Friday 8AM – 11/21/2025
FLOW

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Lab #6

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Abstract

This laboratory experiment investigated several methods of flow measurement and their applications to aerodynamic drag and fluid flow rate determination. Flow around smooth and dimpled golf balls was analyzed in a wind tunnel by measuring the low-pressure wake using a multi-tube manometer, allowing estimation of the pressure-drag component. A second wind tunnel experiment employed a calibrated load cell and Pitot tube to directly determine drag force and calculate the drag coefficient as a function of Reynolds number. Additionally, air flow rates were measured using a rotameter, and its pressure–flow relationship was established through polynomial curve fitting. Finally, a turbine flow meter was calibrated by comparing its readings with volumetric flow rates obtained using a bucket-and-timer method. The results demonstrate the dependence of drag coefficient on Reynolds number, illustrate the effect of surface roughness on wake pressure, and validate the operational principles of common flow-measuring devices used in engineering applications.

Objective

The objective of this lab is to better understand flow. This consists of using different tools to measure flow such as rotameters and turbine flow meters. Being able to measure flow can help better understand how a system is performing with respect to the speed that the fluid is moving at. This flow rate can be converted into a flow velocity of how fast the fluid is moving by dividing the area for which that fluid is traveling in. After finding that, principles of fluids can be used to find other properties of fluids at different points in the system. This could be done by using equations of linear momentum, conservation of mass, or even Bernoulli's equation. Now apart from studying the rate of flow and how that fluid itself acts throughout the system, it's also important to understand how that fluid can affect other objects in a bigger system. Flow is not only a property of fluid but it's a property that can affect variables such as pressure and drag force as the fluid travels over such objects. For this lab, a better understanding will be made on how the flow of air traveling over a sphere affects low-pressure wake and the drag coefficient of air flow. These variables are important to understand because they can help predict forces that act on the object which may have not been considered in the first place. Geometry is also another big component for why these flow tests are done. A good low-pressure wake would be one that does not suck the object backwards as its subjected to that flow and having this smaller wake would be perfect for reducing the drag on the object. Understanding these principles and performing these experiments on these labs will help us determine whether flow has any negative effects on shape of an object that may need to travel efficiently thought the air like a car or a plane.

Introduction

Flow can universally be seen one of the most important aspects of how fluids move. A fluid moving in general is enough to say that the fluid has a flow and in truth it does. However, flow is more complex than just saying that fluid is moving because even though it is moving, that fluid has properties which are affected by flow and other properties caused by flow. Before looking into tools that are used to measure flow, it's best to understand two of the many reasons for why flow is important. The following reasons must deal with the scenario that an object is present in the field of the flow as stated in the objective. These reasons include pressure drag and viscous drag. These two measures of drag are correlated but very different so it's imperative to think they are not the same. Starting with pressure drag and what exactly causes this pressure drag. It has to deal with simple principles of how fluids act when an obstruction is present in the midst of its flow. As that fluid encounters the obstruction, it will flow around the object, but not all the flow present will flow around the object at one specific spot. Instead, that flow gets split up and from the conservation of mass, if the area at point two is smaller than the area at point one, the velocity will increase and in this case it does. Another principle that is also leveraged in this case is Bernoulli's. When the velocity increases, the pressure actually decreases, and this happens for the fluid around the object. Now this increase in velocity and decrease in pressure does not always stay the same because the fluid is now traveled around the sphere back into its original flow but it's not same. This disturbance of flow has caused some sort of turbulent flow in the wake from the laminar flow that the fluid once had a state in. The difference in pressures also affects turbulence towards the end of the obstruction and now a separation has been made; right after the sphere is a flow that is turbulent, and the separated flow is no longer attached to the laminar boundary layer around the front of the sphere. This boundary layer is what causes the low-pressure to trail behind the object, sucking the object back into where it just traveled through. It's important to know that the fluid traveling around the object does not always form a big low-pressure wake. This big low-pressure wake has a direct correlation with how fast the fluid is traveling around the object. A small flow velocity will most likely not cause this to form. Figure 1 can show how this takes place for the sphere.

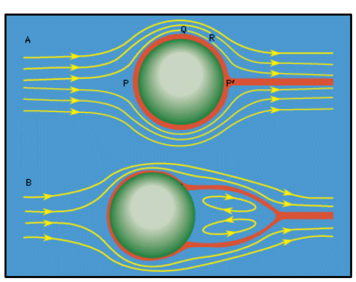

Figure 1:The low-pressure wake forming as fluid flows around the sphere

Now to find the pressures behind the sphere it is easier said this done. For this part of the experiment, another tool will be used called a manometer. This manometer follows static principles of pressures in order to obtain the pressure difference between two points. It does this by relating the pressure of one end of the manometer to the other end with a fluid inside. The difference in height from the new height of the fluid to the original height of the fluid multiplied by the specific weight is the difference of pressure between point one and two as shown in equation 1a. A total of 16 manometers were used to capture the pressure differences across the whole sphere because one simply wouldn't be able to capture the total pressure behind the sphere and an example of that is shown in figure 2.

$$\Delta P_i = (H_{new,i} - H_{original}) * (\rho_{Manometer\ fluid} * g) \tag{1a.}$$

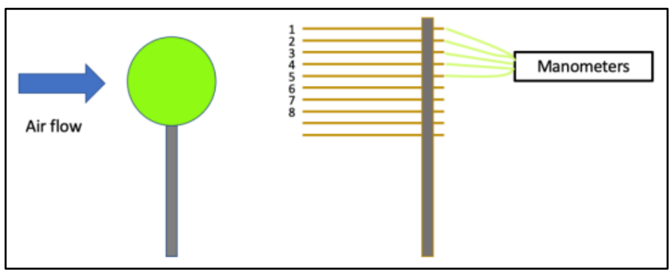

Figure 2: Low-pressure wake lab setup example

Now that the pressure differences are found at different heights across the object, the pressure itself is a property that can induce a force against an object, given that it has a surface area and, in this case, it does because of the sphere we are using. The drag force that is being induced on the object due to the pressure can be calculated after adding up all the pressures and multiplying that by the area for which the pressure is acting on which is shown in equation 1b.

$$F_{D,1} \approx \left(\sum_{i=1}^{16} \Delta P_i\right) * R^2 * \Delta\theta^2 \tag{1b.}$$

The R in equation 1b stands for the radius of the golf ball and $\Delta\theta$ is equal to $\pi/16$. Now that a derivation has been made to find the low-pressure wake of the sphere and drag force as the flow of air travels through it, what can be done with that drag force. This drag force is essential to what is known as the drag coefficient, and these are the variables that are directly related. This would be known as viscous drag, or drag that happens due to the shearing between the moving fluid and the steady surface of the sphere. Given the drag force of the object, a calculation can be made as shown in equation 2a to find the drag coefficient that the flow is acting on the object. As stated before, a property like this is important because finding that an object has no drag coefficient would mean that the object has no drag force, something that would be useful for all objects going through an airflow like the sphere. Now, this equation has the drag force in it but will not be found using the same process that was stated earlier with pressures. Instead, a load cell will be used to find the drag force acting on the object directly. Another component apart of the equation is the velocity of the fluid traveling around the object. To find this another tool will be used called a pitot tube. Similar to a manometer but using different principles, the total pressure, both stagnation and static will be used to find the velocity of the air with dynamic pressure which will be shown in equation 2b.

$$C_D = \frac{2F_D}{\rho u^2 A} \qquad (2a.)$$

$$u = \sqrt{\frac{2\Delta P}{\rho_{air}}} \qquad (2b.)$$

The difference in pressure of equation 2b will be found using equation 1 just like before but this time it will be applied to Bernoulli's equation, and the derivation will come out to equation 2b to where we can relate the change in pressure to the density of the moving air and find its velocity. After finding its velocity, it can be applied to the drag coefficient equation, given that we know the load cell force and the area. The equation for the cross-sectional area of a sphere is given in equation 2c.

$$A = \frac{\pi}{4} D^2 \qquad (2c.)$$

This drag coefficient will also be done at various speeds just like how the low-pressure wake experiment was done for various speeds. By performing this experiment at various speeds, a graph can be made to relate the Reynolds number and the drag coefficient. If the experiment works correctly, the drag coefficient should decrease as the Reynolds number increases. The equation for the Reynolds number is in equation 2d.

$$Re = \frac{uD}{\nu} \qquad (2d.)$$

This nu in equation 2d stands for the kinematic viscosity of the moving air and for this experiment, the assumed temperature will be at 300 Kelvin. Now that the equation for Reynolds number and drag coefficient, drag coefficient with respect to drag force, a clear image of how viscous drag and pressure drag both affect the forces that act on the object can be made hopefully all within the hope that a better understanding of why flow is measured.

Without diving more into depth on why flow is measured, the following portion of the introduction will be dedicated to understanding how flow is measured. This lab only covered two of many tools that are used to specifically measure flow and they are turbine flow meters and rotameters. The principles for each of these tools will be described without deriving any equations because the scope of this lab is to be able to use these tools and know the fundamentals as to how they are recording a flow rate from the fluid its testing. The rotameter will be used with a fluid of air to make a correlation between air pressure and flow rate, all while recording the flow rates through the rotameter. The turbine flow meter will compare theoretical values obtained by students through measurements of fluid and time with the values obtained through the flow meter.

The rotameter consists of a float inside a tapered tube. As the fluid moves upwards, the float will rise until the forces that act on it balance out. This includes the weight of the float, the buoyancy force, and the force of drag from the fluid. These forces can be related to each other in the force equilibrium equations where one of the forces is with respect to the height of where the object lies. This height can be directly associated with the flow rate of the fluid, completing the fundamentals of how rotameters work. As previously stated, this rotameter will be hooked up to a pressure regulator where a relation between the flow rate and pressure will be made. The turbine flow meter follows a different approach in measuring the flow rate. The turbine flow meter has a turbine that spins freely with respect to the flow of the fluid that is traveling inside of it. How fast the fins are moving will relate to the flow rate because the rotational speed of the turbine matches a flow rate. To see how accurate this tool is, a measurement of flow rate will be made against it, where a bucket is filled to certain volume of fluid over a period of time, giving a theoretical flow rate as shown in equation 3a.

$$Q = \frac{Volume}{Time} \tag{3a.}$$

For the part of the lab that requires a load cell to find the drag force that acts on the object, a calibration equation will be made to correlate the force obtained and a voltage given through load cell. This correlation and the one for rotamers will be made using the linear regression function of graphs in excel.

Procedure

For this lab, there were a total of four stations, each with respect to the two tools considered in the introductions and two of the flow properties that were studied such as the viscous drag and pressure drag. The order in which the experiments are performed does not have to be the same, however the procedures for each of the experiments should follow closely to what is stated.

Starting with the drag coefficient experiment that relies on a calibration for the force and simple setup changes throughout the experiment. Since this drag force experiment does not use pressures to find forces like the low-pressure wake experiment, it still needs a way to find the drag force from which it can calculate the drag coefficient, and it does this through a load cell. Fundamentally a force is experienced on the load cell, and a voltage is returned for which can be used. However, to first create the calibration equation that will be used to find the force from the voltage, a simple procedure is done first. The load cell wire is attached to a plate outside of the wind tunnel for which loads of different sizes will be placed on it. For each of the respective weights, the computer will take voltages for which it can average at the click of a button. Once this button is pressed, an average of a range of voltages for the known weight is taken. With a series of weights and voltages, an equation relating the two can be made for when the load cell is in the wind tunnel. After the load cell is calibrated, the load cell wire can be placed around the rod that holds the smooth object in the wind tunnel to calculate the loads from the voltages. Now the setup should be complete because the manometer that is being used to find the pressure difference is already set up to capture pressures in the wind tunnel. All that's left is to first adjust the speed with respect to the speeds that are given on the sheet to record which should be zero, twenty, forty, sixty, eighty, and ninety-five. First adjust the speed nob to the required speed, then let the speed of the air set for roughly 10-20 seconds before taking the average voltage of the load cell on the computer and recording the height of the manometer fluid in the manometer. Repeat this for all speeds but it's imperative to be careful with the las speed as the wind tunnel may experience a shut down at such high speeds. If this does occur, the speed should be changed to somewhere between eighty and ninety percent. That is the experiment for the drag coefficient, but a drag coefficient only becomes present when a drag force is present, and most drag forces become present when a low-pressure wake becomes notable.

Next is the low-wake pressure experiment which determines the drag force based on how big the low-wake pressure is. To find that, a series of manometers behind the object are used to find the pressure differences at each of the manometer's heights. Once each of pressures are added, they can be added and then multiplied by the area of the sphere to get the drag force. To set up this experiment in the wind tunnel, the following must be done. First, you must record the diameter of the object which is being placed inside the wind tunnel and then place that object with its rod inside the wind tunnel. The tunnel door is then closed for which the experiment can begin. Set the speed to the respective speeds that are stated on the recording sheet which should be zero, twenty, forty, sixty, and eighty. After setting the speeds to one of them, record the height of each of the fluids inside the manometer with the ruler provided. There should be a total of 16 heights or manometers to record for each of the speeds. The reference for the original height is set to be one inch height. Once this is done with the first sphere of either dimpled or smooth, the procedure can be repeated with the other sphere.

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After the two bigger experiments are done to better understand why flow is measured, the next experiments are done to understand how flow is measured through the two following tools: turbine flow meter and rotameter. Starting with the setup for the turbine flow meter, it should already be connected to the hose, if not a TA should be contacted in order to complete the setup. After the setup is complete, the procedure can be started. Take the key that is given to open and close the hose valve for the water and open it up not all the way, just a slight bit, as the hose gets placed in the bucket. There is two valves in this experiment, one for the water at the end of the hose, and one for the water from the water supply which requires the key, so water won't splash as soon as the key opens the valve. The experiment requires that dimension for the bucket is taken to find the "gallons" in gallons per minute but a better way to conduct the experiment is to use the volume lines already on the bucket. Primarily, choose a line for which the timer should stop the time and get the person opening the valve ready. After choosing the volume line, start the timer as soon as the person opening the valve opens the valve and have someone record the flow rate stated on the turbine flow meter. As soon as the water reaches the line that was set to be tested, stop the timer and that time is time of flow with that specified volume. Repeat this process for a total of 5 measurements. In theory, the flow rate should be the same across the tests because the key was not used to open the valve more and the theoretical flow rate from the bucket volume and time taken should be relatively the same.

The final tool which was used to measure the flow rate is the rotameter and this was done by connecting the rotameter in an airline setup. First a hose is to be connected from the air supply to the pressure regulator, and the pressure regulator should have a hose from itself to the rotameter. Once all hoses are connected, the experiment can start. First open the valve that allows the air to flow from the air supply, this should allow the pressure regulator to function so that the person conducting the experiment can set the pressure to 40psi. Once this is complete, a nob on the rotameter should be rotated until the flow meter reaches the maximum of 100 SCFH. As of right now, the pressure regulator is set to 40psi, and the rotameter is capturing a flow rate value. Record this value and in increments of 5 psi, go down by limiting the pressure in the pressure regulator until a pressure of zero is reached, each time recording the flow rate. This concludes with all four stations for the lab.

Results and Discussion

After completing all experiments at all four stations, data from the drag experiments and flow rate tools experiments were recorded and placed into tables and graphs that are used to read and visualize data. Certain trends should be present in each of these figures and tables which will be brought attention to in this section.

Table 1:Drag force of both dimpled and smooth spheres for varying speeds by using low-pressure wake

Speed	Smooth Golf Ball Drag Force (Lbs.)	Dimpled Golf Ball Drag Force (Lbs.)
0	0	0
20	-0.000594699	0
40	0.025393627	0.041241112
60	0.077072929	0.094854558
80	0.088015382	0.101924463

This table refers to the low-wake pressure experiment and how the pressure build up behind the smooth surface causes a drag force that acts on the object. From this table, there is one key takeaway which is that surface textures on an object affect the low-pressure wake. It may not seem that present in the first two speeds but following, it’s clear that the forces in the last three speed tests are greater in the dimpled golf ball compared to the smooth gold ball. In general, as speed increases, so will the drag force but it does it more for the dimpled golf ball. This suggests that the dimples on the surface influence the low-pressure wake by increasing turbulence as the flow of air travels over which play into effect of how the behavior of the boundary layer changes drag. Now an experiment that can help expand on drag and look into viscous drag would be the drag coefficient and how it changes with respect to the Reynolds number but more specifically how it changed with respect to the flow velocity, or speed of the air.

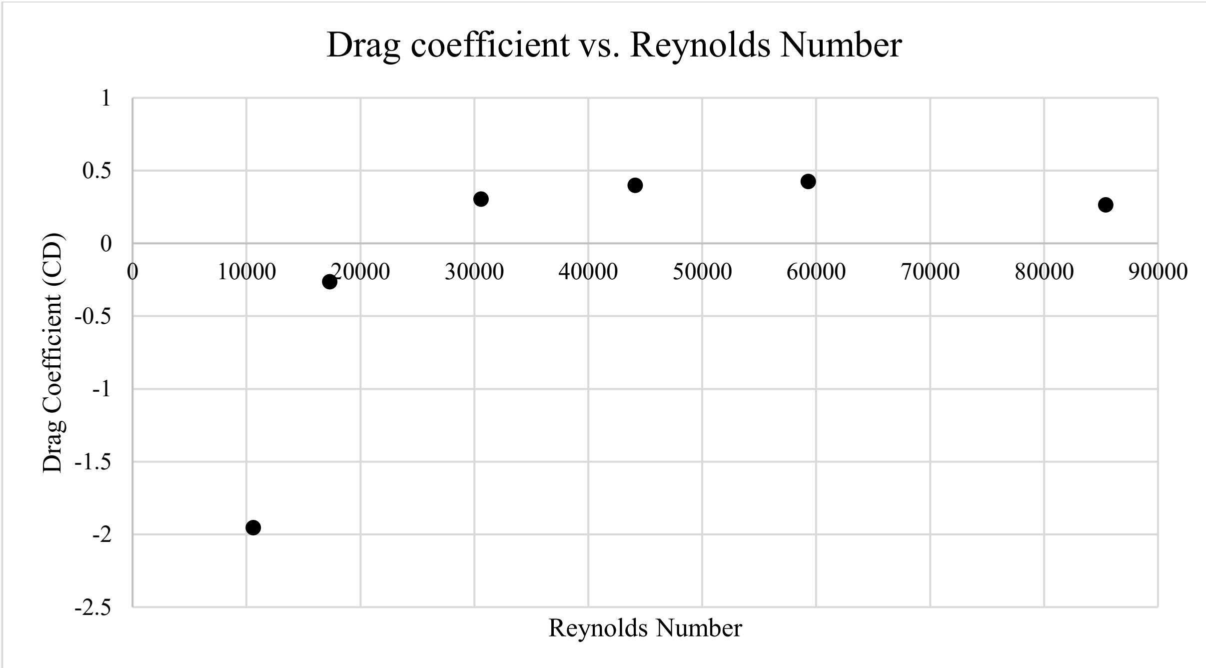

Figure 3:Drag coefficient vs. Reynolds number for drag coefficient experiment on smooth sphere

This figure shows the drag coefficient and its correlation to the Reynolds number. It's important to understand that this graph does not make any physical sense since two of the drag coefficient numbers are negative. This is not possible and likely caused by some error where the drag force that was obtained resulted in some negative number. These negative numbers of force were likely found inserting the voltage into the calibration equation obtained through the first part of the experiment. Other than this error, the chart towards the end follows a trend that makes which would be as the Reynolds number increases, the drag coefficient decreases. The reason that this is present is because the boundary layer becomes turbulent and flow stays attached longer around the object. If the flow stays attached longer, the wake would shrink, causing the overall pressure to decrease which would drop the drag coefficient. At lower velocities, the flow separates a lot earlier than if the velocities were greater and this separation cause the wake to become a lot bigger as the boundary layer is laminar. All of this together would make the drag coefficient become a lot larger.

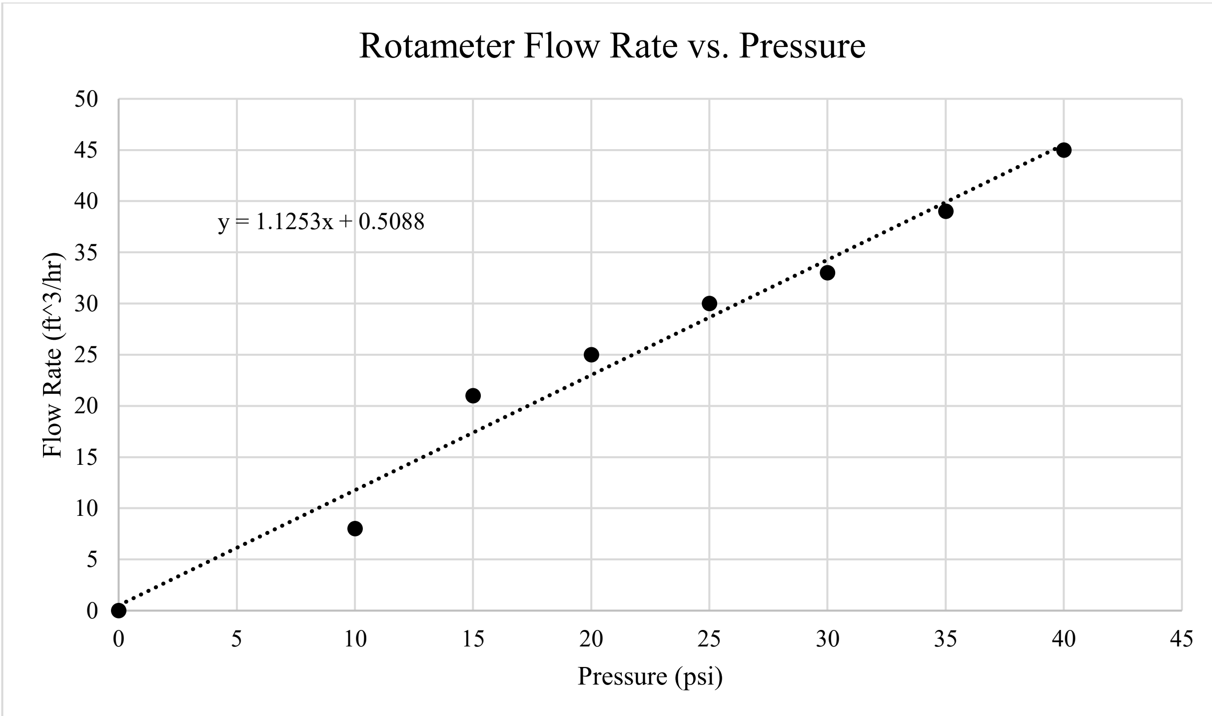

Figure 4:Flow rate vs. Pressure for rotameter experiment with calibration equation

This graph is from the rotameter experiment and relates pressure and flow rate for this particular setup. The trend that the points follow where chosen to be linear and by having a correlation of coefficient be greater than 95 percent, it seems likely that the correlation between the two is linear. Fundamentally the graph follows the principles between air flow and the flow rate recorded. This means that with more pressure, the flow rate would increase, and the graph clearly shows that. With the calibration equation that was made, it can be used to find the flow rates and pressure which were not recorded. An example of this would be a pressure of 90psi and by using the calibration equation, a flow rate of 101.79 SCFH is obtained.

If a compressor capacity of 10 SCFM at 25 psi is given, how many nozzles in parallel would it be able to supply? First the linear calibration for the ratemeter used is y = 1.1253x + 0.5088.

$$Q_{25} = 1.1253(25) + 0.5088 = 28.6\ SCFH \quad (4a.)$$

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To compare the 10 SCFM compressor to the one used in this lab, it needs to be converted to SCFH.

$$10\ SCFM \times \frac{60\ SCFH}{1\ SCFM} = 600\ SCFH \qquad (4b.)$$

Now to find the number or nozzles using the equation below and rounding down to nearest integer, it can be found that:

$$N = \frac{Q_{compressor}}{Q_{nozzle@25}} = \frac{600\ SCFH}{28.6\ SCFH} = 20.97 \qquad (4c.)$$

The number of nozzles in parallel that the compressor can supply is 20.

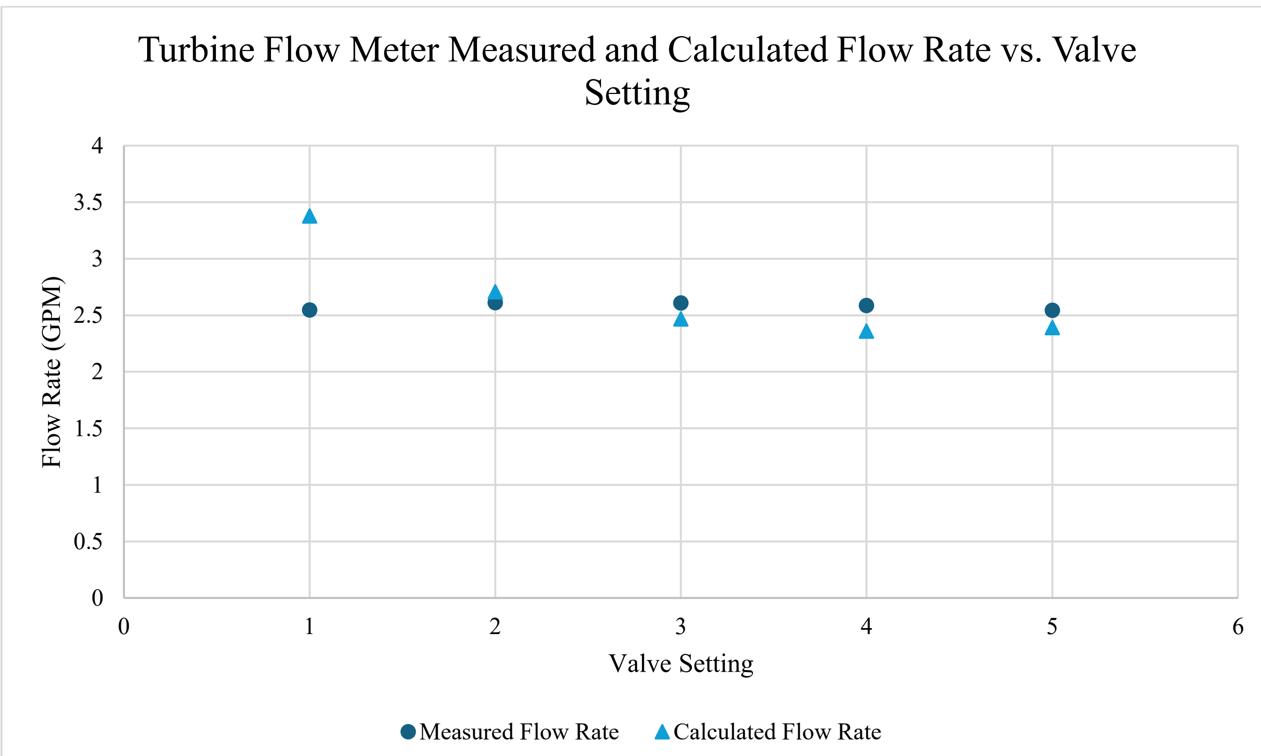

Figure 5:Calculated and measured flow rate for turbine flow rate experiment

This figure shows the calculated and measured values of flow rate that were obtained through the turbine flow meter experiment. Overall, the graph visualizes the data just as expected. It was expected that the flow rate that was measured throughout the experiment would stay the same because the valve using the key was not opened more or less. As for the calculated values, they stayed relatively close to what was measured in the turbine flow meters. Sources of error for this would most likely be human error. In this case there were two people in charge of opening and closing the valve as well measuring the time, starting or stopping the timer exactly when the valve is opening and when the water reaches the volume line is practically impossible. Given this fact, it's reasonable to have differences in flow rate for the tests that were done. If anything, having the turbine flow meter measure values that that close to the calculated values that were obtained, verify the validity of the measured values, suggesting that the tools is good to use.

Conclusion/References

The experiments conducted examined drag and types of flow measurement tools. By conducting two experiments, we were able to determine the effects of both pressure and viscous drag on spherical objects.

For the first experiment, the low-pressure zone behind a spherical object was measured at various heights. With this, we were able to determine the drop in pressure due to the turbulence, and the total drag force on the ball. The experimental data allowed us to conclude that the smooth sphere had a lower pressure drop, and hence a lower drag force compared to the dimpled ball. Now this is adverse to theoretical and realistic drag on dimpled spheres, where the turbulence and drag coefficient are generally lower.

Our second experiment measured the coefficient of drag of a smooth sphere. A pitot tube and a load cell were used to find the flow velocity and drag force, respectively. With these values, the area of the sphere, and the density of air, we were able to determine the drag coefficients at various flow rates. Once the Reynolds number exceeded 30,000, the drag coefficient remained relatively constant and even began decreasing after approximately 60,000. The Reynolds number was recorded to be negative below approximately 20,000, likely due to measurement error. It is believed that the drag coefficient decreased because at higher Reynolds numbers, the flow becomes more turbulent and the boundary layer stays in contact with the sphere for longer.

The last two experiments involved testing flow rate measurement equipment. The results from the rotameter data calibration yielded a direct linear relationship between pressure and flow rate. This regression was performed via Microsoft Excel. Lastly, the turbine flow meter appears to have accurately measured the flow rate of the hose at approximately 2.6 GPM. The experimental calculated flow rate, for comparison, had a similar average of 2.66 GPM, but far more error due to human factors and the bucket measuring volume. Between these two experiments, we were able to accurately calibrate a rotameter and verify the results of a turbine flow meter.

Appendix

Section 1 – Raw Data and Sample Calculations of Wind Tunnel 1

Table 2: Experimental air pressures at varying fan speeds – Smooth Golf Ball

Height	1	2	3	4	5	6	7	8
SP 0	0	0	0	0	0	0	0	0
SP 20	0	0	0	0	0	0	0	0
SP 40	0	0	0.62468	1.5617	6.2468	9.3702	12.4936	13.11828
SP 60	-3.1234	0	0	3.1234	12.4936	21.8638	28.1106	34.3574
SP 80	0	0	0	0	0	0	3.1234	9.3702

Table 3: Experimental air pressures at varying fan speeds continued – Smooth Golf Ball

Height	9	10	11	12	13	14	15	16
SP 0	0	0	0	0	0	0	0	0
SP 20	0	0	0	0	0	0	0	-3.1234
SP 40	13.11828	13.74296	13.11828	12.4936	11.24424	9.3702	9.3702	7.49616
SP 60	40.6042	40.6042	40.6042	40.6042	39.35484	37.4808	37.4808	31.234
SP 80	18.7404	28.1106	37.4808	46.851	65.5914	81.2084	84.3318	87.4552

Sample calculation – Drag Force on Smooth Golf Ball

$$F_{D,SP\ 20} \approx \sum_{i=1}^{16} \Delta P_i * R^2 * \Delta\theta^2 = 0^{15} + \left(-3.1234\frac{lbs}{ft^2} * (0.84331in)^2 * \left(\frac{\pi}{16}\right)^2\right) = -0.0006lbs$$

Table 4: Experimental air pressures at varying fan speeds – Dimpled Golf Ball

Height	1	2	3	4	5	6	7	8
SP 0	0	0	0	0	0	0	0	0
SP 20	0	0	0	0	0	0	0	0
SP 40	15.617	18.7404	18.7404	18.7404	18.7404	18.7404	15.617	15.617
SP 60	18.7404	28.1106	34.3574	34.3574	34.3574	34.3574	34.3574	34.3574
SP 80	0	0	0	0	0	3.1234	6.2468	12.4936

Table 5: Experimental air pressures at varying fan speeds continued – Dimpled Golf Ball

Height	9	10	11	12	13	14	15	16
SP 0	0	0	0	0	0	0	0	0
SP 20	0	0	0	0	0	0	0	0
SP 40	15.617	15.617	12.4936	9.3702	6.2468	6.2468	6.2468	6.2468
SP 60	37.4808	37.4808	34.3574	31.234	28.1106	24.9872	24.9872	31.234
SP 80	21.8638	37.4808	59.3446	74.9616	81.2084	81.2084	81.2084	81.2084

Section 2 – Raw Data and Sample Calculations of Wind Tunnel 2

Table 6: Calibration plate weight and object diameter

Calibration plate weight (gr)	9.5
Object Diameter (mm)	40.02
Object Diameter (ft)	0.131299

Table 7: Experimental voltage readings at varying fan speeds

Weights (gr)	0	9.5	10	20	50	100
Voltage (V)	0.242981	0.249756	0.255972	0.262747	0.282168	0.31746

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Table 8: Voltage and manometer height readings at varying fan speeds

Speed	0	20	40	60	80	95
Voltage (V)	0.244021	0.244899	0.247175	0.250244	0.254723	0.257441
Manometer (in)	0.03	0.08	0.25	0.52	0.94	1.95

Table 9: Experimental voltage readings at various weights

Speed	0	20	40	60	80	95
Force (lbs)	-0.00413	-0.00148	0.005376	0.014625	0.028123	0.036314
ΔP (lbs/ft^2)	0.15617	0.416453	1.301417	2.706947	4.893327	10.15105
Velocity, u (ft/s)	11.46061	18.7151	33.08394	47.71434	64.15214	92.39842
C_D	-1.95305	-0.26313	0.305064	0.399017	0.424468	0.264213
Re	10596.97	17304.78	30590.81	44118.7	59317.79	85435.5

Sample calculation – Drag Force

$$F_{D,SP\ 0\%} = 1365.9V - 335.18 = 1365.9(0.24402V) - 335.18 = -0.0041\ lbs$$

Sample calculation – Change in Pressure

$$\Delta P_{SP\ 0\%} = \frac{\Delta h}{12} * g * \rho_f = \frac{0.03in}{12} * 32.2\frac{ft}{s} * 1.94\frac{lbs}{ft^3} = 0.15617\frac{lbs}{ft^2}$$

Sample calculation – Drag Coefficient and Object Area

$$C_{D,SP\ 0\%} = \frac{2F_D}{\rho u^2 A} = \frac{2(-0.0041lbs)}{1.94\frac{lbs}{ft^3} * \left(11.4606\frac{ft}{s}\right)^2 * 0.01354ft^2} = -1.953$$

$$A_{object} = \frac{\pi}{4}D^2 = \frac{\pi}{4}(0.1313ft)^2 = 0.01354ft^2$$

Sample calculation – Reynolds Number

$$Re_{SP\ 0\%} = \frac{u * D}{\rho_{air}} = \frac{11.4606\frac{ft}{s} * 0.1313ft}{0.00238\frac{lbs}{ft^3}} = 10597$$

Section 3 – Raw Data and Sample Calculations of Rotameter

Table 10: Flow rates at varying pressures in a rotameter

Pressure (psi)	0	10	15	20	25	30	35	40
Flow rate (SCFH)	0	8	21	25	30	33	39	45

Sample calculation – Flow Rate at 90 psi

$$FlowRate_{90psi} = 1.1253(P) + 0.5088 = 1.1253(90psi) + 0.5088 = 101.786SCFH$$

Section 4 – Raw Data and Sample Calculations of Turbine Flow Meter

Table 11: Bucket inner diameter

Bucket Inner Diameter (in)	11.25

Table 12: Turbine flow rate at varying valve positions

Valve setting	1	2	3	4	5
Meter reading (GPM)	2.546	2.611	2.61	2.587	2.543
Time(s)	9.38	23.41	38.53	53.72	66.32
Water Volume (L)	2	4	6	8	10
Water Volume (G)	0.528344	1.056688	1.585032	2.113376	2.64172
Flow Rate Calc (GPM)	3.379599	2.708299	2.468256	2.360435	2.389976

Sample calculation – Calculated Volumetric Flow Rate

$$Q_1 = \frac{Volume}{Time} = \frac{0.528344G}{9.38s * \frac{1min}{60s}} = 3.3796GPM$$