Experiment 3: Airflow System –Bernoulli's Experiment

Aim of this Experiment

Bernoulli Experiment: The duct allows students to quantitatively investigate Bernoulli's equation relating total pressure and dynamic pressure in a stream. The unit also introduces students to the Pitot - static tube, an essential tool for aerodynamic investigation and velocity measurement.

Experimental Set – up

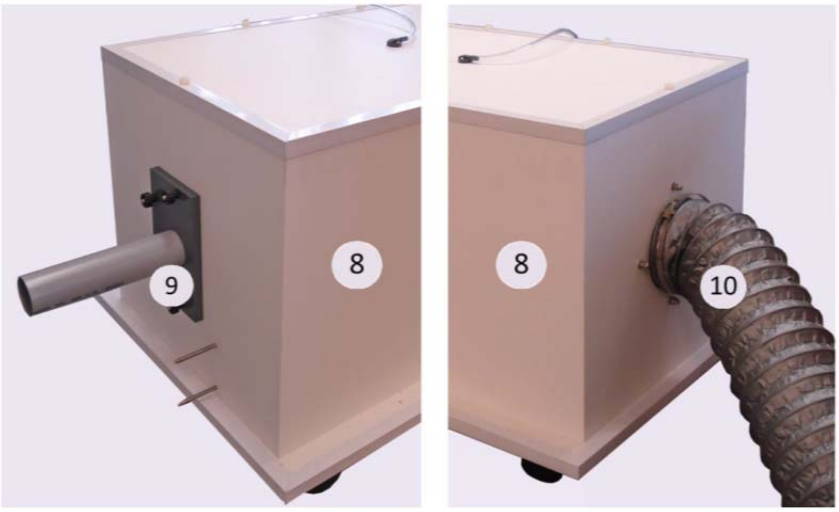
Experimental system has some essential items needed for the experimental use. It features a large capacity **airflow system, a plenum chamber, multi-tube monometer** and **Bernoulli investigation duct**.

The **Airflow System** has been specifically designed to allow students to investigate a wide range of and low speed air flow phenomena and fundamental aerodynamics. Airflow System base unit consists of a large capacity variable speed centrifugal fan with a separate aerodynamically designed plenum chamber containing multiple screens, flow straightener and acceleration section. The fan and plenum chamber are connected by a length of flexible hose and this allows the two components to be arranged in a variety of convenient locations either at bench or floor level.

A large number of optional ducts may be attached to the **plenum discharge** that allow investigation of airflow on the positive side of the fan.
In addition, there are additional optional items that attach to the suction or intake side of the fan.

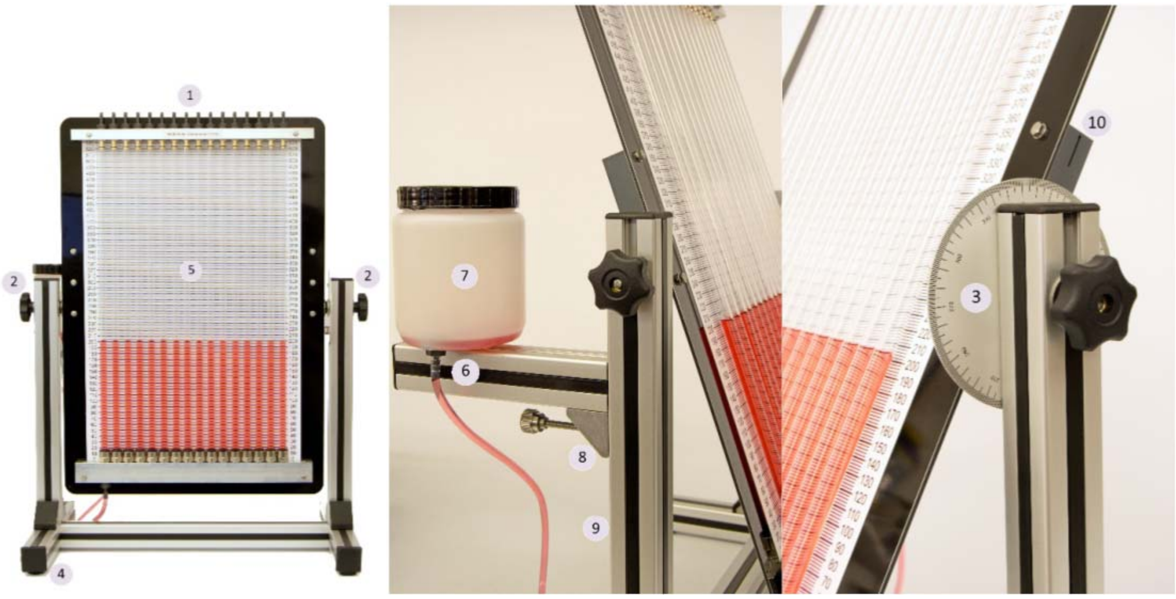
The ability to utilize both the intake and discharge sides of the fan, together with a continuously expanding range of optional accessories makes the **Airflow System** a very flexible and cost effective unit.

General experimental setup of Airflow System: 1. Fan; 2. Fan Speed Control; 3. RCCB & MCB Box; 4. Fan Outlet; 5. Fan Inlet; 6. RCCB; 7. MCB



General experimental setup of Plenum Chamber: 8. Plenum Chamber; 9. Plenum Discharge; 10. Plenum Inlet

Multi-tube Manometer has been designed for operation with the Airflow System. However as a 16 tube manometer it may equally be used in any application that is within its pressure range. Last apparatus for the experimental setup is Bernoulli investigation duct.



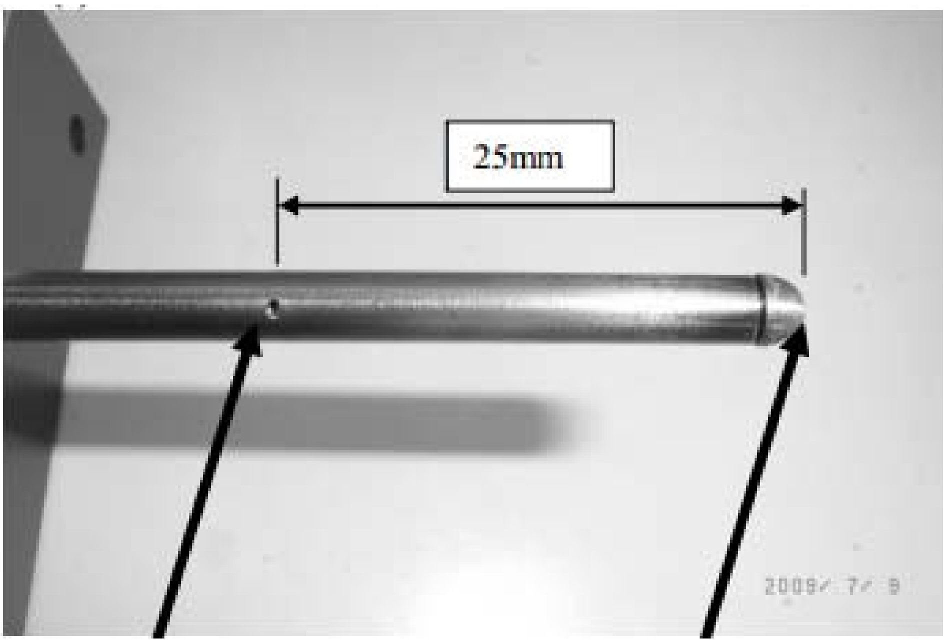
General experimental setup of Multi-Tube Manometer: 1. Manometer Tube Couplings; 2. Side Clamps; 3. Angle Indicator; 4. Rubber Feet; 5. Manometer Tubes; 6. Reservoir Tapping; 7. Reservoir; 8. Reservoir Clamp; 9. Reservoir Track; 10. Marker

General experimental setup of Multi-Tube Manometer: 1. Position Measuring Scale; 2. Profile Retaining Nuts; 3. Duct Profiles; 4. Mounting Nuts; 5. Pitot-Static Tube; 6. Locking Nut; 7. Static Pressure Tapping; 8. Total Pressure tapping

Theory

Duct demonstrates the use of a pitot-static tube and the application of Bernoulli’s equation along a convergent-divergent passage.

The **pitot-static tube (5)** head detail is shown below. The **static pressure (7)** tapping is 25mm behind the **total pressure (8)** tapping. The total pressure tapping brings the flow immediately in front of it to a halt.



According to Bernoulli’s equation the total pressure P is defined as

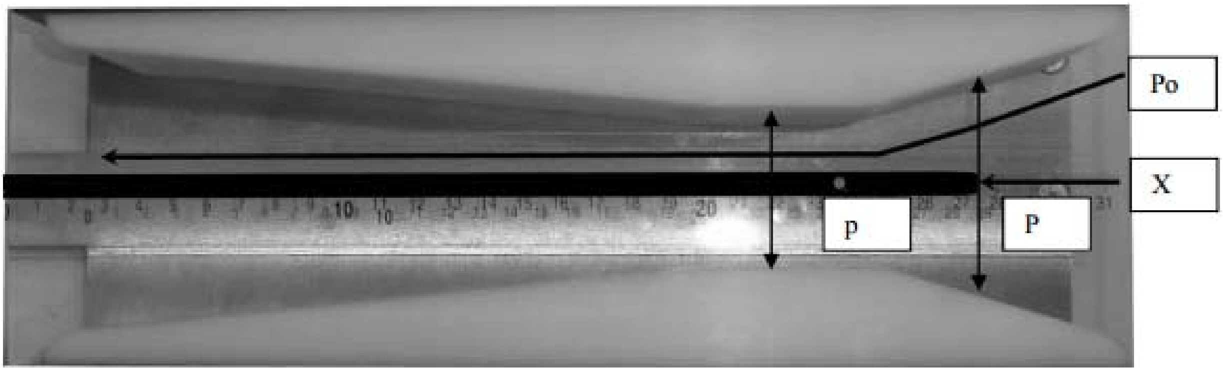
$$P = p + \frac{1}{2}\rho V^2 \qquad (1)$$

Where ρ is the static pressure (N/m^2) measured in a flow field moving at velocity *v*(m/s).

The total pressure P should be constant along the duct providing that the flow is steady and that the air is incompressible and inviscid. If the pressure in the plenum chamber is P_o then the pressure along the streamline shown above should be everywhere the same as P_o. This pressure can be measured using a tapping in the top wall of the box before the contraction as the velocity *v* inside the box is a fraction of that in the duct.

As the flow along the streamline X is brought to a halt at the total pressure tapping this tube will measure the total Pressure P at that point.

The static pressure *p* can be measured by the static pressure tappings in the wall of the pitot-static tube as the air is moving at velocity *v* (m/s) at this point. In order to not be affected by the presence of the tip of the tube (disturbing the streamlines) the static pressure holes are located at a position approximately 5 diameters downstream of the tip (25mm).



If the flow is assumed to be one dimensional (assuming that the velocity over any chosen cross-section to be uniform across that section) then the continuity equation may be written as

$$\dot{Q} = A_t V_t = AV \qquad (2)$$

Where; $\dot{Q}$ is the volume flow (m^3/s); A_t is the area at the throat (m^2); V_t is the velocity at the throat (m/s); A is the area at any point in the duct (m^2); V is the velocity at any point in the duct (m/s)

Re-arranging (2), the velocity distribution along the duct may be written as the ratio

$$\frac{V}{V_t} = \frac{A_t}{A}$$

The depth of the duct is constant (along the duct) and hence the area will be proportional to the duct height H. Hence

$$\frac{V}{V_t} = \frac{H_t}{H} \qquad (3)$$

Therefore, from the continuity equation, the theoretical velocity ratio (relative to the velocity at the contraction) at any point can be calculated purely from the height ratio.

From Bernoulli's equation the velocity at any point can be determined from the following:

$$
\begin{aligned}
P &= p + \frac{1}{2}\rho V^2 \\
2(P - p) &= \rho V^2 \qquad (3) \\
\sqrt{\frac{2(P - p)}{\rho}} &= V
\end{aligned}
$$

The velocity at the throat V_t is;

$$\sqrt{\frac{2(P_t - p_t)}{\rho}} = V_t$$

The actual velocity ratio in the duct may be determined from the following:

$$\frac{\sqrt{\frac{2(P - p)}{\rho}}}{\sqrt{\frac{2(P_t - p_t)}{\rho}}} = \frac{V}{V_t}$$

$$\sqrt{\frac{(P - p)}{(P_t - p_t)}} = \frac{V}{V_t}$$

Note that as the total pressure P will be the same (Pt = P) at all points along the duct the equation may be written as

$$\sqrt{\frac{(P - p)}{(P - p_t)}} = \frac{V}{V_t} \qquad (4)$$

Hence it is possible to measure the total and static pressure along the duct and compare the resulting velocity ratio with the velocity ratio calculated from the duct dimensions.

Velocity Measurement

Due to the Bernoulli relationship [$P = p + (1/2)\rho V^2$]the pitot-static tube is frequently used for the purpose of air velocity measurement. In fact the pitot-static tube or a pitot tube and separate static tapping is used on aircraft for the purpose of airspeed measurement.
Below is an example of a pitot tube on a light aircraft.

By measuring the difference between the total pressure P and static pressure p the air speed may be determined from

$$P = p + \frac{1}{2}\rho V^2$$

$$2(P - p) = \rho V^2$$

$$\sqrt{\frac{2(P-p)}{\rho}} = V$$

Experiment 3.1. Investigation of Bernoulli's Equation

Aim of This Experiment

This experiments aim the use Bernoulli's Equation on air flow system.

Procedure

Connection to the Airflow System
Care must be exercised when connecting the manometer to the airflow system and its optional accessories. The following method is suggested to prevent the manometer liquid from being either driven out of the manometer tubes or drawn into the tubes connected to the accessories. Before starting the fan, connect the pressure hoses to the accessory in use and to the manometer. Note that the two outer tubes (left and right) are not normally connected/used.

Set the manometer to the vertical or inclined condition as required and adjust the reservoir to about mid-height. Record the atmospheric datum or zero level. Then start the fan and slowly increase the speed, at the same time monitoring the manometer levels. As the pressures in the various tubes move up and/or down adjust the reservoir level also up or down, so that the liquid levels are kept within the range of the manometer.

Once the fan is running at the desired speed make any final adjustments to the reservoir level to set the atmospheric datum to a convenient value using the two outer tubes as a reference. Record this atmospheric datum as the reference value. It is this value that will be either taken from, or added to the other levels recorded on the manometer tubes.

Once the fan is at the desired operating speed loosen the locking nut and carefully slide the pitot-static tube along the length of the duct while monitoring the manometer tubes that are connected.

Ensure that the static pressure stays within the limits of the manometer.

Then set the manometer so that the static pressure tapping is located at the intake position (approximately x = 315mm from the duct exit) and record the following:

Po, Plenum Chamber Pressure
P, Total Pressure
p Static Pressure

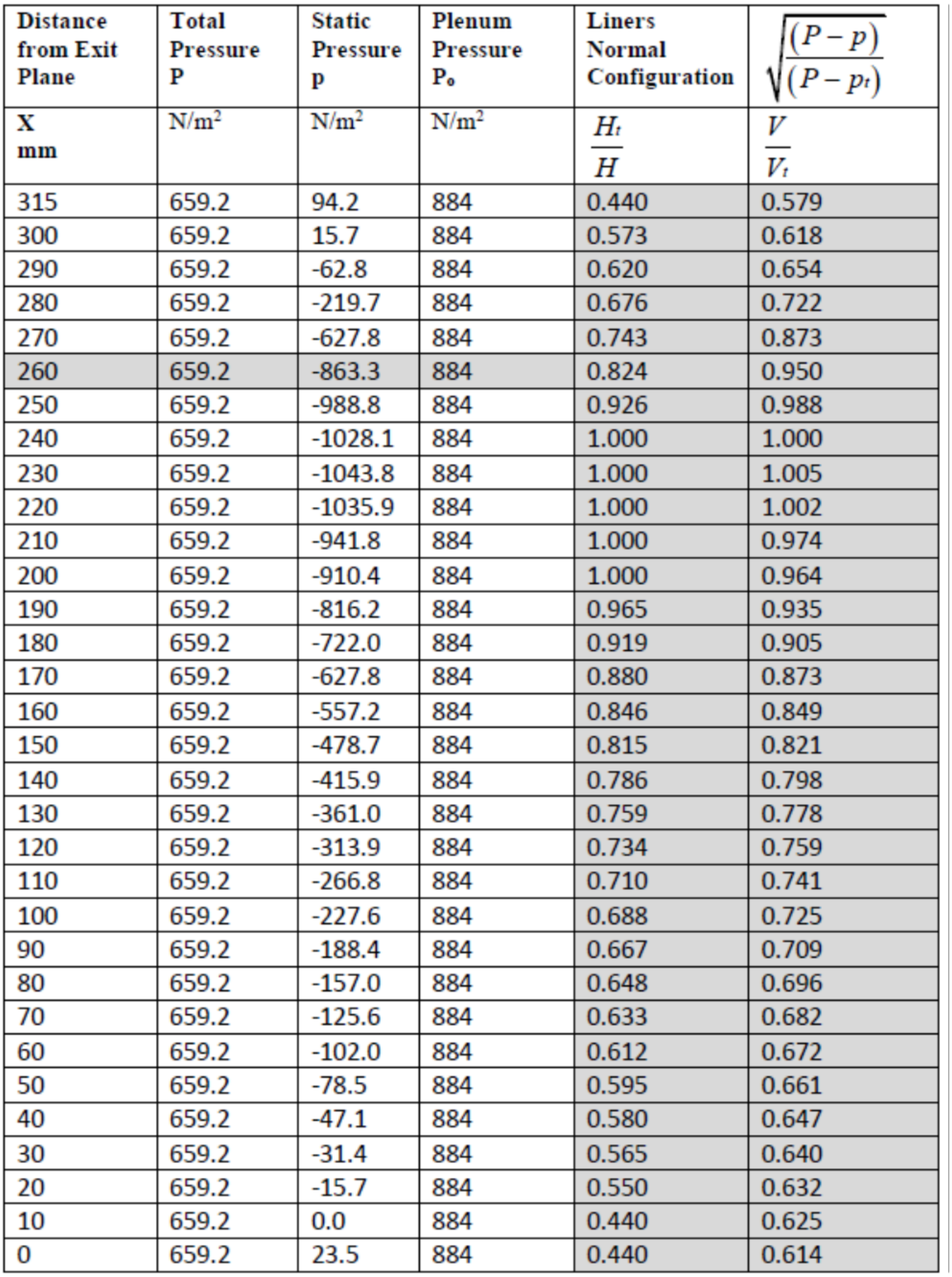
Refer to the useful data on appendix and retract the pitot-static tube a convenient distance, for which towards the discharge (say 10 or 15mm), record the location X and repeat the three pressure measurements Po, P, and p.

Continue retracting the pitot-static tube at regular intervals (data on appendix) record the location X and the three pressures until the tube is at the exit plane of the duct.

Typical Data

The table below shows data as recorded from the manometer. The readings are all measured in mm height on the manometer scales. The table on the following page shows the data processed using the method shown below.

Distance from Exit Plane	Liners Normal Configuration	Total Pressure P	Static Pressure p	Plenum Pressure P_o	Atmospheric Datum
X mm	$\frac{H}{H_t}$	mm	mm	mm	mm
315	0.440	168	240	138	252
300	0.573	168	250	138	252
290	0.620	168	260	138	252
280	0.676	168	280	138	252
270	0.743	168	332	138	252
260	0.824	168	362	138	252
250	0.926	168	378	138	252
240	1.000	168	383	138	252
230	1.000	168	385	138	252
220	1.000	168	384	138	252
210	1.000	168	372	138	252
200	1.000	168	368	138	252
190	0.965	168	356	138	252
180	0.919	168	344	138	252
170	0.880	168	332	138	252
160	0.846	168	323	138	252
150	0.815	168	313	138	252
140	0.786	168	305	138	252
130	0.759	168	298	138	252
120	0.734	168	292	138	252
110	0.710	168	286	138	252
100	0.688	168	281	138	252
90	0.667	168	276	138	252
80	0.648	168	272	138	252
70	0.633	168	268	138	252
60	0.612	168	265	138	252
50	0.595	168	262	138	252
40	0.580	168	258	138	252
30	0.565	168	256	138	252
20	0.550	168	254	138	252
10	0.440	168	252	138	252
0	0.440	168	249	138	252



Distance from Exit Plane	**Total Pressure P**	**Static Pressure p**	**Plenum Pressure P_o**	**Liners Normal Configuration**	$\sqrt{\frac{(P-p)}{(P-p_t)}}$
X mm	N/m^2	N/m^2	N/m^2	$\frac{H_t}{H}$	$\frac{V}{V_t}$
315	659.2	94.2	884	0.440	0.579
300	659.2	15.7	884	0.573	0.618
290	659.2	-62.8	884	0.620	0.654
280	659.2	-219.7	884	0.676	0.722
270	659.2	-627.8	884	0.743	0.873
260	659.2	-863.3	884	0.824	0.950
250	659.2	-988.8	884	0.926	0.988
240	659.2	-1028.1	884	1.000	1.000
230	659.2	-1043.8	884	1.000	1.005
220	659.2	-1035.9	884	1.000	1.002
210	659.2	-941.8	884	1.000	0.974
200	659.2	-910.4	884	1.000	0.964
190	659.2	-816.2	884	0.965	0.935
180	659.2	-722.0	884	0.919	0.905
170	659.2	-627.8	884	0.880	0.873
160	659.2	-557.2	884	0.846	0.849
150	659.2	-478.7	884	0.815	0.821
140	659.2	-415.9	884	0.786	0.798
130	659.2	-361.0	884	0.759	0.778
120	659.2	-313.9	884	0.734	0.759
110	659.2	-266.8	884	0.710	0.741
100	659.2	-227.6	884	0.688	0.725
90	659.2	-188.4	884	0.667	0.709
80	659.2	-157.0	884	0.648	0.696
70	659.2	-125.6	884	0.633	0.682
60	659.2	-102.0	884	0.612	0.672
50	659.2	-78.5	884	0.595	0.661
40	659.2	-47.1	884	0.580	0.647
30	659.2	-31.4	884	0.565	0.640
20	659.2	-15.7	884	0.550	0.632
10	659.2	0.0	884	0.440	0.625
0	659.2	23.5	884	0.440	0.614

The driving pressure for the flow through the duct is the Plenum Pressure Po. This should be close to or greater than the Total Pressure P. There can be differences between the Plenum Pressure Po and the Total Pressure P due to frictional and pressure losses in the transition between the plenum chamber and the duct. The degree of difference between Po and P may vary between F100B units and at different plenum driving pressures. The important factor in the data is the continuity of the Total pressure P along the duct and the relationship between static pressure p and the velocity pressure

$$\frac{1}{2}\rho V^2$$

This in turn confirms the Bernoulli relationship

$$P = p + \frac{1}{2}\rho V^2$$

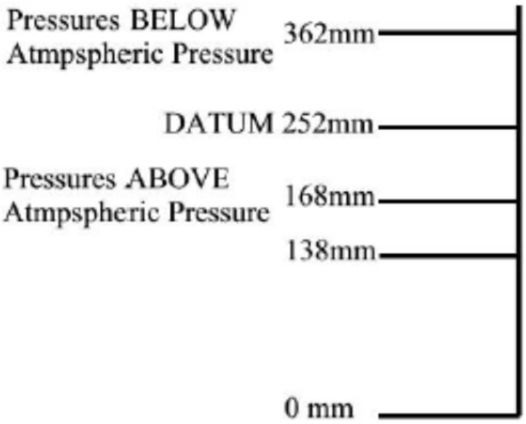
Sample Calculation

The following show the method used to calculate the data in typical data table.

All of the readings were taken in terms of height up the manometer tube using the reference scales.

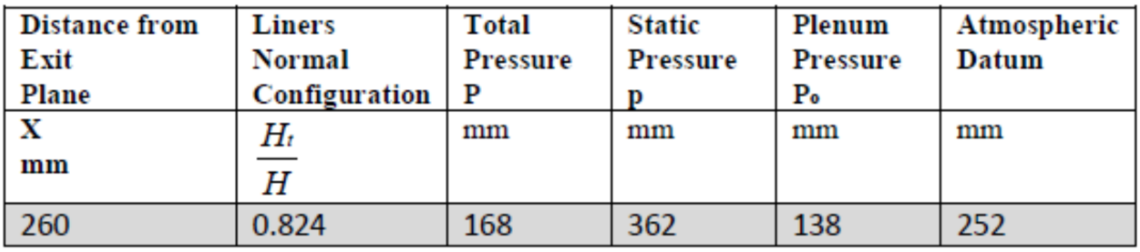
Referring to the reading at X = 260mm

Atmospheric datum = 252 mm, this is the reference value. Some pressures are higher than this (i.e the value will be lower than this) and others lower (i.e the value will be higher than this).

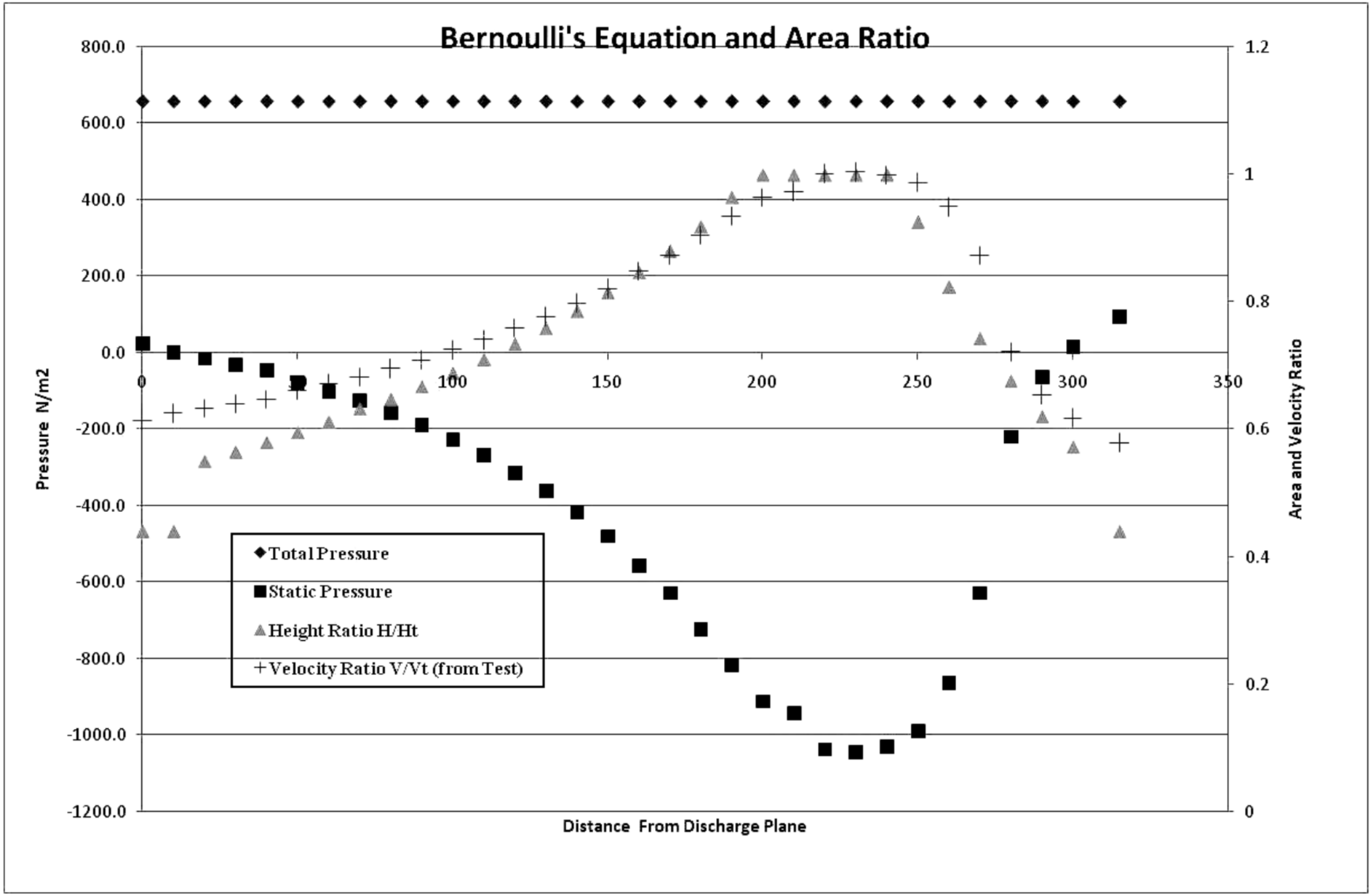


Due to the arrangement of the manometer scale (0mm at the bottom) the pressures can be determined relative to atmospheric pressure by subtracting the values from the DATUM value. Hence pressures below atmospheric pressure will be negative.

The pressures can be determined using the density of the manometer fluid and the fluid height/depth above or below the datum. Hence



Distance from Exit Plane	Liners Normal Configuration	Total Pressure P	Static Pressure p	Plenum Pressure P_o	Atmospheric Datum
X mm	$\frac{H_t}{H}$	mm	mm	mm	mm
260	0.824	168	362	138	252



Bernoulli's Equation and Area Ratio

Experiment 3.2. The Use of the Pitot-Static Tube for Air Velocity Measurement

This experiment aims to calculate velocity measurements by using pitot tube and Bernoulli's equation.

Procedure

The procedure for this experiment is identical to that used for experiment No 1.

The test results obtained from the procedure for experiment No 1 may also be used for this experiment.

The pitot-static tube may be used to determine the air velocity using the difference between Total Pressure P and static pressure p.

$$P = p + \frac{1}{2}\rho V^2$$

$$2(P - p) = \rho V^2$$

$$\sqrt{\frac{2(P-p)}{\rho}} = V$$

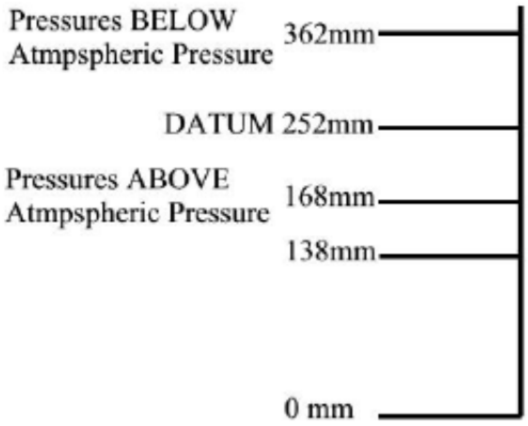
Utilizing the data on page 10 the following results may be calculated. For the test procedure the ambient air temperature was 21°C and the atmospheric pressure was 1.01325 x 10^5 N/m^2.

As may be seen the velocity varies from approximately 30m/s at inlet to 53m/s at the throat and approximately 32m/s at exit.

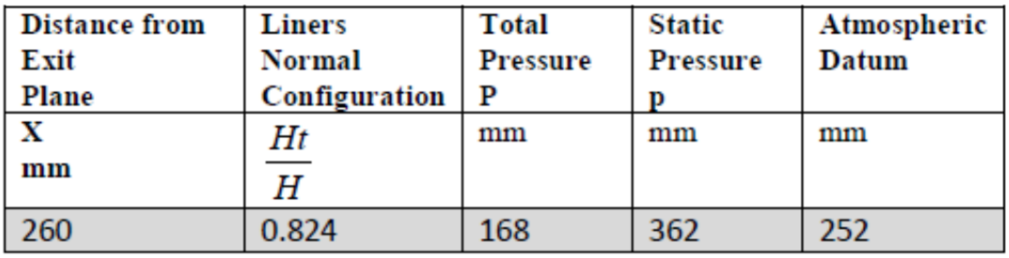
Sample Calculation

Referring to the reading at X = 260mm

Atmospheric datum = 252mm, this is the reference value. Some pressures are higher than this (i.e. the value will be lower than this) and others lower (i.e. the value will be higher than this).

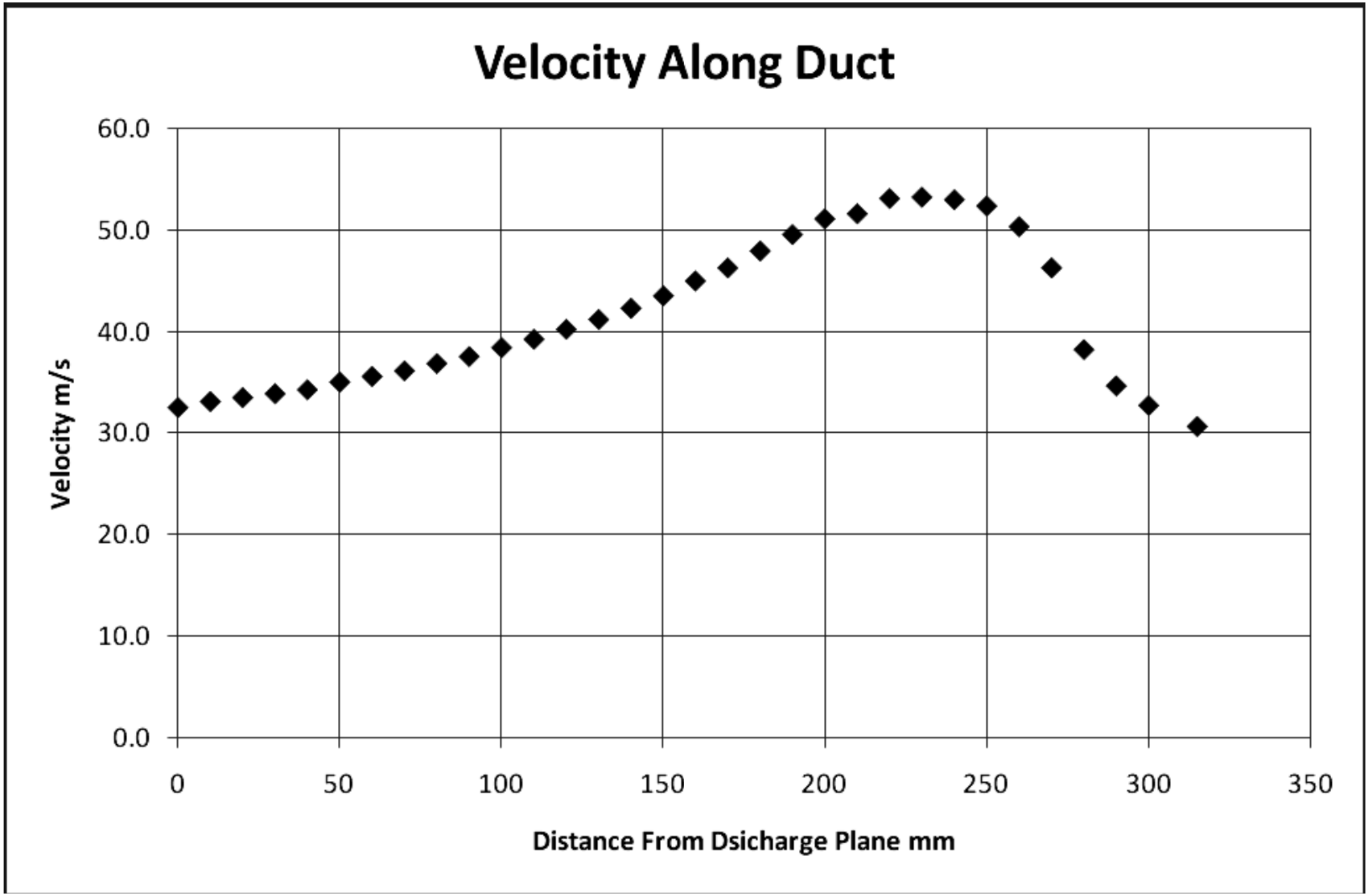


Due to the arrangement of the manometer scale (0mm at the bottom) the pressures can be determined relative to atmospheric pressure by subtracting the values from the DATUM value. Hence pressures below atmospheric pressure will be negative. The pressures can be determined using the density of the manometer fluid and the fluid height/depth above or below the datum.

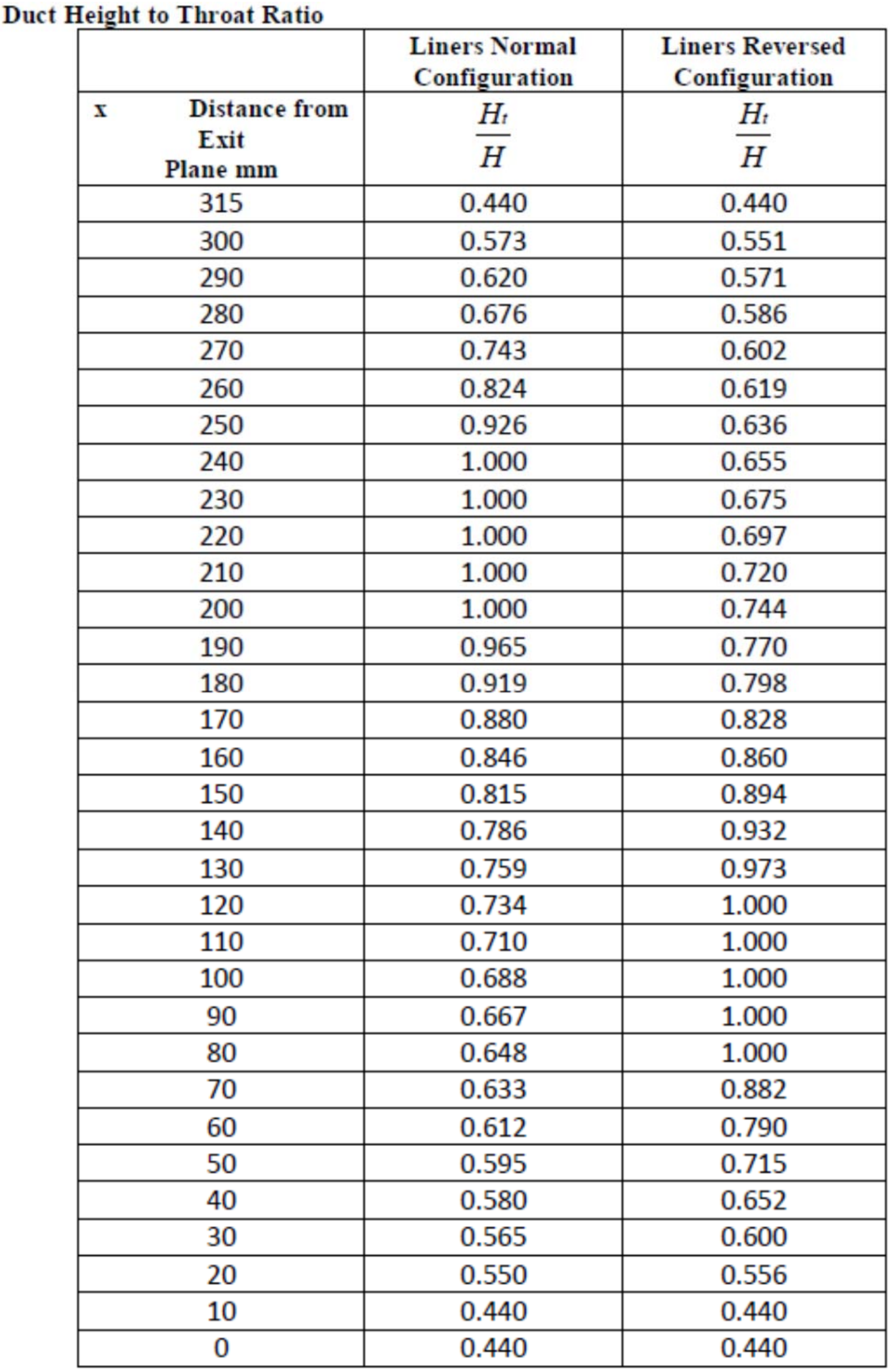


Distance from Exit Plane	**Liners Normal Configuration**	**Total Pressure P**	**Static Pressure p**	**Atmospheric Datum**
X mm	$\frac{Ht}{H}$	mm	mm	mm
260	0.824	168	362	252

Distance from Exit Plane	**Total Pressure P**	**Static Pressure p**	**Air Velocity**
X mm	N/m^2	N/m^2	m/s
315	659.2	94.2	30.7
300	659.2	15.7	32.7
290	659.2	-62.8	34.7
280	659.2	-219.7	38.3
270	659.2	-627.8	46.3
260	659.2	-863.3	50.4
250	659.2	-988.8	52.4
240	659.2	-1028.1	53.0
230	659.2	-1043.8	53.3
220	659.2	-1035.9	53.1
210	659.2	-941.8	51.6
200	659.2	-910.4	51.1
190	659.2	-816.2	49.6
180	659.2	-722.0	48.0
170	659.2	-627.8	46.3
160	659.2	-557.2	45.0
150	659.2	-478.7	43.5
140	659.2	-415.9	42.3
130	659.2	-361.0	41.2
120	659.2	-313.9	40.3
110	659.2	-266.8	39.3
100	659.2	-227.6	38.4
90	659.2	-188.4	37.6
80	659.2	-157.0	36.9
70	659.2	-125.6	36.2
60	659.2	-102.0	35.6
50	659.2	-78.5	35.1
40	659.2	-47.1	34.3
30	659.2	-31.4	33.9
20	659.2	-15.7	33.5
10	659.2	0.0	33.1
0	659.2	23.5	32.5


Velocity Along Duct
Velocity m/s
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
50
100
150
200
250
300
350
Distance From Dsicharge Plane mm

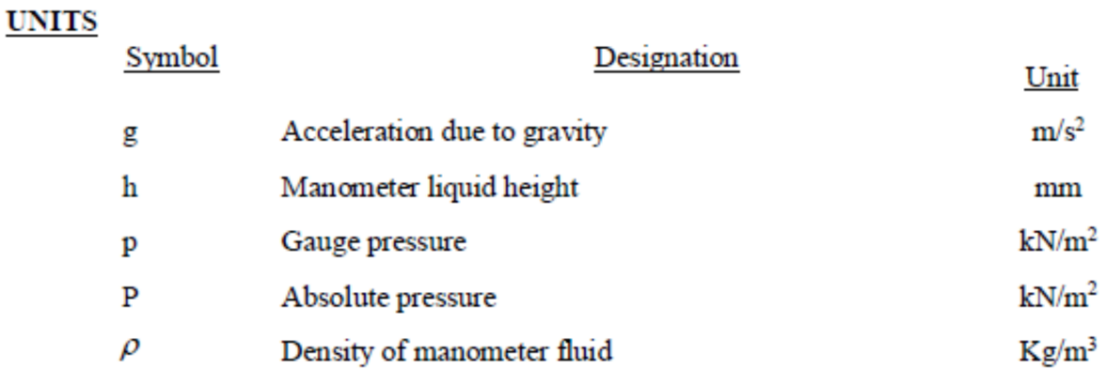
Appendix – I Some Useful Data



Duct Height to Throat Ratio

	Liners Normal Configuration	Liners Reversed Configuration
x Distance from Exit Plane mm	$\frac{H_t}{H}$	$\frac{H_t}{H}$
315	0.440	0.440
300	0.573	0.551
290	0.620	0.571
280	0.676	0.586
270	0.743	0.602
260	0.824	0.619
250	0.926	0.636
240	1.000	0.655
230	1.000	0.675
220	1.000	0.697
210	1.000	0.720
200	1.000	0.744
190	0.965	0.770
180	0.919	0.798
170	0.880	0.828
160	0.846	0.860
150	0.815	0.894
140	0.786	0.932
130	0.759	0.973
120	0.734	1.000
110	0.710	1.000
100	0.688	1.000
90	0.667	1.000
80	0.648	1.000
70	0.633	0.882
60	0.612	0.790
50	0.595	0.715
40	0.580	0.652
30	0.565	0.600
20	0.550	0.556
10	0.440	0.440
0	0.440	0.440

Appendix –II Symbols and Units



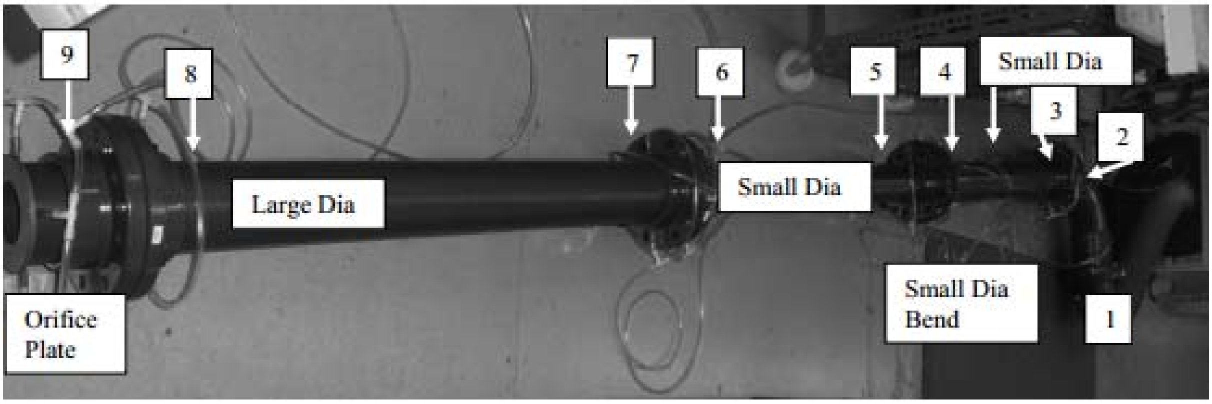
UNITS

Symbol	Designation	Unit
g	Acceleration due to gravity	m/s^2
h	Manometer liquid height	mm
p	Gauge pressure	kN/m^2
P	Absolute pressure	kN/m^2
ρ	Density of manometer fluid	Kg/m^3

Experiment 3.3. Investigation of Total Pressure and Pressure Drop Along a Duct

The **orifice plate (2)** allows the mass/volume flow rate to be measured and this is then used to determine the velocity pressure at points along the duct.

Experimental Setup



The fan is located at the right side of the picture and air will be drawn in through the orifice plate on the left hand side of the picture. The numbers are used to identify the pressure tapping points. Note that each pair of tappings are linked using short lengths of hose and a plastic T. The T is then connected to the user's manometer or optional **Multi-tube manometer**. The pressure tappings on the fan intake are also connected to a tube on the manometer. Note that with a large number of hoses connected it can be useful to identify the tubes on the manometer using paper labels.

Procedure

It is recommended that the fan is operated at a low speed (below 1000rpm) as this reduces the height in the manometer. In fact it is recommended that the manometer is set at an inclined angle. Once the fan is operating at the desired speed, record the manometer heights at each measuring point.

Connection to the Airflow System: Care must be exercised when connecting the manometer to the airflow system and its optional accessories. The following method is suggested to prevent the manometer liquid from being either driven out of the manometer tubes or drawn into the tubes connected to the accessories. Before starting the fan, connect the pressure hoses to the accessory in use and to the manometer. Note that the two outer tubes (left and right) are not normally connected/used. Set the manometer to the vertical or inclined condition as required and adjust the reservoir to about mid-height. Record the atmospheric datum or zero level. Then start the fan and slowly increase the speed, at the same time monitoring the manometer levels. As the pressures in the various tubes move up and/or down adjust the reservoir (7) level also up or down, so that the liquid levels are kept within the range of the manometer. Once the fan is running at the desired speed make any final adjustments to the reservoir level to set the atmospheric datum to a convenient value using the two outer tubes as a reference. Record this atmospheric datum as the reference value. It is this value that will be either taken from, or added to the other levels recorded on the manometer tubes.

Theory and Useful Data for Calculations

For an Orifice plate:

$$\dot{m} = C\frac{\pi d^2}{4}\sqrt{2\rho(p - p_o)}$$

Where C is made up of two factors ε and α . From the EN ISO 5801 standard, from an intake orifice α = 0.598.

The ε factor is based upon the measured pressure ratio at the fan intake. For the purposes of the F100M unit this can be taken as ε = 0.995.

The orifice plate supplied with the F100M unit has an orifice diameter d of 0.071.

Hence the standard equation for the orifice plate is:

$$\dot{m} = 0.598 \times 0.995\frac{\pi 0.071^2}{4}\sqrt{2\rho(p - p_o)}$$

Where

$\dot{m}$ = Mass Flow kg/s
ρ = Air Density kg/m^3
d = Orifice Diameter m
$p - p_o$ = Static Pressure drop across intake N/m^2

Hence

$$\dot{m} = 0.598 \times 0.995 \frac{\pi d^2}{4} \sqrt{2\rho(p - p_o)}$$

$\dot{m}$ = Mass Flow kg/s
ρ = Air Density kg/m^3
d = Orifice Diameter = 0.071 m
$p - p_o$ = Static Pressure drop across intake kN/m^2

Air Density:

$$\rho = \frac{p_a}{R \times T_a}$$

Where
ρ = Air density (kg/m^3)
p_a = Ambient air pressure (N/m^2)
R = Gas Constant for air (286 J/kgK)
T_a = Absolute air temperature (K)

Volume Flow Rate:

If the mass flow $\dot{m}$ is known and the air density calculated then the volume flow can be determined from

$$\dot{Q} = \frac{\dot{m}}{\rho}$$

Where
$\dot{Q}$ = volume Flow (m^3/s)
$\dot{m}$ =Mass flow (kg/s)
ρ = Local Air Density (kg/m^3)

Air Velocity:

If the air mass flow , density and hence Volume flow is determined, then the local air velocity **V** may be estimated from the cross sectional area **A** of the duct at the point of interest.

$$V = \frac{\dot{m}}{\rho \times A}$$

Where
V=Velocity (m/s)
A = Cross sectional area (m^2)

Pipe Dimensions:

Large diameter pipe and bend	106mm Bore	Flow Area	0.0087m^2
Small diameter pipe and bend	82mm Bore	Flow Area	0.0052m^2
Orifice Plate inlet diameter	0.071m		

Sample Calculation

The table below shows data as recorded from the manometer. The readings are all measured in mm height on the manometer scales. The table on the following page shows the data processed using the method shown on the following pages.

Ambient Pressure pa = 1016mBar (101600 N/m2)
Ambient Temperature ta = 21°C
Manometer Datum Zero = 48mm
Manometer Angle = 30°
Fan speed = 934 rpm

Fan Speed	Fan Intake	1	2	3	4	5	6	7	8	9 Orifice Plate
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
934	183	179	175	174	171	171	168	160	174	184

Converting these manometer heights to pressure readings gives the following table

Fan Speed	Fan Intake	1 Static pressure	2 Static pressure	3 Static pressure	Static pressure	5 Static pressure	6 Static pressure	7 Static pressure	8 Static pressure	9 Orifice Plate
N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	
934	-917	-890	-863	-856	-836	-836	-816	-761	-856	-924

The manometer heights can be converted to pressures as follows, taking the orifice plate reading of 184 mm as an example.

Manometer datum zero = 48mm

Manometer pressure = $p = \rho g h \times Cos\theta$

Where

$Cos\theta$ = the angle that the manometer is set to (30°)
ρ = Manometer fluid density (water = 1000 kg/m^3 , red mano fluid 800 kg/m^3)
g = Acceleration due to gravity (9.81 m/s^2)
h = Height of manometer fluid above datum.

Hence pressure at orifice plate

$$p = \rho g h \times Cos\theta$$
$$= 800 \times 9.81 \times (0.184 - 0.048) \times Cos30$$
$$= 924 \text{ N/m}^2$$

Note that due to the direction in which the manometer fluid travels (above the datum) this is a pressure BELOW atmospheric pressure. i.e. -924 M/m^2

From the USEFUL data, the air density can be calculated from

$$\rho = \frac{p_a}{R \times T_a}$$

Where
pa = 101600N/m^2
R = 286 J/kgK
Ta = 21+273K

Substituting gives

$$\rho = \frac{101600}{286 \times 294}$$
$$= 1.204 \text{ kg/m}^3$$

Similarly from Useful data, the air mass flow can be obtained from

$$\dot{m} = 0.598 \times 0.995 \frac{\pi 0.071^2}{4} \sqrt{2\rho(p - p_o)}$$

Where
$\dot{m}$ = Mass Flow kg/s
ρ = Air Density kg/m^3
d = Orifice Diameter = 0.071 m
$p - p_o$ = Static Pressure drop across intake kN/m^2

Substituting for the Orifice plate differential pressure (p - po) = 184 N/m^2 and the air density.

$$\dot{m} = 0.598 \times 0.995 \frac{\pi 0.071^2}{4} \sqrt{2\rho(p - p_o)}$$
$$= 0.598 \times 0.995 \frac{\pi 0.071^2}{4} \sqrt{2 \times 1.204 \times 184}$$
$$= 0.111 \text{ kg/s}$$

If the assumption is made that the air density remains essentially constant along the duct then from the useful data on page 18, the velocity along the duct can be calculated from

$$V = \frac{\dot{m}}{\rho \times A}$$

This is dependant upon the duct cross section (flow are) From the useful data on page 18 the large diameter ducts have a bore of 106mm and a flow area of 0.0087m2. Hence the **theoretical** velocity in the large duct is

$$V = \frac{\dot{m}}{\rho \times A} =$$
$$= \frac{0.111}{1.204 \times 0.0087}$$
$$= 10.6 \text{ m/s}$$

Hence the velocity pressure VP in the large diameter ducts at this condition will be

$$\begin{aligned} VP &= \frac{1}{2}\rho V^2 \\ &= \frac{1}{2}1.204 \times 10.6^2 \\ &= 67.4\ \mathrm{N/m^2} \end{aligned}$$

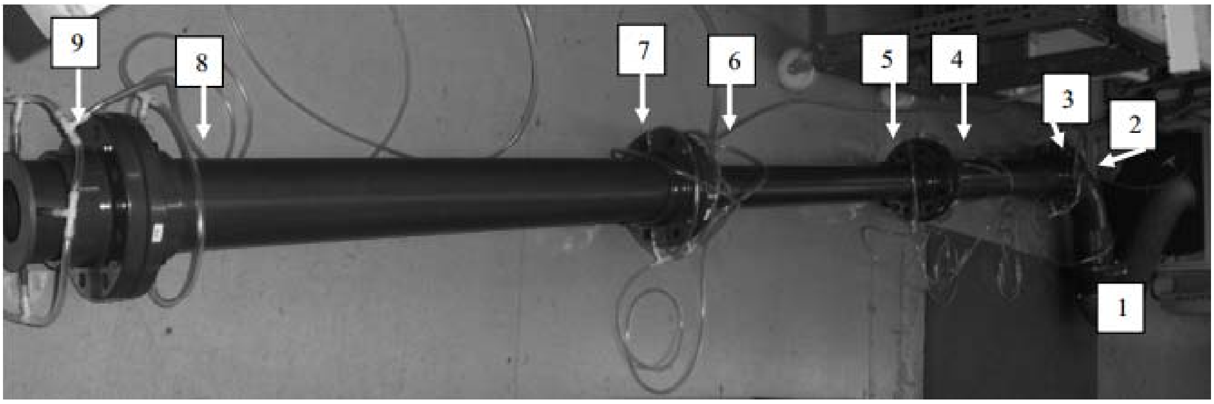
Similarly in the small diameter ducts where the bore diameter is 82mm and the flow area is 0.0052 m2. The **theoretical** velocity in the large duct is

$$\begin{aligned} V &= \frac{\dot{m}}{\rho \times A} = \\ &= \frac{0.111}{1.204 \times 0.0052} \\ &= 17.6\ \mathrm{m/s} \end{aligned}$$

Hence the velocity pressure VP in the large diameter ducts at this condition will be

$$\begin{aligned} VP &= \frac{1}{2}\rho V^2 \\ &= \frac{1}{2}1.204 \times 17.6^2 \\ &= 187.4\ \mathrm{N/m^2} \end{aligned}$$

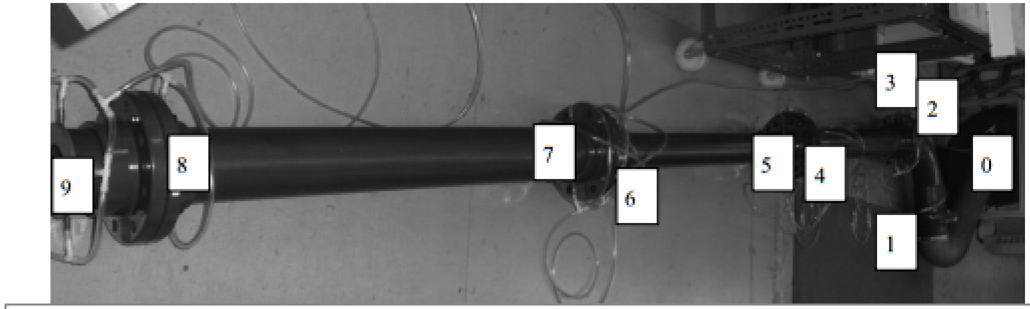
With reference to the duct combination in use the local static pressures and velocity pressures can be combined to give the local Static Pressure SP, Velocity Pressure VP and Total Pressure at each location.

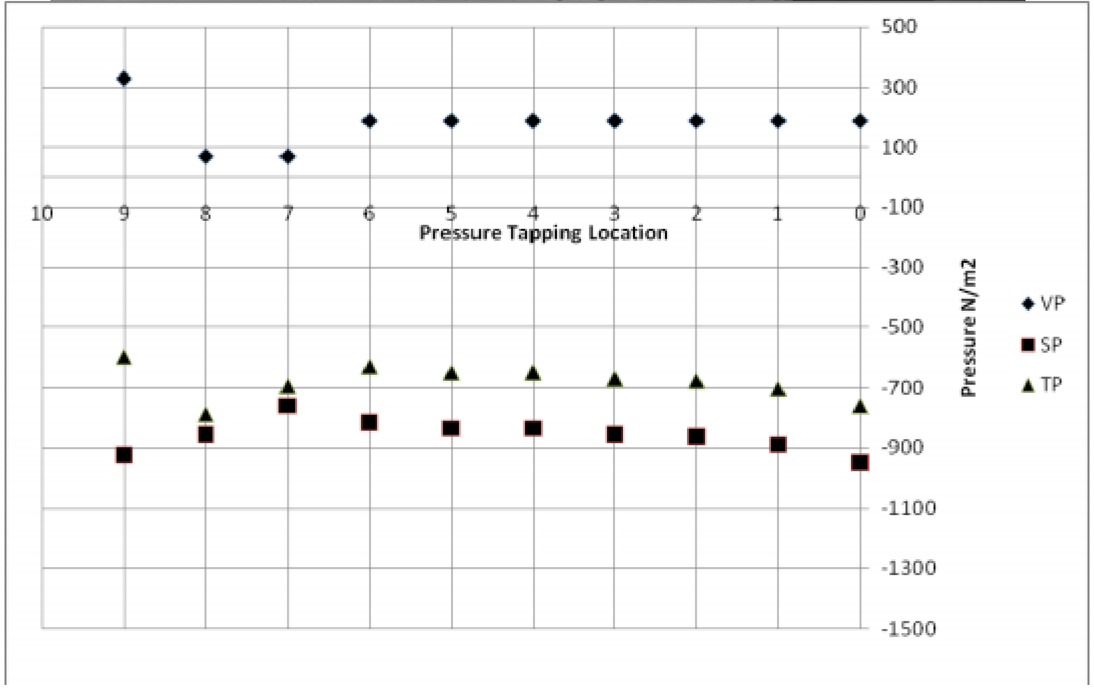


Location	Fan Intake	1	2	3	4	5	6	7	8
Pressure	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2	N/m2
SP	-917	-890	-863	-856	-836	-836	-816	-761	-856
VP	187.4	187.4	187.4	187.4	187.4	187.4	187.4	67.4	67.4
TP	-729.6	-702.6	-675.6	-668.6	-648.6	-648.6	-628.6	-693.6	-78

Note that as the pipe sections are on the intake side of the fan the static pressures are all negative and the velocity pressure reduces this due to its positive nature. However the total pressure available to drive the flow towards the fan falls progressively due to the bend and 2 lengths of small diameter tube. The tapping at 7 and 8 are affected by the turbulent nature of the airflow leaving the orifice plate. With hindsight the remaining large diameter duct should have been included between point 8 and the orifice plate in order to provide a greater settling length before the change in section.

The data is plotted graphically on the next page.


9
8
7
6
5
4
3
2
1
0


500
300
100
-100
-300
-500
-700
-900
-1100
-1300
-1500
Pressure N/m2
10
9
8
7
6
5
4
3
2
1
0
Pressure Tapping Location
◆ VP
■ SP
▲ TP