Western University Faculty of Engineering

ES 1050 - Foundations of Engineering Practice

Studio Section 14 – Dr. Dickinson

Team #7

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Design Project B - Bernoulli's Wind Tubes

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1 - Introduction and Background

Background

This principle is a concept from Fluid Dynamics from Physics that states that a fluid (a fluid can be air or liquid) that moves with a high speed will have a low pressure, and vice versa. This principle is only true if the density of the fluid is constant, no friction is present, or the flow of the fluid is constant. The principle was sought out to be taught through an IID referred to as *Bernoulli's Wind Tubes*. This apparatus was a hair dryer blowing into a plastic bottle (through both ends with the back cut open (each bottle end was a different size), which would then reach an anemometer (a device that measures velocity). The bottle would then rotate 180 degrees and the same process would occur, except there would a different velocity. There was also a tube connected in the bottle that carried dyed water that would display different volumes because higher pressure means low volume. This will be applied to Bernoulli's Equation which was derived from Newton's First Law of Thermodynamics, also known as the Law of Conservation of Energy, which states that energy cannot be destroyed, but it can change forms [1].

Figure 1.1 - Bernoulli's Equation [1]

Energy per unit volume before = Energy per unit volume after

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Introduction

The following report provides an in-depth explanation behind the complete design process in ensuring a successful Design Project B. The team was assigned with delivering an Interactive Instructional Device (IID) that engaged students and acted as a beneficial supplemental learning resource for educators. As mentioned, the team's chosen Instructional Topic is Bernoulli's Principle, so the IID needed to teach this phenomenon effectively. Firstly, the team's thought process behind creating explicit learning outcomes, primary goals, secondary goals, and tertiary goals are outlined. These were the measures of success that the team utilized throughout the following steps in the design process. Secondly, the final design of the complete IID prototype is presented with its features and specifications. Thirdly, the team's supplemental learning resources, such as the lesson plan and instruction sheet, are provided. Finally, the team's plans for the IID past the time constraints of Design Project B are mentioned.

2 - Problem Definition and Problem Specifications

2.1 - Problem Definition

<u>Needs Statement</u>

As the supplier of the Interactive Instructional Device (IID), the essential needs of two core groups must be identified to ensure the IID's primary functions cater to these needs. The two target clients are secondary school educators and students at the grade 12 level.

For secondary school educators, the primary need is for the IID to teach the foundational concepts of the instructional topic, Bernoulli's Principle. The IID needs to instruct the students mostly autonomously and without excessive external assistance, as the purpose of an IID is for students to learn through self-instruction and individual discovery. In the case of the team's chosen IID, *Bernoulli's Wind Tubes*, educators need their students to not only understand the foundational concepts, but relate said concepts to mathematical relationships between experimental quantities (e.g. understand and utilize Bernoulli's Equation).

For the second target client, students, the primary need is for the IID to be extremely user-friendly and able to be operated by first-time users. Furthermore, students must also understand the theory behind the actions they perform while interacting with the IID, which requires clear instructions for IID operation. Additionally, students need a clear visualization of both airflow and pressure differences as well as accurate data collection methods for further, mathematical analysis.

The needs of the two target clients, identified above, lead to the development of explicit learning outcomes, primary, secondary, and tertiary goals which were referenced throughout the whole design process to measure the group's success. Such goals are listed in **Section 2.2**.

<u>Importance of Bernoulli's Principle and Selection of IID</u>

Bernoulli's Principle is a critical aspect of fluid dynamics since it is utilized and relevant in various real-world applications, as described in **Section 1**. *Bernoulli's Wind Tubes* is based off of the existing *Venturi Tube*, but the installed modifications allowed for a significant amount of interaction to enhance student learning. The *Venturi Tube* was an appropriate platform to base our designs due to the fact that it was effective in relating two critical variables, fluid velocity and pressure. However, the *Venturi Tube* was not sufficient in fulfilling the needs of target clients, so the new modifications were designed. The main motive behind the modifications was to increase the level of student engagement, both in terms of learning the theory of Bernoulli's Principle/Equation as well as the participants' level of interaction with the device. The comparison of *Bernoulli's Wind Tubes* merits to other IID alternatives are shown in ***Appendix 8.1*** and ***Appendix 8.2***.

2.2 - Problem Specifications

Learning Outcomes

1. Students will be able to identify the variety of fluid velocities that exist at different points within the system
    - Students need to be able to identify all the variables in a system to draw an implication of the properties of the fluid and how it affects its surroundings
2. Students will be able to explicitly explain the relationship between a fluid's velocity and its simultaneous pressure
    - Students need to be able to explain the Principle to other properly in order to ensure that they themselves understand it
3. Students will be able to relate Bernoulli's Principle to real-world applications
    - This is probably the most important goal as this is the purpose of education, to train students to apply their knowledge to real-world tasks

Primary

- Power for fans must be below 100 watts
    - All the concepts in Section 4 involve some sort of motorized fan, but the project allows for a maximum wattage of 100W. A fan will be needed that satisfies this requirement and also is strong enough to allow the IID to operate as intentioned
- Real-world Visualization and Quantification of fluid properties
    - All existing teaching methods mentioned above do not satisfy this requirement. Software simulations are often not realistic and that is why a real-world demonstration is required a more impactful education
- Student control of device
    - It is very important for the student to be able to change variables of the device and see first-hand the impact that their change has on a fluids' properties

Secondary

- The prototype and solution must be safe to transport and deploy
- Chemicals or materials used must not be hazardous

- Flames, or high temperatures that could cause injuries or fire, must be avoided
- Moving parts must be properly guarded to prevent injuries
- Liquids being used must be non-hazardous and safely contained so as not to cause spills

Tertiary

- Electric Sensors to trigger LED lights
    - If time and expertise permit, lights that change with fluid properties (e.g Red LED'S when pressure is high) can add to the intrigue of using the device and thus learning the concept. If students are fascinated and enjoy using the device, it is more likely for them to remember the lesson more clearly.

Extra Constraints

- Fit within a footprint of 50 cm x 50 cm and be no taller than 100 cm
- Must have a mass of no more than 15 kg
- Maximum of $400 per group cash contribution
- User achieves an average of at least 75% on the post-experiment examination

3 - Final Design

3.1 - Overall Design

The final design of the Interactive Instructional Device consists of a 50x40x10 cm rectangular frame which houses all of the components. On the left-hand side, there is a circular mount for a fan to be placed in. This fan introduces a fluid movement into the system. The top of the frame is "X" shaped, in order to place a stepper motor at its center. An open ended transparent venturi tube is hung horizontally from the shaft of this stepper motor. This tube has a large diameter on one end that transitions to have a smaller diameter on the other end. The stepper motor rotates the tube 180 degrees so that the narrow or wide side of the it aligns itself with the fan and air flows into it so that Bernoulli's Principle can be observed inside. There is also a very narrow tube connected to the sides of the narrow and wide ends of the venturi tube. The narrow tube contains a liquid that will respond to pressure changes in the main tube. On the right hand side of the frame, there is another mount for the a turbine that is aligned with the open ends of the venturi tube. This turbine will measure speed of the air flowing out of the venturi tube. A quick demonstration of the IID can be seen in a YouTube video, linked in ***Appendix 8.3.***

3.2 - Design Documentation

Components

1) Frame

The Interactive Instruction Device is housed in a 50x40x10 cm black rectangular wooden frame. Wood was chosen as the ideal material as it is lightweight and can easily be modified, e.g drilling holes into. There is a rectangular base with four legs on the corners. The legs hold up an “X”-shaped top panel which supports some of the other components of the device. The “X”-shape was specifically chosen to further cut out excess weight and allow for users of the device to easily look into it from different angles above.

2) Fan (Hair Dryer)

On the left hand side of the device is a circular mount for a hair dryer fan. The purpose of this fan is to introduce an air flow into the venturi tube. Three settings allow for users to control the speed of the fan. A battery powered fan that only required 100 watts of power was not sufficient for the uses of the device so a hair dryer that plugs into a power outlet was required.

3) Turbine

This component was used to measure the speed of air that flows out of the venturi tube. The way it works is that the turbine contains a DC motor that generates a voltage when turned. If the air speed is slow, the turbine will produce less voltage. If there air speed is increased, more voltage is produced. The negative terminal of the turbine is connected to the ground on a breadboard, and the positive terminal is connected to an analog signal receiver on the Arduino. The Arduino outputs values ranging from 0 - 1024 [2], so the speed of airflow had to be correlated to these values through a small function in the code. A linear relation between voltage and airspeed was assumed in the device. The Arduino connects connects to any laptop and displays the speed of the air flow in real-time.

4) Venturi Tube (Bottle)

The aforementioned “X”-shaped top frame was also selected to hold a specific component at the center of the device, and this component was the venturi tube. Firstly, a hole was drilled into the center of the ‘X’ for a stepper motor to stepper motor to be fitted into. The motor was simply pushed up and into the hole without the need of any adhesives. The soft wooden frame allowed for this versatility as the hole was just the right size to hold the motor but also allow for its easy removal. Yes, this attribute of the device may wear out over time, but can easily be fixed with adhesives or screws. The shaft of the stepper motor points downward and connects to a round steel bracket. A venturi tube was then glued on so that it can sit inside of the bracket. A metal bracket was chosen so that the weight of this specific component can be increased. As was mentioned above in this report, a fan will be blowing air into this component, and the heavier it is, the less the component will sway. Attached to the bottom of the ends of the venturi tube is a narrow PVC tube that holds a small amount of a liquid. This tube measures the pressure differences in the venturi tube. The purpose of the stepper motor is to change the orientation of the venturi tube with respect to the fan. The stepper motor is programmed through an Arduino to rotate 180 [3] degrees with the push of a button located on top of the device. Changing the orientation of the venturi tube will allow it display different fluid properties for users of the device

5) Cases

In addition to the ability to control and measure air speed and pressure, the device also supports certain "test cases" thats students have to solve. For example, the device currently only supports one test case that is dependent on air speed. The turbine continuously sends the Arduino data on the speed of the air coming out of the right hand side of the venturi tube. If the air speed is too low, a red LED starts to flash If the air speed is high enough, the red LED turns off and a blue LED turns on, indicating that the case has been solved. The case starts off with the large diameter of the venturi tube facing the turbine. This orientation causes the measured air speed to be too low and trigger the red LED. Students have the option of either changing the speed of the fan to increase the speed registered by the turbine, or they can press the button that changes the orientation of the venturi tube so that the narrow side is facing the turbine and thus increasing the registered speed which will turn on the blue LED. These cases cause students to start thinking critically about how to solve specific problems. Increasing the speed from the fan may solve the problem, but at the expense of using more power. On the other hand simply changing the diameter of a tube increases the speed but without using as much energy.

Code

The Arduino code used can be seen in ***Appendix 8.4***.

How to Construct

If this specific design needs to be replicated, CAD drawings and pictures of the final IID prototype is located in ***Appendix 8.5*** and ***Appendix 8.6***, respectively.

4 - Lesson Plans and Usage

The supplemental learning plan to *Bernoulli's Wind Tubes* is twofold. The first feature of the lesson plan consists of a worksheet which briefly reviews Bernoulli's Principle and Bernoulli's Equation. On the same worksheet, five sample questions will be provided for completion at the end of the learning process. The second feature of the lesson plan consists of real-time voice recordings. These recordings will occur after the participants are familiar with the IID in order to avoid operational errors.

First Feature - Worksheet

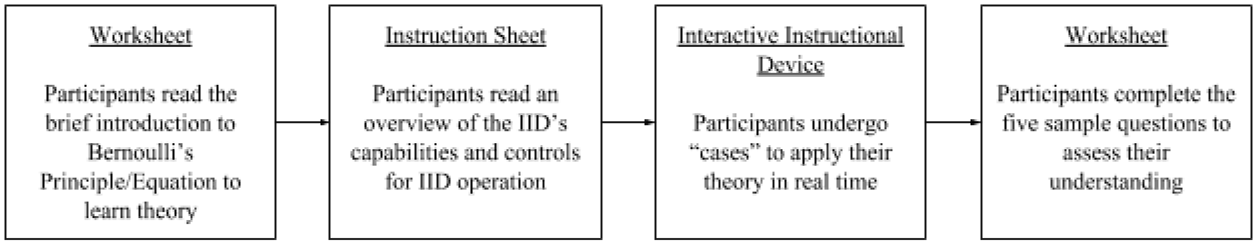
The worksheet's purpose is twofold. Firstly, it acts as a brief introduction to Bernoulli's Principle. Secondly, the worksheet contains five questions to assess the participants' level of understanding of Bernoulli's Principle and Equation after the learning process. It is important to note that the worksheet, shown in ***Appendix 8.7***, acts both as an introduction and conclusion and as a result, is explicitly stated as such in the worksheet and instruction sheet, shown in ***Appendix 8.8***.

Second Feature - Interactive Cases

Participants will be presented with a real-life engineering problem related to fluid dynamics. They will be expected to work together to solve the issue by manipulating the variables within the IID. More specifically, the variables that they can change are the initial fluid velocity coming out of the fan and the orientation of the tube. These real time, interactive "cases" will vary in style and can be customized by educators for further personalization. Depending on the actions of the participants, either a completion or failure message will be outputted. If the team fails the case, another attempt must be undertaken.

In conclusion, the complete learning process can be summed up in *Figure 4.1*.

Figure 4.1 - Complete Learning Process



Fulfillment of Learning Outcomes

In **Section 2.2**, three learning outcomes were identified. The complete learning process does deliver on all three learning outcomes, described in *Table 4.2*.

Learning Outcome	Was it Delivered?	How Was it Delivered?
Students will be able to identify the variety of fluid velocities that exist at different points within the system.	✓	When changing the orientation of the fan, the velocity exiting the smaller diameter of the tube will be greater than that of the larger diameter.
Students will be able to explicitly explain the relationship between a fluid's velocity and its simultaneous pressure.	✓	When examining the water's pressure differential in the smaller tube underneath the main tube, the water level under the larger diameter main tube will decrease due to the greater pressure, and vice-versa.
Students will be able to relate Bernoulli's Principle to real-world applications.	✓	The sample case as well as one sample question is a direct example of an engineering problem related to Bernoulli's Principle, as shown in ***Appendix 8.9***.

Table 4.2 - Delivery of Learning Outcomes

5 - Design Decisions

Based on previous reports and documentation on the progress of the team's IID, it is obvious that the design process has introduced various complications with both previous and current IID designs. The team foresaw some of these minor issues as unavoidable byproducts to the design process, but the first major IID design issue led to the complete overhaul of the initial design. However, this process was experienced early on in the prototyping and testing process, which allowed for adequate adjustments. The three major design decisions' time of initial recognition and subsequent solutions are outlined in *Figure 5.1*.

Complete Redesign of Original IID

The original idea of the IID was to be wind tunnel with objects, such as a model house, to be placed inside to display the effects of pressure and velocity change described by Bernoulli's Equation. After tests with a store bought model housen, the outcome was not as desired. In principle, the roof would blow off due to the pressure change caused by difference in wind speed, but this was not happening. The design was then scrapped as the house was a main component of the IID and needed to consistently and effectively display Bernoulli's Principle.

Keeping the Blow Dryer

The blow dryer was not the intended method of air propulsion in the original design, rather an easy alternative for initial testing. However, when more compact computer fans were tested for their ability to propel air, it was decided that the blow dryer provided a stronger and a more condensed airstream. This was a crucial aspect of the team's design since the airflow had to be precise enough to enter the 3.3 cm diameter mouth of the bottle. When testing the computer fan, two issues were present. Firstly, the airflow was too wide for the smaller diameter side of the bottle, which would have hindered the student from changing the orientation of the bottle. If this option was chosen, the level of student engagement/personalization would have decreased. Secondly, the computer fan was not powerful enough to output a steady stream of air. The initial air velocity of the blow dryer is approximately 17 m/s, but the fan's initial airspeed was only 60% of the blow dryer's, at approximately 10 m/s. These two flaws with the computer fan resulted in keeping the blow dryer as the sole method of propelling air. However, this design decision led to two important consequences. Firstly, the size of the entire IID was increased by 30 cm due to the blow dryer, which negatively impacted secondary goals. Secondly, the inclusion of the blow dryer raised the cost of the IID by $12, as shown in ***Appendix 8.3***

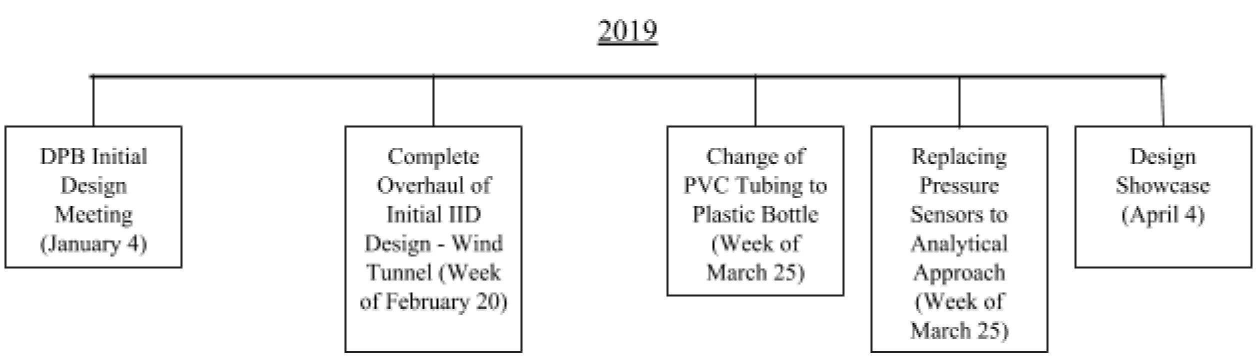
Transferring from PVC Tubing to Plastic Bottle

The first iteration of the IID planned on the use of PVC tubing to act as the pathway for the airflow. After multiple tests using the fan and wind speed detector, the tube was displaying inconsistent results, the speed was not following the principle of Bernoulli's Equation. The length of the tubing needed to be longer in order for the pressure change to be substantial enough for the speed to change, but the frame was already built. A bottle was then used for further testing and produced more consistent and accurate results which aligned with Bernoulli's Principle. A main learning outcome was that students will be able to explicitly explain the relationship between a fluid's velocity and its simultaneous pressure. Since the PVC tubing was not following the relationship shown by Bernoulli's Equation, this learning outcome was obviously not met and the tubing was replaced.

Replacing Pressure Sensors to Analytical Approach

All of the designs of the IID used pressure sensors to produce quantifiable data about the pressure change. This was done to meet the goal of measuring pressure. Unfortunately, due to price restrictions and timing, the pressure sensors in the final design were replaced with a 1.27 cm diameter tube filled with water. The tube displays the pressure change through the bottle as the water changes in height due to the pressure differences. The goal of quantitatively measuring pressure had to be sacrificed in order to complete the IID on time.

Figure 5.1 - Design Decisions' Timeline



6 - Conclusion and Future Work

Measure of Project Success

As outlined in **Section 5**, the team experienced several obstacles in the design process, varying from inherent design flaws to prototyping difficulties. However, the current set of learning outcomes were able to be achieved by the IID and the supplemental lesson plan. The only learning outcome that was somewhat sacrificed was the students' ability to relate fluid velocity to its simultaneous pressure. The initial goal was to be able to collect quantitative pressure data from pressure sensors and present such data on either the LCD or computer display. This data would then be compared with the fluid velocity collected by the turbine. However, this design feature had to be sacrificed, detailed in **Section 5**, causing the IID's fulfillment of the second learning outcome only to be qualitative. Despite the shortage in convincingly achieving the second learning outcome, the team deemed the final IID and its supplemental lesson plan as a success. It was able to fulfill every learning outcome, including the second learning outcome, primary, secondary, and even the tertiary goal. In addition, the interactive cases allowed for further customized learning and therefore, greater student engagement. Since the main motive behind Design Project B was to create greater student engagement, the originally unplanned creation of cases was a fantastic added bonus. In terms of the IID's practicality, the size of the IID does present difficulties with mass production and delivery. However, the team believes that the simplistic, but engaging learning process allows for greater student and teacher benefit despite minor device flaws. In terms of device sustainability, the current IID is effective in its use as a fun, interactive alternative to traditional teaching methods. The possibility for educators to add on to the device in ways that meet their personal teaching preferences by recording more cases allows the current IID to be sustainable.

Future Work

The final IID, *Bernoulli's Wind Tubes*, was the final prototype for Design Project B. However, this does not imply the restriction of the current platform from further development. The various minor issues and sacrificed features mentioned in **Section 5** would have to be corrected in future work. This would begin with the installation of pressure sensors to more accurately measure pressure values from a mere analytical approach to a combination of analytical and numerical approaches. Secondly, the overall size of the IID must be reduced in order for easier storage and use. This would consist of replacing the blow dryer with a strong, but compact fan or propellor to reduce size as well as reduce costs. Furthermore, the length of the base would have to shrink by 22.4 cm to make the unit more compact since the use of the original PVC tubing was deemed ineffective. Finally, the goal would be to make the IID self-powered. Currently, the IID relies on an external wall plug to power the blow dryer and a laptop to power the motor to rotate the bottle. By connecting all electronics to one, internal battery would make the IID self-reliant and portable. Advancing past the correction of existing IID issues, the goal for future work for *Bernoulli's Wind Tubes* is to allow for all three types of analysis: graphical, numerical, and algebraic. Currently, numerical and algebraic analysis is included in the forms of measuring air velocity and working with Bernoulli's Equation, respectively. However, the inclusion of graphical analysis would benefit students and teachers extensively. In order to complete this, a program similar to *Vernier Logger Pro*. Velocity and pressure measurements would be collected in real-time and students would be able to create a trendline to mathematically analyze the relationship between the two variables.

7 - References

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8 - Appendices

Appendix 8.1 - Decision Matrix

Categories	Safety	Feasibility	Originality	Affordability	Interactivity	Total Score
Score Range	0 - 10	0 - 5	0 - 5	0 - 10	0 - 5	Max 35
Wind Tunnel	9	2	5	6	5	27
Water Jet and Balls	3	3	3	7	5	21
Two Ping Pong Balls and an Airstream	9	5	1	8	5	25
Bernoulli's Wind Tubes	9	3	5	7	5	29

Appendix 8.2 - Go/No-Go Screening

Concepts	Fluid Visualization	Safety	Longevity	Price	Feasibility	Final Decision
Water Tunnel	No-Go	Go	Maybe	Go	Maybe	Maybe
Wind Tunnel	No-Go	Go	Maybe	No-Go	No-Go	No-Go
Ping Pong	No-Go	Go	No-Go	Go	Maybe	Maybe
Water Jet	Go	Go	No-Go	No-Go	No-Go	No-Go
Schlieren Imaging	Go	Maybe	Maybe	No-Go	No-Go	No-Go
Bernoulli's Wind Tubes	Go	Go	Go	Go	Maybe	Go

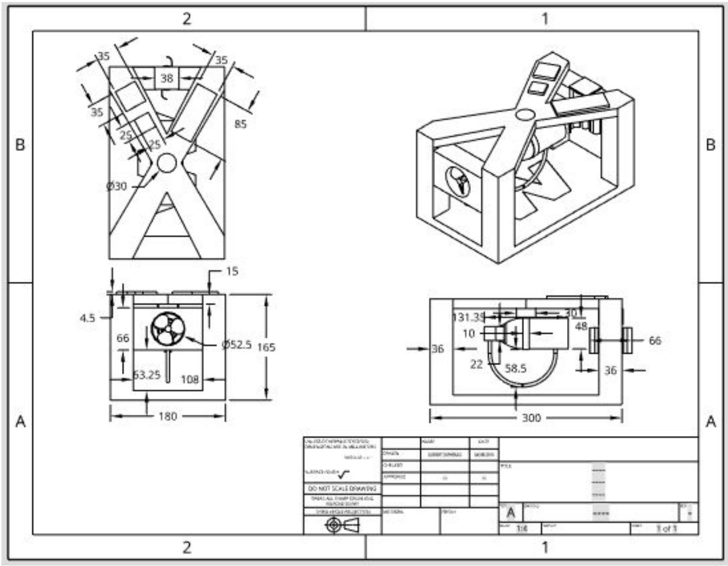
Appendix 8.3 - IID Demonstration

YouTube Link: https://www.youtube.com/watch?v=pqMT_fuygzU

Appendix 8.4 - Arduino Code

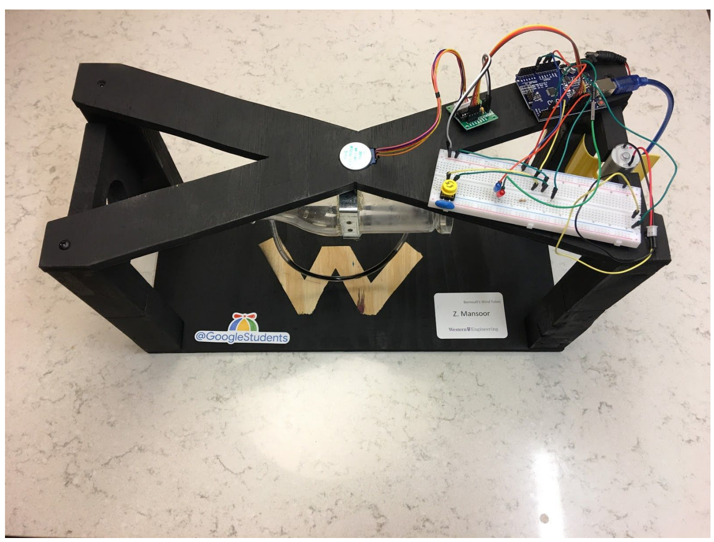
```
#include <Stepper.h>
const int stepsPerRevolution = 2048;      //one revolution is 2048 steps

                                          // initialize the stepper library on pins 8 through 11:
Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11);

void setup() {
  pinMode(13, OUTPUT);
  /
  myStepper.setSpeed(8);                  // set the speed of the motor
  // initialize the serial port:
  Serial.begin(9600);
}

void loop() {

      // When button is pressed, motor will rotate half of a revolution
  if (digitalRead(6) == HIGH) {
    Serial.println("clockwise");
    myStepper.step(stepsPerRevolution /2);

  }

 // makes motor not respond if button is held pressed
  if (digitalRead(6) == HIGH) {
    while (digitalRead(6) == HIGH) {}
    //delay(50);
  }

  // collects voltage data from turbine
fanstate=analogRead(A0);
Serial.print("AIR SPEED: ");   //prints out airspeed on screen
Serial.print((fanstate/35));
Serial.println("m/s");

delay(50);


if(((fanstate/35))>20){digitalWrite(13, HIGH);    //turns on red LED when speed low
                      digitalWrite(2, LOW);
}
else{digitalWrite(13, LOW);     //turns on blue LED when speed high
digitalWrite(2, HIGH);
      delay(50);
      digitalWrite(2, LOW);
      delay(50);}}
```

Appendix 8.5 - CAD Drawing



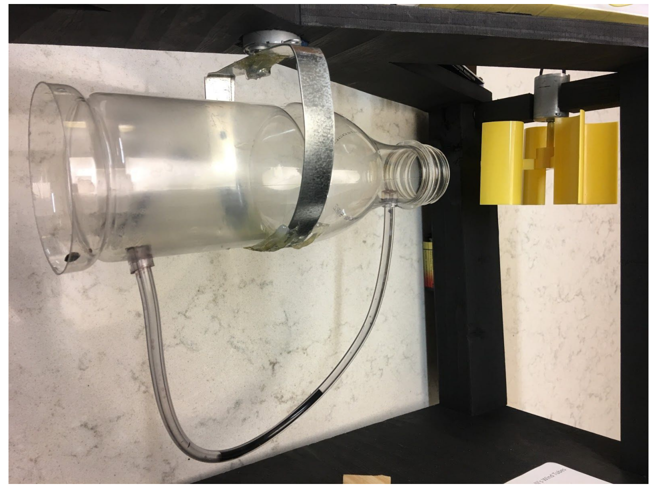
Appendix 8.6 - Photos of Final IID Prototype

Top View

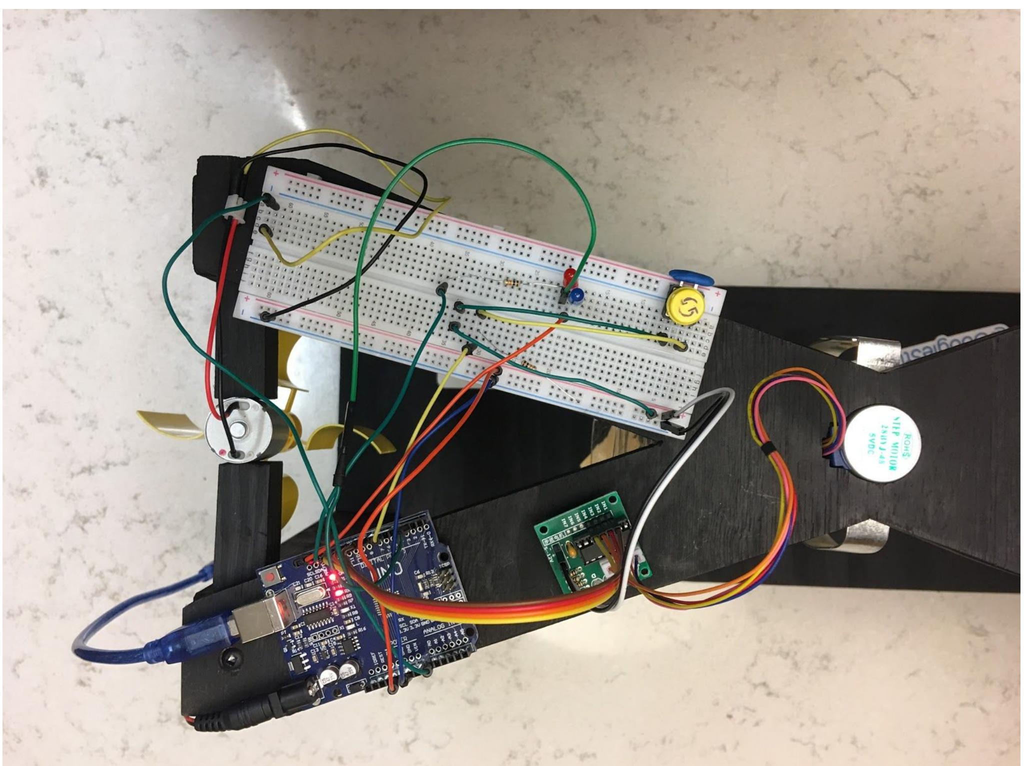


Front View

Orientation of Bottle



Top View of Breadboard, Arduino, & Wiring



View of Blow Dryer

Appendix 8.7 - Worksheet

Bernoulli's Wind Tubes Worksheet

Note: Please follow the following steps when undertaking this experiment:

1. ***Read the introduction to Bernoulli's Principle & Equation on the worksheet***
2. ***Read the operational instructions on the instruction sheet***
3. ***Experiment with the device and solve cases***
4. ***Complete the five assessment questions on the worksheet***

Introduction to Bernoulli's Principle & Bernoulli's Equation

Bernoulli's Principle relates pressure, height, density and velocity of a fluid. However, for this experiment, the height and density variables will remain constant. Therefore, the only variables present are the pressures and velocities at the two respective points.

The following equation is known as Bernoulli's Equation and explains such relationships:

$$\frac{1}{2}\rho v_1^2 + \rho g h_1 + P_1 = \frac{1}{2}\rho v_2^2 + \rho g h_2 + P_2$$

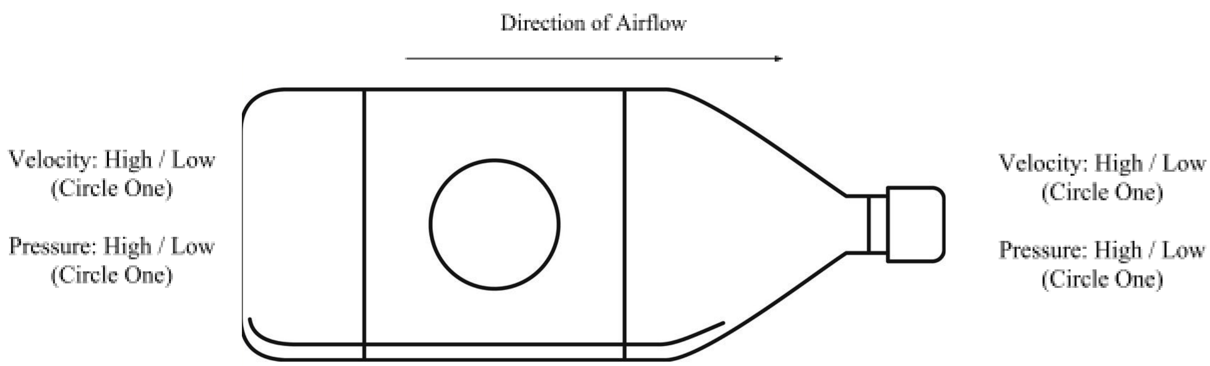
Variable List:
ρ = Density
v = Velocity
P = Pressure
g = Acceleration due to Gravity (9.81 m/s²)
h = Height

As Bernoulli's Equation states, velocity and pressure has an inverse relationship, meaning that when one increases, the other decreases.

Assessment Questions

1. Water is flowing in a fire hose with a velocity of 1 m/s and a pressure of 200 kPa. At the nozzle, the pressure decreases to 101.3 kPa and there is no change in height. Use Bernoulli's Principle to calculate the velocity of the water exiting the nozzle. (The density of water is 1000 kg/m^3). [Answer: 14 m/s]. [1]

2. The flow of air in the diagram below is going from left to right. What is the velocity and pressure at the left side of the bottle (high or low)? What about the right side of the bottle (high or low)? [Answer: Left Side has low velocity, high pressure. Right Side has high velocity, low pressure].



3. Which two variables are constant in this specific experiment? Circle one answer. [Answer: B].
   A. Pressure & Velocity
   B. Density & Height
   C. Velocity & Density
   D. Acceleration due to Gravity & Pressure
   E. Height & Velocity

4. When experimenting with the Interactive Instructional Device (IID), what two variables were you able to manipulate? Choose one answer. [Answer: E].
   A. Acceleration due to Gravity & Velocity
   B. Density & Pressure
   C. Density & Height
   D. Pressure & Acceleration due to Gravity
   E. Velocity & Pressure

5. Through a refinery, fuel ethanol is flowing in a pipe at a velocity of 1 m/s and a pressure of 101,300 Pa. The refinery needs the ethanol to be at a pressure of 2 atm (202,600 Pa) on a lower level. How far must the pipe drop in height in order to achieve this pressure? Assume the velocity does not change. (Hint: Use the Bernoulli equation. The density of ethanol is 789 kg/m^3 and gravity g is 9.8 m/s^2. Pay attention to units!) [Answer: -13.1 m].

Appendix 8.8 - Instruction Sheet

Bernoulli's Wind Tubes Instruction Sheet

Note: Please read the Introduction to Bernoulli's Principle & Equation prior to following this Instruction Sheet and using the Interactive Instructional Device.

Student Instructions

The IID has two controls:

- The initial airspeed can be changed between the low and high setting on the blow dryer. The low speed is approximately 13 m/s and the high speed is approximately 17 m/s. The setting can be changed with the blue switch on the handle of the blow dryer
- The orientation of the plastic bottle can be changed by 180° on the plane it lies on. The orientation change will be triggered by the yellow button on the breadboard.

Educator Instructions

- When examining the groups work with their IID, play the appropriate voice message. If the groups succeed in solving the case, play the congratulatory message. On the contrary, if the group fails in solving the case, play the message indicating failure.

Appendix 8.9 - Sample Case Audio Recording

YouTube Link:

https://www.youtube.com/watch?v=OuWsy6G4xn8&fbclid=IwAR24Qk1ADfSglGZiq58NgUnZSKPcNKzh3zAoTwS7gA0zwlZ6xBTEpmn_hHA

Appendix 8.10 - Materials List

Parts	Quantity	Cost
Wooden Base (50x10 cm)	1	N/A
Wooden Pillars (40x4x2 cm)	4	N/A
Wooden "X" (50x10 cm)	1	N/A
9v Battery	1	$2.50
Turbine	1	$12

Hair Dryer Fan	1	$12 [3]
Venturi tube (Bottle)	1	$1.51
Breadboard	1	$4 [4]
Arduino and other small electrical components	1	$22 [5]
Stepper motor	1	$13 [6]