F9a: Fluid Mechanics & Bernoulli’s Principle

Introduction:

The focus of this experiment is to understand the relationship between flow rate, cross sectional area, velocity and pressure. This is related to Bernoulli’s principle, which states that for an ideal fluid that is assumed to have no viscosity, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure.

Bernoulli’s principle has many real world applications. One such application, which is very important, is lift for airplanes. If the air flowing past the top surface of the wing of a plane is moving faster than the air flowing past the bottom surface, then Bernoulli's principle implies that the pressure on the top surface of the wing will be lower than that on the bottom surface. This difference in pressure results in an upwards lifting force. In the health field, Bernoulli’s principle can be applied to blood vessels that are narrowed by plaque deposits or widened due to an aneurysm. When the blood vessels narrow (stenosis) the velocity of the blood must increase, which in turn decreases the pressure. This can result in further narrowing of the vessel, which can close off the artery completely. On the other hand, if the radius of the blood vessel becomes increased due to an aneurysm which is a balloon like bulge in an artery, the velocity then decreases and the pressure increases. The artery wall then becomes more likely to become weak and rupture.

Unfortunately, or fortunately, we were unable to procure enough blood, so instead we will use air flow for this experiment. In a Venturi apparatus, air flows through a channel of varying widths. For a constant volumetric flow rate, velocity and pressure will change depending on the cross sectional area. In this lab, you will vary your airflow rates through four areas of the apparatus measuring velocity and pressure for each area.

Apparatus:

- Venturi Apparatus
- Vacuum Air Pump
- Spirometer Sensor
- Quad Pressure Sensor
- Computer, Interface, Software

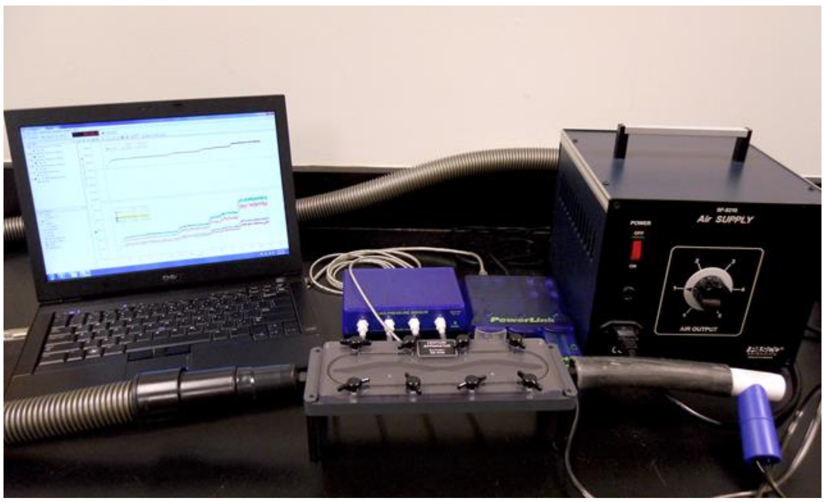

Figure 1

Discussion:

When a force is exerted on a surface, it is frequently more useful to describe it by a quantity called pressure. Pressure is a measure of the force per unit area. Although force has a direction (a vector quantity), pressure has no direction (a scalar quantity). Pressure is defined by:

$$P=\frac{F}{A}$$

Where **P** is the pressure, **F** is the magnitude of the force acting perpendicular on the surface and **A** is the area of the surface over which the force is acting. Typically the force is also considered uniform over the surface. The SI unit for pressure is a *Pascal:* where one Pascal is equal to one Newton per one square meter: ($Pa=N/m^2$)

Due to conservation of mass, when there is no fluid lost or gained the volume flow rate is constant along a pipe or channel. For an incompressible fluid, the volume flow rate is equal to the product of the cross sectional area and the velocity. The relationship between Flow Rate, Cross Sectional Area and Velocity is called the Continuity equation:

$$R=Av$$

Where **R** is the flow rate, **A** is the cross sectional area and **v** is velocity. The continuity equation implies that when a fluid enters a more constricted section its velocity increases. You will use this equation to calculate your velocities based on flow rate and calculated cross sectional area.

Bernoulli's principle states that for an ideal fluid, which is assumed to have no viscosity, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure. For laminar flow, we can ignore the effects of friction, we have Bernoulli’s equation:

$$P+\frac{1}{2}\rho v^2+\rho gh=\text{constant}$$

Where **P** is pressure, **ρ** is air density, **v** is velocity, **g** is acceleration due to gravity and **h** is the height above a reference point. This equation will be valid for most liquids and for gases when no expansion or compression is occurring. Another way to write this equation relates the parameter values at two points along a streamline.

$$P_1+\frac{1}{2}\rho_1 v_1^2 +\rho_1 gh=P_2+\frac{1}{2}\rho_2 v_2^2+\rho_2 gh$$

For a case where there is no change in height (such as in this experiment) you can simplify the equation to:

$$P_1+\frac{1}{2}\rho_1 v_1^2=P_2+\frac{1}{2}\rho_2 v_2^2$$

By using the measured pressure from one section, air density and the calculated velocities you can calculate the pressure for the other sections.

$$P_1+\frac{1}{2}\rho(v_1^2-v_2^2)=P_2$$

Please read/review the following sections in your textbook for each of the main concepts.

Pressure: James Walker. **<u>Physics</u>**, *Chapter* **15** *section* **2**

	Cutnell & Johnson.	**Physics**,	*Chapter* **11** *section* **2**
	Franklin, Muir,.	**Biological Physics**	*Chapter* **11** *section* **2**
Continuity Equation:	James Walker.	**Physics**,	*Chapter* **15** *section* **6**
	Cutnell & Johnson.	**Physics**,	*Chapter* **11** *section* **8**
	Franklin, Muir,.	**Biological Physics**	*Chapter* **14** *section* **3**
Bernoulli's Principle:	James Walker.	**Physics**,	*Chapter* **15** *section* **7**
	Cutnell & Johnson.	**Physics**,	*Chapter* **11** *section* **9**
	Franklin, Muir,.	**Biological Physics**	*Chapter* **14** *section* **4**

Procedures:

1. Using the provided measurements for the Chamber Widths and Depth, calculate the Cross Sectional Areas for each location of Ports 1, 2, 3 and 4 in Table 2.
2. Open the correct Pasco Capstone program (F9a Fluid Mechanics.cap). Check that the quad pressure sensor is properly calibrated. **Ask a lab assistant to help you check the calibration of the quad pressure sensor.**
3. To begin collecting data Press the Record button and watch for the spirometer sensor to change from a red light to a green light.
4. Check that the dial on the air supply is set to the first mark (the number 1) indicating Flow Rate 1. Turn on the air supply.
5. At 60 seconds on Flow Rate 1, turn the dial to the next mark indicating Flow Rate 2 and continue collecting 60 seconds of data at that rate as well.
6. Repeat this process for Flow Rates 3, 4 and 5 each time collecting 60 seconds of data.
7. After 60 seconds on Flow Rate 5, turn the air supply dial back to Rate 1 and then turn the air supply off. Click Stop on the computer software to end the data collection.
8. Once you have finished collecting data, you should have two graphs on the computer screen. One graph with the single plot line is Flow Rate vs. Time. The other graph with four lines plotted is Absolute Pressure vs. Time.
9. On the graph marked Flow Rate vs. Time, determine Flow Rate 1 using the time range between 40 and 60 seconds. By highlighting the data between 40 and 60 seconds, the mean flow rate for the interval will be displayed on the graph. This corresponds to the value for your first flow rate. Enter this on your data sheet Table 3 for Flow Rate 1.
10. On the graph marked Pressure vs Time, you will notice that in the legend you have four different pressures, one for each port. In order to change between the ports for analyzing the pressures, click on the corresponding data icon in the legend.
11. First, click on P1 for Port 1. Highlight the same time region you did for your Flow Rate 1 (this should be between 40 and 60 seconds). The mean pressure for that interval will be displayed on the graph. Record this value under Measured Pressure for Port 1 in Table 3.
12. Next click on P2 for Port 2. Again highlight the same time region you did for Flow Rate 1 and obtain the Measure Pressure for Port 2.
13. Repeat these steps for the P3 and P4, which correspond to Port 3 and Port 4, to get their values for Measured Pressures at Flow Rate 1.

14. Now repeat this process (Steps 9 thru 13) for each of the Flow Rates 2, 3, 4 and 5. The time ranges for each rate are: Flow Rate 2 = 100 to 120 seconds, Flow Rate 3 = 160 to 180 seconds, Flow Rate 4 = 220 to 240 seconds and Flow Rate 5 = 280 to 300 seconds.

Analyses:

1. Calculate the Velocity at each Port using the first Flow Rate. Use the value in Table 3 for Flow Rate 1 and the cross sectional areas for each Port in Table 2. The equation for this relationship can be found in the Discussion.
2. By using your Measured Pressure for Port 1 you can calculate the Expected Pressure for Ports 2 using Bernoulli's equation, also found in the Discussion. **When making the calculation be careful to use the pressure in units of Pascal**. Next use the Measured Pressure for Port 2 and calculate the Expected Pressure for Port 3. Finally use the Measure Pressure for Port 3 and calculate the Expected Pressure for Port 4.
3. Calculate the Percent Difference between the Measured Pressures and Expected Pressures of Ports 2, 3 and 4.
4. **Verify your calculations with a Lab Assistant and ask for explanation for the remaining calculations.**
5. Construct a graph with your Calculated Velocities on the X-axis and the Measured Pressures on the Y-axis for each port at different flow rates. The graph will display each Port as a separate line. Save the graph to show it to your lab instructor and to include it in your lab assignment.

Experiment F9a: Fluid Mechanics & Bernoulli's Principle

Student Name____

*Lab Partner Name*______________________________________

*Lab Partner Name*______________________________________

Physics Course_______________________________________

Physics Professor_____________________________________

Experiment Start Date_________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheet: F9a: Fluid Mechanics & Bernoulli's Principle

NAME: ____________________________ DATE: _________________

Density of Air ______________________________

Table 1: Measured Data for Apparatus	
Chamber Width Port 1 & 3	
Chamber Width Port 2 & 4	
Chamber Depth at all Ports	

Table 2: Calculated Areas (m^2)	
Port 1	
Port 2	
Port 3	
Port 4	

Data Sheet: F9a: Fluid Mechanics & Bernoulli's Principle

NAME: ____________________________ **DATE:** _________________

Table 3	Calculated Velocity (m/s)	Measured Pressure (kPa)	Calculated Pressure (kPa)	Percent Difference Pressure
Flow Rate 1 =				
Port 1			not calculated for port 1	
Port 2				
Port 3				
Port 4				
Flow Rate 2 =				
Port 1			not calculated for port 1	
Port 2				
Port 3				
Port 4				
Flow Rate 3 =				
Port 1			not calculated for port 1	
Port 2				
Port 3				
Port 4				
Flow Rate 4 =				
Port 1			not calculated for port 1	
Port 2				
Port 3				
Port 4				
Flow Rate 5 =				
Port 1			not calculated for port 1	
Port 2				
Port 3				
Port 4				

Data Sheet: F9a: Fluid Mechanics & Bernoulli's Principle

NAME: ____________________________ DATE: _________________

Questions:

Answer the following questions after the experiment is completed.

1. For the ports that have a smaller cross sectional area, is the velocity higher or lower than the ports with the larger cross sectional areas?

2. For the ports that have a smaller cross sectional area, is the pressure higher or lower than the ports with the larger cross sectional areas?

3. What can you conclude about the relationship between Velocity and Pressure between the different ports from your results?