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FLOW METER TEST RIG

FINAL DESIGN REPORT

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Chapter 1: Introduction

There are currently no experiments in the ME fluids laboratory that demonstrate the proper use of flow meters, devices that are necessary and relevant in many fluids-related industries. In order to provide students with exposure to these types of devices and how they work, a test rig was developed with the ability to interchange a variety of flow meters in order to broaden the students' knowledge of the different types of measuring devices. It was also necessary to create an operating manual that will safely guide the user, likely a student, through setup and changing between the test units.

Project Requirements

The test rig must be no larger than 4ft x 8ft to allow for convenient tabletop testing. The air moved through the system will be filtered to remove particulates to maximize the life of the flow meters and air mover. The test rig is modeled as a calibration test, so a control/standard test unit is placed in series with a unit under test (UUT). The standard test unit value will be compared to the other flow meter results with associated losses taken into account. Additionally, piping matching the geometry of each UUT will be attached prior to measuring to determine what losses are only due to geometry and would be present without a flow meter. A preliminary layout can be seen in Figure 1.

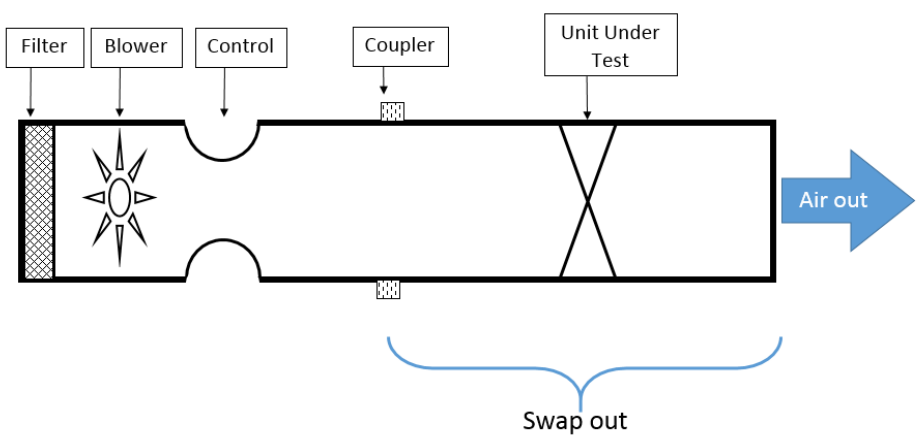

Figure 1. A conceptual cross-section of the test rig, showing most of the elements chosen.

The system will be able to measure flow velocities as much as 75 feet per second and have a minimum turndown ratio of 3:1 (lowest readable velocity is ⅓ of the maximum velocity). This range covers the variety of velocities that would be tested in industry. The goal is to give the students a variety of experiences. A summary of the initial requirements can be found in Table 1. During detailed design it was determined that a larger pipe size is more appropriate than the original size and is further discussed in Chapter 3.

Table 1. Formal Requirements

Requirement	Target	Tolerance	Risk	Compliance
Size (footprint)	4'x8'	Maximum	L	I
Size (pipe diameter)	2"	+2"	L	I
Power Source	220V (Wall outlet)	N/A	L	A
Flow Rate	100 (cfm)	±5 (cfm)	M	A
Air Filter	(1) 70% HEPA filter	Minimum	L	I
Turn Down Ratio	3	Minimum	L	A
UUT procedure document	Specific instructions for use	N/A	N/A	N/A

Even though these requirements were initially specified, most are flexible so long as they emulate industry standards. For example, the line size can change depending on the operating point of the system based on UUTs and air movers.

Chapter 2: Background

Some preliminary analysis was done to verify the assumptions that the flow is incompressible and has a uniform velocity profile. The same analysis was also used to determine the initial design point for the air mover. The system is meant to operate at a maximum velocity of 75 ft/s, which has a Mach number far below the threshold for incompressible flow (lower than 0.3). The maximum Mach number for this project will be less than 0.1, meaning compressible flow considerations can be ignored. Next, the Reynolds number was calculated to determine whether or not the flow would be turbulent in the system. The threshold value for turbulent flow is around 2300. As seen in Table 2, for pipe much larger than 2" in diameter, the flow can be considered turbulent at our minimum flow speed of 25 ft/s. This means that the velocity profile is more uniform and will obtain fully developed flow more quickly than laminar flow. Starting out more uniform allows less pipe dedication before reaching fully developed flow, reducing the rig's footprint.

Table 2. Reynolds numbers for a variety of pipe diameters; flow will be turbulent all diameters at minimum speed of 25 fps.

d (in)	Re_{min}
1.50	19400
1.75	22700
2.00	25900
2.25	29200
2.50	32400
2.75	35600
3.00	38900

The layout for this experiment will be similar to existing experiments used to calibrate metering devices. There are two types of setups. The first is a prover setup; data is calibrated by moving an object through a pipe and measuring the times it takes to move a distance. Most of these setups incorporate a bend in the pipe to conserve space but introduces an additional head loss on top of frictional ones.

Figure 2. Example Setup for a Prover type calibration.
(Courtesy of EnergoFlow)

In addition to pipe provers, there is the reference method. In this case, one meter is directly compared to another. Scientists attach a Data Acquisition System (DAQ) to the system so that while measuring and recording data for the standard, they are able to immediately compare those values to the ones being populated in the DAQ.

Lots of experiments incorporate a standard with which to compare the UUT. Our standard and UUTs should have a fine resolution so that the associated uncertainties fall within each device's' resolution. This also extends to the differences between standard and UUT uncertainties. To maintain that the standard is more precise than the UUT, company Tuv Nel suggests that the standard have an uncertainty 10 times smaller than the UUT but usually three times is all that can be achieved.

The Control Standard

Since this experiment will be set up as a learning opportunity for students, it is necessary that every step and calculation is easily reproducible. With these requirements, orifice plates, Venturi meters, and ASME standard nozzles come to mind as potential standards. Each of these standards are differential pressure flow meters which are generally easy to make and to implement (Universal Flow Monitors). Unfortunately, these types of meters tend to have a lot of associated losses due to the contracting flow. Further analysis and the final choice for the standard is described in detail in Chapter 3: Design Development.

Flow Meter

In addition to the standard, there are many options for UUTs to be incorporated into the experiment. An automotive mass air flow meter will be included so students can be exposed to a common type of meter. Additional UUTs will be used to broaden their understanding of industrial flow meters. There are several different types of flow meters: differential pressure, positive displacement, magnetic, ultrasonic, thermal, rotation based meters, float (variable area), and Coriolis mass meters. Universal Flow Monitors describes each flow meter in detail and a quick description of each is listed below:

- Differential Pressure: Equates fluid pressure drop to fluid speed with Bernoulli's
- Positive Displacement: Measures time to move a given, known volume of fluid
- Magnetic: Equates a voltage to the fluid flux through a magnetic field with Faraday's Law
- Ultrasonic: Finds flow rate via the frequency change of a sound wave by Doppler Effect
- Thermal: Measures heat loss of a probe as fluid moves past it
- Rotation: Correlates the rotation of a vane or turbine to the speed of the fluid
- Variable Area: Balances weight of a float to force applied by the moving fluid for a flow rate
- Coriolis Mass: Measures acceleration of fluid moving away from a center of rotation

The abundance of flow meters allows the experiment to be flexible, both now and in the future. As the experiment includes a modular section, more flow meters can easily be added in the future. The variety of meters can be altered to meet the needs and shortcomings that may be present from a purely theoretical knowledge of flow meters.

Chapter 3: Design Development

Developing a full concept for the flow meter test rig involves three main decisions: control meter selection, UUT selection, and air mover selection. The majority of these are completely independent of each other. The main air movers considered were fans, blowers and compressors. A fan or blower would be located at the inlet of the system, to push air through. A compressor would be located at the end of the system to pull air through, modeled to match the existing converging-diverging nozzle experiment in the fluids lab. The control meter was selected from an orifice plate, a venture nozzle, or an ASME nozzle. The UUTs were selected from the list at the end of the previous chapter.

Potential Layouts

The preliminary designs differed in two aspects: component selection for each design decision and order of components in terms of layout. There are dozens of slight variations, but a few key designs are outlined below. The air mover choice most impacts the design layout most, while control meter choice has almost no influence on layout.

Design 1: Compressor with orifice plate

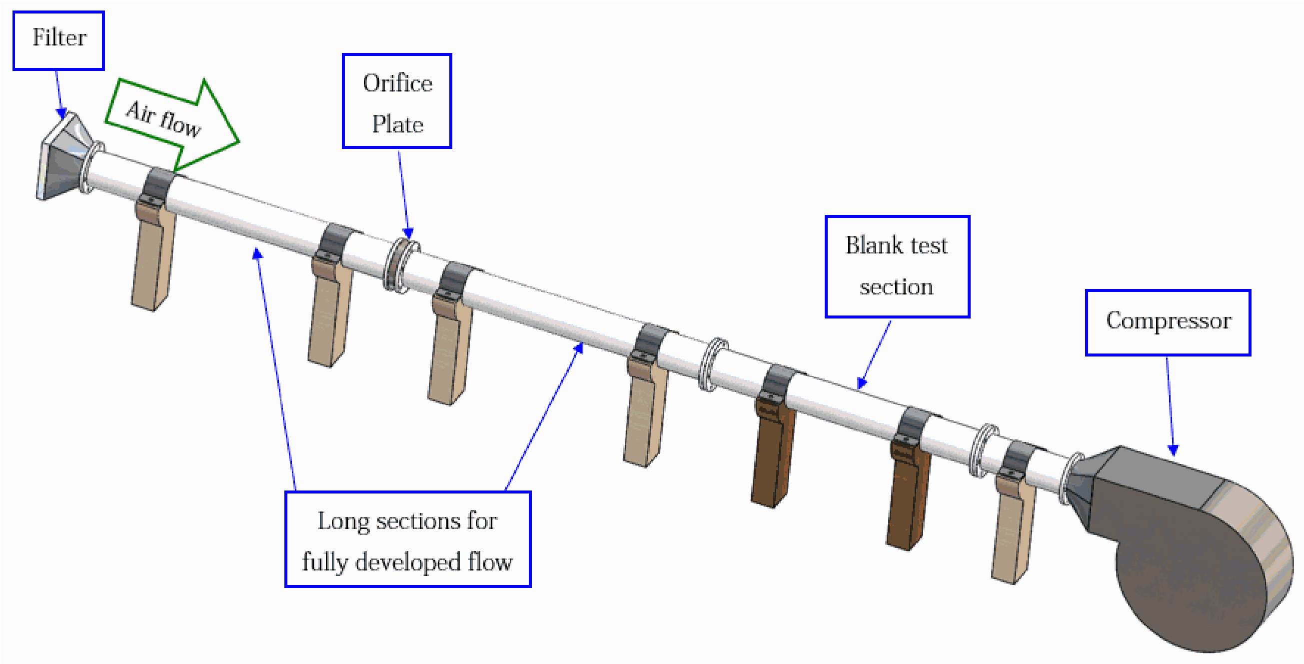

Figure 3. A preliminary concept design. This one is structured similarly to the converging-diverging nozzle experiment currently in the lab.

Design 2: Fan between ASME nozzle and UUT

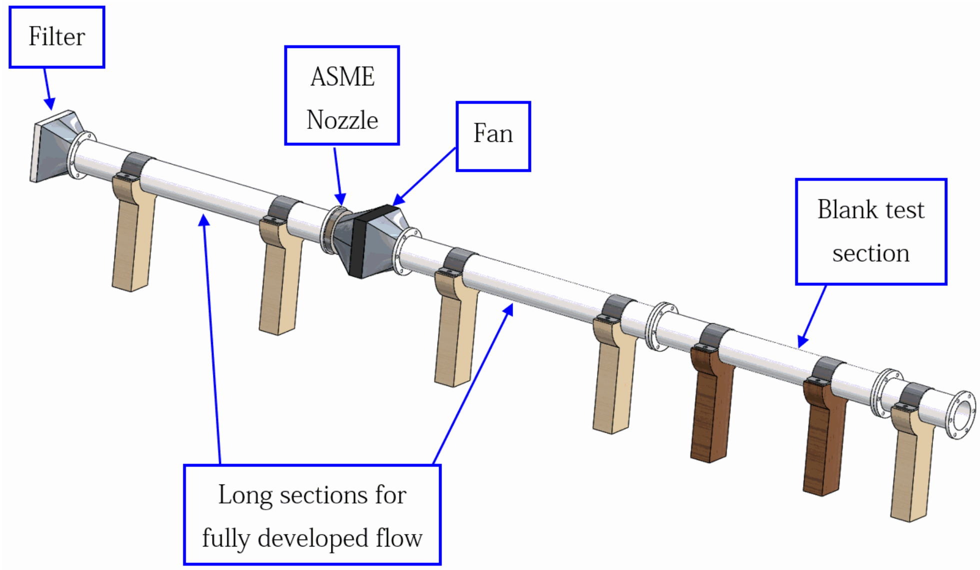

Figure 4. An early concept, with the fan in between the nozzle and UUT sections.

Selecting Control Flow Meter

The control meter was selected from an orifice plate, a venture nozzle, or an ASME nozzle. Table 3 compares the notable aspect of each. Specs for each type of nozzle come from Amity Flow. The Venturi nozzle was ultimately chosen due to the balance between cost and head loss. The first choice was an ASME nozzle, but the drastic head loss would impact our system too much and drive up the cost of the blower.

Table 3. Comparison of resolution, head loss, and cost for different calibration meters.

Meter	Inches H_2O Diff. Pressure for 220 cfm	Head Loss (inches H_2O)	Cost
Low Loss Flow Tube	10.00	0.35	$1200
Venturi Nozzle	10.00	0.5013	$900
ASME Nozzle in pipe	15.00	9.11	$750
ASME Nozzle at pipe entrance	1.14	0.709	$750

Selecting Units Under Test

The UUTs were one of the earliest decisions made during the design process. The simplest meters are differential pressure, positive displacement, and float meters. The more technically involved and conceptually complex are the Coriolis, magnetic, and thermal flow meters. Ultrasonic is in the middle for complexity as it uses the Doppler Effect and shifting frequencies of a wave as well as rotation based where the RPM has to be converted to flow rate. We would like a range of complexity for the experiment flow meters with one meter from each complexity group. A listing of the ultimate decisions on UUTs is shown in Table 4. The table shows the primary reasoning behind each UUT choice. Since this test rig is designed to be a learning experience, we chose meters that gave a varying amount of loss and operated with different principles.

Table 4. UUT choices

Y/N?	Flow Meter	Prime Reasons
Y	Automotive MAF	Commercial common, simple (volt) output
N	Rotameter	Industry common, easy to read/understand, outputs flow directly
Y	Turbine	Common, medium price, simple (volt) output
N	Laminar Flow	Big losses (want variety), easy to explain, easy to integrate.
N	Coriolis	Expensive, sensitive, poor shape for a table-top rig
N	Magnetic	Does not work for air
N	Ultrasonic	Highly expensive

Mover Selection, Airspeed Control, and Filtration

In order to test air flow speeds, it is necessary to move air through the system. There are 3 primary types of gas movers: compressors, blowers, and fans, each with its own range of flow rates (usually given in cubic feet per minute, or cfm) and pressure rise (usually in inH_2O). In order to select the appropriate mover, a design point with flowrate and pressure rise is required. In order to determine the design point, it is necessary to do an analysis of the system using a modified version of Bernoulli's equation.

Generally speaking, fans are designed to deliver high flow rates at low pressure rise (typically less than 1 inH_2O), while compressors deliver flow at pressures in excess of atmospheric pressure (34 ftH_2O). Blowers deliver head rises in between these two ranges.

In order to determine the minor losses through a UUT, it was necessary to estimate the loss coefficient of the UUTs, filter, and pipe. Filter values could be found online at EngineeringToolBox.com and the pipe values determined with the Moody chart. Research on flow meter manufacturers and distributors concluded that most losses are determined in-house and not publicly published. To obtain estimates, a test was set up with Dr. Westphal to take sample measurements and loss values with a turbine meter available in the Fluids Laboratory. The results can be seen in Table 5 below and a sample calculation can be found in Appendix E.

Table 5. Data and results from UUT loss coefficient test. Density of air of 1.187 kg/m3 used.

Inlet Pressure (Pa)	Outlet Pressure (Pa)		Change in Pressure (Pa)		Pressure Drop Over UUT (Pa)	V (m/s)	Loss Coefficient, k
	Blank	UUT	Blank	UUT			
8	74	223	66	215	149	10.3	2.4
19	157	614	138	595	457	14.9	3.4
27	220	856	193	829	636	17.7	3.4
35	283	1076	248	1041	793	20.0	3.3

Despite a suggested 2” line size and 75ft/s, a 3” line size was found to match the system best after researching UUT sizes. With the turbine meter, rotameter, and nozzle, each had many sizes available, allowing them to be flexible with any line size we chose. However, the MAF limited size selection the most since any size other than 3” would be hard to find. By changing the line size, the flow rate changed. To obtain flow rates analogous to a car’s intake, the engine of a 1996 Ford Taurus presented some values. Assuming an engine speed of 2500 rpm at 60 mph for a 3.0L engine and intake on every other stroke, the Taurus engine would take in about 130 cubic feet each minute. Ultimately, the selected mover was able to deliver more than 130 cfm.

At a flow rate of about 220 cfm (3’’ diameter pipe at 75 ft/s), the system requires a head rise of about 5 inH_2O. These calculations can be seen in Appendix E. With this design point, it was determined that an air blower would be necessary for this system. The blower chosen is outlined in Chapter 4: Final Design.

Chapter 4: Final Design

The final design for the test rig is laid out in Figures 5 through 8. Figure 5 depicts the base assembly containing the blower, filter, and Venturi meter. Figures 6, 7, and 8 depict the modular UUT sections. One of these is a “blank,” with a straight section of pipe in place of a UUT. This is so that students may see the pressure drop solely due to the UUTs: the pressure drop across the blank pipe acts as a “zero,” to be subtracted from the UUT section pressure drops in order to find the pressure drop across the UUT.

The final concept begins with a filter box at the inlet, to keep clean air going through the rig. The filter box is designed to maximize the area of the inlet to reduce pressure loss across filter while still obtaining the system flow rate. The filter box’s outlet feeds into the blower, which pushes the air through an ASME standard Venturi meter, followed by the UUT section and outlet. There are extra-long pipe sections in front of the nozzle and each of the UUTs to allow flow to become fully developed. These are the primary driving dimensions of the rig. Each piece should be at least ten times the diameter of the pipe, so 30” long for the MAF and 20” for the turbine meter.

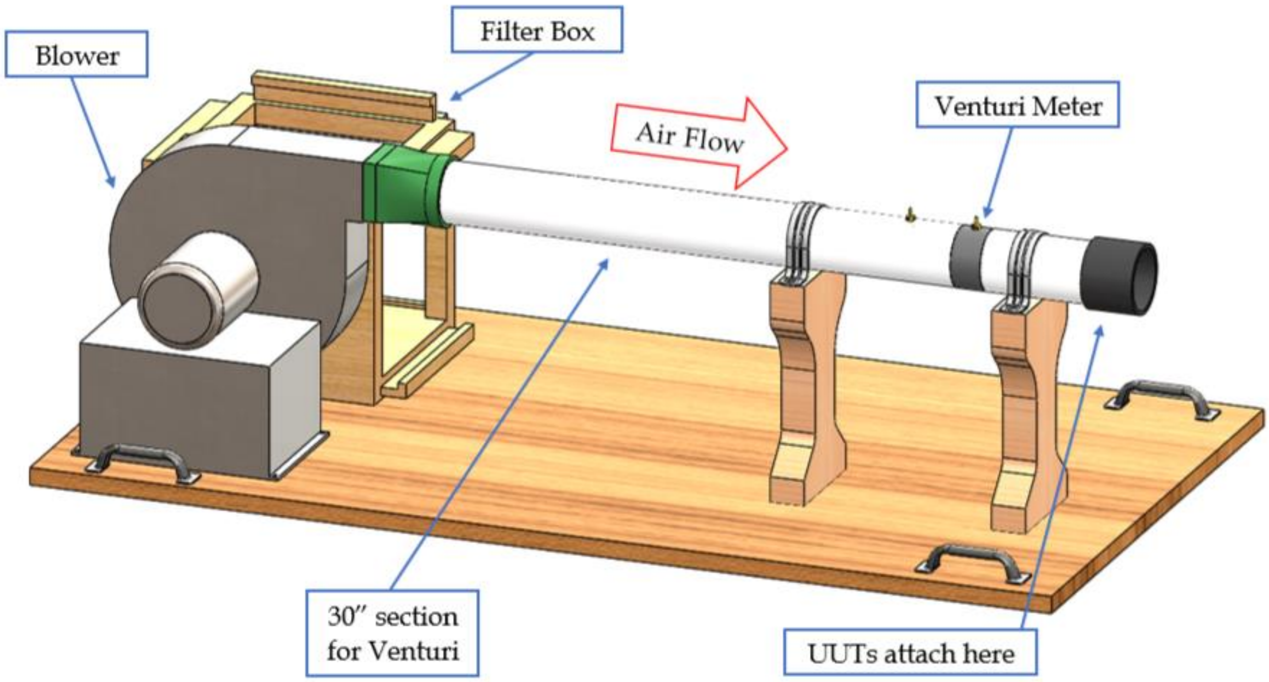

Figure 5. Base assembly of the test rig with a no UUT sections.

In total, there are three modules of UUTs: the MAF, a turbine meter, and a blank section. These can all be seen in Figures 6 through 8. The piping for each is secured to the wooden supports with metal mounting clamps.

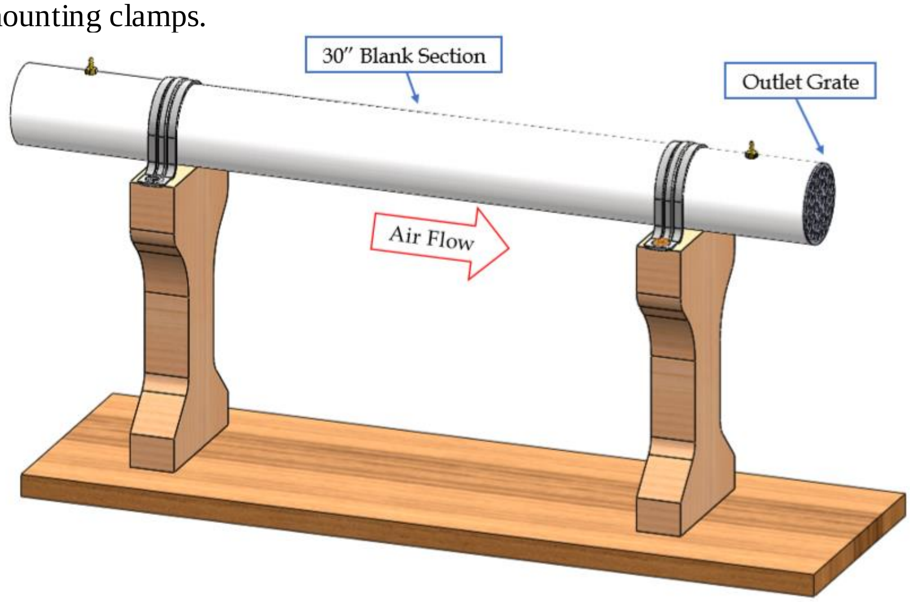

Figure 6. Blank UUT section

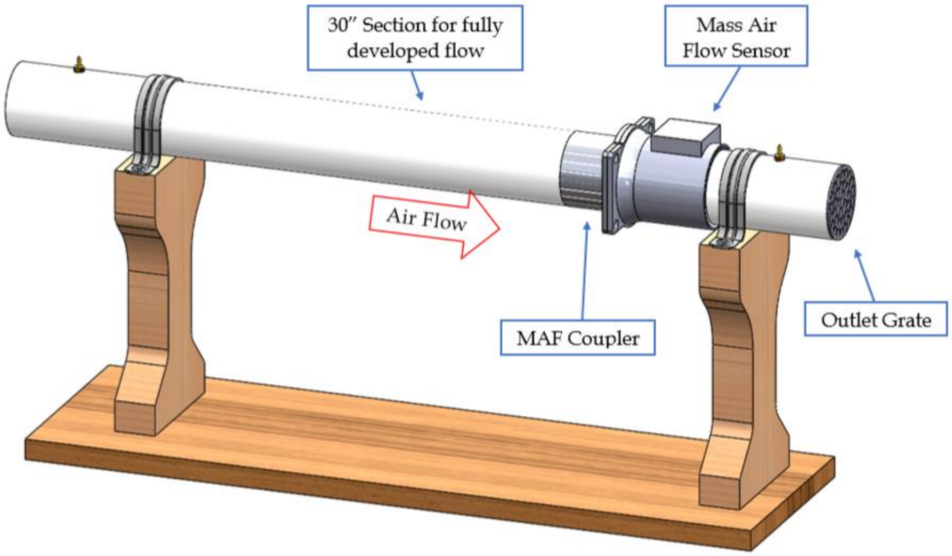

Figure 7. MAF test section

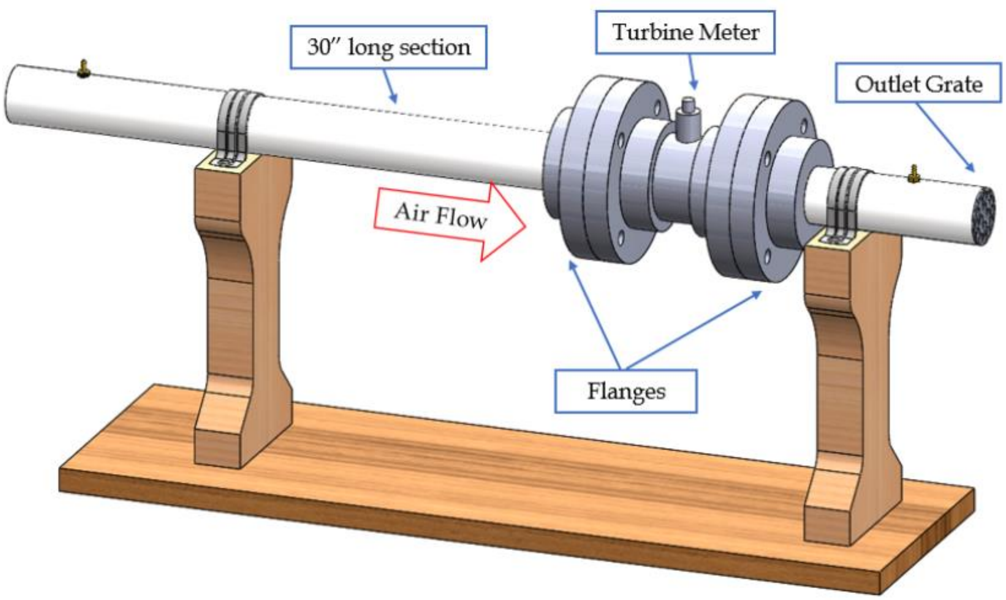

Figure 8. Turbine meter test section.

One of the primary limitations was size; the rig must be table-top size, less than 4ft by 8 ft. The overall length of the design is shown below in Figure 9; the largest parts are the two 30 inch sections required to get fully developed flow before the meters. Overall, the current length is about 8ft. Appendix B contains more complete assembly and part drawings. For portability, the rig has attached handles.

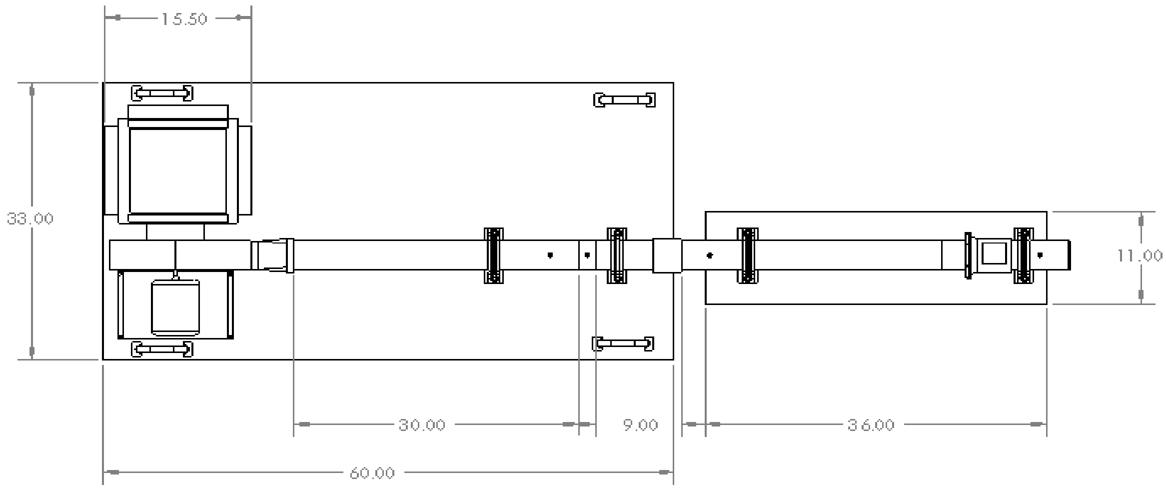

Figure 9. Top view of test rig, showing primary dimensions.

Blower Model Selection

With the layout determined and a system curve developed, the next step was to select a particular blower. Grainger Industrial Supply was the recommended distributor for this type of product. After discussing the design point with Grainger's technical support, the Dayton 7D749 blower was recommended. The blower curve for the 7D749 and the 7C744 along with the system curve seen in Figure 10 show that the system operates further down the 7D749 curve, matching better with the design requirements.

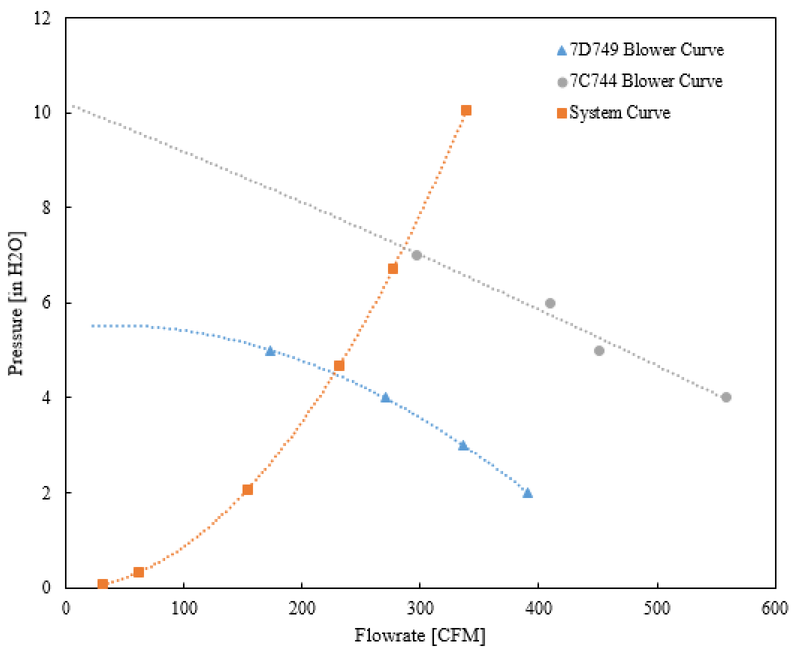

Figure 10. System curve along with 7D749 and 7C744 blower curves.

Methods of controlling the flow were also discussed with the Grainger tech support, who recommended simply restricting the inlet or outlet. Cincinnati Fan offers an attachment to their products that allows the operator to close a sheet of metal over the inlet, restricting the flow, seen in Figure 11 below. Grainger does not provide this option; creation of a functional restriction was done in house and modeled after the example in Figure 11.

Figure 11. Cincinnati fan inlet restriction valve. Image from www.cincinnatifan.com

In order to protect the system components such as the blower and UUTs from particles and debris, it was necessary to include a method of filtering the inlet air to the system. Dr. Westphal suggested a type of box filter assembly, with multiple faces of the box being filters. With 4 square feet of inlet area, it was found that the speed at each filter would only be 0.5 ft/s, making the minor losses at the filter almost insignificant when included with the losses through the UUT. A model of the filter box can be seen in Figure 12 below.

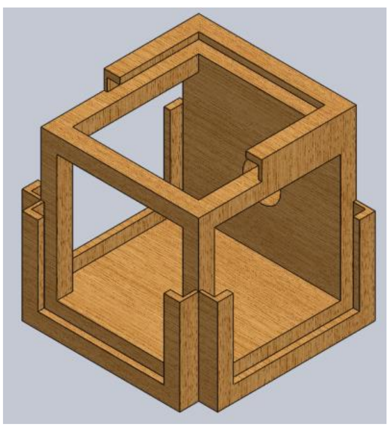

Figure 12. Preliminary design of filter box. The four faces are shown open and will contain replaceable filters.

Venturi Meter

A 3D rendered model of the Venturi meter is shown in Figure 13 along with the drawing from Amity Flow in Figure 14. Full data sheets from Amity Flow are located in Appendix D

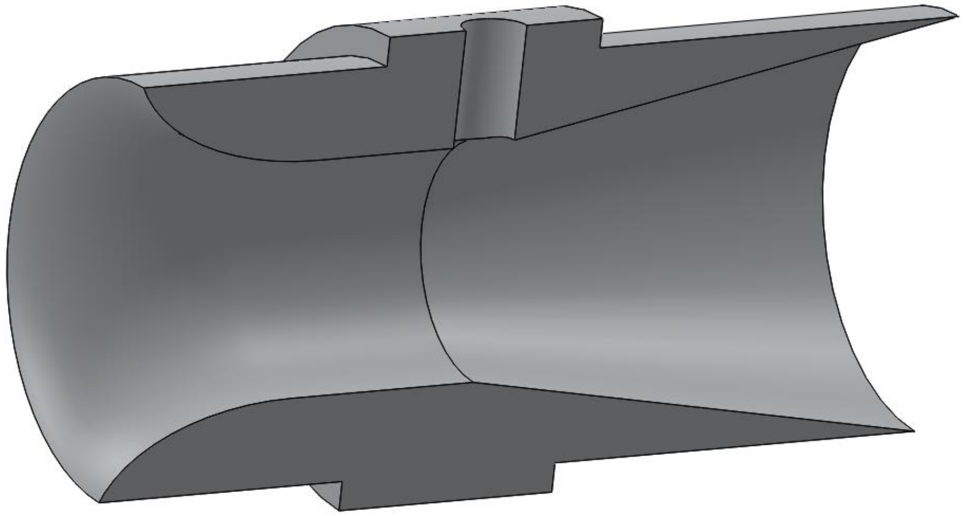

Figure 13. Section diagram of Venturi nozzle

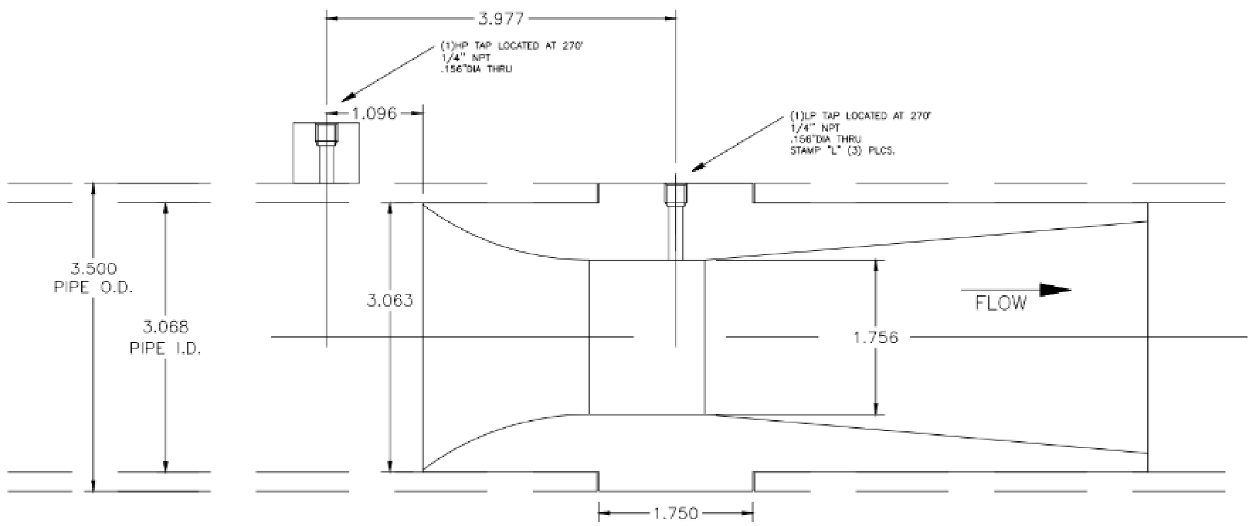

Figure 14. Venturi Nozzle Drawing from Amity Flow.

Mass Air Flow Sensor Model Selection

The MAF selected was a Cardone Reman sensor that will fit a 3.0L 1996 Ford Taurus engine. As described in the previous chapter, at 60 mph, this engine would intake about 130 cfm of air. A MAF adapter from Speed by Spectre is bolted so that both sides of the MAF can connect to 3" pipe. Pictures of both can be seen in Figure 15.

Figure 15. Cardone Reman MAF (left), Spectre MAF Adapter (right)

Turbine Meter Sensor Model Selection

Unfortunately, a 3" turbine meter would have been too expensive; Hoffer Flow meters had the least expensive 3" sizes at $1000 each. Instead, a 2" size from Blancett is adopted, though is only mildly less expensive at $877 for their Gas Quiksert B142-20M model, shown in Figure 16. At a 2" line size, a 3"-2" Flexible coupler is necessary to maintain quick swapping. The turbine meter bolts to two ANSI PVC raised face flanges of which both have Female NPT connections and require 2" Male NPT connections on any adjoining pipe.

Figure 16. Dimensioning of Gas Quiksert B142-20M

Design Safety

In addition to ensuring the rig works, a few safety precautions have been implemented. These include making sure the blower cannot harm the user during operation, cannot be used for a reason other than the experiment. The moving parts of the blower are covered by the filter box, so that the blower cannot harm the operator.

To prevent foreign objects from entering the rig and being launched, wire mesh has been added to the end of the rig. Though a mesh screen won't prevent a tenacious person from putting debris in the pipe, it will hinder enough that it won't be an issue. Also, by preventing foreign objects from entering the flow, the wire mesh reduces the chance the end gets clogged, which would pressurize the system. If the system is clogged, though, the maximum pressure delivered by the blower is estimated to be about 5.5 inH_2O, obtained from the specifications from the distributor and the blower curve seen in Appendix D. This pressure corresponds to about 0.2 psi, which was determined to be a safe overpressure given the pipe has a max operating pressure of 260 psi from Georg Fischer Harvel.

Chapter 5: Product Realization

The first stage of creating the test rig was construction of the base assembly. This was done as the base assembly doesn't change with each setup and must be properly aligned with each of the modular sections. Other than shortening pressure taps for pressure readings, PVC and wood were the only materials requiring modifications after acquisition.

Plywood Bases

The base was made of plywood and painted for appearance and splinter reduction. On the perimeter of the underside of the base, 2" x 2"s were added to raise the base so that the motor housing bolts could pass through the plywood and properly secure the blower. The 4ft x 8ft plywood in Figure 17 shows the cuts made for the woodworked parts.

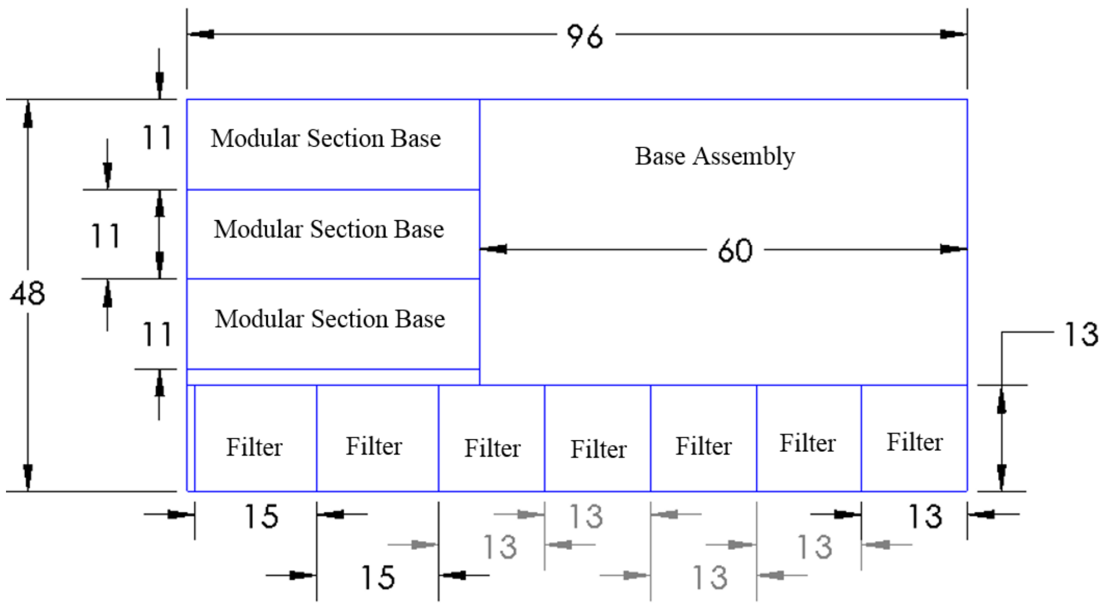

Figure 17. Cuts made on Plywood (dimensions in inches).

Filter Box

The next steps in building the base was constructing the filter box. To do this, three of the 13" square pieces as well as a 13" x 15" piece for the top of the box have an 11" inch square hole cut for airflow, using a handheld jigsaw. The last 13" square side was cut to fit around the inlet to the blower. The circular inlet was outlined to match to the height of the blower inlet and cut out with a scroll saw.

With all of the faces of the box constructed, two brackets to hold each of the filters to the box were cut from 1" x 2" lumber. Each of the filters are 1" thick so the wood was cut with slots 7/8" tall and 3/8" deep. Before attaching the brackets to the faces, the box faces and brackets are all lightly sanded and spray painted to minimize splinters. Once prepped, the brackets were lined up on the faces using the filters and secured using wood glue. With every part cut and spray painted, the faces of the box are combined into box form using thin finishing nails.

For this rig, a gate valve was chosen to limit flow, allowing for the greatest range of flow rates. In order to incorporate this into the filter box, material was added to the outlet of the box. Constructing this required a gate (rectangular sheet metal), and wood for the bonnet (enclosure). Additionally, a ring of wood was cut as a collar to fit over the blower inlet and connect to the filter box. The collar is glued to the back of the filter box, checking the gate can still slide up and down as shown in Figure 18 below.

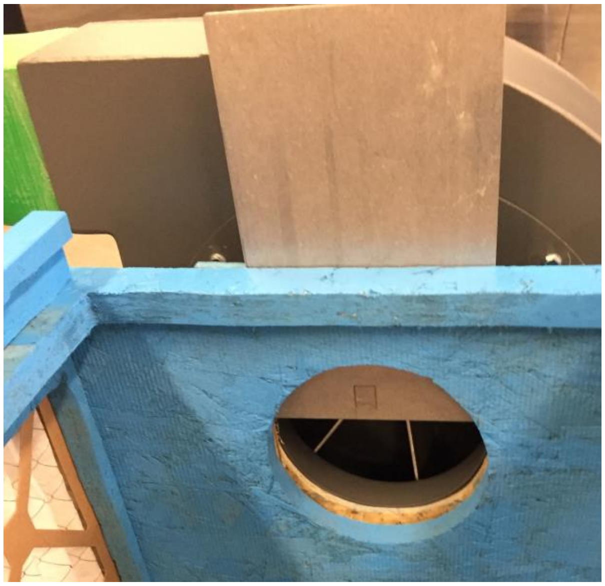

Figure 18. The gate valve restricts airflow into the blower, shown half-open.

Supports

Supports are needed to ensure all piping is straight and level for easy connection. Since the turbine meter connects with 2" pipe, not all supports are the same height or design. The base material used for the supports were two 6-foot-long 2"x6" s. In total, there are 6 supports (2 per section of piping) for 3" pipe and 2 for 2" pipe. The supports have minimal loading conditions, mostly hollow PVC, but there must be two per piping section to prevent one becoming a pivot. As a designed part, there are a few critical dimensions though the numerical values will depend on pipe size. The primary driving dimension is height, where the pipe center of the UUT section must line up with the base assembly. Secondary is width across the top of the support to ensure proper securement of the pipe. Third, the geometry of the support must lend itself to proper base securement; the screws must be able to go through both support and the plywood of the base. These notable dimensions are outlined in Figure 19. For dimensions used in construction of project supports, see part drawings in Appendix B.

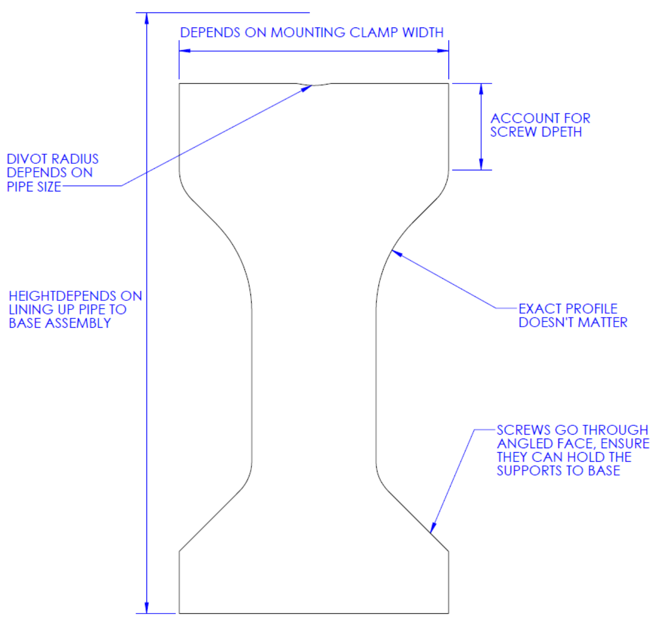

Figure 19. Guideline dimensions for building wooden supports.

Piping

PVC pipe was used to channel flow through the various flow meters. There are three sections of 3" pipe cut to be at least 30" long each. These were placed prior to the flow meters to ensure fully developed flow. Holes for pressure taps were drilled in each section to fit the threaded end of barbed hose fittings with very little clearance. There are two holes in the section for the blank module, as close to 30" apart as possible. The holes were placed such that the flexible coupling does not interfere. The pre-UUT sections have one hole drilled near the beginning of the 30" long inlet and one in the outlet. The section that precedes the Venturi meter was carefully measured so that the pipe pressure tap is 3.977" inches from the tap hole machined into the Venturi, according to Amity Flow specifications. The upstream end of the long section into the Venturi was sanded down so that it tapered into the transition piece and could be epoxied into place.

To attach the pressure taps, the threaded end of each tap had a few threads machined off so that it would not extend into the pipe and interrupt the flow. The amount machined off depended upon what size pipe the tap was going to be fixed into. Once the pressure taps were readied, they were epoxied into the holes in the pipes, making sure to remove any extra epoxy on the interior of the pipe.

Constructing the Base Assembly

The blower was the primary step in construction of the base assembly. It was secured to the base plywood with 1 ½" long, 5/16 -18 bolts, leaving enough space for the filter box and two handles. The blower chosen was the Dayton 7D749, which can run on wall-outlet voltages and has a full load current of 5Amps. It was installed into the system using the provided instructions (see Appendix D). The motor was wired for 115 VAC clockwise, and a switch with thermal overload protection was wired in. A NEMA 1 switch was chosen due to the lab environment with thermal overload protection rated for 4.91-5.35 Amps.

Once the blower was secure, the filter box was also added to the base. The outlet was fit over the blower inlet and the box was nailed into place using slender finishing nails. With the airflow entrance and air mover fixed in place, the transition piece and upstream Venturi pipe could be fitted. The primary goal was to level the pipe so that the entire system would easily fit together. When level, it was discovered that the supports were too short, and leftover wood was glued to the bottom to add height. When the pipe was properly leveled in the supports, the transition piece was epoxied to the blower for additional securement. The two locations for base assembly supports are prior to the Venturi meter and under the Venturi outlet section, the Venturi has not been attached to the pipe at this point, but the close fit allowed it to stay together without encouragement. The exact location along the pipe does not matter, though it is important that there are two supports and they do not interfere with the coupler at the outlet or any of the pressure taps. . At this point, the Venturi meter was placed within the pipe and attached using the PVC primer and cement, with the pressure tap vertical. The free end of the Venturi was then attached with the primer and cement to one of the two short pipe pieces. Mounting clamps were placed over the pipe at each support. The mounting clamps were attached to the supports using wood screws. Lastly, a flexible coupler was fit over the free end of the pipe. At this point, the calibrating, unchanging portion of the test rig is complete, with a coupler for easy interchanging of sections.

Mass Air Flow Sensor

The 1996 Ford Taurus mass air flow sensor supplied has 4 outputs, while the sensor connector from RockAuto came with 6 wires. The outer 2 wires, shown as 1 and 6 in Figure 20, are used for the air intake temperature, which are not used for this make and model. In Figure 20, wire 4 is a ground from the Engine Control Unit of the Taurus but is not used for this setup. Wire 2 is the 12V power supply, wire 3 is the power supply ground, and wire 5 is the output voltage.

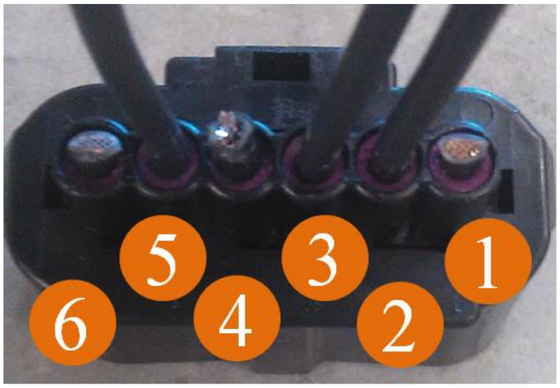

Figure 20. MAF Sensor Circuit Description.

A 12 volt wall wart was used for the MAF power input. A wiring diagram is shown in Figure 21, showing how the wires were soldered together. Wires with banana plug ends were soldered in to be terminals A and B.

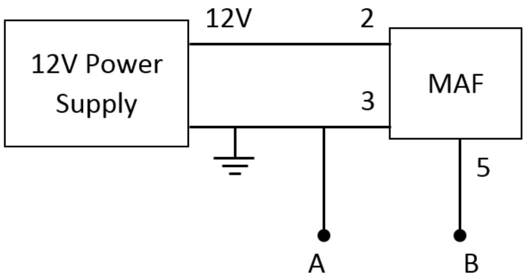

Figure 21. Wiring diagram for the MAF.

The MAF requires an adapter to fit with the 3" PVC pipe, both pictured in Figure 22. The adapter was secured to the MAF using ½" long ¼-20 bolts. The adapter was inserted into the upstream pipe, it had minimal clearance and was epoxied into place. The MAF outlet was secured to the outlet section of PVC using a 3" flexible coupler. The outlet section was pressure tapped and a mesh screen epoxied to the end.

Figure 22. MAF piping.

With the MAF pipe section assembled, it was placed into supports on the UUT plywood base. Proper alignment was ensured by attaching the MAF pipe section inlet to the base assembly outlet and leveling the pipe of the MAF section. The supports were located so that they did not interfere with the pressure taps. They were screwed into the base plywood and the PVC was secured to supports with mounting clamps.

Figure 23. Test rig set up with MAF section attached.

Blank Section

This section of the test rig will be used to compare pressure head losses from each section of pipe. It was the simplest section to assemble. Once pressure tapped, the singular section of PVC was placed in supports on the UUT base plywood and secured with mounting clamps similarly to the MAF section. The final assembly is shown in Figure 24.

Figure 24. Blank Section, inlet to the right.

Recommendations for future manufacturing (of UUTs)

Since the purpose of this project is expose students to a variety of flow metering devices, being able to increase device variety is important. As of now, the only flow device built is the MAF; though the support pieces for a turbine meter are constructed, the turbine meter itself has not been ordered. With a flexible coupler at the end of the base assembly, incorporating other devices is made simple. A few recommendations of devices to add in the future are the turbine meter, a rotameter (variable area meter), or an ultrasonic flow meter. Each addition will have the same general layout; a few construction guidelines are listed below:

- Include a long section of pipe to ensure fully developed flow entering the flow meter.
- The supports have driving dimensions based on the pipe used, they must be designed to accommodate.
- The plywood for the UUT section must be long enough for the piping, and have 2x2's added to the base to ensure it is the proper height.
- Level supports and ensure pipe rests evenly and lines up with the base assembly.
- Do any necessary setup for the particular device as prescribed by the manufacturer. This includes wiring, gluing, and bolting flanges or adapters.
- Permanently attach device to pipe so that the UUT section is a singular, solid unit.
- Be sure that mounting clamp/support location does not interfere with the UUT or pressure taps.

Chapter 6: Design Verification (Testing)

In order to verify the operating conditions, it was necessary to run sample tests and develop a calibration curve for the MAF. Before connecting any modular section to the base assembly, a test was run to verify the system can operate at the desired 75 ft/s. Using a Dwyer manometer from the ME 347 laboratory, the pressure difference across the Venturi meter was collected as the blower was set to different air flows. In Figure 25 below, the manometer can be seen hooked up to the Venturi pressure taps.

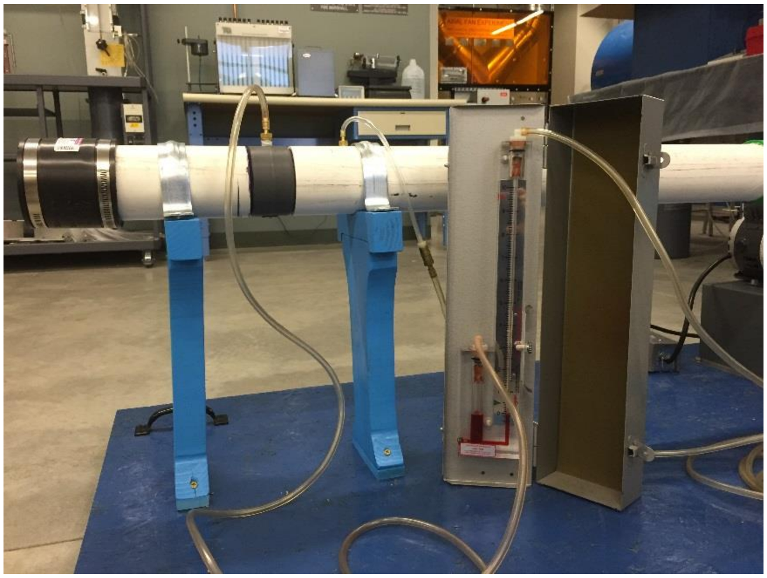

Figure 25. Venturi meter connected to Dwyer manometer.

After the manometer was hooked up, the blower was turned on with the gate valve fully closed. The gate valve was opened incrementally while data was collected. Using Equation 1, the air velocity in the 3'' section of pipe was determined. The pressure difference (in inH_2O), the volumetric flowrate (in CFM), and the air velocity in the 3'' section (in ft/s) can be seen in Figure 26. It can be seen that the base section sees speeds as high as 63 ft/s (194 cfm) and when the gate valve is fully closed, the speed is 23 ft/s (72 cfm).

$$Q = C_D\, A_{throat} \sqrt{\frac{2\Delta p}{\rho(1-\beta^4)}}$$

Equation 1. Calculation of air velocity from pressure difference.

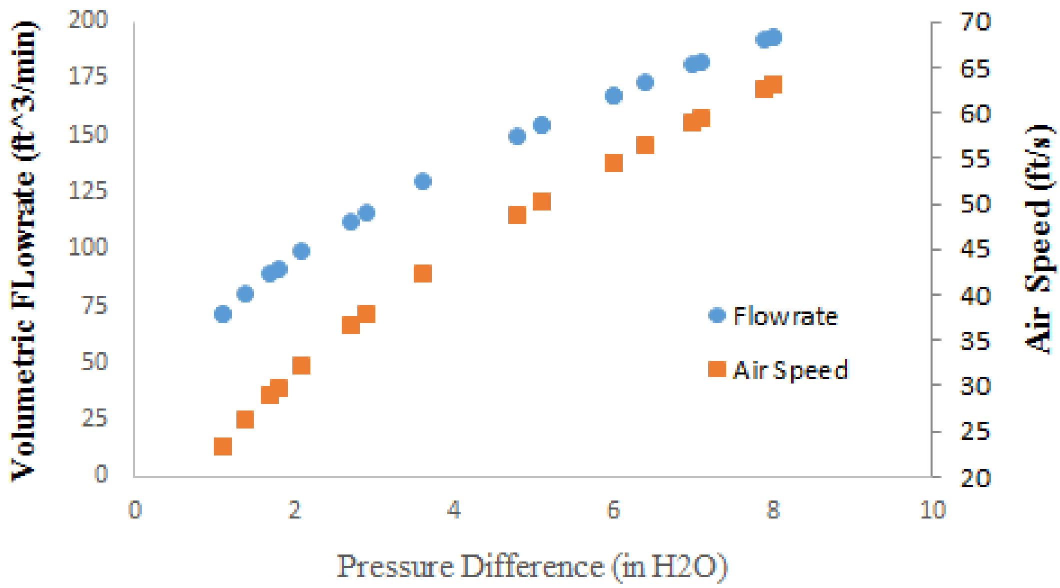

Figure 26. MAF Sensor Circuit Description

Next, the MAF module was connected so that a sample calibration curve could be determined for the device. In order to prevent damage to the MAF, it is necessary that power supply for the MAF is not connected until the blower is turned on. First the blower was turned on, then the power supply was connected and sample data was taken. This sample data can be seen in Appendix E. Using the velocity found with the Venturi nozzle as described above, it is possible to calibrate the voltage output of the MAF to corresponding flow rates. A calibration curve can be seen in Figure 27 below. Flowrate in CFM was plotted as a function of voltage to show the relationship between the two. The slope of this curve represents the MAF calibration constant.

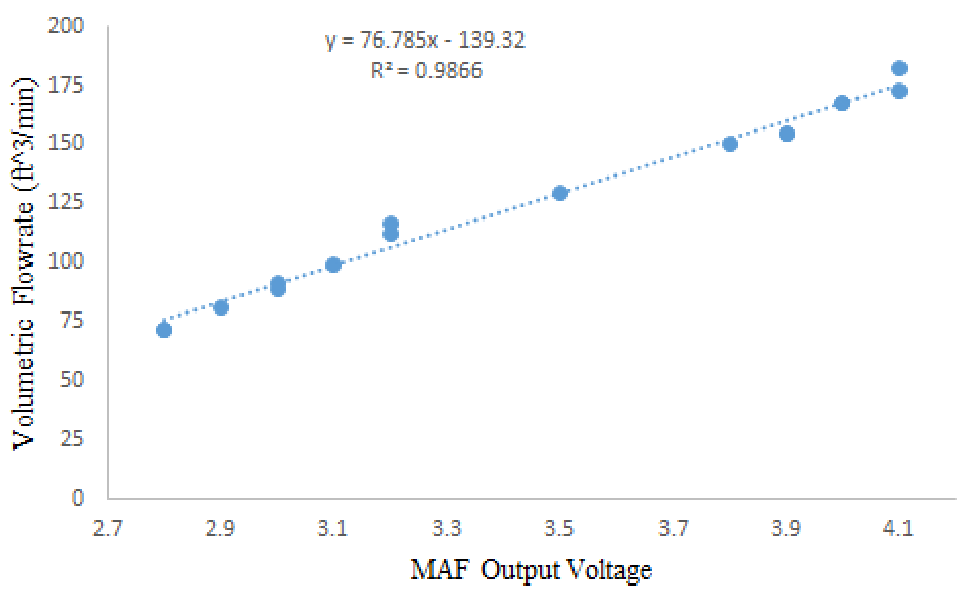

Figure 27. Calibration curve for MAF voltage output.

With the MAF section attached, the maximum output of the blower is different than just the base assembly. When the gate valve was fully closed, the velocity going through the pipe was about 23 ft/s (72 cfm), while the velocity when the gate valve was fully open was about 63 ft/s (194 cfm). It is interesting to notice, though, that the readings from the MAF seem to lose linearity around 4.1 Volts, corresponding to about 56 ft/s (170 cfm). Given that the voltmeter is working correctly, this implies that the MAF cannot accurately read air velocities higher than 56 ft/s (170 cfm).

Chapter 7: Conclusions and Recommendations

This project was intended to give students in the ME 347 Laboratory exposure to the different types of metering devices used to measure air speed in a pipe, experimenting over a range of velocities. The device is functional and has two modular sections (MAF and blank) that are ready to be used as a part of the experiment. The base assembly (filter, blower, and Venturi meter) sees velocities as high as 75 ft/s, while the assembly with the MAF section attached sees a maximum velocity of about 63 ft/s and as low as 23 ft/s. Even though the blower can get the speed to 63 ft/s with the MAF section attached, the voltage output of the MAF loses linearity at an airspeed of about 56 ft/s.

The modular characteristic of this project lends itself to the addition of units under test that would expose students to more methods of air velocity measurement. Additionally, the design for this project also includes a turbine meter 2’’ pipe unit, but the turbine meter was never purchased. The base, supports, and pipe were cut to size, drilled and are nearly ready for assembly whenever the turbine meter is purchased.

When continuing to make modular sections, it would be more convenient to keep the distance of the pressure taps on each unit consistent. The blank section does not have the same distance as the MAF unit, but going forward the comparison of pressure losses would be most intuitively seen if the distances were the same as the MAF.

While running tests on the device, there was access to only one manometer with tube connections. In order to run the test completely, it is necessary to have at least two manometers, one for the Venturi meter and one to collect pressure data on the modular unit. There are other manometers in the laboratory that could be used, but it would be necessary to produce tubing with the right size considering the manometer input taps are different sizes than the pressure taps on the units.

The set-up for this experiment is designed to be as accessible as possible for students; a detailed operating manual is included in Appendix G. It will be exciting to learn that students are using this test rig as a part of the curriculum.

Appendix A: References

1. Beebe, Stanley Ikuo. “Hole-Type Aerospike Compound Nozzle Thrust Vectoring.” Diss. California Polytechnic State University, San Luis Obispo, 2009. Web.

2. “Calibration of Turbine Meters.” *Physical Measurement Library*. The National Institute of Standards and Technology. 9 Sept 2015. Web. 13 Nov 2015.

3. *Energo Flow.* Energoflow AG. 2015. Web. 22 Nov 2015.

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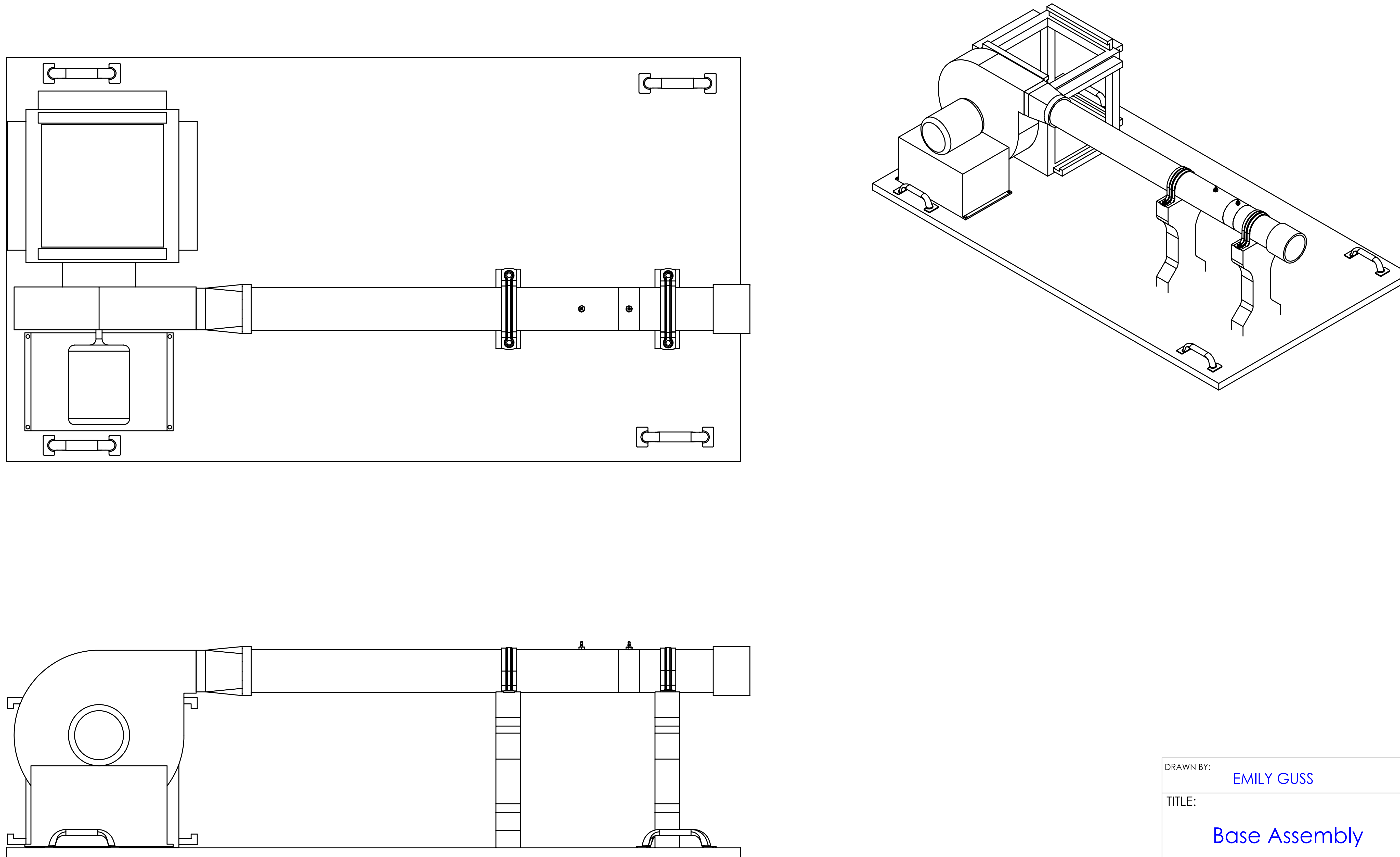
9. *Universal Flow Monitors.* Universal Flow Monitors, n.d.Web. 13 Nov. 2015.



DRAWN BY: EMILY GUSS

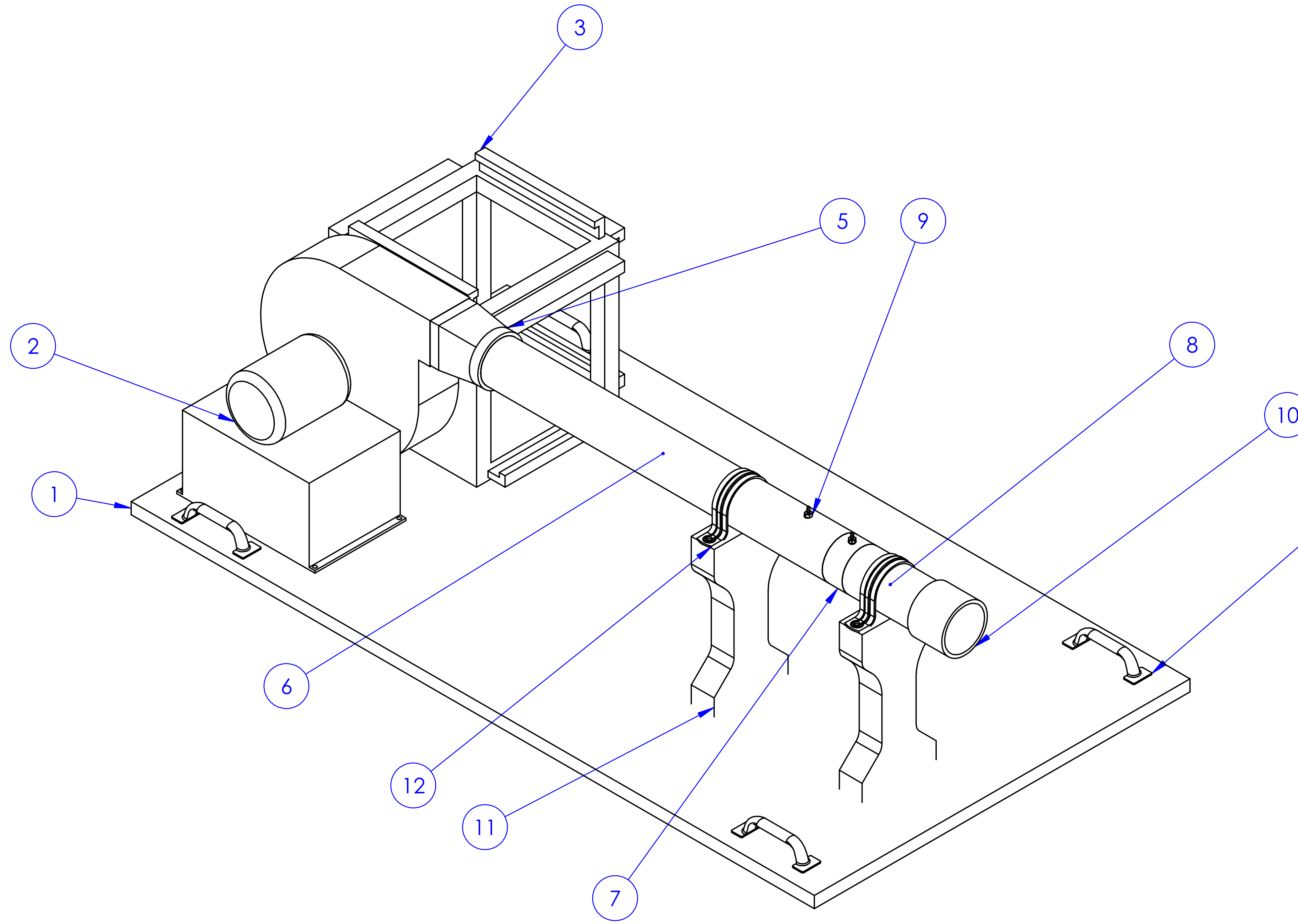
TITLE:

Base Assembly

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

SIZE	DWG. NO.	REV
B	FMTR-	

SCALE: 1=8   DATE: 6/3/2016



ITEM NO.	DESCRIPTION	QTY.
1	PlywoodBase	1
2	DaytonBlower	1
3	FilterBox	1
4	Handle	4
5	Transition Duct	1
6	3" Venturi Inlet Pipe	1
7	VentruiMeter	1
8	3" Venturi Outlet Pipe	1
9	PressureTap	2
10	Flexible Coupler	1
11	3" Support	2
12	3" Mounting Clamp	2

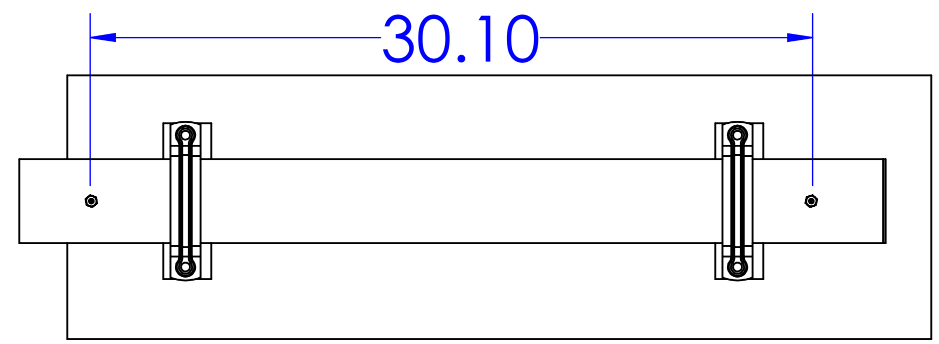
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

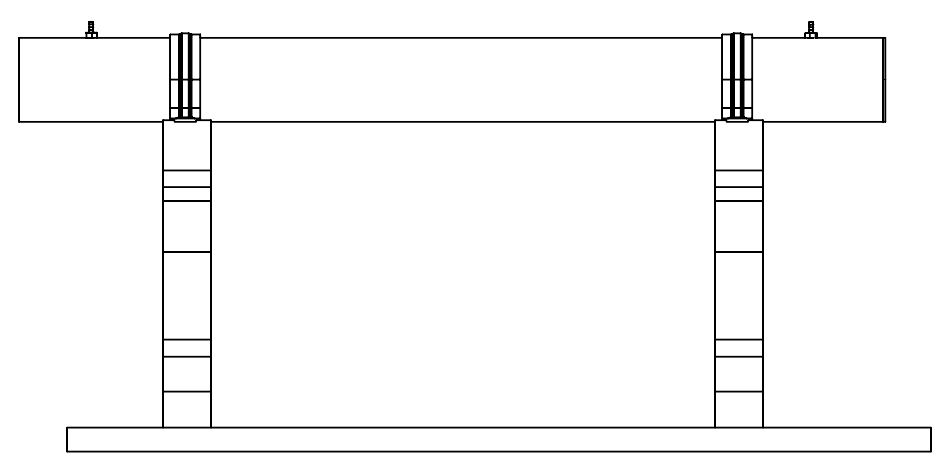
DRAWN BY: EMILY GUSS

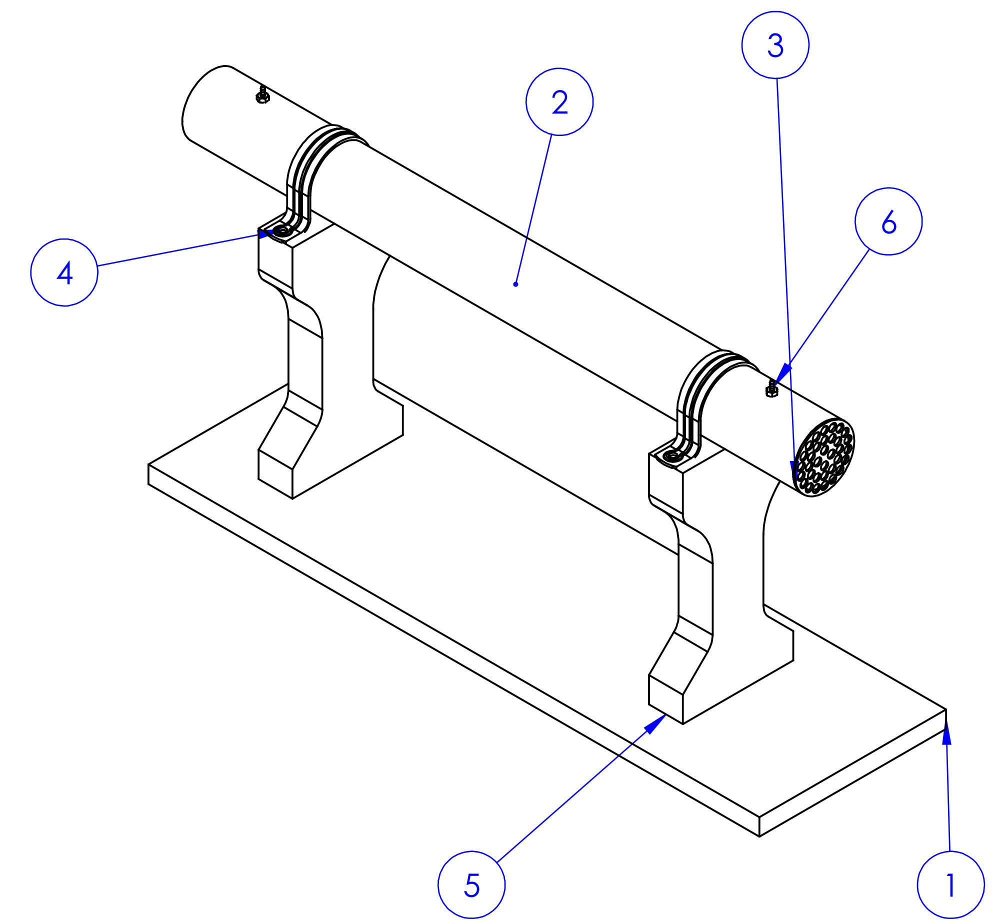
TITLE: Base Assembly W/BOM

SIZE: B | DWG. NO.: FMTR- | REV

SCALE: 1=8 | DATE: 6/5/2016







ITEM NO.	DESCRIPTION	QTY.
1	Plywood UUT Base	1
2	30" Long 3" PVC Pipe	1
3	3" End Grate	1
4	3" Mounting Clamp	2
5	3" Support	2
6	Pressure Tap	2

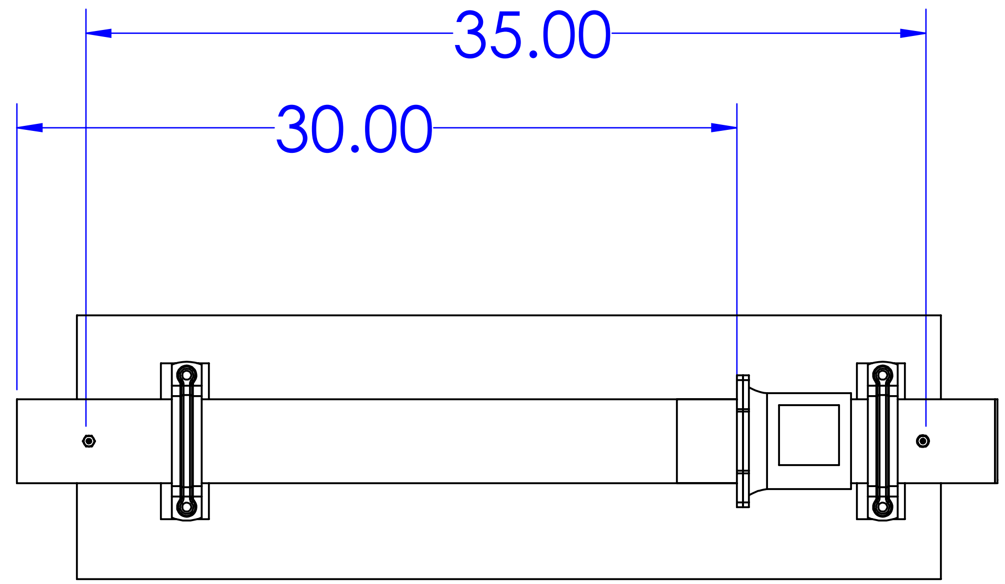
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

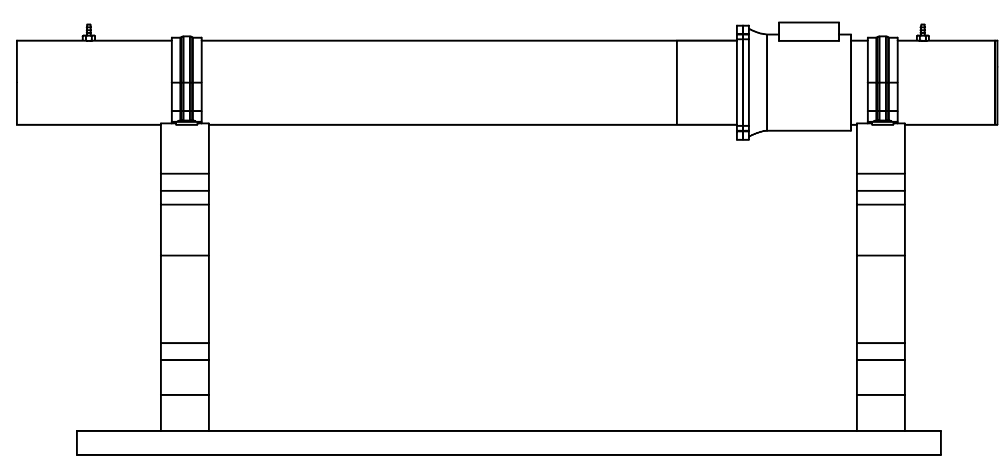
DRAWN BY: EMILY GUSS

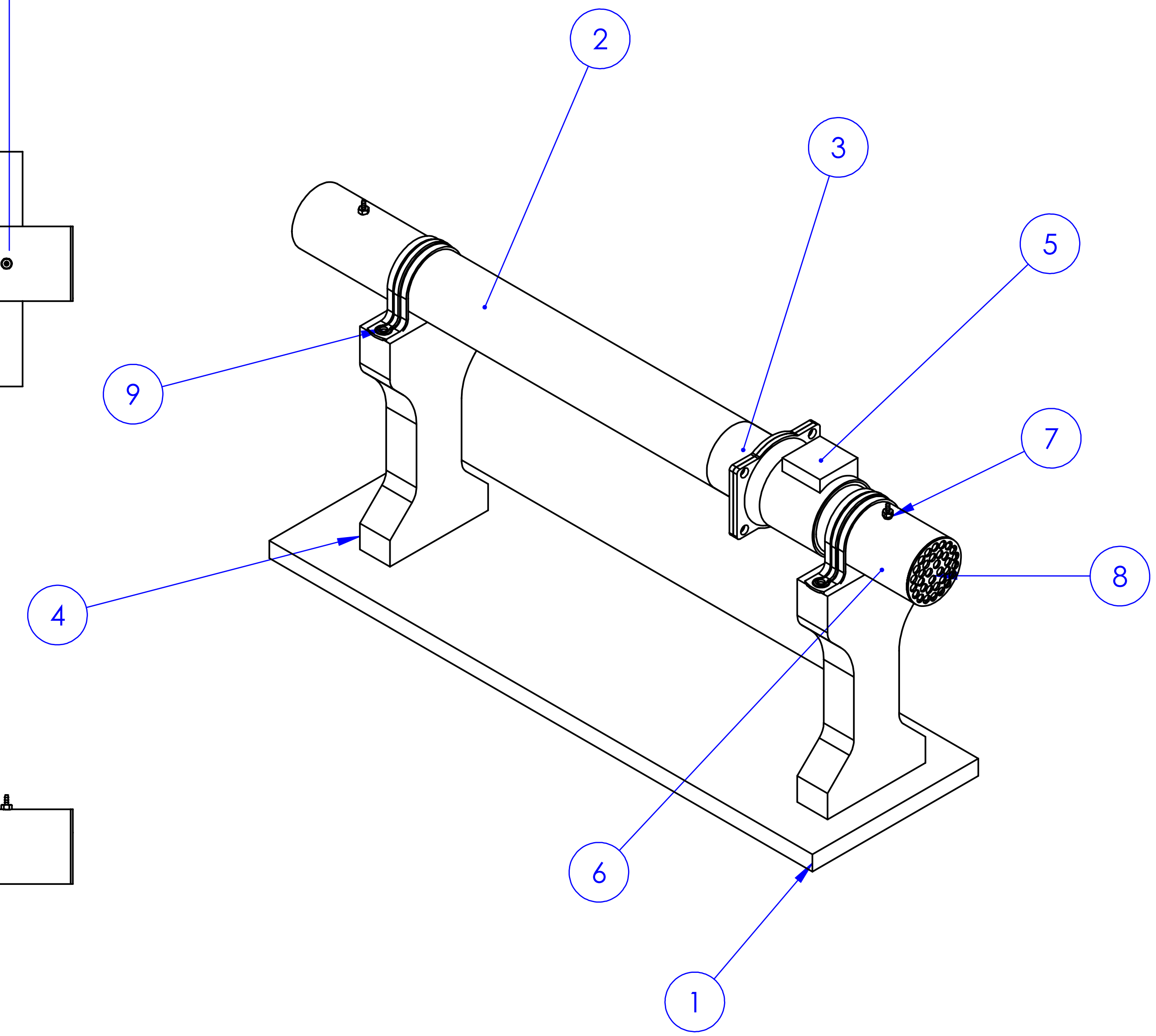
TITLE: Blank Section w/BOM

SIZE: B
DWG. NO.: FMTR-
REV

SCALE: 1=8
DATE: 6/5/2016







ITEM NO.	DESCRIPTION	QTY.
1	Plywood UUT Base	1
2	"3 MAF Inlet Pipe	1
3	MAF Adapter	1
4	3" Support	2
5	MAF	1
6	3" MAF Outlet Pipe	1
7	Pressure Tap	2
8	3" End Grate	1
9	3" Mounting Clamp	2

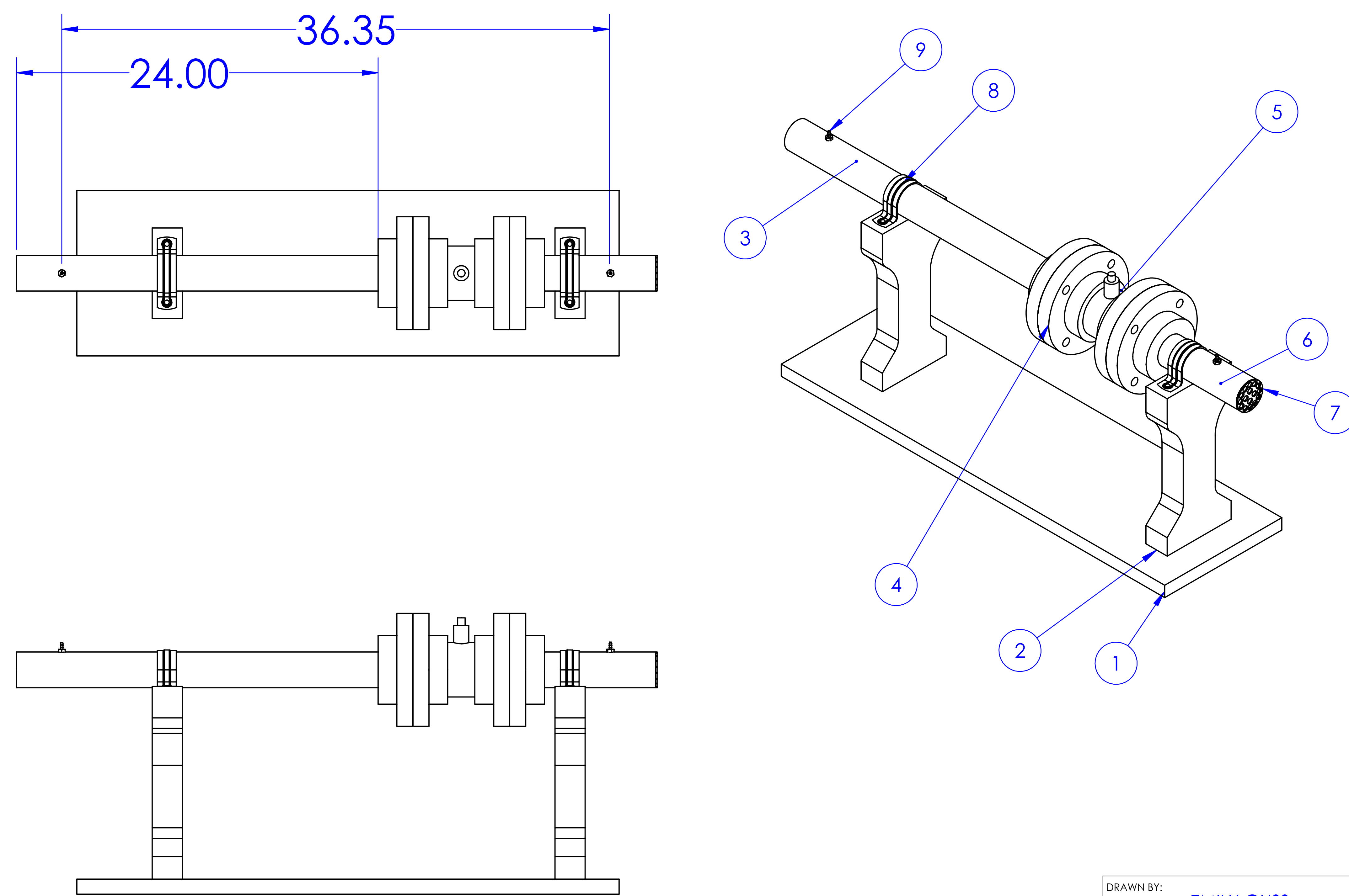
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

DRAWN BY: EMILY GUSS

TITLE: MAF Assembly w/BOM

SIZE: B | DWG. NO. FMTR- | REV

SCALE: | DATE: 6/3/2016



ITEM NO.	DESCRIPTION	QTY.
1	Plywood UUT Base	1
2	2" Support	2
3	2" Turbine Inlet Pipe	1
4	Turbine Flange	4
5	Turbine Meter	1
6	2" Turbine Outlet Pipe	1
7	2" End Grate	1
8	2" Mounting Clamp	2
9	Pressure Tap	2

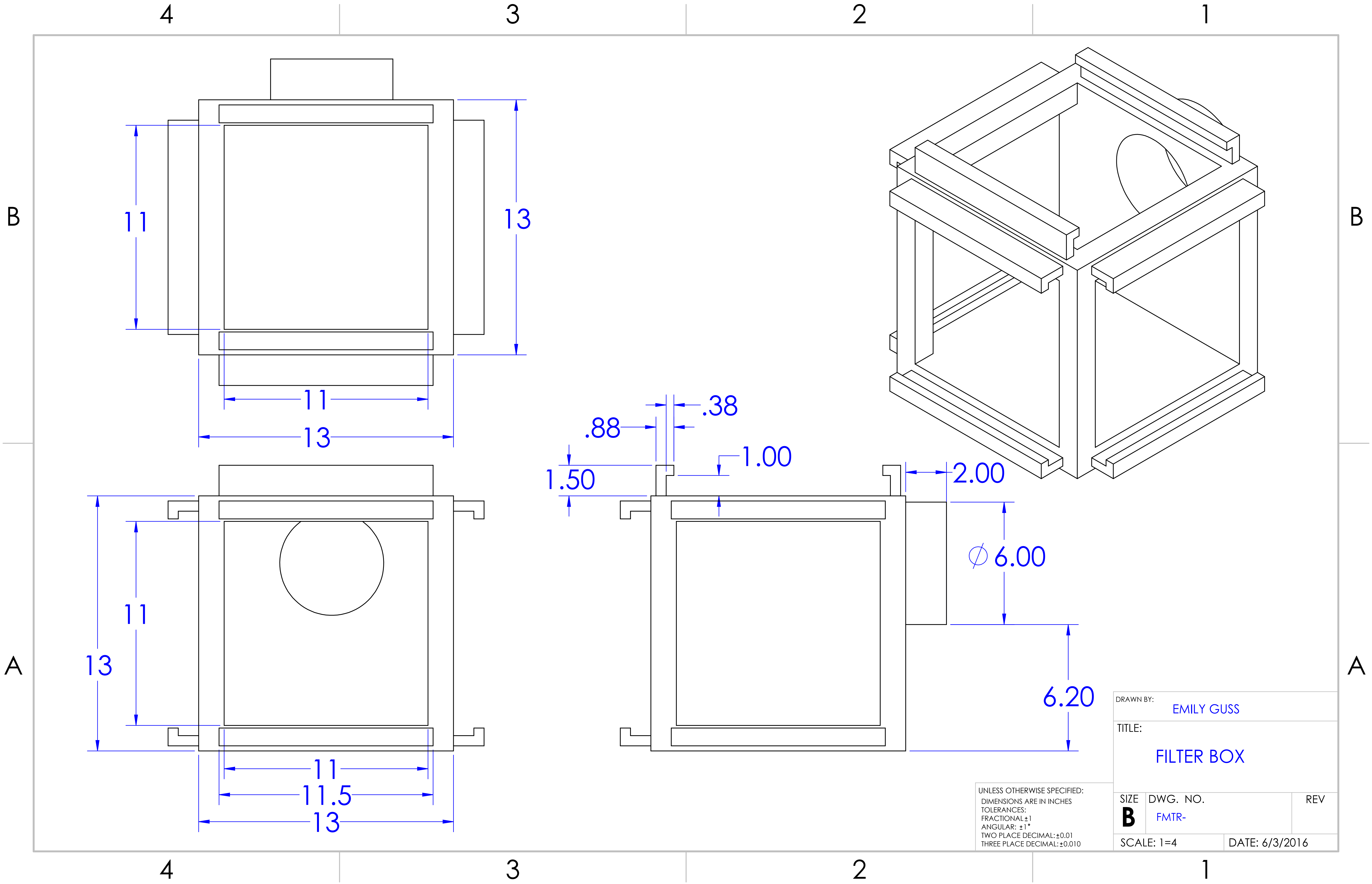
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

DRAWN BY: EMILY GUSS

TITLE: Turbine Meter Assembly w/BOM

SIZE: B
DWG. NO.: FMTR-
REV

SCALE: 1=8
DATE: 6/5/2016



DRAWN BY: EMILY GUSS

TITLE: FILTER BOX

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

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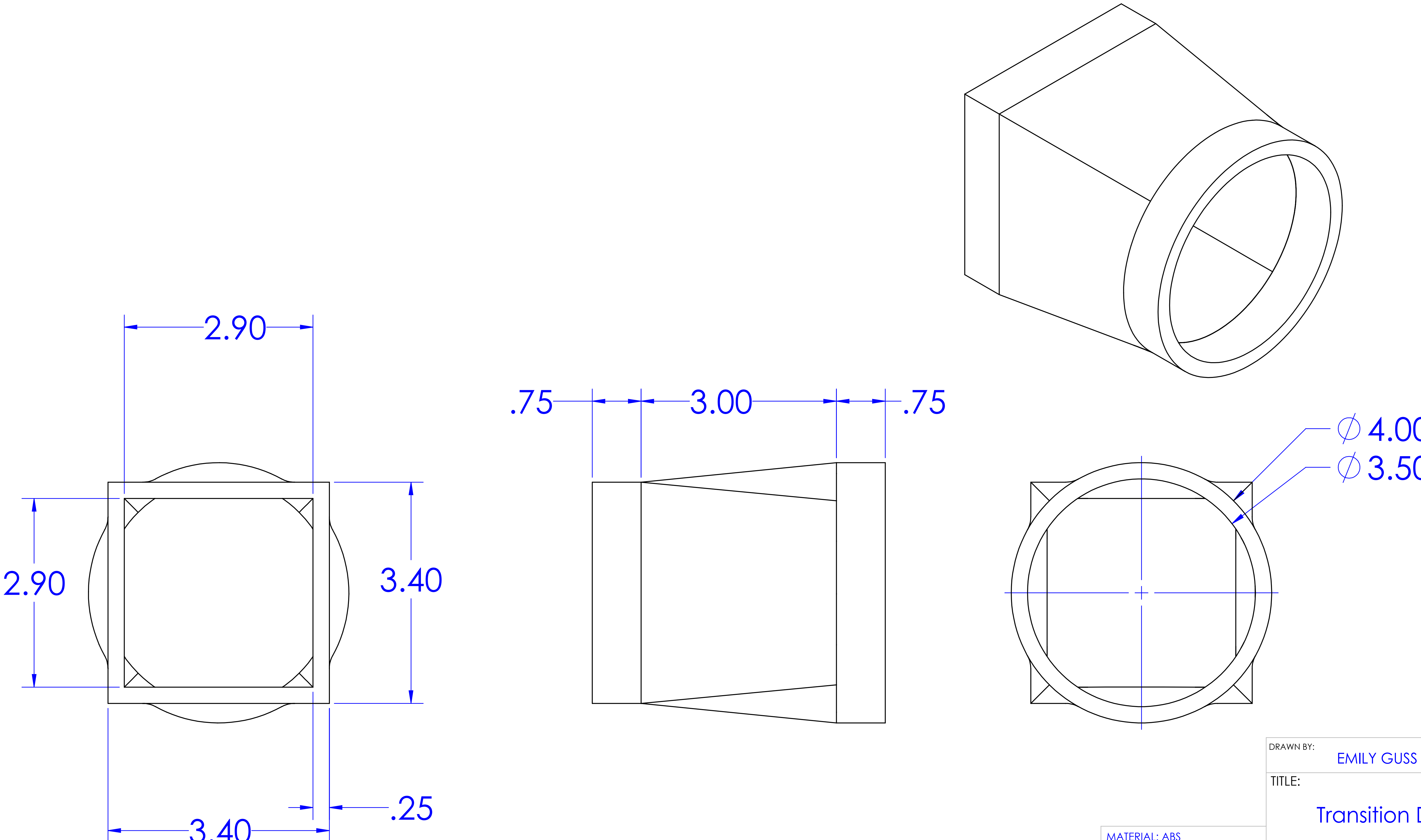
B	FMTR-	

SCALE: 1=4 DATE: 6/3/2016



DRAWN BY: EMILY GUSS

TITLE: Transition Duct

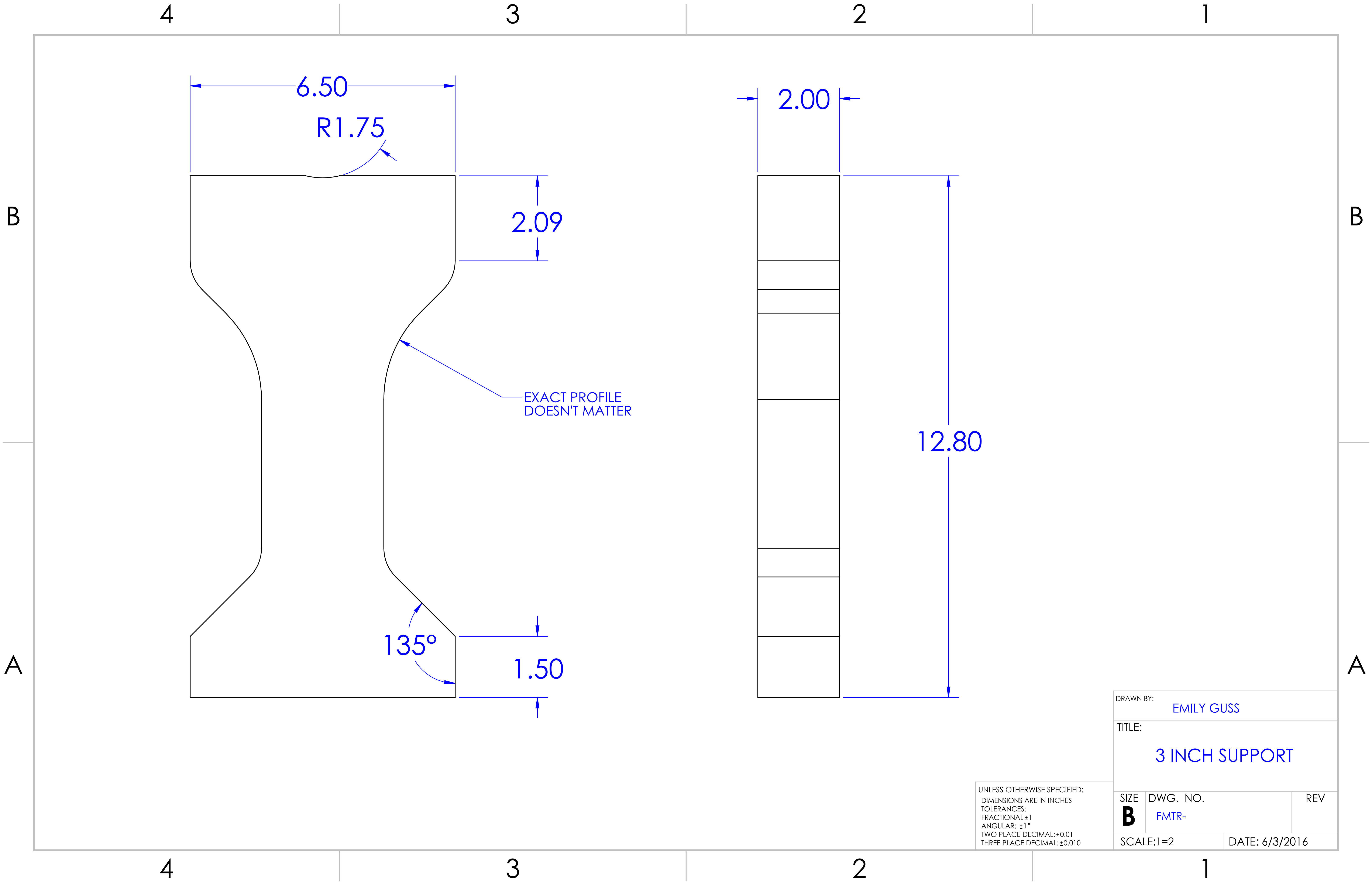
MATERIAL: ABS

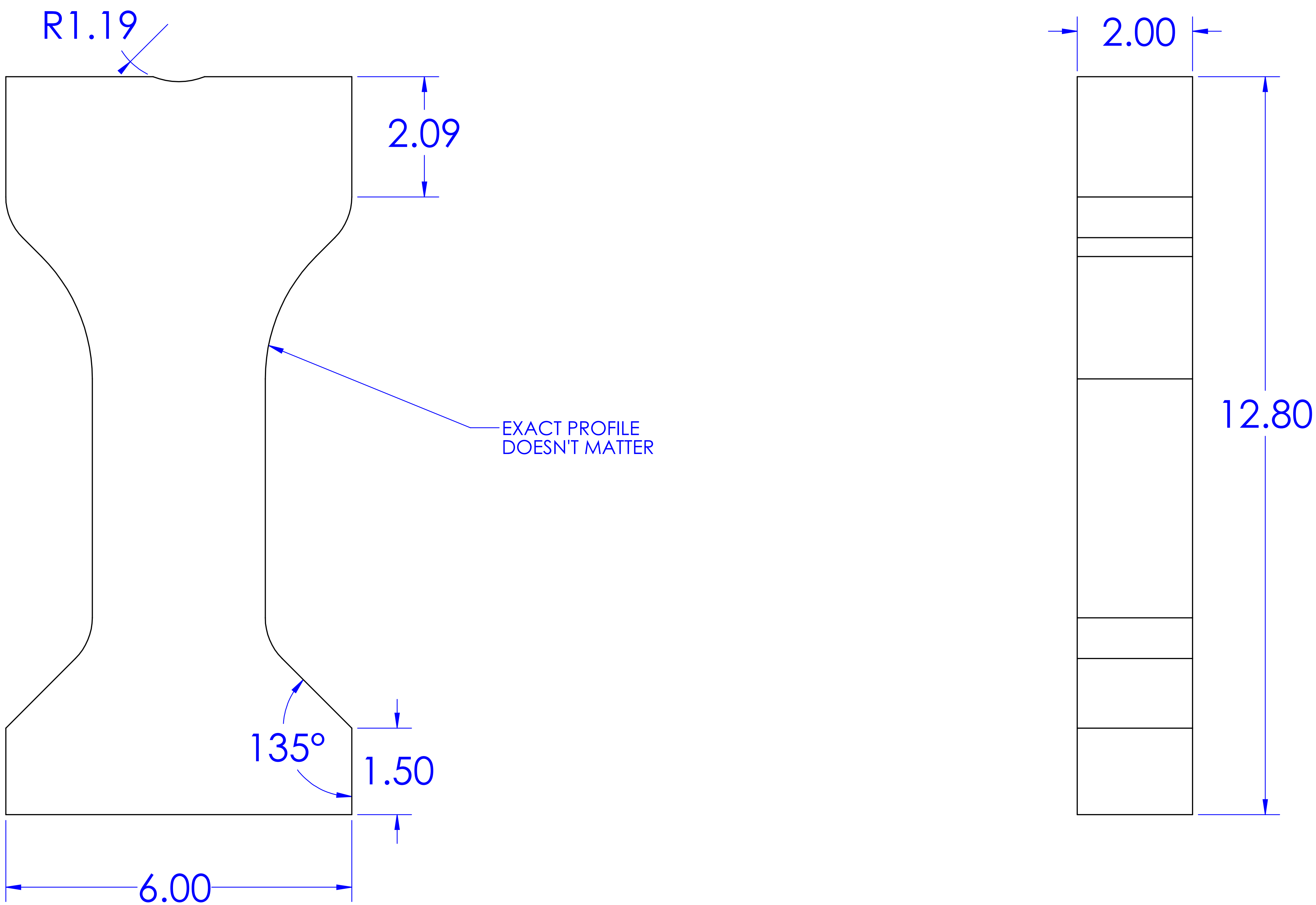
UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
ALL WALL THICKNESSES ARE 0.25in

SIZE: B | DWG. NO. FMTR- | REV

SCALE: 2=3 | DATE: 6/3/2016


4
3
2
1
B
A
6.50
R1.75
2.09
EXACT PROFILE
DOESN'T MATTER
135°
1.50
2.00
12.80
DRAWN BY:
EMILY GUSS
TITLE:
3 INCH SUPPORT
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010
SIZE
B
DWG. NO.
FMTR-
REV
SCALE:1=2
DATE: 6/3/2016



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1
ANGULAR: ±1°
TWO PLACE DECIMAL: ±0.01
THREE PLACE DECIMAL: ±0.010

DRAWN BY: EMILY GUSS

TITLE: 2 INCH SUPPORT

SIZE: B | DWG. NO.: FMTR- | REV

SCALE: 1=2 | DATE: 6/3/2016

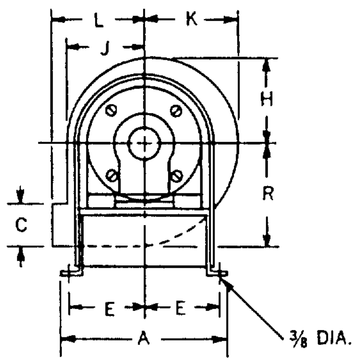
Part Number	Product	Vendor	Quantity
FMTR-001	ASME nozzle	Cal Poly ME Dept	1
FMTR-002	Wood support for 2" pipe	N/A	1
FMTR-003	Wood support for 3" pipe	N/A	7
FMTR-004	Square-to-circle transition	Cal Poly ME Dept	1
FMTR-005	Filter Box	N/A	1
FMTR-10	2"x6" (10ft long)	Home Depot	1
FMTR-11	Plywood 96"x48"x7/16"	Home Depot	1
FMTR-12	3" Conquest Bronze pull	Home Depot	4
FMTR-13	2" long philips 18-8 (pack of 25)	McMaster carr	1
FMTR-14	3" White Sch40 pipe	Ace Hardware	9
FMTR-15	5/8"-11 Low Strength Steel Cap Screw, 2.5" Long (10 pack)	McMaster Carr	1
FMTR-16	5/8"-11 Hex nuts (pack of 10)	McMaster Carr	1
FMTR-17	Steel bracket	McMaster Carr	7
FMTR-18	Thermoseal, Flange Gasket, 3", Green, 1/16"	Grainger	3
FMTR-19	Gray Sch80 flange for 3" pipe	McMaster Carr	3
FMTR-20	8oz pack purple primer & cement	Home Depot	1
FMTR-21	Speed by Spectre MAF Adapter	O'Reilley	1
FMTR-22	Ace 3x2 flexible coupling	Ace Hardware	1
FMTR-23	2" PVC Sch. 40	Ace Hardware	3
FMTR-24	3 in. x 3 in. PVC DWV Mechanical Flexible Coupling	Home Depot	2
FMTR-25	3" straight coupling	Ace Hardware	1
FMTR-26	Rheem Basic Household Air Filter 12"x12"x1"	Home Depot	4
FMTR-27	Garden Zone Hardware Cloth	Ace Hardware	1
FMTR-28	Blancett Gas QuikSert	Instrumart	1
FMTR-29	Cardone Reman	Morro Bay Autozone	1
FMTR-30	Dayton 7D749	Zoro	1
FMTR-31	2" PVC 150# Raised Face Solid ANSI Flange x FNPT	New Line Fitting	2
FMTR-32	Square DThermal Unit for Manual Motor Starter	Consolidated Eletrical	1
FMTR-33	Square D Manual Starter 277 VAC	Consolidated Eletrical	1
FMTR-34	Electrical Tape	N/A	1
FMTR-35	Teflon Pipe Tape	N/A	1
FMTR-36	Digital Multimeter	N/A	1
FMTR-37	Dwyer Oil Manometer	N/A	1

2C820

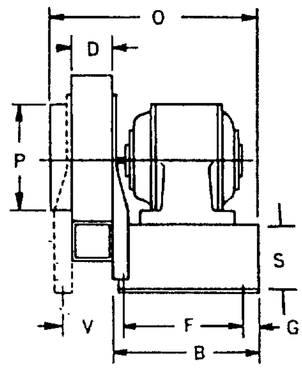
Centrifugal Blowers
Direct Drive Radial Blade

SPECIFICATION SHEET

Dayton



Side View



Front View

AVAILABLE FROM LOCAL STOCK

EXHAUST BLOWER FEATURES:

- Dynamically Balanced Cast Aluminum Radial Blade Wheel with Backplate
- 16 Gauge Housing and Motor Base
- Clockwise or Counter-Clockwise Rotation
- Housing Adjustable for Eight Discharge Positions
- Motors Packed Separately when Ordered
- Maximum Inlet Temperature is 180° F (82° C)
- Air Deliveries Based on Standard Test Codes of AMCA

OPTIONAL ACCESSORIES

- Vibration Isolators

DIMENSIONS (Side View)

Stock No.*	Wheel Size Dia	W	Bore	Motor Frame	A	C	E	H	J	K	L	R	Shpg. Wt.
2C940	7-3/4"	2-5/16"	1/2"	48	11"	3"	5"	5-3/8"	4-7/8"	5-7/8"	5-7/8"	6-5/8"	13.0
2C820	9	2-13/16	1/2	48	12-1/8	3-1/2	5-5/8	6-3/8	5-3/4	6-7/8	6-3/4	7-1/2	17.0
4C108	10-9/16	3	5/8	56	14-3/4	4	6-7/8	7-1/4	6-1/2	8	7-5/8	8-5/8	25.0
4C329	12-1/2	3	7/8	145T	17	5	8	8-1/4	7-1/2	9	9-5/8	10	37.0
4C330	13-1/2	4-3/8	1-1/8	182T	17-1/2	7-1/8	8	10-1/2	9-5/8	11-3/8	11	11-1/2	64.0

(*) Blower less motor and drive

DIMENSIONS (Front View)

Stock No.*	Wheel Dia	B	D	F	G	O	P	S	V	Optional Vibration Isolators No. Needed	Stock No.
2C940	7-3/4"	8"	3"	7"	1/2"	12-1/4"	4"	5-1/2"	—	4	4C950 or 4C954
2C820	9	8	3-1/2	7	1/2	12-3/4	5	6-3/8	—	4	4C950 or 4C954
4C108	10-9/16	9	4	7-1/2	3/4	14	6	8-1/4	—	4	4C950 or 4C954
4C329	12-1/2	11-1/4	5	9-3/4	3/4	17	7	7-1/8	—	4	4C950 or 4C954
4C330	13-1/2	11-1/4	7-1/8	9-1/2	1	18-7/8	8	8-1/8	7-1/4"	6	4C950 or 4C954

(*) Blower less motor and drive

PROJECT / LOCATION			ARCHITECT
CONTRACTOR	DATE	SUBMITTED BY	ENGINEER

SPECIFICATIONS		FAN					MOTOR	
FAN NO. / LOCATION	QTY.	STOCK NO.	CFM	SP	FAN RPM	SOUND RATING	HP	ELECTRICAL

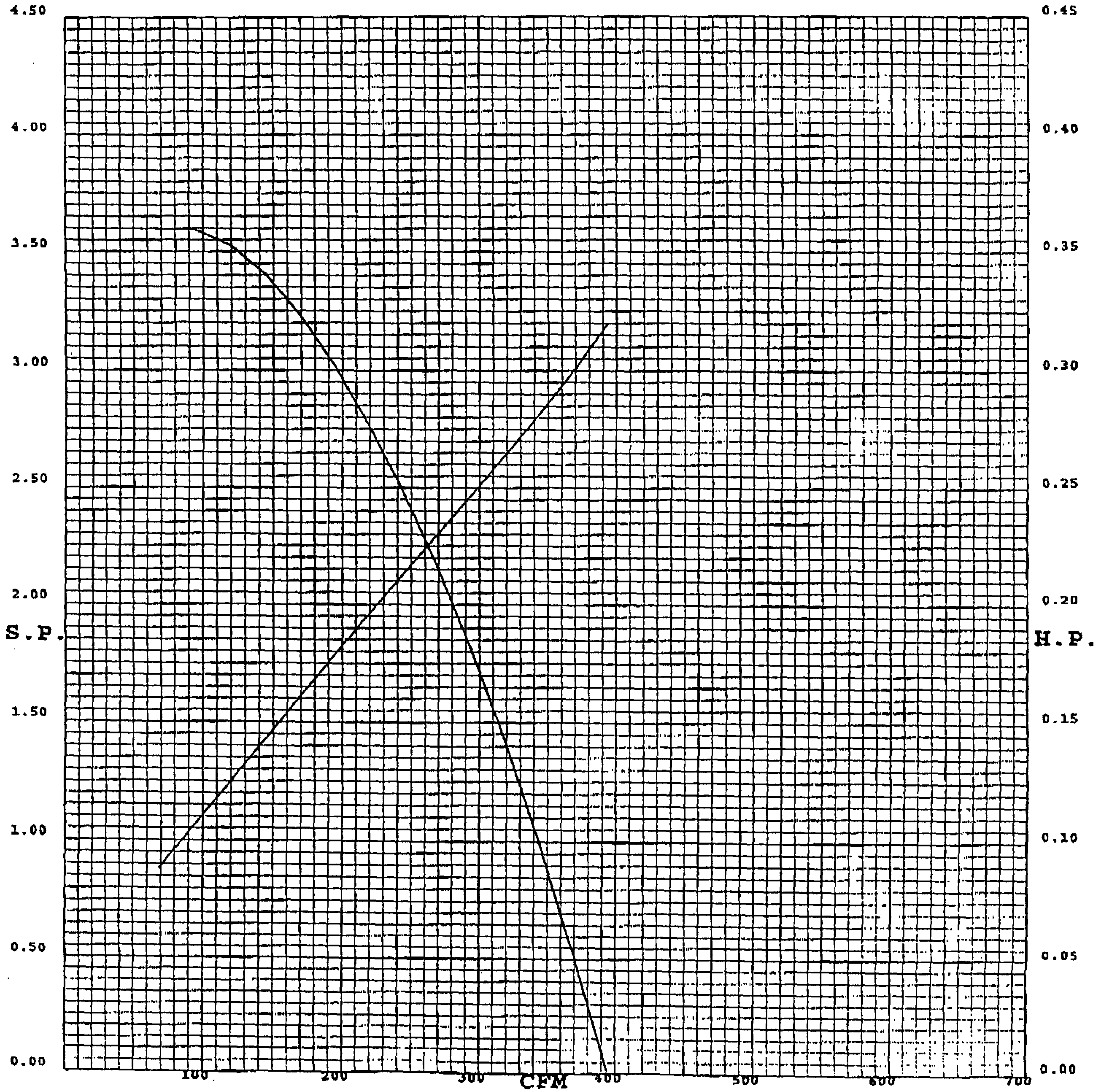
ACCESSORIES / NOTES

GRAINGER PART NO.	RPM.	dB (A) @ 5 FEET	MAXIMUM OPERATING TEMPERATURE IN °F
3C106	2811	89.5	250°
	3045	92.6	
	3341	94.6	
3C107	2257	90.8	250°
	2445	92.6	
	2711	94.8	
3C108	1883	92.0	250°
	2096	94.4	
	2250	95.9	
2C940	3450	74.0	*
2C820	3450	78.6	*
4C108	3450	83.6	*
4C329	3450	88.5	*
2C739	3450	88.5	
4C330	3450	90.9	*
2C652	3450	90.9	
4C129	3250	82.3	180°
	3500	83.9	
	3750	85.4	
	4000	86.8	
	4250	88.1	
	4625	90.0	
4C130	2810	82.7	180°
	3065	86.0	
	3250	87.3	
	3500	88.9	
	3860	91.0	
	3950	91.5	

* Maximum operating temperature determined by limitation of motor used.

PERFORMANCE CURVE

CUSTOMER: Grainger **CUSTOMER'S NO.:** 2C820
SIZE: PW 9 **AT:** 2850 **RPM**



TOTAL P.02

2C820

PERFORMANCE DATA

With Dripproof Motor Stock No.	With Totally Enclosed Motor Stock No.	Wheel Dia	Motor Data HP	Ph	Volts, 60 Hz	CFM @ SP Shown, 3450 RPM‡ 1" SP	2" SP	3" SP	4" SP	5" SP	6" SP	7" SP	8" SP	Shpg. Wt.
7C650*	7C481	7-3/4"	1/3	1	115/230	290	230	160	—	—	—	—	—	27.0
7C504*	7C483	9	1/3	1	115/230	530	470	415	335	165	—	—	—	31.0
7C447	—	10-9/16	1	1	115/230	800	745	680	610	510	375	225	—	49.0
7C741	—	10-9/16	1	3	200-230/460	800	745	680	610	510	375	225	—	47.0
7C561	—	12-1/2	3	3	200-230/460	1200	1140	1070	1010	940	870	790	695	73.0
7C562	7C487†	13-1/2	5	3	200-230/460	2140	2030	1930	1820	1710	1615	1500	1375	129.0

(*) 115V Motor only.
(†) 230-460V only.
(‡) Motor overload will result if blower is operated at static pressure below performance shown.

DISCLAIMER: Dayton Electric Manufacturing Co. has made a diligent effort to illustrate and describe the products in this literature accurately; however, such illustrations and descriptions are for the sole purpose of identification, and do not express or imply a warranty that the products are merchantable, or fit for a particular purpose, or that the products will necessarily conform to the illustrations or descriptions.

PRODUCT SUITABILITY: Many states and localities have codes and regulations governing sales, construction, installation, and/or use of products for certain purposes, which may vary from those in neighboring areas. While Dayton attempts to assure that its products comply with such codes, it cannot guarantee compliance, and cannot be responsible for how the product is installed or used. Before purchase and use of a product, please review the product application, and national and local codes and regulations, and be sure that the product, installation, and use will comply with them.

Manufactured for Dayton Electric MFG. Co., 5959 W. Howard St., Chicago, IL 60648

8S370, Edition 1 Litho in U.S.A. 92/0010 January 1992

Please read and save these instructions. Read carefully before attempting to assemble, install, operate or maintain the product described. Protect yourself and others by observing all safety information. Failure to comply with instructions could result in personal injury and/or property damage! Retain instructions for future reference.

Dayton® High Pressure Direct Drive Radial Blade Blowers

ENGLISH

ESPAÑOL

FRANÇAIS

Description

Dayton high pressure direct drive radial blade blowers are used for small exhaust systems where air is laden with dust or where dust-collection bags are necessary. Applications include handling long stringy material, paper trim, fibrous material such as textile scrap, wool and ensilage. Not suitable for coarse material, heavy or abrasive dust. Dynamically balanced, self-cleaning cast aluminum wheels. 16 ga housing and motor base. Maximum operating temperature 180°F (82°C). Finished in baked-on gray polyester/epoxy. Blower can be assembled for CW or CCW rotation and any one of eight standard discharge positions. See Figure 2. Dayton motors packed separately when blowers are ordered complete.

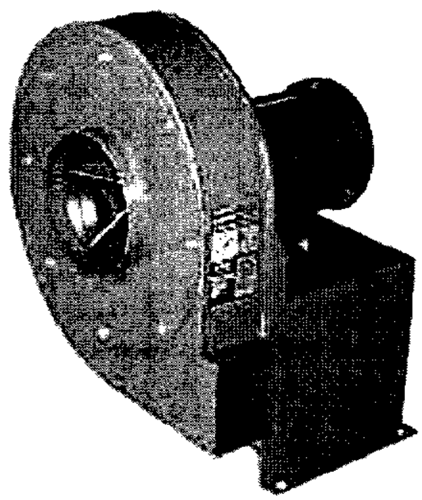


Figure 1 – High Pressure Direct Drive Radial Blade Blowers

⚠WARNING ***Keep hands away from inlet while blower is in operation.***

General Safety Information

1. Follow all local electrical and safety codes, as well as the National Electrical Code (NEC) and the Occupational Safety and Health Act (OSHA) in the United States.
2. Blower must be securely and adequately grounded. This can be accomplished by wiring with a grounded, metal-clad raceway system, by using a separate ground wire connected to the bare metal of blower frame, or other suitable means.
3. Always disconnect power source before working on or near a motor or its connected load. If the power disconnect point is out-of-sight, lock it in the open position and tag to prevent unexpected application of power.
4. Be careful when touching the exterior of an operating motor – it may be hot enough to be painful or cause injury. With modern motors, this condition is normal when operated at rated load and voltage – modern motors are built to operate at higher temperatures.
5. Protect the power cable from coming in contact with sharp objects.
6. Do not kink power cable and never allow the cable to come in contact with oil, grease, hot surfaces, or chemicals.
7. Make certain that the power source conforms to the requirements of your equipment.
8. When cleaning electrical or electronic equipment, always use an approved cleaning agent such as dry cleaning solvent.
9. Not recommended as a hazardous location blower. Do not use where explosive fumes or gases are present.
10. If blower is operated without an inlet or outlet duct, guard openings in accordance with OSHA regulations to prevent contact with rotating blower wheel.

Form 5S2052

Printed in U.S.A.
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PB-18978

Dayton®

Dayton® High Pressure Direct Drive Radial Blade Blowers

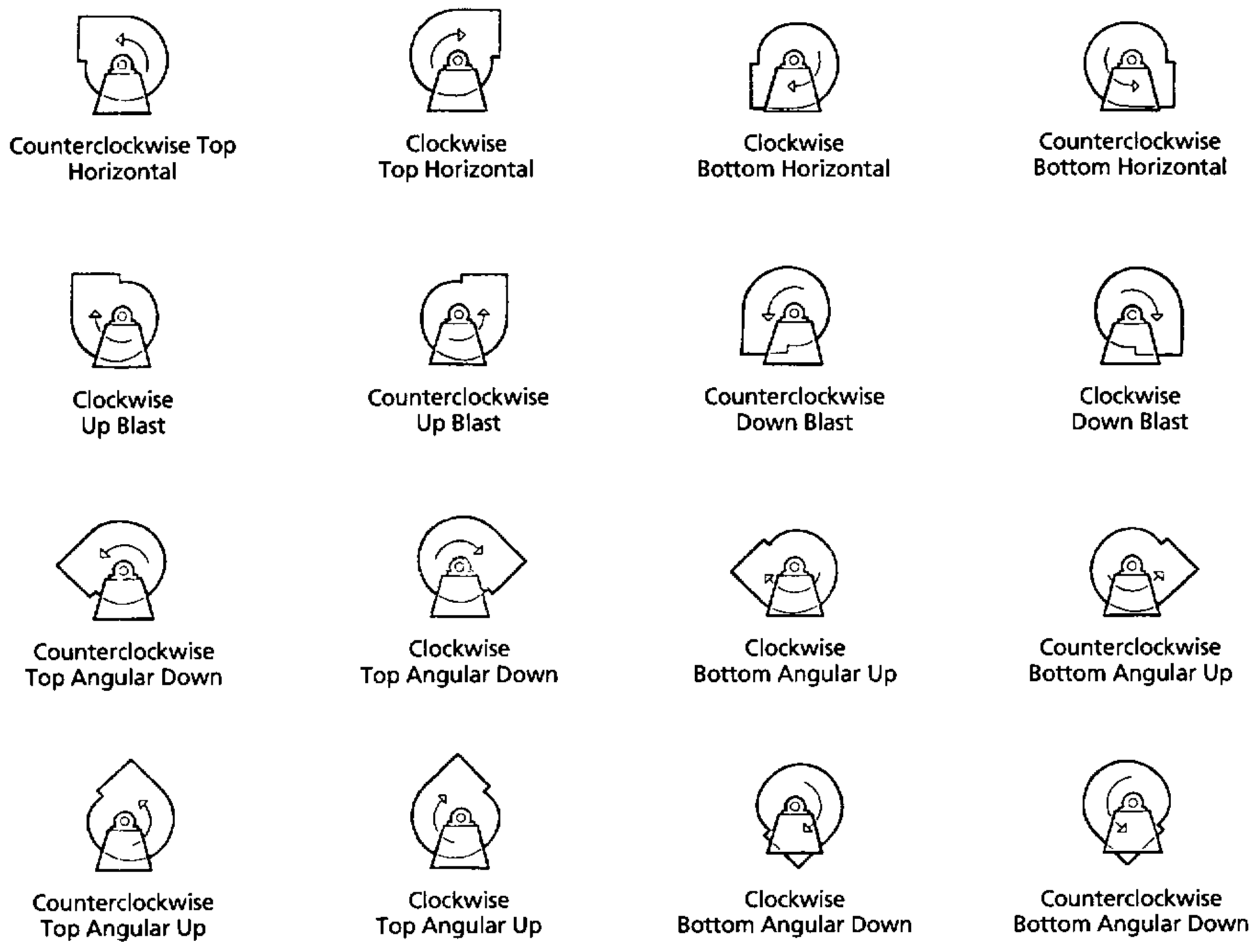


Figure 2 – Rotation and Discharge Positions

NOTES:

1. Direction of rotation is determined from drive side of fan.
2. For fan inverted for ceiling suspension, or side mounting, direction of rotation and discharge is determined when fan is resting on floor.
3. Reprinted from AMCA, STD. 99-2406-83, with the express written permission from the Air Movement and Control Assoc. Int., Inc., 30 West University Dr., Arlington Heights, IL 60004-1893.

Models 2C940, 2C820, 6YG63, 4C108, 4C329 and 4C330

Troubleshooting Chart

Symptom	Possible Cause(s)	Corrective Action
Noise	1. Foreign objects in housing 2. Loose set screw on wheel 3. Incorrect wheel rotation	1. Remove 2. Tighten 3. Reverse rotation
Motor bearing noise	Lack of bearing lubrication	Lubricate
Excessive vibration	1. Loose wheel on shaft 2. Loose mounting bolts 3. Motor out of balance 4. Wheel out of balance 5. Accumulation of material on wheel	1. Tighten setscrews 2. Tighten 3. Replace 4. Replace or rebalance 5. Clean
Motor overloaded	System static pressure less than 1" water column	Increase system static pressure

⚠ CAUTION ***Must not be used where static pressure is less than shown in table. Severe motor overload will result. Motor overload protection, closely matched to motor full-load current, is highly recommended.***

Dayton® High Pressure Direct Drive Radial Blade Blowers

Specifications

Wheel (in.) Dia	Bore	dBA @ 5 ft.#	Mtr. Frame	CFM @ STATIC PRESSURE SHOWN, 3450 RPM 1" SP	2" SP	3" SP	4" SP	5" SP	6" SP	7" SP	8" SP	Blower Less Motor Stock No.	Shpg. Wt.	Motor HP	PH.	BLOWERS WITH 3450 RPM MOTORS Drip Proof 115/230V, 1PH or 200-230/460, 3PH Stock No.	Totally Enclosed 115/230V, 1PH or 200-230/460, 3PH Stock No.
7 3/4	1/2	74	48	252	210	157						2C940	13	1/2	1	7D747	7D748
8 15/16	1/2	77	48	*	391	336	270	173				2C820	17	1/2	1	7D749	7D750
8 15/16	5/8	77	56	437	391	336	270	173				6YG63	17	3/4	1	7E252	7E253
10 9/16	5/8	84	56	*	*	*	559	491	410	297		4C108	25	1	1	7C447	—
10 9/16	5/8	84	56	734	679	621	559	491	410	297		4C108	25	1 1/2	3	7D751	—
12 1/2	7/8	90	145T	1127	1071	1014	953	888	817	736	638	4C329	37	3	3	7C561	—
13 1/2	1 1/8	92	182T 184T	*	*	1832	1741	1647	1547	1438	1319	4C330	64	5	3	7C562	7C487
13 1/2	1 1/8	92	184T 182T	2005	1919	1832	1741	1647	1547	1438	1319	4C330	64	7 1/2	3	7D752	—

(*) Motor overload will result if blower is operated at static pressure below performance shown.
(#) Values shown are estimated sound pressure levels.

Assembly

1. Attach base upright to the motor mounting base as shown in the exploded view. See Figure 4. Hand tighten (4) 1/4 -20 x 1/2" bolts, washers, and nuts through slotted holes in base upright. Place motor on motor base and align the center hole of the base upright with the motor shaft. Secure the four 1/4-20 bolts. Models 4C329 and 4C330 have a welded motor base assembly.
2. Bolt the housing to the base upright in the desired discharge position using #10 x 3/8 or 5/16 -18 x 3/4" self tapping bolts. Blower is clockwise rotation. Refer to exploded view showing clockwise bottom horizontal discharge.
3. With the motor shaft through the center hole of the base upright, align the mounting holes of the motor to the predrilled holes in the motor base. Install two bolts to retain proper motor alignment but do not tighten. Mount the wheel to the motor shaft. Refer to exploded view drawing.
4. Mount the inlet ring to the housing and secure with #10 x 3/8" or 5/16 -18 x 3/4" self tapping bolts.
5. Slide the wheel toward the inlet ring so there is at least 1/4" clearance between the wheel and cone. The motor shaft should extend through the hub of the wheel so when the set screws are securely tightened, they will make contact with the motor shafts.
6. Install the remaining nuts, bolts, and washers (not provided) to the motor mounting holes of the motor and secure to the blower motor base.

Installation

1. Make sure all bolts and screws are tightened before mounting on a rigid, flat, level foundation. Bolt the blower securely into position.
2. With power disconnected, check the interior of the fan housing to be sure it is free of debris. Rotate the wheel to insure that it is not rubbing or binding. Check the clearance of the wheel and the inlet ring. If rubbing exists, loosen the bolts on the ring and shift the ring until clearance is obtained. If still rubbing, loosen the set screw on the wheel and shift the wheel rearward to obtain clearance. Retighten the set screw.

Models 2C940, 2C820, 6YG63, 4C108, 4C329 and 4C330

Operation

1. Before connecting the motor to the electric supply, check the electrical characteristics as indicated on the motor nameplate to insure proper voltage and phase.

⚠ CAUTION ***A ground wire must run from the blower motor housing to a suitable electrical ground such as a properly grounded metallic raceway or a ground wire system.***

2. After electrical connections are completed, apply just enough power to start the unit. Be sure that the rotation of the wheel is correct as indicated by directional arrows on the unit. If proper rotation, apply full electrical power.
3. With the air system in full operation and all ducts attached, measure current input to the motor and compare with the nameplate rating to determine if the motor is operating under safe load conditions.

Maintenance

⚠WARNING ***Before attempting any repair work, be certain that all power to the motor and electrical accessories are turned off and locked in off position.***

A. Periodically remove dirt from blower wheel and housing.

B. Check tightness of wheel set screw.

C. After disconnecting the power source, check the wiring to see if insulation is damaged or frayed.

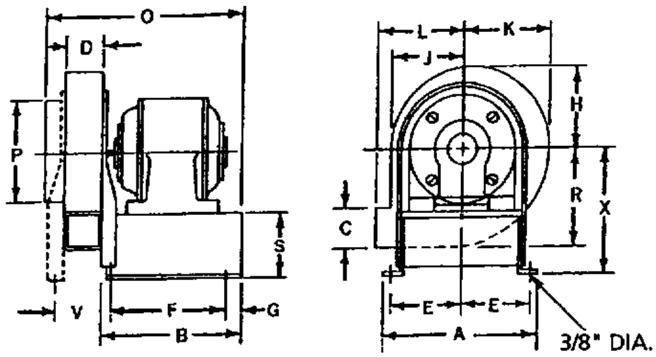
D. Relubricate motor per manufacturers' instructions. Remove any excess lubricants.

E N G L I S H

Dimensions

Dimensions (inches)																					
	WHEEL			HIGH PRESSURE DIRECT DRIVE RADIAL BLADE BLOWER																X Adj. Min.	X Adj. Max.
Model	Dia.	W	Bore	A	B	C	D	E	F	G	H	J	K	L	O	P	R	S	V		
2C940	7 3/4	2 5/16	1/2	11	8	3	3	5	7	1/2	5 3/8	4 7/8	5 7/8	5 7/8	12 1/4	4	6 5/8	5 1/2	-	8 1/4	9 3/4
2C820	9	2 13/16	1/2	12 1/8	8	3 1/2	3 1/2	5 5/8	7	1/2	6 3/8	5 3/4	6 7/8	6 3/4	12 3/4	5	7 1/2	6 3/8	-	9 1/8	10 5/8
6YG63	9	2 13/16	5/8	12 1/8	8	3 1/2	3 1/2	5 5/8	7	1/2	6 3/8	5 3/4	6 7/8	6 3/4	12 3/4	5	7 1/2	6 3/8	-	9 1/8	10 5/8
4C108	10 9/16	3	5/8	14 3/4	9	4	3 1/2	6 7/8	7 1/2	3/4	7 1/4	6 1/2	8	7 5/8	14	6	8 5/8	8 1/4	-	11 3/8	12 7/8
4C329	12 1/2	3	7/8	17	11 1/4	5	4	8	9 3/4	3/4	8 1/4	7 1/2	9	9 5/8	17	7	10	7 1/8	-	10 5/8	10 5/8
4C330	13 1/2	4 3/8	1 1/8	17 1/2	11 1/4	7 1/8	5 3/4	8	9 1/2	1	10 1/2	9 5/8	11 3/8	11	18 7/8	8	11 1/2	8 1/8	7 1/4	12 5/8	12 5/8

Figure 3 – Dimensions



For Repair Parts, call 1-800-323-0620

24 hours a day - 365 days a year

Please provide the following information:
-Model number
-Serial number (if any)
-Part description and number as shown in parts list

Address parts correspondence to:
Grainger Parts
P.O. Box 3074
1657 Shermer Road
Northbrook, IL 60065-3074 U.S.A.

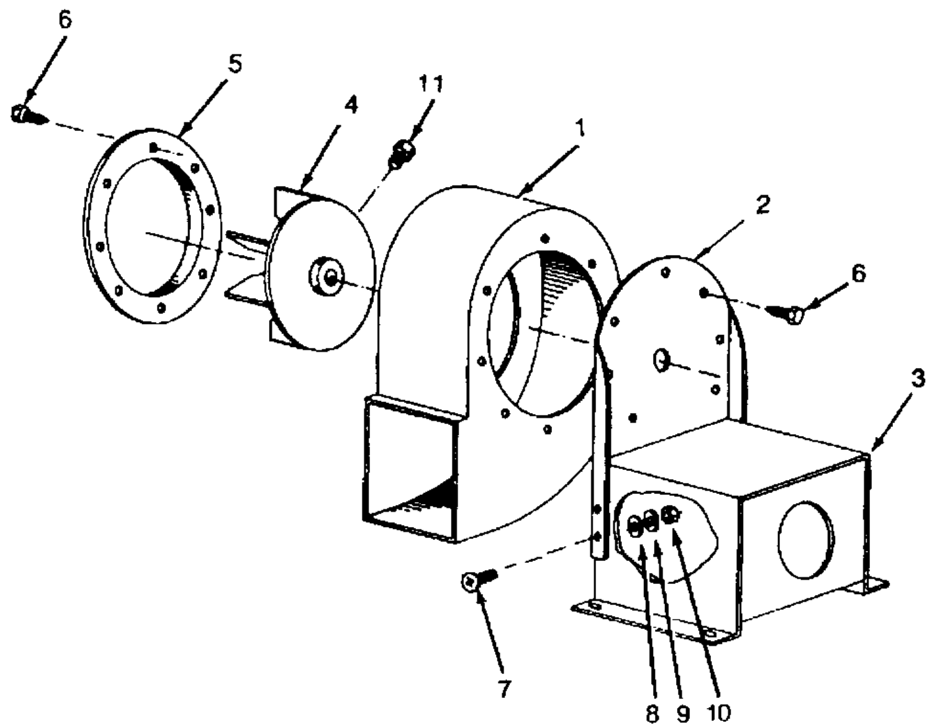


Figure 4 – Repair Parts Illustration

Repair Parts List

Reference Number	Description	Part Numbers for Model: 2C940	2C820	6YG63	4C108	4C329	4C330 (‡)
1	Housing	201-08-4005-5	201-09-4003-5	201-09-4003-5	201-11-4005-5	201-12-4004-5	201-14-4005-5
2	Base upright	618-08-7001-5	618-09-7001-5	618-09-7001-5	618-11-7002-5	—	—
3	Motor base assembly	203-08-7001-5	203-09-7001-5	203-09-7001-5	203-11-7005-5	203-12-4016-5	203-14-4011-5
4	Wheel	602-08-4001-5	602-09-4001-5	602-09-4002-5	602-11-4002-5	602-12-4004-5	602-14-4003-5
5	Inlet ring	609-08-4002-5	609-09-4001-5	609-09-4001-5	609-11-4003-5	602-12-4003-5	609-14-4001-5
6	Hex hd. screw	#10 x 3/8" (8 Req'd.)	#10 x 3/8" (14 Req'd.)	#10 x 3/8" (14 Req'd.)	#10 x 3/8" (14 Req'd.)	5/16-18 x 3/4" (16 Req'd.)	5/16-18 x 3/4" (16 Req'd.)
7	Slotted machine screw*	1/4-20 x 1/2" (4 Req'd.)	1/4-20 x 1/2" (4 Req'd.)	1/4-20 x 1/2" (4 Req'd.)	1/4-20 x 1/2" (4 Req'd.)	—	—
8	Flat washer*	1/4 (4 Req'd.)	1/4 (4 Req'd.)	1/4 (4 Req'd.)	1/4 (4 Req'd.)	—	—
9	Split washer*	1/4 (4 Req'd.)	1/4 (4 Req'd.)	1/4 (4 Req'd.)	1/4 (4 Req'd.)	5/16 (16 Req'd.)	5/16 (16 Req'd.)
10	Hex nut*	1/4"-20 (4 Req'd.)	1/4"-20 (4 Req'd.)	1/4"-20 (4 Req'd.)	1/4"-20 (4 Req'd.)	—	—
11	Setscrew	†	†	†	†	†	†

NOTE: Models 4C329 and 4C330 have welded 1 piece motor base & upright assembly.

(‡) Model 4C330 has inlet upright supports (not shown) to support housing. Order by P/N 617-13-7002-5.

(*) Standard hardware item, available locally.

(†) Available with wheel.

Models 2C940, 2C820, 6YG63, 4C108, 4C329 and 4C330

E N G L I S H

LIMITED WARRANTY

DAYTON ONE-YEAR LIMITED WARRANTY. *Dayton® High Pressure Direct Drive Radial Blade Blowers, Models covered in this manual, are warranted by Dayton Electric Mfg. Co. (Dayton) to the original user against defects in workmanship or materials under normal use for one year after date of purchase. Any part which is determined to be defective in material or workmanship and returned to an authorized service location, as Dayton designates, shipping costs prepaid, will be, as the exclusive remedy, repaired or replaced at Dayton's option. For limited warranty claim procedures, see PROMPT DISPOSITION below. This limited warranty gives purchasers specific legal rights which vary from jurisdiction to jurisdiction.*

LIMITATION OF LIABILITY. *To the extent allowable under applicable law, Dayton's liability for consequential and incidental damages is expressly disclaimed. Dayton's liability in all events is limited to and shall not exceed the purchase price paid.*

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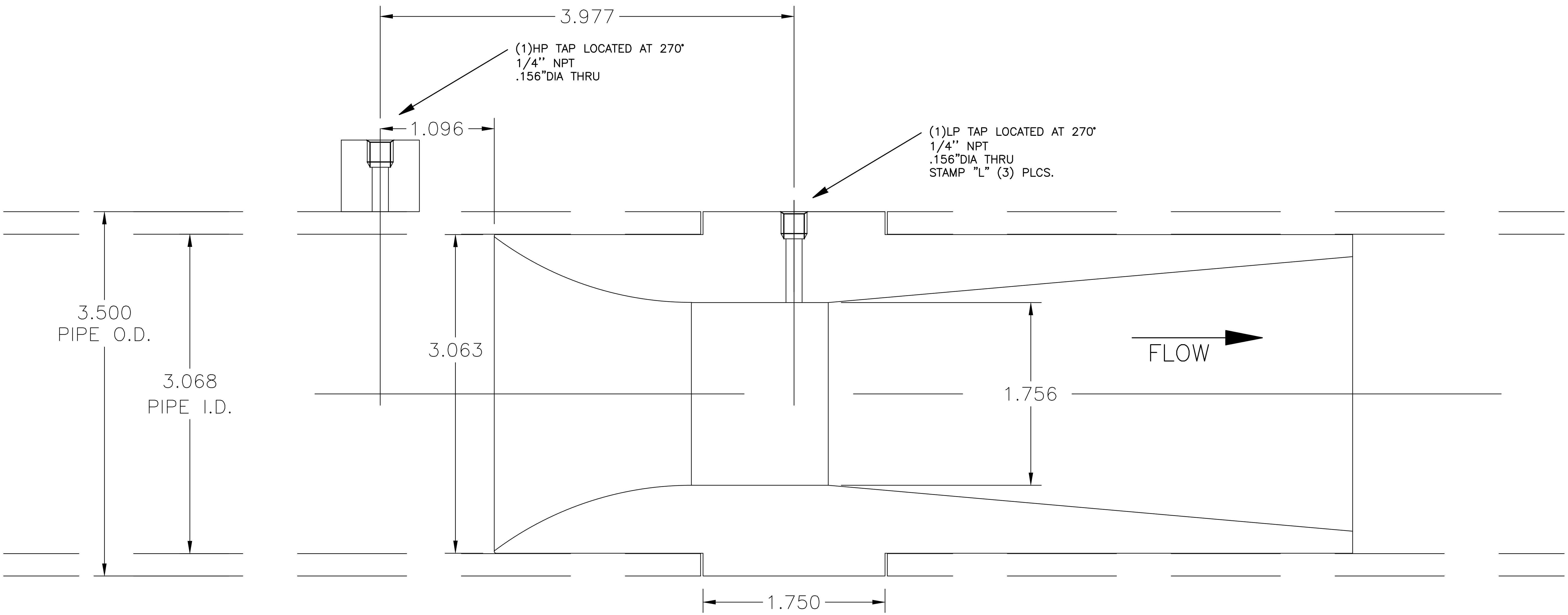
PRODUCT SUITABILITY. *Many jurisdictions have codes and regulations governing sales, construction, installation, and/or use of products for certain purposes, which may vary from those in neighboring areas. While Dayton attempts to assure that its products comply with such codes, it cannot guarantee compliance, and cannot be responsible for how the product is installed or used. Before purchase and use of a product, review the product applications, and all applicable national and local codes and regulations, and be sure that the product, installation, and use will comply with them.*

Certain aspects of disclaimers are not applicable to consumer products; e.g., (a) some jurisdictions do not allow the exclusion or limitation of incidental or consequential damages, so the above limitation or exclusion may not apply to you; (b) also, some jurisdictions do not allow a limitation on how long an implied warranty lasts, consequently the above limitation may not apply to you; and (c) by law, during the period of this Limited Warranty, any implied warranties of implied merchantability or fitness for a particular purpose applicable to consumer products purchased by consumers, may not be excluded or otherwise disclaimed.

PROMPT DISPOSITION. *Dayton will make a good faith effort for prompt correction or other adjustment with respect to any product which proves to be defective within limited warranty. For any product believed to be defective within limited warranty, first write or call dealer from whom the product was purchased. Dealer will give additional directions. If unable to resolve satisfactorily, write to Dayton at address below, giving dealer's name, address, date, and number of dealer's invoice, and describing the nature of the defect. Title and risk of loss pass to buyer on delivery to common carrier. If product was damaged in transit to you, file claim with carrier.*

Manufactured for Dayton Electric Mfg. Co., 5959 W. Howard St., Niles, Illinois 60714 U.S.A.



AMITY FLOW
DOUGLASSVILLE, PA U.S.A.
TAG# N/A

MODEL: AVM-S-PVC
SIZE: 3"
SERAIL NO.: 115-1

NOTES:
MATERIAL: PVC - GREY

AMITY FLOW

SCALE: NONE	THIS PRINT IS CONFIDENTIAL PROPERTY OF AMITY INDUSTRIES INC. TO BE RETURNED UPON REQUEST AND USED ONLY IN REFERENCE TO CONTRACTS OR PROPOSALS OF AMITY IND. INC.. REPRODUCTION OF THIS PRINT OR UNAUTHORIZED USE OF FEATURES DISCLOSED HEREON IS PROHIBITED.	DRAWN BY:
DATE: 03/31/16		JAMES CARE

TAG# N/A

3'' PVC METER | DWG NO. AVM-S-PVC 3.068 X 1.756 | REV. A

Amity Flow
491 Old Swede Road
P.O.Box 355
Douglassville, PA 19518
Ph 610 385 6075
Fx 610 385 6079

AmityFloCalc

Primary Flow Element Sizing Application v. 1.0.0 Beta2

Gas Flow - Volumetric Units

Bore Calculation

GENERAL INFORMATION

Date:	8-Mar-2016	Customer:	Cory Davis
Serial No.:	115-1		
Tag No.:	FE-1		U.S.A.
Quote:	I-115-16T	P.O. No.:	
Calculation by:	Jim	Project Name:	
		Project Engr.:	

PRIMARY ELEMENT INFORMATION

Primary Element Type:	LowLoss Flow Tube		Body Material:	PVC
Primary Element Style:	Machined		Throat Material:	PVC
Pipeline Nominal Size:	3"		Pipeshell Material:	PVC
Pipe Schedule:	40		Flange Material:	PVC
Pipeline Inside Dia.:	3.068	in	Flange Rating:	125
Calculated Throat Dia.	1.921	in.	Flange Type:	Unknown
			Pressure Conn Nom. Size:	1/4"

Beta Ratio:	**0.62606**	**Discharge Coefficient:**	**0.80810**

FLUID FLOW AND PHYSICAL PROPERTIES OF THE FLOWING FLUID

Flowing Fluid:	AIR		Operating Temp.:	68.00	F
Fluid State:'	GAS		Operating Press.:	14.90	psia
Full Scale Flow Rate:	220	SCFM	Operating Comp. Zf:	0.99947	
Maximum Flow Rate:	220	SCFM	Base Temp.:	60.00	F
Normal Flow Rate:	154	SCFM	Base Press.:	14.70	psia
Minimum Flow Rate:	25	SCFM	Base Comp. Zb:	0.99943	
Molecular Weight:	28.962		Viscosity:	0.0170	cP
Specific Gravity:	1.0000		Isentropic Exponent:	1.410	
Density:	0.076200	lbm/ft3	Critical Temp.:	-221	F
			Critical Temp.:	547	psia

SOME IMPORTANT VALUES WHICH ARE DEPENDENT UPON THE FLOW RATE

	Full Scale Design Point	At Maximum Flow	At Normal Flow	At Minimum Flow
	220 SCFM	220 SCFM	154 SCFM	25 SCFM
Diff. Press.(In. of water):	10	10.00	4.90	0.1272
Head Loss (In. of water):		0.35	0.174	0.0045
Pipe Reynolds No.:		122,122	85,486	13,878
Gas Exp. Factor:		0.98371	0.99216	0.9998
Random Uncert (+/-%):		0	0	0
Bias Error(%):		0	0	0

PRIMARY ELEMENT SIZING CALCULATION

GAS – VOLUMETRIC FLOW

Customer Information

Customer:	Cory Davis	Date:	2/24/2016
Address:		Project Name:	
		Quote No.:	I-115-16T
	U.S.A.	Tag No.:	FE-_____

Contact Name:
Telephone:
Fax No.:
Email Address:

Primary Flow Element

Model:	AF-WI		
Line Size:	3"		
Pipe ID:	3.068 In.	Throat ID:	1.618 In.
Tap Size:	1/4"		
Pipe Schedule:	40		
Pipeshell Material:	PVC		

ASME Nozzle

Body Material:	PVC
Throat Material:	PVC
Flange Material:	PVC
Flange Type:	ANSI
Flange Rating:	150

Flow Conditions

Fluid:	AIR		Oper.Temp.:	68.00	ºF	Base Temp.:	60.00	ºF
State:	GAS		Oper.Press.:	14.90	psia	Base Press.:	14.70	psia
Max. Flow:	220	SCFM	Op.Comp Zf:	0.99947		Base Comp Zb:	0.99943	
Norm. Flow:	154	SCFM	Oper Dens:	0.076200	Lb_m/ft^3	Rel. Humidity:	0	%
Min. Flow:	25	SCFM	Oper Visc:	0.0170	cp	Crit Temp	-221 F.	
Mole Wgt:	28.962		Isentropic Exp	1.410		Crit Pres	547 psia	
Sp. Gravity:	1.0000		Exp Factor Ya:	0.97839				

Beta Ratio 0.5273 **Discharge Coefficient 0.9848**

Calculated Values

	At The Maximum Flow of: 220 SCFM	At The Normal Flow of: 154 SCFM	At The Minimum Flow of: 25 SCFM
Differential Pressure =	15.00 In of water	7.22 In of water	.20 In of water
Pipe Reynolds Number =	122122	85486	13878
Head Loss of Meter =	9.11 In of water	4.39 In of water	0.120 In of water
Random Error =	0.0 %	0.0 %	0.0 %
Bias Error =	0.0 %	0.0 %	0.0 %

A2

AMITY FLOW

Amity Flow
491 Old Swede Road
P.O.Box 355
Douglassville, PA 19518
Ph 610 385 6075
Fx 610 385 6079

AmityFloCalc

Primary Flow Element Sizing Application v. 1.0.0 Beta2

Gas Flow - Volumetric Units

Bore Calculation

GENERAL INFORMATION

Date:	9-Mar-2016	Customer:	Cory Davis
Serial No.:	115-1		
Tag No.:	FE-2		U.S.A.
Quote:	I-115-16T	P.O. No.:	
Calculation by:	Jim	Project Name:	
		Project Engr.:	

PRIMARY ELEMENT INFORMATION

Primary Element Type:	ASME Nozzle		Body Material:	PVC
Primary Element Style:	Long Radius		Throat Material:	PVC
Pipeline Nominal Size:			Pipeshell Material:	PVC
Pipe Schedule:			Flange Material:	PVC
Pipeline Inside Dia.:	Plenum	in	Flange Rating:	125
Calculated Throat Dia.	3.068	in.	Flange Type:	Unknown
			Pressure Conn Nom. Size:	1/4"

Beta Ratio:	**0.0000**	**Discharge Coefficient:**	**0.97940**

FLUID FLOW AND PHYSICAL PROPERTIES OF THE FLOWING FLUID

Flowing Fluid:	AIR		Operating Temp.:	68.00	F
Fluid State:'	GAS		Operating Press.:	14.90	psia
Full Scale Flow Rate:	220	SCFM	Operating Comp. Zf:	0.99947	
Maximum Flow Rate:	220	SCFM	Base Temp.:	60.00	F
Normal Flow Rate:	154	SCFM	Base Press.:	14.70	psia
Minimum Flow Rate:	25	SCFM	Base Comp. Zb:	0.99943	
Molecular Weight:	28.962		Viscosity:	0.0170	cP
Specific Gravity:	1.0000		Isentropic Exponent:	1.410	
Density:	0.076200	lbm/ft3	Critical Temp.:	-221	F
			Critical Temp.:	547	psia

SOME IMPORTANT VALUES WHICH ARE DEPENDENT UPON THE FLOW RATE

	Full Scale Design Point		At Maximum Flow		At Normal Flow		At Minimum Flow	
	220	SCFM	220	SCFM	154	SCFM	25	SCFM
Diff. Press.(In. of water):	1.14		1.14		0.5586		0.01569	
Head Loss (In. of water):			0.709		0.35		0.00982	
Pipe Reynolds No.:			62,445		43,712		7,096	
Gas Exp. Factor:			0.9984		0.99921		0.99998	
Random Uncert (+/-%):			0		0		0	
Bias Error(%):			0		0		0	

Amity Flow
491 Old Swede Road
P.O.Box 355
Douglassville, PA 19518
Ph 610 385 6075
Fx 610 385 6079

AmityFloCalc

Primary Flow Element Sizing Application v. 1.0.0 Beta3

Gas Flow - Volumetric Units

Bore Calculation

GENERAL INFORMATION

Date:	31-Mar-2016	Customer:	Cal Poly Mechanical Engineering
Serial No.:	1140		One Grand Avenue
Tag No.:	FE-_____		San Luis Obispo, CA 93407 USA
Quote:	I-115-16T	Email:	rvwestphal@calpoly.edu
Project Name:		Phone:	
Project Engr.:	Cory Davis	Contact:	Russel V Westphal
Calculation by:	Jim	P.O. No.:	Verbal

PRIMARY ELEMENT INFORMATION

Primary Element Type:	Venturi		Body Material:	PVC
Primary Element Model:	AVT-S-I		Throat Material:	PVC
Pipeline Nominal Size:	3"		Pipeshell Material:	By Customer
Pipe Schedule:	40		Flange Material:	None
Pipeline Inside Dia.:	3.068	in		
Calculated Throat Dia.	1.755	in.		
			Pressure Conn Nom. Size:	1/4"

Beta Ratio: 0.57214 **Discharge Coefficient: 0.99330**

FLUID FLOW AND PHYSICAL PROPERTIES OF THE FLOWING FLUID

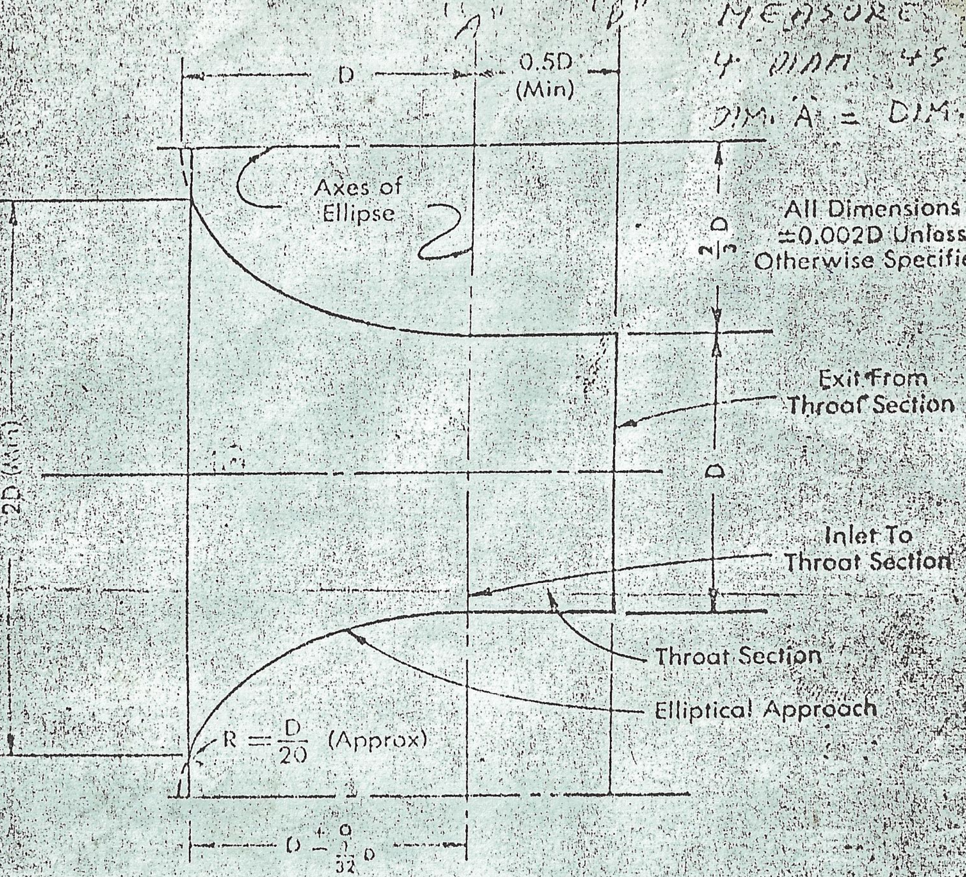
Flowing Fluid:	AIR		Operating Temp.:	68.000	F
Fluid State:'	GAS		Operating Press.:	14.900	psia
Full Scale Flow Rate:	220.0	SCFM	Operating Comp. Zf:	0.99947	
Maximum Flow Rate:	220.0	SCFM	Base Temp.:	60.000	F
Normal Flow Rate:	154.0	SCFM	Base Press.:	14.696	psia
Minimum Flow Rate:	22.00	SCFM	Base Comp. Zb:	0.99943	
Molecular Weight:	28.962		Viscosity:	0.0170	cP
Specific Gravity:	1.0000		Isentropic Exponent:	1.410	
Density:	0.076200	lbm/ft3	Critical Temp.:	-221	F
			Critical Temp.:	547	psia

SOME IMPORTANT VALUES WHICH ARE DEPENDENT UPON THE FLOW RATE

	Full Scale Design Point	At Maximum Flow	At Normal Flow	At Minimum Flow
	220.0 SCFM	220.0 SCFM	154.0 SCFM	22.00 SCFM
Diff. Press.(In. of water):	10.00	10.00	4.90	0.09857
Head Loss (In. of water):		0.5013	0.245	0.004
Pipe Reynolds No.:		122,122	85,486	12,212
Gas Exp. Factor:		0.98477	0.99267	0.99985
Random Uncert (+/-%):		0.5	0.5	0.5
Bias Error(%):		0	0	0

Carrier

MEASURE A&B AT
4 DIAM 45° APART
DIM. A = DIM. B ± TOL.

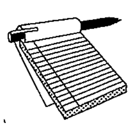


AIR FLOW MEASURING NOZZLE

FIG. B-2

P400 - Plastic Material ABS
FDM 1600, 1650, 2000, and 8000

FDM System Parameters	FDM Tip Inner Diameter 1600, 1650 0.012"	1600, 1650 0.025"	2000 0.010"	2000/8000 0.012"	2000/8000 0.016"
Speed inches/sec					
(maximum)	0.800	0.800	1.000	1.000	1.500
(recommended)	**0.800**	**0.800**	**1.000**	**1.000**	**1.000 - 1.5000**
Road Height					
(maximum)	0.016"	0.020"	0.010"	0.012"	0.014"
(minimum)	0.004"	0.010"	0.007"	0.007"	0.010"
(recommended)	**0.010"**	**0.012"**	**0.007"**	**0.007"**	**0.012"**
Road Width					
(maximum)	0.040"	0.060"	0.030"	0.040"	0.040"
(minimum)	0.012"	0.030"	0.010"	0.012"	0.016"
Liquefier Temp °C					
(maximum)	270	270	290	270	270
(minimum)	270	270	290	270	270
(recommended)	**See Spool**	**See Spool**	**See Spool**	**See Spool**	**See Spool**
Envelope Temp °C					
(maximum)	70	70	70	70	70
(minimum)	70	70	50	70	70
(recommended)	70	70	60	70	70
Room Temp °F					
(maximum)	82	82	82	82	82



It is recommended to use the parameter values indicated in bold for perimeter roads. The values in this table may also be applied to fill and support roads if desired.

Material Specifications*			
Tensile Strength (psi):	5,000	Unnotched Impact (ft*lb/in):	---
Flexural Strength (psi):	9,500	Elongation (%):	50.00
Tensile Modulus (psi):	360,000	Hardness (Shore D):	R105
Flexural Modulus (psi):	380,000	Softening Point (R&B) (F):	220
Notched Impact (ft*lb/in):	2.00	Specific Gravity (GMS/CM³):	1.05

* Material specifications are based on ASTM tests.

External Client Order and Service Agreement

Mechanical Engineering Department Rapid Prototyping

Send Completed Agreement to:
Cal Poly Mechanical Engineering
College of Engineering
California Polytechnic State University
1 Grand Avenue
San Luis Obispo, CA 93407

For questions and information:
Contact: Larry Coolidge
Voice: (805) 756-1260
Fax: (805) 756-5460
Email: lcoolidg@calpoly.edu
On campus location: Bldg 13, Rm 103

Rapid Prototyping	**Cost**	**Unit**	**Quantity**	**Total**
Stratasys - use fee	$69.00	Job		
Stratasys – Modeling materials	$7.28	Cubic inch		
Stratasys – Support materials	$7.01	Cubic inch		
Eden 250 – use fee	$69.00	Job		
Eden 250 – Modeling materials	$0.37	Gram		
Eden 250 – Support materials	$0.20	Gram		
Plotter				
Plotter printing	$14.00	Job		
Personnel				
Staff Technician	$51.00	Hour		

To Be Completed by Client:

Please note page three of this document also requires signature.

Order Authorized by: ____

Authorized Signature: ____

Department/Unit Name: ____

Contact phone/email: ____

Date of Order: ____

Payment Method:

Corporation/Foundation Project: ☐Yes ☐ No
Project Number/Org Key:

____

State Account: ☐Yes ☐ No
Account Number:

____

Note: Terms and Conditions attached. Retain copy for your records. Forms must be completed prior to commencement of work. A confirmation of the order will be provided.

To be completed by Cal Poly Lab Director

Date Order Received:___________________________

Anticipated Completion Date:_________________________

Confirmed Total Cost:___________________________

Signature of Lab Director:___________________________

FullCure®720

FullCure720 Transparent is the original material developed for Objet PolyJet-based 3-Dimensional Printing Systems.

Please, find the complete FullCure® General Purpose Family Data Charts Below:

Property	ASTM	Results in Metric Units		Results in Imperial Units	
Tensile Strength	D-638-03	MPa	60.3	psi	8744
Modulus of Elasticity	D-638-04	MPa	2870	psi	416150
Elongation at Break	D-638-05	%	20	%	20
Flexural Strength	D-790-03	MPa	75.8	psi	10991
Flexural Modulus	D-790-04	MPa	1718	psi	249110
Compressive Strength	D-695-02	MPa	84.3	psi	12224
Izod Notched Impact	D-256-06	J/m	21.3	ft lb/in	0.40
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	ºC	48.4	ºF	119
HDT at 1.82MPa	D-648-07	ºC	44.4	ºF	112
Tg	DMA, E"	ºC	48.7	ºF	120
Ash Content	NA	%	<0.01	%	<0.01
Water Absorption	D570-98 24 Hr	%	1.53	%	1.53

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Objet Geometries Inc. 5 Fortune Drive, Billerica, MA 01821 USA

Internal Client Order and Service Agreement

Mechanical Engineering Department Rapid Prototyping*

Send Completed Agreement to:
Cal Poly Mechanical Engineering
College of Engineering
California Polytechnic State University
1 Grand Avenue
San Luis Obispo, CA 93407

For questions and information:
Contact: Larry Coolidge
Voice: (805) 756-1260
Fax: (805) 756-5460
Email: lcoolidg@calpoly.edu
On campus location: Bldg 13, Rm 103

Rapid Prototyping	Cost	Unit	Quantity	Total
Stratasys - use fee	$61.00	Job		
Stratasys – Modeling materials	$6.44	Cubic inch		
Stratasys – Support materials	$6.20	Cubic inch		
Eden 250 – use fee	$61.00	Job		
Eden 250 – Modeling materials	$0.33	Gram		
Eden 250 – Support materials	$0.18	Gram		
Plotter				
Plotter printing	$13.00	Job		
Personnel				
Staff Technician	$45.00	Hour		

*** These are all internal rates which are only for Cal Poly faculty, staff, and students working on Cal Poly projects.**

To Be Completed by Client:

Please note page three of this document also requires signature.

Order Authorized by: ______________________________

Authorized Signature: ______________________________

Department/Unit Name: ______________________________

Contact phone/email: ______________________________

Date of Order: ______________________________

Payment Method:

Corporation/Foundation Project: ☐Yes ☐ No
Project Number/Org Key:

____

State Account: ☐Yes ☐ No
Account Number:

____

Note: Terms and Conditions attached. Retain copy for your records. Forms must be completed prior to commencement of work. A confirmation of the order will be provided.

To be completed by Cal Poly Lab Director

Date Order Received:______________________ Anticipated Completion Date:______________________

Confirmed Total Cost:______________________ Signature of Lab Director:______________________

Blancett® Turbine Flow Meters

Turbine Flow Meter

Gas QuikSert®

DESCRIPTION

The Gas QuikSert turbine flow meter provides long service life by offering a durable construction design composed of stainless steel and tungsten carbide shaft and bearings. The unique wafer style design allows for quick installation and easily fits between two flanges. Gas QuikSert is fully compatible with B2800 Flow Monitors, K-Factor Scalers, Intelligent Converters and B3000 Flow Monitors; pre-configured when purchased together. The Gas QuikSert is compatible with most instruments, PLCs and computers.

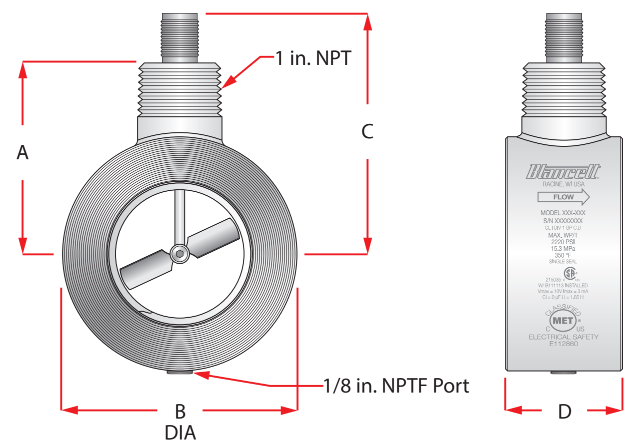
FEATURES AND BENEFITS

- Consistent, reliable gas flow measurement.
- Wafer mounting configuration for limited space requirements.
- Light weight, balanced rotor provides instantaneous response to changes in flow.
- No mating flange design allows for quick and easy install.
- Superior material of construction for high performance in aggressive environments.

SPECIFICATIONS

Installation	Mounts between two 2 in. ANSI raised face flanges, ideally sized for 2 in. schedule 40 or 80 pipe; horizontal or vertical orientation
Working Pressure	Vacuum to 2220 psig (15.3 MPa) max.
Pressure Loss	3 in. of water column (7.5 mbar) max. (dry air)
Temperature	–40…330° F (–40…165° C)
Linearity	±2% of reading over the specified measuring range (see *"Part Number Construction" on page 2*)
System Uncertainty	±1% of reading when integrated with a properly configured Blancett flow monitor or signal conditioner
Repeatability	±0.5% of reading
Output Signal	100 mVpp minimum (with Blancett B111113 magnetic pickup installed)
Nominal K-Factor	See *"Part Number Construction" on page 2*
Materials of Construction	316/316L, 410 and 304 grade stainless steels, tungsten carbide
Certifications	
Intrinsically Safe	Class I Division 1 Groups C, D [Entity Parameters Vmax = 10V, Imax = 3 mA, Ci = 0 µF and Li = 1.65 H with Blancett B111113 magnetic pickup installed] for US and Canada. Complies with UL 913 and CSA 22.2 No. 157-92
Explosion-Proof	Class I Division 1 Groups C, D. complies with UL1203 and CSA C22.2 No. 30-M1986
Single Seal	Complies with ANSI/ISA 12.27.01-2003

DIMENSIONS



A	B	C	D
2.95 in. (74.90 mm)	3.61 in. (92.00 mm)	3.12 in. (79.20 mm)	1.80 in. (45.70 mm)

Badger Meter®

TRB-DS-00284-EN-02 (March 2015)

Product Data Sheet

PART NUMBER CONSTRUCTION

Flow Meter*	Flow Rate		K-Factor Pulses/ft³ (Pulses/m³)	Repair Kit***	Hardware Kit
	ACFM**	MCFD			
B142-20L	7…70	10…100	365 (12,900)	B142-20L-KIT	B142-20-150KIT
B142-20M	14…210	20…300	190 (6710)	B142-20M-KIT	
B142-20H	35…350	50…500	85 (3000)	B142-20H-KIT	

*Does not include magnetic pickup. Order Blancett B111113 Low Drag Pickup
**At 0 psig (0 bar) and 60° F (15.6° C)
***Compatible with Cameron/NuFlo 2 in. wafer gas meter

Control. Manage. Optimize.

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www.badgermeter.com

The Americas | Badger Meter | 4545 West Brown Deer Rd | PO Box 245036 | Milwaukee, WI 53224-9536 | 800-876-3837 | 414-355-0400
México | Badger Meter de las Americas, S.A. de C.V. | Pedro Luis Ogazón N°32 | Esq. Angelina N°24 | Colonia Guadalupe Inn | CP 01050 | México, DF | México | +52-55-5662-0882
Europe, Middle East and Africa | Badger Meter Europa GmbH | Nurtinger Str 76 | 72639 Neuffen | Germany | +49-7025-9208-0
Europe, Middle East Branch Office | Badger Meter Europe | PO Box 341442 | Dubai Silicon Oasis, Head Quarter Building, Wing C, Office #C209 | Dubai / UAE | +971-4-371 2503
Czech Republic | Badger Meter Czech Republic s.r.o. | Maříkova 2082/26 | 621 00 Brno, Czech Republic | +420-5-41420411
Slovakia | Badger Meter Slovakia s.r.o. | Racianska 109/B | 831 02 Bratislava, Slovakia | +421-2-44 63 83 01
Asia Pacific | Badger Meter | 80 Marine Parade Rd | 21-06 Parkway Parade | Singapore 449269 | +65-63464836
China | Badger Meter | 7-1202 | 99 Hangzhong Road | Minhang District | Shanghai | China 201101 | +86-21-5763 5412

Legacy Document Number: 02-TUR-BR-00457-EN

Blancett®

B142 GAS QUIKSERT® TURBINE FLOW SENSOR

INSTALLATION MANUAL

8635 Washington Avenue
Racine, Wisconsin 53406
Toll Free: 800.235.1638
Phone: 262.639.6770 • Fax: 262.417.1155
www.blancett.com

TABLE OF CONTENTS

FIGURES

NOTE: *Blancett reserves the right to make any changes or improvements to the product described in this manual at any time without notice.*

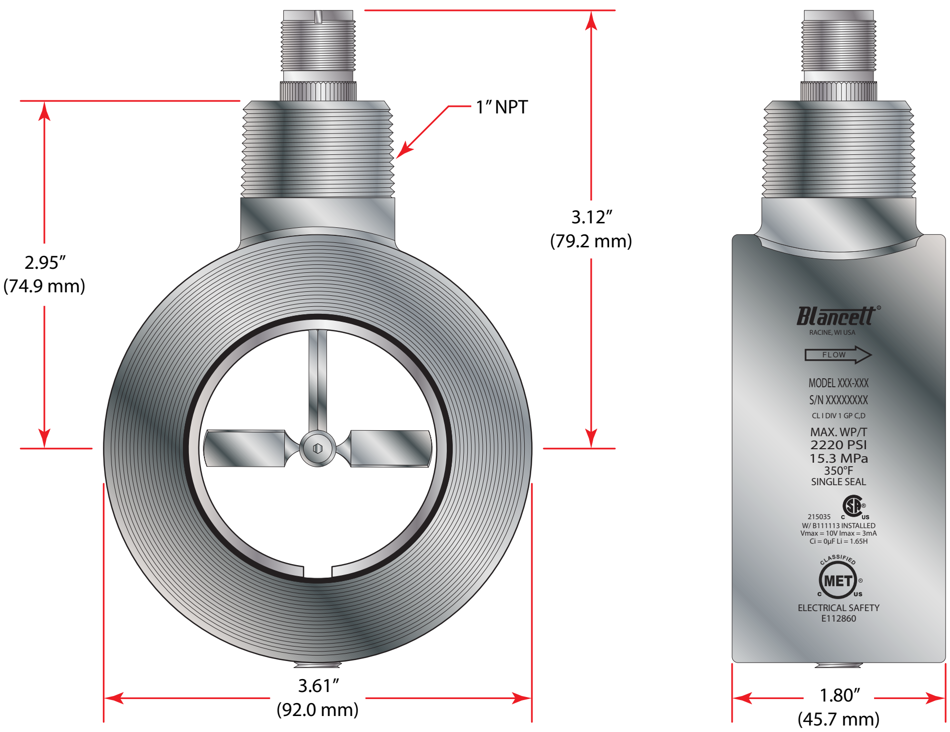


FIGURE 1 - DIMENSIONS

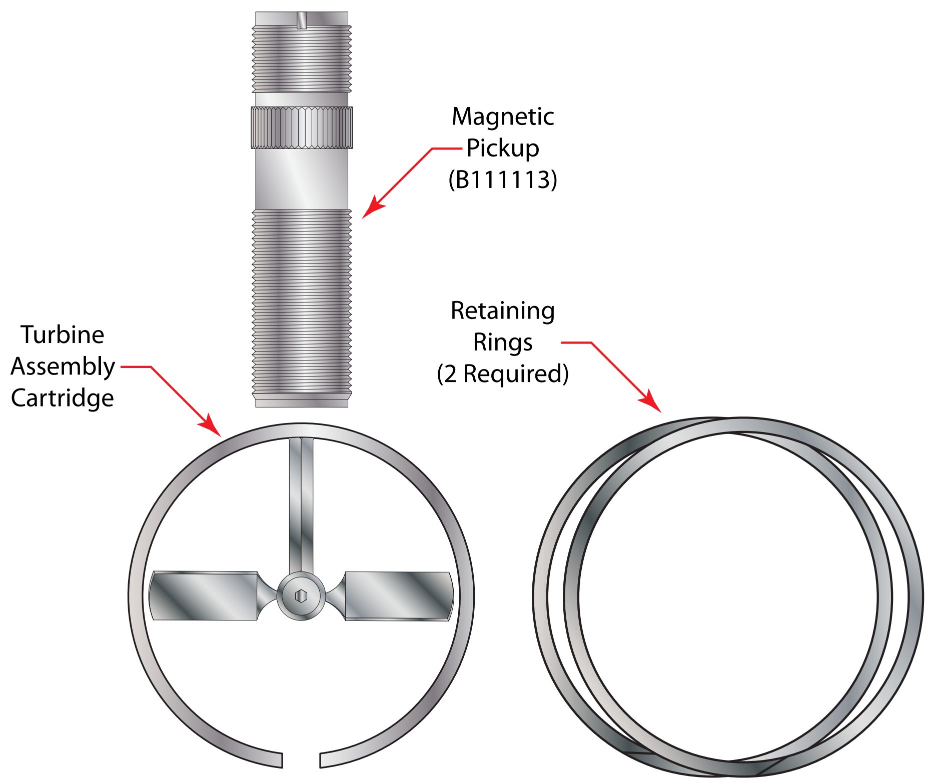


FIGURE 2 - PARTS IDENTIFICATION

INTRODUCTION

The B142 gas turbine flow meter is designed with wear resistant moving parts to provide a long service life with very low maintenance. Should the B142 meter be damaged the turbine is easily replaced in the field with a drop in repair kit rather than replacing the entire flow meter (see the Appendix for repair kit information). Repair parts are constructed of stainless steel alloy and tungsten carbide.

THEORY OF OPERATION

Gas moving through the turbine flow meter causes the rotor to turn at a speed proportional to the flow rate. The rotor blade cuts the magnetic field that surrounds the magnetic pick-up, which in turn generates a frequency output signal that is directly proportional to the volumetric flow rate (***Figure 3***). The signal is used to represent flow rate and/or totalization of a gas passing through the turbine flow meter and is always expressed as the number of electric pulses that the meter produces per cubic feet. This value, called the K-factor, is constant over each flow meter's range and is unique to the meter.

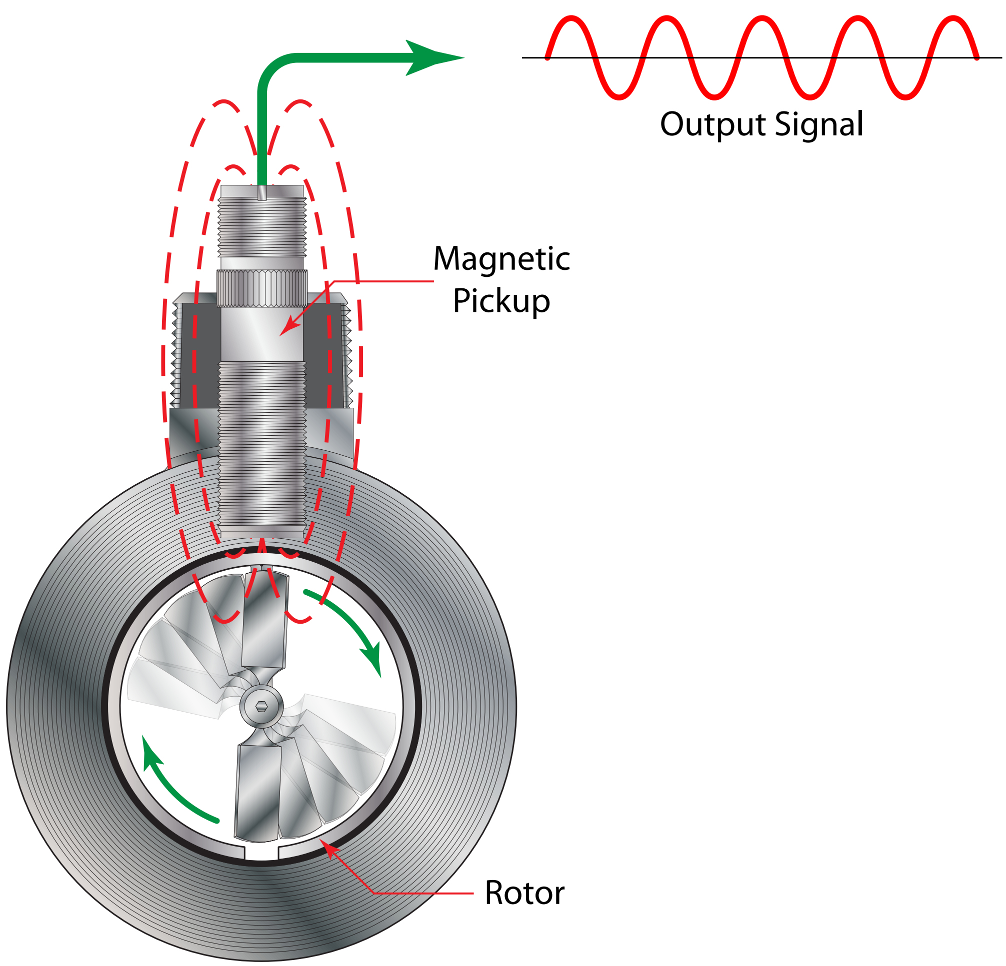


FIGURE 3 - B142 TURBINE FLOW SENSORS

INSTALLATION

Before installation, the flow meter should be checked internally for foreign material and to be sure that the rotor spins freely. Gas lines should also be cleared of all debris. The flow meter must be installed with the flow indication arrow, etched on the exterior of the meter body, pointing in the correct direction of flow. The preferred mounting orientation is to have the meter installed in horizontal piping, with the pick-up facing upward. However, the meter will function in any position.

While the flow meter body and magnetic pickup are sold as separate items, in most instances they are ordered at the same time and come assembled from the factory. If the magnetic pickup was not ordered with the meter body or replacement of the magnetic pickup becomes necessary, all that is needed to install it is to thread the pickup into the pickup port until it is bottomed out. Finger tightening is all that is required for proper installation.

The gas that is to be measured must be free from any large particles that may obstruct rotor from turning. If particles are present, a filter of at least 60 mesh (0.0092 clearance) should be installed upstream before operation of the flow meter).

The preferred plumbing setup is one containing a bypass line (***Figure 4***) that allows for meter inspection and repair without interrupting flow. If a by-pass line is not utilized, it is important that all control valves be located down-stream of the flow meter (***Figure 5***).

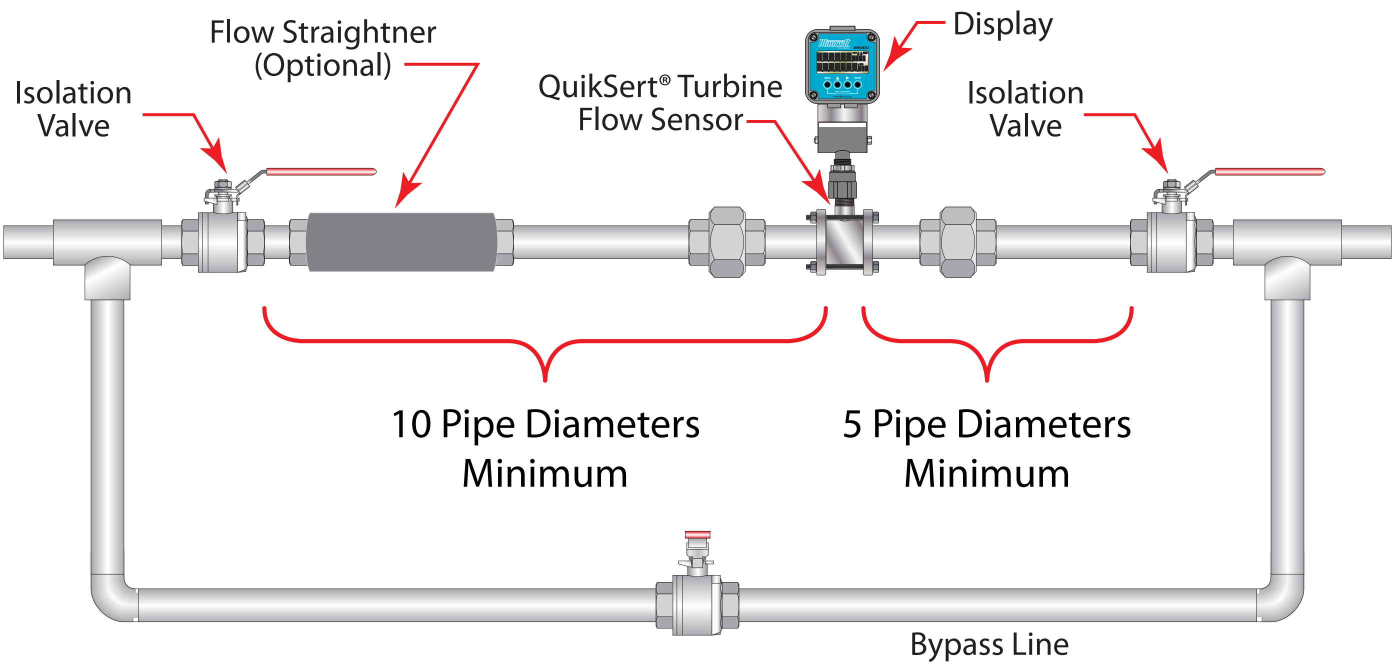


FIGURE 4 - BYPASS LINE INSTALLATION

It is recommended that a minimum length, equal to ten **(10)** pipe diameters of straight pipe, be installed on the up-stream side and five **(5)** diameters on the down-stream side of the flow meter. Otherwise meter accuracy may be affected. Piping should be the same size as the flange size. If adequate straight runs of pipe are not available or if erratic flow readings are experienced, place a bundled-tube flow straightener upstream of the flow meter installation.

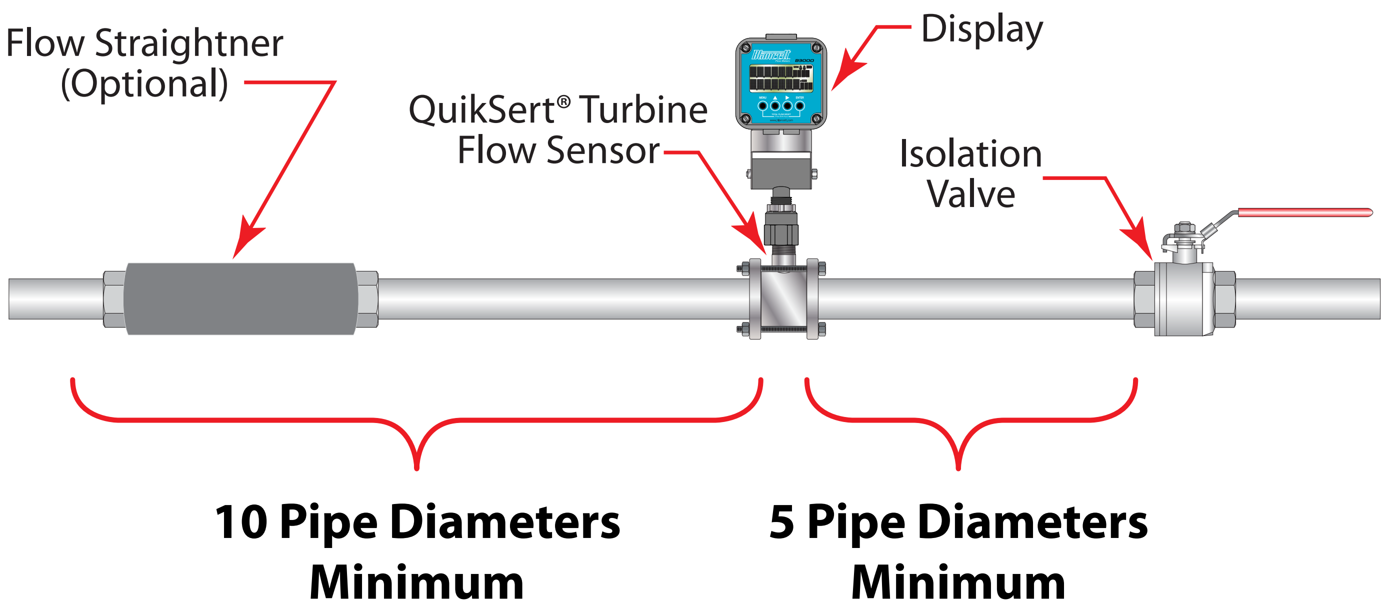


FIGURE 5 - INSTALLATION WITHOUT BYPASS LINE

OTHER FACTORS AFFECTING PERFORMANCE

Do not locate the flow meter or connection cable close to electronic motors, transforming, sparking devices, high voltage lines, or place connecting cable in conduit with wires furnishing power for such devices. These devices can induce false signals in the flow meter coil or cable, causing the meter to read inaccurately.

Severe pulsation and/or severe mechanical vibration will affect accuracy and shorten the life of the meter. Steps should be taken to remedy these conditions if they are present.

NOTE: *Incompatible gases will deteriorate internal parts, and cause the meter to read inaccurately.*

MOUNTING

The B142 turbine meter is supplied with two "centering rings" that make installation straightforward. Gaskets and either bolts or threaded rods supplied by the customer are also required. ***See figure 4***.

1) Insert the bottom or bottom two bolts between the mounting flanges and install nuts loosely.
2) Place the centering rings on the outside diameter of the B142 meter and align the bolt notches.
3) Place the centering rings with the B142 meter installed on the two bottom bolts between the flanges.
4) Insert and center the face gaskets.
5) Insert the remaining bolts and nuts.
6) Tighten nuts to the flange manufacturers specifications.

If problems arise with the flow meter or monitor consult the **Troubleshooting Guide**. If further problems arise, consult factory. If the internal components of the turbine flow meter are damaged beyond repair, replacement turbine cartridges are available.

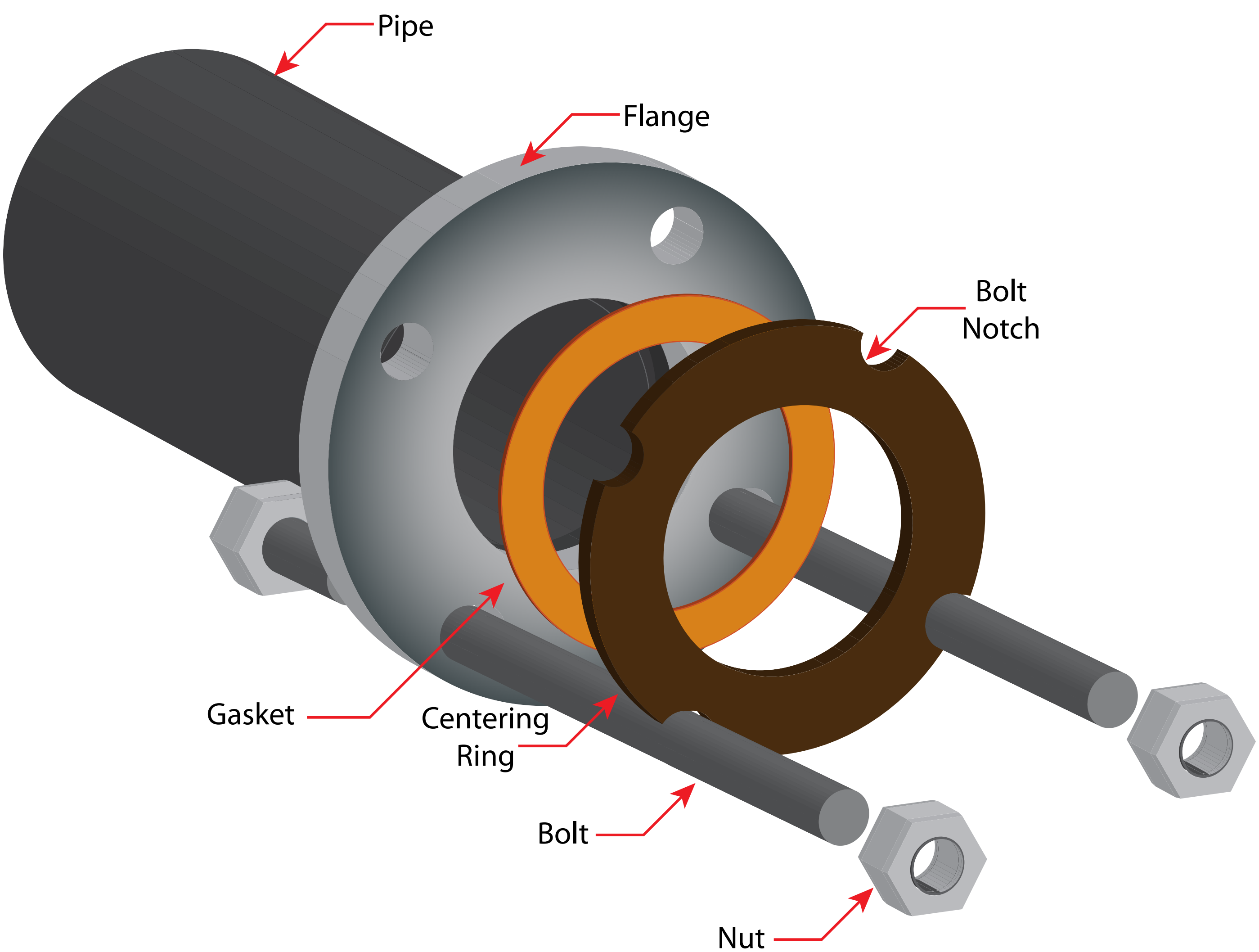


FIGURE 6 - INSTALLATION USING CENTERING RINGS

OPERATIONAL STARTUP

The following practices should be observed when installing and starting the meter.

Warning: Make sure that gas flow has been shut off and pressure in the line released before attempting to install the meter in an existing system.

1) After meter installation, close the isolation valves, and open the by-pass valve.
2) Open up-stream isolating valve slowly to eliminate hydraulic shock while charging the meter with gas. Open the valve to full open.
3) Open down-stream isolating valve to permit meter to operate.
4) Close the bypass valve to a full off position.
5) Adjust the downstream valve to provide the required flow rate through the meter.

NOTE: *The downstream valve may be used as a control valve.*

Appendix E: Pressure Requirement Calculations

Pressure requirement for the blower:

$$P_{blower} = \Delta P_{elevation} + P_{major} + P_{minor} \quad \text{(eq. 1)}$$

For major losses:

$$P_{major} = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2}\right)\rho \quad \text{(eq. 2)}$$

L = 6 ft
D = 3 in
V_{pipe} = 75 ft/s
ε = 0.5$x10^{-5}$ ft (from Engineering Toolbox for PVC)

Calculations for Moody Diagram: Roughness ratio and Reynold's number are required to get *f*

Roughness Ratio:

$$\frac{\varepsilon}{D} = \frac{0.5 * 10^{-5}}{3/12}$$

$$\frac{\varepsilon}{D} = 2 * 10^{-5}$$

Reynold's Number:

$$Re = \frac{\rho * V_{pipe} * D}{\mu}$$

$$Re = \frac{(0.002329\frac{slug}{ft^3})(75\frac{ft}{s})(^3/_{12}\frac{ft}{s})}{(3.82 * 10^{-7}\frac{lb_f s}{ft^2})}$$

$$Re = 114\,000$$

From Moody Diagram, *f* = 0.018

Using (eq.2) to find the major losses:

$$P_{major} = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2}\right)\rho \quad \text{(eq. 2)}$$

$$P_{major} = (0.018)\left(\frac{6\,ft}{^3/_{12}ft}\right)\left[\frac{\left(75\,\frac{ft}{s}\right)^2}{2}\right](0.002329\frac{slug}{ft^2})$$

$$P_{major} = 2.83\frac{lb_f}{ft^2} = 0.0197\,psi$$

For minor losses:

$$P_{minor} = \Delta P_{UUT} + \Delta P_{filter} \qquad \text{(eq. 3)}$$

For losses due to the UUT:

$$\Delta P_{UUT} = \frac{K_{UUT} * (V_{pipe})^2 * \rho}{2} \qquad \text{(eq. 4)}$$

$$\Delta P_{UUT} = \frac{(3.5) * \left(75\ \frac{ft}{s}\right)^2 * (0.002329\ \frac{slug}{ft^3})}{2}$$

$$\Delta P_{UUT}\ =\ 22.9\ \frac{lb_f}{ft^2}\ = 0.159\ psi$$

For losses due to the filter:

$$\Delta P_{filter} = \frac{K_{filter} * (V_{filter})^2 * \rho}{2} \qquad \text{(eq. 5)}$$

K_{filter} = 30 [from Engineering Toolbox]

Finding the velocity through the filter, assuming there are four 12"x12" filters:

$$Q_{filter} = Q_{pipe} \text{ (eq. 6)}$$

$$V_{filter} * A_{filter} = V_{pipe} * A_{pipe}$$

$$V_{filter} = \frac{V_{pipe} * A_{pipe}}{A_{filter}}$$

$$V_{filter} = \frac{\left(75\frac{ft}{s}\right)\left(\frac{\pi\left({}^{3}/_{12}\, ft\right)^2}{4}\right)}{4ft^2}$$

$$V_{filter} = 0.920\, {}^{ft}/_{s}$$

Using that velocity in (eq. 5):

$$\Delta P_{filter} = \frac{(30) * \left(0.920\frac{ft}{s}\right)^2 * (0.002329\frac{slug}{ft^3})}{2}$$

$$\Delta P_{filter}\ =\ 0.0296\ \frac{lb_f}{ft^2}\ =\ 2.06 * 10^{-4}\ psi$$

Using (eq. 1) and (eq. 3) to find the total pressure requirement for the blower:

$\Delta P_{filter} = 2.06\times10^{-4}$ psi
$\Delta P_{UUT} = 0.159$ psi
$P_{major} = 0.0197$ psi

$$P_{blower} = P_{major} + (\Delta P_{UUT} + \Delta P_{filter}) \qquad \text{(eq. 1 and 3 combined)}$$

$$P_{blower} = 0.0197 + 0.159 + 2.06 * 10^{-4}\ psi$$

$$P_{blower} = 0.179\ psi$$

$$P_{blower} = \frac{0.179\ psi}{\rho_{water} * g}$$

$$P_{blower} = \frac{0.179\ psi}{\left(1.936\frac{slug}{ft^3}\right)\left(32.174\frac{ft}{s^2}\right)\left(\frac{slug\ {}^{ft}/_{s^2}}{lb_f}\right)\left(\frac{144in^2}{ft^2}\right)}$$

$$P_{blower} = 0.414\ ft\ H_2O$$

$$\boxed{P_{blower} = 4.96\ in\ H_2O}$$

Appendix E: UUT Loss Coefficient

From experimental data and with an inlet pressure of 27 Pa:
ΔP without UUT = 193 Pa
ΔP with UUT = 829 Pa
Therefore, the ΔP due to UUT = 636 Pa
Equation for loss coefficient K:

$$\Delta P_{UUT} = \frac{1}{2} * K * \rho * V^2$$

$$K = \frac{2 * \Delta P_{UUT}}{\rho * V^2} \quad \text{(eq. 1)}$$

First we require V:

$$V = C * \sqrt{\frac{2}{\rho} \Delta P_{withoutUUT}} \quad \text{(eq. 2)}$$

$$V = 0.98 * \sqrt{\frac{2}{1.187 \frac{kg}{m^2}} * 193 \text{ Pa} * \left(\frac{\frac{N}{m^2}}{Pa}\right) * \left(\frac{kg \cdot m}{s^2\, N}\right)}$$

$$V = 17.7 \frac{m}{s}$$

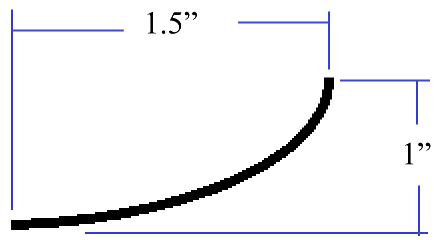
Plugging that V into (eq. 1):

$$K = \frac{2 * (636\ Pa)}{1.187 \frac{kg}{m^3} * (17.7 \frac{m}{s})^2}$$

$$\boxed{K = 3.43}$$

Appendix E: Nozzle Calculations

For nozzle, drawn by ellipse



As equation

$$\left(\frac{x}{1.5}\right)^2 + y^2 = 1 \quad \text{(eq. 1)}$$

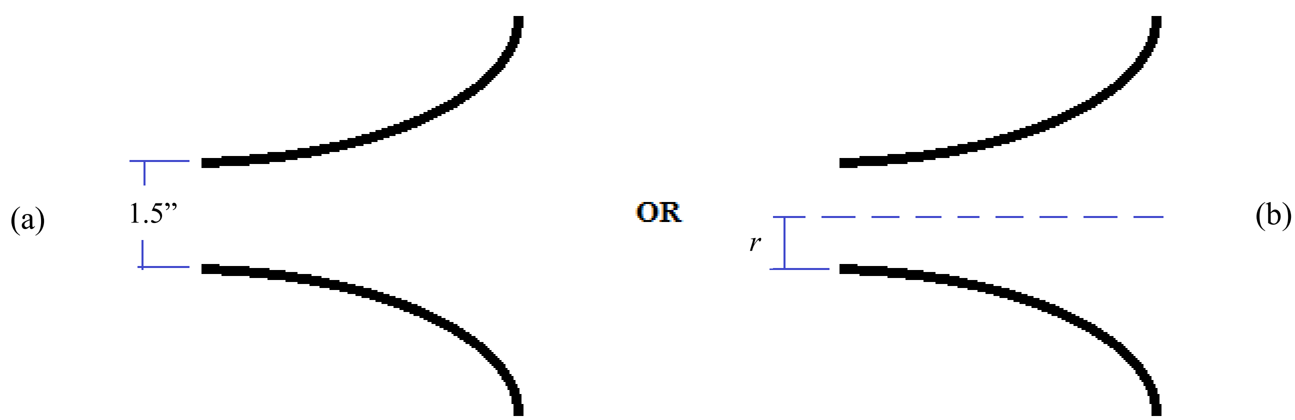
To determine force on nozzle

$$\sum F = \int_{cv} \vec{v} \cdot \rho \cdot \vec{v} \cdot \vec{n}\, dA \qquad \text{(eq. 2)}$$

We know flowrate Q (one of the independent variables) has a max of 2200cfm, then:

$$\vec{v} = \frac{Q}{A} \qquad \text{(eq. 3)}$$

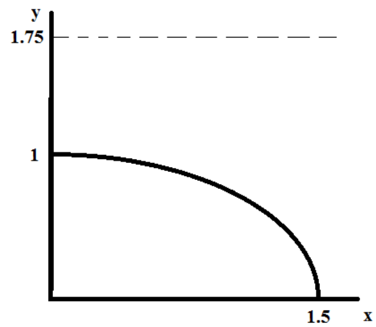
Now the nozzle area changes as it moves downstream



Looking at the full ellipse, the first quadrant demonstrates the bottom of our nozzle. But to get cross-sectional area we want *r* from (b), above. Using (eq. 1) solved for y:

$$y = \sqrt{1 - \left(\frac{x}{1.5}\right)^2}$$

This only shows the first quadrant.



Thus we can find *r*, using (eq. 1):

$$r = 1.75 - \sqrt{1 - \left(\frac{x}{1.5}\right)^2} \qquad \text{(eq. 4)}$$

We know area for a circle is given by $A = \pi r^2$, so that:

$$A = \pi\left(1.75^2 - 3.5 * \sqrt{1 - \left(\frac{x}{1.5}\right)^2} + 1 - \left(\frac{x}{1.5}\right)^2\right) \quad \text{(eq. 5)}$$

Back to (eq. 3):

$$\vec{v} = \frac{Q}{A} = \frac{Q}{\pi r^2}$$

From polar coordinates, we know $A = 2\pi r\, dr$. Plugging that into (eq. 2):

$$\sum F = \int_{cv} \left(\frac{Q}{\pi r^2}\right)^2 \rho 2\pi r\, dr$$

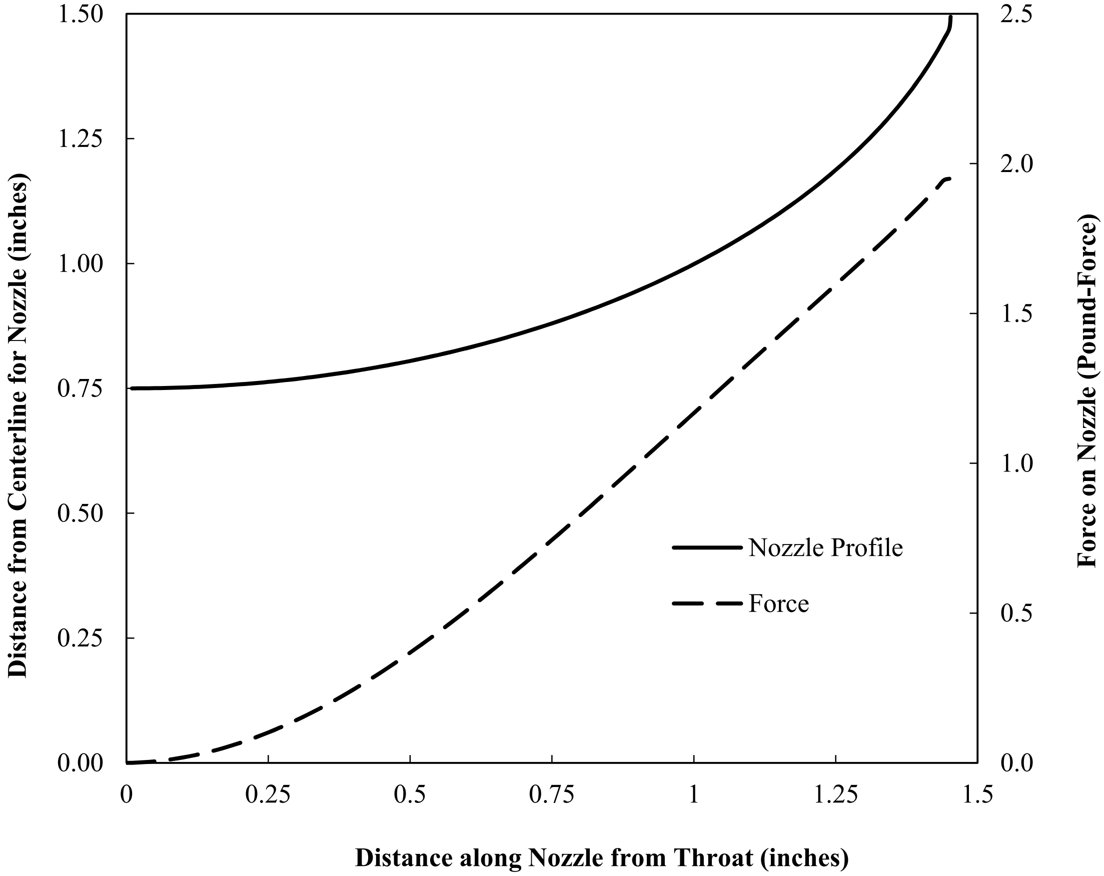
$$\sum F = \frac{2\rho Q^2}{\pi} \int_0^R \frac{1}{r^3}\, dr$$

Integrating to find forces on nozzle as a function of x after replacing all *r*'s with (eq. 4):

$$F = \frac{2\rho Q^2}{\pi} \left(\frac{-1}{2} r^{-2}\right)$$

$$F = -\left(\frac{\rho Q^2}{\pi r^2}\right)$$

The negative values indicate the forces act in the opposite direction to the flow.



Forces on Nozzle at 220 cfm.

This figure shows the forces due to the moving air on the nozzle at specific points along its profile. This is for a volumetric flowrate of 220 cfm, which is the max our system could do. However, the system will operate from 0 to 130 cfm, meaning the forces will be much lower when operating.

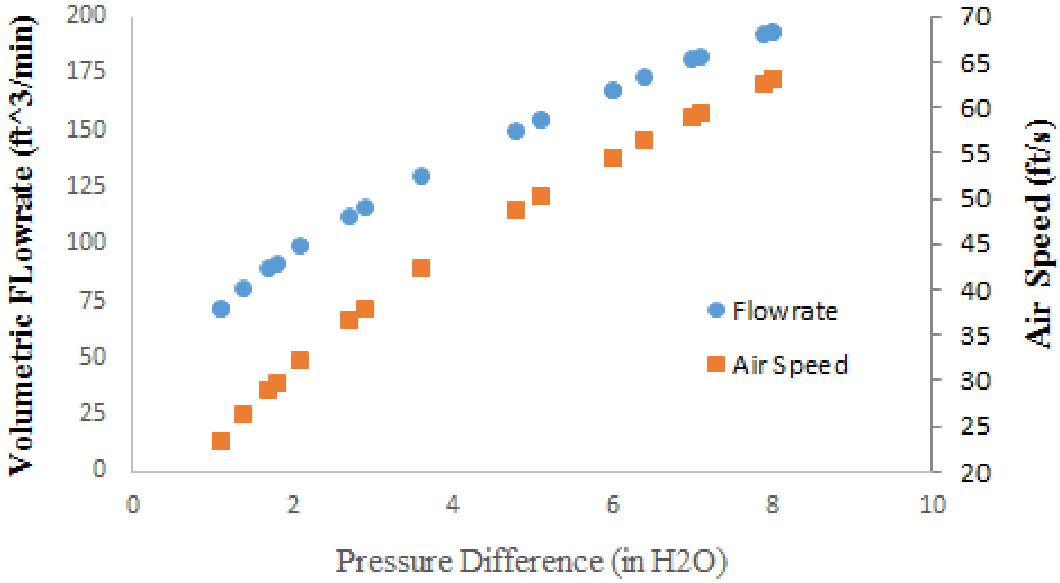
Appendix E. Test data and Calibration Curves

Test Data for Trial 1, for calibrating the MAF.

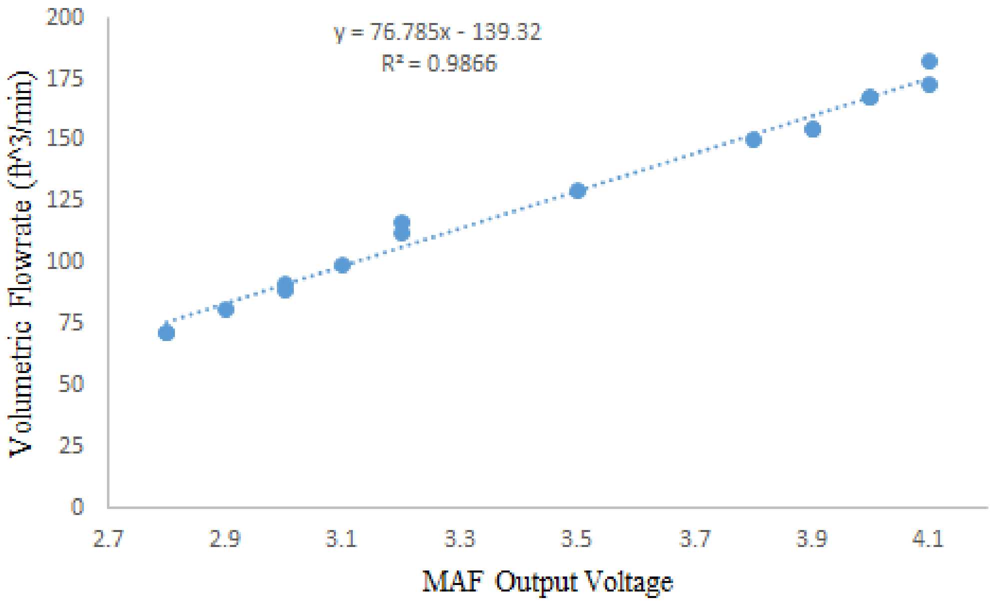
Venturi Measurements				MAF
Differential Pressure (in H2O)	Differential Pressure (psi)	Flowrate (cfm)	Line Speed (ft/s)	Voltage
1.1	30.5	71.9	23.4	2.8
1.8	49.9	92.0	30.0	3.0
2.9	80.4	116.8	38.0	3.2
4.8	133.0	150.2	48.9	3.8
5.1	141.3	154.8	50.4	3.9
6.0	166.2	167.9	54.7	4.0
6.4	177.3	173.4	56.5	4.1
7.0	194.0	181.4	59.1	4.1
8.0	221.7	193.9	63.2	4.1

Test Data for Trial 2, for calibrating the MAF.

Venturi Measurements				MAF
Differential Pressure (in H2O)	Differential Pressure (psi)	Flowrate (cfm)	Line Speed (ft/s)	Voltage
1.1	30.5	71.9	23.4	2.8
1.4	38.8	81.1	26.4	2.9
1.7	47.1	89.4	29.1	3.0
2.1	58.2	99.4	32.4	3.1
2.7	74.8	112.7	36.7	3.2
3.6	99.7	130.1	42.4	3.5
5.1	141.3	154.8	50.4	3.9
6.0	166.2	167.9	54.7	4.0
7.1	196.7	182.7	59.5	4.1
7.9	218.9	192.7	62.8	4.1
8.0	221.7	193.9	63.2	4.1



Plotted Data for Calibration.



Calibration for MAF based on MAF output Voltage.

Task Name	Durati	Start	Finish
Preliminary Design Report	16 days	Mon 10/26/15	Mon 11/16/15
PDR Presentation	6 days	Mon 11/9/15	Mon 11/16/15
Fall end status memo	6 days	Mon 11/23/15	Mon 11/30/15
Winter Quarter schedule	4 days	Wed 11/25/15	Mon 11/30/15
Analysis	37 days	Fri 11/20/15	Mon 1/11/16
Final Design	2 days	Mon 1/11/16	Tue 1/12/16
Bill of Materials	3 days	Wed 1/13/16	Fri 1/15/1
Critical Design Report	16 days	Mon 1/4/16	Mon 1/25/16
CDR presentation	6 days	Tue 2/2/16	Tue 2/9/16
Order materials	7 days	Tue 2/16/16	Wed 2/24/16
Manufacturing	11 days	Tue 3/1/16	Tue 3/15/16
Assembly	14 days	Thu 3/10/16	Tue 3/29/16
Winter end assembly status	6 days	Tue 3/8/16	Tue 3/15/16
Project update memo	11 days	Mon 3/28/16	Mon 4/11/16
Testing	35 days	Tue 4/5/16	Mon 5/23/16
Operating Manual	35 days	Tue 4/5/16	Mon 5/23/16
Aesthetics	4 days	Mon 5/2/16	Thu 5/5/16
Project Expo	7 days	Fri 5/13/16	Mon 5/23/16
Final Design Report	30 days	Mon 5/2/16	Fri 6/10/16