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JME 4110 Seed Cross-Breeze Distance Tester

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University of Missouri–St. Louis ▪ Washington University in St. Louis

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Because seeds vary in shape, size, and weight, their behaviors in cross-breezes vary as well. The customer's laboratory is researching seeds for prairie grasses. Their laboratory currently has data for seed structures; however, data for seed dispersion is needed to provide a better correlation to known environmental and genetic factors such as precipitation and DNA changes. The Seed Cross-Breeze Distance Tester is a controlled chamber designed to test the distance a seed will travel in a user-specified windspeed.

JME 4110
Mechanical Engineering
Design Project

Seed Cross-Breeze Distance Tester

Emily Dahlberg
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Ty Krewson

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- Emily Dahlberg
- John Jensen
- Ty Krewson

2 BACKGROUND INFORMATION STUDY

2.1 DESIGN BRIEF

Because different seeds vary in shape, size, and weight, their behaviors in cross-breezes vary as well. The customer's laboratory is researching seeds for prairie grasses. Their laboratory currently has data for seed structures; however, data for seed dispersion is needed to provide a better correlation to known environmental and genetic factors such as precipitation and DNA changes. The Seed Cross-Breeze Distance Tester is a controlled chamber designed to test the distance a seed will travel in a user-specified windspeed.

2.2 BACKGROUND SUMMARY

We could not find any existing designs that exactly met the user needs. Our design requires a wind tunnel with the ability to drop a projectile from the top and as it be collected in a fashion where the distance traveled could be measured. However, we were able to find some wind tunnel designs.

The first existing design was found at http://www.instructables.com/id/How-to-make-a-wind-tunnel/ and it is constructed from cardboard and duct tape. It has a wide opening at one end where a fan supplies the wind. There is a clear panel that allows the user to see in the tunnel. This panel can be removed to place an object inside. An image of this design can be seen in Fig. 2.1.

Fig. 2.1 shows the first existing design we found.

The second existing design that was chosen was the AEROLAB Educational Wind Tunnel System. This design is a very precise and well-engineered piece of equipment. It can generate wind speeds of 10 mph to 145 mph. it comes with built-in monitoring equipment to help with data collection. An image of this wind tunnel can be seen in Fig. 2.2.

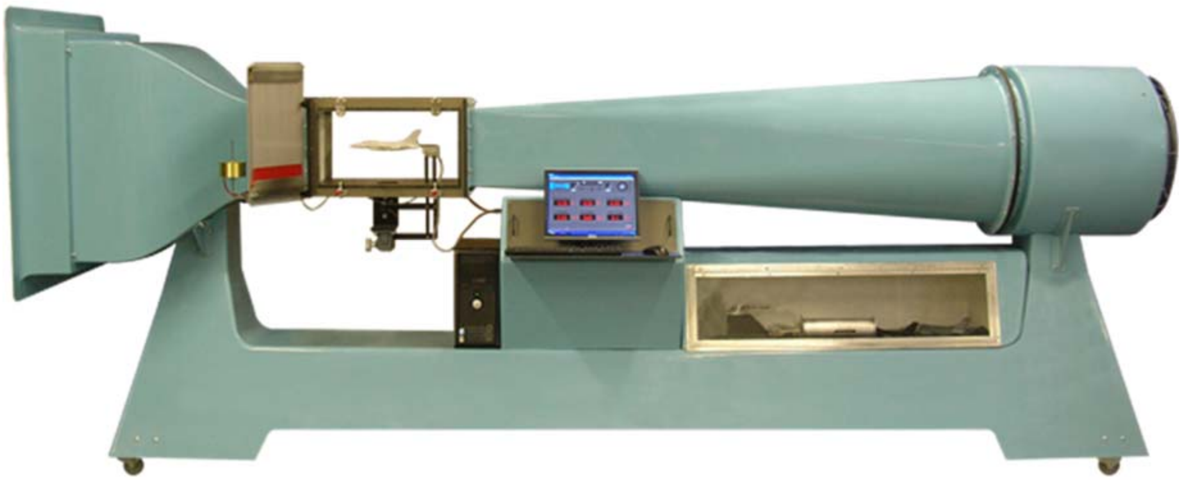


Fig. 2.2 shows the AEROLAB Educational Wind Tunnel System [from aerolab.com]

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS AND METRICS

Table 3.1.1 lists the user's needs and ranks them on a scale of one to five based on their level of importance, with five being most important, and one being least important.

Table 3.1.1 Seed Cross-Breeze Tester (SCBT) Needs Table.

Need Number	Need	Importance
1	SCBT can determine distance seeds will travel under multiple different breeze velocities (between 0-25 mph)	5
2	SCBT is automated with minimal human assistance required	3
3	SCBT results are precise and an accurate representation of the seed type	4
4	SCBT is small enough to be disassembled and moved through doorways and elevators	5
5	SCBT is not too noisy	2
6	SCBT can obtain the results as quickly and efficiently as possible for each seed type	5
7	SCBT leaves the seeds viable after testing	1
8	SCBT has multiple seed drop heights	3

Table 3.1.2 Metrics Table for Seed Cross-Breeze Tester.

Metric Number	Associated Needs	Metric	Unit	Minimum Value	Maximum Value
1	1	Range of wind speeds (ex. Between 5-25 mph = 20)	mph	0	25
2	2, 6	Operators required	Integer	1	3
3	4	Length	Feet	3	12
4	4	Width	Inches	12	32
5	4	Height	Feet	2	6
6	5	Noise	dB	30	80
7	7	Percentage of seeds that can be reused after testing	%	0	100
8	6	Time	Minutes	0.25	5
9	8	Number of drop heights	Integer	1	4
10	3	Standard deviation	In	0	7

3.1.1 Record of the user needs interview

Question 1: What seed varieties will we be working with and will they be at full maturity?

Answer 1: You will be working with seed from big bluestem, little bluestem, and broomsedge bluestem, or equivalent. We also have seed from corn, teosinte (a wild corn ancestor), sorghum, and many other wild species that related to these. The seeds will be fully mature. The figure I've attached is a morphometric analysis (principal components) of seed shape. The different colors refer to different species and the little thumbnail photos are representatives from particular points in the graph. There is no scale in the photos but the small ones are about 3 mm and the large ones are a couple of cm. The hairs affect the aerodynamics.

Question 2: Are you looking to find the speed based on individual distance morphology or an average distance given a specific with the speed and seed variety?

Answer 2: It would be good to tie wind speed and distance travel to the seeds of a particular plant. I'm envisioning getting a value that may be averaged over several seeds from one plant. These single-plant values could be averaged among plants of a single population or a single species.

Question 3: What are the size and weight constraints for the machine?

Answer 3: It would be good if it could fit in the lab or greenhouse, i.e not huge. But if it needs a long measuring chamber we could probably figure that out.

Question 4: What facilities (electric, high pressure air, high pressure nitrogen, water, etc) will the machine have access to?

Answer 4: If it's in the lab, then electric, water, vacuum, and gas are available. I don't know if I can find high pressure air in the building but can look. High pressure nitrogen is not likely. However, we have plenty of dry ice and liquid nitrogen if the machine requires cooling for some reason.

Question 5: Will the system be a fixed installation or will it need to be mobile?

Answer 5: It doesn't need to be particularly mobile. We can bring the seeds to the machine. We could set it up and leave it for a while. But that may depend on how big it is.

Question 6: Will the system be indoors, outside, or both?

Answer 6: I was thinking about indoors, but if it works better outdoors then we'd make it work. An outdoors machine might have to be moved easily though because there isn't an obvious place to leave it.

Question 7: What are the environmental restrictions (no need for outside venting, noise under a certain dB, low vibrations, etc)?

Answer 7: If it's in the lab, then it can't give off any fumes unless we can connect to the hood somehow. Noise would have to be at a level consistent with a standard workplace; ditto with vibrations.

Question 8: What is the desired throughput (seeds/day) for the system?

Answer 8: The perfect world would be to test 3-5 seeds per plant and 2 or 3 plants per species, for ca. 200 species, so up to 3000 seeds in as short a time as possible.

Question 9: Will the system need to be automated or will an operator be available for data collection and certain operational functions?

Answer 9: We could have an operator, but more automation is better. Again thinking of the perfect world, if the data could be sent directly to a computer without the necessity of someone copying and entering it, it would save time and a lot of errors.

Question 10: What is the desired accuracy of the distance measurement?

Answer 10: Do you mean accuracy or precision? It would be good to have precision high enough that an accurate estimate of the velocity could be attained with 3 to 5 measurements, mostly because of the desire for good throughput. This could be tested by measuring 1 seed 20 or 30 times and then randomly sampling subsets of the data to see if 3 to 5 random measurements provide the same mean as all 20 or 30.

Question 11: Will the seed need to remain viable after testing?

Answer 11: No. I can't think of a reason why we would want to germinate the exact same seed as used in testing.

Question 12: What is the height range of the plants in question?

Answer 12: The plants in question are from the KS, Missouri, Kenya, etc. regions. Their height can range from 0.3 to 3m high.

Question 13: Can the results be binned into several distinct distances? Somewhere in the range of one bin per inch or two?

Answer 13: So long as the accuracy is better than somebody just “eyeballing” it then binning is fine, but more accuracy is always better. If binning allows for greater speed and easier automation, then that is good too. It is not worth an extra $10K in order to increase accuracy down to the millimeter.

3.1.2 List of identified metrics

A. Range of wind speeds [mph]
B. Number of operators required [integer]
C. Length [ft]
D. Width [in.]
E. Height [ft]
F. Noise level [dB]
G. Percentage of reusable seeds after testing [%]
H. Duration of test [min]
I. Number of drop heights [integer]
J. Standard deviation of results [in.]

3.1.3 Table/list of quantified needs equations

Table 3.1.3 Table of Quantified Needs Equations.

Seed Cross Breeze Tester Design		Metric												
		Speed	Operators required	Length	Width	Height	Noise	% of seeds reusable	Time	Number of drop heights	Standard deviation	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	SCBT velocity range	1										0	0.153846	0
2	SCBT is automated with minimal assist		1									0	0.115385	0
3	SCBT results are precise & acurate										1	0	0.153846	0
4	SCBT fits in lab			0.4	0.2	0.4						0	0.115385	0
5	SCBT isn't too noisy						1					0	0.076923	0
6	SCBT obtains results quickly & efficietly		0.25						0.75			0	0.192308	0
7	SCBT leaves seeds viable							1				0	0.038462	0
8	SCBT has multiple drop heights									1		0	0.153846	0
Units		mph	# people	ft	in	ft	Db	%	min	integer	in	Total Happiness		0
Best Value		20	1	12	32	5	30	100	0.25	5	0			
Worst Value		5	5	5	12	2	85	0	5	1	5			
Actual Value														
Normalized Metric Happiness														

3.2 CONCEPT DRAWINGS

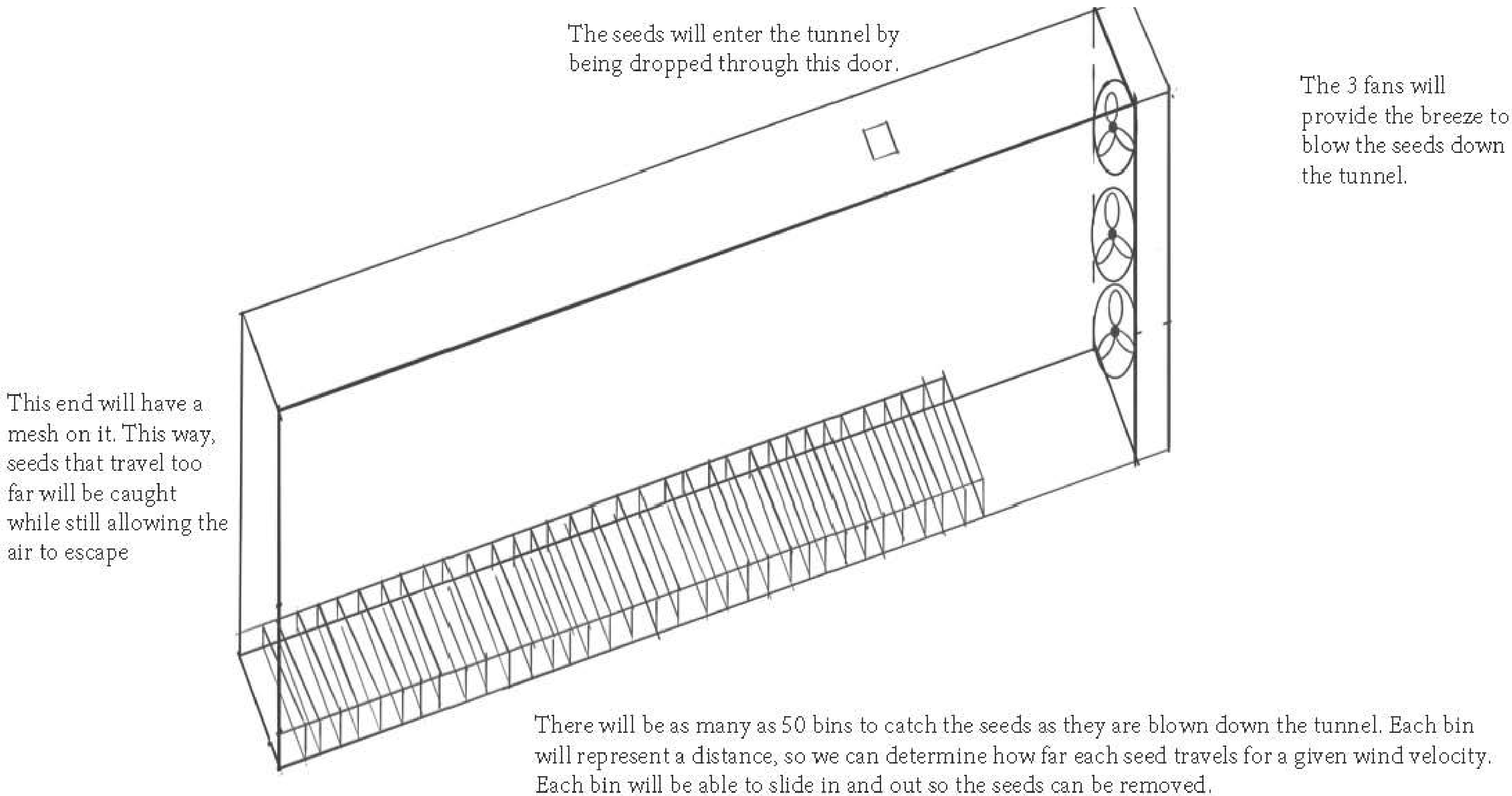


Figure 3.2.1 Drawing of First Concept Design.

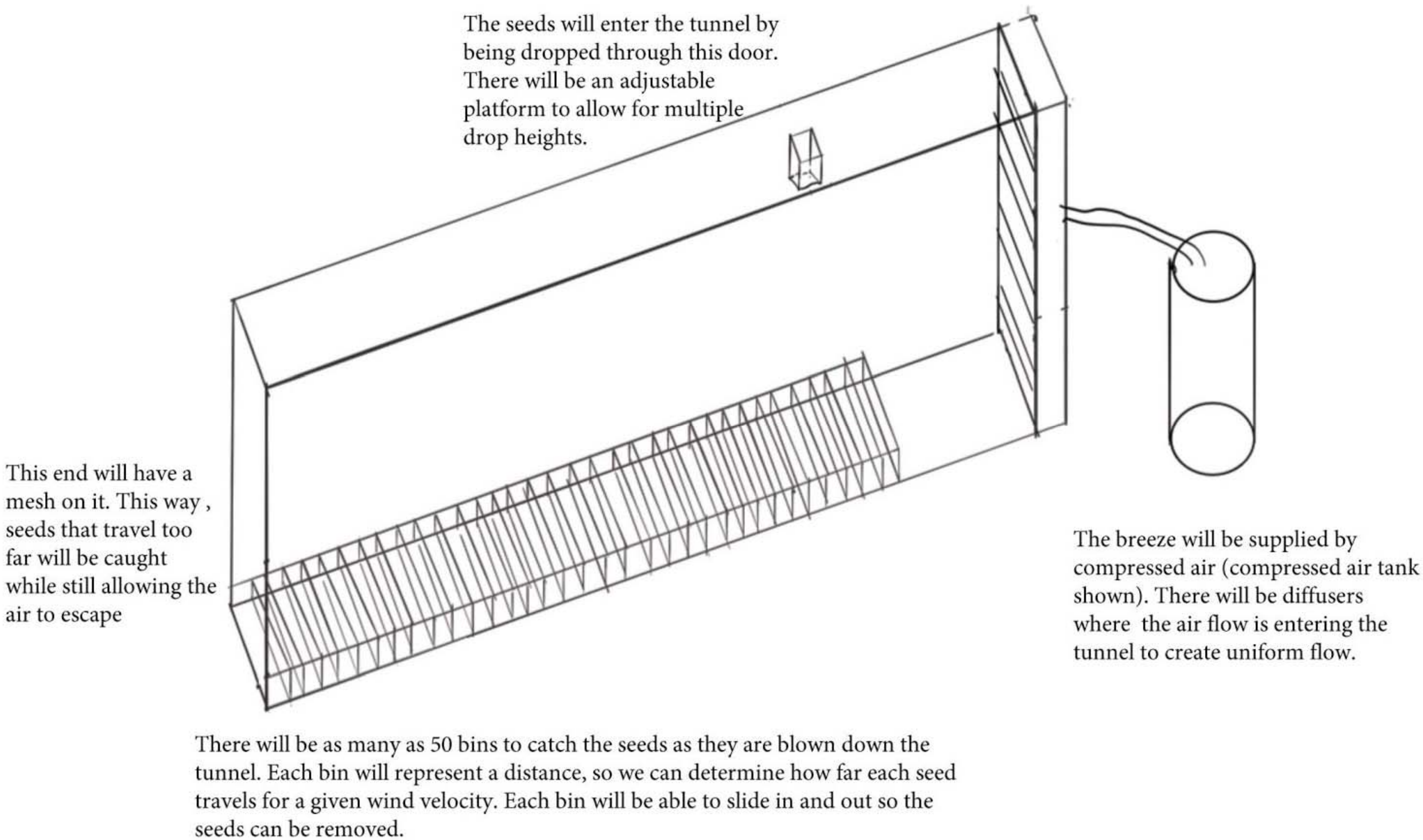


Figure 3.2.2 Drawing of Second Concept Design.

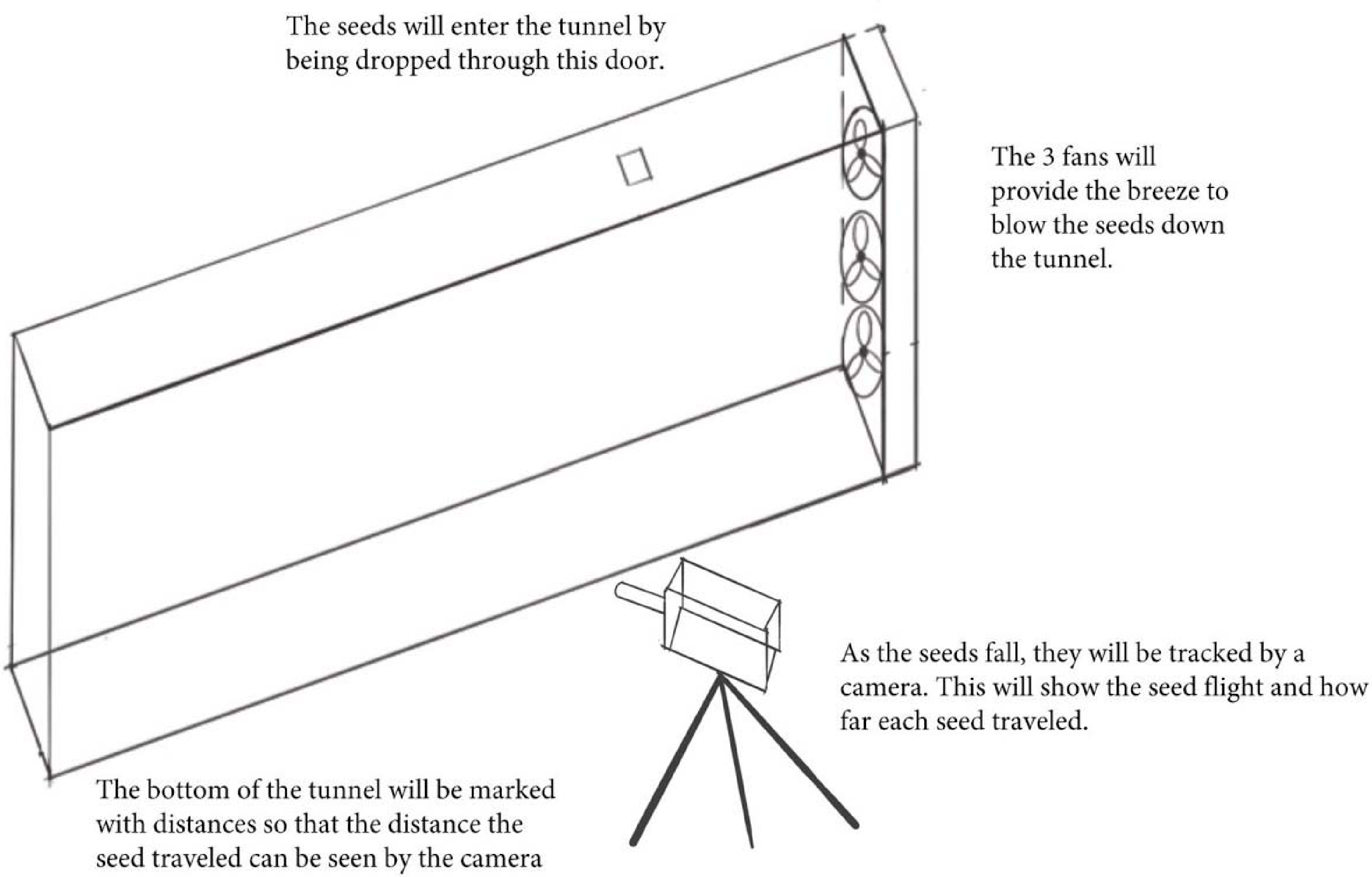


Figure 3.2.3 Drawing of Third Concept Design.

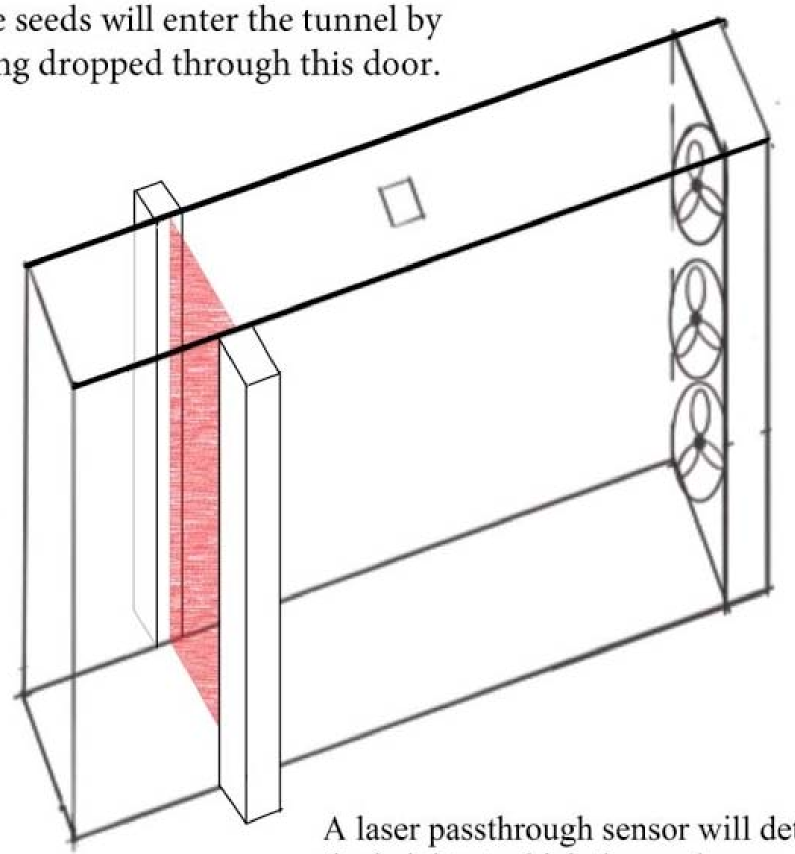


Figure 3.2.4 Drawing of Fourth Concept Design.

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Table 3.3.1 Design 1 Concept Scoring.

Seed Cross Breeze Tester Design #1		Metric												
		Speed	Operators required	Length	Width	Height	Noise	% of seeds reusable	Time	Number of drop heights	Standard deviation	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	SCBT velocity range	1										1	0.153846	0.153846
2	SCBT is automated with minimal assist		1									0.8	0.115385	0.092308
3	SCBT results are precise & acurate										1	0.7	0.153846	0.107692
4	SCBT fits in lab			0.4	0.2	0.4						0.84	0.115385	0.096923
5	SCBT isn't too noisy						1					0.8	0.076923	0.061538
6	SCBT obtains results quickly & efficietly		0.25						0.75			0.7625	0.192308	0.146635
7	SCBT leaves seeds viable							1				1	0.038462	0.038462
8	SCBT has multiple drop heights									1		0.4	0.153846	0.061538
Units		mph	# people	ft	in	ft	Db	%	min	integer	in	Total Happiness		0.758942
Best Value		20	1	12	32	5	30	100	0.25	5	0			
Worst Value		5	5	5	12	2	85	0	5	1	5			
Actual Value		20	2	10	24	4	50	90	2	1	2			
Normalized Metric Happiness		1	0.8	0.8	0.8	0.9	0.8	1	0.75	0.4	0.7			

Table 3.3.2 Design 2 Concept Scoring.

Seed Cross Breeze Tester Design #2		Metric												
		Speed	Operators required	Length	Width	Height	Noise	% of seeds reusable	Time	Number of drop heights	Standard deviation	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	SCBT velocity range	1										0.6	0.153846	0.092308
2	SCBT is automated with minimal assist		1									0.8	0.115385	0.092308
3	SCBT results are precise & acurate										1	0.7	0.153846	0.107692
4	SCBT fits in lab			0.4	0.2	0.4						0.84	0.115385	0.096923
5	SCBT isn't too noisy						1					0.2	0.076923	0.015385
6	SCBT obtains results quickly & efficietly		0.25						0.75			0.7625	0.192308	0.146635
7	SCBT leaves seeds viable							1				1	0.038462	0.038462
8	SCBT has multiple drop heights									1		0.9	0.153846	0.138462
Units		mph	# people	ft	in	ft	Db	%	min	integer	in	Total Happiness		0.728173
Best Value		20	1	12	32	5	30	100	0.25	5	0			
Worst Value		5	5	5	12	2	85	0	5	1	5			
Actual Value		10	2	10	24	4	85	90	2	3	2			
Normalized Metric Happiness		0.6	0.8	0.8	0.8	0.9	0.2	1	0.75	0.9	0.7			

Table 3.3.3 Design 3 Concept Scoring.

Seed Cross Breeze Tester Design #3		Metric												
		Speed	Operators required	Length	Width	Height	Noise	% of seeds reusable	Time	Number of drop heights	Standard deviation	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	**Need**	1	2	3	4	5	6	7	8	9	10			
1	SCBT velocity range	1										1	0.153846	0.153846
2	SCBT is automated with minimal assist		1									0.6	0.115385	0.069231
3	SCBT results are precise & acurate										1	0.9	0.153846	0.138462
4	SCBT fits in lab			0.4	0.2	0.4						0.84	0.115385	0.096923
5	SCBT isn't too noisy						1					0.8	0.076923	0.061538
6	SCBT obtains results quickly & efficietly		0.25						0.75			0.825	0.192308	0.158654
7	SCBT leaves seeds viable							1				1	0.038462	0.038462
8	SCBT has multiple drop heights									1		0.4	0.153846	0.061538
Units		mph	# people	ft	in	ft	Db	%	min	integer	in	**Total Happiness**		0.778654
Best Value		20	1	12	32	5	30	100	0.25	5	0			
Worst Value		5	5	5	12	2	85	0	5	1	5			
Actual Value		20	3	10	24	4	50	90	1	1	1			
Normalized Metric Happiness		1	0.6	0.8	0.8	0.9	0.8	1	0.9	0.4	0.9			

Table 3.3.4 Design 4 Concept Scoring.

Seed Cross Breeze Tester Design #4		Metric												
		Speed	Operators required	Length	Width	Height	Noise	% of seeds reusable	Time	Number of drop heights	Standard deviation	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10			
1	SCBT velocity range	1										1	0.153846	0.153846
2	SCBT is automated with minimal assist		1									0.6	0.115385	0.069231
3	SCBT results are precise & acurate										1	1	0.153846	0.153846
4	SCBT fits in lab			0.4	0.2	0.4						0.84	0.115385	0.096923
5	SCBT isn't too noisy						1					0.8	0.076923	0.061538
6	SCBT obtains results quickly & efficietly		0.25						0.75			0.825	0.192308	0.158654
7	SCBT leaves seeds viable							1				1	0.038462	0.038462
8	SCBT has multiple drop heights									1		0.4	0.153846	0.061538
Units		mph	# people	ft	in	ft	Db	%	min	integer	in	Total Happiness		0.794038
Best Value		20	1	12	32	5	30	100	0.25	5	0			
Worst Value		5	5	5	12	2	85	0	5	1	5			
Actual Value		20	3	10	24	4	50	90	1	1	1			
Normalized Metric Happiness		1	0.6	0.8	0.8	0.9	0.8	1	0.9	0.4	1			

3.3.2 Preliminary analysis of each concept's physical feasibility

Design 1: Of all the designs, this one is the simplest. The main part of the design is a long rectangle. It would be best if one of the sidewalls could be clear so that the person conducting the test can see the seed as it is blown down the tunnel. This should not be any issue as there are many different types of clear materials that could be used. The biggest challenge with this design would be with the fans. In order to create a laminar velocity stream from the top to the bottom of the tunnel, each fan would have to be supplying with at the same velocity. Therefore, each fan will need to be identical and tested to make sure the wind flow output each is generating or equal.

Design 2: This design will most likely require a very large compressed air tank, or the compressor will have to be running very frequently. If the compressor runs out of air, then the experiment must be put on hold. Another challenge with this design is making sure that the airflow being supplied to the tunnel is laminar. There has to be a very carefully designed piece that takes the air from the compressor and distributes it equally from side to side and top to bottom of the wall distributing the air to the tunnel.

Design 3: This design will require careful calibration of the camera. If there is any issue with the camera, then all of the data will be skewed. For this reason, a very sturdy base for the camera would need to be designed. This design will also require backlighting so that the camera can easily track each seed. Also, as with Design 1, each fan will have to be tested and calibrated properly in order to ensure there is a laminar flow in the tunnel. Another challenge for this design is the additional cost of the camera and backlighting systems. Our budget is most likely not large enough to complete this design.

Design 4: This is likely to be an expensive design due to the potential high cost of the laser passthrough sensor. This sensor would give us a high degree of accuracy, but likely with a high cost. We would need to ensure that the sensor was mounted rigidly and in a calibrated location relative to the seed drop opening. As with designs 1 and 3, the fans will need to be tested and calibrated to ensure laminar and consistent air flow in the tunnel.

3.3.3 Final summary statement

The design that the group chose to go with it is Design #1. This design is very straightforward and should satisfy the user needs the best. The use of the fans is best because they run off electricity and therefore there will be facility adaptation required. The resources needed for this design should cost the least out of any design, and therefore fit into our budget the best. Even though Design 1 is the best, there are some aspects that it would be best to change. This design should incorporate the adjustable platform for dropping seeds, like Design #2 has. In addition, it may be best to go with a one fan design and then create a duct system that disperses the air evenly. This would help solve the issue of having even flow throughout the tunnel.

Design #2 was ruled out because it required compressed air. In order to continuously run this experiment over and over again, a large amount of compressed air would be required. To meet this requirement the group would need a very large compressed air tank or an efficient compressor that would be running constantly while the machine is being used. Compressors are often even louder than the type of fans that will be required. The latter it is, the more disturbing it will be to other researchers working in close proximity. Lastly, it is more difficult to get compressed air to generate a laminar flow. As a result, it would most likely require additional designing and testing time to make sure laminar flow is achieved.

Design #3 was ruled out because of the camera equipment. This equipment will no doubt be very expensive and will not fit into our budget. In addition, the camera will need to be calibrated and checked frequently to make sure that the resulting data is correct.

Design #4 was ruled out because of the likely high cost of the laser passthrough sensor. In addition, there would need to be frequent checks on the system calibration since this is the only measurement made on the system. There would need to be some sort of standard drop items for a system check.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

After evaluating our consumer's needs, we determined that there were two main performance measures. The Seed Cross-Breeze Tester must first, and foremost, be able to determine how far different seeds travel under multiple different wind velocities. This is the overall performance measure because this is the data that our client absolutely needs to get out of this machine. If the machine cannot determine this data, then it is more or less useless to them. The second performance measure that is extremely important is the ability to obtain results that are precise and accurate. This is important because if the results are not precise and accurate than the data is basically useless.

3.5 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

After examining the different designs, and considering the desired outcome while running experiments, minor adjustments were made to the design metrics and importance levels:

1.We concluded that having the proper range of windspeeds is of high importance and that the range should be 0-25 mph given that the average windspeeds are in the range of 10-15mph for our crop growing areas of interest.

2. The size restriction is based on its ability to be disassembled and moved and therefore is restricted by doors and elevators. This is also now of high importance as it is unknown exactly where the apparatus will be deployed.

3. We reduced the importance of the multiple drop heights when we considered how the data was being collected. The height that is now important is the loading height due to ergonomic restrictions.

4. The maximum number of operators was reduced to three since after examining all the designs it was shown that none should require more than three.

5. The maximum noise level was reduced to dB based on the fact that NIOSH has a level of 85 dB for eight hours as the limit. We want to be below that limit.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING

ITEM NO	PART NUMBER	QTY.
1	Box Frame	2
2	Front Panel	4
3	Top Panel	2
4	Bin_model	24
5	Air Dispersion Manifold	1
6	Mesh	1
7	Bottom Panel	2
8	Lower Cover Panel	2

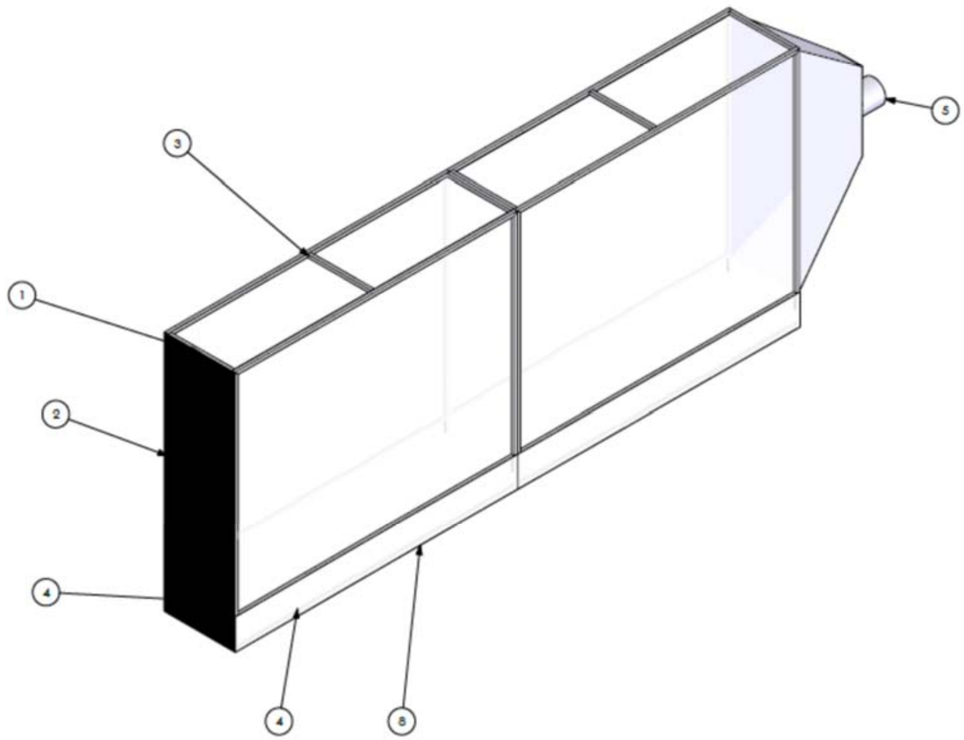


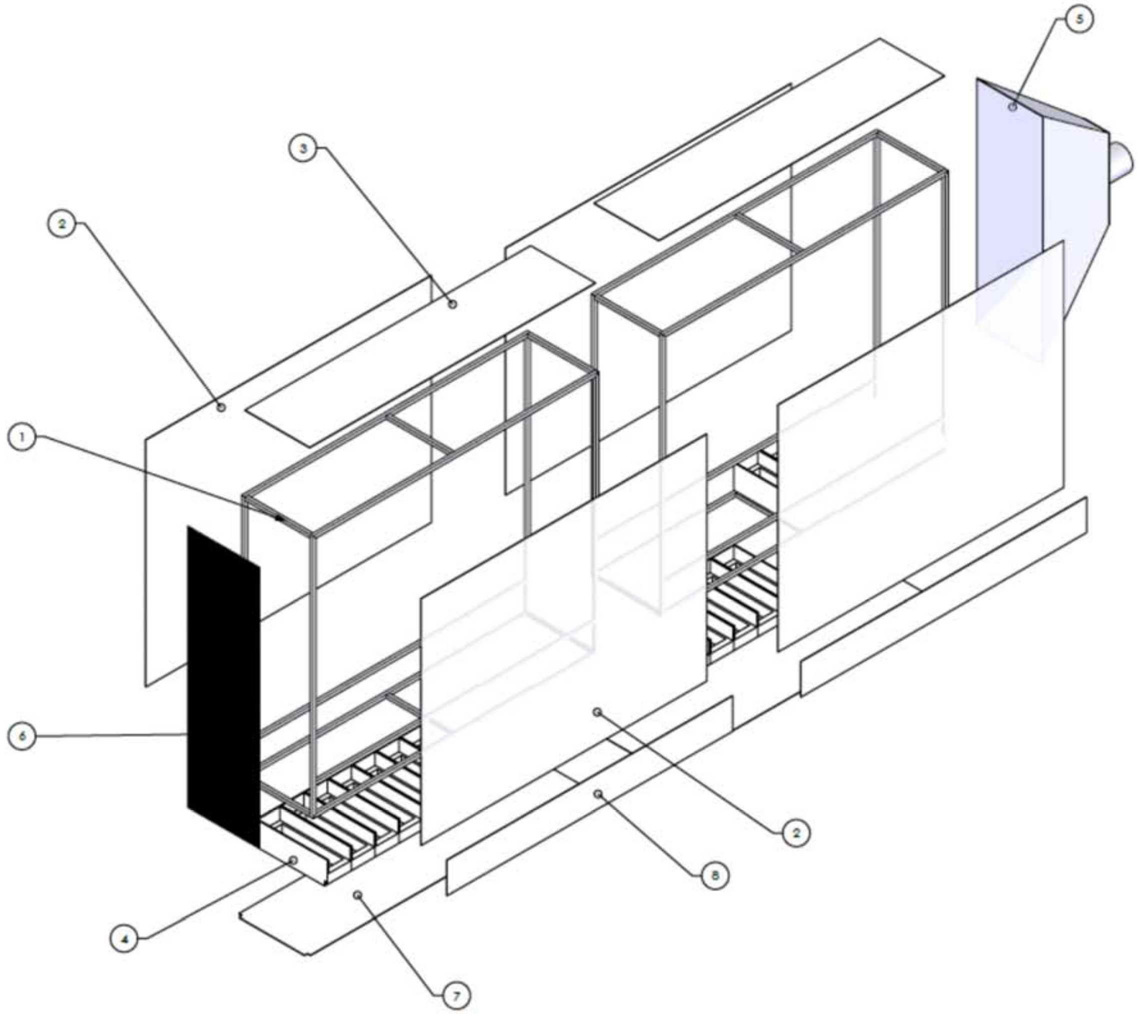
Figure 4.1.1 Embodiment Drawing of the Wind Tunnel.

4.2 PARTS LIST

Parts List

Ordered Parts							
Part Name	**Manufacturer/Vendor**	**Model Number**	**Size**	**Individual Price [$]**	**Quantity**	**Total Cost [$]**	**Additional Comments**
Fan	Air Foxx/Home Depot	AM4000a	21.5"H x 20.5"W x 19"Dp.	245.65	1	245.65	1 HP, 4000 CFM (Cleanfreak.com has it for $239.99)
VFD	KB Electronics			50	1	50	
Paneling							
Clear Cast Acrylic Sheets	Professional Plastics	Plexiglass Acrylic	36"H x 48"L x 0.062"Th.	29.57	4	118.28	
Clear Cast Acrylic Sheets	Professional Plastics	Plexiglass Acrylic	10.875"H x 48"L x 0.062"Th.	10	2	20	
Clear Cast Acrylic Sheets	Professional Plastics	Plexiglass Acrylic	12"H x 48"L x 0.062"Th.	10.02	2	20.04	
Clear Cast Acrylic Sheets	Professional Plastics	Plexiglass Acrylic	5.18"H x 48"L x 0.062"Th.	10	2	20	
Mesh				50	1	50	
Framing (need to specify)							
Steel Tubing	McMaster-Carr	6527k154	1/2" x 1/2" x 6'	8.72	20	174.4	
Bin	ULINE	S-13396	4"W x 12"L x 4"H	1.45	24	34.8	
Tubing/Ducting							
Metal Duct Pipe	Home Depot	BCP4X24	Length=2 ft., Diameter=4"	3.38	1	3.38	30-gauge galvanized steel, snap-lock design, crimped end
Wye Fitting	Home Depot	Y4X4X4	Diameters 4" x 4" x 4"	10.65	2	21.3	galvanized steel, 1 branch to 2 branches
90-Degree Adjustable Elbow	Home Depot	B90E4	4" diameter	3.9	4	15.6	30-gauge, galvanized steel
Worm Gear Clamp	Home Depot	MC4HD	4 in.	1.67	1	1.67	Galvanized steel
Fabricated Parts							
Part Name	**Manufacturer/Vendor**		**Size**	**Individual Price [$]**	**Quantity**	**Total Cost [$]**	**Additional Comments**
						775.12	

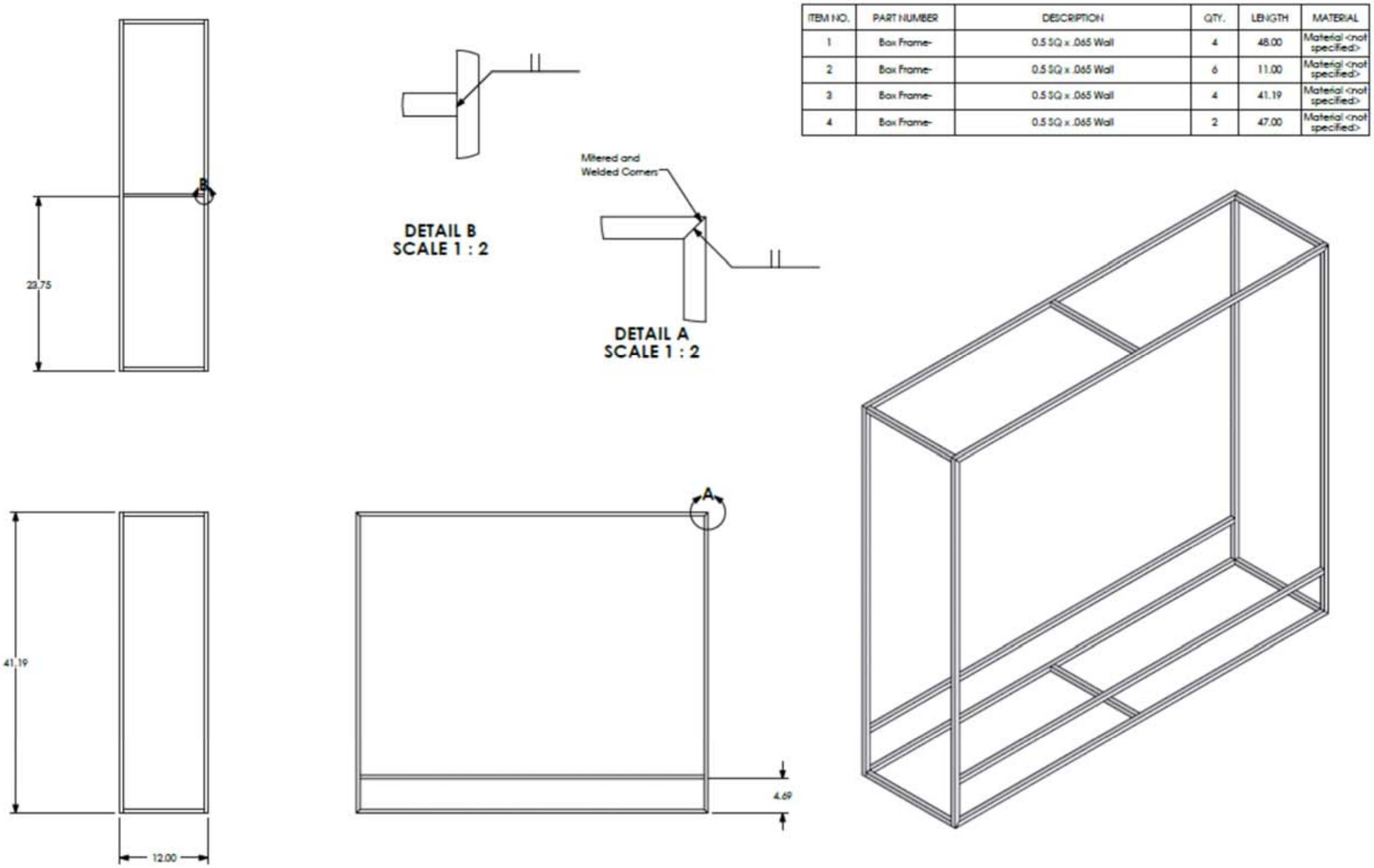
4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART



ITEM NO.	PART NUMBER	QTY.
1	Box Frame	2
2	Front Panel	4
3	Top Panel	2
4	Bin_model	24
5	Air Dispersion Manifold	1
6	Mesh	1
7	Bottom Panel	2
8	Lower Cover Panel	2

SEE SHEET 1 FOR NOTES AND TOLERANCES

Figure 4.3.1 Blown-Out View of Wind Tunnel.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	LENGTH	MATERIAL
1	Box Frame-	0.5 SQ x .065 Wall	4	48.00	Material <not specified>
2	Box Frame-	0.5 SQ x .065 Wall	6	11.00	Material <not specified>
3	Box Frame-	0.5 SQ x .065 Wall	4	41.19	Material <not specified>
4	Box Frame-	0.5 SQ x .065 Wall	2	47.00	Material <not specified>

Figure 4.3.2 Box Frame.

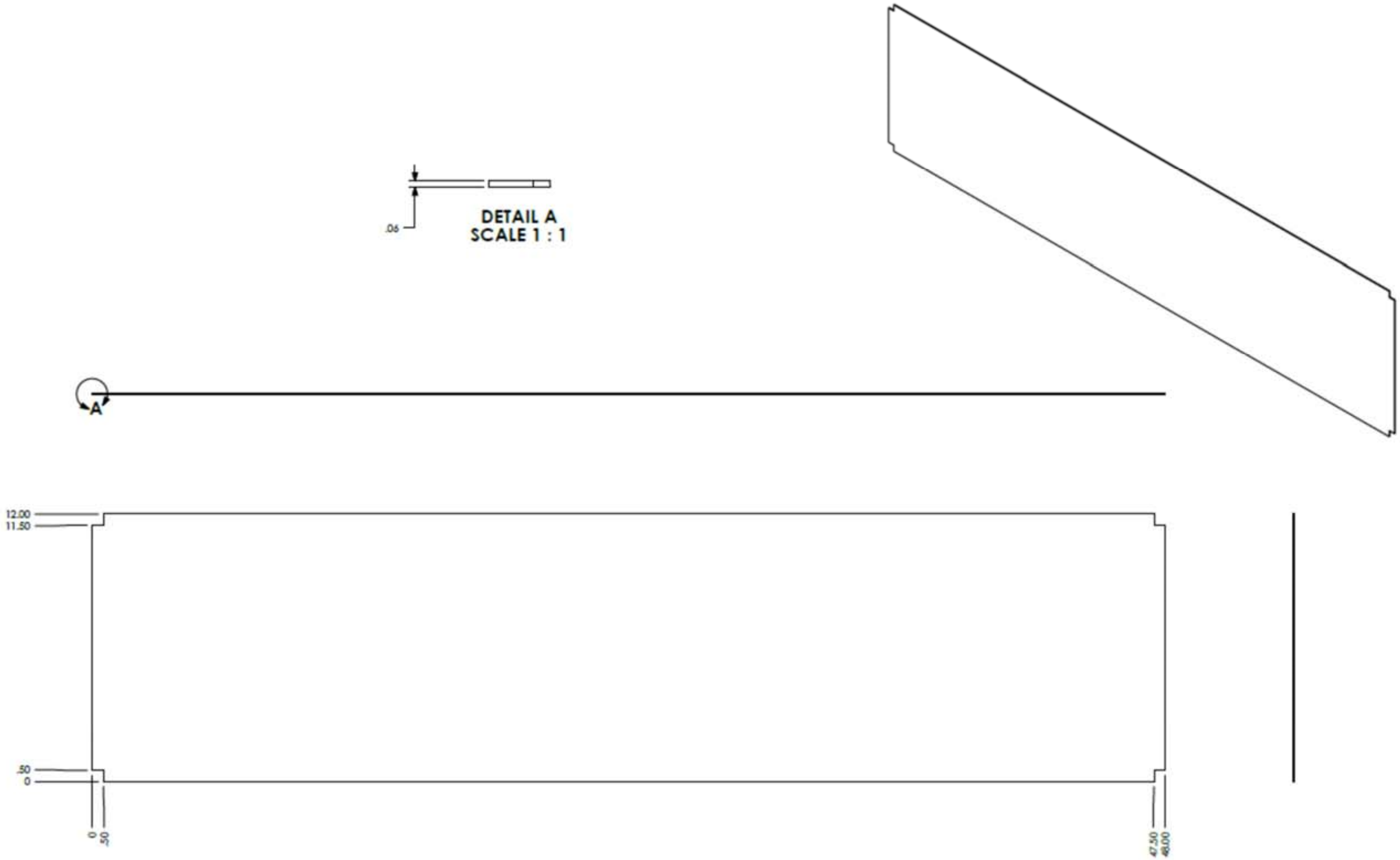


Figure 4.3.3 Bottom Panel.

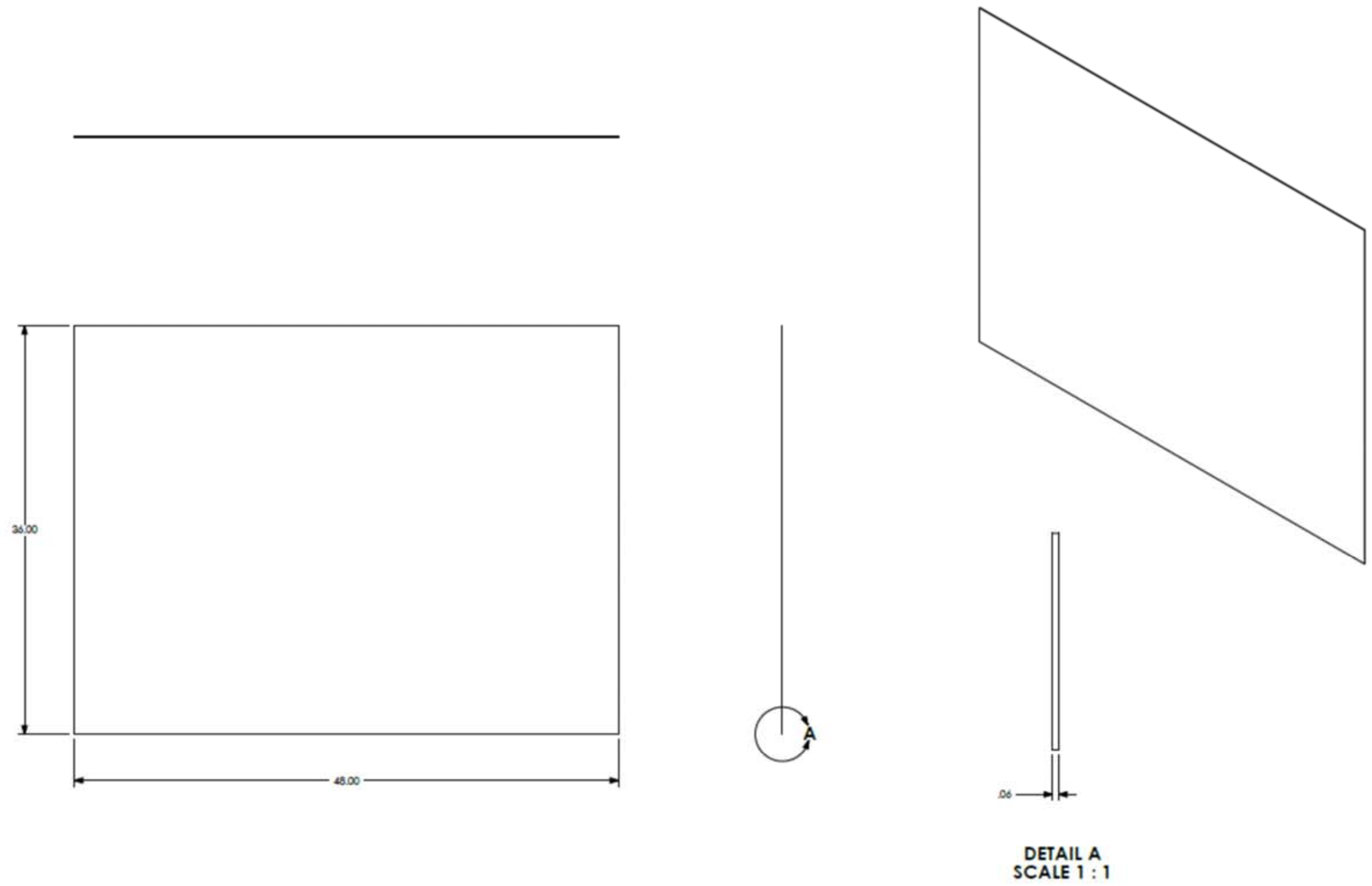


Figure 4.3.4 Front Panel.

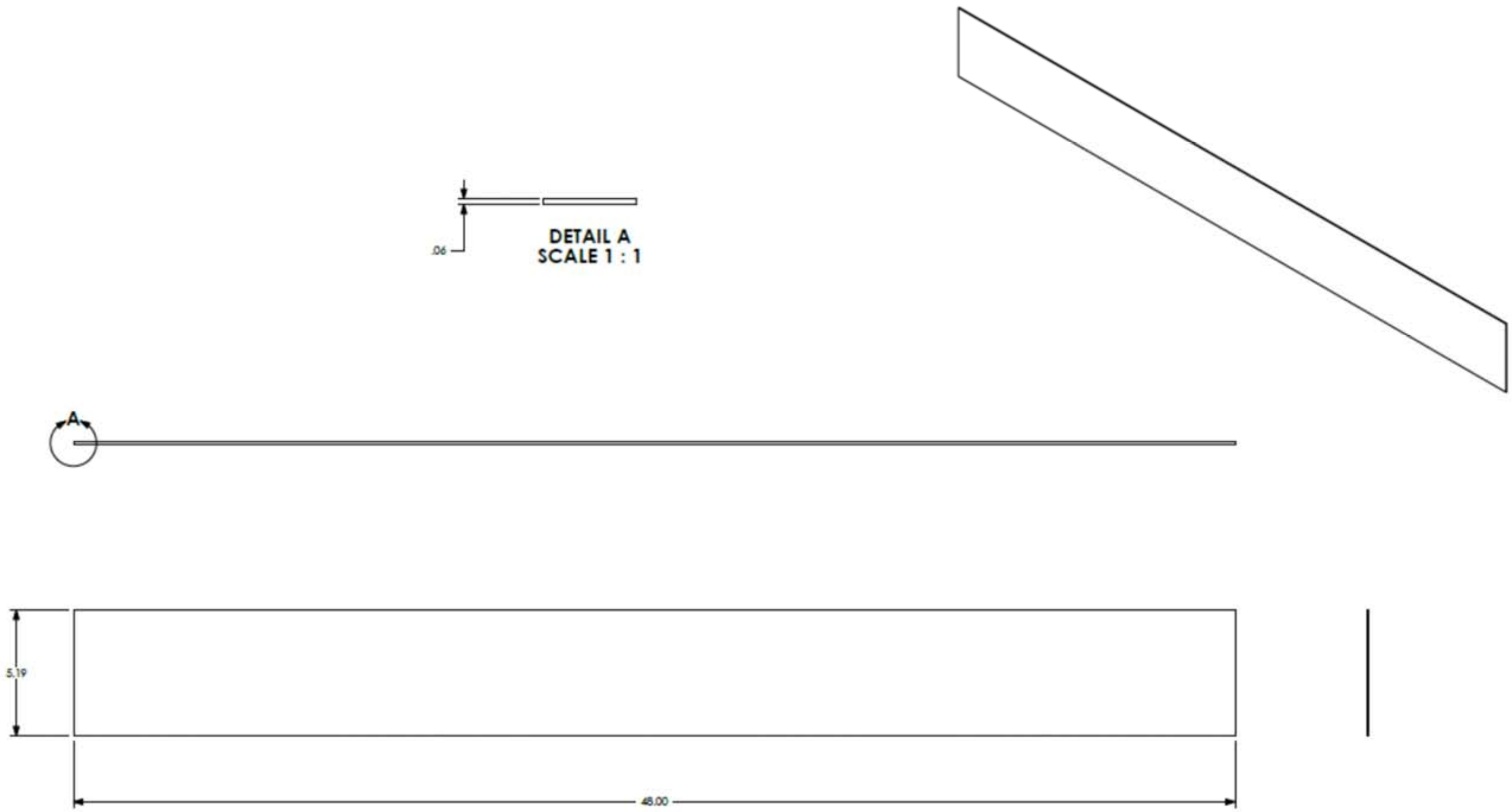


Figure 4.3.5 Lower Cover Panel.

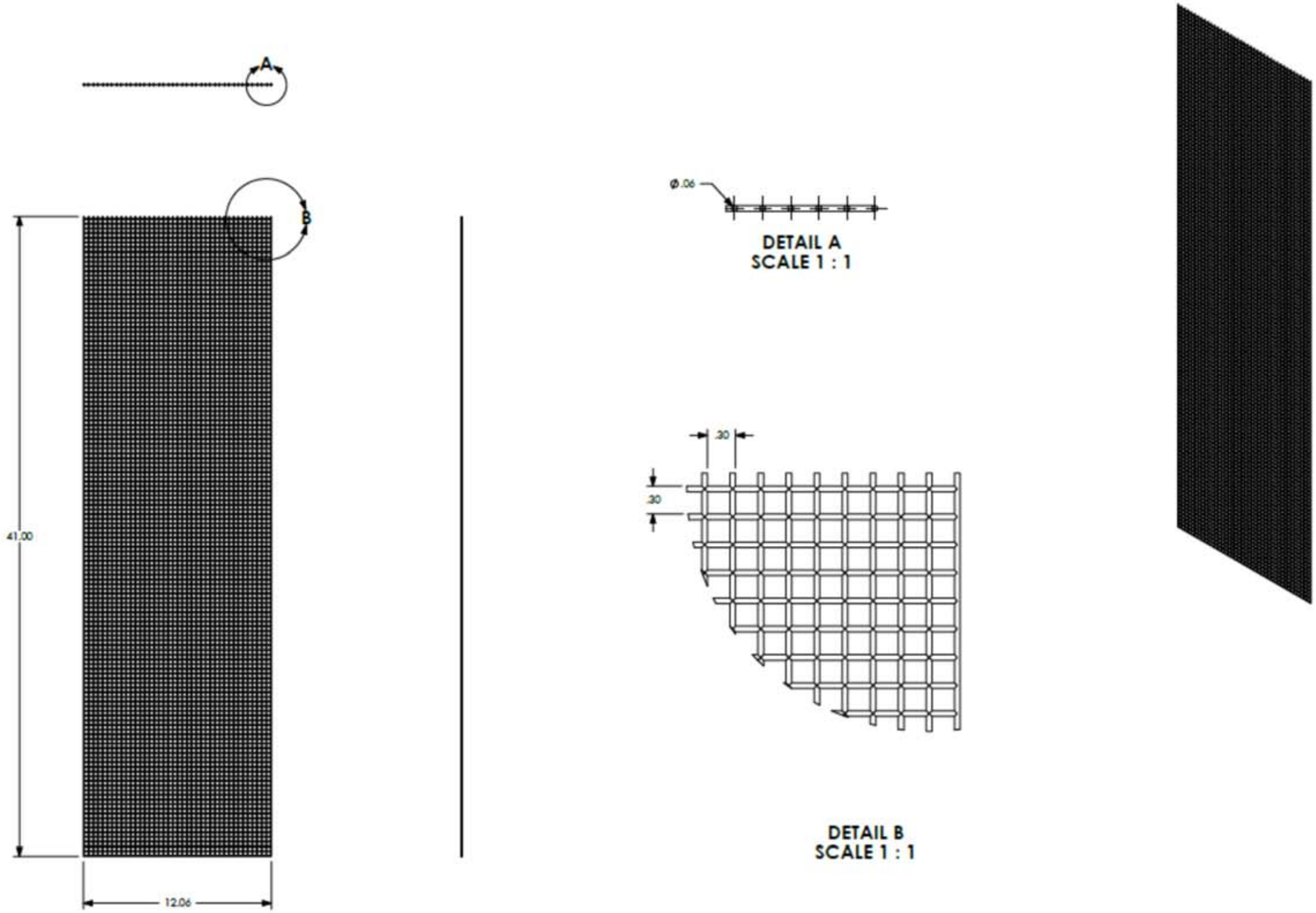


Figure 4.3.6 Mesh.

4.4 DESCRIPTION OF THE DESIGN RATIONALE

For the frame/structure of the machine, the group decided to go with steel square tubing (1/2” x 1/2"). PVC pipe was initially considered, but ruled out because it was not as structurally sound and would have been more difficult to mount the acrylic panels to. The overall size of the frame was originally going to be 10 feet long, 4 feet tall and 2 feet wide. After considering the customer’s needs, the size of the overall frame of the machine will be 8 feet long, 3 ft tall and 1 ft wide. This was done so that the required amount of airflow to reach the customer’s target wind speeds in the tunnel would be less.

The fan that was chosen was the Air Foxx AM4000A. This fan was chosen because of its high CFM output. This fan is capable of producing 4000 CFM. This amount of CFM will give our machine the capability of testing at wind speeds as high as 15 mph. This was determined by dividing the CFM output by the cross-sectional area of the tunnel then converting feet per minute to miles per hour.

The group decided to go with acrylic side panels. This choice was made because rigid side panels will provide a better airflow in the tunnel. The only other option would have been plastic liner. The problem with the plastic liner is there would have been more static buildup and higher air resistance along the walls. The group also decided to purchase the panels from a company that provides panels that are cut to the exact size needed. This decision was made because it would not require the group to cut each panel and risk breaking them. In addition, the cut to size panels were cheaper.

Considering that the motor is a single-phase motor, a Triac speed controller was found to be the best option. The Triac is capable of handling both the max current of the motor while providing us with the small speed control increments we need. Plastic bins: The plastic bins that were chosen were 4 inches wide, 12 inches long and 4 inches tall. These bins were chosen because their width was within the acceptable range for collection and they were the cheapest.

We intend to make a large shroud of either sheet metal or plastic that will divert the flow from the blower motor outlet to the entire cross section of the test frame. Design and testing needs to be done to achieve the correct internal geometries. Initial testing will be done in CAD using flow analysis software. Final testing will be done with the actual motor and an anemometer placed within the fluid flow. Senior

The far end of the testing tunnel with have a mesh to keep any seeds from exiting the apparatus. The mesh needs to be coarse enough to not restrict any airflow but fine enough to capture any seeds. We are going on the assumption that the seeds which will travel far enough to interact with the mesh will be the “fluffy” type. Given this assumption we can determine the necessary mesh size.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

The first aspect of the design that was subjected to an engineering analysis was the wind tunnel structural frame. This analysis was done to find a material and structural member shape that will give us a structure whose deflection is minimal but whose cost is minimized while also being readily available and easy to machine and assemble. Once the materials that could meet the design requirements were determined, the most cost-effective material was selected. This analysis was important because cost was a huge factor in producing a prototype.

The second aspect of the design that was subjected to an engineering analysis was the height and width of the tunnel and their correlation with the amount of air being produced by the fan. The machine needed to produce wind speeds of at least 15 miles per hour. The type of fans that were required for our application were all rated in CFM (cubic feet per minute) outputs. The amount of fan options that could produce over 3500 CFM were very limited and expensive. As a result, it was easier to tailor the height and width of the tunnel opening to obtain the required velocities inside the tunnel.

The third aspect of the design that was subjected to an engineering analysis was how the air was going to be dispersed by the airflow duct. This was very important because the goal is to have a uniform flow everywhere inside the tunnel. The fins inside the air duct are the pieces of equipment responsible for spreading the air out from the small outlet of the fan to the inlet of the tunnel. This analysis helped determine the fin design inside the duct.

5.2.2 Summary statement of analysis done

5.2.2.1 Material Analysis

To determine the best material to use for the wind tunnel's support structure, several material characteristics needed to be evaluated. The first characteristic is deflection. If we assume the deflection of the member is due mainly to the weight of the member itself, then the forces can be represented as a distributed load. Maximum deflection occurs at the center of the member and is found by the standard physics equation shown below in Eq. 1:

$$\delta = \frac{5}{384}\frac{wL^3}{EI} \ , \tag{1}$$

where w is the weight of the member (N), L is the length (m), E is the Young's modulus of the material (N/m^2), I is the second moment of inertia for the member (m^4), and δ is the deflection (m). The property of a member relating its deflection to the force applied is called its bending stiffness as shown in Eq. 2:

$$S = \frac{F}{\delta} \ , \tag{2}$$

where F is the force applied to the member (N) and S is the stiffness value (N/m). Knowing that the force applied is the weight of the member itself, we can combine Eq. 1 and Eq. 2 to create an equation for the stiffness as shown in Eq. 3.

$$S = \frac{384}{5}\frac{EI}{L^3} \tag{3}$$

We will use a solid rectangle as our standard shape for analysis. This will be modified later by a shape factor later in the analysis. Cost is our main objective and it is directly related to the mass of the material and its cost per mass as shown in Eq. 4.

$$C = mC_m = ALC_m\rho = bhLC_m\rho \ , \tag{4}$$

where C is the total cost ($), C_m is the cost per unit mass ($/kg), m is the mass of the member (kg), A is the cross-sectional area (m^2), L is the length (m), b is the length of the base (m), h is the height (m), and

ρ is the density (kg/m^3). Combining Eq. 3 and Eq. 4, using the moment of inertia for a rectangle (I=bh^3/12) and solving for C, we get an equation that describes what is needed to reduce the overall cost as shown in Eq. 5:

$$C = \left(\frac{60}{384}\frac{S}{b}\right)^{1/3} bL^2 \left(\frac{C_m \rho}{E^{1/3}}\right) \tag{5}$$

From Eq. 5, we can see that when the material properties are grouped, we get a formula that represents the material performance index as shown in Eq. 6.

$$M_1 = \frac{E^{1/3}}{C_m \rho} \tag{6}$$

When this material index is maximized, the cost will be minimized and we will have achieved the best ratio of performance to cost. If we plot these material properties for various materials with the modulus on the y-axis and the density x price on the x-axis, the best materials will be in the upper left-hand corner. If the materials are plotted on a log-log chart as shown in Fig. 5.2.1, the material index M_1 can be represented by a line of slope 3. This means that all materials residing on that line will be equal in their performance and any materials to the upper left of that line will be better than those on the line.

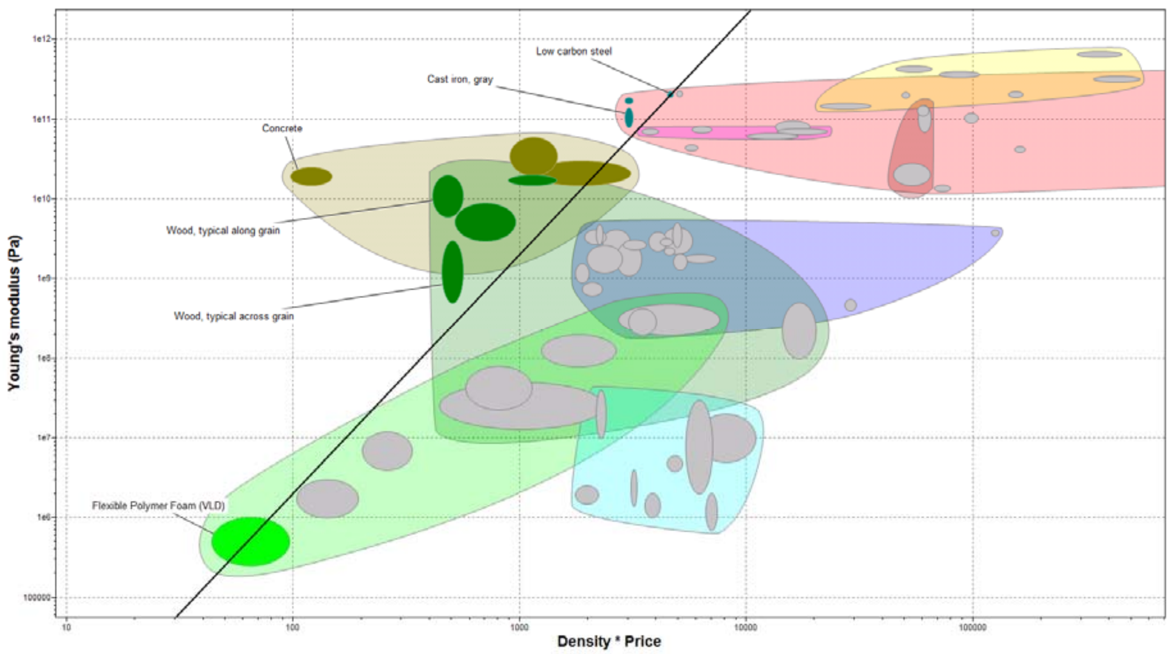


Figure 5.2.1 Log-log plot of Young's modulus to density x price for a variety of materials.

All considered materials have drastically different maximum shape factors. This is due to the materials' abilities to be formed into different shapes like round tubing or I-beams. It is quantified by the ratio of the new shapes stiffness to that of a square one as shown in Eq. 7.

$$\phi_B^e = \frac{S}{S_0} = \frac{EI}{EI_0} = \frac{12I}{A^2}\ , \tag{7}$$

where ϕ_B^e is the shape factor, I is the second moment of inertia (m^4), and A is the cross-sectional area (m^2). Substituting for I in Eq. 3 results in a new equation for stiffness, as shown in Eq. 8.

$$S = \frac{384}{60}\frac{E}{L^3}\phi_B^e A^2 \tag{8}$$

Substituting for A in Eq. 4, gives a new equation for finding the total cost of the member, as shown in Eq. 9.

$$C = \left(\frac{60\,S}{384}\right)^{1/2} L^{5/2} \left(\frac{C_m \rho}{\left(E\phi_B^e\right)^{1/2}}\right) \tag{9}$$

This provides a new material index, as shown in Eq. 10, which we want to maximize.

$$M_2 = \frac{(E\phi_B^e)^{1/2}}{C_m \rho} \tag{10}$$

Since the total defection is our main functional constraint, we calculate the total deflection for the specific materials of interest with the shapes defined to see if one performs better than the other. To do this, we use Eq. 1 but define weight in terms of area, density, and gravity which results in Eq. 11:

$$\delta = \frac{5}{384}\frac{A\rho g L^4}{EI}\ , \tag{11}$$

where δ is the total deflection (m), A is the cross-sectional area (m^2), ρ is the material's density (kg/m^3), g is the acceleration due to gravity (9.8 m/s^2), L is the length (m), E is the Young's modulus of the material (N/m^2), and I is the second moment of inertia for the member (m^4).

5.2.2.2 Wind Tunnel Analysis

When designing the wind tunnel, it had to be capable of having a maximum flow velocity of 15 mph. As previously stated, the fans that we were looking at were all rated in volumetric flow of CFM. The volumetric flow rate needs to be converted to a velocity. This conversion is a factor of the cross-sectional area that the flow is passing through, which is a rectangular shape for our application. As a result, Eq. 12 can be used to determine the velocity of the flow in the tunnel:

$$v = \left(\frac{f_v}{bh}\right) \times \left(\frac{60 min/hr}{5280 ft/mile}\right) \tag{12}$$

where v is the wind speed velocity in miles per hour [mph], f_v is the volumetric flow rate in cubic feet per minute [CFM[, b is the width of the tunnel [ft], and h is the total height [ft].

5.2.2.3 Air Flow Duct Analysis

The air flow duct is the most important part of the design. For accurate results, the flow needs to be as close to uniform from side to side and top to bottom of the tunnel. The main piece of equipment responsible for creating this uniform flow is the inlet duct because it expands the air from the small inlet of the fan to the size of the opening of the tunnel. To test the designs to determine how the flow was dispersed by the inlet duct, a computational fluid dynamics (CFD) analysis was done using Solidworks. CFDs are created using finite element analysis, and they can help determine what the theoretical flow should be within the tunnel given specified parameter.

5.2.3 Methodology

5.2.3.1 Determining Materials

To determine the best material for our application, a theoretical analysis was done using the equations from section 5.2.2.1. The basic wind tunnel assembly is shown in Fig. 5.2.3, and an isolated view of the frame itself is shown in Fig. 5.2.4. In the design, the lengths of the structural members have been defined, but the specific shapes and sizes of the members have not.

The frame has very little load on it since the only thing that will be attached to it is thin plexiglass panels and the internal pressure of the wind tunnel will be only slightly above ambient. Because of this, the primary forces on the structural members will be due to the weight of those members themselves. The horizontal members are the ones for which we are most concerned. They will have the plexiglass attached to them and if they deflect too much then the plexiglass will bow. This is an undesirable situation so our main functional constraint will be deflection. We know from experience that there are many materials that can resist deflection but, as stated in the background section, we have a need to achieve the lowest material cost possible; therefore, cost will be our primary objective. Table 5.2.1 lists the necessary constraints, objectives, and free variables.

Table 5.2.1 Design Requirements for the Wind Tunnel Frame.

Function	Structural member
Constraints	Deflection (functional constraint)
	Length specified (geometric constraint)
Objective	Minimize cost of structural member
Free variables	Choice of material
	Shape factor
	Height and thickness of member

It can easily be seen from Table 5.2.1 that some of the possible material choices are concrete, flexible polymer foam (VLD), wood, cast iron, and low carbon steel. However, there are several things that could keep a certain material from being a good choice. By using CES Edupack 2016, we can look at the materials individually to identify typical uses and specific material properties that my influence our decision.

Table 5.2.2 lists a few key properties. Compressive strength is important since some of our members will be incompression and fexural strength since some will be flexing under their weight. Their compatablility with machining is important since we will need to cut each member and fasten them together. Welding or using adhesive could be an option for fastening if needed. All data was aquired using CES Edupack 2016.

Table 5.2.2 Material Properties.

Material	Compressive Strength (Pa)	Flexural Strength (Pa)	Machining Compatibility	Max Shape Factor
Concrete	$1.3 \times 10^7 - 3.0 \times 10^7$	$1.7 \times 10^6 - 2.4 \times 10^6$	Very minimal	3
Polymer Foam (VLD)	$1.0 \times 10^4 - 1.5 \times 10^4$	$1.0 \times 10^4 - 1.5 \times 10^4$	Some after molding	2
Wood (Pine)	$3.7 \times 10^7 - 4.5 \times 10^7$	$6.7 \times 10^7 - 8.2 \times 10^7$	Yes, also glue and fastener	5.2
Cast Iron	$1.3 \times 10^8 - 2.0 \times 10^8$	$7.5 \times 10^7 - 1.1 \times 10^8$	Some, also fastener	25
Low Carbon Steel (1020)	$2.9 \times 10^8 - 3.6 \times 10^8$	$2.9 \times 10^8 - 3.6 \times 10^8$	Yes, also weld and fastener	59

Concrete is typically used in construction for columns, walls, and floors. It has very high compressive strength but when used it is often reinforced with steel or other metals. This material is also typically used for large profiles and, in our application, may be difficult form into the shapes we will need.

Polymer foam is typically used in packaging, insulation, or cushioning. It is not listed as a structural material. It has the lowest compressive and flexural strength. Polymer foam is typically molded into the shapes needed and has limitations on the use of fasteners or adhesives. This material has a low maximum shape factor, limiting the level of improvement a change in shape can make.

Wood, in this case pine, is commonly used as lumber for construction of structures and furniture. It had both very good compressive and flexural strength. It is compatible with glue and a variety of fasteners. This material has limitations on the profile shpes it can take so a basic rectangle will likely be the shape used.

Cast iron is used for large solid items like engine blocks, machine tools, structural parts. It has excellent compressive and flexural strength. There are limitations to how it can be machined and fastened with bolts or rivets being the most likely choice. It can be cast into a variety of shapes, but doing this requires special equipment that we will not have so the shapes want will need to be commercially available.

Low carbon steel, 1020 in this case, is used for general contruction parts and general mechanical parts including automotive, pressure vessels, and pipes. It has high compressive and flexural strengths. It can be easily machined to produce a wide variety of shapes. It is fastened by welding, fasteners, or high strength adhesives. The material is commercially available in a wide variety of pofiles with the maximum shape factor approaching 60.

As previously stated, we will need to easily source this material and be able to machine and assemble it using tools we have easy access to with a preference for hand tools. Because of this fact and using the analysis from the previous section we can eliminate a few of the materials. First, concrete was eliminated due to the difficulty and uncertainty in creating the smaller shapes we will be using for our assembly. Secondly, polymer foam was eliminated due to the need to mold it into the primary shape but also for its low compressive and flexural strength properties. Lastly, cast Iron was eliminated due to the likely problem in finding the small, long profiles we will be using for the frame and the limitations in how the pieces can be fastened. This left us with two potential materials: wood (pine) and low carbon steel (1015).

If we think about the design and assembly, we can define some basic shapes and sizes which will give us the shape factors. If we use wood, we will want to stick with a standard lumber size. One size that will likely be practical is a square 1x1 profile which is actually 0.75" x 0.75" (0.01905 m x 0.01905 m). This gives us a shape factor of 1 for wood. If we use steel, a square tube profile will likely be the best choice when considering assembly and machining. One possible size that is readily available is 0.5" x 0.5" with a 1/16" wall (0.0127 m x 0.0127 m, 0.0016 m thick). This gives us a shape factor of 5.5 for low carbon steel.

By using these shape factors, the two material index equations, and the values for Young's modulus, cost of material, and density from CES EduPack 2016, we can show which material is best both when the shape of the members is the same and when the shape factors we determined are used. These results are summarized in Table 5.2.3.

Table 5.2.3 Material Performance.

Material	Young's Modulus (GPa)	Cost of Material ($/kg)	Density (Mg/m³)	Shape Factor	$\frac{E^{1/3}}{C_m \rho}$	$\frac{(E\phi_B^e)^{1/2}}{C_m \rho}$
Wood (Pine)	9.4	1.00	0.49	1	4.3	6.3
Low Carbon Steel (1020)	210	0.58	7.85	5.5	1.3	7.5

Although steel outperforms wood by more than 25% when deflection is calculated, both wood and steel have very low maximum deflection of less than 0.5 mm. This means that either of these could be good choices for out wind tunnel frame.

We know the overall length of the longest member from the current design which is 48 inches (1.2192 m). We have also specified the shapes and sizes for the two materials in the previous section. Using these parameters, we can calculate the total maximum deflection as shown in Table 5.2.4.

Table 5.2.4 Total Maximum Deflections.

Material	Area (m²)	Density (kg/m³)	Length (m)	Young's Modulus (Pa)	Second Moment of Inertia (m⁴)	Total max Deflection (mm)
Wood (Pine)	3.63×10^{-4}	490	1.2192	9.4×10^{9}	1.097×10^{-8}	0.486
Low Carbon Steel (1020)	7.1×10^{-5}	7.85×10^{3}	1.2192	2.1×10^{11}	2.185×10^{-9}	0.342

Considering the specific structural members in question, wood is the cheapest when the bulk cost is considered; however, we must realize that these are bulk cost numbers and the cost for purchasing those materials from a vendor in the shapes we desire will likely be much more expensive. The relative difference between the materials should be pretty close to what we show here but the cost of forming the raw material into the various shapes may be lead to variation in the final cost of the structural member.

5.2.3.2 Determining Air Duct Dimensions

To obtain our required wind velocities, our fan needed to be able to produce a volumetric flow of over 3500 CFM. After looking into fan options, a fan with the capability of producing 4000 CFM was chosen. Using Eq. 12, we manipulated the height and width of the wind tunnel to determine if our 15-mph wind velocity goal was obtainable for the chosen dimensions.

While performing the CFD analysis, many variations in fin location, orientation, the number of fins and the angle at which the air was expanded from the fan outlet were attempted. The final design of the duct featured two main sections. One section was horizontal and one was diagonal. The diagonal section was to spread out the flow so that it would move to the top and bottom of the tunnel. The purpose of the horizontal section was to flatten out the flow so that it would flow straight down the tunnel and not create turbulence.

The design of the fins inside the duct where the next parts tested. The main design started with only four horizontally oriented fins. More simulations were then run with additional horizontal fins. Adding these additional fins helped to more evenly spread out the flow from the top to the bottom of the wind tunnel. Vertically oriented fins were then tested in the models. The purpose of these fins was to make the flow even throughout the width of the tunnel. By adding these fins in between each horizontal layer and placing them at different angles, it was found that the flow was better spread out from the front to the back of the tunnel.

5.2.4 Results

5.2.4.1 Material Results

When all of the design constraints, physical properties, and additional machining and assembly constraints are taken into account, wood (pine) is the best material choice for our wind tunnel frame. In this analysis, we used a square 1x1 standard profile as our member shape. The results showed that we may be able to reduce the size or alter the geometry of this shape while having negligible impact on its performance. This can help with the cost and allow for additional adjustments to the design. When a new profile is desired, only Eq. 11 is needed to ensure the desired deflection is maintained. Some additional standard profiles to be considered are 1 x 2, ½” x ¾” and ½” x ½”. These results make complete sense. Given the requirements of the design, wood had sufficient strength and is usually always cheaper than metal.

Conducting this analysis helped determine what tunnel width and height configurations would allow the airflow velocity inside the tunnel to reach the design requirements. Using this analysis, and the consumers requirements, the width and height for the final design of the tunnel was determined. These results make sense because it is just simply converting the volume flow into a velocity.

5.2.4.2 Computational Fluid Dynamics Results

Performing computational fluid dynamic analyses on many different design configurations of the inlet duct was extremely helpful. They showed us how the flow would be impacted by each alteration made. This analysis even helped verify that the flow velocities in the tunnel would reach our design requirements. These results support the theory that if you want the air to be dispersed evenly, in a short amount of distance, it must be directed. By using additional fins inside the duct, the analysis showed that the air should be more evenly distributed throughout the duct. This analysis was run and the results of the final design for the inlet duct can be seen in Fig. 5.2.2.

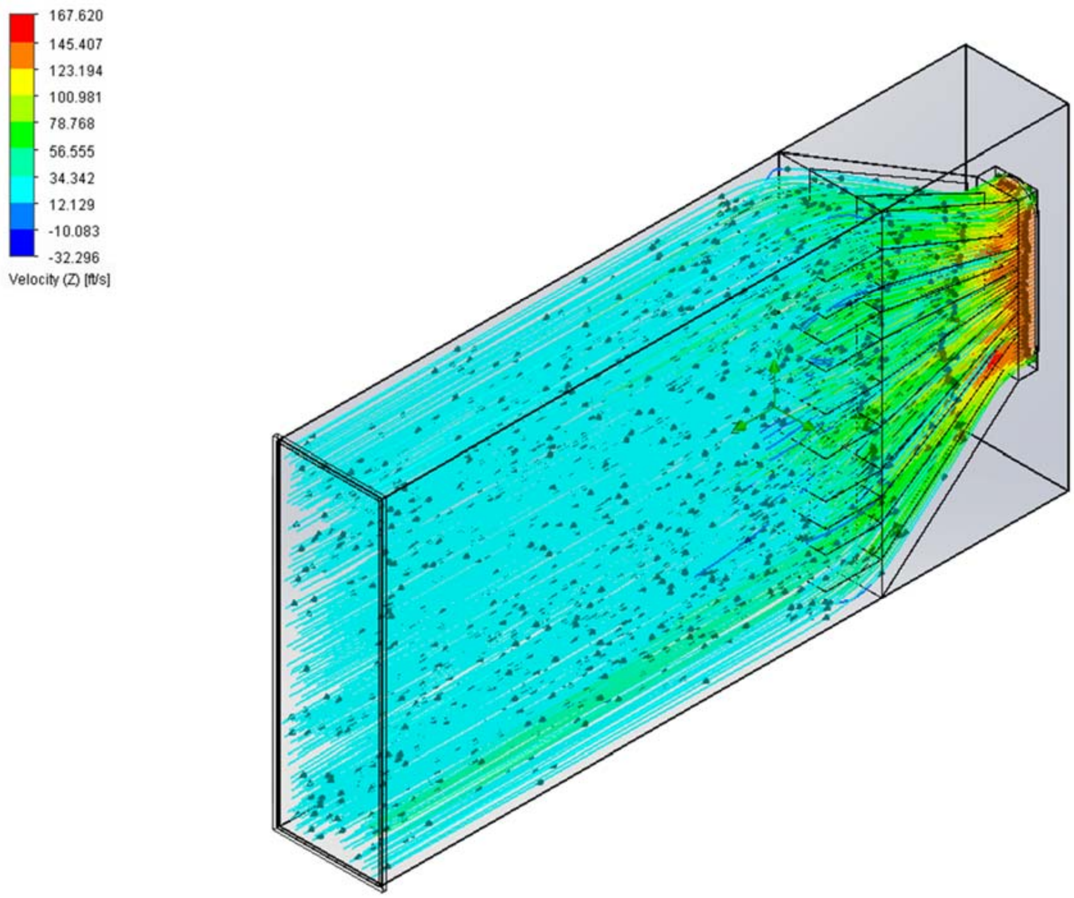


Figure 5.2.2 CFD Analysis of Final Inlet Duct Design.

5.2.5 Significance

The frame analysis caused the support members of the tunnel to be constructed out of wood instead of steel. The initial design called for using steel square tubing. Making this change attributed to a 50% savings in the cost of the tunnel structure materials.

The analysis on the height and width of the tunnel's effect on the flow velocity helped determine the final dimensions of the tunnel. Prior to analysis, the design called for a tunnel height of 4 feet and a width of 2 feet. If these dimensions were used, the required flow velocity would not have been met. As a result, the final dimensions of the opening of the tunnel were 11 inches wide and 36 inches tall.

The CFD analysis was extremely instrumental in arriving at the final design of the inlet duct. The very first design was simply a V-shaped duct with no fins inside. This design would have had extremely poor performance and the results generated would have been very inaccurate. The duct design progressed from no fins, to only horizontal things, to finally a duct with horizontal and vertical fins. The analysis allowed us to create an outlet flow into the tunnel that will be very close to evenly distributed. The final design calls for a 6-inch flat section connecting to the inlet of the tunnel and a 1 ½ foot section of the duct with a diagonal orientation. The final design will also feature 32 fins inside. Ten of which will be horizontally oriented and the remaining 22 will be vertically oriented.

6 RISK ASSESSMENT

6.1 RISK IDENTIFICATION

Possible barriers to completing the project successfully are identified below:

- **Budget**
  - Need for additional funding
  - Funding is not provided on-time
- **Supply Chain and Schedule**
  - Parts not ordered on-time
  - Parts not delivered on-time
  - Damaged parts from manufacturer
- **Integration and Performance**
  - Sections do not connect smoothly
  - Blower does not supply sufficient flow

6.2 RISK ANALYSIS

- **Need for additional funding**
  - If the group needs to ask for additional funding, the project could be delayed.
- **Funding is not provided on-time**
  - Not receiving funding in a timely manner will cause the group to coordinate other arrangements, which may delay ordering and fabrication.
- **Parts not ordered on-time**
  - If parts are not ordered in a timely manner, the fabrication will be rushed and the project may not be completed on-time.
- **Parts not delivered on-time**
  - If parts are delivered past the expected delivery date, this will delay fabrication and project completion.
- **Damaged parts from manufacturer(s)**

    - If the parts delivered from the manufacturer are damaged, then parts might need to be re-ordered, which would delay project completion. If parts cannot be re-ordered, the group may have to redesign the project according to the amount of non-damaged material. This could affect the performance and reliability of the project, as well as delay its completion.
- **Sections do not connect smoothly**
    - If the group is unable to successfully connect the different sections during fabrication, then the project will not perform as expected in the analyses.
- **Blower does not supply sufficient flow**
    - If the blower does not supply the flow as stated in the manufacturer's specifications, then the wind tunnel will have decreased performance and will not be able to test as many types of seeds as anticipated.

6.3 RISK PRIORITIZATION

The group made a scale of risk levels to prioritize risks, as shown in Table 6.3.1. The scale is based on the severity of the impact that the risk will have on the project.

Table 6.3.1 Scale of Risk Levels Used to Prioritize Risks.

Risk Level	Impact Description
5	Severe impact, critical objectives may not be completed
4	Significant impact, critical objectives may not reach acceptable level
3	Moderate impact, desired results may be acceptable, but not maximized
2	Minor impact, some less-critical, but desired, results may meet minimal acceptance standards
1	Minimal impact, there will be little to no impact on desired results or project objectives

Table 6.3.2 displays the impact severity rating for each identified risk.

Table 6.3.2 Impact Rating for Identified Risks.

Risk	Rating
Need for additional funding	5
Funding is not provided on-time	4
Parts not ordered on-time	3
Parts not delivered on-time	4
Damaged parts from manufacturer(s)	3
Sections do not connect smoothly	3
Blower does not supply sufficient flow	2

7 CODES AND STANDARDS

7.1 IDENTIFICATION

7.1.1 Occupational Safety and Health Standards (OSHA)

OSHA Standard 1910.212 applies to machinery and machine guarding. This standard has four sections that are applicable to the Seed Cross-Breeze Distance Tester.[1]

Standard 1910.212(a)(1) requires that one or more methods of machine guarding must be provided to "protect the operator and other employees in the area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks."

Standard 1910.212(a)(2) requires guards to be "affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible."

Standard 1910.212(a)(3)(ii) states that when specific standards are not applicable, the design should be made to take a person out of the zone where there could be bodily harm.

Standard 1910.212(a)(5) regards exposure of blades. It states that "when the periphery of the blades of a fan is less than seven feet above the floor or working level, the blades shall be guarded. The guard shall have openings no larger than one-half inch."

7.1.2 American Section of the International Association for Testing Materials (ASTM)

Standard D4802-16 regards standard specifications for Poly(Methyl Methacrylate) Acrylic plastic sheets. This standard covers acrylic sheets produced by various processes. The standard requires that manufacture must test for certain material properties upon production and make them accessible to customers. The following tests must be performed: index of refraction, specific gravity, luminous transmittance, haze, water-absorption, shrinkage, thermal stability, deflection temperature under flexural load, tensile strength and elongation at break, impact strength, abrasion resistance, coating adhesion, and chemical resistance.[2]

7.1.3 International Electrotechnical Commission (IEC)

Standard UL 61800-5-1 applies to adjustable-speed electrical power drive systems. This standard provides safety requirements for adjustable speed power drive systems with respect to electrical, thermal, and energy safety considerations.[3]

7.2 JUSTIFICATION

Standard 1910.212{(a)(1), (a)(2), and (a)(3)(ii)} – These standards apply to the seed cross-breeze testing machine because the machine will use air blowing at various speeds. Although the seeds being tested will have minimal mass, there is a potential for injury (such as an eye injury) if a seed blew a distance in excess of the machine's length. Additionally, a foreign particle could enter the fan and blow through the machine causing the same type of injury. Air blowing from the machine also has the potential to damage other equipment in the laboratory or affect other laboratory items in such a way that causes bodily harm.

Standard 1910.212 {(a)(5)} – This standard applies to the seed cross-breeze testing machine because a high-volume fan will be used to create wind through the machine.

Standard ASTM D4802-16 – This standard applies to the seed cross-breeze testing machine because the machine will use clear cast acrylic sheets.

Standard UL 61800-5-1 – This standard applies to the seed cross-breeze testing machine because the machine will use a variable frequency drive to obtain various windspeeds.

7.3 DESIGN CONSTRAINTS

7.3.1 Functional

Standard ASTM D4802-16 affected the design for functional reasons. For ease of operation, the machine needs a clear viewing window, so it was not an option to substitute this material; however, this standard influenced the manufacturer choice. Manufacturers with the lowest prices that had published data sheets for their materials were considered first.

7.3.2 Safety

Standard 1910.212{(a)(1), (a)(2), and (a)(3)(ii)} caused design constraints related to safety. Attaching a guard is not necessarily applicable in this case, because that would just involve lengthening the machine and therefore increase expenses. So, the machine will be constructed to fit along a wall of the laboratory, and the operator will be instructed to position the machine's discharge end toward a wall, with no equipment in the discharge path. The operators will also be instructed to make all laboratory personnel aware of the machine's operating times and forbid anyone from walking through, near, or around the machine's discharge end.

Standard 1910.212 {(a)(5)} required the group to consider only fans which provided the necessary protection from fan blade exposure.

7.3.3 Quality

Standard UL 61800-5-1 led the group to choose a manufacturer that is ISO 9001 certified. This means they hold a quality management system (QMS) certification which requires them to adhere to all applicable product safety standards. The device must be reliable and durable. It must be able to produce consistent results by creating repeatable wind speeds and flows for each use, so choosing quality manufacturers was a high priority.

7.4 SIGNIFICANCE

Standards 1910.212{(a)(1), (a)(2), and (a)(3)(ii)} affected the maximum dimensions of the machine. As the customer prefers to use the machine indoors, the group obtained the laboratory dimensions from the customer, which became the starting point for determining the machine's allowable size. Initially, the machine's total panel-section length was intended to be ten feet, but after incorporating an allowable discharge area between the machine and the wall it faces, and with an attempt to reduce overall cost, the length of the panel section was shortened to eight feet.

Standard 1910.212 {(a)(5)} had a minimal effect on the final design. The group was able to find a fan that met both the machine's air flow requirements and the safety requirements. The chosen fan has a protective grill covering the fan blades and the motor.

Standard ASTM D4802-16 significantly impacted the manufacturer choice. Because high volumes of air at varying speeds will be flowing through the testing machine, it was important to select acrylic sheets from a manufacturer that published technical data on their products. The chosen distributor has a data sheet available to download, as well as the contact information for the actual manufacturer. Choosing this distributor also proved to be optimal because they will ship acrylic sheets in custom sizes. This allowed the group to create a final design that required less sections, which will result in a shorter assembly time and less possibility for error.

Standard UL 61800-5-1 impacted the VFD manufacturer choice. Choosing a VFD manufacturer who was QMS certified gave the group greater confidence in the safety and success of the final design, but it did not change the overall design.

8 WORKING PROTOTYPE

8.1 PROTOTYPE PHOTOS

The completely constructed Cross Breeze Seed Tester device can be seen in Fig. 8.1.1 and 8.1.2. A frontal view can be seen in Fig. 8.1.1 and an isometric view seen in Fig. 8.1.2. These views show how all the components fit together to complete the machine. The fan provides the wind to blow the seeds down the tunnel. The air duct spreads out the air so that it is evenly distributed throughout the cross-section of the tunnel. At the bottom of the tunnel are collection bins, where the seeds will fall into. There are plexiglass panels to keep the wind flow from escaping the sides and top of the wind tunnel.

Figure 8.1.1 Front View of the Working Prototype.

Figure 8.1.2 View of the Working Prototype with a Closer Look at the Blower.

8.2 WORKING PROTOTYPE VIDEO

A short video clip that shows the final prototype performing. Include YouTube link. Make sure your video is public

8.3 PROTOTYPE COMPONENTS

There is a clear plexiglass panel inserted into each top, front and back section of the tunnel. The plexiglass panels can be seen in Fig. 8.3.1. These panels help keep the wind flowing down the tunnel. They also allow the tester to see the trajectory of the seed as it is blown down the tunnel. Figure 7 also shows one section of the wind tunnel. The tunnel was constructed in two sections. It was designed this way so that it would be easier to transport and construct. Each section is 4 feet long 3 ½ feet tall and 1foot wide.

Figure 8.3.1 The Working Prototype's Tunnel Section.

The collection bins are also a component of the design. They line the bottom of the wind tunnel and can be seen in Fig. 8.3.2. These bins are made by Uline. Each bin is made from clear plastic and is 4 inches wide and 4 inches tall. Their length stretches the width of the tunnel. There is a total of 24 bins lining the entire length of the tunnel.

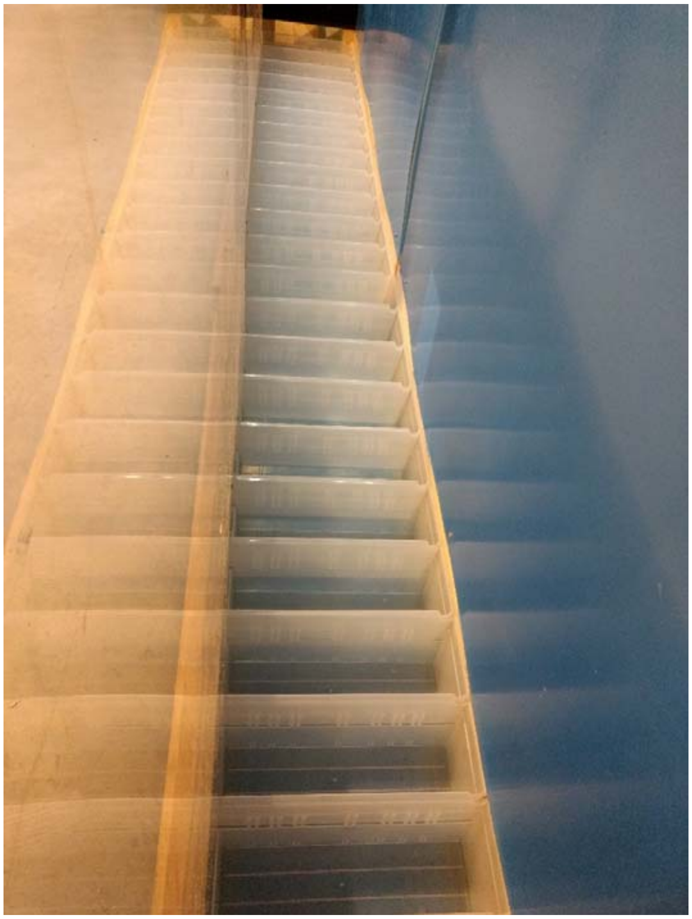


Figure 8.3.2 Bin Arrangement in the Wind Tunnel.

Providing the airflow for the device is an Air Foxx AM4000A air mover. The manufacturer specified that it is capable of producing 4000 CFM. It has been outfitted with a variable frequency drive, made by Vari-Speed. This allows for fine adjustment of the fan speed. This was needed because the original fan was only capable of three different speed settings. What these components look like, and how they were integrated together can be seen in Fig. 8.3.3.

Figure 8.3.3 The Working Prototype's Blower.

Another component of the machine is the air dispersion manifold and it can be seen in Fig. 5. This component is fabricated from 20gauge galvanized steel for the outer shell, and 24gauge galvanized steel for the internal fins. It is responsible for evenly distributing the wind flow throughout the cross-section of the wind tunnel. Ten horizontal fins can be seen in Fig. 8.3.4. There are an additional 22 vertical fins inside the duct to also help disperse the airflow.

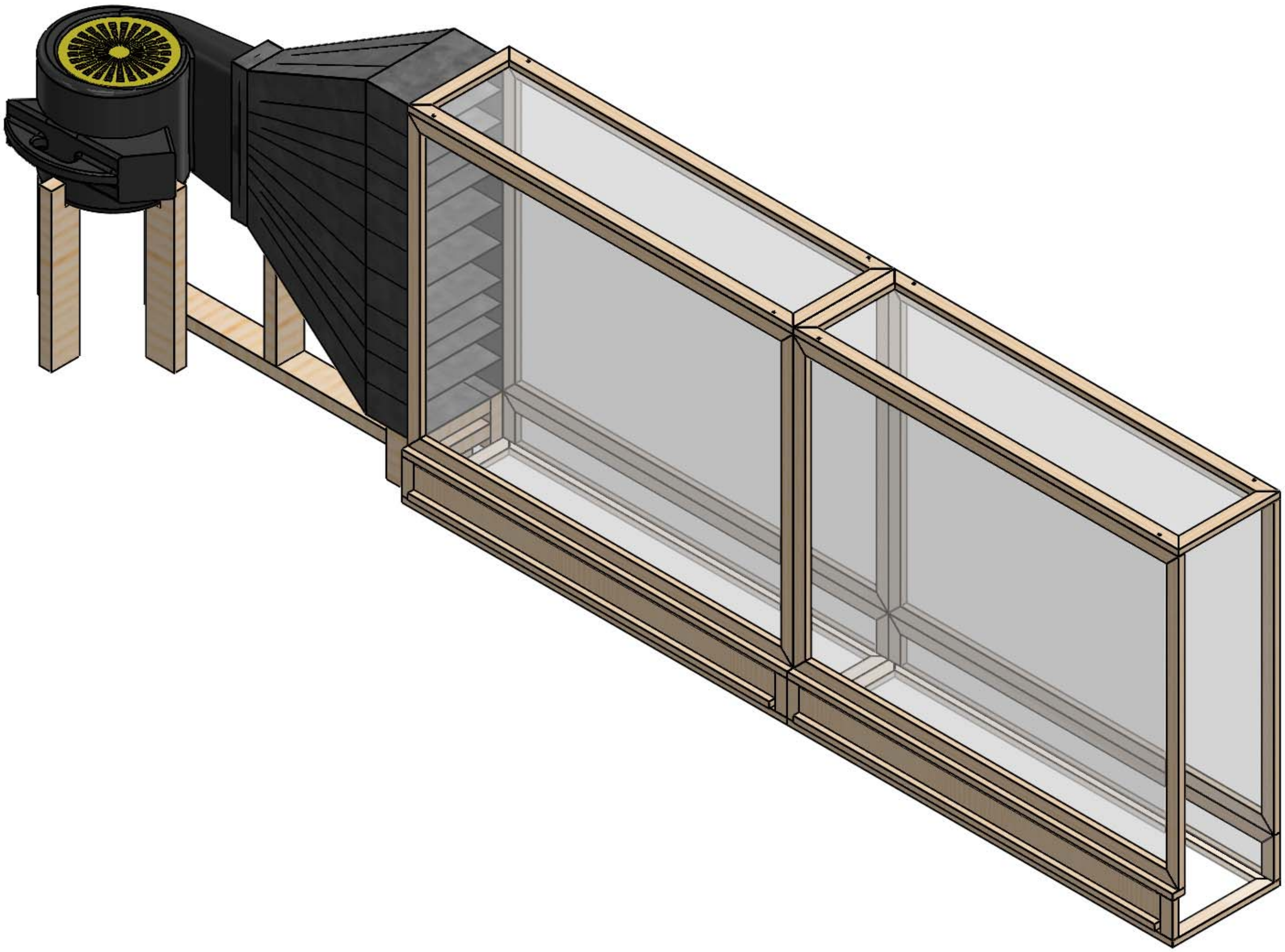
Figure 8.3.4 The Working Prototype's Air Dispersion Section.

9 DESIGN DOCUMENTATION

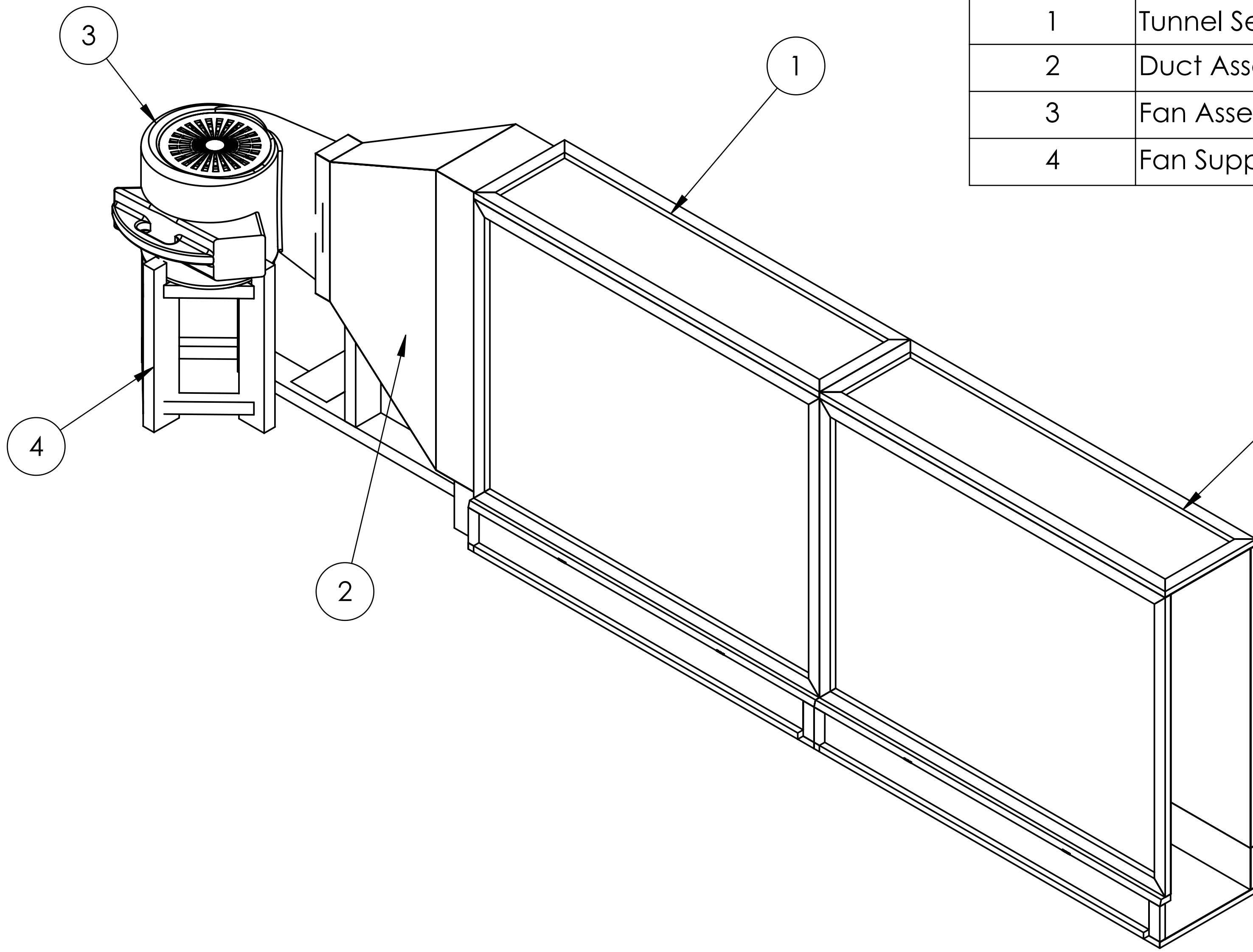
9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 Engineering Drawings

See Appendix C for the individual CAD models.



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Seed Cross-Breeze Tester Prototype
Scale : 1:15	Material:



ITEM NO.	PART NUMBER	QTY.
1	Tunnel Section	2
2	Duct Assembly 2	1
3	Fan Assembly	1
4	Fan Support Frame	1

UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

Part: Wind Tunnel - Upper Level Assembly

Scale : 1:32

Material: See individual Part Drawings

9.1.2 Sourcing instructions

Part	description	Source
4.25 Straight	used for dispersion manifold support	Home Depot
5 half miter	used for dispersion manifold support	Home Depot
12_625	used for dispersion manifold support	Home Depot
13_375	used for dispersion manifold support	Home Depot
36 miter	used for dispersion manifold support	Home Depot
48 miter with notch	Used in top panel assembly, side panel assembly	Home Depot
48 miter	Used in top panel assembly, side panel assembly	Home Depot
48 straight	Used in top panel assembly, side panel assembly	Home Depot
Bottom acrylic	Used in Bottom panel assembly	Professional Plastics
Bottom back acrylic	Used in Bottom panel assembly	Professional Plastics
door face	Used in Bottom panel assembly	Home Depot
fan support front cross	Used for fan support	Home Depot
fan support front vertial	Used for fan support	Home Depot
fan support lower	Used for fan support	Home Depot
fan support manifold vertical	Used for fan support	Home Depot
fan support vertical	Used for fan support	Home Depot
Side Acrylic	Used in side assembly	Professional Plastics
H_Fin 1	Used in dispersion manifold	Home Depot
H_Fin 2	Used in dispersion manifold	Home Depot
H_Fin 3	Used in dispersion manifold	Home Depot
H_Fin 4	Used in dispersion manifold	Home Depot
H_Fin 5	Used in dispersion manifold	Home Depot
V_Fin 1	Used in dispersion manifold	Home Depot
V_Fin 2	Used in dispersion manifold	Home Depot
V_Fin 3	Used in dispersion manifold	Home Depot
V_Fin 4	Used in dispersion manifold	Home Depot
V_Fin 5	Used in dispersion manifold	Home Depot
V_Fin Middle	Used in dispersion manifold	Home Depot
Manifold side	Used in dispersion manifold	Home Depot
Manifold top/bottom	Used in dispersion manifold	Home Depot

9.2 FINAL PRESENTATION

Video is attached

10 TEARDOWN

The final prototype was delivered to the client for the to keep.

11 APPENDIX A - PARTS LIST

Starts on the next page

Parts List

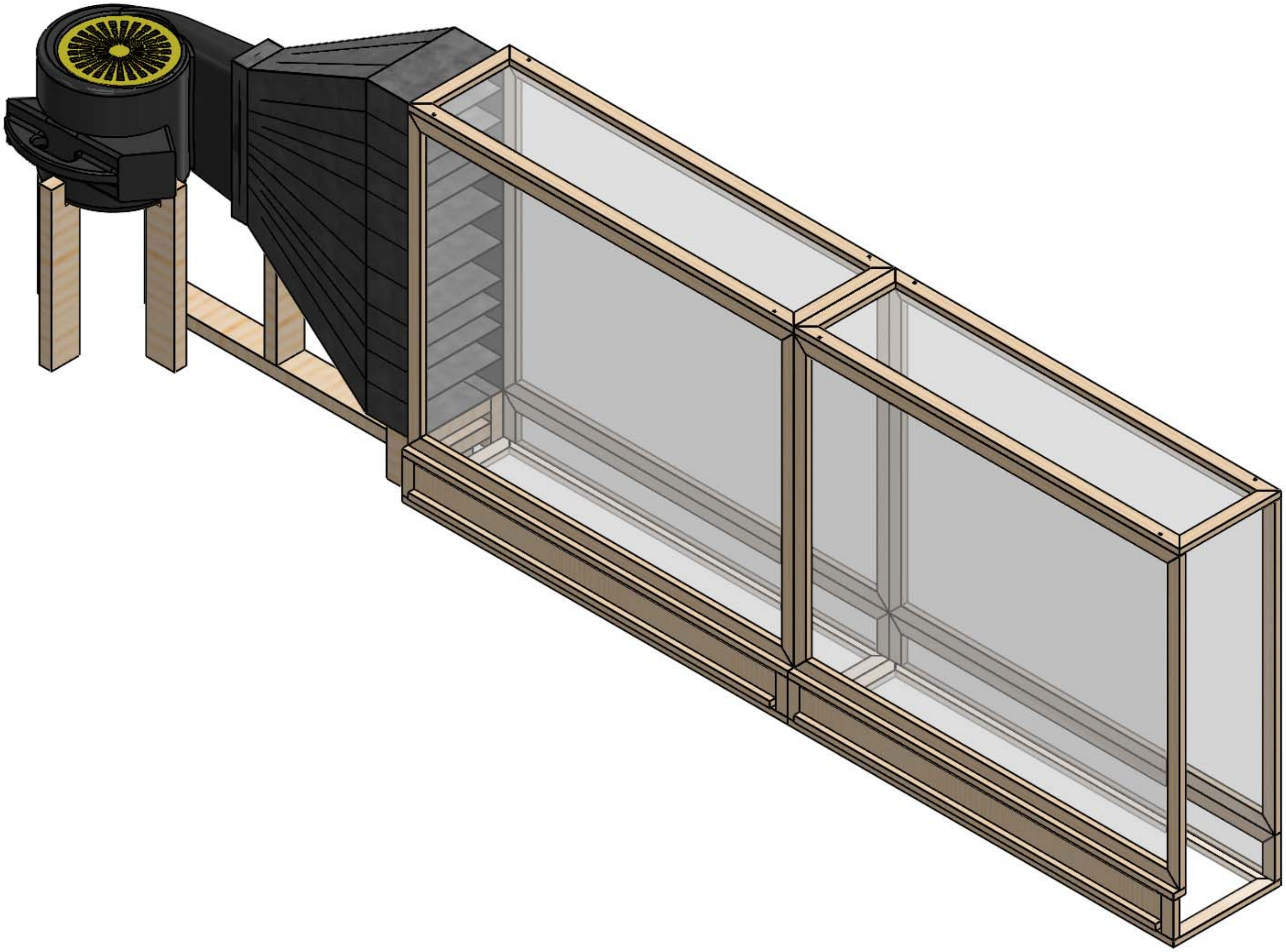
Part Name	Manufacturer	Vendor	Model Number	Size	Individual Price [$]	Quantity	Total Cost [$]	Tax [$]	Shipping [$]	Additional Comments
Ordered Parts										
Fan										
Air Mover Floor Fan	Air Foxx	Amazon	AM4000a	21.5"H x 20.5"W x 19"Dp.	214.78	1	214.78	12.78	0	1 HP, 4000 CFM; discounted open-box purchase
Speed Controller										
	KB Electronics	Amazon	KBWC-115K	15A Variable Speed Controller	34	1	34	0	0	
Paneling										
Clear Cast Acrylic Sheets	Professional Plastics	Professional Plastics	Plexiglass Acrylic	36"H x 48"L x 0.062"Th.		4				Main side panels
Clear Cast Acrylic Sheets	Professional Plastics	Professional Plastics	Plexiglass Acrylic	10.875"H x 48"L x 0.062"Th.		2				Front bottom panels
Clear Cast Acrylic Sheets	Professional Plastics	Professional Plastics	Plexiglass Acrylic	12"H x 48"L x 0.062"Th.		2				Top panels
Clear Cast Acrylic Sheets	Professional Plastics	Professional Plastics	Plexiglass Acrylic	5.18"H x 48"L x 0.062"Th.		2				Back bottom panels
(Order Total)					125.2	1	125.2	0	62.35	Cost of full order
Mesh										
Galvenized wire mesh	N/A	McMaster-carr	9217T438	8x8 galv. steel mesh	3.14	1	3.14	0	6.15	
Framing										
Pine Board	N/A	Menards	1031568	1 x 2 x 8' Pine Board	3.39	12	40.68	3.4	0	
Pine Board	N/A	Menards	1031558	1 x 2 x 4' Pind Board	1.75	2	3.5	0.29	0	
Air Dispersion Manifold										
Sheet Metal	N/A	Shapiro Supply	N/A	4' x 10' 20ga Sheet Steel	50	1	50	0	0	
Bin										
Seed catch bins	ULINE	ULINE	S-13396	4"W x 12"L x 4"H	1.65	24	39.6	0	15.67	
Fan Stand										
2x4 Stud	N/A	Donation	N/A	2 x 4 x 8'	0	2	0	0	0	Donated wood
Assembly Hardware										
Hinges	N/A	Home Depot	30699151615	1" Zinc Plated Hinge, 2 pk	1.48	2	2.96	0.24	0	
Epoxy	Loctite	Home Depot	79340648302	Quickset Clear Epoxy	4.57	3	13.71	1.09	0	
Wood Screws	N/A	Donation	N/A	3" wood screws	0	0	0	0	0	Donated Screws
Wood Screws	N/A	Donation	N/A	#6 x 1-1/2" wood screws	0	0	0	0	0	Donated Screws
						Subtotal:	$527.57			
						Tax:	$17.80			
						Shipping:	$84.17			
						Total Cost	**$629.54**			

12 APPENDIX B - BILL OF MATERIALS

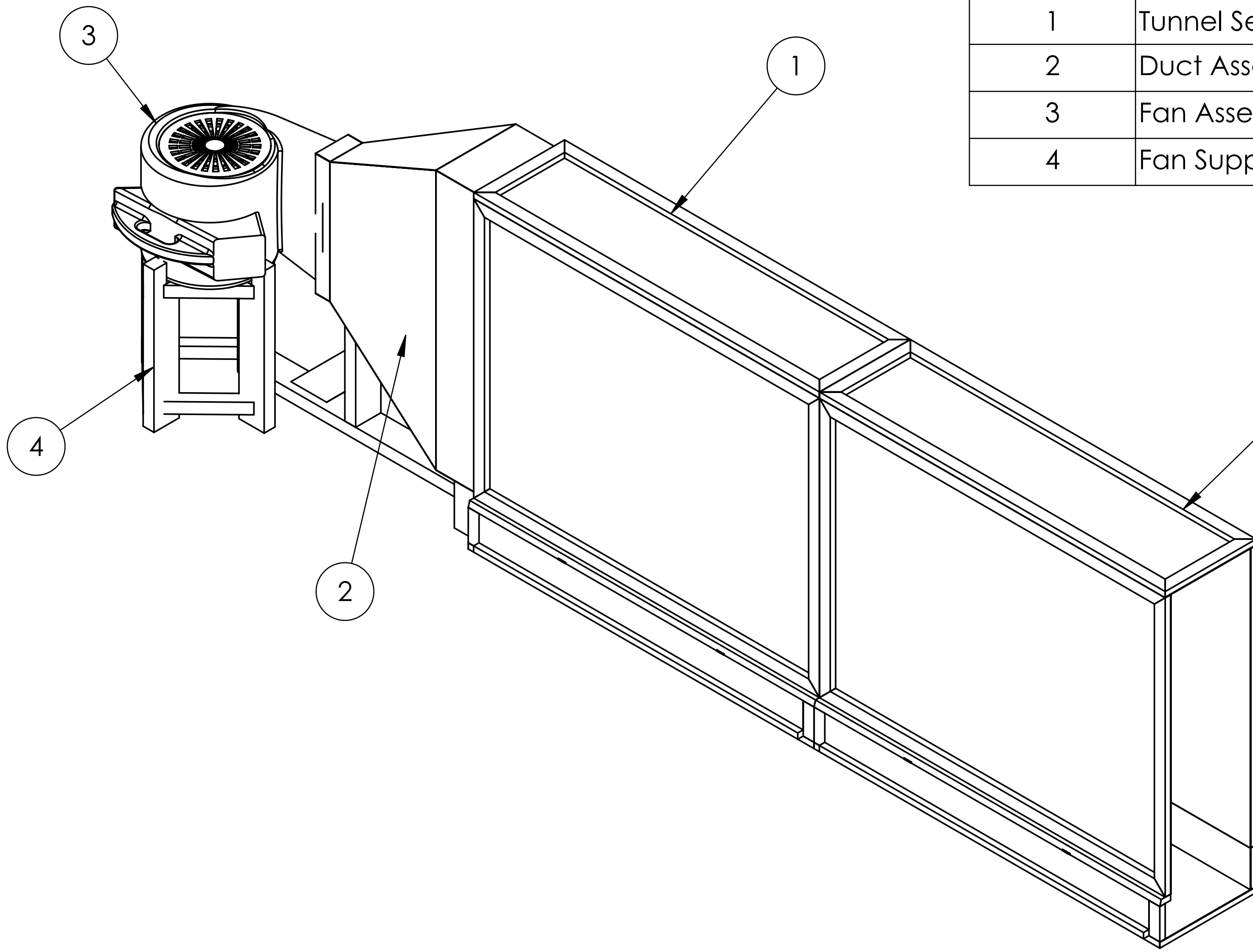
Part	description	Source
4.25 Straight	used for dispersion manifold support	Home Depot
5 half miter	used for dispersion manifold support	Home Depot
12_625	used for dispersion manifold support	Home Depot
13_375	used for dispersion manifold support	Home Depot
36 miter	used for dispersion manifold support	Home Depot
48 miter with notch	Used in top panel assembly, side panel assembly	Home Depot
48 miter	Used in top panel assembly, side panel assembly	Home Depot
48 straight	Used in top panel assembly, side panel assembly	Home Depot
Bottom acrylic	Used in Bottom panel assembly	Professional Plastics
Bottom back acrylic	Used in Bottom panel assembly	Professional Plastics
door face	Used in Bottom panel assembly	Home Depot
fan support front cross	Used for fan support	Home Depot
fan support front vertial	Used for fan support	Home Depot
fan support lower	Used for fan support	Home Depot
fan support manifold vertical	Used for fan support	Home Depot
fan support vertical	Used for fan support	Home Depot
Side Acrylic	Used in side assembly	Professional Plastics
H_Fin 1	Used in dispersion manifold	Home Depot
H_Fin 2	Used in dispersion manifold	Home Depot
H_Fin 3	Used in dispersion manifold	Home Depot
H_Fin 4	Used in dispersion manifold	Home Depot
H_Fin 5	Used in dispersion manifold	Home Depot
V_Fin 1	Used in dispersion manifold	Home Depot
V_Fin 2	Used in dispersion manifold	Home Depot
V_Fin 3	Used in dispersion manifold	Home Depot
V_Fin 4	Used in dispersion manifold	Home Depot
V_Fin 5	Used in dispersion manifold	Home Depot
V_Fin Middle	Used in dispersion manifold	Home Depot
Manifold side	Used in dispersion manifold	Home Depot
Manifold top/bottom	Used in dispersion manifold	Home Depot

13 APPENDIX C – COMPLETE LIST OF ENGINEERING DRAWINGS

Here include a set of engineering drawings for all CAD modelled and downloaded parts (e.g from McMaster). You can insert a zip file of your CAD models or include pictures of the drawings.



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Seed Cross-Breeze Tester Prototype
Scale : 1:15	Material:

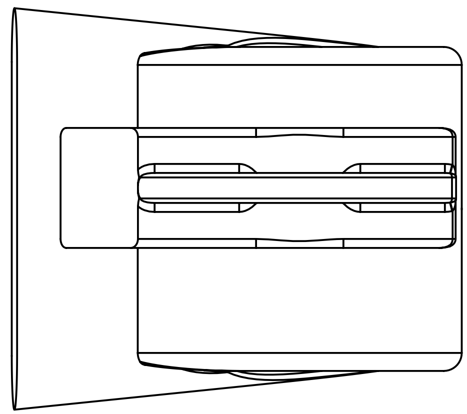


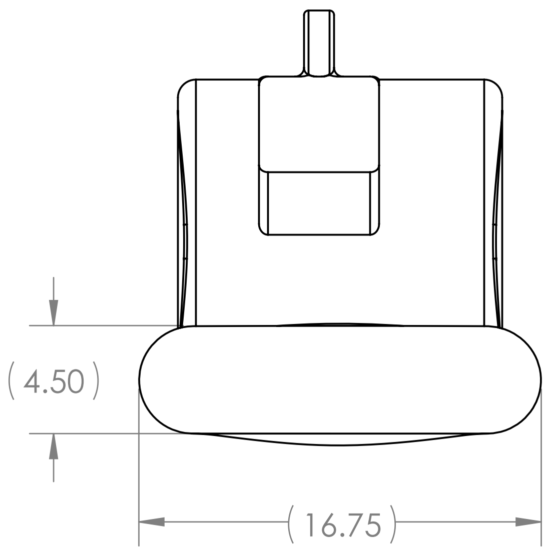
ITEM NO.	PART NUMBER	QTY.
1	Tunnel Section	2
2	Duct Assembly 2	1
3	Fan Assembly	1
4	Fan Support Frame	1

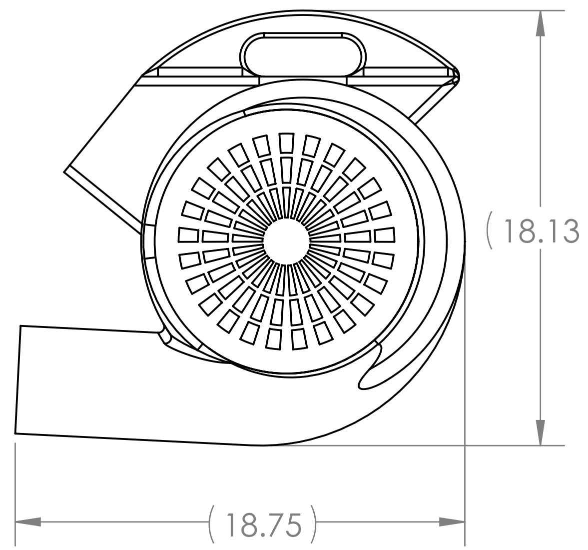
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Wind Tunnel - Upper Level Assembly
Scale : 1:32	Material: See individual Part Drawings

NOTE:
This item is a purchase part. DImensions are shown for reference only.

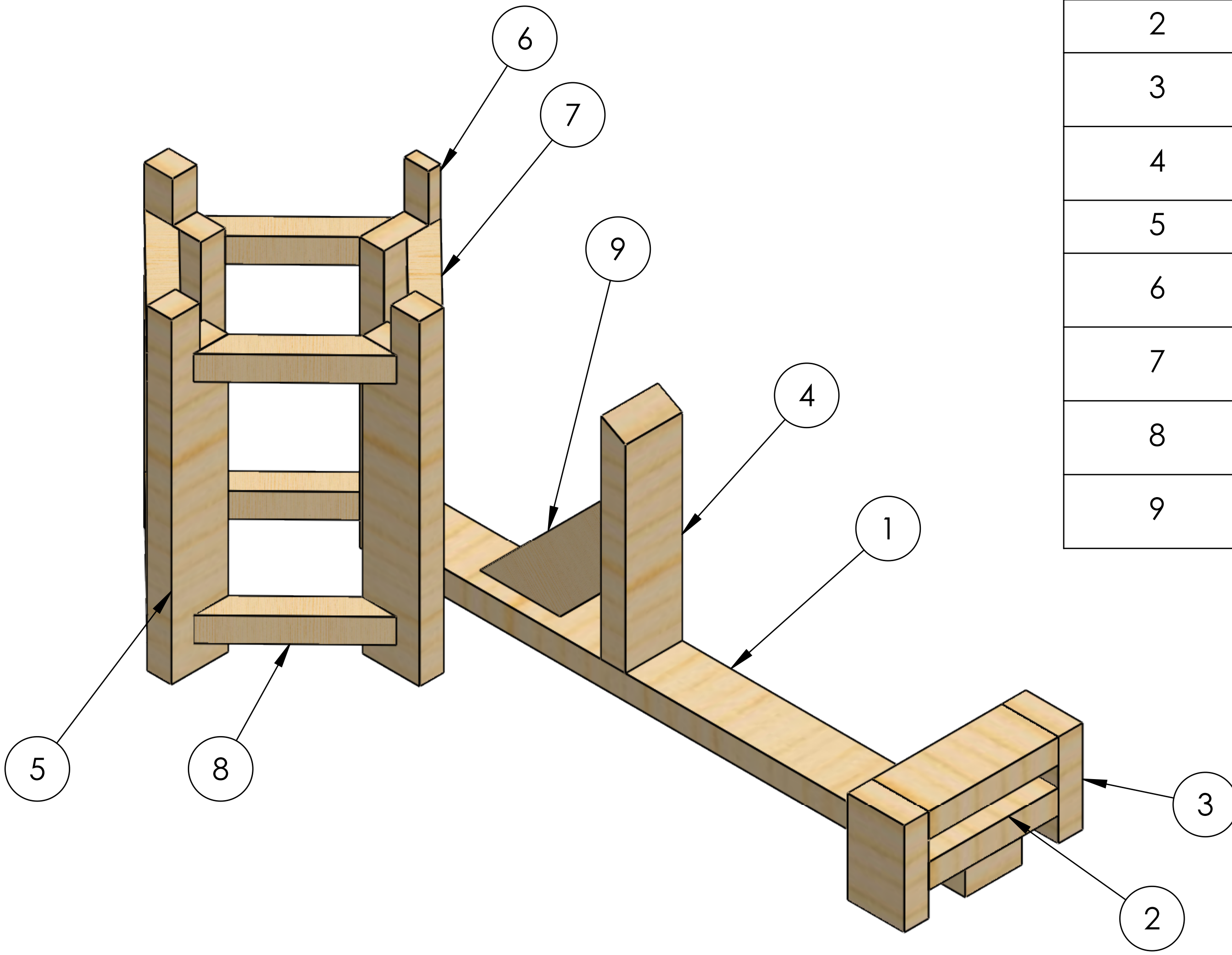
Manufacturer: Air Foxx
Model Nubmer: AM4000a





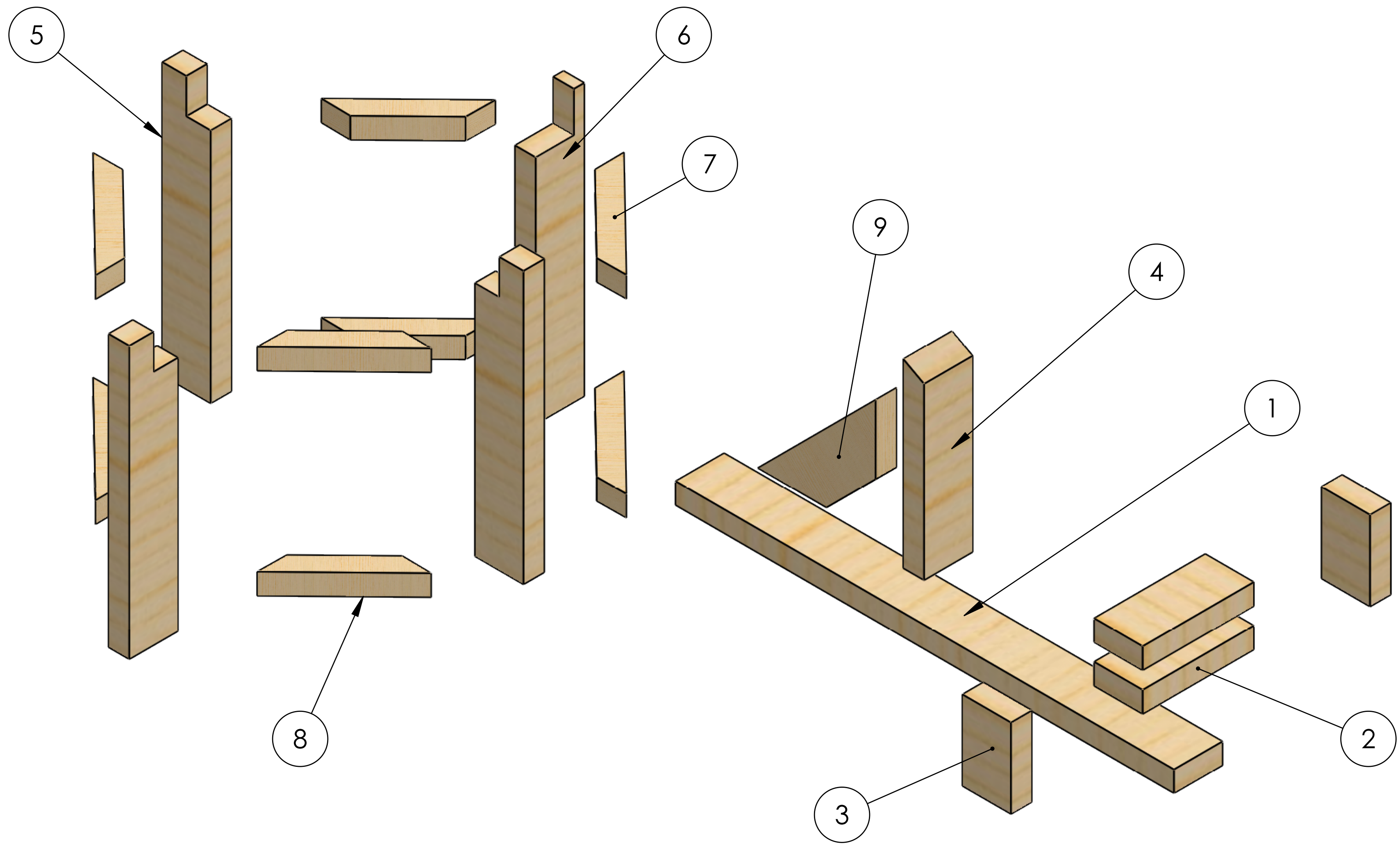


UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Fan Assembly
Scale : 1:8	Material: See manufacturer's documentation



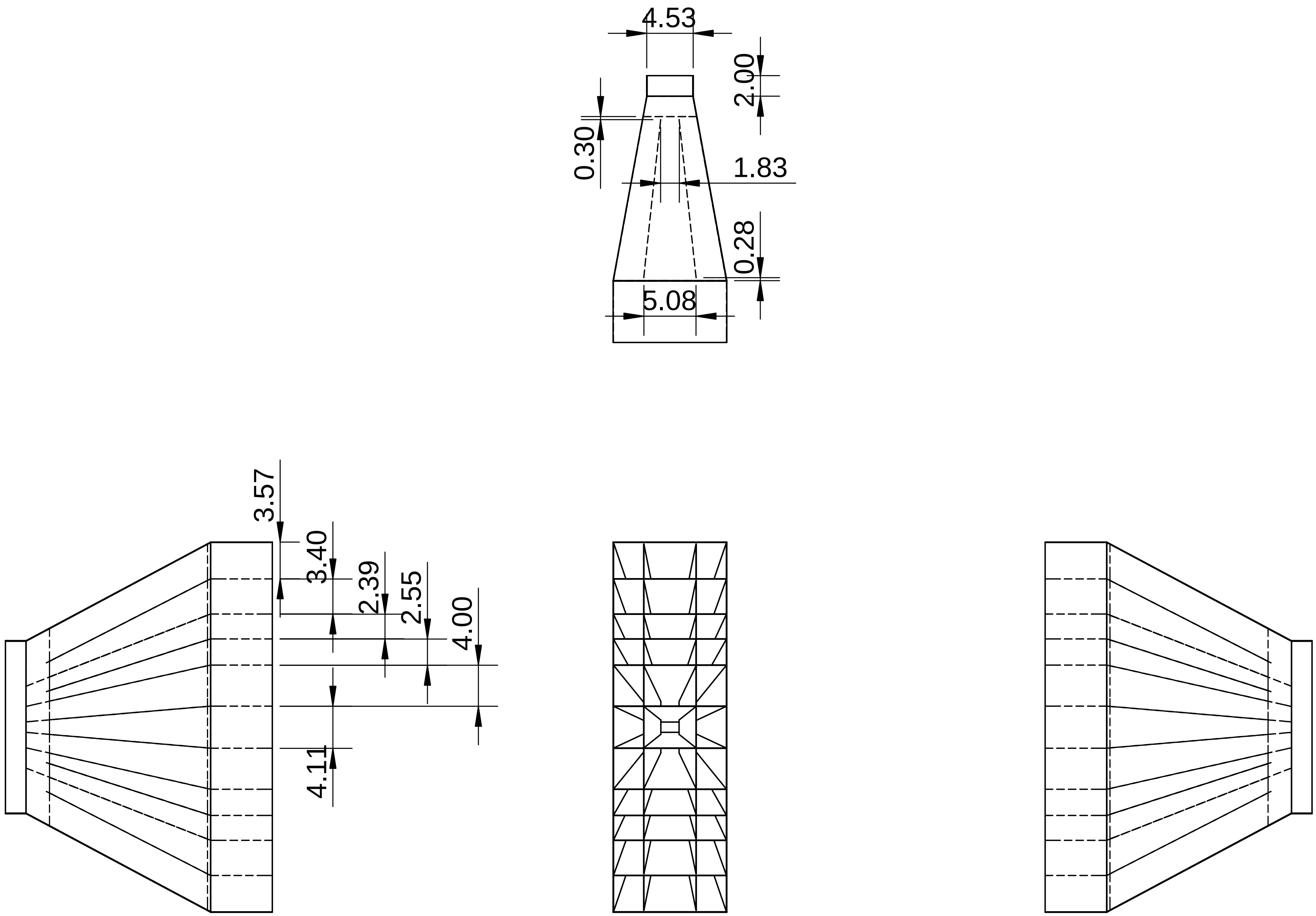
ITEM NO.	PART NUMBER	QTY.
1	fan support lower	1
2	fan support front cross	2
3	fan support front vertical	2
4	Fan support manifold vertical	1
5	fan support vertical	3
6	fan support vertical alternate	1
7	Fan long support brace	4
8	Fan short support brace	4
9	Manifold Support Brace	1

UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Fan Support Frame
Scale : 1:8	Material: See individual Part Files



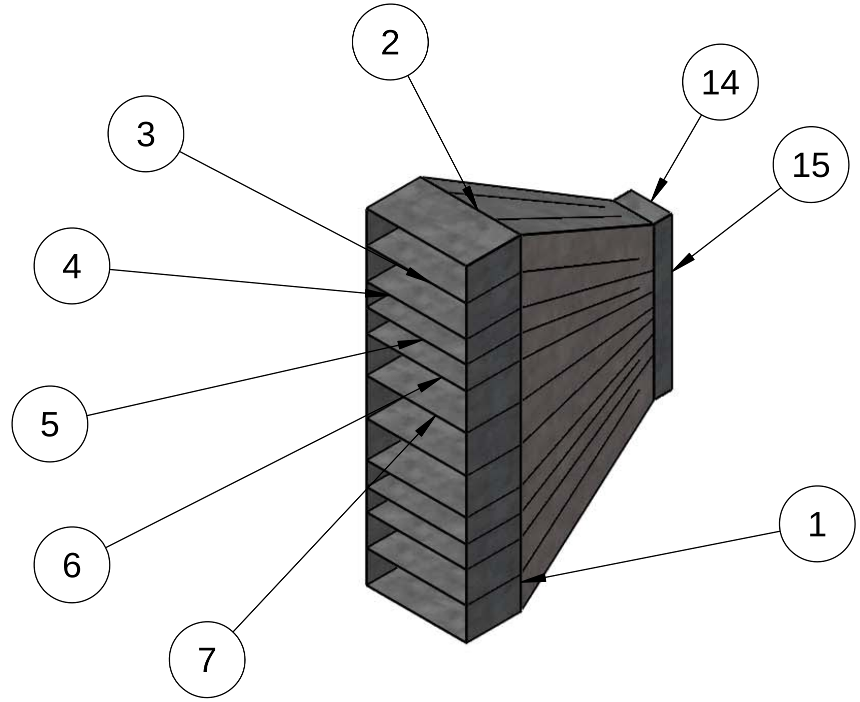
SOLIDWORKS Educational Product. For Instructional Use Only

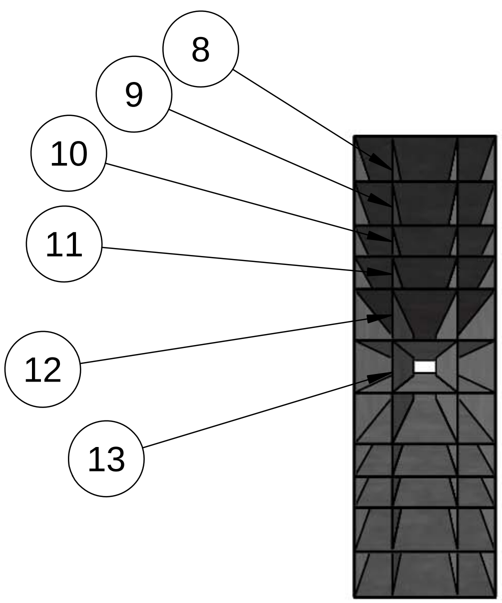
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Fan Support Frame
Scale : 1:8	Material: See individual Part Files



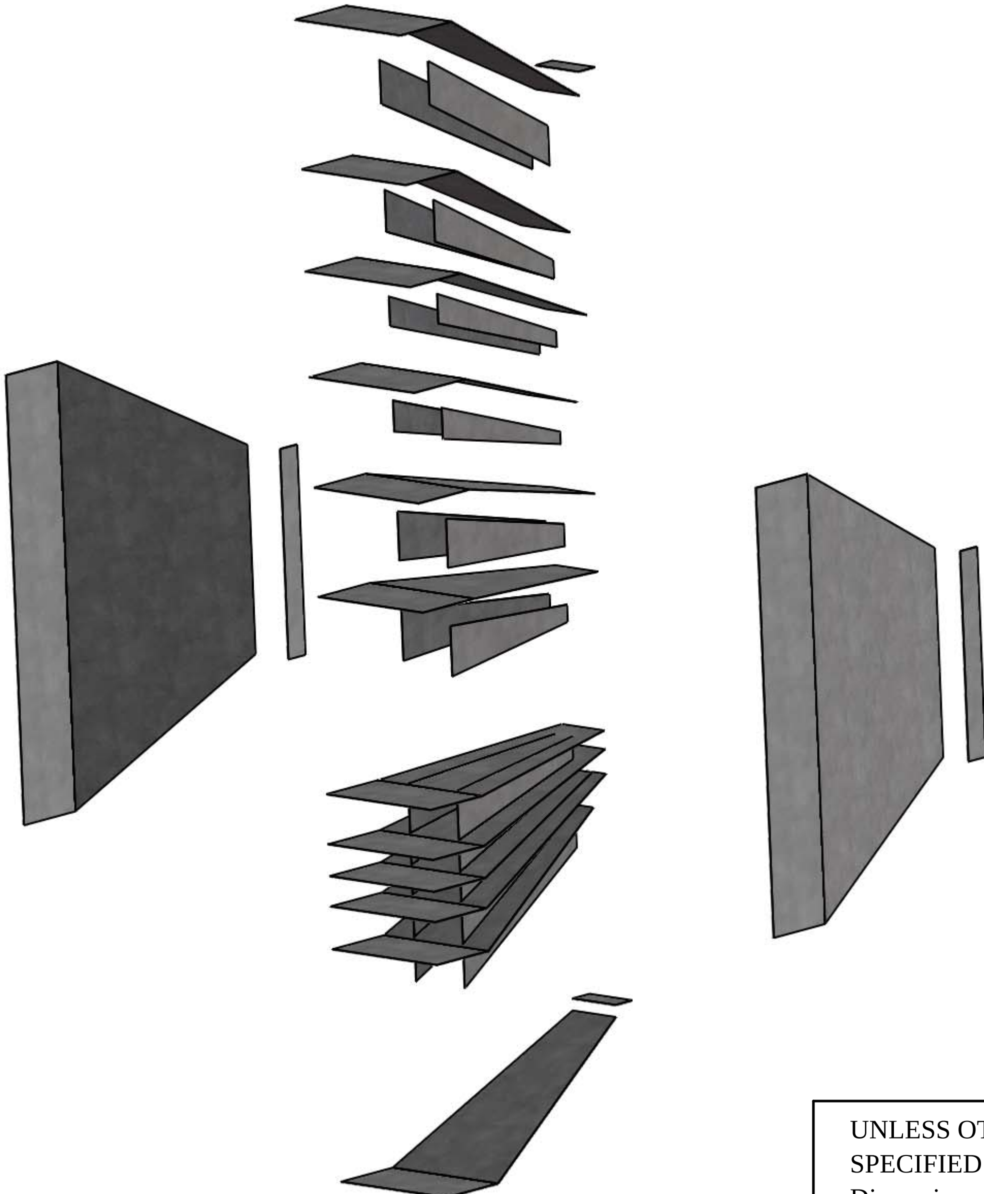
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Dispersion Manifold
Scale : 1:15	Material: See individual part files

Item	Part	Description	QTY.
1	Shell T/B	Outer Shell	2
2	Shell L/R	Outer Shell	2
3	H_Fin 1	Horizontal Fin	2
4	H_Fin 2	Horizontal Fin	2
5	H_Fin 3	Horizontal Fin	2
6	H_Fin 4	Horizontal Fin	2
7	H_Fin 5	Horizontal Fin	2
8	V_Fin 1	Vertical Fin	4
9	V_Fin 2	Vertical Fin	4
10	V_Fin 3	Vertical Fin	4
11	V_Fin 4	Vertical Fin	4
12	V_Fin 5	Vertical Fin	4
13	V_Fin Middle	Vertical Fin	2
14	IB_Top	Inlet Box	2
15	IB_Side	Inlet Box	2



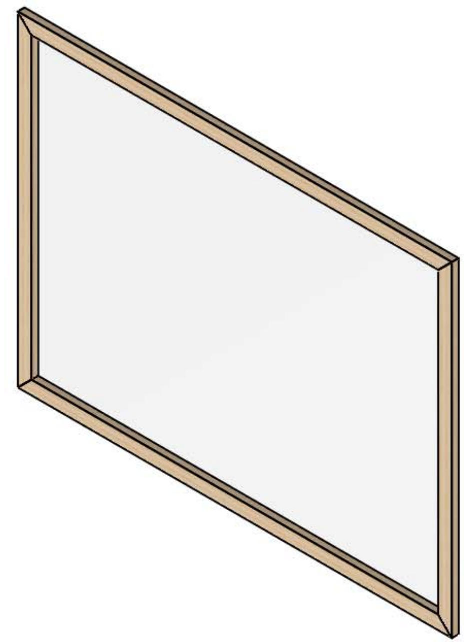


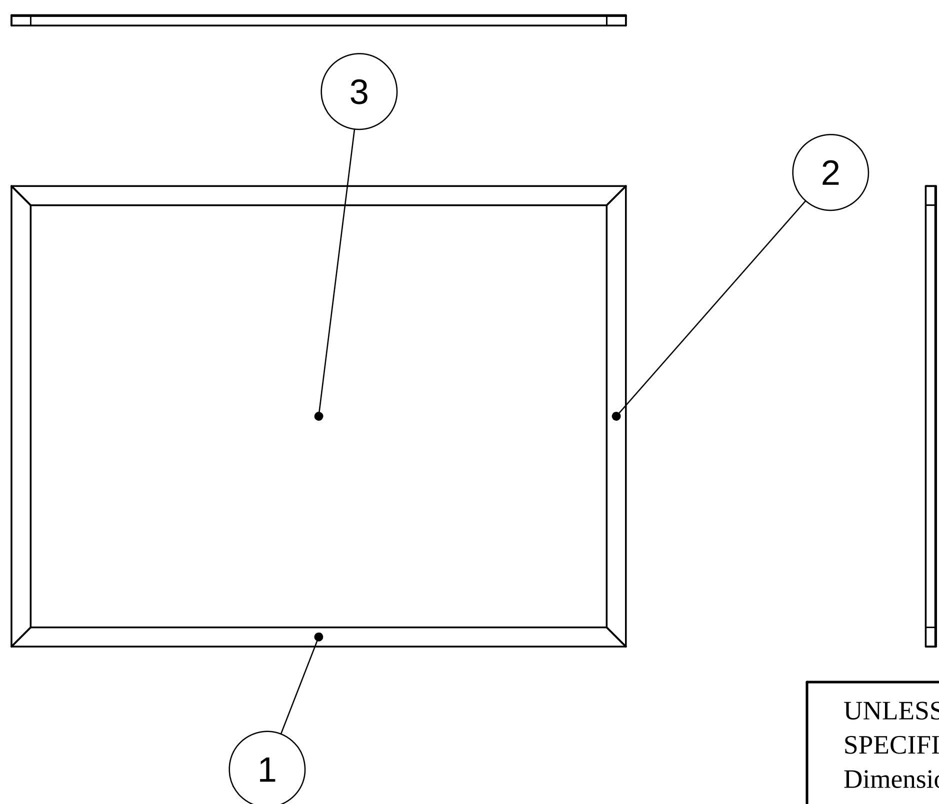
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Dispersion Manifold
Scale :1:15	Material: See individual part files



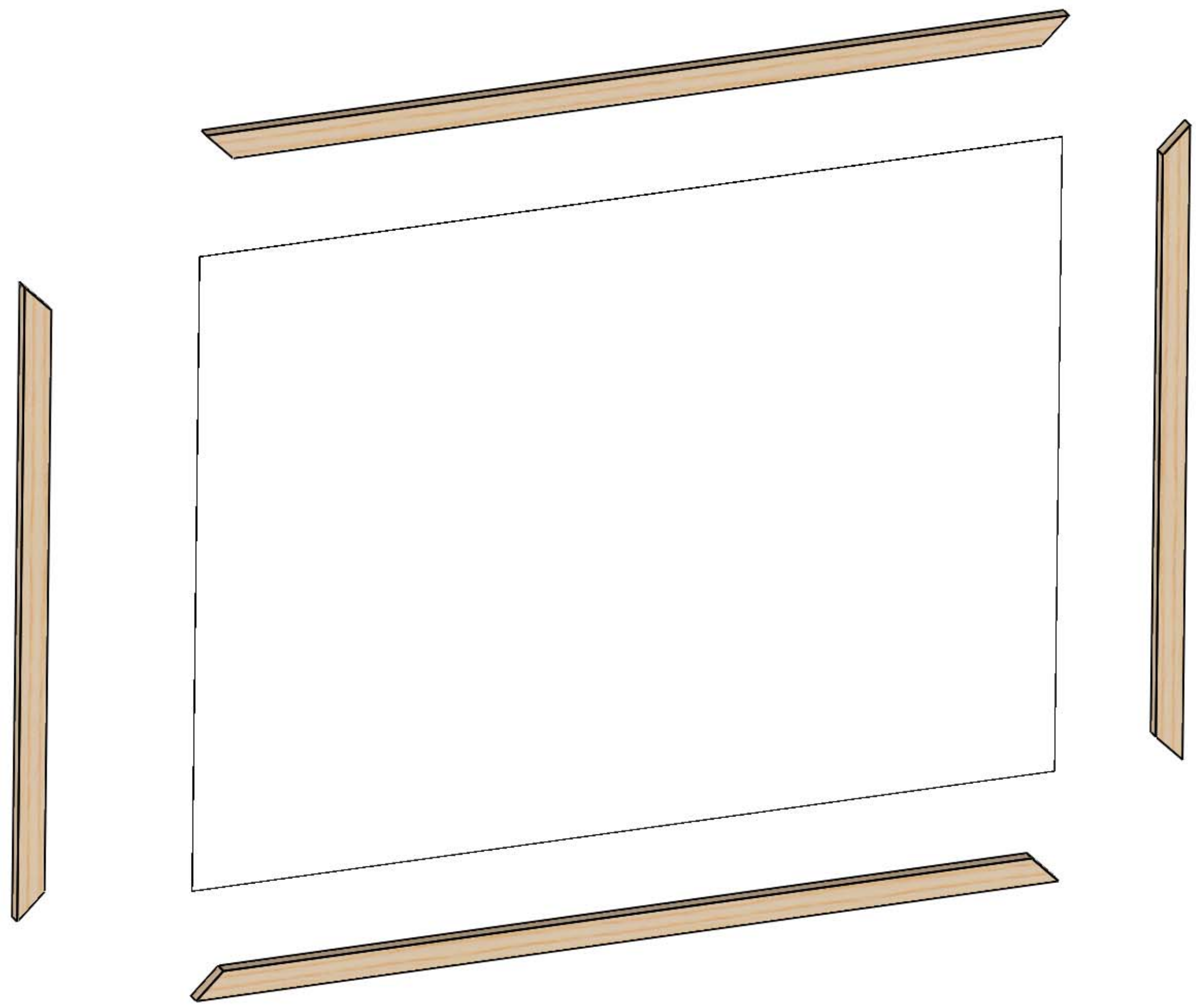
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Dispersion Manifold
Scale : 1:15	Material: see individual part files

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	48 miter		2
2	36 miter		2
3	Side Acrylic		1



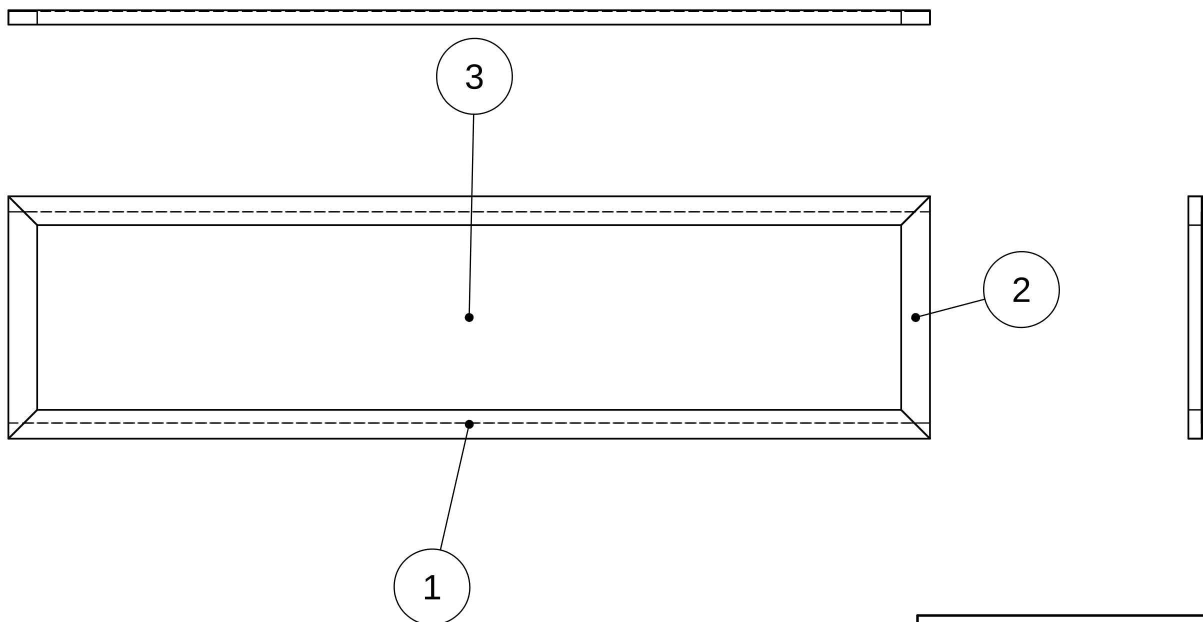


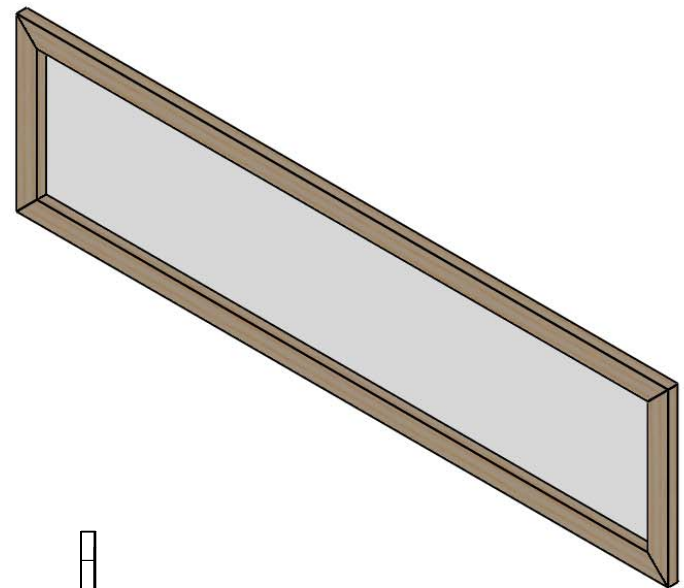
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Side Panel Assembly
Scale :1:15	Material:



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Side Pannel Assembly
Scale : 1:10	Material:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	48 miter with notch		2
2	12_625 miter		2
3	Top Acrylic		1



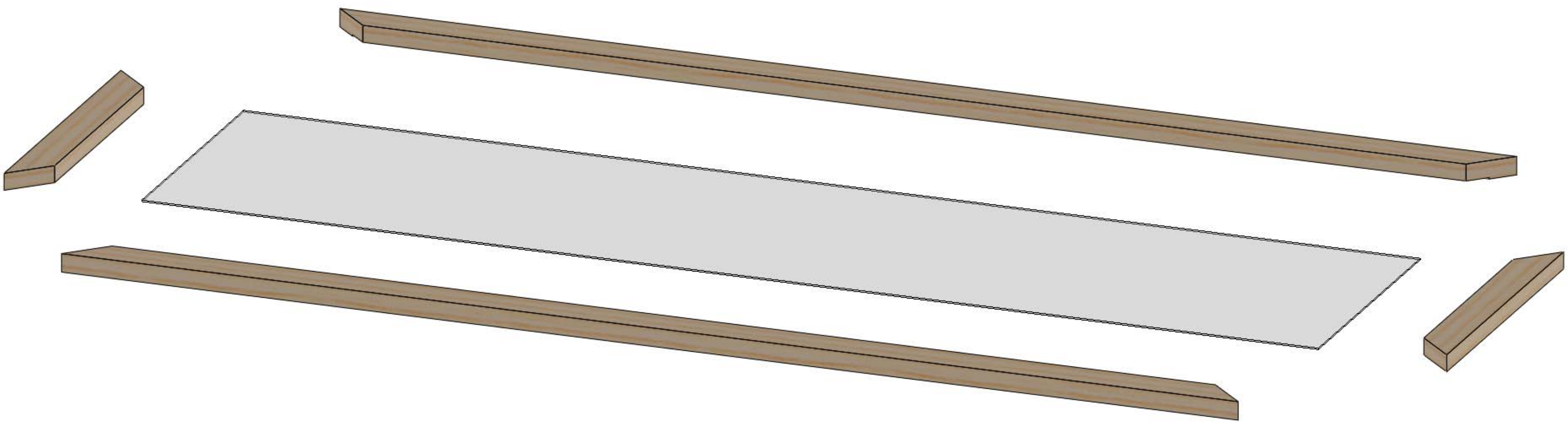


UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

Part: Top Panel Assembly

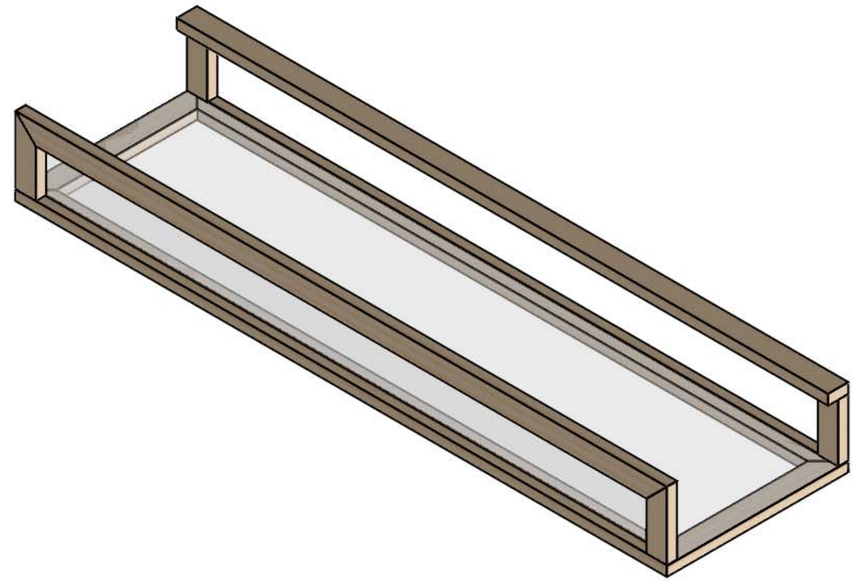
Scale :1:10

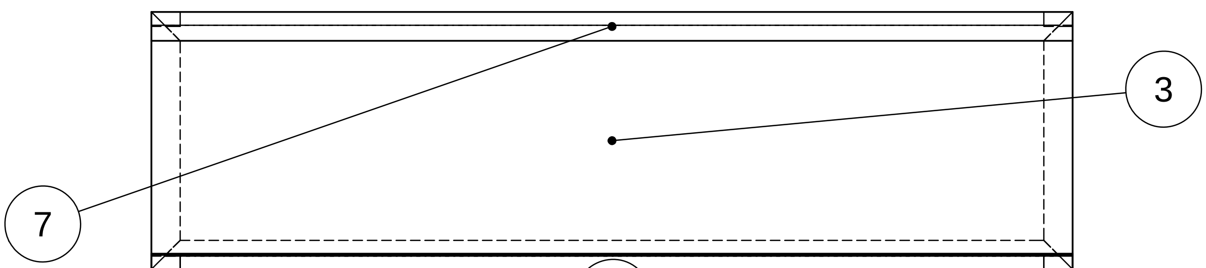
Material:

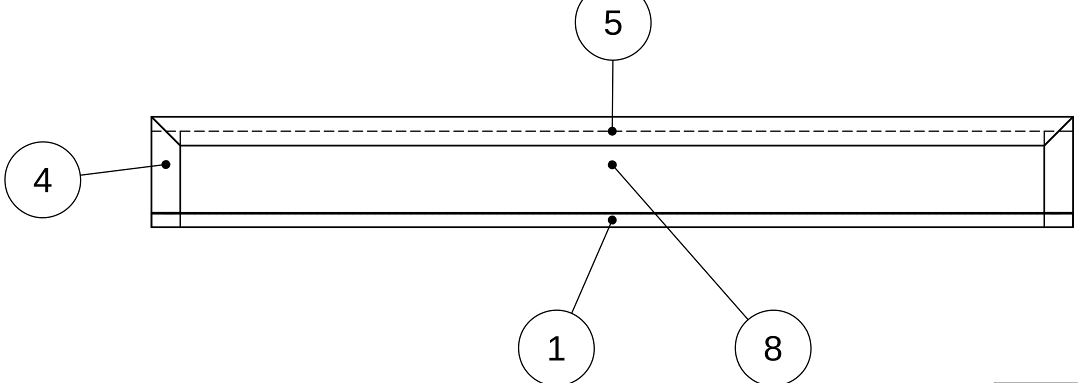


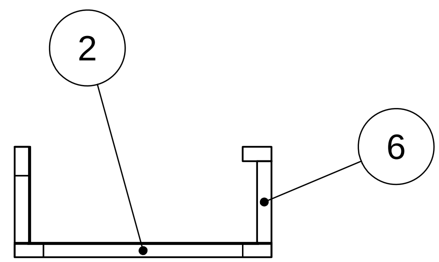
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Top Panel Assembly
Scale :1:6	Material:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	48 miter with notch bottom panel		2
2	13_375 miter		2
3	Bottom Acrylic		1
4	5 half miter		2
5	48 miter		1
6	4.25 striaght		2
7	48 straight		1
8	Bottom Back Acrylic		1

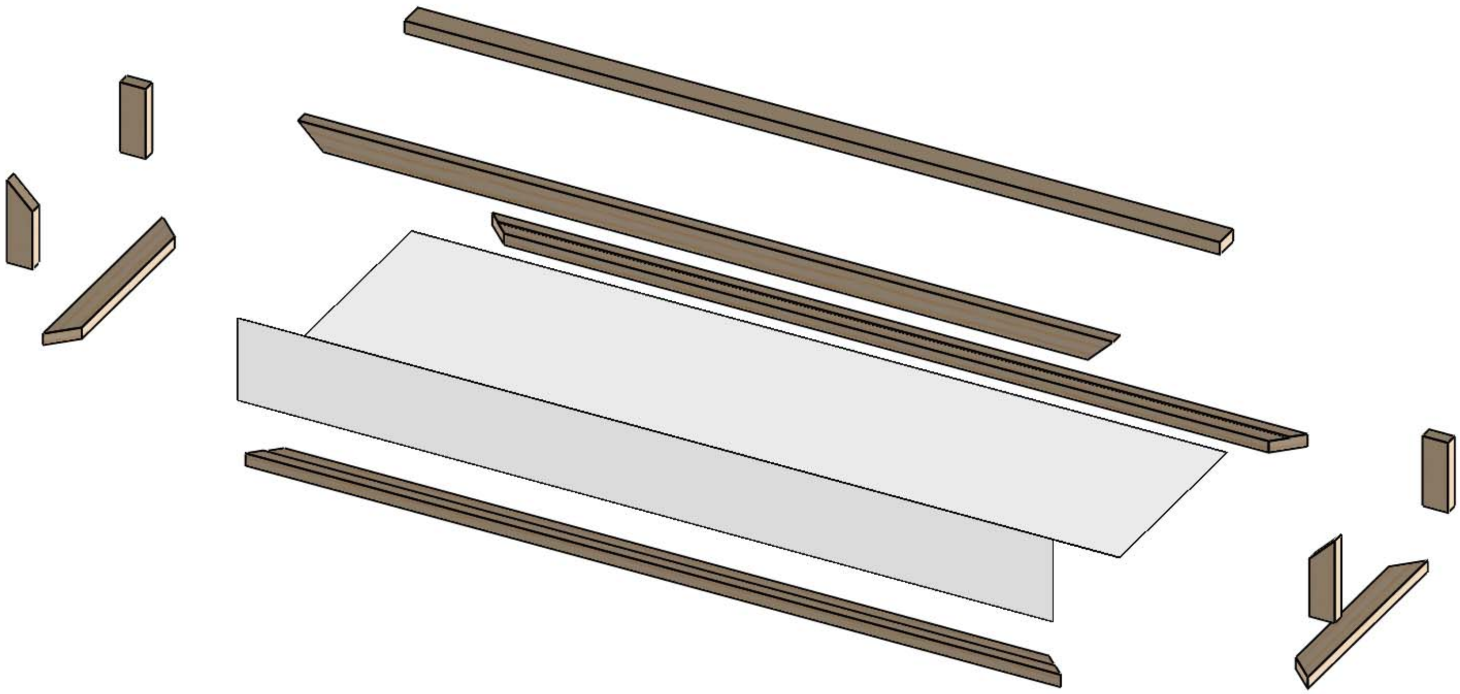




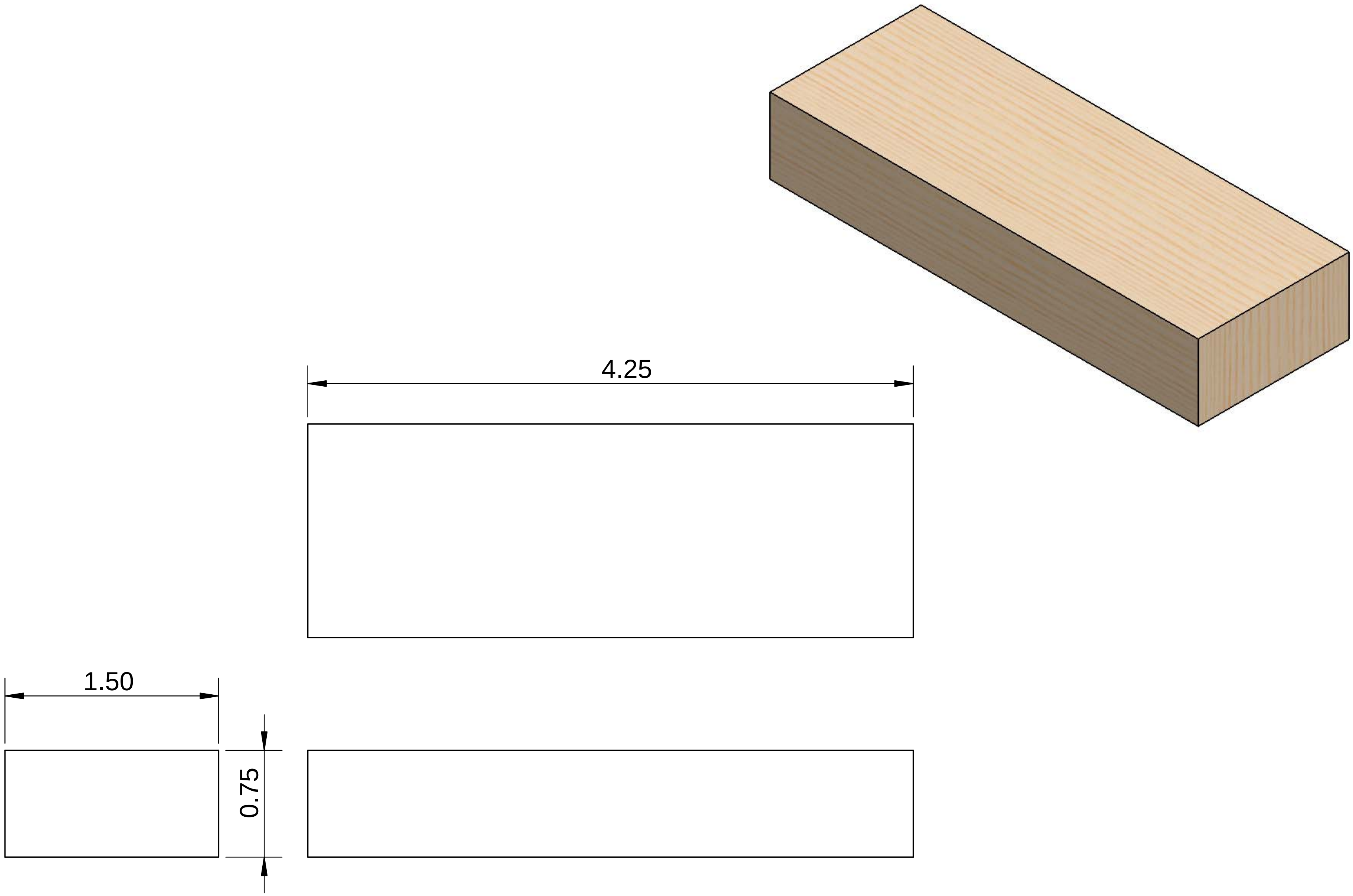




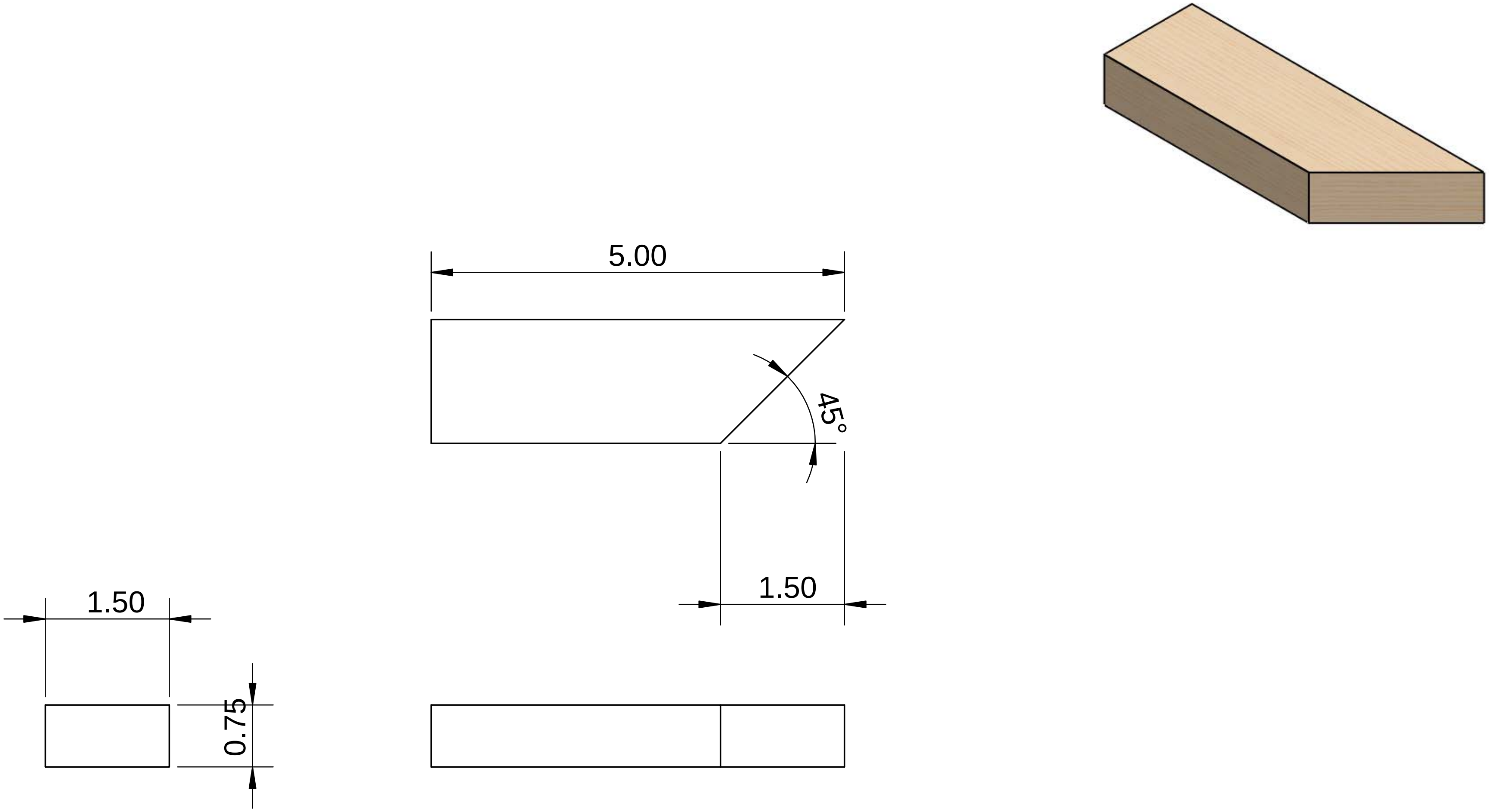
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Bottom Bin Holder Frame
Scale :1:10	Material:



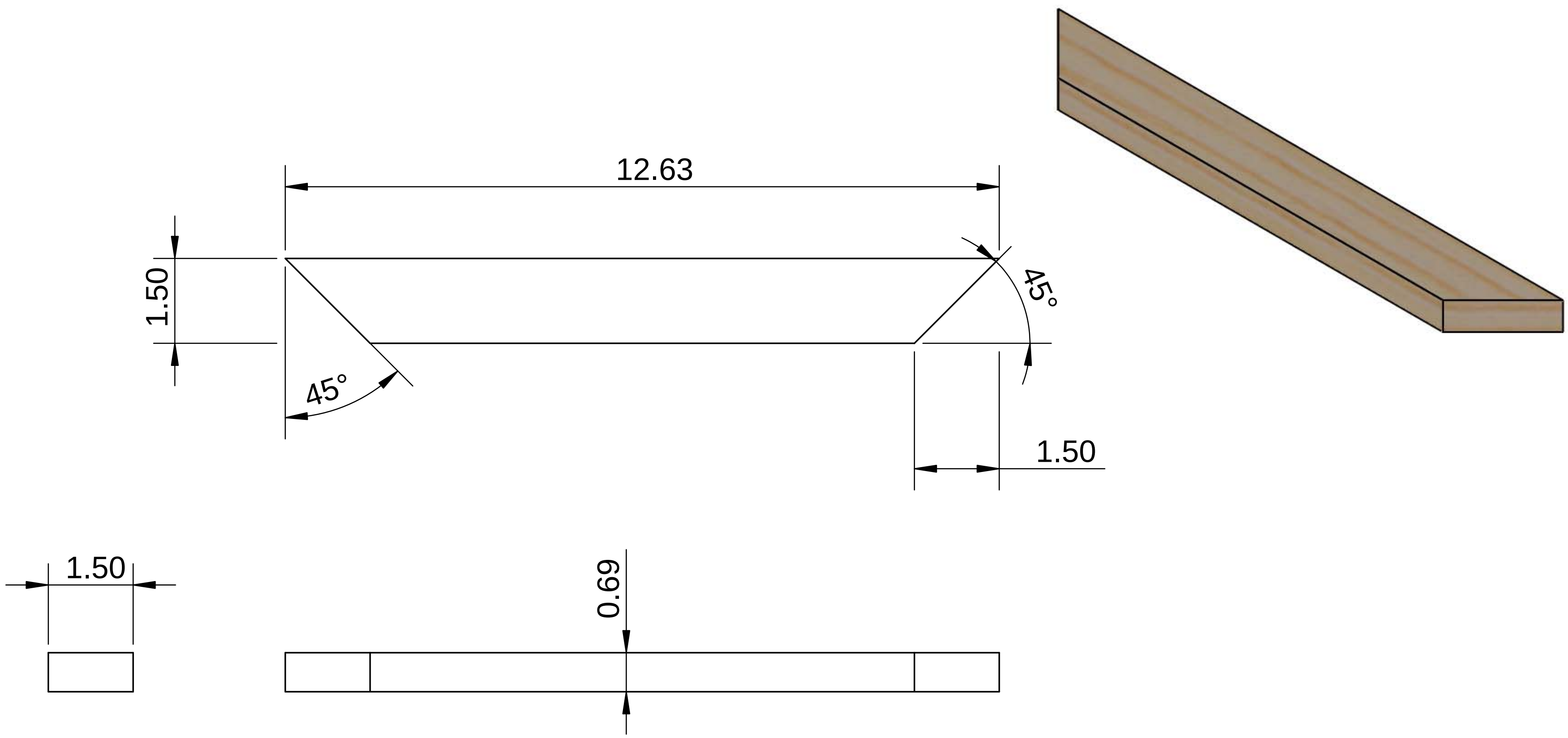
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Bottom Bin Holder Frame
Scale :1:10	Material:



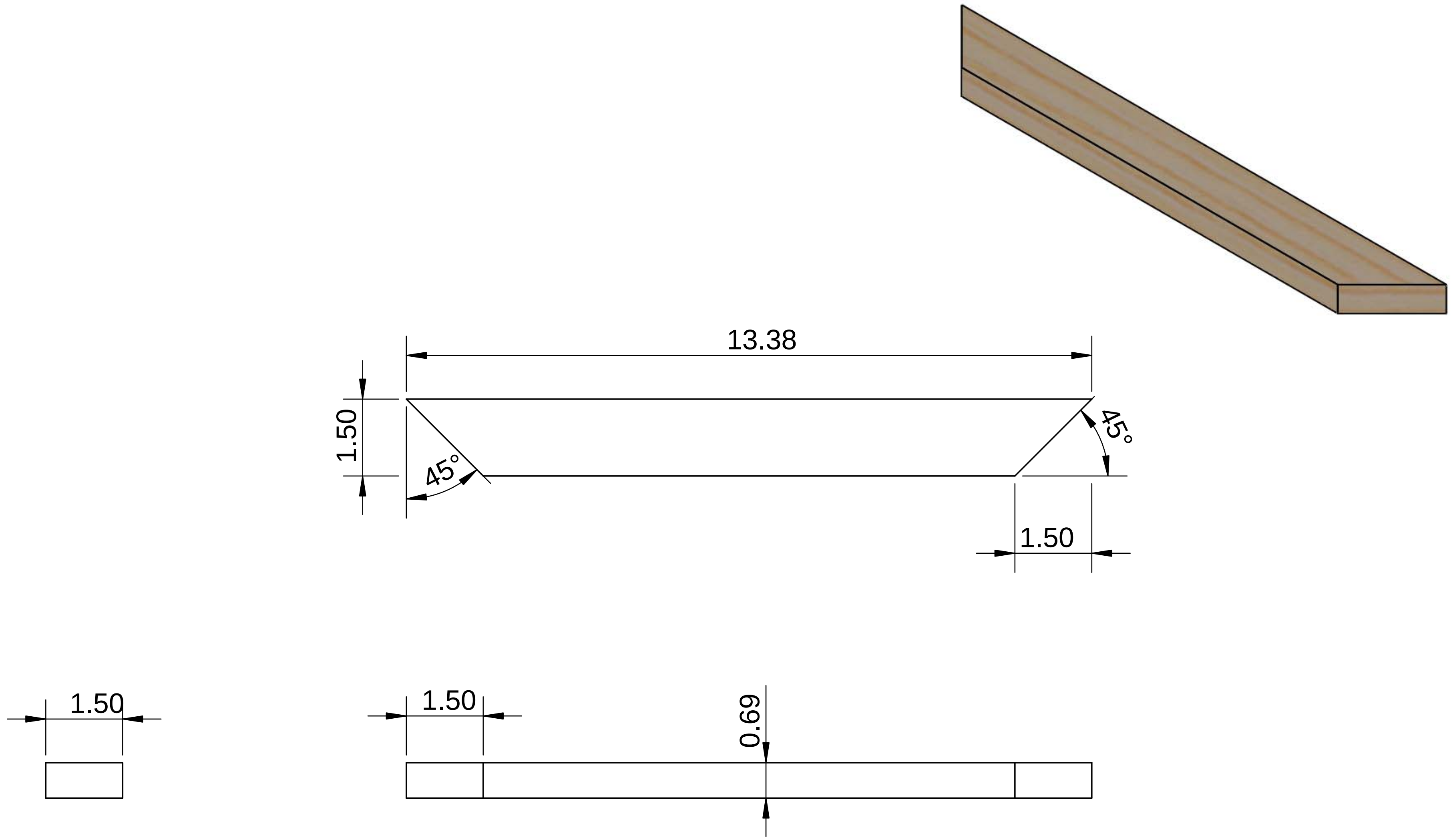
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 4.25 Straight
Scale :1:1	Material: Wood



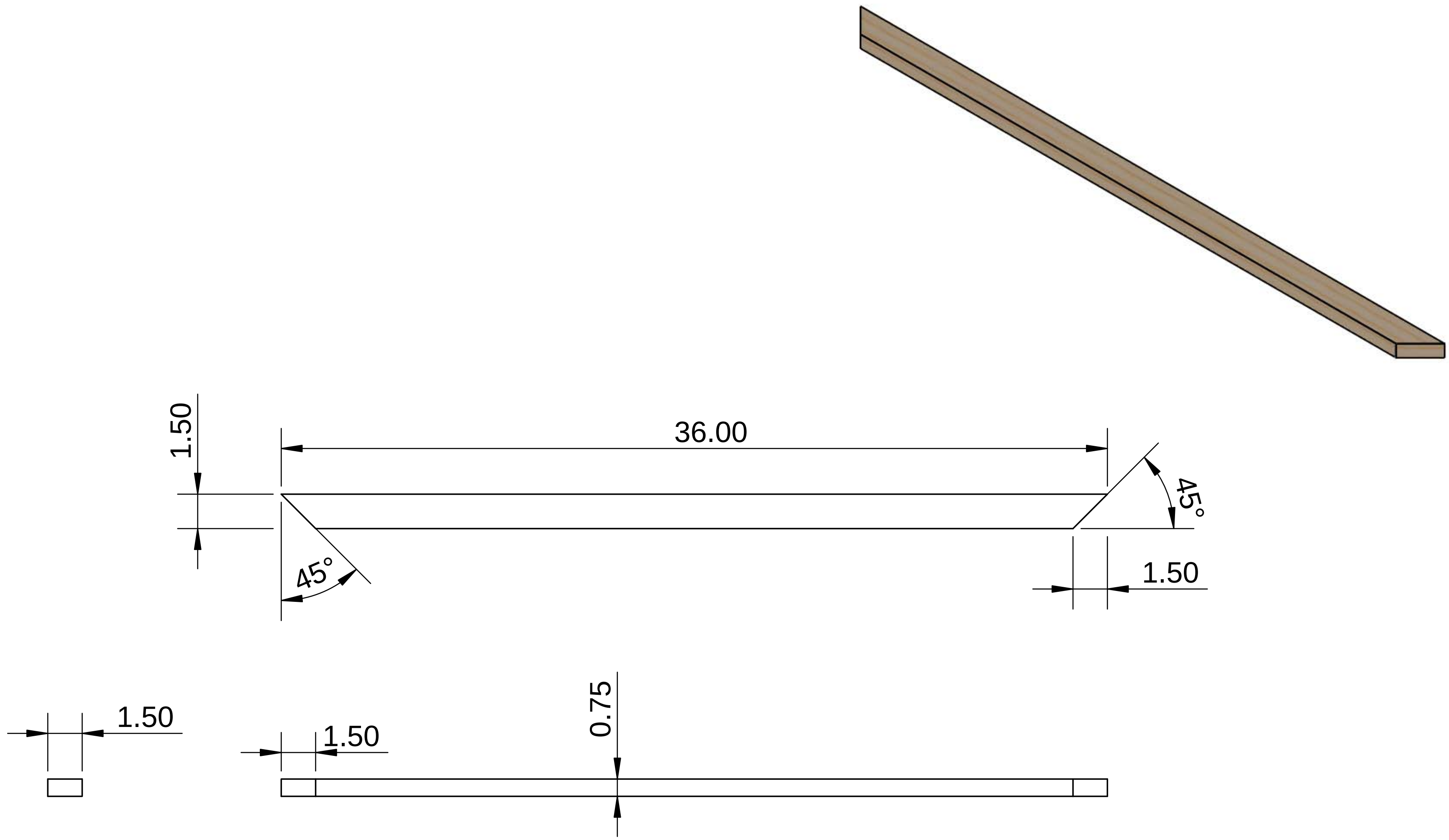
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 5 half miter
Scale :1:2	Material: wood



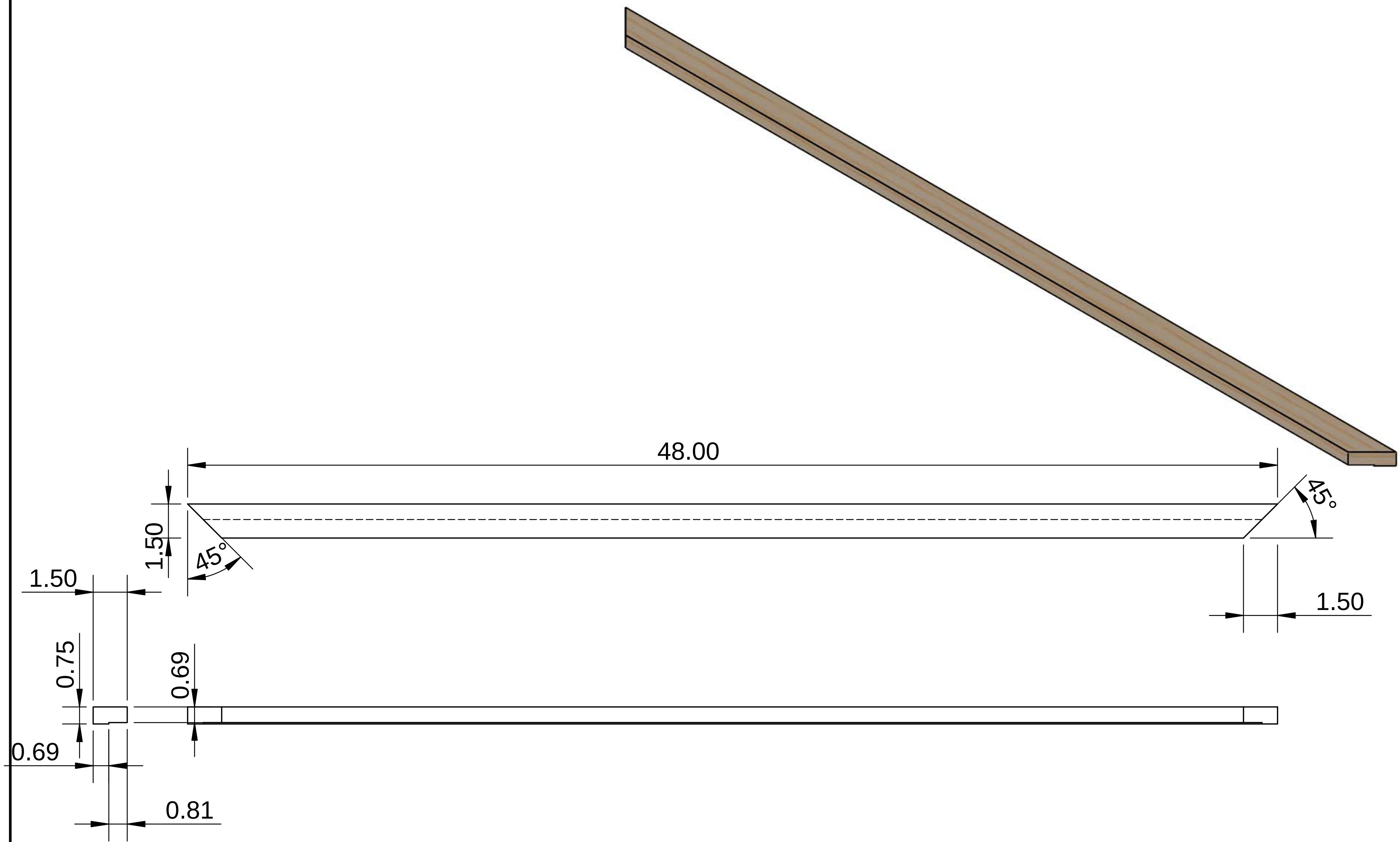
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 12_625 miter
Scale :1:3	Material: Wood



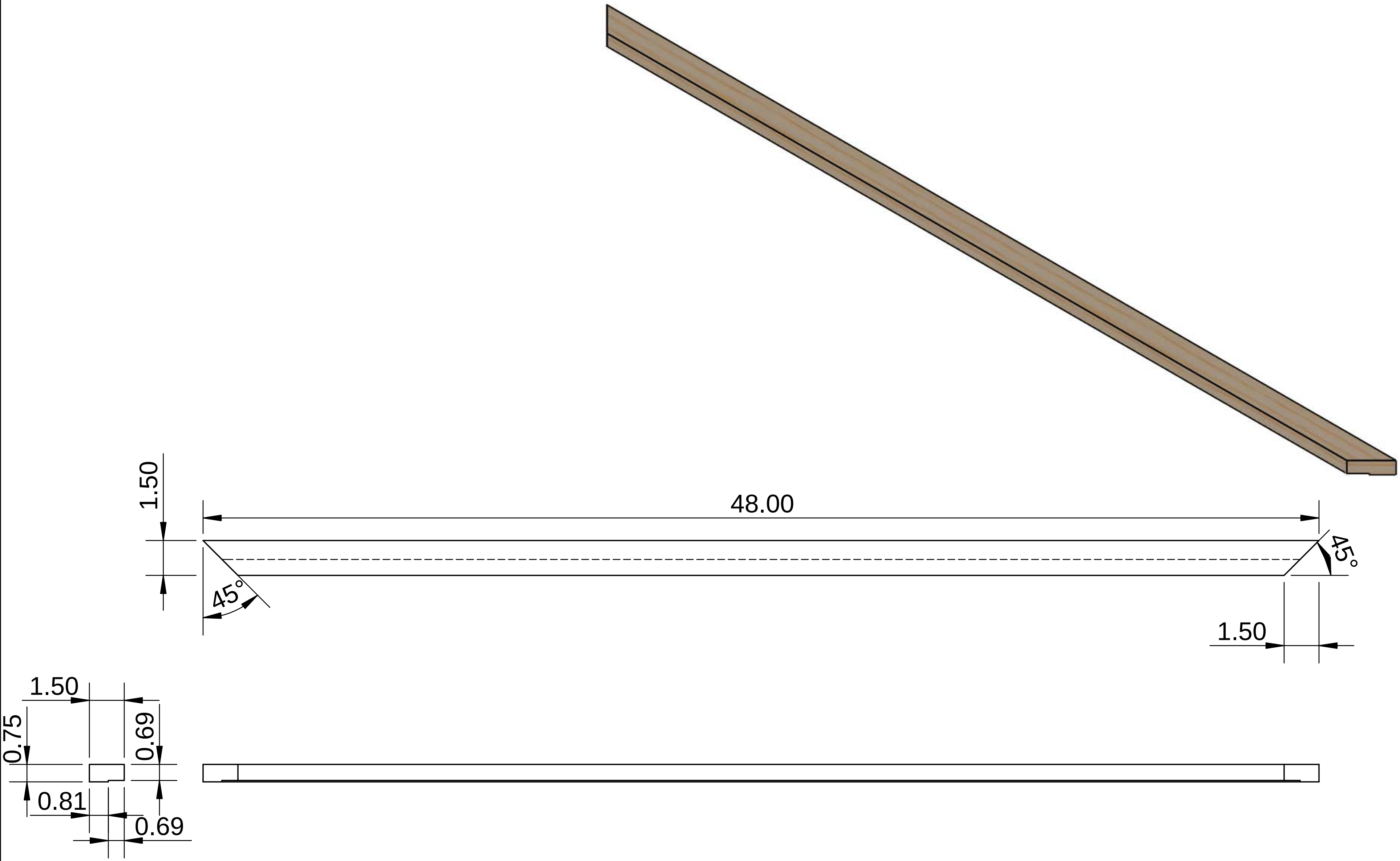
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 13_375 miter
Scale :1:3	Material: wood



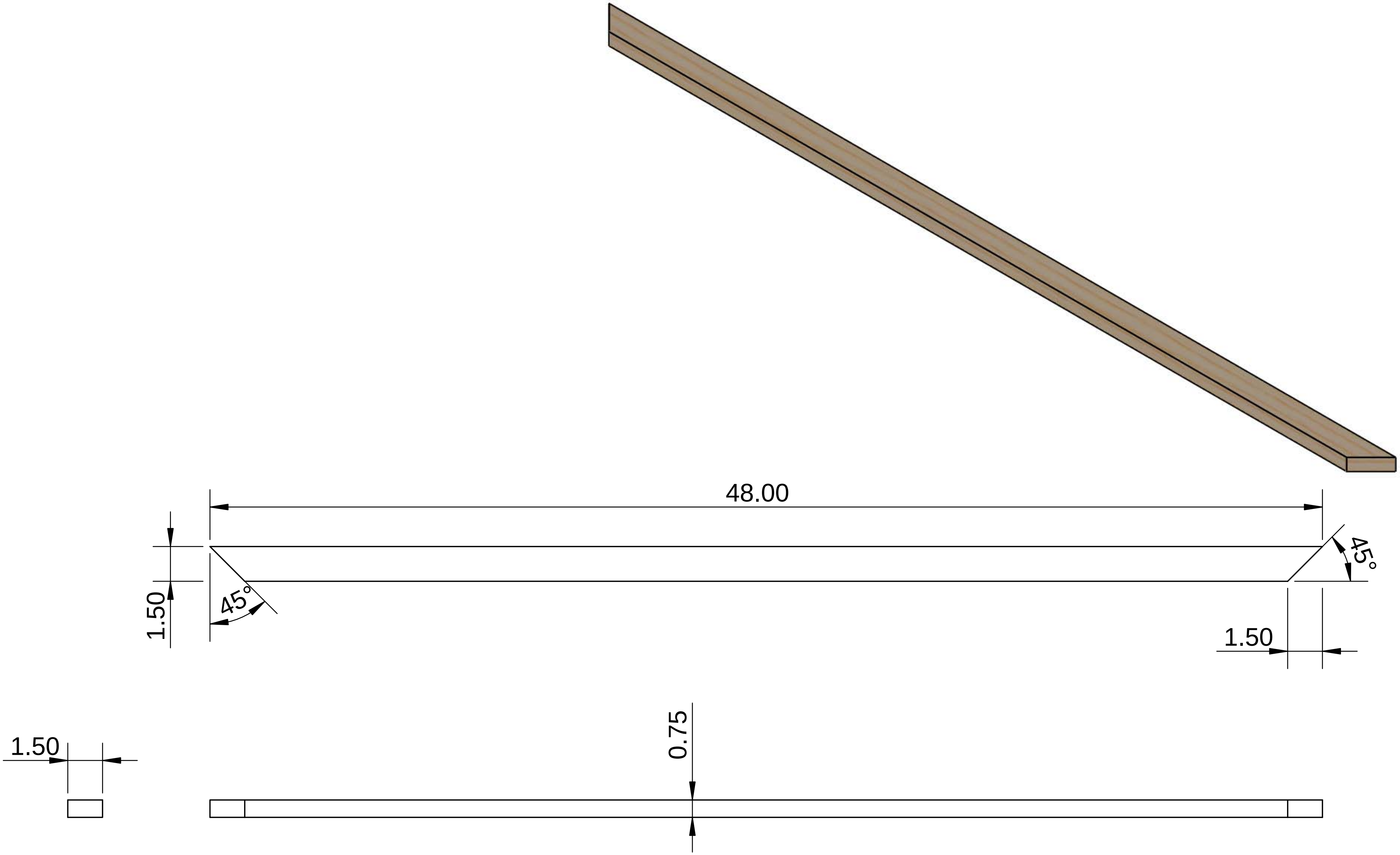
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 36 miter
Scale :1:7	Material: wood



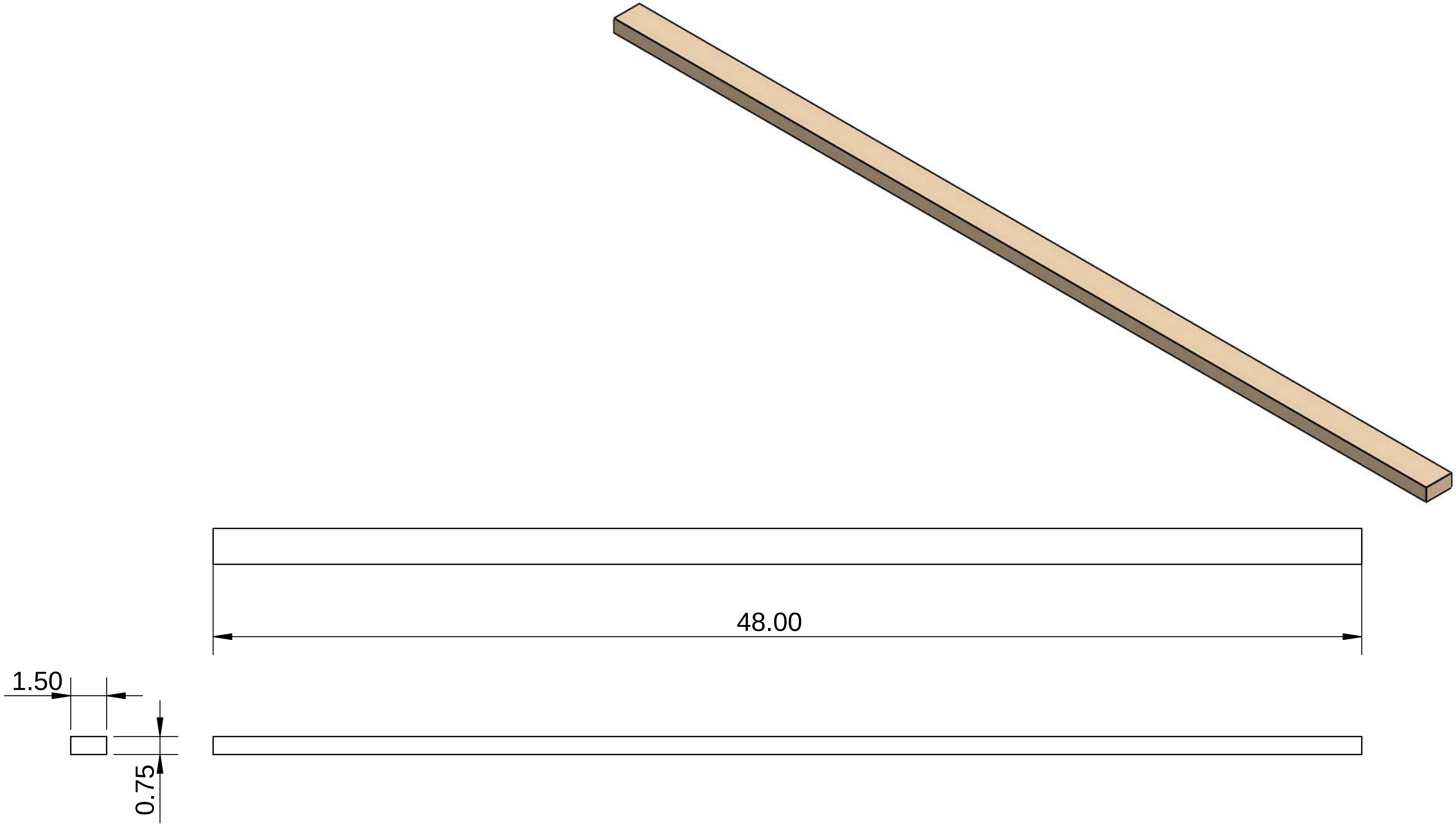
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 48 miter with notch bottom panel
Scale :1:6	Material: wood



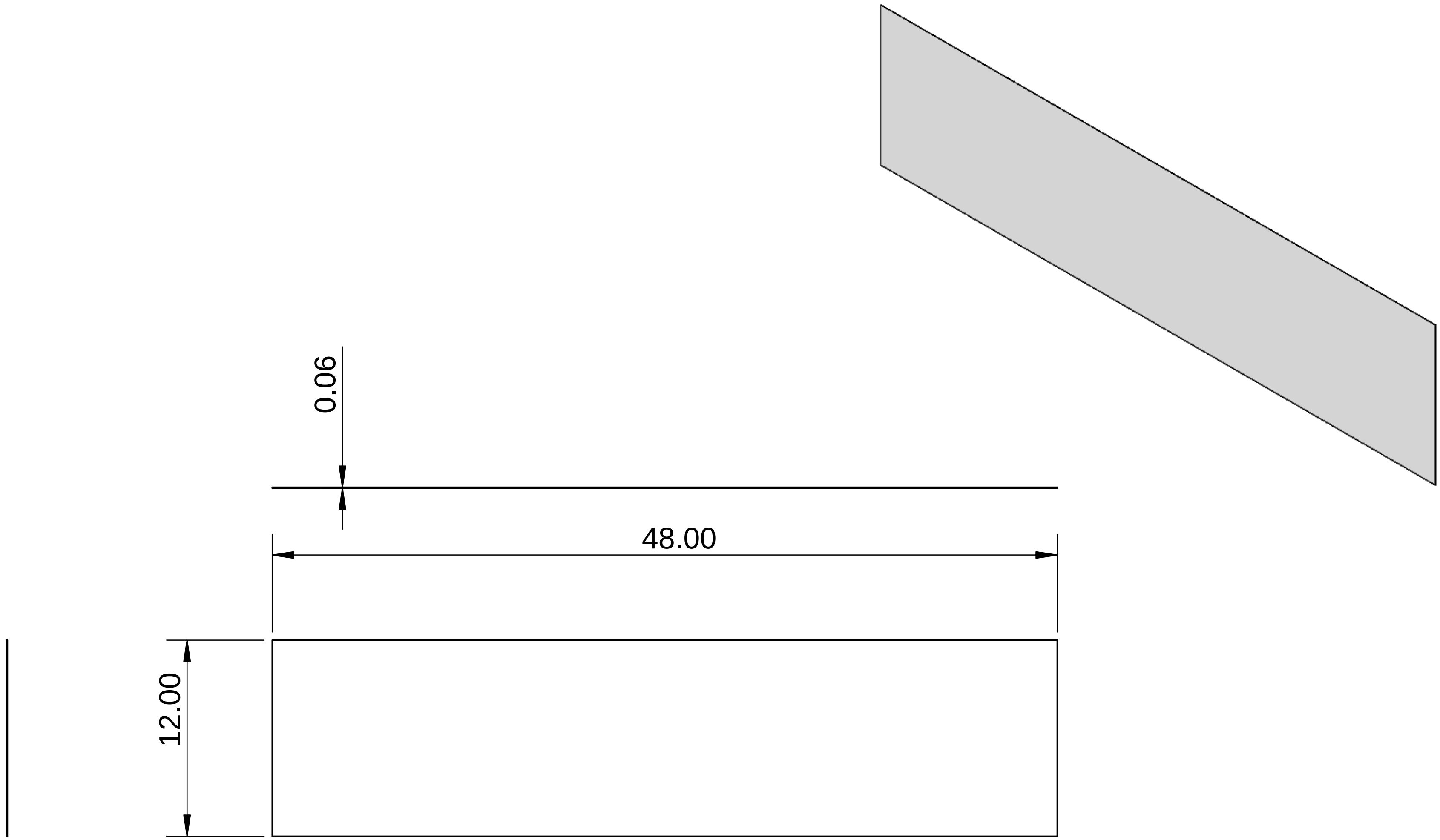
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 48 miter with notch
Scale :1:6	Material: wood



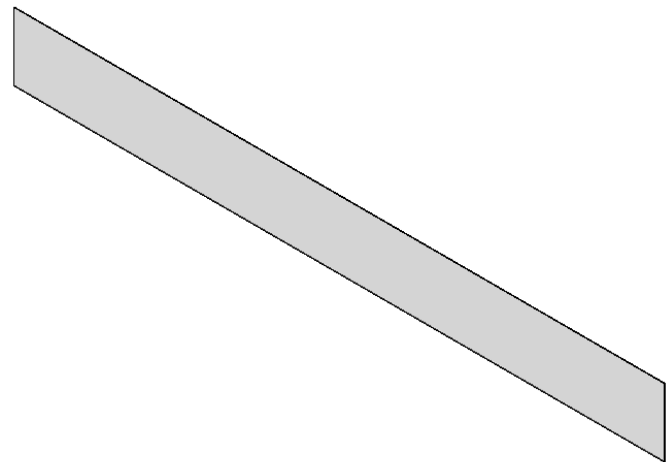
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 48 miter
Scale :1:6	Material: wood

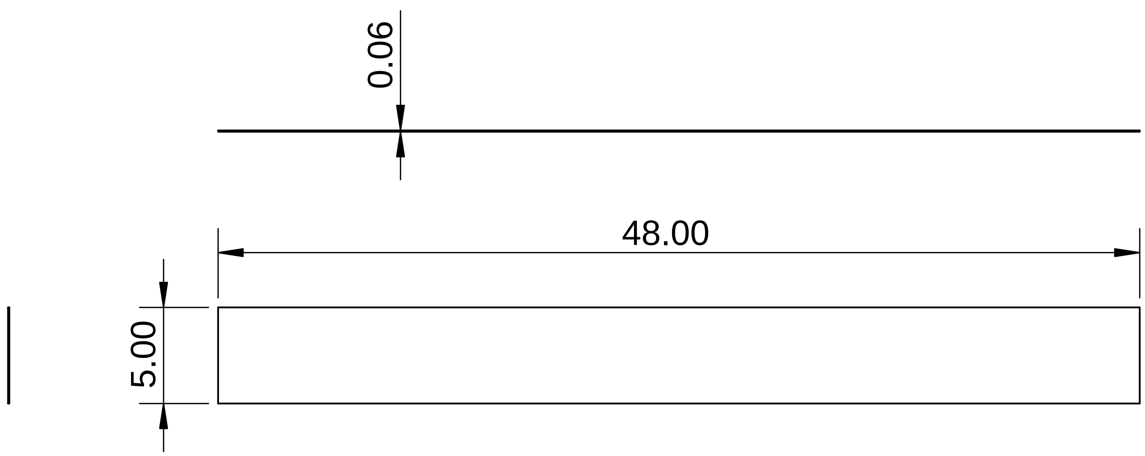


UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: 48 miter
Scale :1:6	Material: wood

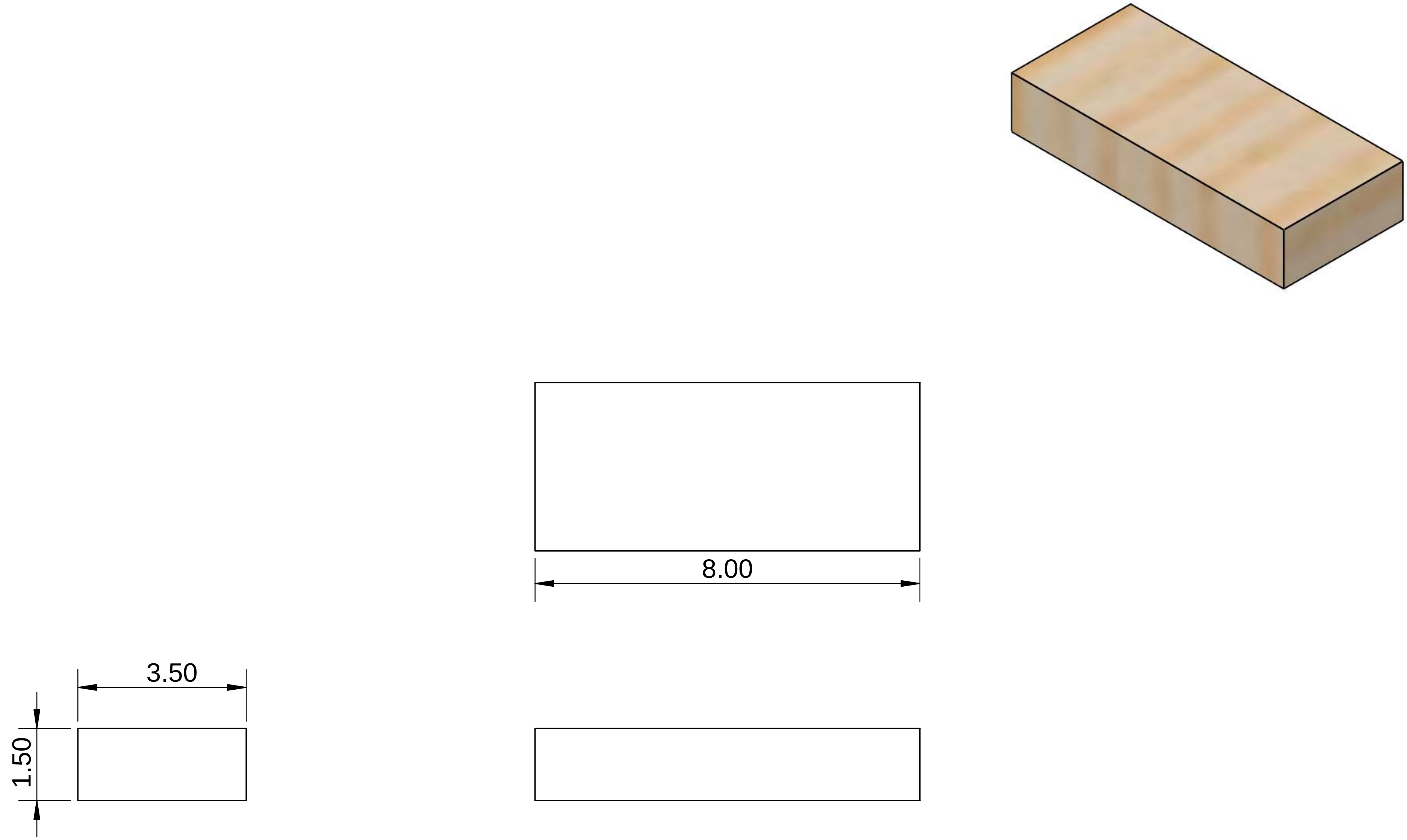


UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Bottom Acrylic
Scale :1:10	Material: plexiglass acrylic

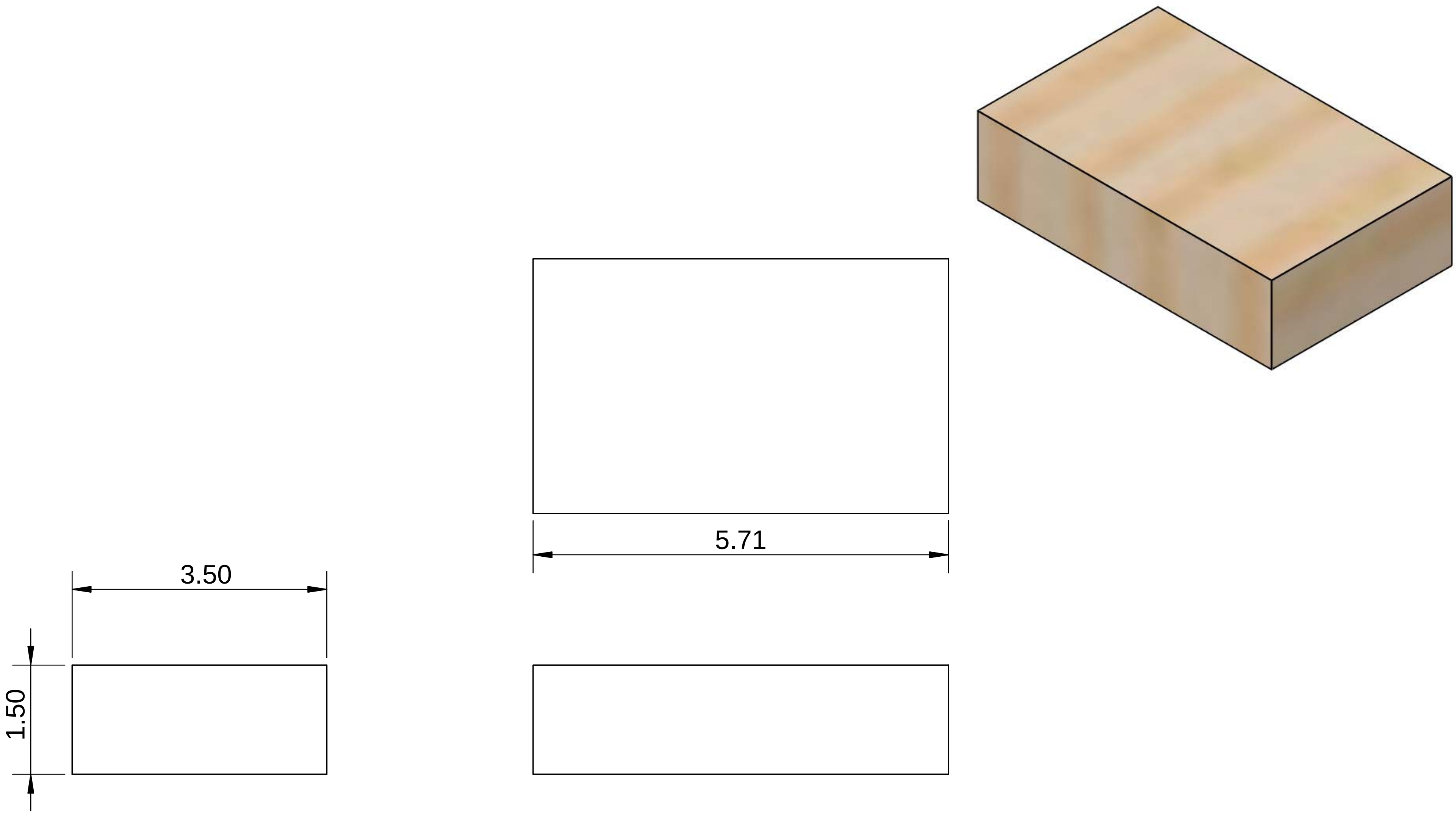




UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Bottom Back Acrylic
Scale :1:10	Material: plexiglass acrylic



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: fan support front cross
Scale :1:3	Material: wood

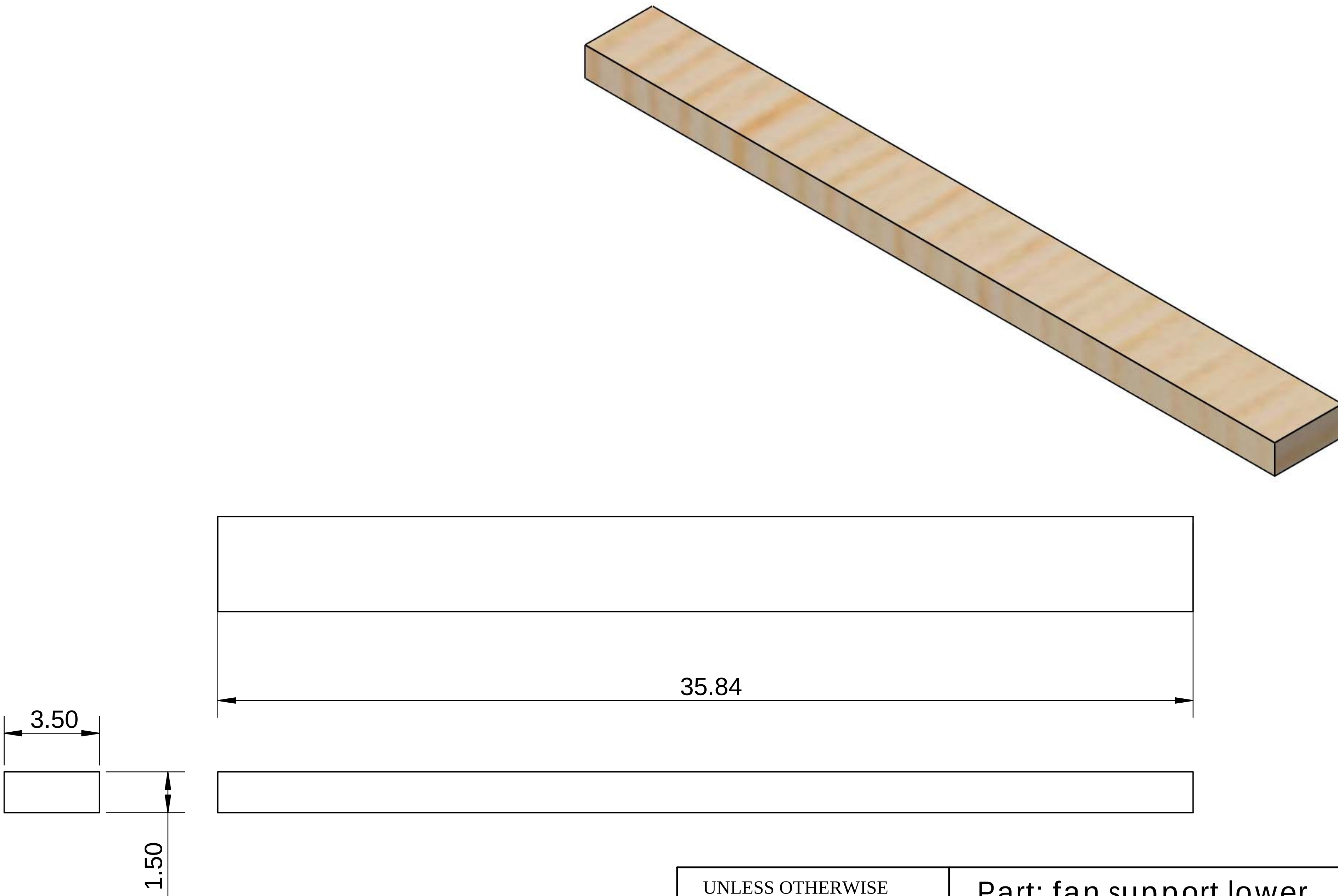


UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

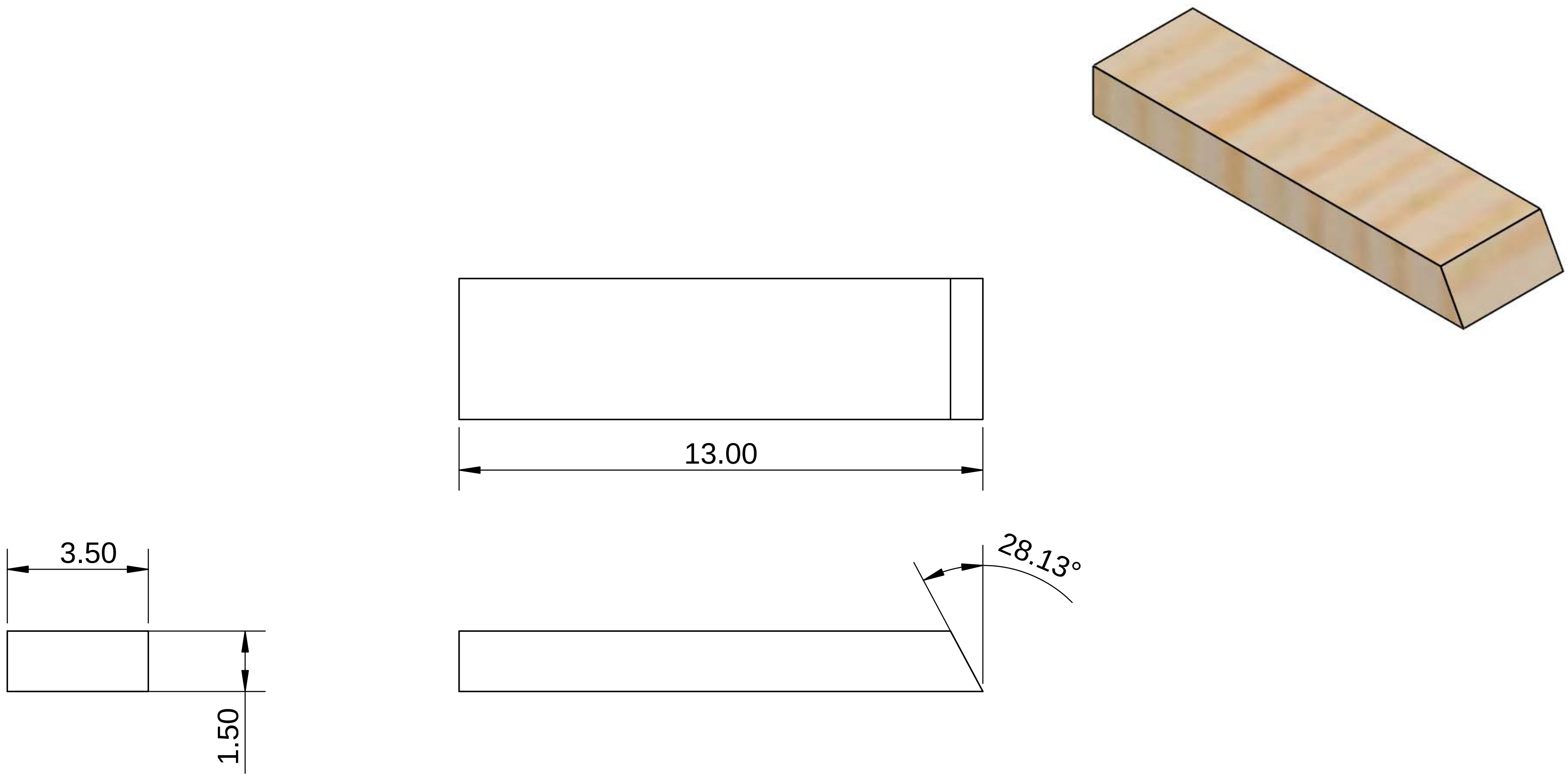
Part: fan support front vertical

Scale :1:2

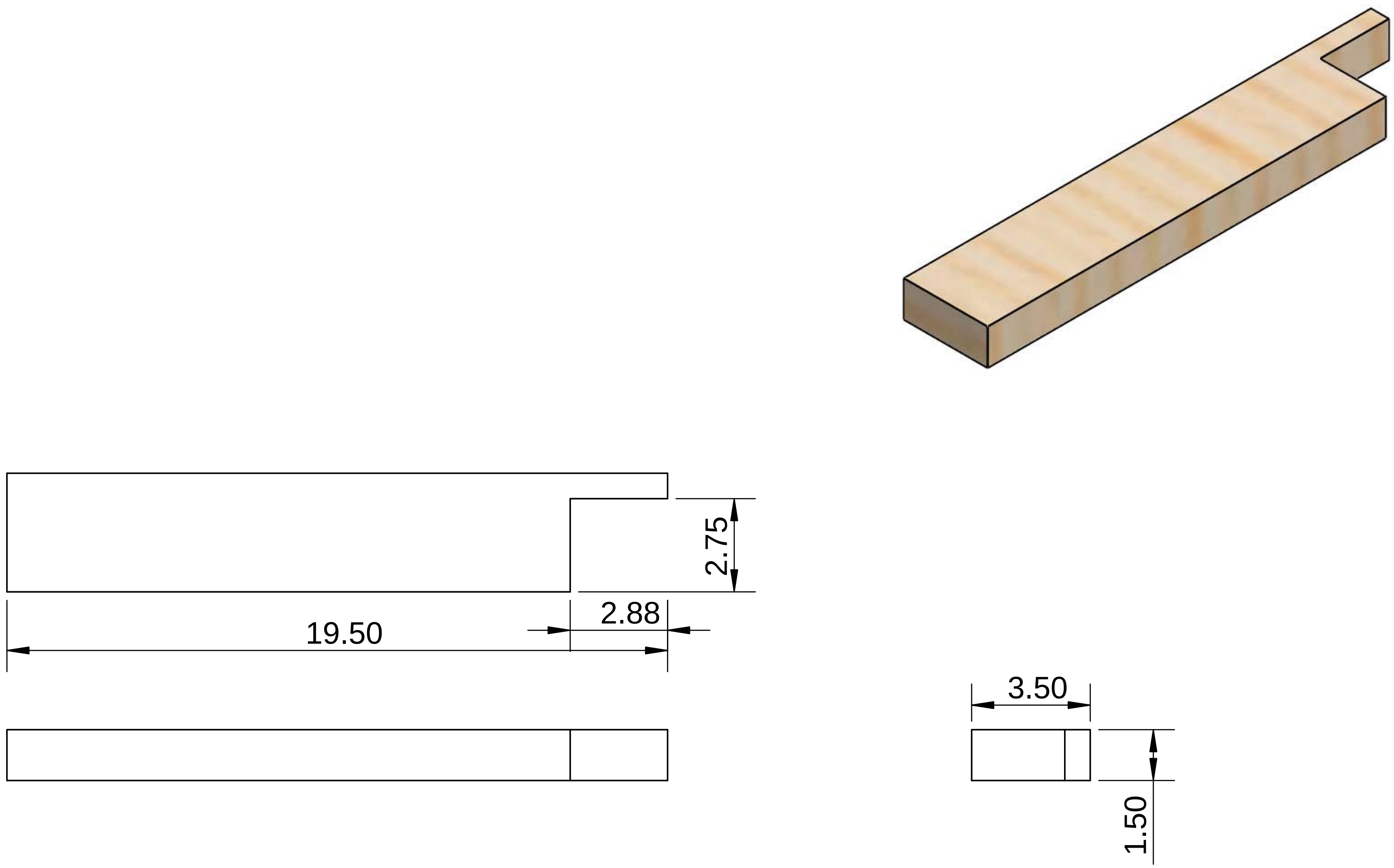
Material: wood



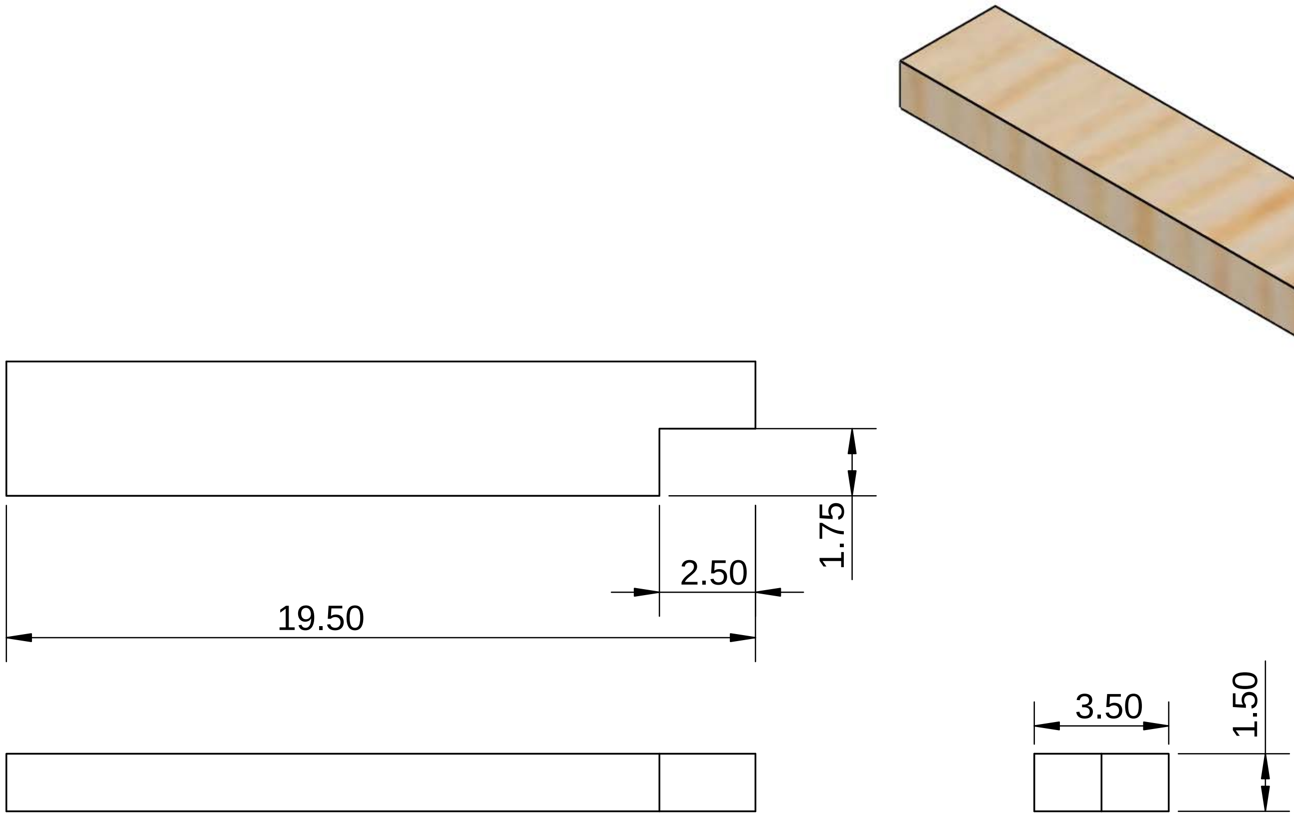
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: fan support lower
Scale :1:5	Material: wood



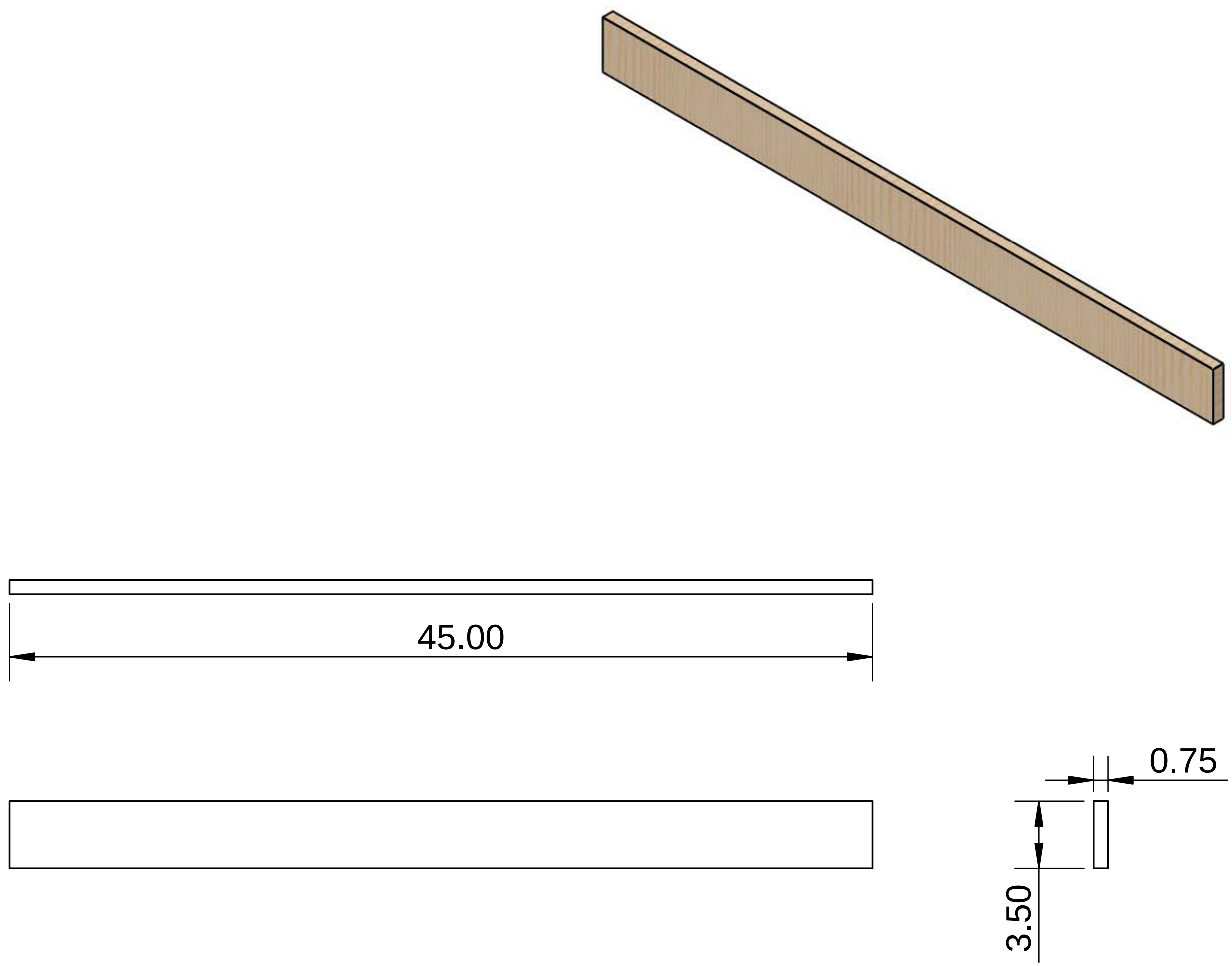
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Fan support manifold vertical
Scale :1:4	Material: wood



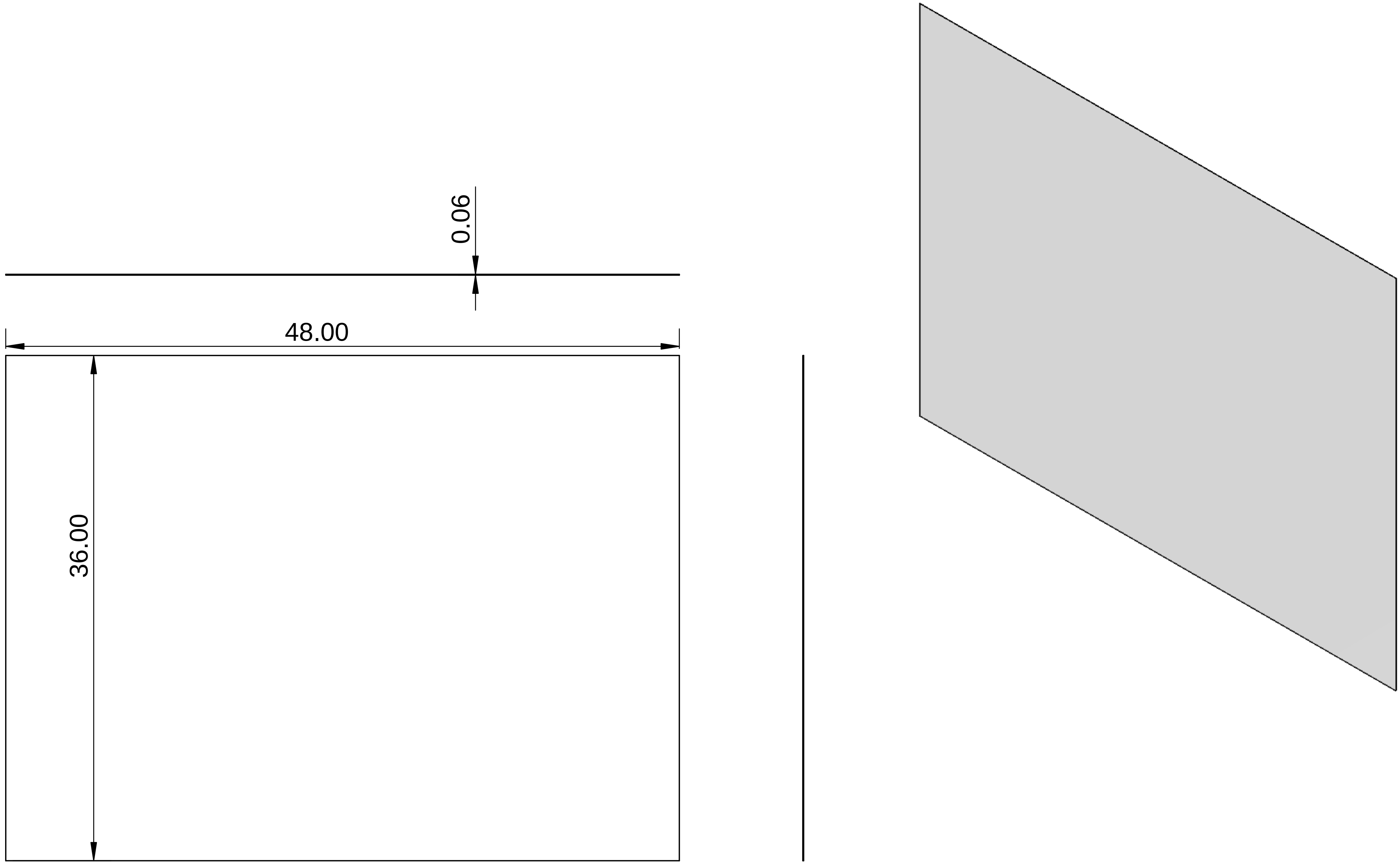
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: fan support vertical alternate
Scale :1:5	Material: wood



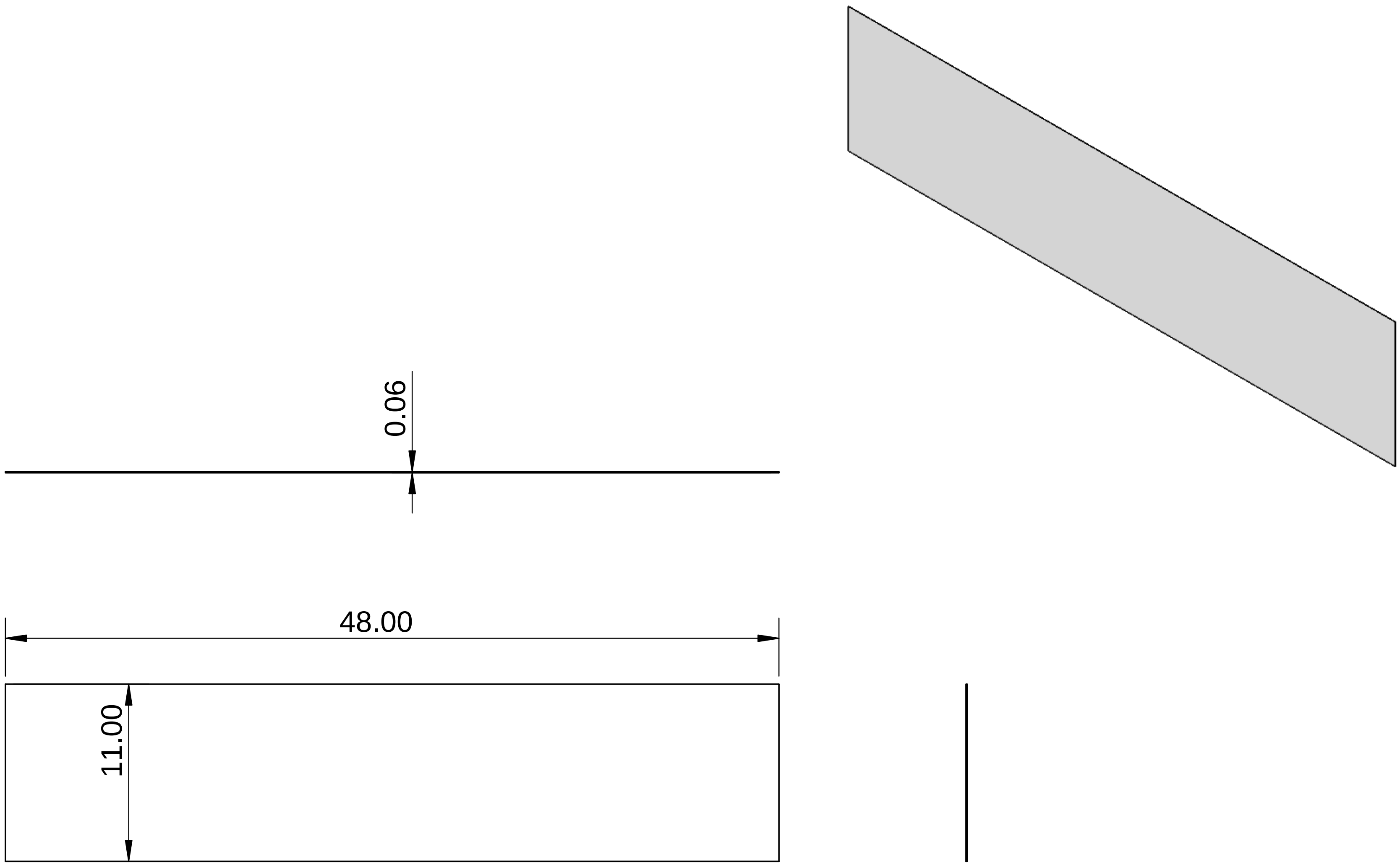
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: fan support vertical
Scale :1:5	Material: wood



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Door Face
Scale :1:10	Material: wood

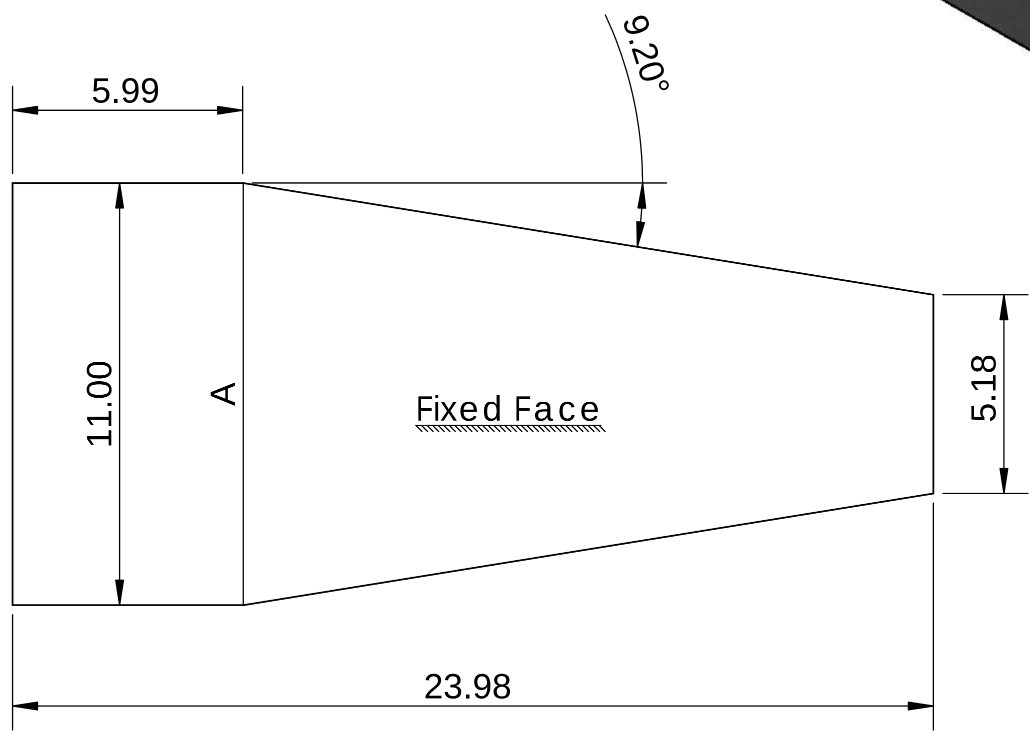


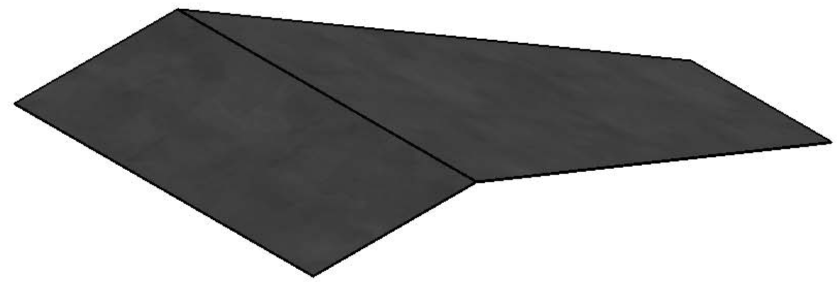
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Side Acrylic
Scale :1:10	Material: plexiglass acrylic



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Top Acrylic
Scale :1:10	Material: plexiglass acrylic

Tag	Direction	Angle	Inner Radius
A	UP	27.1°	0.05





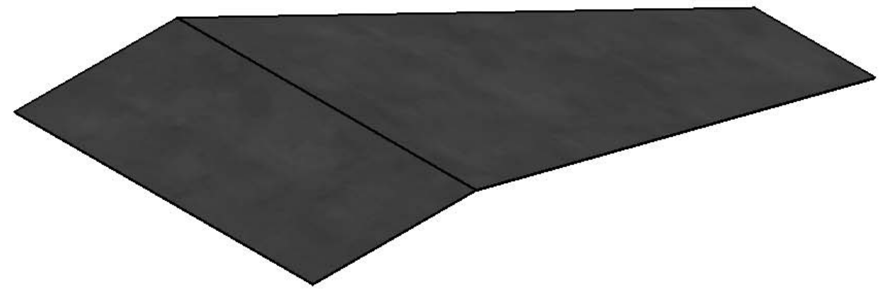
UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

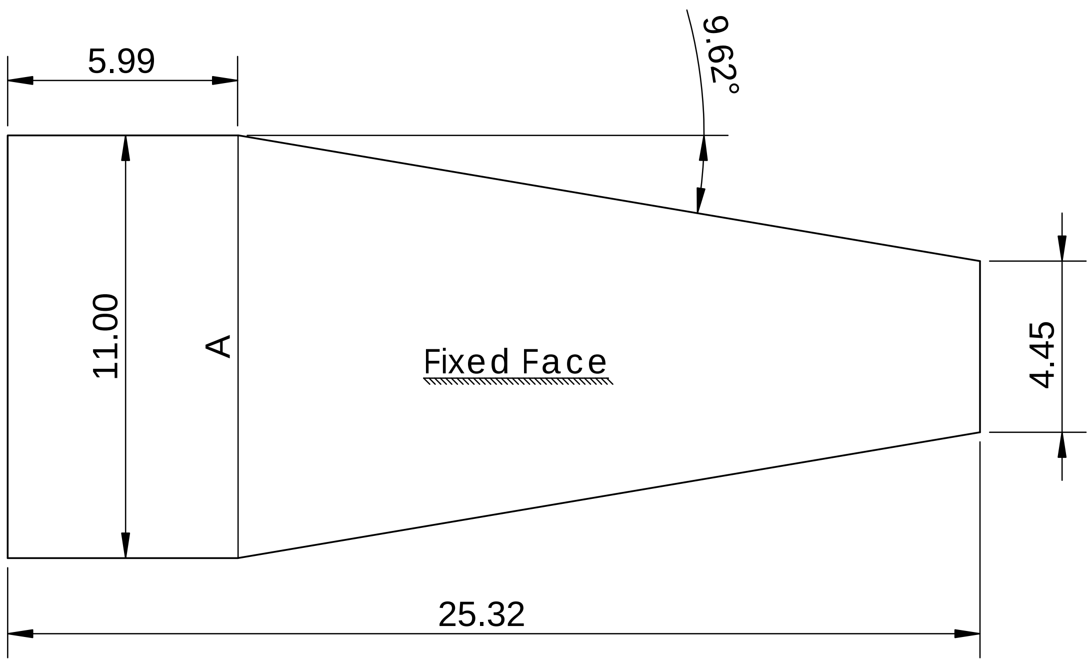
Part:
H_Fin 1

Scale : 1:5

Material: 24 Gauge Galvinized Steel

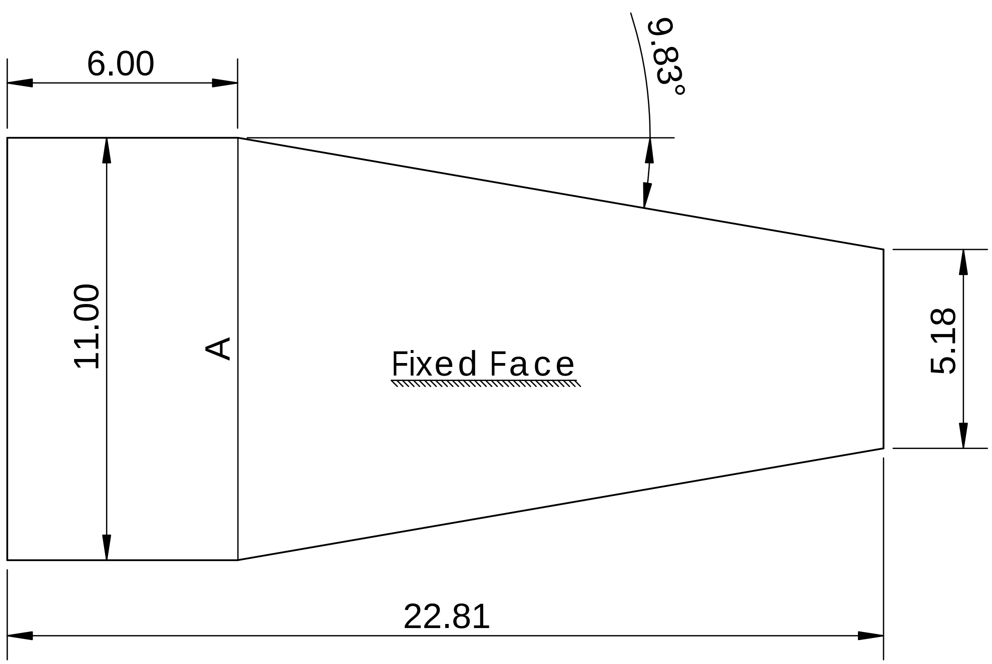
Tag	Direction	Angle	Inner Radius
A	UP	21.36°	0.05

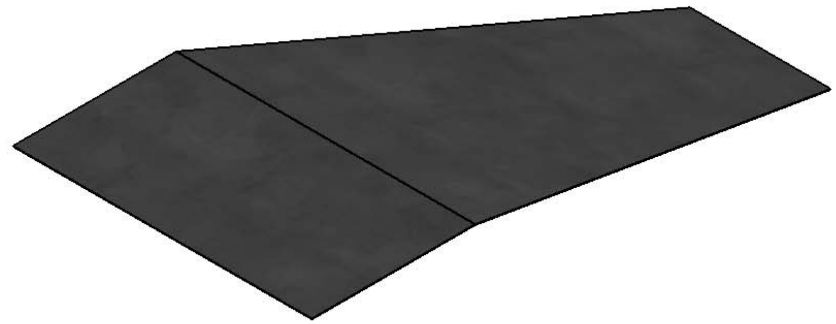




UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: H_Fin 2
Scale :1:5	Material: 24 Gauge Galvinized Steel

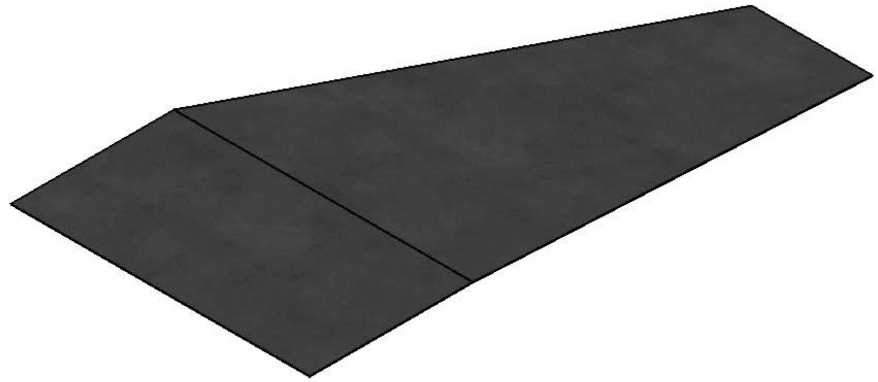
Tag	Direction	Angle	Inner Radius
A	UP	17.82°	0.05

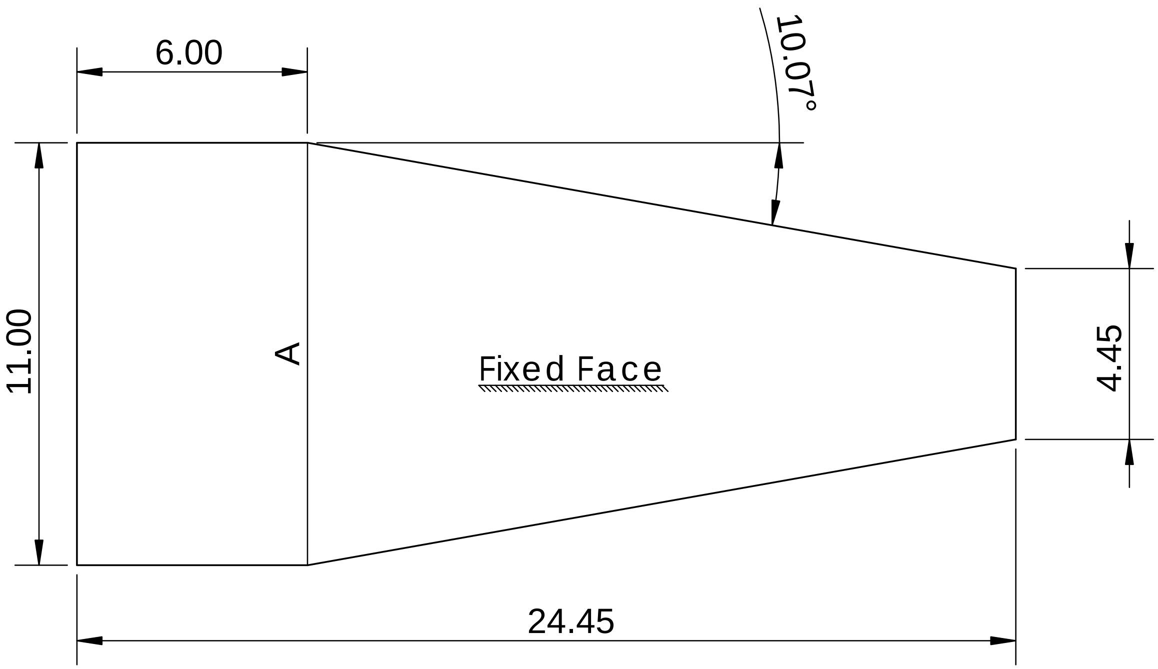




UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: H-Fin 3
Scale :1:5	Material: 24 Gauge Galvinized Steel

Tag	Direction	Angle	Inner Radius
A	UP	12.65°	0.05





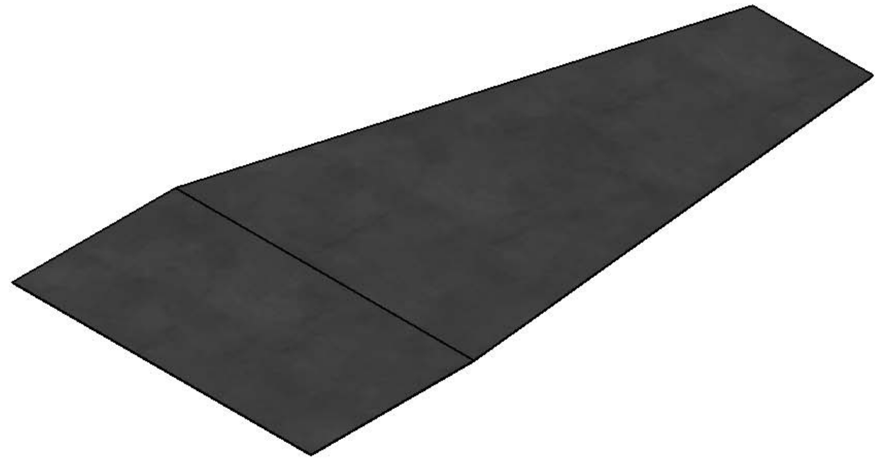
UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

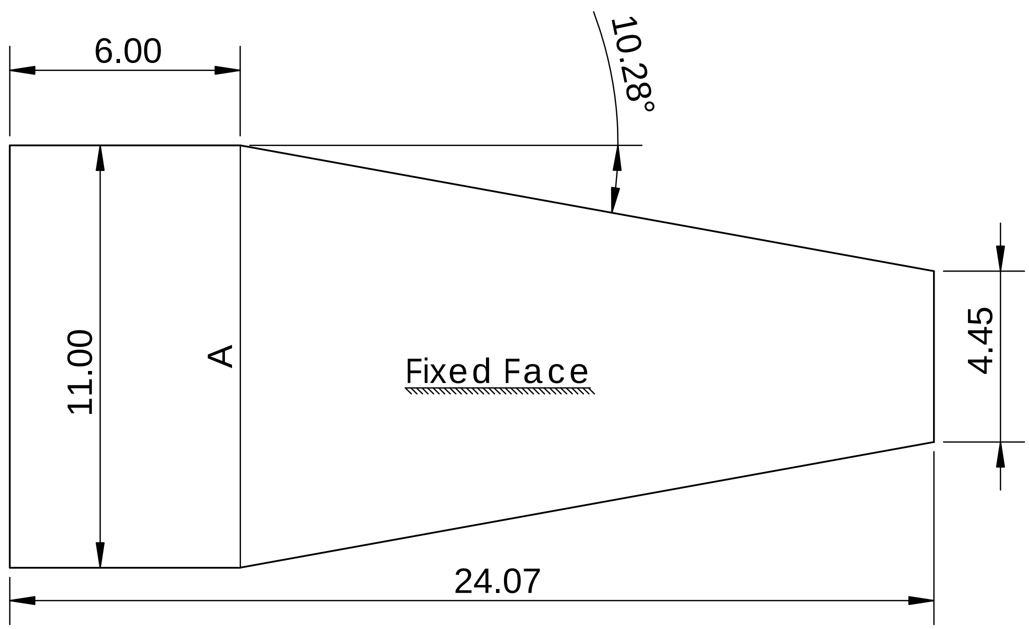
Part:
H_Fin 4

Scale :1:5

Material: 24 Gauge Galvinized Steel

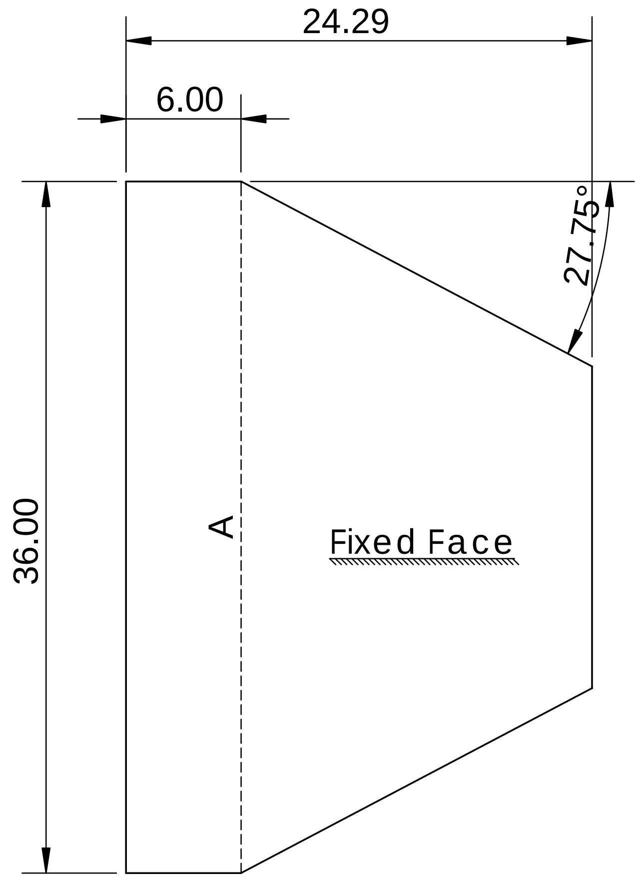
Tag	Direction	Angle	Inner Radius
A	UP	4.89°	0.05





UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: H_Fin 5
Scale :1:5	Material: 24 Gauge Galvinized Steel

Tag	Direction	Angle	Inner Radius
A	DOWN	10.31°	0.05



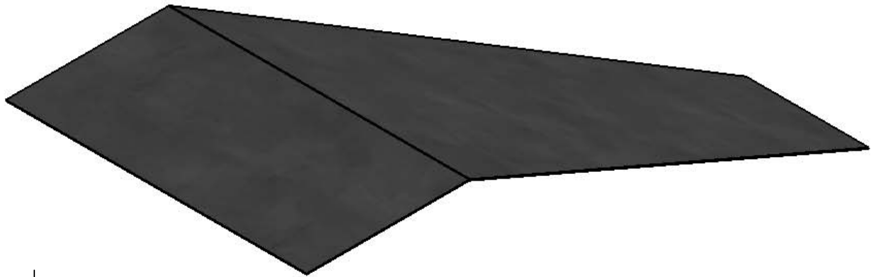
UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches and Degrees

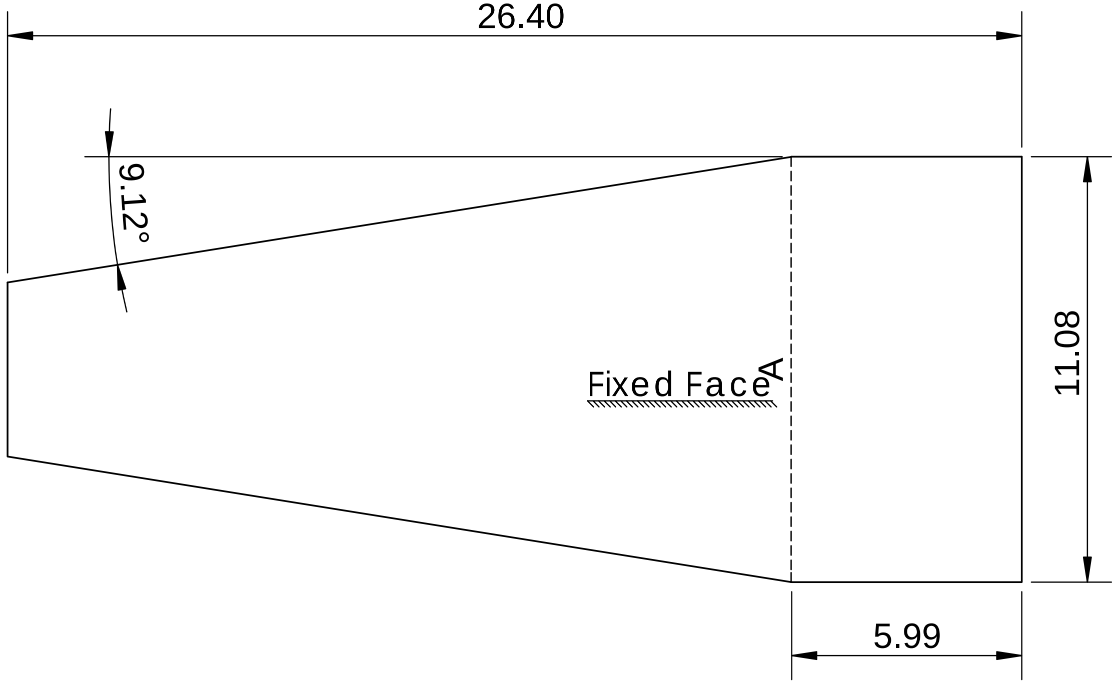
Part:
Shell L/R

Scale :1:10

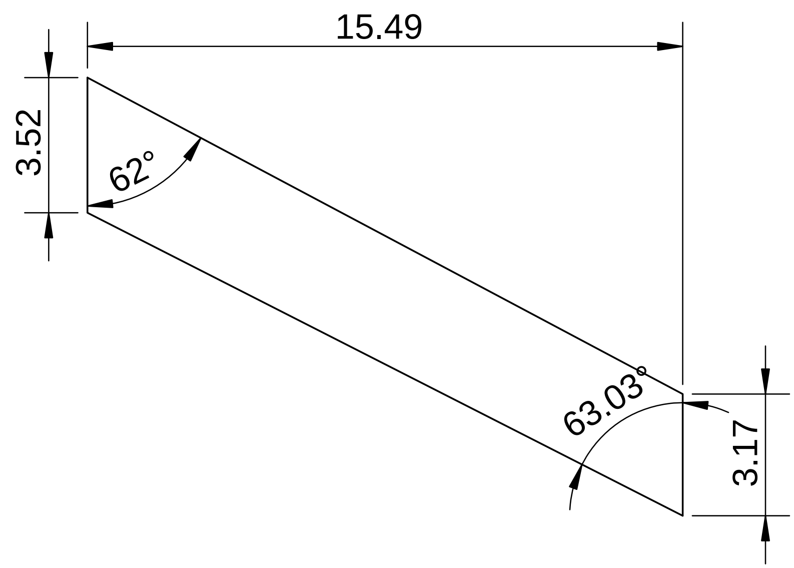
Material: 20 Gauge Galvinized Steel

Tag	Direction	Angle	Inner Radius
A	DOWN	28.13°	0.05

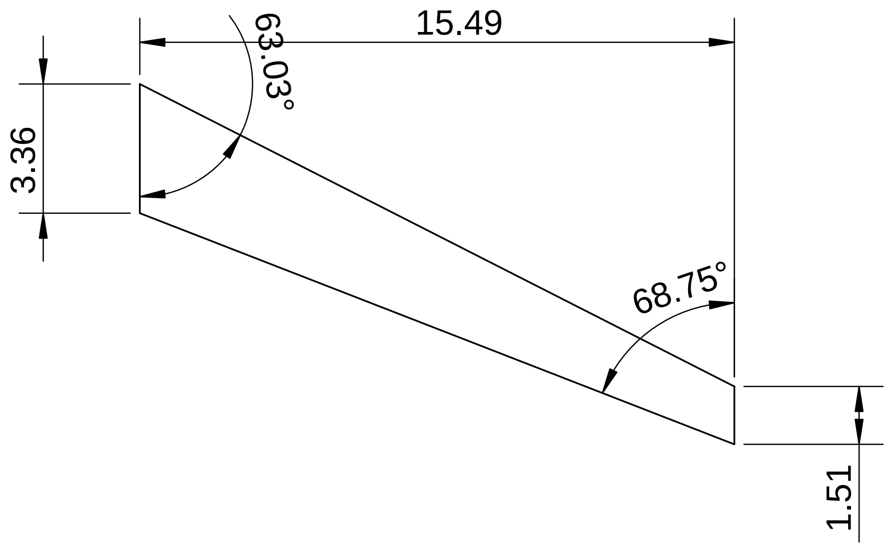




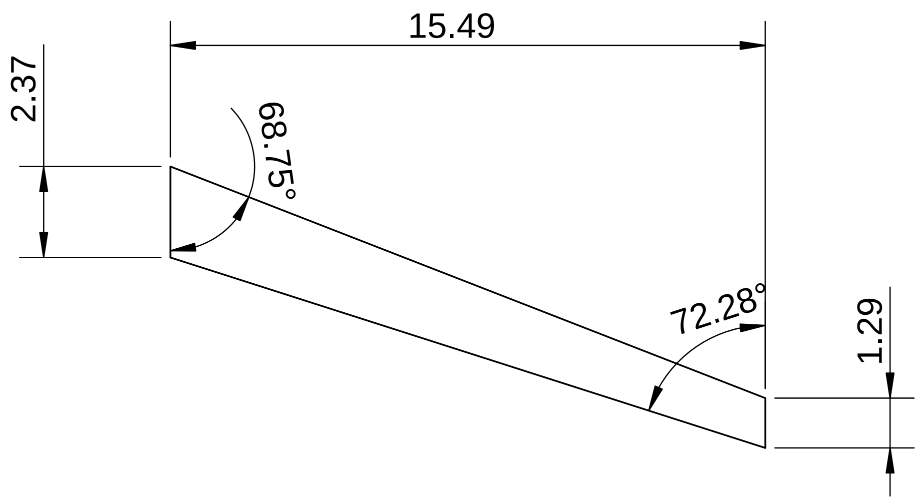
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: Shell L/R
Scale :1:5	Material: 20 Gauge Galvinized Steel



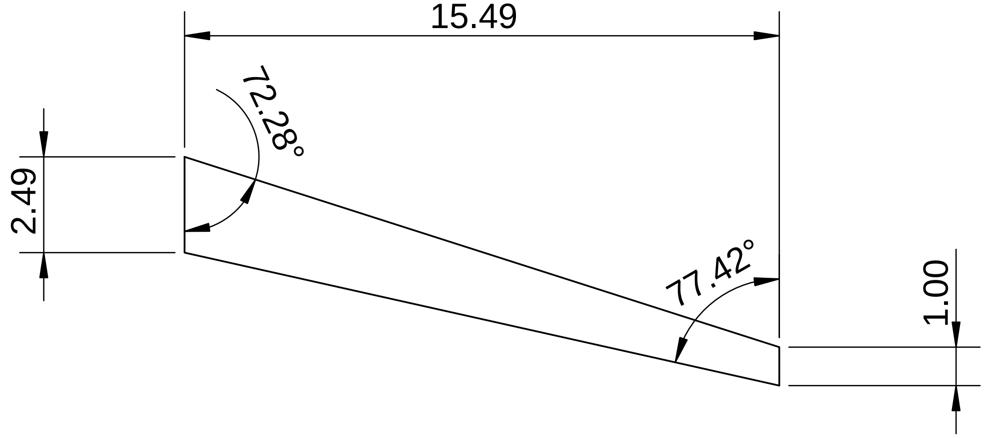
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin 1
Scale :1:5	Material: 24 Gauge Galvinized Steel



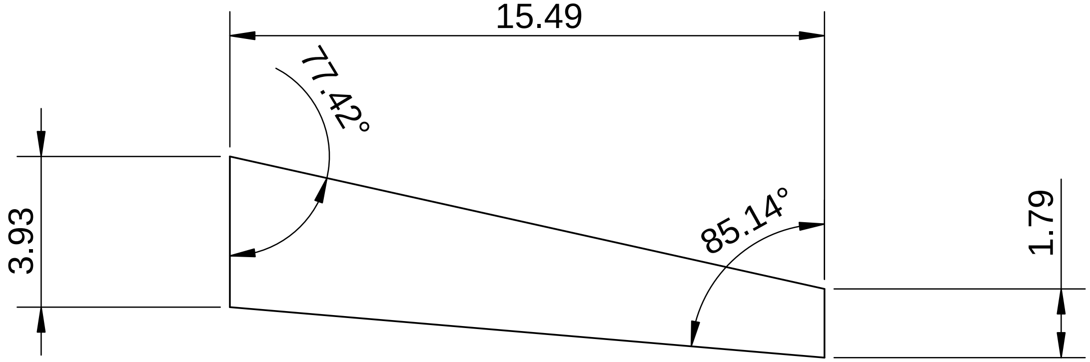
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin 2
Scale :1:5	Material: 24 Gauge Galvinized Steel



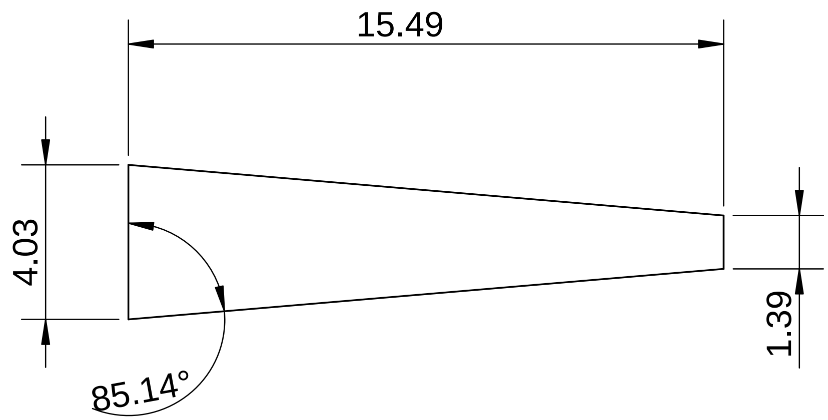
UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin 3
Scale :1:5	Material: 24 Gauge Galvinized Steel



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin 4
Scale :1:5	Material: 24 Gauge Galvinized Steel



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin 5
Scale :1:5	Material: 24 Gauge Galvinized Steel



UNLESS OTHERWISE SPECIFIED Dimensions are in Inches and Degrees	Part: V_Fin Middle
Scale :1:5	Material: 24 Gauge Galvinized Steel

14 ANNOTATED BIBLIOGRAPHY

[1] Occupational Safety and Health Standards: Machinery and Machine Guarding (Standard Number 1910.212). United States Department of Labor. URL: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9836

[2] ASTM D4802-16, Standard Specification for Poly(Methyl Methacrylate) Acrylic Plastic Sheet, ASTM International, West Conshohocken, PA, 2016, www.astm.org, DOI: 10.1520/D4802-16.

[3] UL 61800-5-1, Standard for Adjustable Speed Electrical Power Drive Systems: Safety Requirements – Electrical, Thermal and Energy. International Electrotechnical Commission, https://standardscatalog.ul.com/standards/en/standard_61800-5-1_1.