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The Body Dryer Project

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The information contained in this report pertains to the engineering practices to develop a working prototype of a body dryer. A body dryer that is described in the context of this report, is defined as a static structure with two air streams. The main function of the body dryer project is to investigate a replacement for a towel when one is finished showering or after swimming. This report will contain future improvements that were investigated but were not able to implement in the working prototype due to the boundaries of the system. A special shout out to Indoor Comfort Team, this project could not have been possible without your donations. Thank you!

JME 4110
Mechanical Engineering
Design Project

Body Dryer

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1 INTRODUCTION

1.1 VALUE PROPOSITION / PROJECT SUGGESTION

The design is synonymous to how an automobile would be dried after being washed or at least that is where our inspiration is generated. Therefore, our application is designed for commercial use. The ideal type of setting that is described in this report would be in locker rooms, pool areas, and possibly used for the disabled population.

1.2 LIST OF TEAM MEMBERS

Laura Bailey: Idea, inquiry and testing generation, drawings, and review
Luke Maichel: Conducted theoretical and experimental calculations
Nickalous Zuelke: Keeping the project on schedule and main fabricator

2 BACKGROUND INFORMATION STUDY

2.1 DESGIN BRIEF

When one is finished showering or swimming, one could use a body dryer, instead of a towel, and be dry in under three minutes. The prototype was designed for a residential setting, however, could be retrofitted to well serve an industrial setting such as a hotel, gym, or swimming pool. Consideration for energy consumption for the device was such that less electrical power would be consumed by the Body Dryer, than what would be used during a lifetime of washing and drying towels.

Defining the constraints throughout the project lent to several iterations. The notion that the unit must be portable was dismissed by the project's sponsor at the start. User comfort provided by heated air for the unit was a primary concern; however, was abandoned once it was understood that power for the unit would have to be increased. To satisfy the timeline for the coursework, the heating constraint was completed on paper, and then side stepped, in order to progress with a working prototype. It was important for universal functionality that the design be serviceable on a simple 120 V, 20 Amp circuit.

2.2 BACKGROUND SUMMARY

The following two patents is where we draw our inspiration for the project.

Patent 1: US4871900A

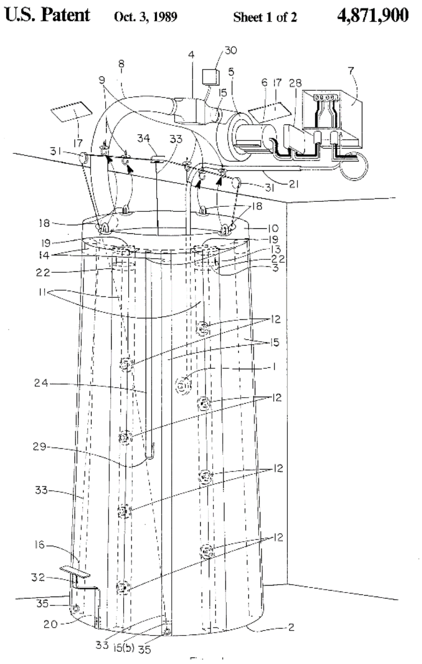


Figure 1: Enclosure Type Body Dryer

The design to left has separated air chambers in the enclosure. These chambers taper down the further away from the blower the air gets. This is important because this design allows for an even flow through the nozzles, thus air balancing the system. If the system is not balanced properly, there will be uneven drying of the body.

Patent 2: US20130025149A1

Instead of an enclosure, the design to the right is more like a car wash type drying system. However, we would like to eliminate the need for the person to turn, but this can inspire design ideas for how the blower system can be designed and where it can be positioned.

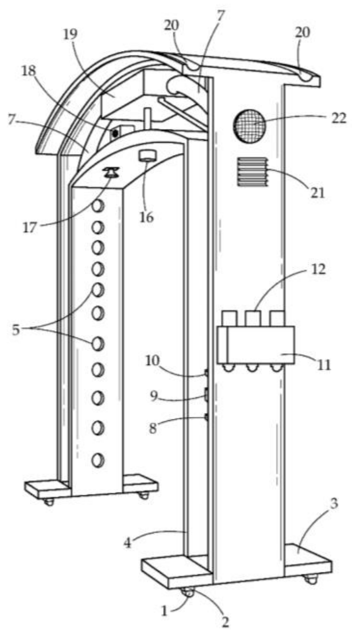


Figure 2: Car Wash Type Body Dryer

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS AND METRICS

3.1.1 Record of the user needs interview

Table 1: User Needs Interview

Project/Product Name: Body Dryer			
Customer: Craig Giesmann Address: WashU Willing to do follow up? Yes Type of use: Shower/swimming		Interviewer(s): Luke, Nick, Laura Date: 6/17/2019 Currently uses: Towels	
Question	Customer Statement	Interpreted Need	Importance
What is the time requirement for dry off?	About three minutes or less	Body dryer dries one off in 1-3min	5
What kind of power source is allowed?	No 3 phase	120 or 240AC	5
Should it be heated?	Yes	Body dryer will have warm air	4
Personal or Industrial application?	Personal use- at home, but something that could be outfitted at a hotel	Body dryer should be able to do both	3
Can it be larger than a bread box?	Yes	Body dryer does not have to be small	3
Should it be a static structure or portable?	Static	Body dryer does not have to be portable.	3
Is noise a concern?	No	Body dryer motor and machinery is not limited by noise requirements	2
Must it access hard to reach areas?	No, good feature add-on, but not initially necessary. It is good if it gets to 90% of the body.	Body dryer should be 90% effective	5
Must it dry the hair?	No	Body dryer does not have to be able to dry hair	2
Are you envisioning anything in particular about this project?	I'm thinking of something outside of the shower stall because of electrical concerns.	Body dryer must be safe	5

3.1.2 List of identified metrics

Table 2: Metrics

	Need	Metric	Unit	Ideal	inferior
1	1,2,3,4,6,8,10,11,13	# of parts is low	#	20	50
2	1,3,4	cost of parts	$	400	1000
3	3,5,7,8,9,12	time to use it	sec	30	180
4	1,2,11,13	Longevity- time between service	months	12	1
5	3,5,7,12	Air Speed	mph	200	50
6	2,5	Temperature	deg F	100	50
7	3,5,7	noise level	dB	1	85
8	2,	installation time	day	1	3
9	2,6,10	installation ease	scale	3	1
10	2,7,	energy use (kW based on voltage needed)	kW	2.4	4.8
11	8,12	% of body dry	%	100	10

3.1.3 Table/list of quantified needs equations

Table 3: Quantified Needs Table Example

BODY DRYER- binary needs are that it runs on 120V or 240V and that it is SAFE.		Metric													
		# of parts is low	Cost of parts	Time to use it	Service time (longevity)	Air Speed	Temperature (range?)	Noise	Installation Time	Installation Ease	Energy use	% of body dry	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Ratable needs	1	2	3	4	5	6	7	8	9	10	11			
1	Durable (reliable parts?)	0.55	0.1		0.35								1.000	0.05	0.050
2	Heated air	0.1			0.1		0.2		0.2	0.2	0.2		1.000	0.15	0.150
3	Air speed controllable	0.15	0.1	0.25		0.25		0.25					1.000	0.025	0.025
4	Cost to build/purchase	0.4	0.6										1.000	0.075	0.075
5	Comfort to user is high			0.2		0.3	0.3	0.2					1.000	0.15	0.150
6	Easy to retrofit existing bathroom	0.5								0.5			1.000	0.075	0.075
7	Energy consumption is low			0.2		0.2		0.2			0.4		1.000	0.05	0.050
8	Easy to use	0.1		0.4								0.5	1.000	0.05	0.050
9	User can multi-task			1									1.000	0.05	0.050
10	Aesthetically pleasing	1											1.000	0.05	0.050
11	Low Maintenance	0.3			0.4					0.3			1.000	0.075	0.075
12	WOW! Factor is high			0.3		0.4						0.3	1.000	0.175	0.175
13	Easily servicable	0.3			0.7								1.000	0.025	0.025
Units		#	$	sec	months	m/hr	deg F	dB?	day	#	kW	%	Total Happiness		0.975
Best Value		20	400	30	12	200	100	1	1	3	2.4	100		1	
Worst Value		50	1000	180	1	10	50	85	3	1	4.8	10			
Actual Value		20	400	30	12	200	100	1	1	3	2.4	100			
Normalized Metric Happiness		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			

3.2 CONCEPT DRAWINGS

Concept #1

A

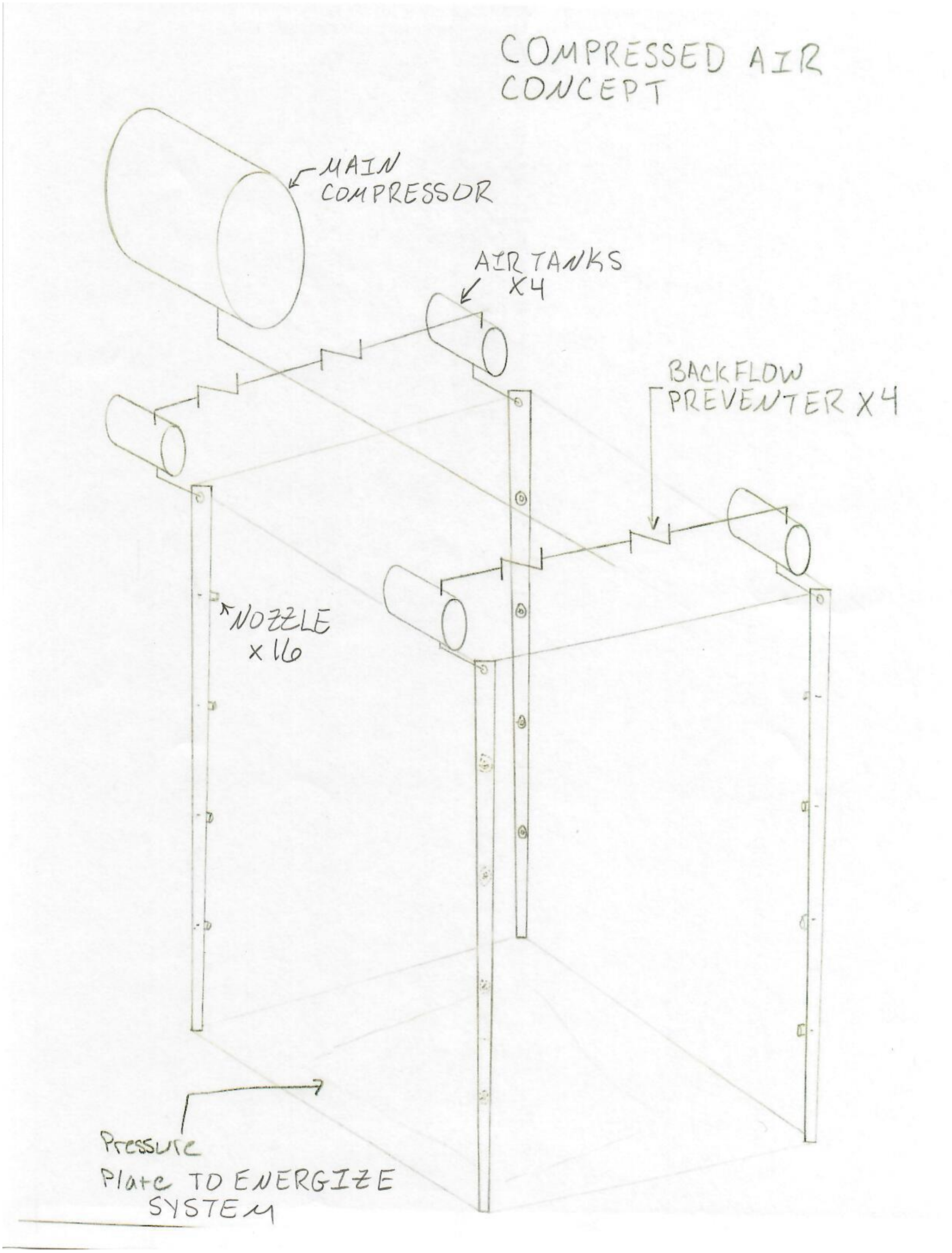


Figure 3: Compressed Air Concept

Concept #2

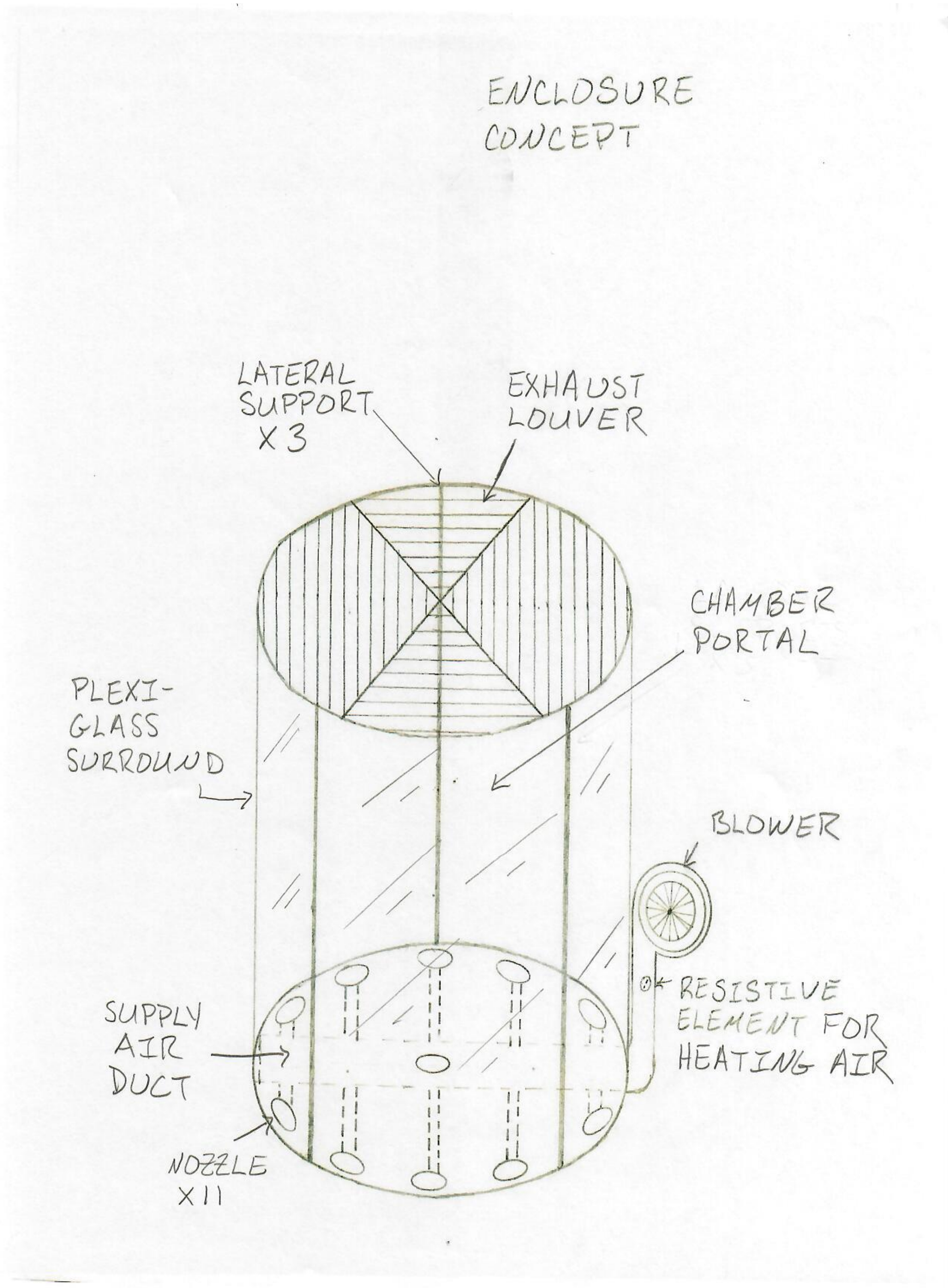


Figure 4: Enclosure Concept

Concept #3

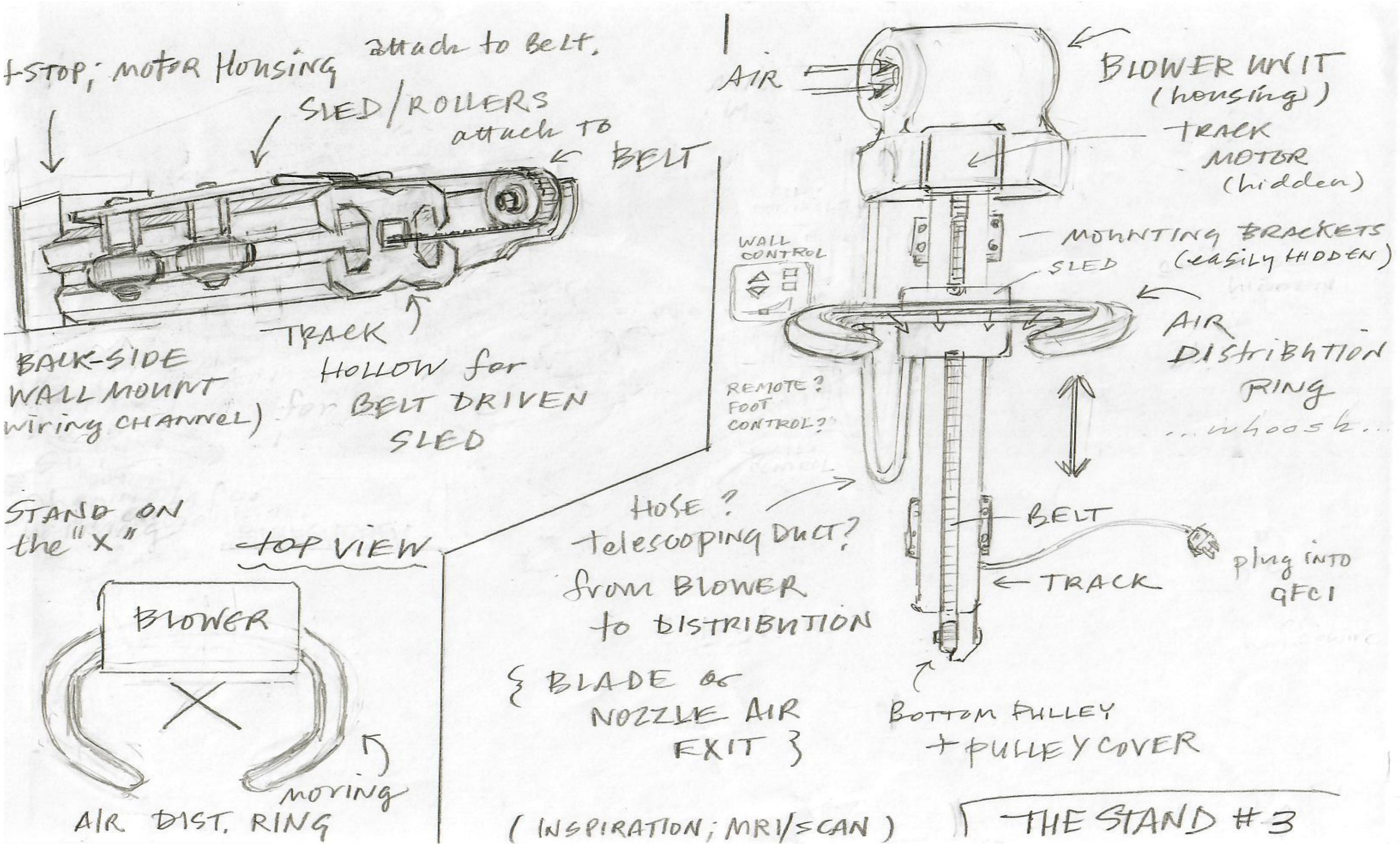


Figure 5: Stand Concept

Concept #4

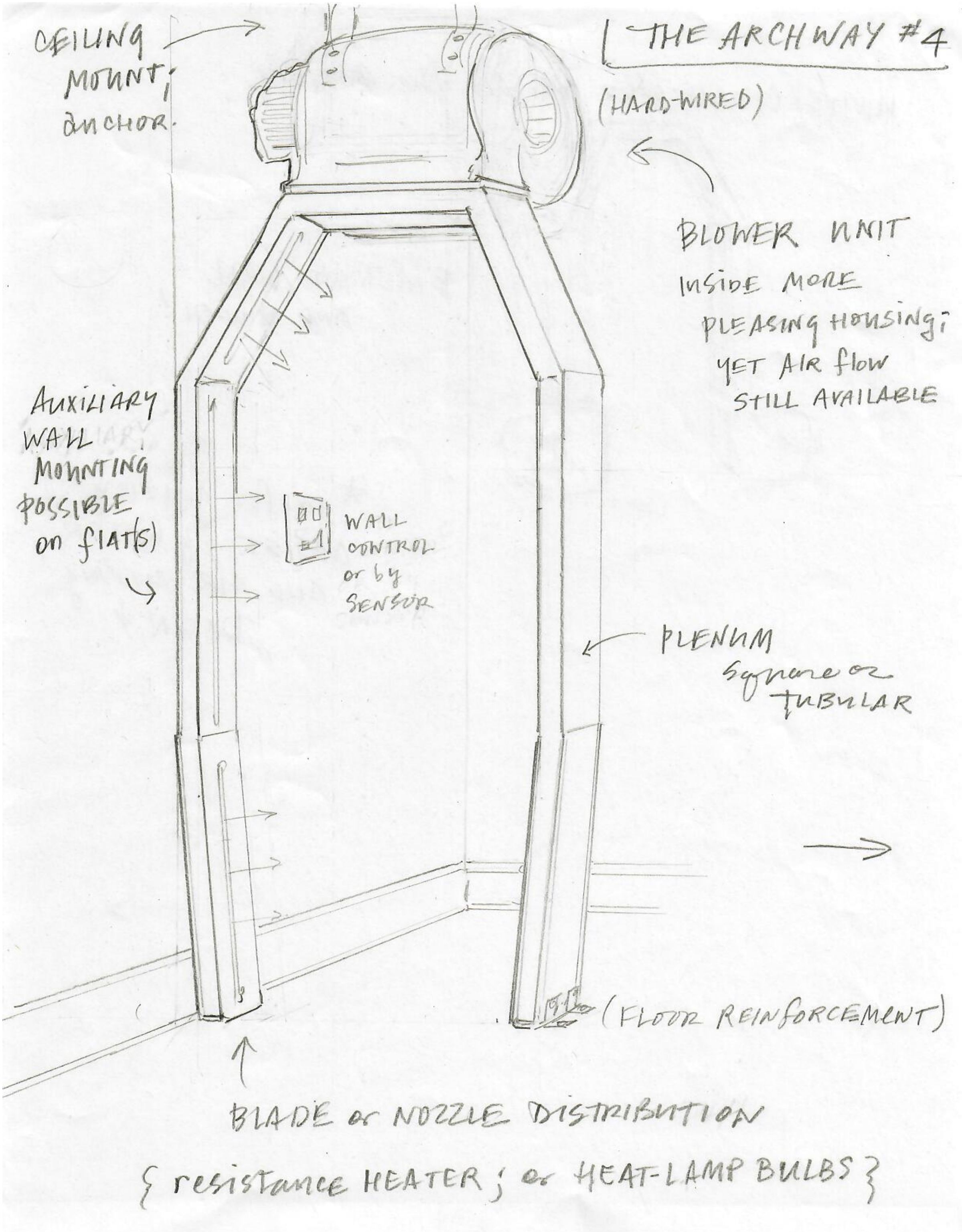


Figure 6: Archway Concept

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Table 4: Compressed Air Happiness Matrix

BODY DRYER- binary needs are that it runs on 120V or 240V and that it is SAFE.		Metric													
		# of parts is low	Cost of parts	Time to use it	Service time (longevity)	Air Speed	Temperature (range?)	Noise	Installation Time	Installation Ease	Energy use	% of body dry	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Ratable needs	1	2	3	4	5	6	7	8	9	10	11			
1	Durable (reliable parts?)	0.55	0.1		0.35								0.37	0.05	0.018
2	Heated air	0.1			0.1		0.2		0.2	0.2	0.2		0.40	0.15	0.061
3	Air speed controllable	0.15	0.1	0.25		0.25		0.25					0.46	0.025	0.012
4	Cost to build/purchase	0.4	0.6										0.01	0.075	0.001
5	Comfort to user is high			0.2		0.3	0.3	0.2					0.44	0.15	0.066
6	Easy to retrofit existing bathroom	0.5								0.5			0.02	0.075	0.001
7	Energy consumption is low			0.2		0.2		0.2			0.4		0.77	0.05	0.038
8	Easy to use	0.1		0.4								0.5	0.77	0.05	0.038
9	User can multi-task			1									0.80	0.05	0.040
10	Aesthetically pleasing	1											0.03	0.05	0.002
11	Low Maintenance	0.3			0.4					0.3			0.41	0.075	0.031
12	WOW! Factor is high			0.3		0.4						0.3	0.80	0.175	0.140
13	Easily servicable	0.3			0.7								0.71	0.025	0.018
Units		#	$	sec	months	mph	deg F	dB?	day	#	kW	%	Total Happiness		0.448
Best Value		20	400	30	12	200	100	1	1	3	2.4	100		1	
Worst Value		50	1000	180	1	10	50	85	3	1	4.8	10			
Actual Value		49	999	60	12	150	50	60	2	1	2.4	90			
Normalized Metric Happiness		0.03	0.00	0.80	1.00	0.74	0.00	0.30	0.50	0.00	1.00	0.89			

Table 5: Enclosure Happiness Matrix

BODY DRYER- binary needs are that it runs on 120V or 240V and that it is SAFE.		Metric													
		# of parts is low	Cost of parts	Time to use it	Service time (longevity)	Air Speed	Temperature (range?)	Noise	Installation Time	Installation Ease	Energy use	% of body dry	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Ratable needs	1	2	3	4	5	6	7	8	9	10	11			
1	Durable (reliable parts?)	0.55	0.1		0.35								0.692	0.05	0.035
2	Heated air	0.1			0.1		0.2		0.2	0.2	0.2		0.450	0.15	0.068
3	Air speed controllable	0.15	0.1	0.25		0.25		0.25					0.500	0.025	0.013
4	Cost to build/purchase	0.4	0.6										0.600	0.075	0.045
5	Comfort to user is high			0.2		0.3	0.3	0.2					0.661	0.15	0.099
6	Easy to retrofit existing bathroom	0.5								0.5			0.250	0.075	0.019
7	Energy consumption is low			0.2		0.2		0.2			0.4		0.287	0.05	0.014
8	Easy to use	0.1		0.4								0.5	0.627	0.05	0.031
9	User can multi-task			1									0.400	0.05	0.020
10	Aesthetically pleasing	1											0.500	0.05	0.025
11	Low Maintenance	0.3			0.4					0.3			0.550	0.075	0.041
12	WOW! Factor is high			0.3		0.4						0.3	0.665	0.175	0.116
13	Easily servicable	0.3			0.7								0.850	0.025	0.021
Units		#	$	sec	months	m/hr	deg F	dB?	day	#	kW	%	Total Happiness		0.526
Best Value		20	400	30	12	200	100	1	1	3	2.4	100		1	
Worst Value		50	1000	180	1	10	50	85	3	1	4.8	10			
Actual Value		35	600	120	12	150	100	60	2	1	4.8	85			
Normalized Metric Happiness		0.50	0.67	0.40	1.00	0.74	1.00	0.30	0.50	0.00	0.00	0.83			

Table 6: Stand Happiness Matrix

BODY DRYER- binary needs are that it runs on 120V or 240V and that it is SAFE.		Metric													
		# of parts is low	Cost of parts	Time to use it	Service time (longevity)	Air Speed	Temperature (range?)	Noise	Installation Time	Installation Ease	Energy use	% of body dry	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Ratable needs	1	2	3	4	5	6	7	8	9	10	11			
1	Durable (reliable parts?)	0.55	0.1		0.35								0.159	0.05	0.008
2	Heated air	0.1			0.1		0.2		0.2	0.2	0.2		0.645	0.15	0.097
3	Air speed controllable	0.15	0.1	0.25		0.25		0.25					0.449	0.025	0.011
4	Cost to build/purchase	0.4	0.6										0.000	0.075	0.000
5	Comfort to user is high			0.2		0.3	0.3	0.2					0.717	0.15	0.108
6	Easy to retrofit existing bathroom	0.5								0.5			0.250	0.075	0.019
7	Energy consumption is low			0.2		0.2		0.2			0.4		0.759	0.05	0.038
8	Easy to use	0.1		0.4								0.5	0.820	0.05	0.041
9	User can multi-task			1									0.800	0.05	0.040
10	Aesthetically pleasing	1											0.000	0.05	0.000
11	Low Maintenance	0.3			0.4					0.3			0.332	0.075	0.025
12	WOW! Factor is high			0.3		0.4						0.3	0.772	0.175	0.135
13	Easily servicable	0.3			0.7								0.318	0.025	0.008
Units		#	$	sec	months	m/hr	deg F	dB?	day	#	kW	%	Total Happiness		0.521
Best Value		20	400	30	12	200	100	1	1	3	2.4	100		1	
Worst Value		50	1000	180	1	10	50	85	3	1	4.8	10			
Actual Value		50	1000	60	6	120	100	50	2	2	2.4	100			
Normalized Metric Happiness		0.000	0.000	0.800	0.455	0.579	1.000	0.417	0.500	0.500	1.000	1.000			

Table 7: Archway Happiness Matrix

BODY DRYER- binary needs are that it runs on 120V or 240V and that it is SAFE.		Metric													
		# of parts is low	Cost of parts	Time to use it	Service time (longevity)	Air Speed	Temperature (range?)	Noise	Installation Time	Installation Ease	Energy use	% of body dry	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Ratable needs	1	2	3	4	5	6	7	8	9	10	11			
1	Durable (reliable parts?)	0.55	0.1		0.35								0.983	0.05	0.049
2	Heated air	0.1			0.1		0.2		0.2	0.2	0.2		0.800	0.15	0.120
3	Air speed controllable	0.15	0.1	0.25		0.25		0.25					0.646	0.025	0.016
4	Cost to build/purchase	0.4	0.6										0.900	0.075	0.068
5	Comfort to user is high			0.2		0.3	0.3	0.2					0.709	0.15	0.106
6	Easy to retrofit existing bathroom	0.5								0.5			0.750	0.075	0.056
7	Energy consumption is low			0.2		0.2		0.2			0.4		0.730	0.05	0.036
8	Easy to use	0.1		0.4								0.5	0.920	0.05	0.046
9	User can multi-task			1									0.800	0.05	0.040
10	Aesthetically pleasing	1											1.000	0.05	0.050
11	Low Maintenance	0.3			0.4					0.3			0.850	0.075	0.064
12	WOW! Factor is high			0.3		0.4						0.3	0.856	0.175	0.150
13	Easily servicable	0.3			0.7								1.000	0.025	0.025
Units		#	$	sec	months	m/hr	deg F	dB?	day	#	kW	%	Total Happiness		0.801
Best Value		20	400	30	12	200	100	1	1	3	2.4	100		1	
Worst Value		50	1000	180	1	10	50	85	3	1	4.8	10			
Actual Value		20	500	60	12	160	100	80	2	2	2.4	100			
Normalized Metric Happiness		1.000	0.833	0.800	1.000	0.789	1.000	0.060	0.500	0.500	1.000	1.000			

3.3.2 Preliminary analysis of each concept's physical feasibility- Ranking the Designs

Concept 1: Compressed Air: Happiness Score (44.8%)

This is a robust design and in theory seems to accomplish the goal of drying at least 90% of the body; however, the amount of materials and the complexity of the design was the major deposition of this concept. To overcome this, an increase in the capital to account for the extended installation time and number of parts. Furthermore, it has not been decided how the compressed air will be heated to increase the evaporation of the water. Perhaps the inclusion of infrared bulbs.

Concept 2: Enclosure: Happiness Score (52.6%)

The largest drawback of this concept is its drying time because the further the air is from the nozzle it will lose velocity. To overcome this, we will have to incorporate a larger blower to force more air in the chamber. Also, since the supply air is being treated with a resistive heating element, the water that is evaporated will be exhausted out the top louver.

Concept 3: Stand: Happiness Score (52.1%)

The largest drawback of this concept is its complexity. Many parts, including a moving track, are needed to satisfy a body dryer in motion around the user. This allows for questionable part reliability, a more difficult product to build, higher cost of parts, and questionable air movement via the flexible plenum (to satisfy the moving track). Positive attributes include relatively easy installation for the end user and close-range air velocity. Hypothetically, this unit could be wall mounted and plugged in. Control could be through a remote control, much like that of ceiling fan operation. Dry time may be lacking due to flexible plenum; however, if this detail could be tackled, proximity of warm air velocity would well serve the end user. There are too many unknowns; the simpler solutions have more appeal.

Concept 4: Arch: Happiness Score (80.1%)

This seems like a very good design. Something that makes it very appealing is how simple the design is, and also the expected effectiveness. One reason why it is expected to be so effective at drying someone off is because the air will be blowing from the ductwork very close to where the person is standing. This will result in a very high air velocity. The ductwork that makes the arch could be very simple and cheap to manufacture and be very effective at the same time. Possibilities of what the duct could be made of are sheet metal or PVC pipe. The heating element could be done by using electrical resistance to heat the air, or it could be done by using infrared light bulbs. Although it would be cheaper to use one motor instead of two, it may be more effective if we have one motor on each side of the arch. This will have to be decided by in depth testing.

3.3.3 Final summary statement

The winner is the archway design. This design scored 80.1%, while the others only ranked 44.8%, 52.6%, and 52.1%. This made the arch design the clear winner.

One of the reasons why the compressed air design was ruled out was because it seemed very expensive to make. An air compressor that would have enough air would be very expensive to purchase. Another thing that helped rule this design out was that it seemed like it would be hard to heat the air, so the air would be very cold. Also, not many homeowners know how air compressors work, so homeowners would have to hire an outside person to maintain and repair this device, which would add to the cost. Because of these reasons, this design was ruled out.

Although the appeal of stepping into a cylinder and experiencing something like a tornado was very appealing, the sheer amount of air that would be needed ruled this design out. A huge amount of air would be needed in order to create a wind inside the cylinder that would dry someone off. With the resources that we had; this design was impossible.

Something that initially seemed good about the stand was that it would not require a lot of air. Something that ruled the design out though, was the complexity of the design. There would have to be a lot of parts in order to make it work, which would mean there would be a lot of places for things to break. An example of this is that it required another motor to move the apparatus up and down. It was also doubtful that the air would be blowing out at a high enough velocity to dry someone off, because a flexible duct would be required in order to let it move up and down. Because of these reasons, this design was ruled out.

The arch design was the clear winner by the scoring that was done, ranking at 27.5%, higher than any of the others. The reason for this was how simple and effective the design was. It does not seem like it will require a lot of pieces, but at the same time it looks like it will perform better than any of the others. The amount of air that is required is relatively small, but the air is directed in a manner that will optimize it. It also seems like it will be simple to install and not take up a lot of space, making it very convenient to the consumer. All these things add up to make this design the clear winner that will ultimately result in a product that is easy to use, and very effective

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

Customer Satisfaction is our top priority. Our sponsor has a vision, and our goal is to meet that need. Customer satisfaction embodies that the product delivers as promised while providing a comfortable experience. The metric of dry time “Time to use” of under 3 minutes will clearly express our meeting of the performance criterion.

3.5 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

Changes occurred after selection of the initial archway concept. Because the prototype was not going to be installed into a wall or hung from the ceiling, it was decided to put the blower unit at floor level. This configuration had been discussed and represented on the back side of the initial concept drawing Concept #4. The project's sponsor encouraged this decision for ease of the build via locating the heaviest structure at the bottom. Once it was determined that two blower units could be attained, it became clear that a symmetric bottom up design was favorable. This iteration led to the embodiment drawing.

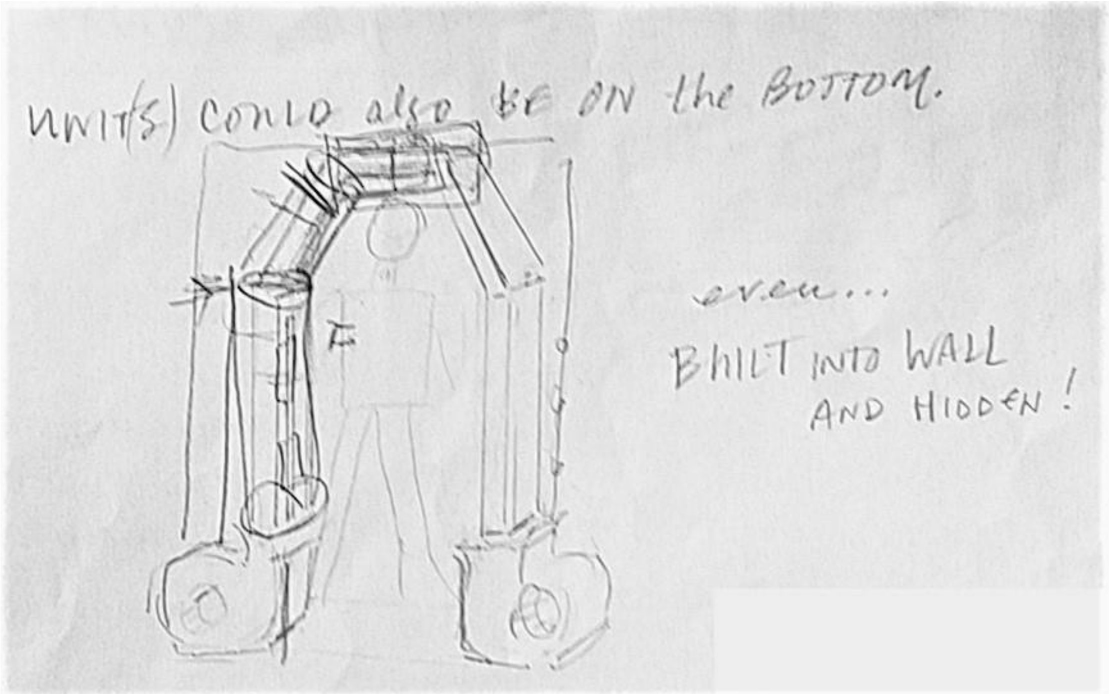


Figure 7: Back of the page thumbnail of Concept #4.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING

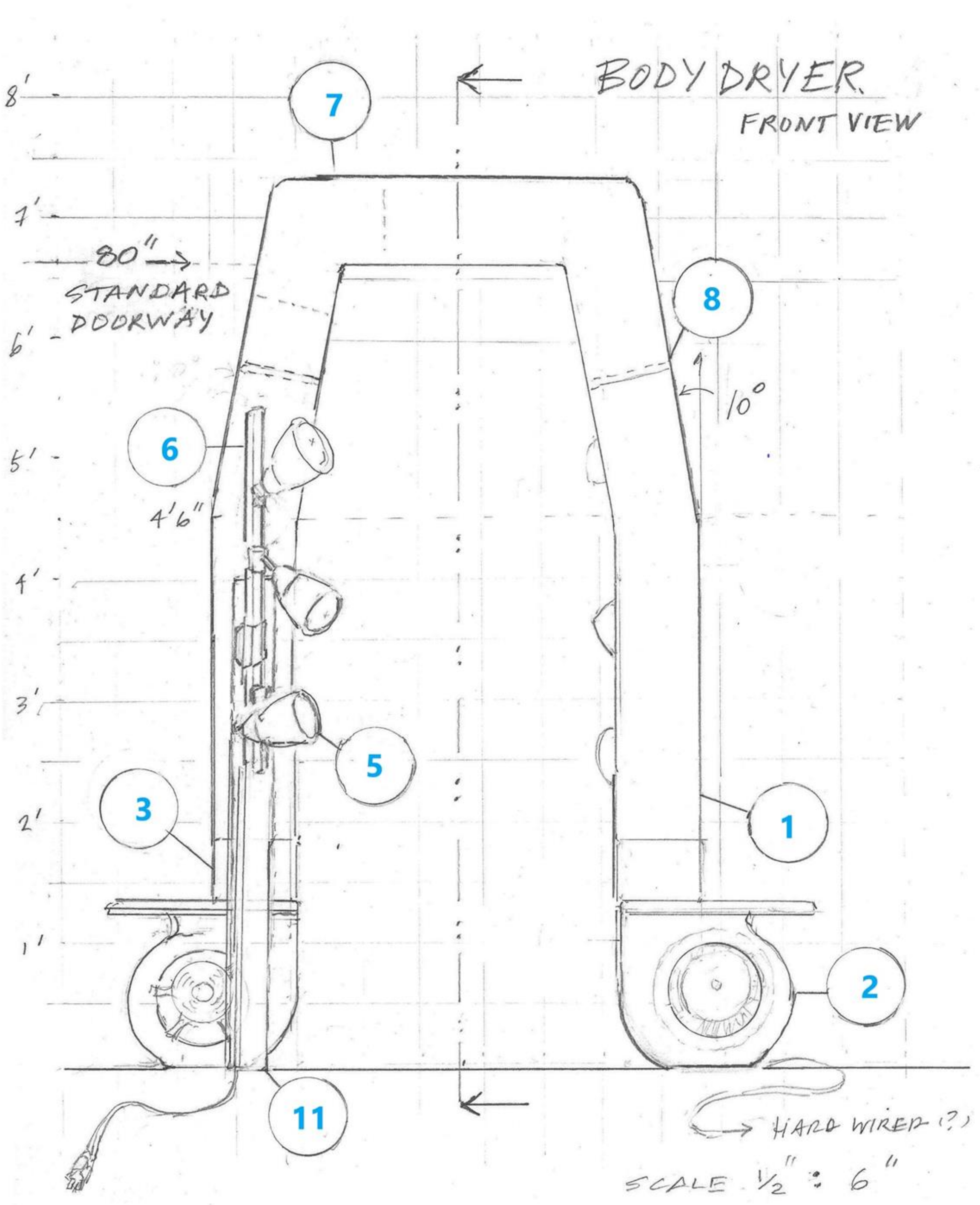


Figure 8: Front View of Archway Design

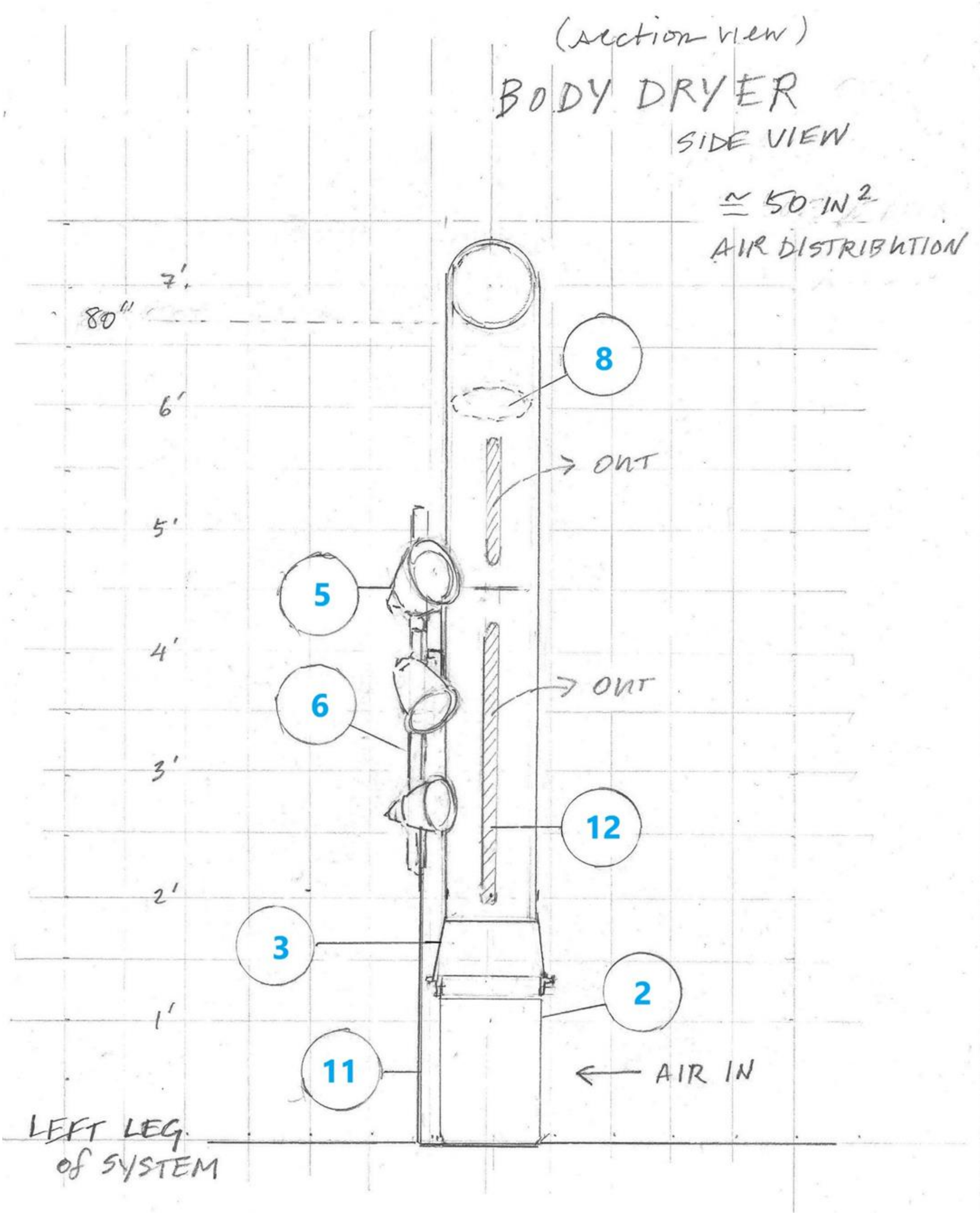


Figure 9: Left Side of Archway Design

4.2 PARTS LIST

Table 8: Initial Part List for Body Dryer

Body Dryer Parts List					
Part Name	Supplier	Part Number	Quantity	Unit Price	Total
8" X 60" Round Pipe	Home Depot	148695	4	$ 11.98	$ 47.92
Blower Assembly	Supplyhouse.com	901282	2	$ 299.95	$ 599.90
28 Ga 12" X 24" Sheet Metal (Galv)	Home Depot	1001195	3	$ 10.98	$ 32.94
#8 3/4" Hex Self Tapping Screws	Home Depot	156906	1	$ 6.71	$ 6.71
250 Watt Heat Lamps	Home Depot	332769	6	$ 9.97	$ 59.82
Track Lighting	Home Depot	1001406717	2	$ 74.32	$ 148.64
8" Elbow	Home Depot	148768	2	$ 7.21	$ 14.42
8" Cap	Home Depot	206881	2	$ 5.98	$ 11.96
12-2 Wire	Home Depot	374710	1	$ 14.77	$ 14.77
20 Amp Switch	Home Depot	700096	1	$ 2.99	$ 2.99
			Grand Total		$ 940.07

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

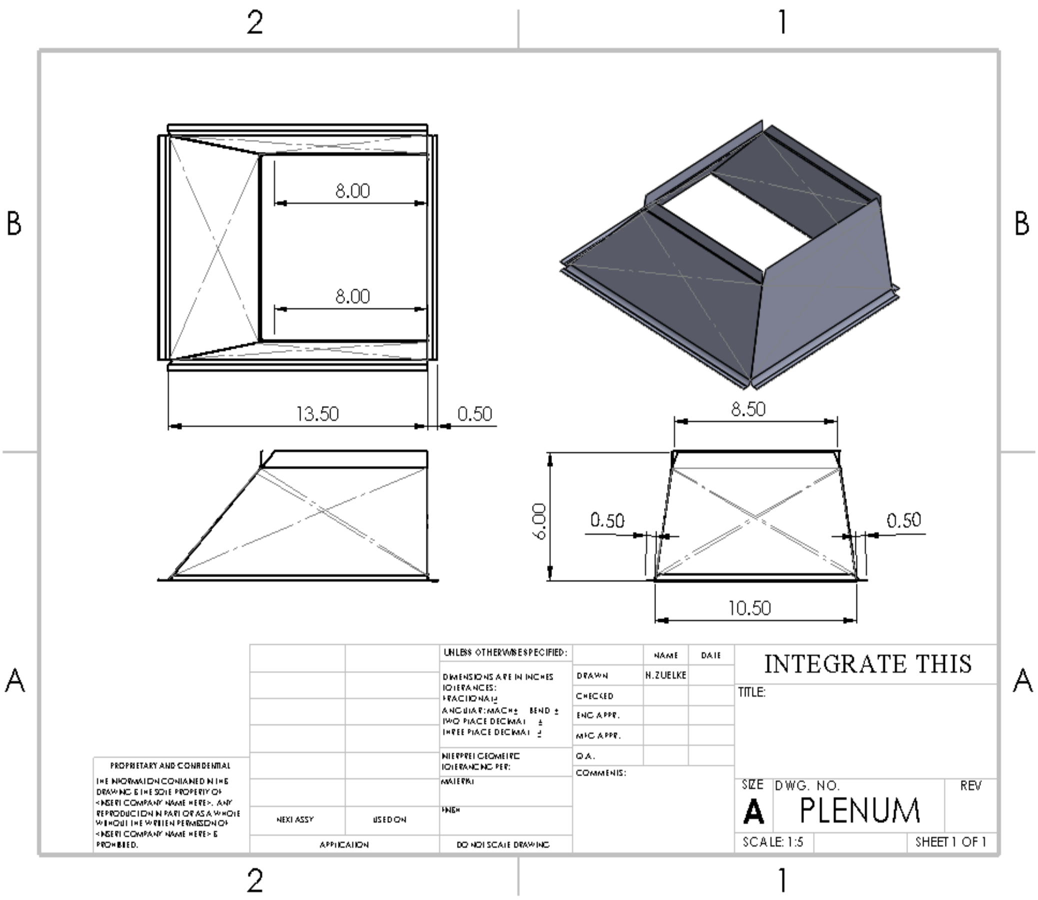


Figure 10: Sheet Metal Plenum

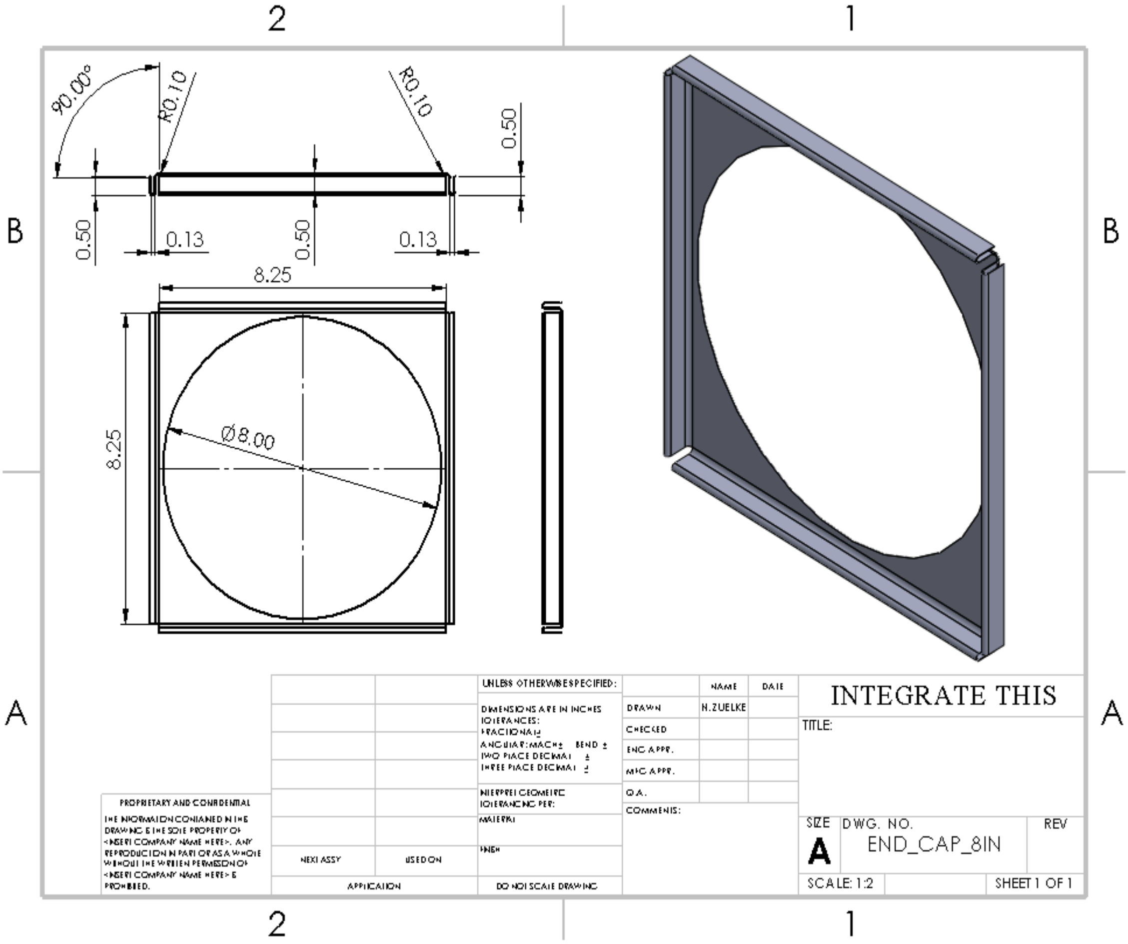


Figure 11: Sheet Metal Cap

4.4 DESCRIPTION OF THE DESIGN RATIONALE

To satisfy the initial vision of the project's sponsor, the team moved forward on the archway design. A blower was deemed necessary. An HVAC blower component was chosen for testing as the team had access to 'dead' HVAC components. Blower units for leaves or air curtains were also investigated. Final choice was what was available and worked. The embodiment concept and drawing for the blower system of the Body Dryer was estimated through calculation, and ultimately determined through the testing outlined below. Various tested output sizes and shapes on both a 4-ton and 3-ton HVAC blower unit indicated that two 3-ton units would most effective. This would easily facilitate the team's desire to provide extensive amounts of airflow to both dry and dazzle the end user. Further calculations of air flow, duct pressure, and output were also tested to determine the final choice of the 8" round duct and output area which was realized at 48 in^2 on each side.

The need to have the air heated for the body dryer posed a more challenging task. After calculating power constraints affiliated with resistance heating, radiant heat provided by infrared heat lamp bulbs was chosen. The project's sponsor appeared disappointed by the inclusion of the bulbs, therefore, a week was allotted for testing of other methods, including, again, resistance heating. In end, the maximum temperature increase provided from a 1600W nichrome wire was 8°F. This was attainable only at the expense of lowering the airspeed of the blower unit. It was estimated that 5000W was the minimum power needed for each side to successfully elevate the air to 100°F. This collided with the desire to keep the assembly powered with a single 120-V, 20 Amp circuit.

After a day of testing and holding the prototype for each other, it was also determined that the rolling blower bases needed a stand, so that they would remain upright. A built-in wall model mock-up seemed overzealous. Instead, a simple base was constructed from spent 2”x4”s.

Inquiry and calculations follow, here, in section 4. Further results from testing can be found in section 5.

If two 3-ton blower assemblies are used:

There will be a blower on each side of the archway, and there will be a divider separating the two air streams on the top. The calculations shown below are for one side of the arch. The other side of the arch will be the exact same.

The analysis will be conducted in two different ways. There will be a theoretical section using calculations, and an experimental section using testing.

What should the diffuser area be?

For the theoretical part of calculating air flow, the desired exit velocity is 80mph. In order to get this velocity, the area that the air is exiting from needs to be calculated.

$$v = 80mph\, x\, \frac{1.4667fps}{1mph} = 117.3\, fps$$

$$Flow = 3ton\, x\, \frac{400cfm}{ton} = 1200cfm = \frac{20ft^3}{s}$$

$$Area = \frac{V}{v} = \frac{\frac{20ft^3}{s}}{\frac{117.3ft}{s}} = 0.1705\, ft^2 = 24.55in^2$$

According to the theoretical calculations, the area of the diffusers should be 24.55in^2

How much pressure should ductwork handle?

The pressure inside the duct will need to be calculated in order to know what gage of sheet metal to use. This will be done by using Bernoulli’s equation.

$$P_1 + \frac{1}{2}pv_1^2 + pgh_1 = P_2 + \frac{1}{2}pv_2^2 + pgh_2$$

The elevations are approximately equal, so that part will cancel. P2 will be zero because it is at atmospheric pressure.

$$P_1 + \frac{1}{2}pv_1^2 = 0 + \frac{1}{2}vp_2^2$$

The entering velocity will need to be calculated.

Area of 3ton blower = 10.25" by 7.5"

$$Area = 76.88in^2 = 0.534ft^2$$

$$v_1 = \frac{V}{A} = \frac{\frac{20ft^3}{s}}{0.534ft^2} = \frac{37.45ft}{s}$$

$$Density\ of\ air\ at\ atmospheric\ pressure\ and\ room\ temperature = p = \frac{0.0765Ibm}{ft^3}$$

$$P_1 + \frac{1}{2}(\frac{0.0765Ibm}{ft^3})\left(\frac{37.45ft}{s}\right)^2 = \frac{1}{2}(\frac{0.0765Ibm}{ft^3})\left(\frac{117.3ft}{s}\right)^2$$

$$P_1 = \frac{469.96Ibm}{ft\ s^2}\ x\ \frac{Ibf}{32.174Ibm}\ x\ \frac{ft^2}{144\ in^2}$$

$$P_1 = 0.1014\ psi$$

According to the theoretical calculations, the ductwork should be strong enough to cope with a pressure of 0.1014psi. Therefore, 28 gage or less sheet metal will be considered in the design.

Theoretical heating analysis before prototype:

Heating would be desirable so that the air would not feel so cold and evaporate the water off the body quicker. In order to see if heating is plausible for a 20 amp circuit, we need to determine how much wattage is available for heating.

Wattage of circuit = 20A x 120V = 2400W

Wattage of 2 3ton blowers = 2 x (4A x 120V) = 960W

Wattage left over = 2400W – 960W = 1440

An idea of heating would be heat bulbs.

Wattage of 6 heat bulbs 250W

Number of possible heat bulbs = 5

Another idea of heating is to use nichrome wire/resistive wire.

Amount of Wattage for wire = 1440W

The experimental observations will be contained in the section, 5 Engineering Analysis of this report.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: Body Dryer NAMES: Nick Zuelke, Luke Maichel, Laura Bailey INSTRUCTOR: Professor Giesmann

The following engineering analysis tasks will be performed:

Engineering analysis will be composed of three targeted areas; the electrical power source, airflow design, and the heating requirements (lighting) for the Body Dryer design.

Electrical

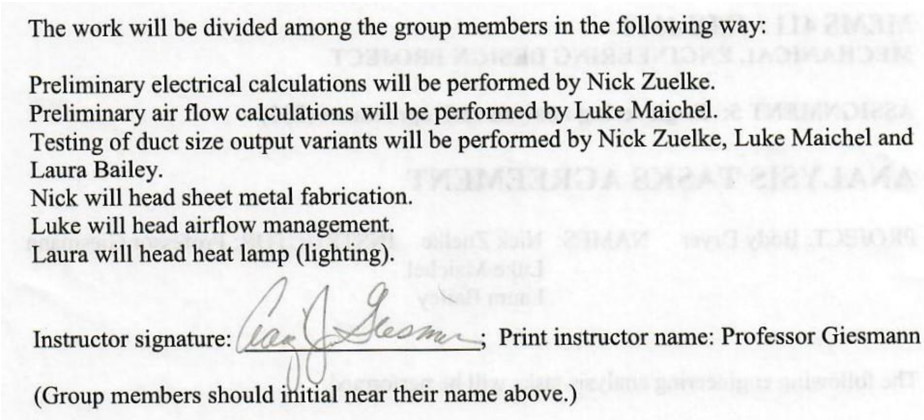
- Calculations for voltage use of no more than 240-V service
- Calculations for utilization of two (2) 3-ton blower motors
- Calculation of remainder power supply for heating elements (lighting) to ensure safe operation

Airflow

- Preliminary calculations using Bernoulli's energy conservation equation to understand required duct pressure
- Preliminary calculations using Venturi principle to understand airflow regarding cross sectional area and velocity
- Testing- comparing the voltage output from a small turbine generator (in lieu of anemometer), to indicate air velocity optimization among various duct configurations. Multiple rectangular and round portals will be tested using wood reinforced cardboard cutouts to indicate varying output sizes.
- Shape and placement of nozzles (slots) along the plenum to encourage optimal dry time
- Possible vane inclusion to encourage and test for the even distribution of air output

Heating

- Bulb placement and sizing will be tested by utilizing the temperature capability of the voltmeter as well as the trial and error of test subjects among multiple bulb locations


The work will be divided among the group members in the following way:

Preliminary electrical calculations will be performed by Nick Zuelke.
Preliminary air flow calculations will be performed by Luke Maichel.
Testing of duct size output variants will be performed by Nick Zuelke, Luke Maichel and Laura Bailey.
Nick will head sheet metal fabrication.
Luke will head airflow management.
Laura will head heat lamp (lighting).

Instructor signature: ______; Print instructor name: Professor Giesmann

(Group members should initial near their name above.)

Figure 12: Image of the Engineering Analysis Contract

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

It was important to understand how the air would flow and how the heat would be administered by using testing to support the preliminary calculations. This helped to identify the power needed, configuration of components, and viability of the proposed solution. Demonstrated below, various testing was done to solve the problems which had not been anticipated on paper.

5.2.2 Summary statement of analysis to be done

We have chosen to study different parts of the system to test and learn about. One section is how big the nozzle should be. This will have a huge impact on our final design. If the nozzle size is not correct, we will not have enough air flow, or not enough speed to dry someone off. Another test that will be done is to determine the shape of the nozzles in order to maximize the air flow and velocity. A big step that needs to be taken is whether there should be a heating element or not. A heating element is preferable, but it needs to be determined if it is possible or not. Determining these things carries the project forward. In deciding the area and the shape of the nozzles, it will allow us to start making the ductwork. It is important to decide whether or not heating is possible. If it is, then we need to design how the heating will work, if heating is not possible, then we can move on from that section and start fabricating the system.

5.2.3 Methodology

The analysis was done by conducting tests for all possible situations pertaining to the system parameters. However, some equations and theoretical work were done earlier, which can be seen in section 4.4. The inlet size of the ductwork was tested by taking some cardboard and placing it in front of the blowers, then cutting different sections out of the cardboard and measuring the velocity of the air. The velocity was measured by taking a computer fan and wiring it to a voltmeter. The air would then blow the fan and we could read how much voltage was being created. The greater the voltage, the higher the velocity. The outlet area of the ductwork was measured by taking some ductwork and cutting different sections out. Different sections were cut out and the velocity was measured for each section. The shape of the nozzles was decided by testing different kinds of nozzles and the velocity that they delivered. Many different nozzle shapes were tested, including triangle shape slots, square slots, a cone shaped nozzle, and a damper.

Heating was tested by putting different heating devices in the ductwork and testing the exit temperature with a thermometer. The different heating elements tested in the ductwork were a water heating element, and a resistive wire. Heat bulbs were also tested outside of the ductwork.

5.2.4 Results

Air flow:

Summary of inquiry for theoretical analysis before prototype:

How big should the nozzles be?

From the theoretical calculations, the desired exit velocity is 80mph.

According to the theoretical calculations, the area of the nozzles should be 24.55in^2

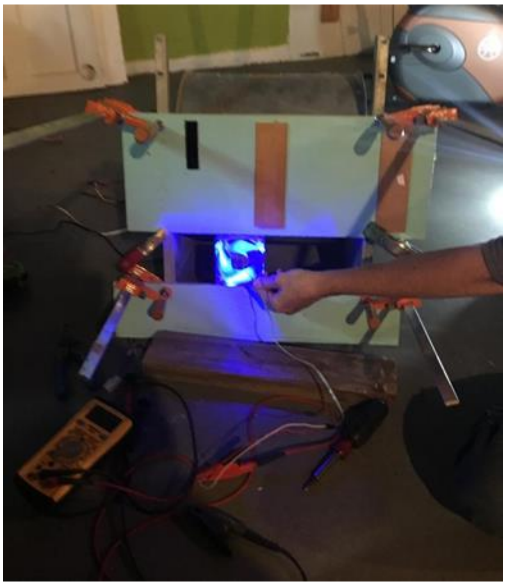
How strong should ductwork be?

According to the theoretical calculations, the ductwork should be strong enough to cope with a pressure of 0.1014psi which is approximately 3” of water.

Experimental analysis with prototype:

What should the area of the duct be?

Testing was done to determine what the area of the duct should be. Since we did not have access to an anemometer to test the velocity of the air, we used a computer cooling fan and attached a voltmeter to the external leads. We then experimented with different areas by placing the fan up to the opening and measured the voltage. The higher the voltage, the faster the air was blowing, which is the desired effect. Two tests were carried out; one with a rectangular opening and the other with a circular opening. The results are contained with the following tables and the following figure shows how the tests were conducted.



The testing rig to the left was used to determine the optimal size of a rectangular supply opening.

Figure 13: Checking voltage using a back driven computer fan to indicate changes of air velocity.

Table 9: Rectangular Opening Voltage Measurements

width (in)	height (in)	volts (V)
10.25	7.5	4.6
10.25	5.5	7.0
10.25	4.3	7.5

Table 10: Circular Opening Voltage Measurements

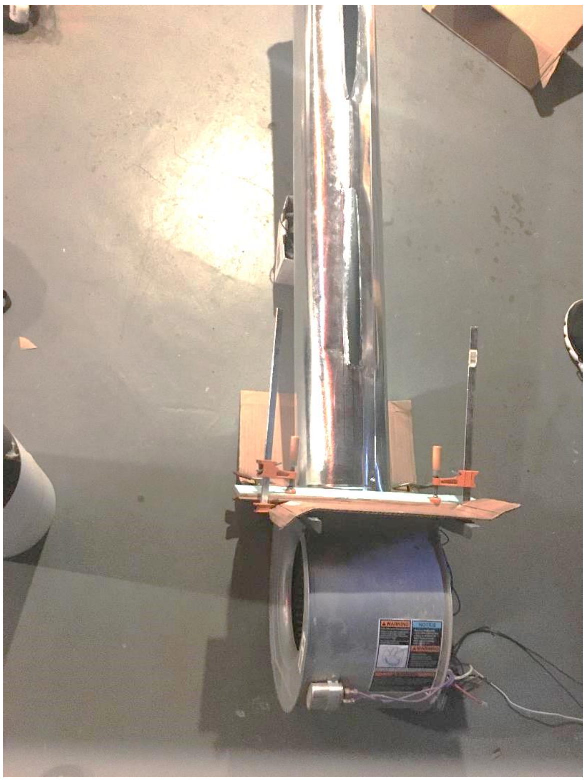
diameter (in)	volts (V)
3	6.50
4	6.95
5	7.15
6	7.20
7	7.40
8	8.00
9	8.25

It was seen from these experiments that the circular opening was better than the rectangular opening. It was also seen that the larger the diameter, the higher the velocity. The reason for this is because when the area got smaller, the current went up, and the amount of air flow dropped due to the motor not having the power to overcome the restriction. The 9in diameter duct is uncommon and an odd size, and 10in duct would be too big to fit on the fan, so it was decided that the 8in duct would be used.

What should the diffuser area be?

Something that needed to be decided was the area of the nozzles. This was tested by taking an 8in diameter duct that was 5ft long and attaching it to the front of the blower. The voltage was then tested in the same manner as before to find the highest velocity.

The first test was done by splitting the seam of the duct at one end and still having it attached next to the blower. This made a triangular opening. The width at the end was 1.75in, and the length of the slit was 50in. This made a total area of 26in^2. The voltage was then measured at the beginning of the duct, the middle, and the end. The results are shown below in the table and the following figure shows the initial balancing testing rig.



The testing rig to left was used as our initial setup to determine a general idea on the nozzle size and placement that is required to balance the system with optimal flow.

Figure 14: Initial balance testing of the rig with the side wall slots.

Table 11: Triangular Opening Voltage Measurements

position	volts (V)
end	0.07
middle	0.02
beginning	0.01

The next test was done by cutting two slots in the ductwork. The voltage was then measured on the bottom slot and the top slot. The figure to the left is the testing rig used for the remainder of our experiments. A sheet metal plenum was fabricated out of scrap sheet metal flashing to simulate our finished product and add rigidity because the cardboard was beginning to sag, and the metal supply duct was hitting the fan blades. Figure below is the sheet metal plenum used for experimentation.

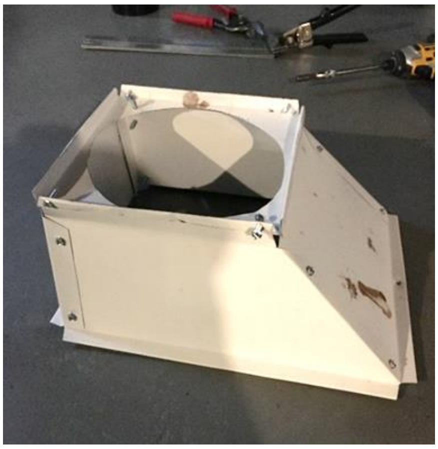


Figure 15: Testing Plenum

Figure 16: Main Testing Rig

Both slots in each run were 16.5in tall. The width of the slots was changed for three different tests. The results are shown below in the following table.

Table 12: Various shapes and sizes were tested for the slot openings in effort to balance the system.

RECTANGULAR hole			
slot width (in)	slot area (in^2)	TOP volt (V)	BOTTOM volt (V)
0.75	24.75	0.03	0.03
1.25	41.25	0.08	0.04
TRAPEZOIDAL hole			
2.00 b; 1.25 t	53.63	0.07	0.12

It was seen that, contrary to the theoretical calculations, the greater the area, the greater the velocity. The discrepancy between the test results and the theoretical results can be explained by the fact that the Bernoulli equation that was used does not account for turbulent flow. It also did not account for the fact that when the area got smaller, the current went up and the amount of air flow plummeted. This started to change a little once the area got greater than $50in^2$. So, by running the experiments and analyzing the results it was decided that the exit area should be equal to $50in^2$, which is equal to the entrance area of the 8" supply duct. It also worked best when the bottom slot was larger, and the top slot was smaller, so this will be taken into consideration for the final design.

Unless the bottom slot was much larger, the air came out faster on the top, and we could not get a steady and even flow throughout the entire duct. More testing was done for even flow.

To get an even flow, a damper was put into the duct between the top and bottom slot. The damper was then adjusted to try and get an even flow. The results are shown below.

Table 13: Voltage measurements at top and bottom output slots with damper set at various angles.

angle (deg)	TOP volt (V)	BOTTOM volt (V)
0	0.18	0.190
15	0.16	0.200
45	0.11	0.245
90	0	0.250

As can be seen, the damper did not have a real positive impact on air flow unless in the closed position. It was speculated that having the damper in the stream of air disturbed the natural spiral flow through duct with a circular cross-section.

The next test was to have 5 slots for the air to come out. The width of each slot was 2in, but different lengths of the slots were different sizes to test which size worked. The slot numbered 1 is the bottom slot, and 5 is the top slot. The results are shown below in the table.

Table 14: Five Slot Test Results

slot (#)	height (in)	volt (V)
1	3	0.04
2	7	0.26
3	3	0.18
4	7	0.17
5	4	0.19

As can be seen, having a lot of slots spread the air flow out somewhat evenly, but the bottom was still not very strong.

A test was done with all the slots being the same size. In order to try and get the air to come straight out though, the slots and fins placed on the inside of the duct to angle the air out. The figure below is a Solidworks model and it was designed to gather inspiration for how a nozzle could be fabricated with fins to direct the airflow. Table 17, below, shows how the fins interacted with the system.

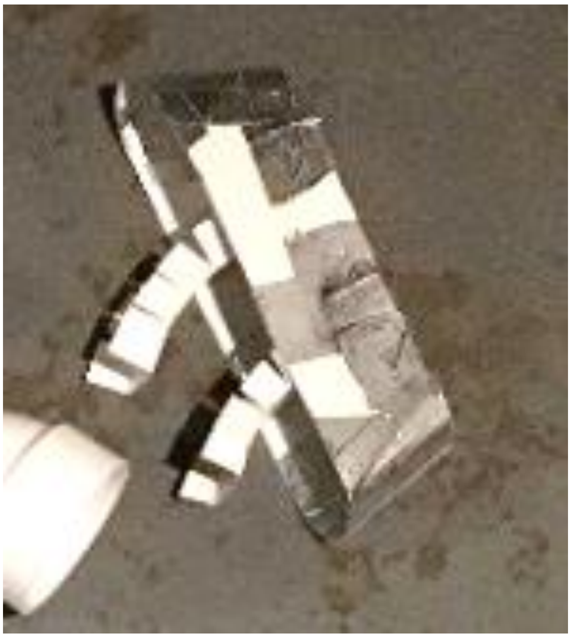
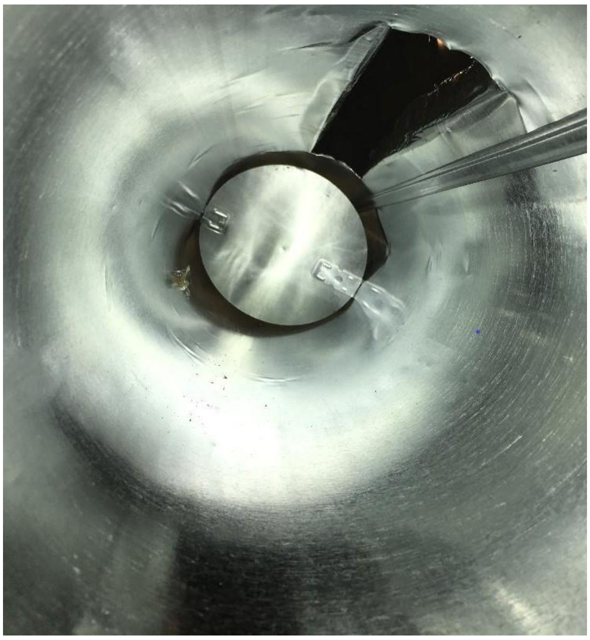



Figure 17: Left: Fabricated nozzle with fins from designed Solidworks model. Right: Damper in ductwork.

Table 15: Supply Duct Test with Fins

slot (#)	volt (V)
1	0.19
2	0.17
3	0.19
4	0.19
5	0.20

As can be seen, this made the air flow relatively even.

A test was then done to see what different size fins would do. The fins were made to not go as deep into the duct. The results are shown below in the table.

Table 16: Supply Duct Test with Small Fins

slot (#)	volt (V)
1	0.19
2	0.15
3	0.16
4	0.18
5	0.22

As can be seen from the results, by making the fins smaller, it did not improve the air flow.

A test was then done to see if the fins had a positive effect, or if the positive effect was having the same size slots. This test was done by removing of the fins, but still having the same size slots. The results are shown below in the table.

Table 17: Evenly Spaced Slots

slot (#)	volt (V)
1	0.22
2	0.22
3	0.23
4	0.24
5	0.19

As can be seen, these seem to be the optimal results. The air flow was relatively even for all the slots, and it had a great velocity through all the slots. Even though this is not what we had originally expected, it makes sense because the fins were disrupting the air flow. It also makes sense that having a lot of smaller slots that are the same size yielded the best results. The air always came out the top of the 16.5" long slots, so if there were more slots, there were more top of the slots, which means there were more spaces for the air to come out at a high velocity while being balanced.

Experimental heating analysis with prototype:

Water heating resistive heating elements were considered to determine if they will provide the optimal heating level. The heating elements were placed directly above the blower via a hole cut in the side of the supply plenum. After running tests on the water heater resistive heating elements connected to 240-volt power supply, it has been determined that this method of heating the air is not the right application due to the convective heating coefficient of the fluid being too low. Therefore, the amount of air needed to maintain a nominal operating temperature of the resistive heating element is much higher than the system that we have designed is able to maintain. After the element is energized for 20 seconds, it melts and catches fire. However, when the element was connected to a 120-volt power supply the system was able to maintain the nominal operating temperature, but it only yielded a 3°F increase in temperature. Therefore, another heating method will need to be investigated or changing the location of the elements. The figure below shows the testing setup.

Figure 18: The setup for testing the water heater element viewed through the duct nozzle opening.

A 1500W nichrome wire was put into the duct, and the temperature of the air coming out was measured. The temperature was measured with and without the heater. The results are shown below in the table and a figure showing the placement in the system.

Figure 19: Nichrome resistive heating element before duct was attached to plenum.

Table 18: Nichrome wire temperature increase with blower running.

Room T (F)	Heater (F)
75.6	82.7

As can be seen, this made a small difference.

Heating bulbs were then tried. An infrared heat bulb was put next to the duct and the temperature was measured at different distances without and with the blower running. The results are shown below.

Table 19: Air temperature at duct using infrared bulbs both without and with the blower running.

distance (in)	temp w/o air flow (F)	temp w/ air flow (F)
1	117.0	79.0
6	86.5	77.7
12	83.0	76.7

The temperature decreased as the distance increased, which is expected.

As can be seen, the air flow made the bulbs less effective. This makes sense, because wind blows the heat away, which cools things down, and the effects of the radiant heat felt was not registered on the traditional thermometer.

5.2.5 Significance

The testing done over 3 weeks significantly directed the project towards simplicity. Heating was expired, as it was found that the most viable method involved resistance heating. To be effective for the air velocity and capacity, it was found that at the very least, 4000-5000 W were needed for each leg of the component. Therefore, to include the heating feature, the circuit capacity would be increased from a 20 Amp circuit to a 50 Amp circuit. This put a strain on budget, time, and power requirements, and was cleared for abandonment.

After exhausting the heating stipulations, focus returned to balancing the air flow output of the unit. After multiple attachments, configurations, and sub-flows were tested, it was, again, noticed that the simplest of design choices, was most effective. Each test resulted in taping up our pseudo- prototype, spinning it a few degrees, and cutting new holes. Endless options and testing are possible, fortunately, deadlines determined final decisions and satisfied the coveted balanced 'working prototype'.

Figure 20: Nozzle Materials Tested

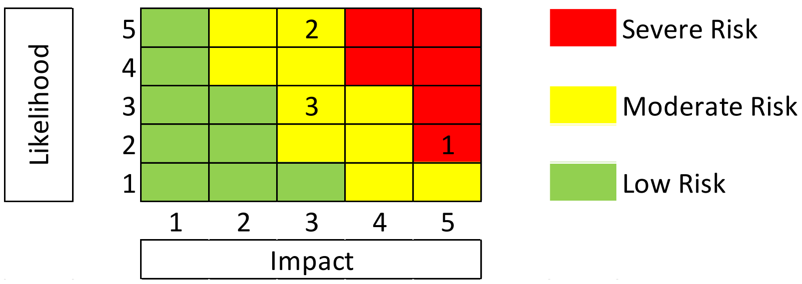
6 RISK ASSESSMENT

6.1 RISK IDENTIFICATION

Throughout the design process of the project we are under a constrained timeline that will allow completion. However, the drafted schedule will contain days that will mitigate the effects of the risks by an overestimation in the work package completion dates. The following items will impact the project by causing delays in the completion date. To understand the level of severity a risk assessment matrix is used.

- 1: Electrocution during testing
- 2: Lacerations during the construction or testing phase of the project
- 3: Not knowing when to move on in the project

Table 20: Risk Assessment Matrix



6.2 RISK ANALYSIS

6.2.1 Electrocution during testing

Since we are conducting tests with different heating mediums, we will need to maintain a vigilance and conscience notion of live wires. If one of the project members is to receive an electric shock by touching a live wire, then this could cause an injury or death to the project member.

6.2.2 Lacerations during the construction or testing phase of the project

The construction and testing phase of the project will involve the handling, manipulating, and the use of fabrication machines of sheet metal. If sheet metal is handled or manipulated incorrectly, it can result in sever lacerations, thus a reduction in the member's ability to physically handle and manipulate the materials.

6.2.3 Not knowing when to move on in the project

We are undertaking a project that requires several avenues of investigation/testing. If we continue to try to continue testing after exhausting all possibilities within the constraints of the system, then we are trying to force an outcome that is not possible.

6.3 RISK PRIORITIZATION

6.3.1 Electrocution during testing

To mitigate this risk, we will use safe practices when connecting and adjusting the conductors. When connecting and adjusting the conductors, the wire will be tested with a multimeter to ensure the wire is not hot/live or making sure the equipment is disconnected from the receptacle. Also, the connections will be made sure that the hot wire will not touch the neutral wire.

6.3.2 Lacerations during the construction or testing phase of the project

This risk will be reduced by wearing safety gear such as gloves because when handling and manipulating sheet metal, gloves will protect against the majority of injuries. To fabricate the plenums and caps, sheet metal equipment such as a Pittsburgh lock former, sheet metal brake, and various sheet metal tools will be used. The only person that will be operating the equipment during the fabrication phase, will be the member that is qualified due to extensive knowledge and experience operating such equipment or supervise a member with little to no knowledge when using the equipment.

6.3.3 Not knowing when to move on in the project

After exhausting all avenues of testing, just need the realization when to abandon a portion of the project. However, the documentation will be classified as a future improvement if applicable. It will contain the necessary information to carry the project to the original expectations.

7 CODES AND STANDARDS

7.1 IDENTIFICATION

Electrical Codes:

All codes have come from the NFPA 70 National Electrical Code (NEC) 2017.

110.4 Voltages

The voltages will be at which the circuit operates. Voltage rating will not be less than the voltage of the circuit to which it is connected. Therefore, all components connected to the branch circuit will not exceed the voltage rating of the circuit. If voltage rating is exceeded or not sized properly, then this may result in unsafe operating conditions.

110.5 Conductors

Conductors shall be made of copper or aluminum. If other material is used, the size will be changed accordingly. All wires that are used for the build will be inspected to determine the material of the wire to ensure the system has the proper operating characteristics. The reason this is important is due to the materials used to make the wire have physical properties that can only handle a specific load on a conductor. If these physical properties are exceeded, then the system will not be properly sized.

110.6 Conductor Size

The sizing of the wiring is expressed in American Wire Gage (AWG) or in circular mils. When sizing the wires for the circuit, they will be inspected to ensure they are following the nominal expression set forth by this code. If wire is too small to supply the required current to the system, then the wire will exceed its operating capabilities and may result in a fire.

110.26 Spaces About Electrical Equipment

(A) Working Space: Allows clearance and access for examination, adjustment, servicing, and maintenance. Every component that will be installed will be installed such that every component will comply with 110.6.

110.27 Guarding of Live Parts

Any component that is installed will be enclosed to avoid accidental physical contact with exposed conductors. The enclosure types will comply with 110.28.

110.28 Enclosure Types

The type of enclosure will be able to protect against a hose down and splashing water for indoor use. This water-tight enclosure is an Enclosure Type 4. When knowing the enclosure type it allow us to know what steps are necessary to achieve the level of water tightness.

240.4 Protection of Conductors

The wire that we have sized for the build is a 12 AWG with copper conductors. According to 240.4(D) Small Conductors (5) a 12 AWG with copper conductors is rated for a maximum overcurrent rating of 20 Amps. This specifies the maximum breaker size that can be connected to a 12 AWG with copper conductors.

Duct Fabrication and Design:

All codes have been taken from NFPA 90A (and NFPA 90B) 2018 Edition and will comply with SMACNA HVAC duct construction standards.

The joints and seams will be fastened and made airtight because it will be designed to have a duct pressure of 2” of water column. The supply plenum joints will be constructed out of a Pittsburgh lock style joinery. This joinery will aid in keeping the system airtight. The supply plenum will be a three-sided transition that will fasten directly to the squirrel cage of the blower assembly. The plenum end cap with an 8” diameter hole will act as the link between square to round duct, and it will be connected via a slip joint. The excess metal from the plenum will be bent over to secure the cap to the plenum. The 8” hole in the cap will be connected to a starting collar and this will act as the point where the 8” rigid supply duct will be fastened to. Along the supply duct, holes will be cut into the sidewall of the pipe. Then nozzles will be fastened where the holes in the sidewall are. Where there are sharp edges in the metal, they will have rounded over hemmed seems to reduce lacerations where possible. Since the supply is less than 10’ tall and oriented vertically, thus there will need to be at least one support to comply with SMACNA standard duct construction.

Other:

Heating elements:

NFPA 2018 Edition items which pertain to the use of resistance heating and could be applicable.

11.5.3 Portable Electric Heaters

11.5.3.1 The AHJ shall be permitted to prohibit use of portable electric heaters in occupancies or situations where such use of operation would present an undue danger to life or property.

11.5.3.2 Portable electric heaters shall be designed and located so that they cannot be easily overturned.

No mention in Chapter 50 Commercial Cooking *to infrared heat lamp or other warming devices.*

From the 2000 ASHRAE Systems and Equipment Handbook, Section 15.4 gives information about electrical infrared systems:

Infrared heaters should be operated at rated input. As a variety of infrared units with a variety of reflectors and shields are available, the manufacturers’ information should be consulted.

Lamp holders and grounding for infrared heating lamps should comply with Section 422-15 of the NEC (NFPA Standard 70).

Indoor Air Quality:

EPA or IECC (MEC) 95- (ASHRAE 90.2- residential referenced ASHRAE 62.2 referenced) pertains more for a “system”

No statewide code in MO.

7.2 JUSTIFICATION

The body dryer project presented a combination of safety concerns, however, because it was not an item already in use, it adhered to no one code already in place. Areas of concern involved electricity, heating, and ventilation.

Electrical requirements are controlled by the NEC and the UL. Equipment is rated per use. The combined power needed through use of blowers and lightbulbs (or resistance heating) was calculated to withstand what the wiring, individual components, and overall circuit would safely tolerate. Power upon upstart is higher, however, the blowers employ a capacitor to alleviate startup amperage draw. The power and safety for use of high wattage luminaires and resistance heating were noted for determining component sizing and wiring.

Consideration of fire code was important if resistance heating was used. The only close relative found in the fire code pertains to use of small electrical appliances. Obviously if Nichrome wire is strung inside the body dryer duct, careful attention would be taken to use ceramic hangers, and keep the heating element away from any combustible surfaces. Both the NFPA and ASHRAE default to the NEC code, section 422-15 for electrically powered infrared heaters and bulbs. A future iteration would certainly have to carry heat.

Ventilation and duct design were also of concern. There were multiple codes and standards pertaining to the traditional use of ducts for HVAC applications. It was important to be aware of these for the duct design, however, adhering to energy standards was not applicable, as the body dryer device would be used for very short durations and is not tied to an entire residential system.

Indoor air quality was noted. Although, for the prototype, a filter was not employed, it would be important to address this concern prior to hitting the marketplace and would be a place in which to improve the prototype. A quick google search on germs in the bathroom unleashes a deluge of information pertinent to possible problems of invoking a tornado in the bathroom.

7.3 DESIGN CONSTRAINTS

7.3.1 Functional

The largest constraint was heating and the power limitation. The body dryer design needs to be usable in a residential setting and should not employ more than a 40-Amp circuit breaker. It is preferred to keep it usable with one 20-Amp circuit. Maintaining a quick dry off time and a super WOW! factor while maintaining reasonable power consumption was the most defining and difficult part of the project.

7.4 SIGNIFICANCE

Beyond a safe design, most significant, was that the body dryer performed. The constraints on power have driven what we were able to do. At the time of this writing, several iterations have taken place. Balancing the power needed to dry a person and how many (and early on- what types of) components were needed were investigated. Dimensions and material choices for the ductwork resulted more from physical constraints, than those of codes and standards. Most design ideas became simpler after testing. Calculations and theoretical embodiments employed tapered and smaller duct designs than the current prototype. Once the blowers were utilized, it was found that traditional sheet metal ductwork of uniform measure, was optimal.

The constraints on power and safety have been important in consideration of the heating. It left us in a conundrum on how best to provide heat for the unit. Finding the most bang per Watt (and buck) consumed and efforts to minimize heat loss were investigated.

Calculations and expected outcomes did not always give us the right answers, due to the involvement of turbulent air flow.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS

The two figures below represent the entirety of our rendition of the Body Dryer. The design consists of two 3-ton blower assemblies with a horse power rating of 1/3 hp. The blowers provide the pressure difference in the duct to produce the optimal air velocity the system is able to handle without surpassing the ability of the motors. Therefore, the rectangular nozzles are nearly equal to the amount of cross-sectional area of the 8” diameter supply duct. Having the nozzles equal to the cross-sectional area of the supply duct makes balancing the system a less arduous task. This system uses a total of four 8” adjustable elbows. They are used to direct the air and create the angles of the archway. At the very top of the prototype are two 8” caps. This is where the two air streams are separated from each other. Also, since the caps are located at least 18” upstream of the last nozzle, it gives the system an opportunity to pressurize the duct evenly to enhance the balancing of the air.

Figure 21: Working prototype of the body dryer

8.2 WORKING PROTOTYPE VIDEO

https://youtu.be/MgRLFgSZtIs

8.3 PROTOTYPE COMPONENTS

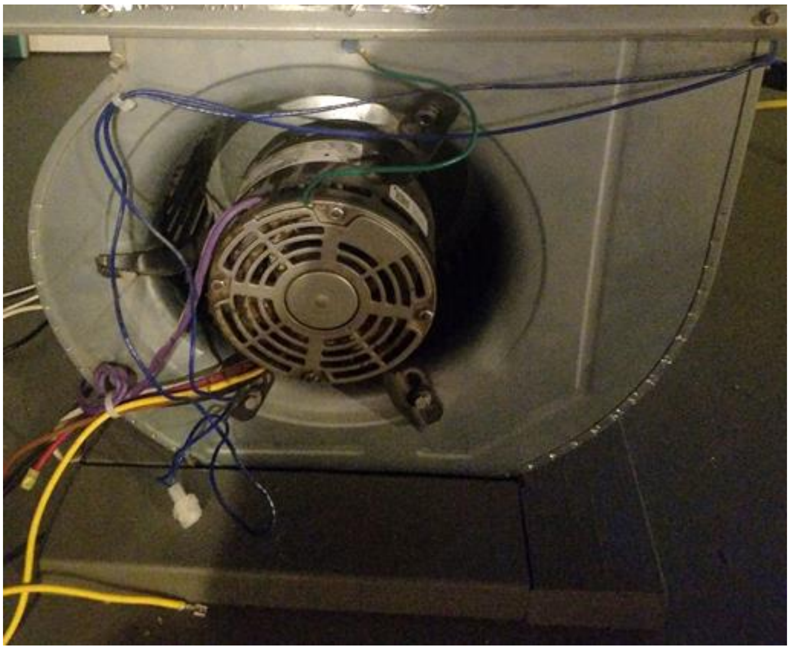


Figure 22: Blower Assembly

To the left is an image of one of the 3-ton blower assemblies. The blowers are wired in parallel to each other and both of the blowers are wired to their highest fan speed. Currently the wires are connected via a spade connector with electrical tape wrapped around the connector to reduce accidental contact or disconnection.

To the right is the sheet metal transition and cap with a collar. The transition and cap were fabricated out of 26 ga metal. The seams of the transition are joined with Pittsburgh lock style joinery and the ½" flanges connecting the transition to the squirrel cage of the blower assembly have a hemmed edge. Since this is where the majority of the air is going to leak, it is sealed with a DC 181 metal tape.

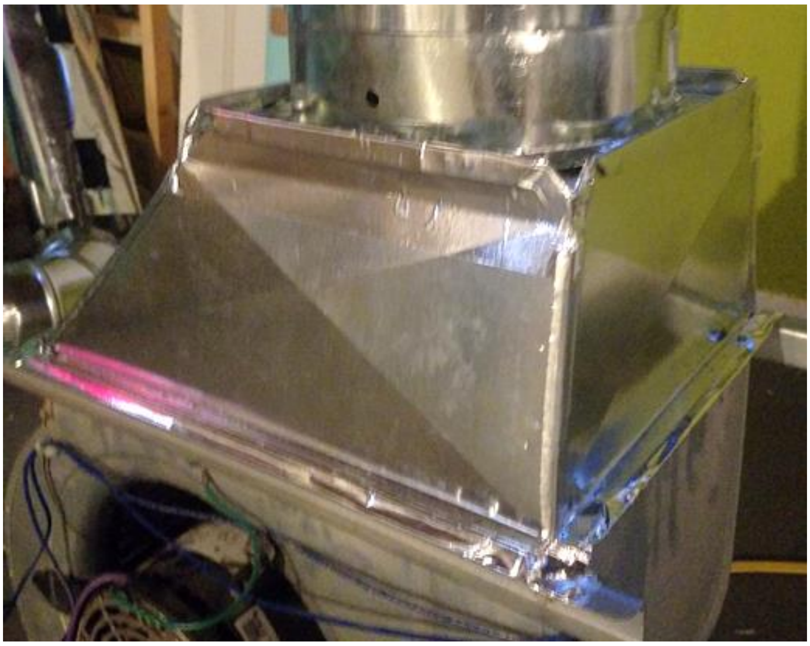


Figure 23: Supply Plenum with Cap

Figure 24: Supply Stack with Nozzles

The image to the left is to show the number of the nozzles that were included in the prototype and where their location is in relation to the rest of the design. The first nozzle coming straight off of the starting collar is 1½” above the edge of the pipe to avoid running into where the fitting and pipe overlap. The nozzle that is above the 8” elbow follows the same principle of the first nozzle, 1½” above where the pipe and elbow overlap.

The image to the right is to show the profile of the how the nozzles are constructed. The finish dimension of the nozzles is 4” by 2”. The rough dimension of nozzles added about .25” around the perimeter which is used to fabricate the hemmed edge. The hemmed edge’s main function is to protect against lacerations by creating an edge that is rolled over, thus smooth to touch without injury.

Figure 25: Detailed image of Nozzle

Figure 26: The supply duct vents are capped and meet at the apex of the archway.

The image to the left is used to focus on where the archway connects at an elevation of 6’6” and where the two air streams are separated. At the connection point, there are two 8”caps. The DC 181 metallic tape is used to create the illusion that they are connected and make the connection look uniform.

9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

All drawings are in English units; INCHES.

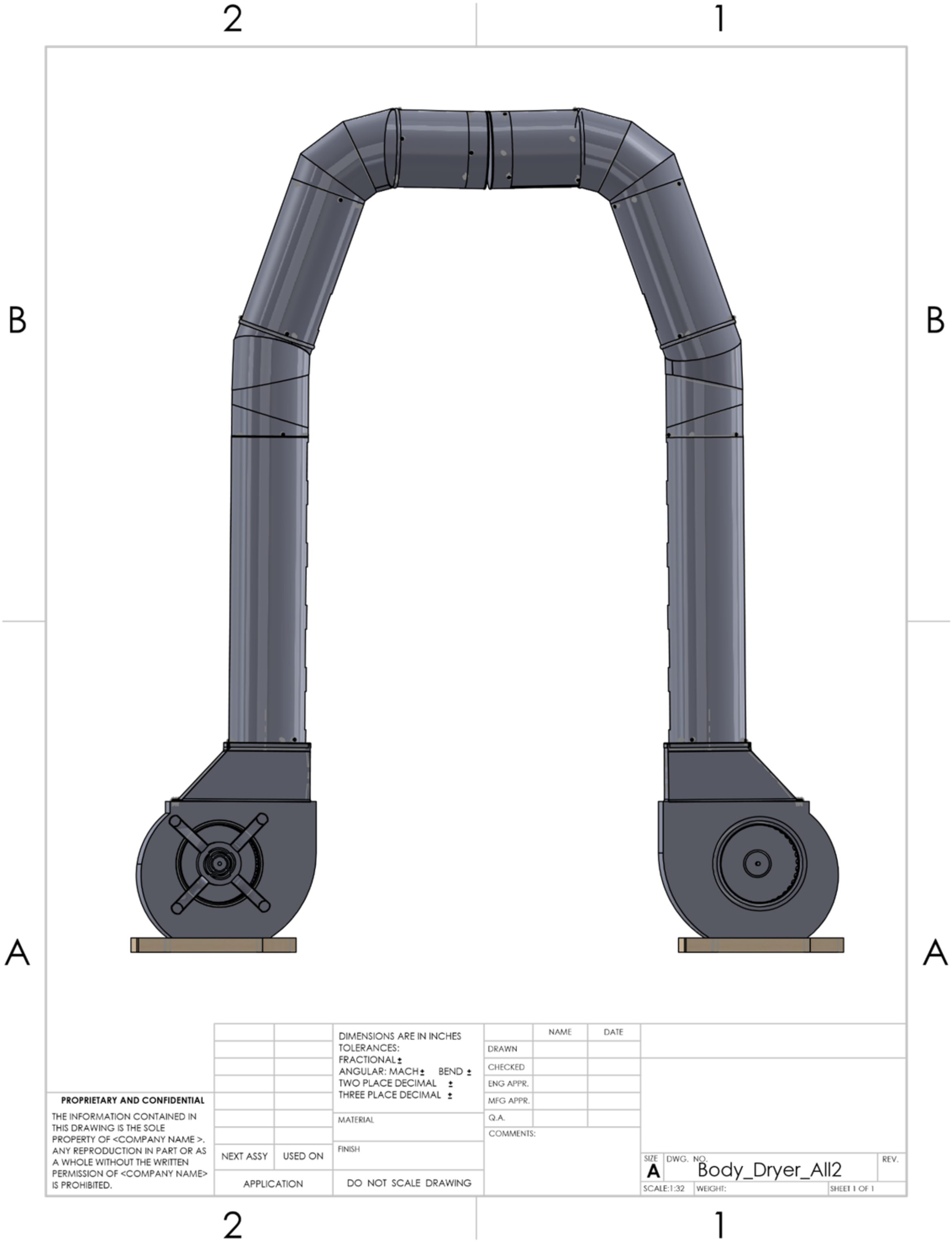


Figure 27 Front View of Body Dryer Assembly

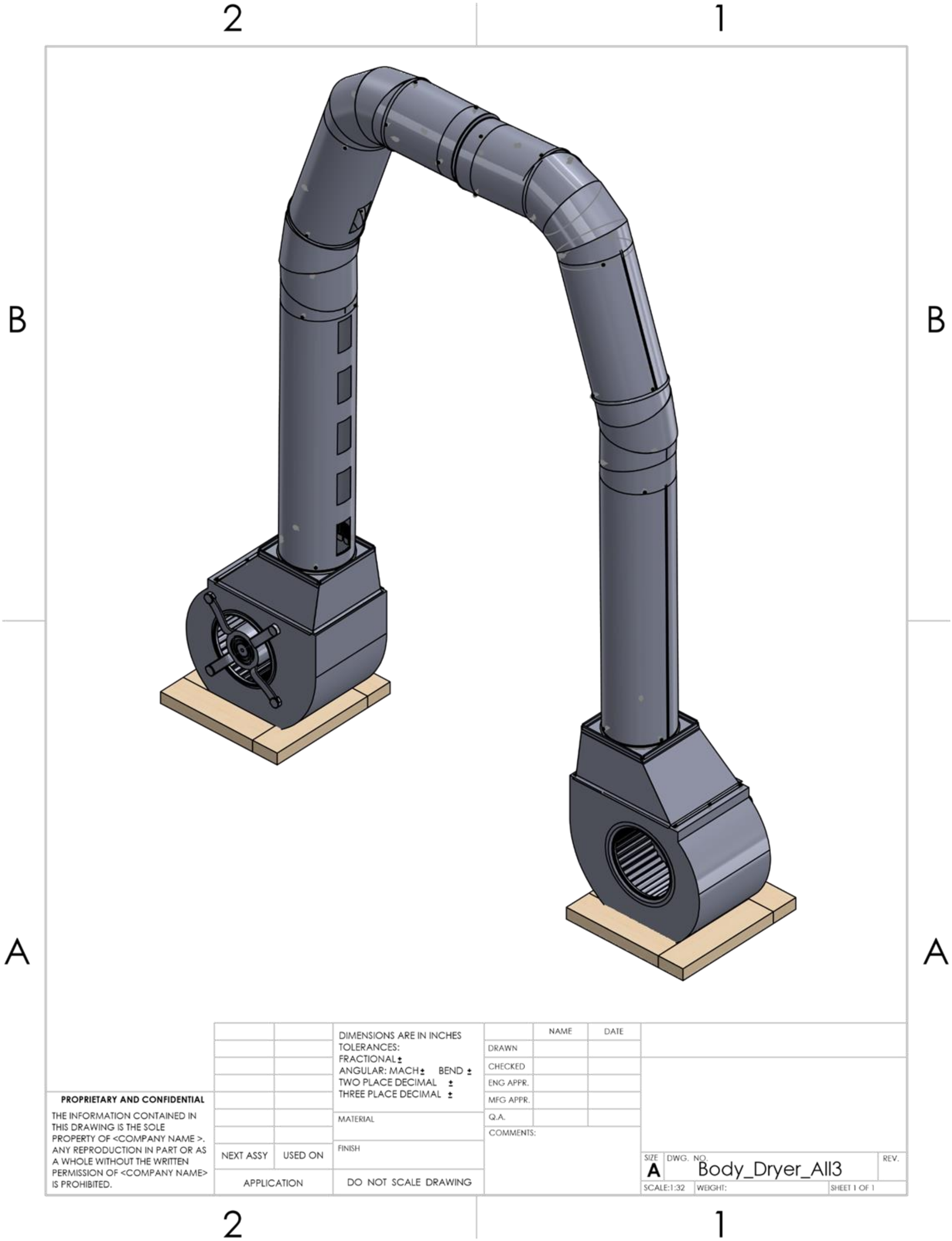


Figure 28 Isometric View of Body Dryer Assembly

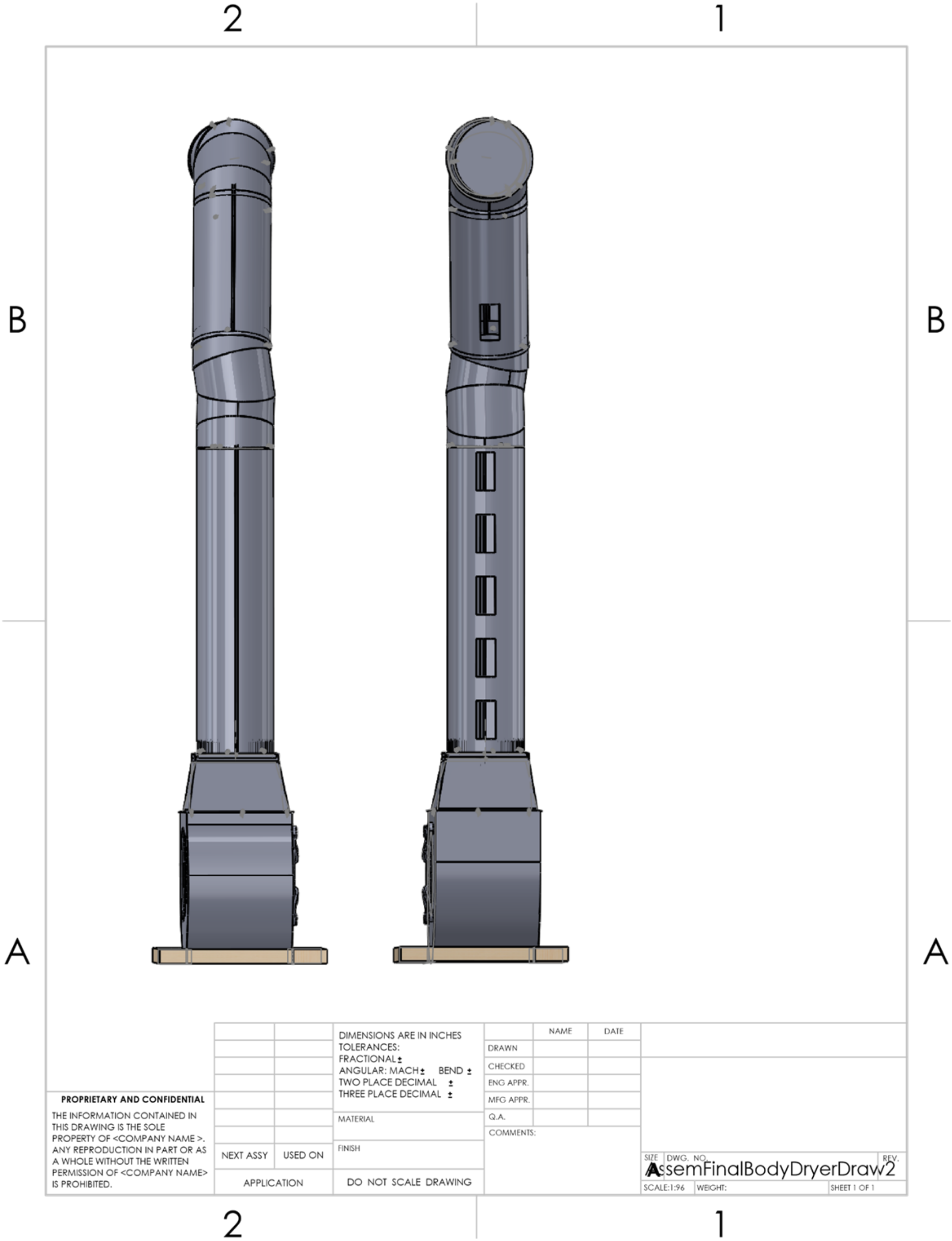
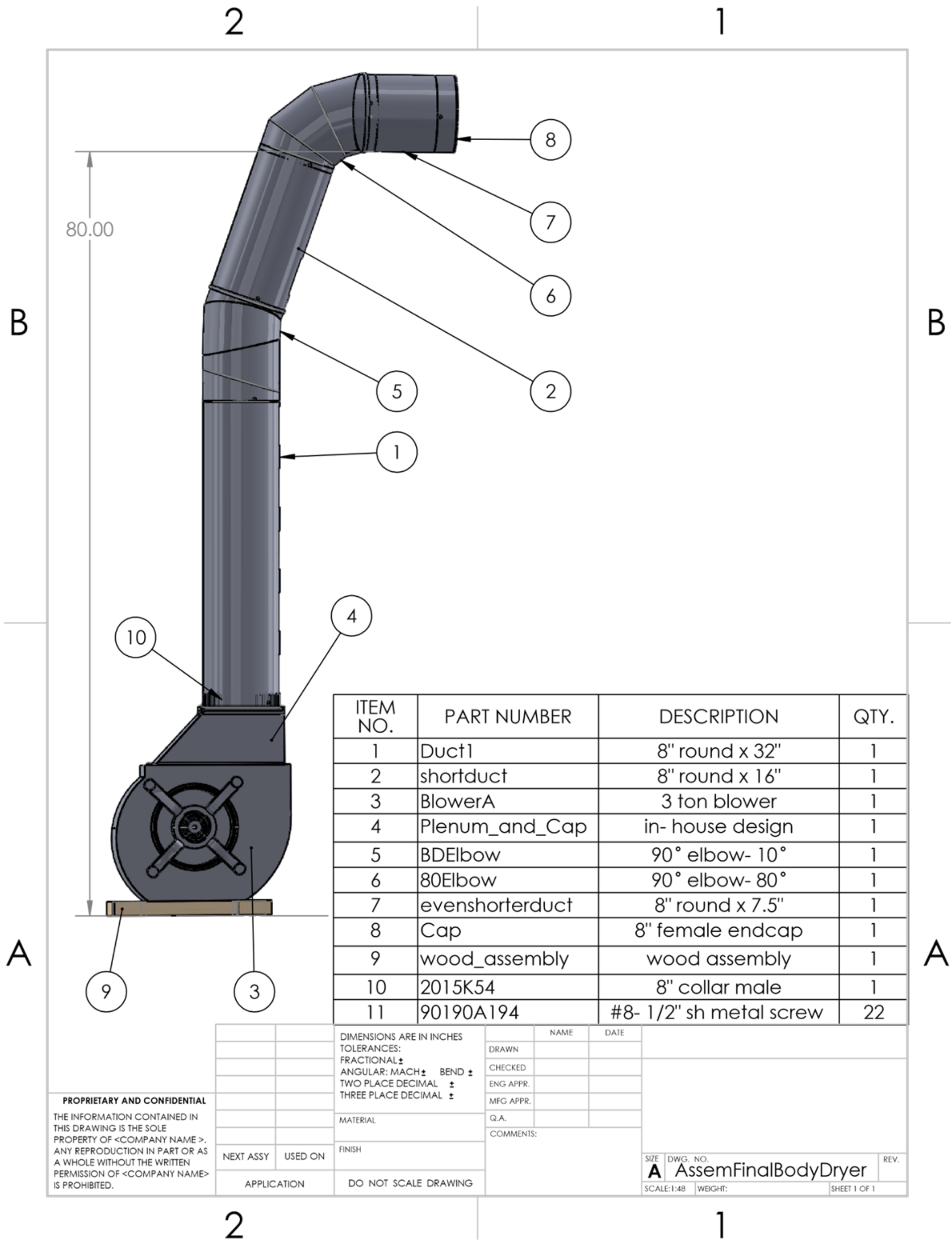


Figure 29 Right and Left Views of Body Dryer- one leg



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Duct1	8" round x 32"	1
2	shortduct	8" round x 16"	1
3	BlowerA	3 ton blower	1
4	Plenum_and_Cap	in- house design	1
5	BDElbow	90° elbow- 10°	1
6	80Elbow	90° elbow- 80°	1
7	evenshorterduct	8" round x 7.5"	1
8	Cap	8" female endcap	1
9	wood_assembly	wood assembly	1
10	2015K54	8" collar male	1
11	90190A194	#8- 1/2" sh metal screw	22

Figure 30 Bill of materials for Body Dryer assembly. The parts listed are for one of two legs of the entire system.

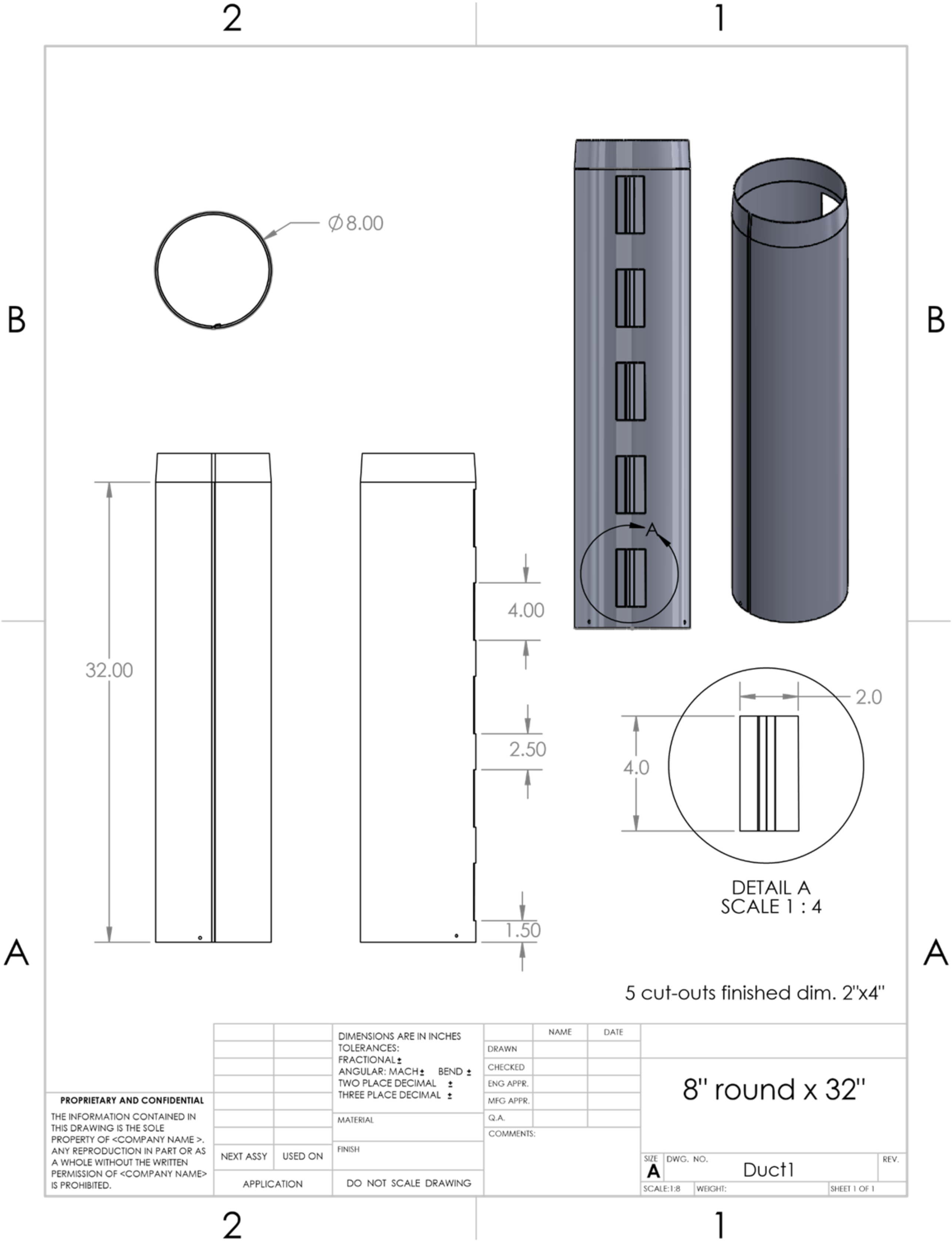


Figure 31 The 32” duct was altered from stock 5’ section. Five 2” x 4” holes were made for air flow.

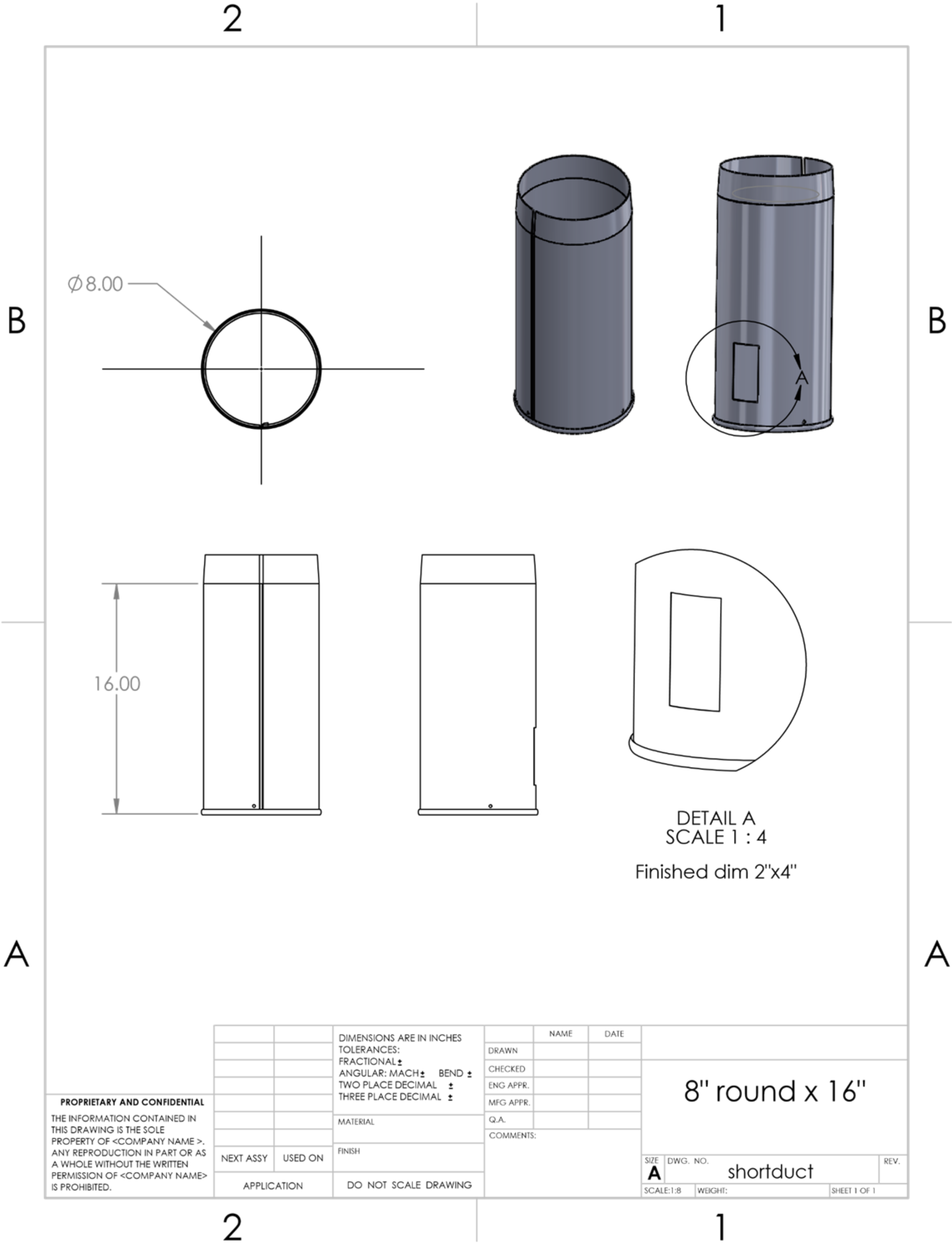


Figure 32 Fabricated from the 5' stock, this is the duct at shoulder height. One 2"x4" hole is cut out for air flow.

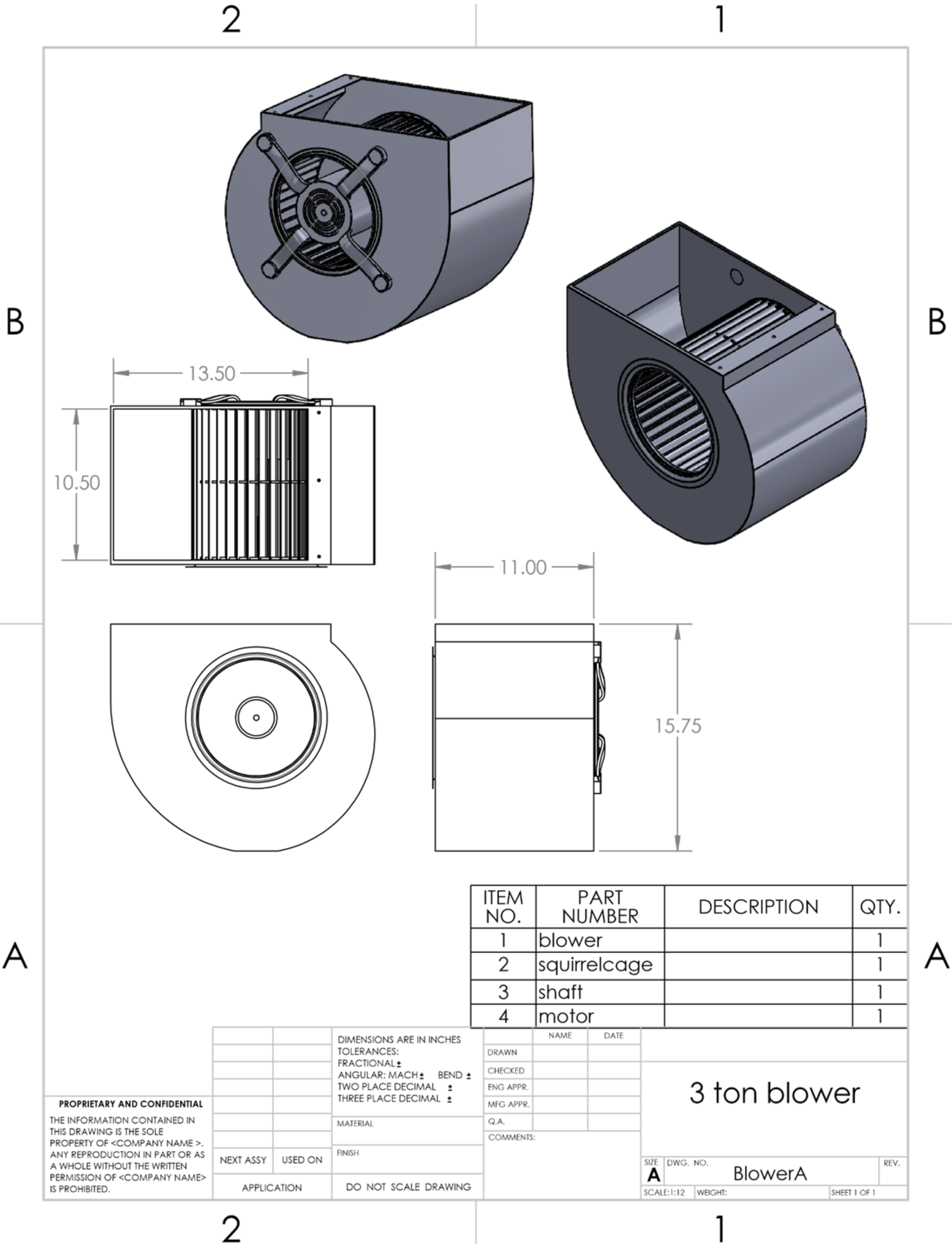


Figure 33 Not meant for fabrication purposes, the blower unit can be purchased or parted as a whole.

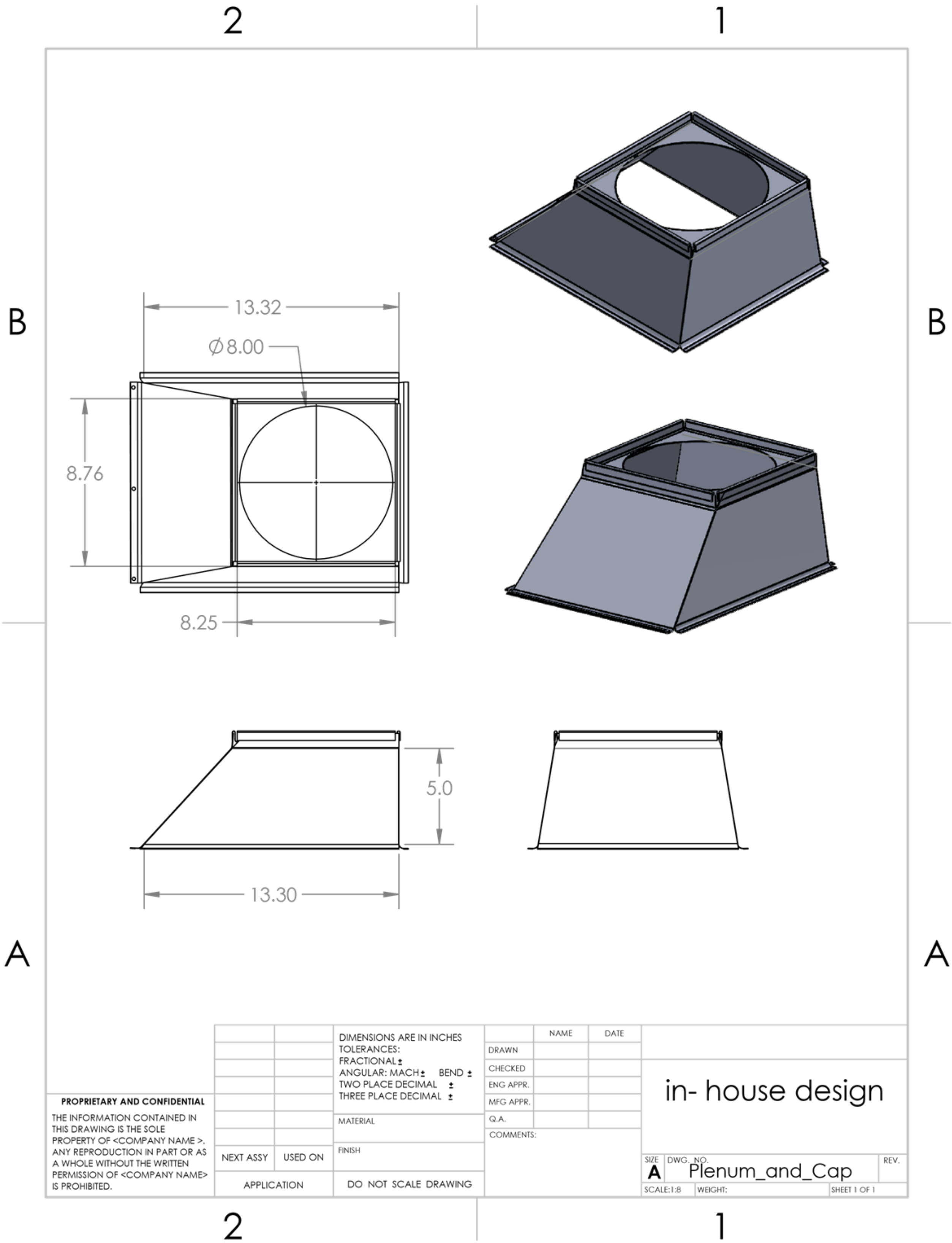


Figure 34 The plenum and cap were designed and fabricated in-house to provide transition from blower to duct.

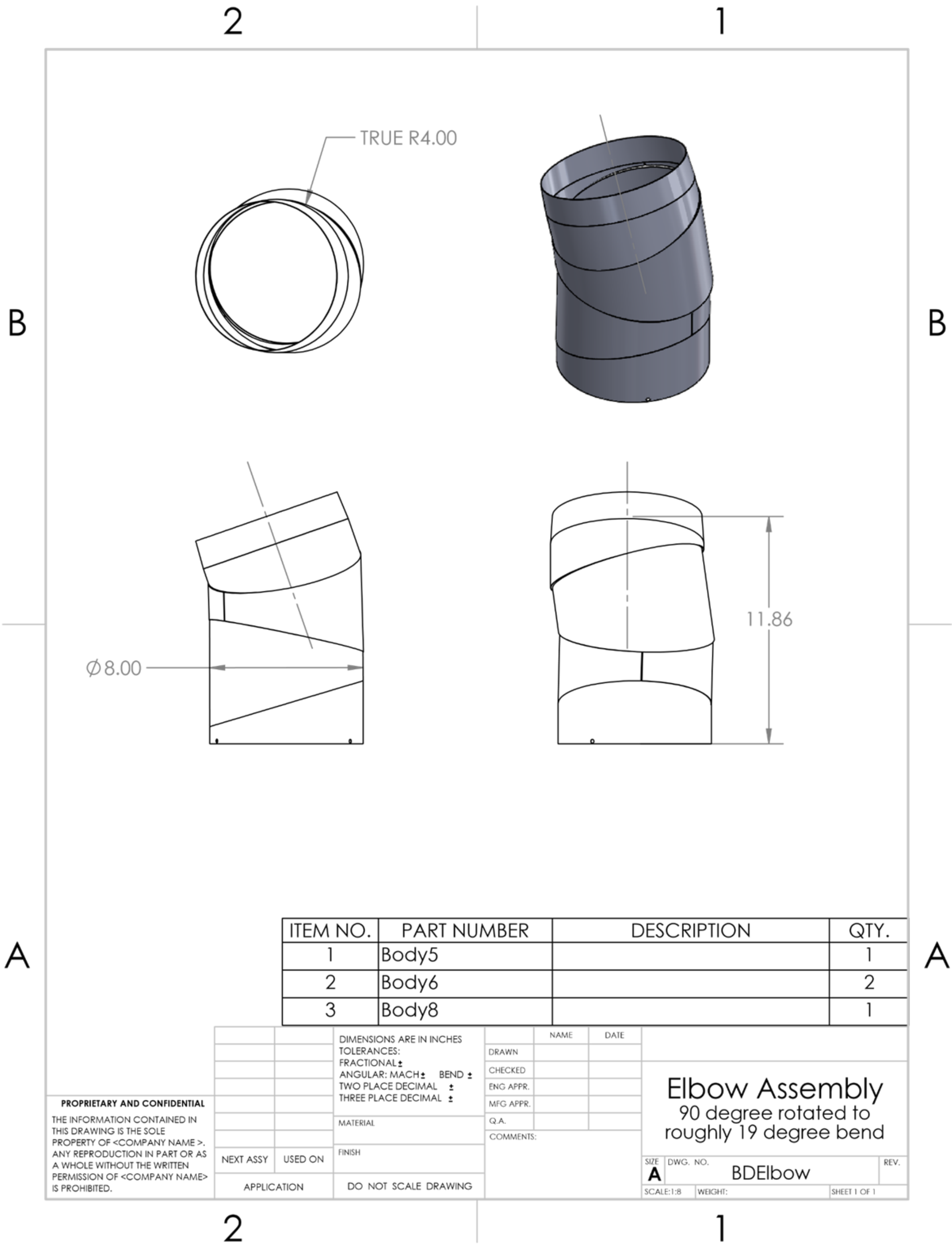


Figure 35 A 90-degree elbow was purchased from The Home Depot, however, had to be fabricated to satisfy the CAD drawings

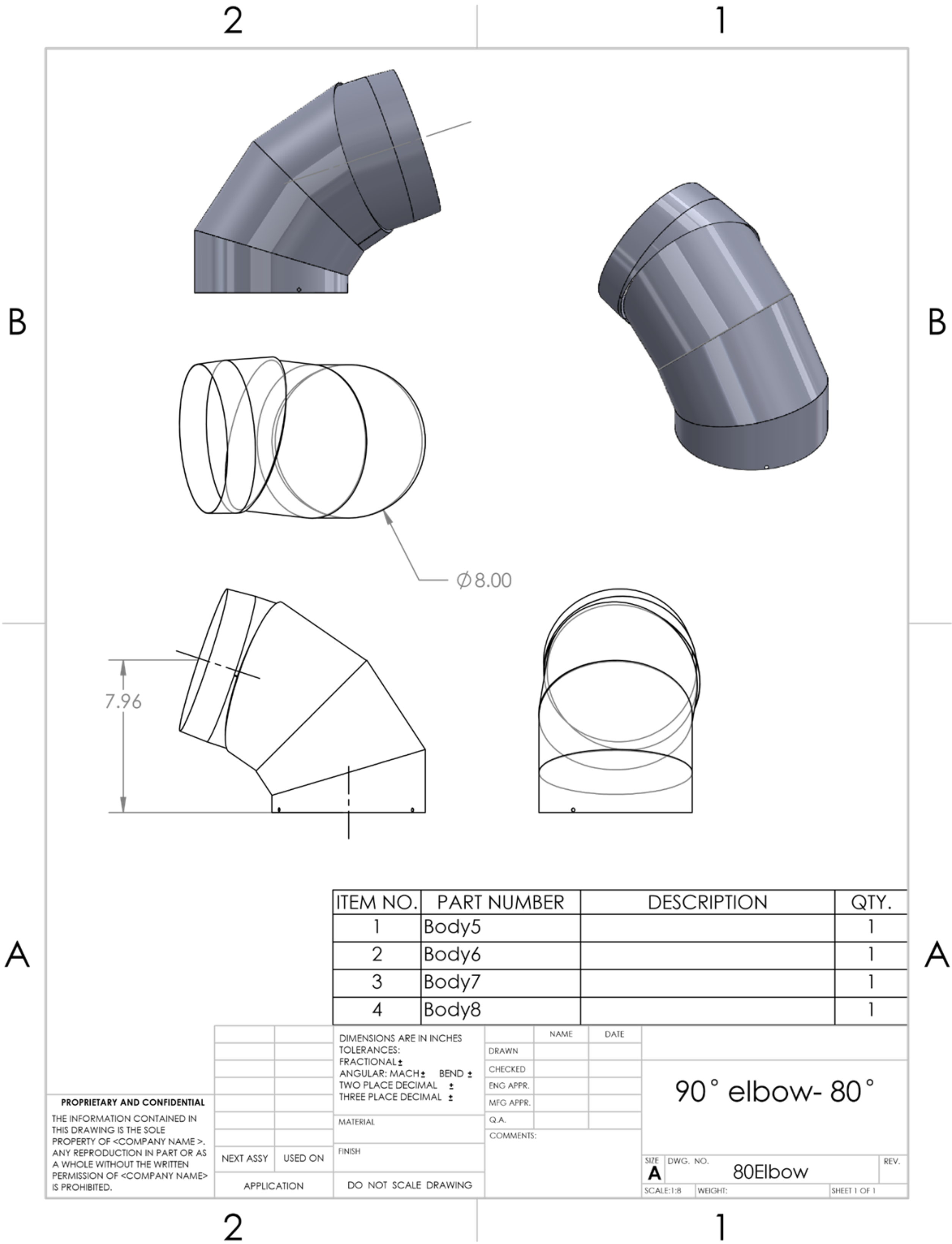


Figure 36 Another 90- degree elbow rotated into roughly a 70-degree position in the final working prototype.

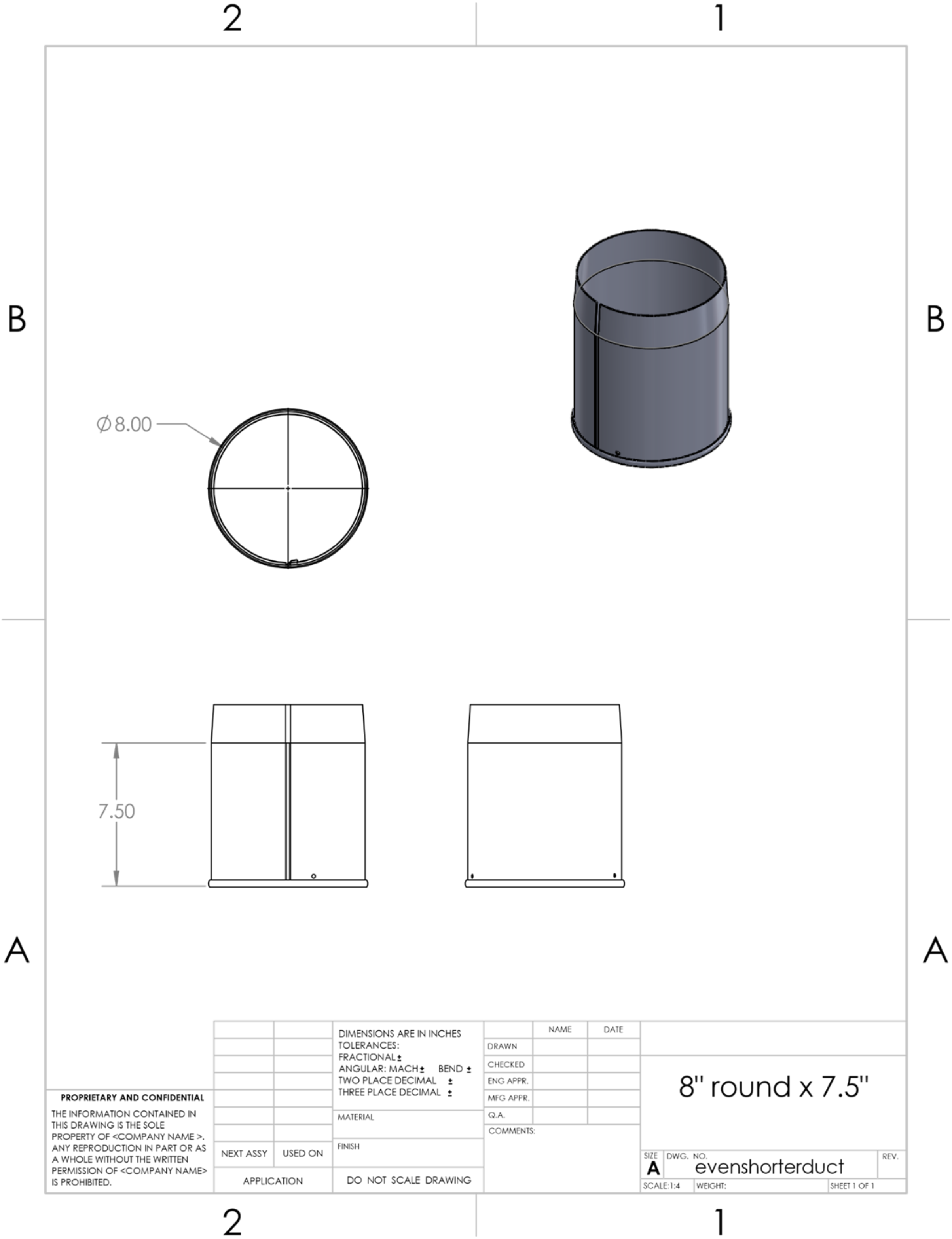


Figure 37 The short duct for the overhead part of the system was cut from the 8” round 5’ stock.

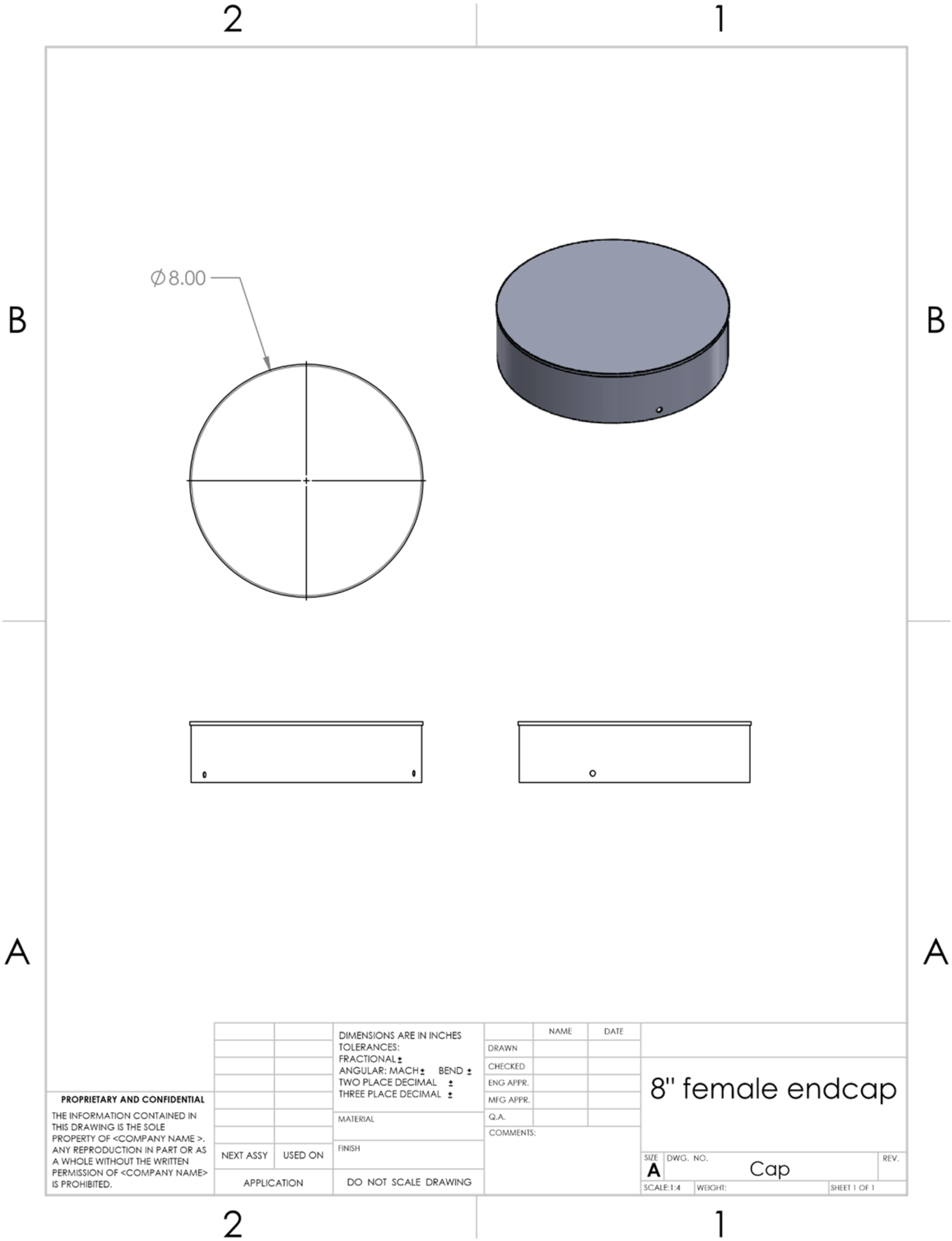


Figure 38 The end caps were purchased and screwed together to provide coupling at the top of the system.

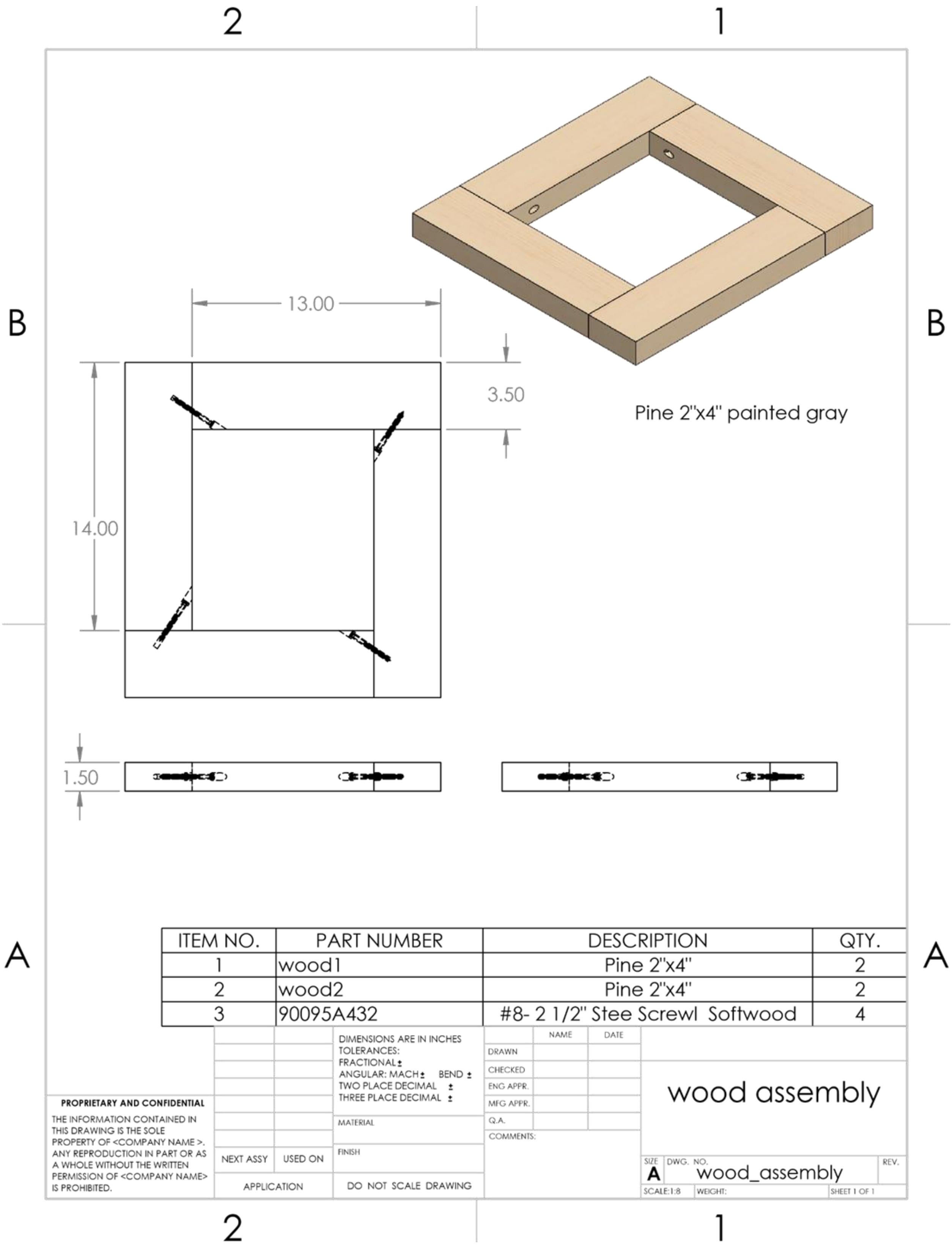


Figure 39 This assembly keeps the blowers upright and in place.

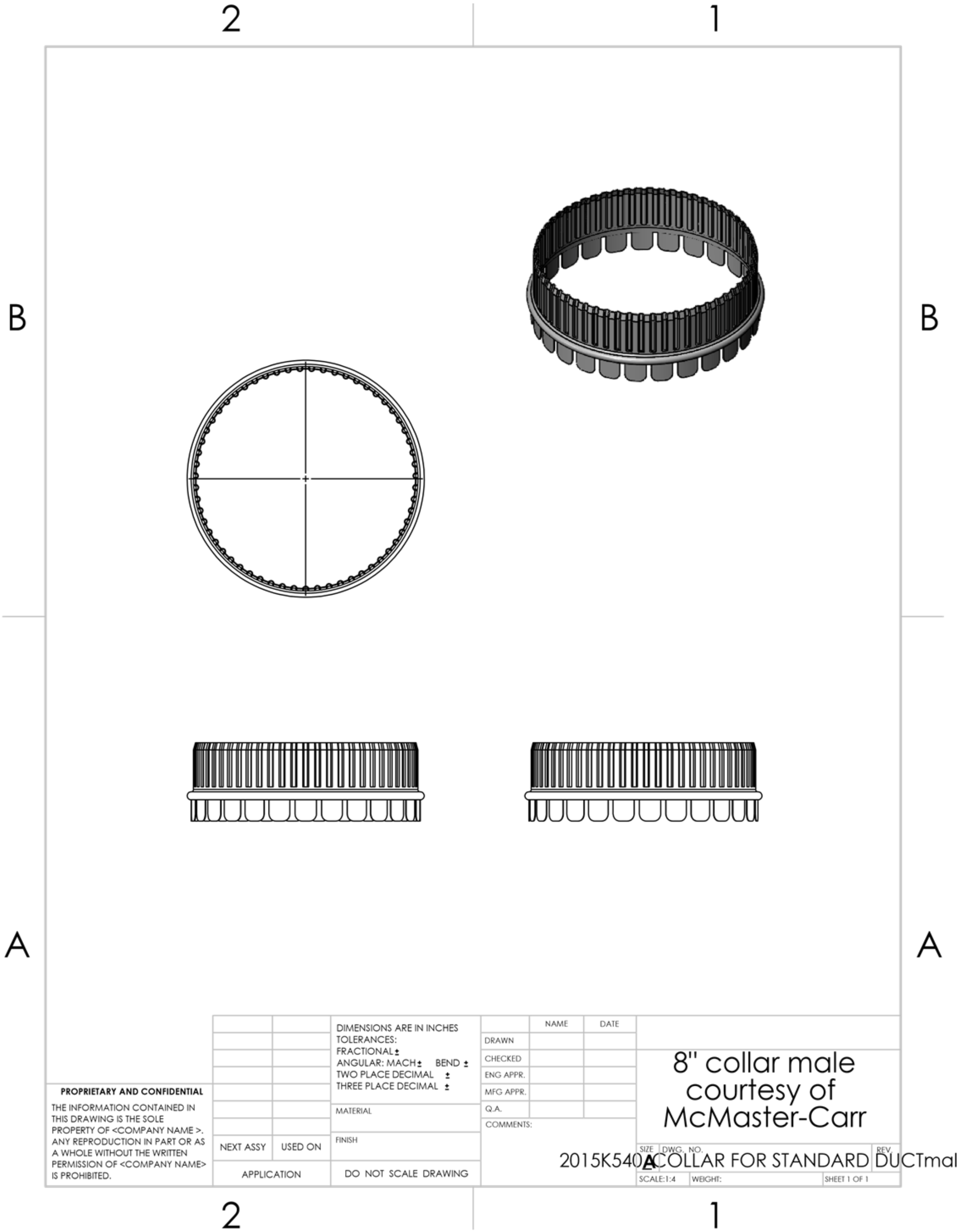


Figure 40 The male collars were purchased at home depot. These drawings are courtesy of McMaster-Carr.

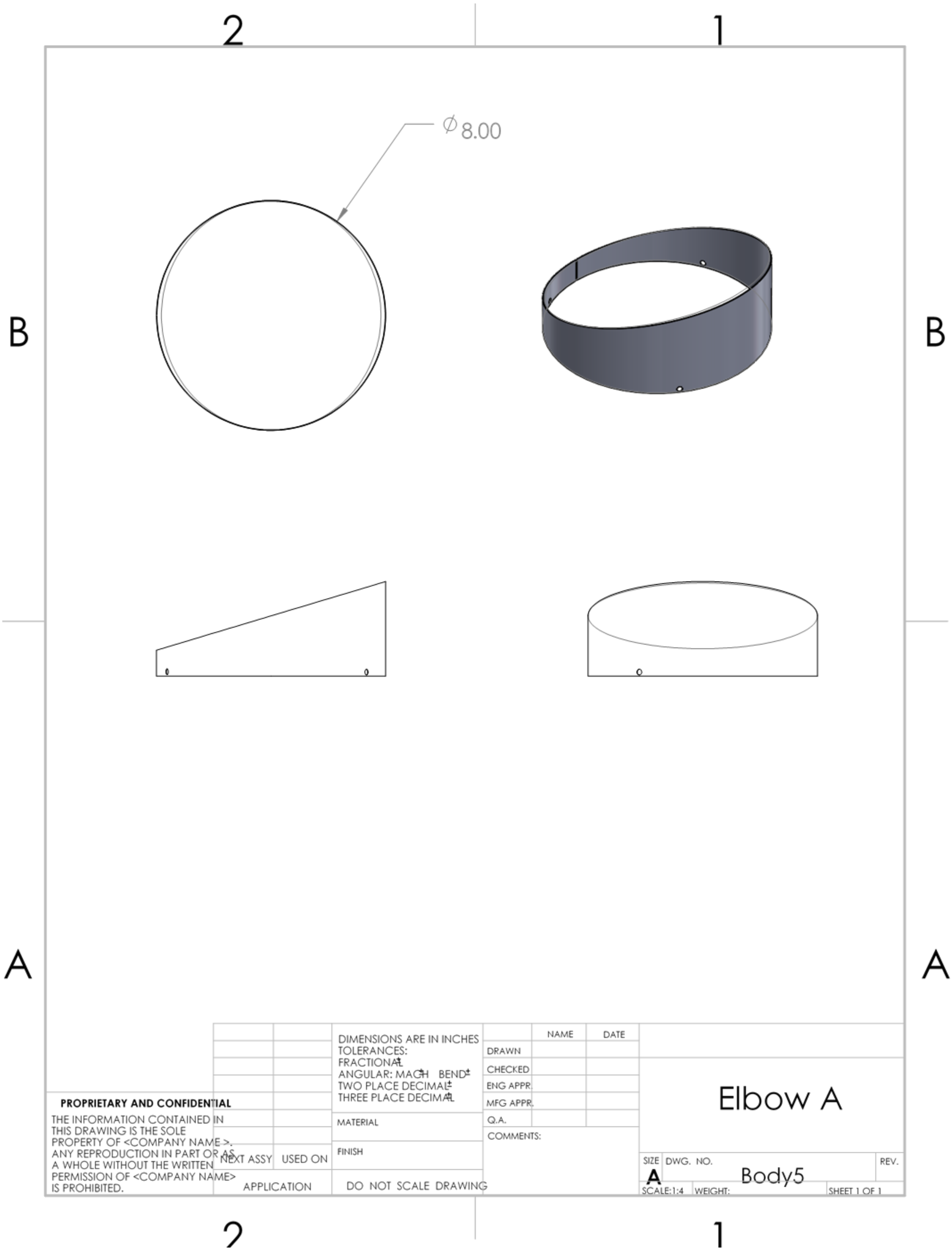
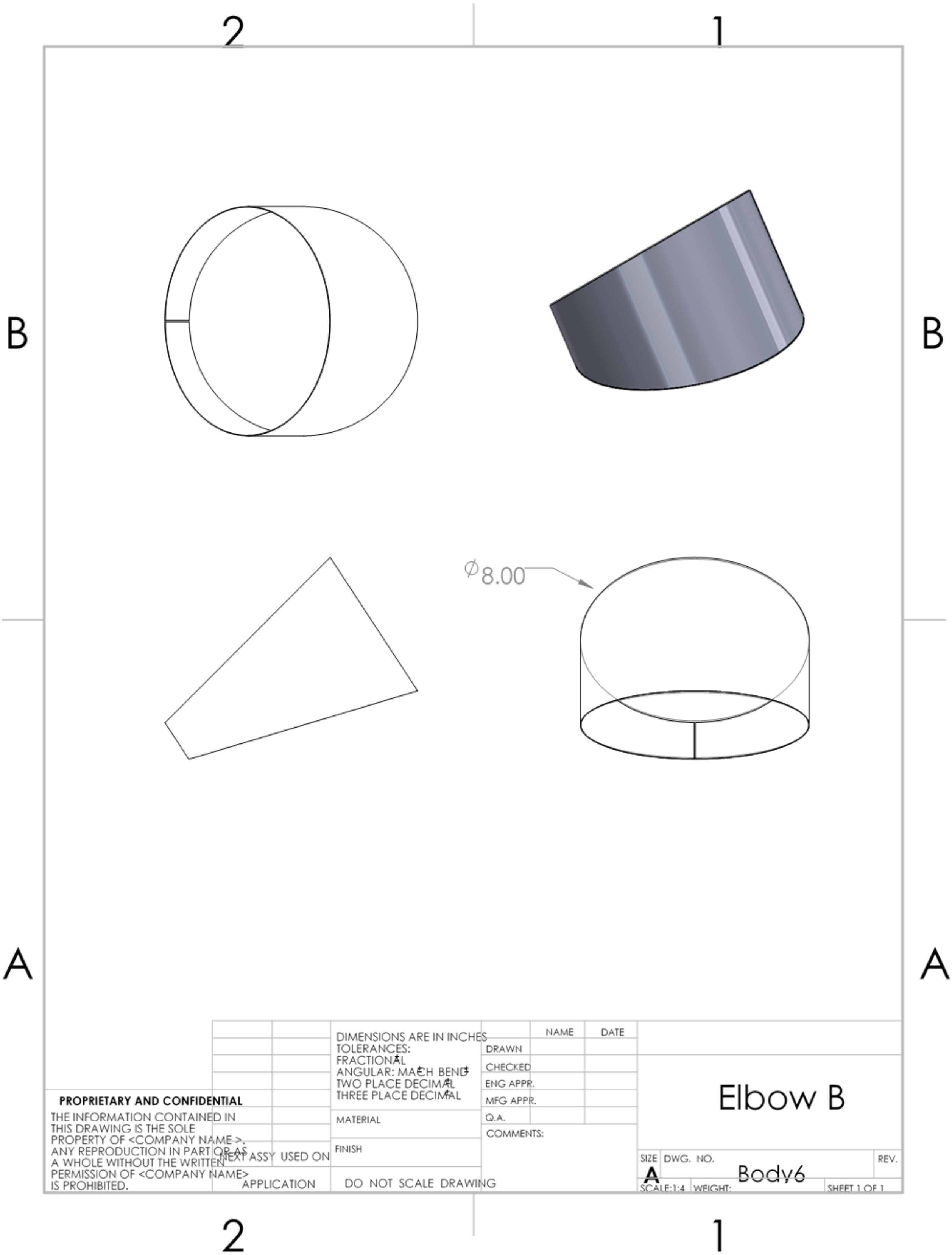


Figure 41 Elbow A,B,C,D were needed for the drawings to establish a rotational component. In reality these parts are the 90-degree 8” round elbows purchased at The Home Depot.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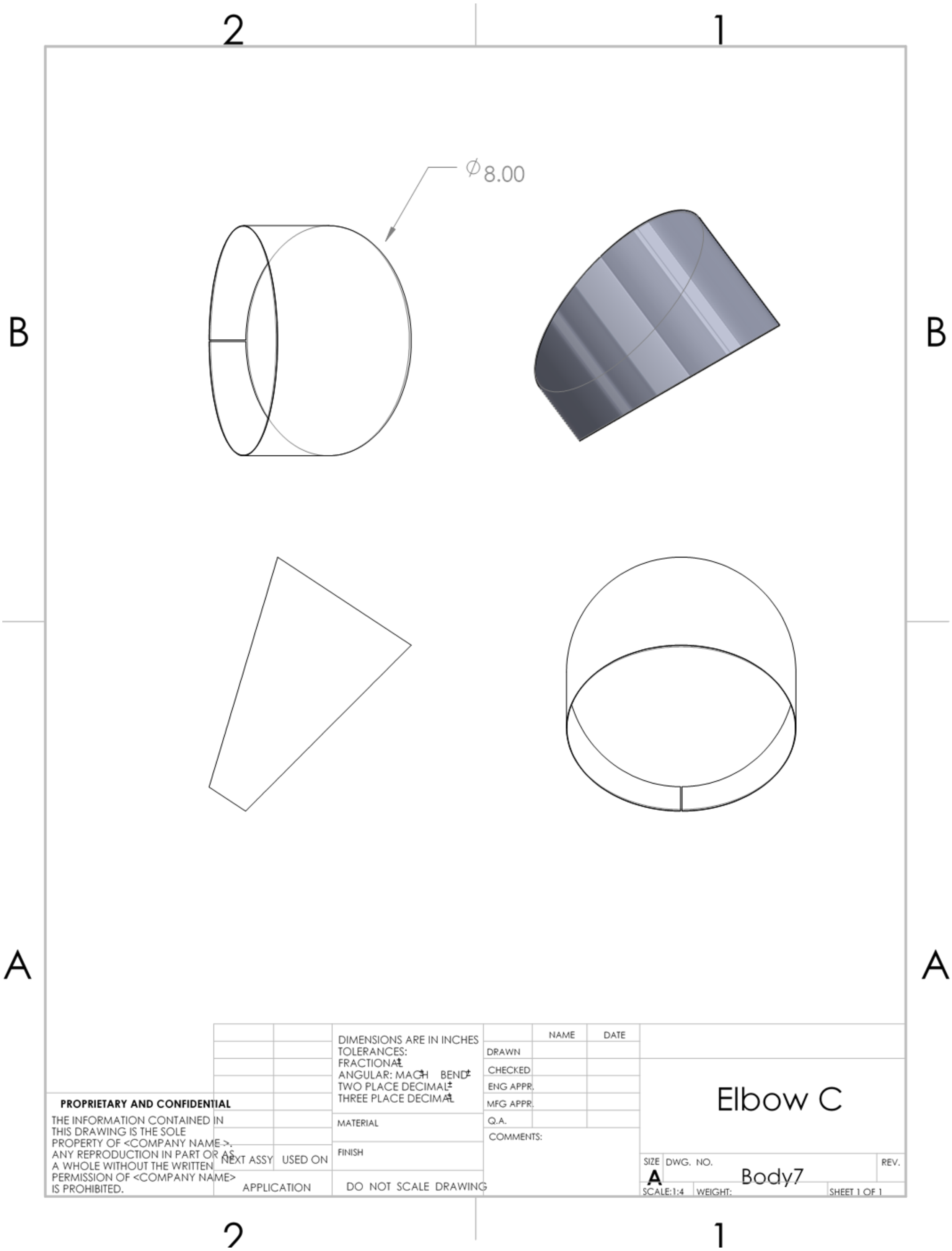
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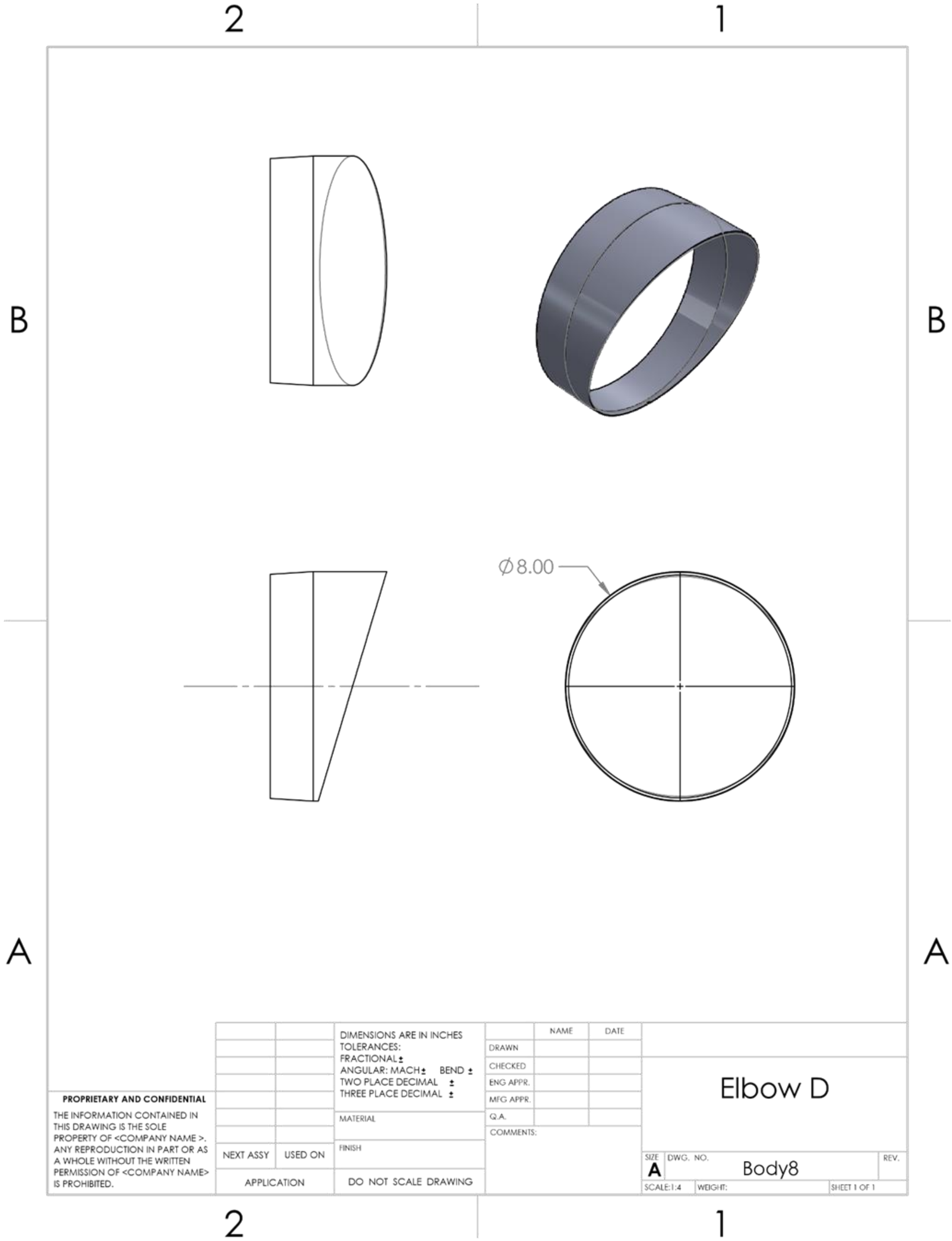
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9.1.2 Sourcing instructions

The Body Dryer team was fortunate to have a contact and purveyor for many parts (specifically, the brunt of the expense; two 3-ton blowers) through a team member, Nick Zuelke, and the generosity of his prior employer, The Indoor Comfort Team, who are located around the metropolitan area of St. Louis. The South County Indoor Comfort Team is location at 2613 Telegraph Rd, 63125 and allowed the Body Dryer team to source the blowers and fabricate the designed plenum and cap transition from the blowers to the commercially available ductwork. Access was granted for various sized brakes and a Pittsburgh lock former machine capable of folding and locking sheet metal joints needed for the plenum. The body dryer team realizes the use of blowers for personal use nears that of a luxury item and may have otherwise limited the project through budget restrictions. Because the Body Dryer team enjoyed this resource, the limiting factor became one of power rather than money. Possible sourcing may be possible at similar HVAC locations throughout any region, in that the largest failure within an HVAC system is rarely the blower component.

Much of the ductwork is available at local hardware or big box stores. The decision to use 8" round enabled mainstream sourcing from places such as Lowe's, Ace Hardware, The Home Depot, or Menards. Local and nationwide wholesale establishments such as Brauer Supply, Mar-Cone Supply, or Grainer are also possible sources of material, however, often require a tax identification number for purchase. Habitat for Humanity's RE-store is always a good place to support and gather materials for a project, however, rarely satisfies a seek and find conquest.

Auxiliary systems, such as heating and electric, can be found at the above locations, or be constructed ("McGyvered") from various components already in circulation.

A binary switch, in the form of The Clapper® was added for novelty sake, generally proving functional upon start- up. Some difficulty was had in terminating the Body Dryer, due to noise pollution generated from the two 3-ton blowers.

9.2 FINAL PRESENTATION

https://youtu.be/AFVtEULYykw

10 TEARDOWN

TEARDOWN TASKS AGREEMENT

PROJECT: Body Dryer NAMES: Luke Maichel (L.M.) INSTRUCTOR: Mark Jakiela

Laura Bailey (L.B.) Craig Giesmann

Nick Zuelke (N.T.Z.)

The following teardown/cleanup tasks will be performed:

1) The Body Dryer Team will take the entirety of the finished product and it will be donated to a retired Navy veteran. The Navy veteran will take it to their campground where it will be set up outside and blow air directly on them while playing a computer naval battle game while sipping fine bourbon.

2) Most of the assembly was done at Nick's house, so we will all go over there and clean up the basement. There are a lot of tools, extra ductwork, and screws that will need to be cleaned up.

Instructor comments on completion of teardown/cleanup tasks:

OK. CLEAN UP A SMALL PART OF STORAGE SPACE AT WU.

Instructor signature: Mark J. Jakiela Print instructor name: JAKIELA

Date: 8/10/19

11 APPENDIX A - PARTS LIST

Table 21: Parts list for Body Dryer

Body Dryer Parts List					
Part Name	Supplier	Part Number	Quantity	Unit Price	Total
8" X 60" Round Pipe	Home Depot	148695	4	$ 11.98	$ 47.92
Blower Assembly	Supplyhouse.com	901282	2	$ 299.95	$ 599.90
28 Ga 12" X 24" Sheet Metal (Galv)	Home Depot	1001195	3	$ 10.98	$ 32.94
#8 3/4" Hex Self Tapping Screws	Home Depot	156906	1	$ 6.71	$ 6.71
8" Elbow	Home Depot	148768	2	$ 7.21	$ 14.42
8" Cap	Home Depot	206881	2	$ 5.98	$ 11.96
12-2 x 25' Wire	Home Depot	374710	1	$ 14.77	$ 14.77
20 Amp Switch	Home Depot	700096	1	$ 2.99	$ 2.99
			Total		**$ 731.61**

12 APPENDIX B - BILL OF MATERIALS

The bill of material (#) corresponds to the numbers found on the Solidworks engineering drawing found on page 51 of the report. Cells without numbers are for parts within the assembly, or auxiliary fasteners or switch.

BILL OF MATERIALS						
#	**Part Name/No.**	**Description**	**Qnty.**	**Purveyor**	**Price**	**ext. Price**
1	50206921302 Duct	8" round duct x 60" altered	2	The Home Depot	11.98	23.96
2	Duct	8" round duct x 16" altered				
3	Blower Assembly	3-ton blower unit	2	Supplyhouse.com	299.95	599.9
4	Plenum and Cap	in house fabrication				
		28 Ga 12"x24" galv sheet	3	The Home Depot	10.98	32.94
5	90 deg Elbow	8" round 90 Elbow	4	The Home Depot	10.02	40.08
6	90 deg Elbow	8" round 90 Elbow				
7	Duct	8" round duct x 7.5" altered				
8	63933397	8" round female end cap	2	Menards	6.28	12.56
9	2"x4" pine	2x4x10' softwood lumber	1	The Home Depot	4.09	4.09
	fastener	1 lb #8 x 2-1/2" phillips coarse	1		3.98	3.98
10	50206931806	8" male collar	2	The Home Depot	5.96	11.92
11	887480014723	#8 1/2" hex head sh mt screw	1	The Home Depot	5.58	5.58
	12- 2x25' wire	copper 12 gage wire	1	The Home Depot	14.77	14.77
	The Clapper	switch	1	Amazon.com	14.98	14.98
						$764.76

Actual purchased parts for the assembly include 2 Ducts, 2 collars, sheet metal fasteners, 2 end caps, and the Clapper® totaling **$69.00** before tax. Other material tested and not used, for nozzles and heating was returned except for components which they disintegrated during the failed experiments.

13 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

Here is a list of engineering drawings for all CAD modelled and downloaded parts (from McMaster) found in section 9 of the report.
The following link will take you to a Google drive that contains all of the CAD models used throughout the project.

https://drive.google.com/open?id=1L8AdLmeK1fUCKSf82a5K7wcF3k5YMzpV

LIST OF SOLIDWORKS FILES	
80Elbow.SLDASM	Cap.SLDPRT
2015K540_COLLAR FOR STAN..	Duct1.SLDPRT
90095A432_SCREWS FOR SOF..	End_Cap_8in.SLDPRT
90190A194_PAN HEAD PHILLI..	evenshorterduct.SLDPRT
AssemFinalBodyDryer.SLDASM	motor.SLDPRT
BDElbow.SLDASM	Nozzle.SLDPRT
BDElbow.SLDPRT	Plenum.SLDPRT
blower.SLDPRT	Plenum_and_Cap.SLDPRT
BlowerA.SLDASM	shaft.SLDPRT
Body_Dryer_All.SLDASM	shortduct.SLDPRT
Body5.sldprt	squirrelcage.SLDPRT
Body6.sldprt	wood_assembly.SLDASM
Body7.sldprt	wood1.SLDPRT
Body8.sldprt	wood2.SLDPRT

14 ANNOTATED BIBLIOGRAPHY

[1] B.R. Munson, B.R., T.H. Okiishi, T.H., W.W. Huebsch, W.W., and A.P. Rothmayer, A.P., 2013, Fundamentals of Fluid Mechanics, 7th Edition, John Wiley & Sons, Inc., Hoboken,NJ.

[2] National Fire Protection Association (NFPA), 2016, NFPA 70 National Electrical Code (NEC), 2017 ed., NFPA, Quincy, Ma.

[3] National Fire Protection Association (NFPA), 2017, NFPA 90A Standard for the Installation of Air-Conditioning and Ventilating Systems, 2018 ed., NFPA, Quincy, Ma.

[4] National Fire Protection Association (NFPA), 2016, NFPA 90B Standard for the Installation of Warm Air Heating and Air-Conditioning Systems, 2018 ed., NFPA, Quincy, Ma.