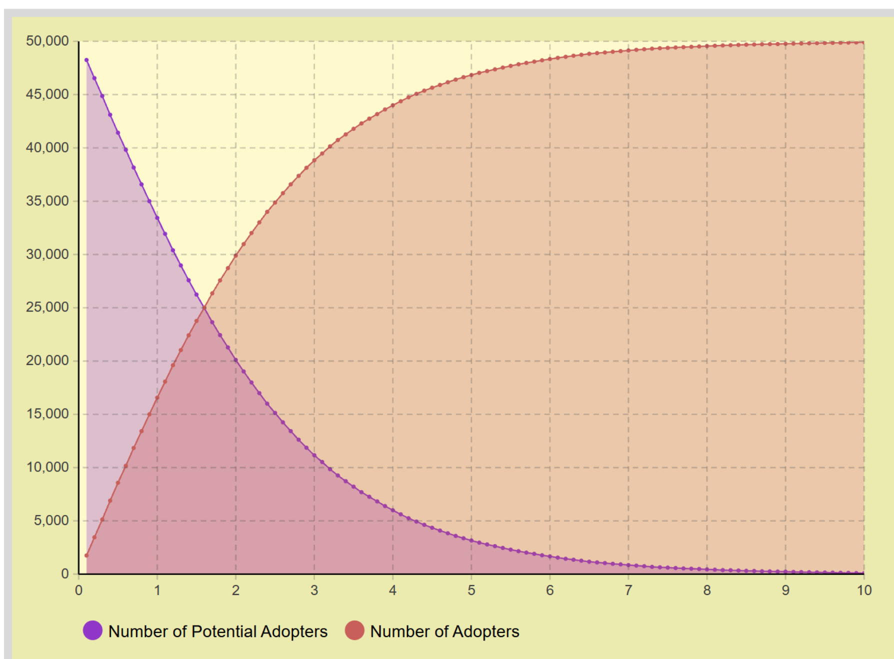


Figure 28. Bass Model Forecasting Adoption Prediction

The results of the Bass Model suggest that the number of adopters will increase for around 8 years before reaching a steady state value that is maximized at our population size of 50,000 agents. At around 1.6 years after the product reaches the market, the number of adopters will begin to exceed the number of potential adopters in our sample size.

3.5 Production Costs

3.5.1 What manufacturing process will you use? Justify using charts from manufacturing lectures

The primary manufacturing process will involve a combination of injection molding with thermoplastic polymers and assembling the base components. Injection molding proved an effective method for our parts since they have low complexity, relatively low weight (0.1 - 1 kg), and do not require specialty finishes. For a majority of the injection molding components, HDPE was selected as a generic plastic for this low-intensity use case. For the clips specifically, LSR was selected as an alternative for the TPU used in prototyping to replicate to flexible attributes required for fixturing. More specifically, we are targeting an LSR with flexibility similar to 50A shore silicone.

3.5.2 Tooling parameters and costs

The following metrics for volume are based on the assumption that the initial scaling phase would require 1000 devices, a figure comparable to other similar start-ups. From this, our initial estimates provide net material cost, production costs, tooling estimates, and expected unit cost.

Item	Quantity	Production Method/Source	Material	Production	Tooling	Total	Cost/Unit	CPU
Clips	2000	Injection Molding from HDPE	$1,603.83	$91.55	$800.00	$2,495.38	$1.25	$2.50
Tube	1000	Injection Molding from HDPE	$2,834.22	$91.55	$790.00	$3,715.77	$1.86	$1.86
Tube Cap	1000	Injection Molding from HDPE	$585.37	$91.55	$200.00	$876.92	$0.44	$0.44
Nozzles	20000	Injection Molding from HDPE	$2,723.58	$735.58	$500.00	$3,959.06	$0.20	$1.60
Nozzle Adapter	20000	Injection Molding from HDPE	$1,224.00	$735.58	$500.00	$2,459.58	$0.12	$0.96
Fan Grill	1000	Injection Molding from HDPE	$2,834.22	$91.55	$500.00	$3,425.77	$1.71	$1.71
Fan Adapter	1000	Injection Molding from HDPE	$4,161.96	$55.77	$900.00	$5,117.74	$5.12	$5.12

							Total Per Unit	**$14.19**

3.6 Cost of Goods Sold

3.6.1 Materials, labor, off-the-shelf components

Item	Quantity	Source	Pack. Units	Total Costs	Unit Cost	CPU
Delta Electronics Axial 24V DC Fan	1000	DigiKey	1 (Discounts at High Units)	$19900.00	$19.90	$19.90
18-8 Stainless M3 8mm Thread Forming Screws	2000	MacMaster-Carr	80 (25 per PCK.)	$1133.60	$0.57	$1.13
18-8 Stainless M4 20 mm Socket Head Screw	8000	MacMaster-Carr	800 (100 per PCK.)	$109.00	$1.09	$8.72
M4 Steel Nut	8000	MacMaster-Carr	800 (100 per PCK.)	$2488.00	$0.31	$2.49
Flexible Zip Ties	20000	Amazon	2 (1000 per PCK.)	$221.98	$0.11	$0.22
					Total Per Unit	**$32.56**

Production Parameters for US Operation (Neglecting Indirect Costs)	Estimated Cost
Mean Production Worker (From BLS, 2024) (Direct Costs)	$19.90/hr
Estimated Assembly Time	0.25 units/hr
Production Cost	$4.98/unit

Unit Cost Components	Unit Estimate (CPU)
Injection Modelling (Material/ Production) Costs	$14.19

Off-the-Shelf Costs	$32.56
Assembly Production Costs	$4.98
Total Expected CPU (No Revenue)	$51.73

3.7 Net Present Value detailed analysis

Based on the spreadsheet, the project's NPV comes out to about $3.8 million, which indicates that the product still generates more value than it costs over its full timeline. Compared to the model's $10 million base NPV, the current scenario is about 62% lower, mainly because of the higher upfront burn rates during development, testing, and market introduction.

Even with that reduction, the NPV remains strongly positive, which suggests the project is still financially viable. The long sales period—from months 9 through 60—and the solid margin between the unit price ($35) and unit production cost ($8) help drive profitability. With a 10% discount rate already accounting for risk and time value, the analysis shows that as long as sales hold steady, the product can realistically create meaningful economic value.

4. Legal Requirements (10%)

4.1 Required or Recommended Certifications

- ENERGY STAR Certification:
    - Recommended for energy efficiency considerations: "To earn the ENERGY STAR label for products, manufacturers are required to sign a formal agreement with EPA and products must be third-party certified against strict performance requirements" [5].
- Underwriters Laboratories (UL) certification
    - UL507, required for electric fans: "UL certification is only necessary for products that plug into an AC power outlet. Most battery-powered products need to have their battery recharged at some point with an AC power outlet" [3].
- Air Movement and Control Association (AMCA) Certification
    - "The AMCA Certified Ratings Program ensures products meet designated ANSI/AMCA standards through periodic checks and retesting" [6]
- NSF Protocol P154: Sanitization Performance of Residential Clothes Dryers
    - "establishes minimum performance requirements for residential clothes dryers to demonstrate their ability to sanitize washed laundry when dried on the unit's sanitation cycle. The protocol also confirms there is no significant carryover of bacteria or contamination into future dryer loads" [4].
- NSF Protocol P407: Fans for Home Use
    - "establishes minimum protection and safety requirements for the materials, design, construction, and performance of electric fans intended for sale in the retail consumer market. This includes box, tabletop, blower, and pedestal fans. Fans can be made of one or more of these materials: metal, plastic, wood, ceramic, and natural or synthetic fiber" [4]

4.2 Potential Liability Issues

Liability	Description	Design Mitigation
Electrical fire	Internal short circuits can lead to an electrical fire, which, if it occurs when the device is unattended, can lead to fire damage and even death.	The product's electronics are housed to be completely insulated from outside conditions, and a warning is included on the device packaging to inform users of potential fire hazards.
Injury from rotating fan blades	Injury resulting from loose clothing or body parts (fingers, hair, etc) getting caught in the rotating element of the fan. Can result in serious injury or death.	The product features a completely shrouded fan, with the upstream of the fan being guarded by a grid to prevent users from accidentally coming into contact with the fan blades.
Injury from loud noise	Injury resulting from loud noises that are released if the air compressor is disconnected from the main flow line of the device due to an anomaly of usage or damage. It can result in ear pain, partial, and even full hearing loss.	Ensure connection between the air compressor and the main body of the device via a threaded NPT connector to prevent disconnection due to jostling and rough handling of the device.
Mold growth	Running the device in a space with no air circulation, like a bathroom with no fan or a completely closed closet, could lead to mold growth on the device, which will continue circulating if not cleaned. Risks include illnesses from breathing in mold.	Include instructions in the user manual that the device should be operated in an open-air space/with the user's closet door open to eliminate the risk of mold growth.
Electrocution	Users could be at risk of electrocution if they touch any exposed wires.	Provide safety warnings in the manual. Use a fuse to prevent the current from getting too high.

4.2.1 Prediction of Misuse Cases

Case No.	Misuse Description	Risk	Mitigation
1	Running the product with the closet door completely closed so no air circulation is allowed.	Low efficiency in clothes drying ability of the device and potential risk of mold buildup on clothes and inside the tubing	Include instructions in the user manual that the device should be operated in an open-air space/with the

		of the device.	user's closet door open.
2	Swinging the device around/holding the device while the fan is running.	Clamp and connection damage due to rough handling. It may result in injury to the user if the swinging device comes in contact with a person.	Include a warning in the user manual that the device should not be handled while in use/used for any purpose other than the intended purpose.
3	Using the device on clothes that have not been put in the dryer at all (soaking wet clothes).	Drying time that exceeds the predicted drying time because the device is designed to dry damp clothing that has already been run through a dryer.	Include instructions in the user manual that the produce (and the advertised drying time) is based on damp clothing, not wet clothing.
4	Adding water to the device tube to induce a "steaming" function into the airflow of the device.	Water damage to the electronic internals of the device and potential mold buildup in the tube due to excess moisture.	Include a warning in the user manual that water should not be added to the device in any way.

4.2.1.1 Failure Modes and Effects Analysis

Process Step/Input	Potential Failure Mode	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?				
Product Operating Conditions	**Operating the product in a tightly closed-air space (like a closed closet door)**	7	3	2	42
Product Operating Conditions	**Swinging the device around/holding the device while the fan is running.**	7	3	2	42
Product Operating Conditions	**Electrocution**	10	1	2	20
Product Operating Conditions	**Electrical Fire**	10	3	2	60

Product Set Up	**Using the device on clothes that have not been put in the dryer at all (soaking wet clothes).**	3	8	2	48
Product Set Up	**Adding water to the device tube to induce a "steaming" function into the airflow of the device.**	9	2	2	36

4.3 Intellectual Property Considerations

4.3.1 Pursue Utility, Design patents? Why?

- Patentable Subject Matter:
  - Attachable clothes dryer device that can be integrated directly onto most hanging closet rods.
- Not previously sold or publicly described:
  - There are no clothes drying devices on the market that attach to one's closet hanging rod.
- Novel:
  - Patent research shows that there exists only clothes dryer closets: as in, the drying functionality is built into the closet, thus neither removable nor customizable.
  - Prior Art Citation, Current/Existing Patents:
    - JP4858321B2 - Clothes dryer - Google Patents
    - US11591746B2 - Clothes care apparatus and control method thereof - Google Patents
    - CN218910890U - cabinet dryer - Google Patents
    - US9410281B2 - Fabric treating systems and accessories - Google Patents
    - KR20090066992A - A well-dried machine - Google Patents
    - KR20060038796A - Clothes dryer integrated laundry device - Google Patents
    - US4572364A - Clothes drying garment bag - Google Patents
    - US10273626B2 - Portable, collapsible clothes dryer - Google Patents
    - KR20070096416A - Hanger with built-in iron for steam - Google Patents
- Useful:
  - The intended use case is to create an adaptable clothes-drying product to be useful for most hanging closet rods.
- Not obvious:
  - The combination of features: air flow, fan adjustment, size adjustable for one's closet, and a simple rod design makes this not obvious

4.3.2 Trade secrets

Much of the design is mechanical and thus unable to be a trade secret. It could be taken apart by anyone, and the design could be copied. The software is also not novel: it is just a control loop to set the fan speed and a set a timer based on the user's input.

5. Sources (5%)

5.1 Bibliography (APA format)

[1] ConsumerAffairs. "Home appliance industry statistics 2025 [2024]" ConsumerAffairs.com. Mar. 27, 2024, https://www.consumeraffairs.com/homeowners/home-appliance-industry-statistics.html

[2] IBISWorld. (n.d.). *Products and markets: Industry 33521*. Retrieved December 1, 2025, from https://my.ibisworld.com/us/en/industry/33521/products-and-markets

[3] Teel, J. (n.d.). *Understanding certifications for electronic hardware products*. Predictable Designs. Retrieved December 1, 2025, from https://predictabledesigns.com/understanding-certifications-for-electronic-hardware-products/ (predictabledesigns.com)

[4] NSF. (n.d.). *Home products protocols and standards*. Retrieved December 1, 2025, from https://www.nsf.org/nsf-standards/standards-portfolio/home-products-protocols-standards

[5] EPA. (n.d.). *ENERGY STAR Certification*. In How ENERGY STAR works. Retrieved December 1, 2025, from https://www.energystar.gov/about/how-energy-star-works/energy-star-certification (energystar.gov)

[6] AMCA International. (n.d.). *Certify — AMCA Certified Ratings Program*. Retrieved December 1, 2025, from https://www.amca.org/certify/

[7] National Student Clearinghouse Research Center. (2025, May 22). *Current term enrollment estimates*. Retrieved December 1, 2025, from https://nscresearchcenter.org/current-term-enrollment-estimates/ (nscresearchcenter.org)

[8] Del Valle, S. Y., Hyman, J. M., Hethcote, H. W., & Eubank, S. G. (2007). *Mixing patterns between age groups in social networks*. *Social Networks, 29*(4), 539–554. https://doi.org/10.1016/j.socnet.2007.04.005 (researchgate.net)

[9] Delta Electronics. (n.d.). *PFB0824DHEP0 — 80×80×38 mm 24 VDC axial fan*. DigiKey. Retrieved December 1, 2025, from https://www.digikey.com/en/products/detail/delta-electronics/PFB0824DHEP0/21556251

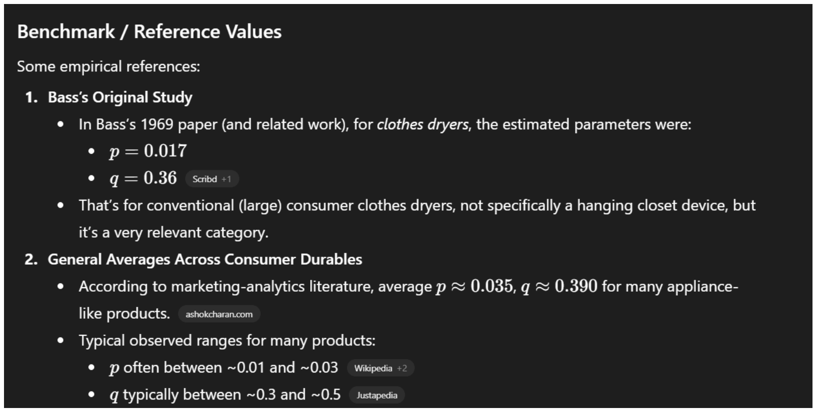
[10] Amazon. (n.d.). *WDERAIR 97 mm × 33 mm BBQ blower fan 120 V*. Amazon. Retrieved December 1, 2025, from https://www.amazon.com/WDERAIR-97mm-33mm-Blower-120V/dp/B0BWR8ZQHH (Amazon)

[11] McMaster-Carr. (n.d.). *10095K77*. Retrieved December 1, 2025, from https://www.mcmaster.com/10095K77/

[12] OpenAI. (2025, December 1). *ChatGPT* [Large language model]. https://chatgpt.com/share/692e41b3-cc00-8006-b95c-c298c6a4022f (APA Style)

6. Appendices

Bass Model Forecasting Using Generative AI



Benchmark / Reference Values

Some empirical references:

1. **Bass's Original Study**
   - In Bass's 1969 paper (and related work), for *clothes dryers*, the estimated parameters were:
     - $p = 0.017$
     - $q = 0.36$ Scribd +1
   - That's for conventional (large) consumer clothes dryers, not specifically a hanging closet device, but it's a very relevant category.
2. **General Averages Across Consumer Durables**
   - According to marketing-analytics literature, average $p \approx 0.035$, $q \approx 0.390$ for many appliance-like products. ashokcharan.com
   - Typical observed ranges for many products:
     - p often between ~0.01 and ~0.03 Wikipedia +2
     - q typically between ~0.3 and ~0.5 Justapedia

Figure 29. Sample of Generative AI Output :

Analytical Mechanical Analysis – MATLAB Script

```
%% Aerodry Initial Sizing - Pipe With Holes, Pressure/Velocity Drop
clear; clc; close all;
%% Geometry
pipe_d = 2.0 * 0.0254;          % 2 in → m
pipe_L = 3.0 * 0.3048;          % 3 ft → m
n_holes = 11;
hole_d  = 0.25 * 0.0254;        % 0.25 in → m
%% Fan parameters
Q_max = 25 * 0.00047194745;   % CFM → m³/s
%% Air properties
rho = 1.225;
mu  = 1.81e-5;
%% Derived geometry
A_pipe  = pi*(pipe_d^2)/4;
A_hole  = pi*(hole_d^2)/4;
seg_L   = pipe_L/(n_holes+1);   % spacing between holes
%% Initial conditions at inlet
p(1) = 6894.75729*0.25 + 101325;     % Pa (fan gauge pressure + atm)
v(1) = Q_max / A_pipe;           % initial pipe velocity
Re(1) = rho * v(1) * pipe_d / mu;
% Roughness (PVC)
epsilon = 0.0002e-3;
eD = epsilon / pipe_d;
%% Loop through segments between holes
for i = 1:n_holes
   % Compute Darcy-Weisbach friction factor (Haaland)
   inv_sqrt_f = -1.8 * log10( (eD/3.7)^1.11 + 6.9/Re(i) );
   f(i) = 1/(inv_sqrt_f^2);
   %% Pressure drop along segment
   dp_fric = f(i) * (seg_L/pipe_d) * 0.5*rho*v(i)^2;

   %% Pressure before hole
   p_pipe = p(i) - dp_fric;
   p(i+1) = p_pipe;
   %% === FLOW OUT OF HOLE ===
   dp_hole = p_pipe - 101325;   % pressure difference driving jet

   if dp_hole < 0
       v_hole(i) = 0;
       m_hole(i) = 0;
   else
```

```
        % Orifice equation (Cd ≈ 0.5-0.7)
        Cd = 0.6;

        v_hole(i) = Cd * sqrt(2*dp_hole/rho);  % exit jet velocity
        m_hole(i) = rho * A_hole * v_hole(i);  % mass flow out hole
    end
    %% Reduce pipe flow due to leakage
    m_pipe = rho * A_pipe * v(i);       % mass flow entering
    m_after = m_pipe - m_hole(i);       % mass flow remaining
    if m_after < 0
        m_after = 0;
    end

    %% New pipe velocity
    v(i+1) = m_after / (rho * A_pipe);
    %% Update Reynolds number
    Re(i+1) = rho * v(i+1) * pipe_d / mu;
end
%% Distance array
x = linspace(0, pipe_L, n_holes+1);
%% Plots
set(groot, 'DefaultLineLineWidth', 2);
set(groot, 'DefaultAxesFontSize', 14);
set(groot, 'DefaultAxesLineWidth', 1.2);
set(groot, 'DefaultAxesGridAlpha', 0.25);
set(groot, 'DefaultAxesMinorGridAlpha', 0.15);
set(groot, 'DefaultFigureColor', 'w');
%% Pressure Distribution Plot
%% Convert pressure to psi
p_psi = p / 6894.75729;
%% Pressure Distribution Plot (PSI)
figure;
plot(x, p_psi, 'b-');
grid on; grid minor;
xlabel('Distance Along Pipe (m)');
ylabel('Pressure (psi)');
title('Pressure Distribution Along Device');
xlim([0 pipe_L]);
ylim([min(p_psi)*0.999999 max(p_psi)*1.00000001]);
hold on;
plot(x, p_psi, 'bo', 'MarkerFaceColor', 'b');
%% Velocity Distribution Plot
figure;
plot(x, v, 'r-');
grid on; grid minor;
xlabel('Distance Along Pipe (m)');
ylabel('Internal Pipe Velocity (m/s)');
title('Velocity Distribution Along Device');
xlim([0 pipe_L]);
ylim([min(v)*0.99999 max(v)*1.000001]);
hold on;
plot(x, v, 'ro', 'MarkerFaceColor', 'r');
%% Jet Velocity From Each Hole
figure;
plot(x(1:end-1), v_hole, 'k-');
grid on; grid minor;
xlabel('Distance Along Device (m)');
ylabel('Hole Jet Velocity (m/s)');
title('Exit Velocity From Each Hole');
xlim([0 pipe_L]);
ylim([min(v_hole)*0.99999 max(v_hole)*1.000001]);
hold on;
plot(x(1:end-1), v_hole, 'ko', 'MarkerFaceColor', 'k');
%% Quiver plot for hole velocities along pipe (blue, smaller arrows)
% Hole positions along pipe (x-axis)
x_holes = x(1:end-1);   % positions of holes
% Pipe y-position (for visualization only)
y_pipe = zeros(size(x_holes));
% Velocity vector components
U = v_hole;   % vertical velocity magnitude
V = zeros(size(U));  % no horizontal component
```

```
% Scale arrows smaller
scale = 0.02*pipe_L / max(U);  % smaller arrows
U_plot = U * scale;
figure;
quiver(x_holes, y_pipe, V, U_plot, 0, 'b', 'LineWidth', 1, 'MaxHeadSize', 1.5);
% Pipe representation
hold on;
plot([0 pipe_L], [0 0], 'k-', 'LineWidth', 4);  % horizontal pipe
grid on;
xlabel('Distance along pipe (m)');
ylabel('Velocity magnitude (scaled)');
title('Relative Hole Jet Velocities Along Pipe');
% Optional: label each hole with velocity
for i = 1:length(x_holes)
   text(x_holes(i), 0.005, sprintf('%.2f m/s', v_hole(i)), ...
       'HorizontalAlignment', 'center', 'VerticalAlignment', 'bottom', 'FontSize', 12);
end
ylim([-0.01 pipe_L*0.03]);  % adjust y-axis to fit arrows
```