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# Aerodynamic Insight and Geometric Body Analysis By Wind Tunnel Testing

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***Abstract:***
*In engineering design, wind tunnel testing may prove to be necessary as it provides an insight of air flow characteristics around a model for simulation of a full scale prototype. These fluid mechanic characteristics were observed to gain a greater understanding of the setup and theory behind wind tunnel testing. The primary objectives of the lab were to learn the pitot static probe principle for measurement of wind tunnel airspeed, and study the aerodynamic forces such as lift and drag acting on varying geometric bodies. The testing of varying bodies allowed for a direct comparison of the changes caused by the differing dimensions of the shapes used for the experiment.*

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## I. Introduction:

Wind is a native force that interacts with the world around us whether directly or indirectly. The force exerted by the wind can not be fully observed but rather calculated as to determine its effects on us or other objects. This becomes especially apparent when the wind is subjected to a condensed enclosed area as it rushes out through one or any exit available.

The velocity of wind in an inclosed area can be calculated based on the entrance shape of the tunnel; square, rectangle, circle, triangle. Furthermore the wind within the tunnel can then be measured using a form of Bernoulli's number based on the area of the entrance shape, incline of the tunnel and any power fluctuations when fans are presented inside the tunnel. This style of experimentation/ calculation is important because it allows us to replicate the behaviors of the wind in a controlled environment for objects in flight. Allowing any design to be tested without the complications or irregularities of outside forces which are usually beyond our means to mitigate.

The main focus of this paper is to experiment with the notion of wind velocity within an enclosed tunnel to calculate the speed of the wind and illustrate the effects of lift/ drag that it has on different geometric bodies. We plan to do this by first understanding and applying the principle of the pitot-static probe to calculate the velocity within a specified tunnel, as the ratios can change due to the size and shape of the tunnel. Secondly applying the calculated velocity on different geometrical shapes facing in 2 different directions, this is to compare the changes if any, occur between the different sides of the shapes. Lastly plotting the results as to show a side by side comparison of the different shapes drag/ lift forces that were affected by the different wind speeds within the tunnel.

Theoretical Background:

Aerodynamics use wind tunnels to test possible plane models. Throughout the tunnel, the engineer will control the flow conditions that influence the aircraft's forces with care.

By carefully testing the strengths on the model, the engineer will predict the forces on the aircraft at full scale. And the engineer can better understand and improve the use of special diagnostic techniques.Wind tunnels are designed for a specific purpose and speed range and there are a wide variety of types of wind tunnels and model instruments available.

The model which will be tested in the wind tunnel is put in the tunnel test section.
Velocity in the test section is determined by tunnel construction. Owing to compressibility effects the choice of speed range affects the nature of the wind tunnel.

Experiments with the wind tunnel.We're using a list of equations such as:
-Conservation of mass
-Conservation of momentum
-Isentropic flow, and many more

Experimental Setup and Procedure:

**Part A:**
**Calibration of Wind Tunnel Airspeed Using a Pitot-static Probe**

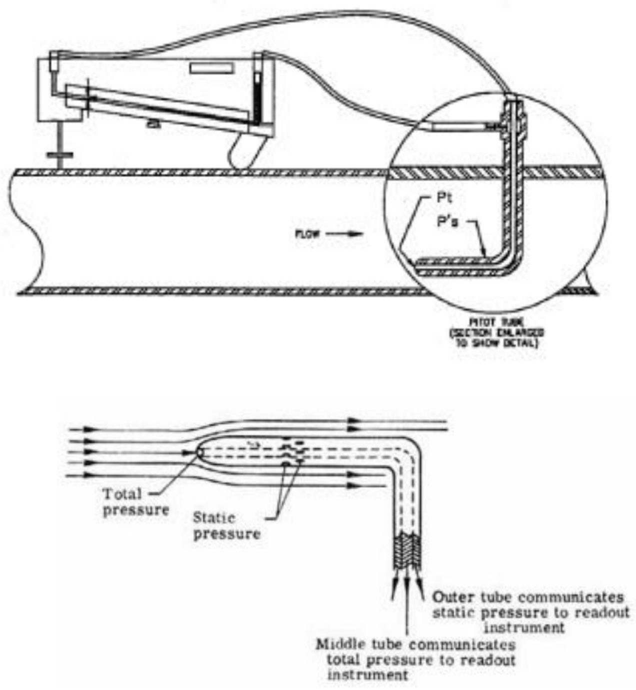



Fig. 1

| Materials/ Instruments | Specifications (if necessary) |
|---|---|
| Wind tunnel facility | H-6910-12-55 Wind tunnel Hvac |
| Pitot-static Probe | |
| Pressure sensor Board | |
| Power supply | 5w or above |
| DVM | |
| Water | |
| Ruler | Yard or meter |

**Fig. 2 Simmons, Matthew, Carlos Montalvo, and Sytske Kimball. "Wind Tunnel Tests of a Pitot-Static Tube Array to Estimate Wind Velocity."** ***arXiv preprint arXiv:1901.10600*** **(2019).**

**Part B:**
**Demonstration of Lift and Drag Forces For Different Geometric Bodies**

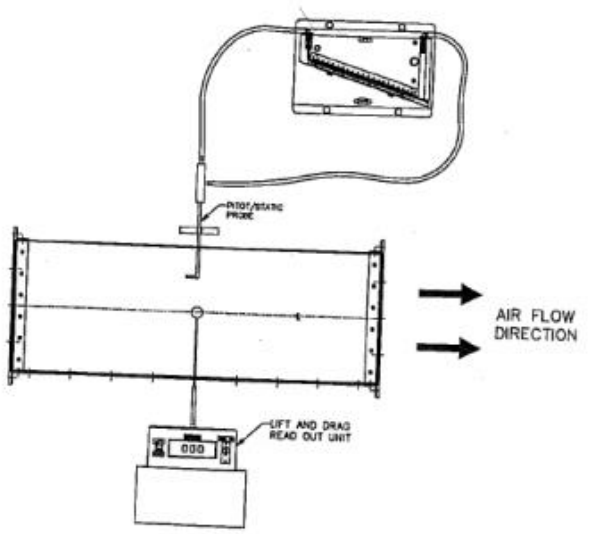



Fig. 1

| Materials/ Instruments | Specifications (if necessary) |
|---|---|
| Wind tunnel facility | H-6910-12-55 Wind tunnel Hvac |
| Drag test Section | H-6910-12-55 Wind tunnel Hvac |
| Pitot tube | |
| Test Shape | Sphere, Cylinder, Hemisphere, Rectangular Wedge |

Fig.1

**Step 1**. Install the listed materials/ instruments and arrange them similar to the picture shown above the graph. Slip the rod end of the test shape through the hole in the bottom of the test section. Attach the rod end of the test shape to the connector rod protruding from the top of the indicator housing. Align the test shape so that it is perpendicular to the air flow. Install a pitot-static probe in the probe positioner and carefully insert the probe head into one of the access holes in the test section. Connect the pressure taps on the pitot-static probe to one of the differential manometers using flexing tubing.
**Step 2.** Turn the lift/drag measurement display "on" and watch for the zero reading. The load cell and display unit has been factory calibrated in Newtons and should not need any further adjustment. The tare button can be pressed to zero to test the weight of the specific piece. (fig. 3)
Results and Discussions:

**Part A**

The first part of our experiment consisted in using a pitot-static probe to calibrate the air speed in the wind tunnel. A pitot-static system generally consists of a pitot tube, a static port, and the pitot-static instruments.It works by measuring pressures or pressure differences and using these values to assess the speed and altitude. These pressures can be measured either from the static port (static pressure) or the pitot tube (pitot pressure). The static pressure is used in all measurements, while the pitot pressure is used only to determine airspeed.

Although this is a very effective way to measure air speeds, it also comes with possible errors that may occur. For example, if the pitot-static tube is not aligned with the flow, an error of inclination will occur known as yaw.

In order to have a complete analysis, we need to calculate the velocity of the air flow, the volumetric flow rate, and the Reynolds number in order to identify the flow as turbulent or laminar. The following equations were used to calculate the previous values:

To calculate velocity:

$$V = 795\sqrt{\Delta P} \text{ (For Air at 0.075 lb ft3 , 70 °F, 29.92 inches of Hg Barometric Pressure)}$$

It is important to note that this equation will give us the velocity in ft/minute. To run some further calculations we will need to convert this velocity to ft/sec. Also, $\Delta P$ needs to be in mm of H2O.

To calculate volumetric flow rate:

$$Vf = V = Vave * A$$

To calculate Reynolds number:

$$Re = (\rho * Vave * Dh)/\mu$$

It is important to note that for this calculation, we need to change the velocity from ft/min to ft/sec. We have to do this, because the units of our dynamic viscosity are in sec not min.

Below we have a chart with all the previous calculations:

| | | | | | | |
|---|---|---|---|---|---|---|
| VFD (%) | 45 | Density (lbm/ft3) at 70 F | 0.07489 | | | |
| Fan Speed (RPM) | 879 | Dh (in) | 0.667 | | | |
| Area | 0.444 | Dynamic Viscosity (lbm/ft*s) | 1.23E-05 | | | |
| No. Of Observations | DP-2 (mm of H2O) | Distance Pitot-Static Proe Was Submerged (cm) | Position of the PSP | Velocity (ft/min) | Volumetric Flow Rate (ft3/min) | Reynolds Number |
| 1 | 7.62 | 22 | Center (Maximum Velocity) | 2194.55 | 974.38 | 148773.54 |
| 2 | 7.11 | 20 | | 2119.83 | 941.2 | 143689.7 |
| 3 | 7.62 | 18 | | 2194.55 | 974.38 | 148773.54 |
| 4 | 6.86 | 16 | | 2082.23 | 924.51 | 141127.44 |
| 5 | 6.86 | 14 | | 2082.23 | 924.51 | 141127.44 |
| 6 | 7.62 | 12 | | 2194.55 | 974.38 | 148773.54 |
| 7 | 6.6 | 10 | | 2042.39 | 906.82 | 138443.17 |
| 8 | 6.35 | 8 | | 2003.34 | 889.48 | 135799.57 |
| 9 | 6.1 | 6 | Close to Wall (Lowest Velocity) | 1963.05 | 871.94 | 133074.63 |

As we can see from the values obtained, we have a completely turbulent flow from the fan.

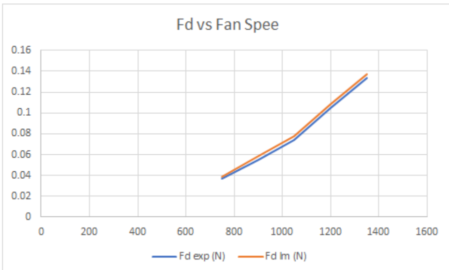
**Part B**

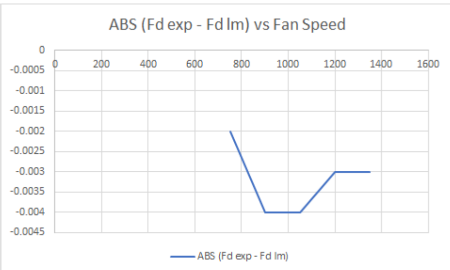
For the second part of our project, we will see how the aerodynamic forces behave when we have different geometric bodies in a moving airstream, We will be using a sphere, cylinder, hemisphere facing forward, hemisphere facing rearward, rectangular wedge facing forward, and a rectangular wedge facing rearward.

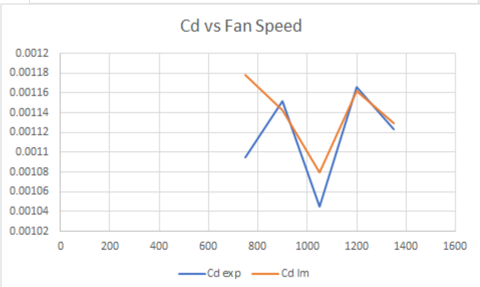
For each of these bodies we will be calculating the drag force, coefficient of drag and Reynolds number. We will also compare them with the fan speed to see how they behave.

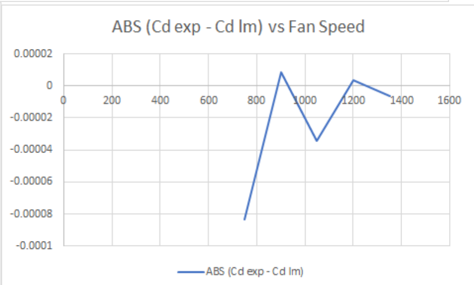
**Sphere:**

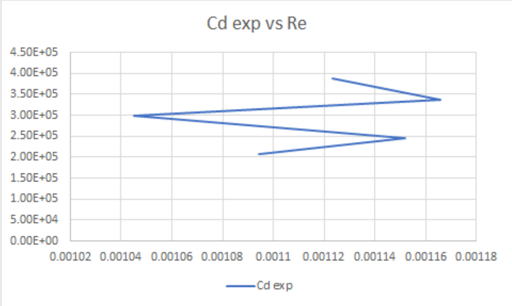
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sphere | Diameter (in) | 1 | Area (in2) | 0.784 | Perimeter (in) | 3.14 | Dh (in) | 1 | |
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 6.55 | 0.037 | 0.001094457 | 7 | 0.039 | 0.0011778 | -0.002 | -8.33477E-05 | 2.07E+05 |
| 900 | 9.25 | 0.055 | 0.001151875 | 10 | 0.059 | 0.00114308 | -0.004 | 8.79475E-06 | 2.46E+05 |
| 1050 | 13.72 | 0.074 | 0.001044901 | 14 | 0.078 | 0.00107928 | -0.004 | -3.43789E-05 | 2.99E+05 |
| 1200 | 17.45 | 0.105 | 0.001165753 | 18 | 0.108 | 0.00116224 | -0.003 | 3.51635E-06 | 3.38E+05 |
| 1350 | 23.11 | 0.134 | 0.001123256 | 23.5 | 0.137 | 0.00112953 | -0.003 | -6.27339E-06 | 3.88E+05 |



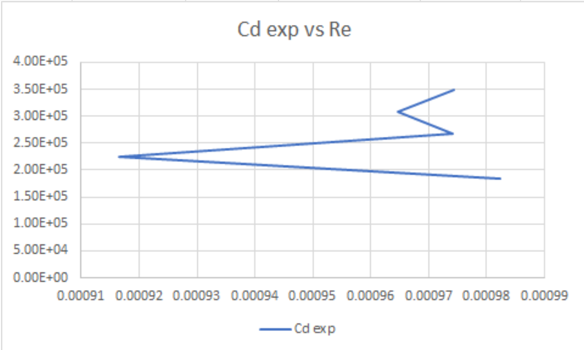





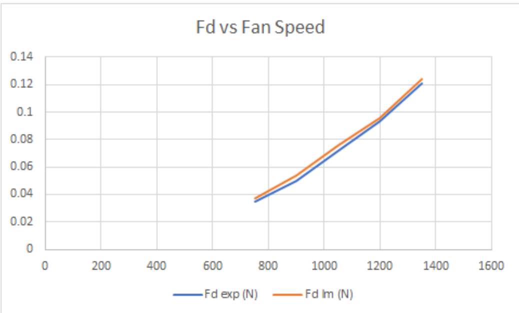

## Cylinder:

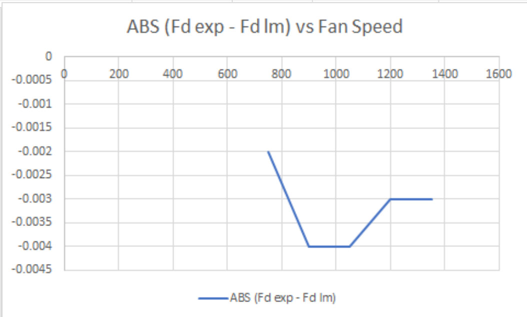
| Cylinder | Lenght (in) | 5.44 | Diameter (in) | 1.01 | Area (in2) | 5.48 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 5.08 | 0.18 | 0.000982384 | | 0.19 | | | | 1.84E+05 |
| 900 | 7.62 | 0.252 | 0.000916434 | | 0.276 | | | | 2.25E+05 |
| 1050 | 10.67 | 0.375 | 0.000974193 | | 0.39 | | | | 2.67E+05 |
| 1200 | 14.22 | 0.495 | 0.000964661 | | 0.51 | | | | 3.08E+05 |
| 1350 | 18.29 | 0.643 | 0.0009743 | | 0.65 | | | | 3.49E+05 |

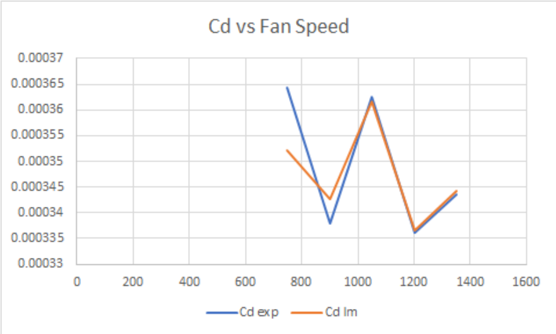


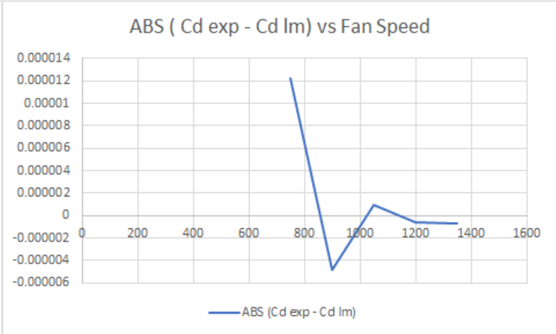

## Hemisphere Facing Forward:

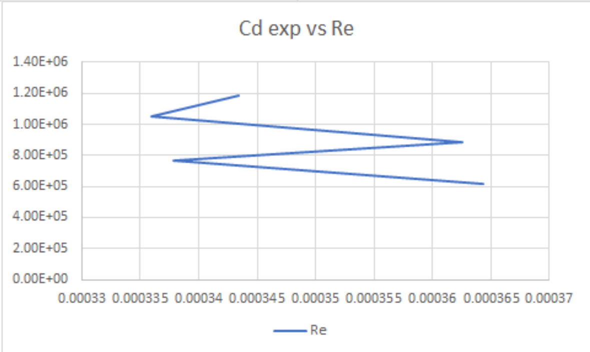
| Hemisphere Facing Forward | Radius (in) | 0.49 | Diameter (in) | 0.98 | Area (in2) | 2.28 | Perimeter (in) | 3.02 | Dh (in) |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 6.4 | 0.035 | 0.000364326 | 7 | 0.037 | 0.00035213 | -0.002 | 1.21938E-05 | 6.17E+05 |
| 900 | 9.86 | 0.05 | 0.000337828 | 10.5 | 0.054 | 0.00034262 | -0.004 | -4.7875E-06 | 7.66E+05 |
| 1050 | 13.23 | 0.072 | 0.000362556 | 14 | 0.076 | 0.00036165 | -0.004 | 9.06389E-07 | 8.87E+05 |
| 1200 | 18.44 | 0.093 | 0.000335988 | 19 | 0.096 | 0.0003366 | -0.003 | -6.16074E-07 | 1.05E+06 |
| 1350 | 23.47 | 0.121 | 0.000343459 | 24 | 0.124 | 0.0003442 | -0.003 | -7.42741E-07 | 1.18E+06 |



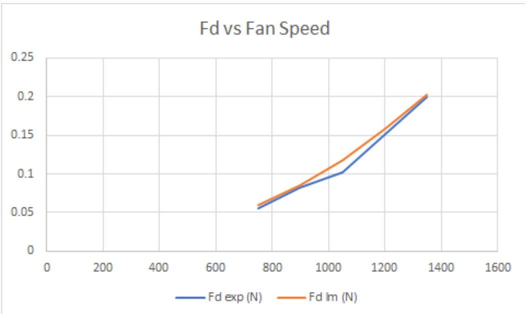


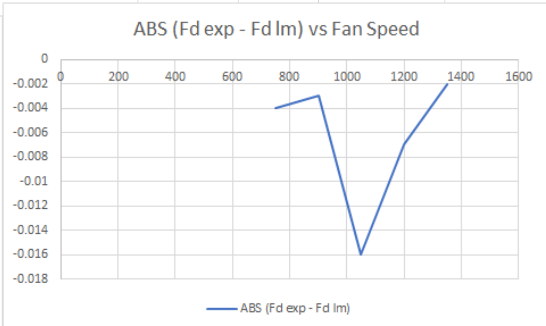



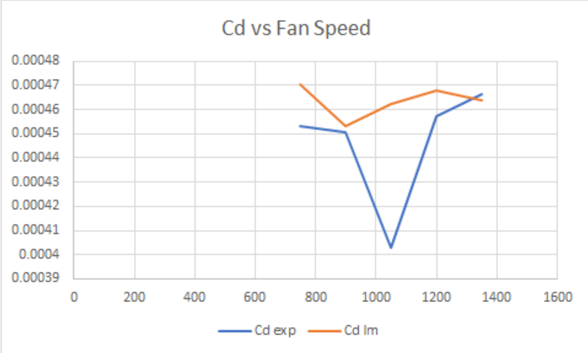



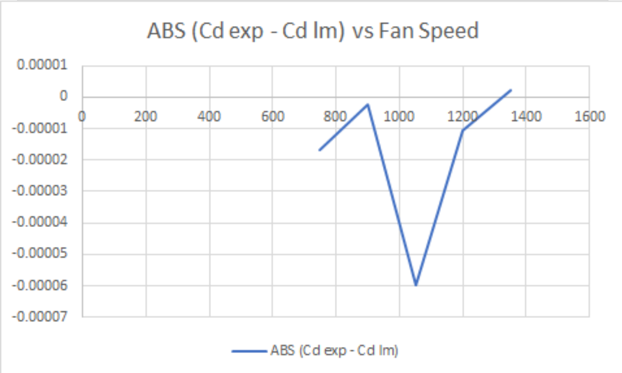

## Hemisphere Facing Rearward:

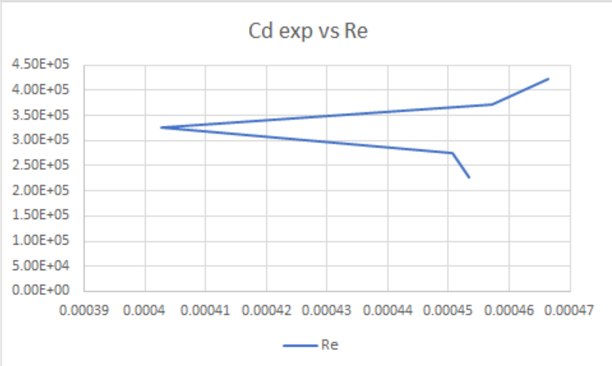
| Hemisphere Facing Rearward | Radius (in) | 0.49 | Diameter (in) | 0.98 | Area (in2) | 2.28 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 8.23 | 0.056 | 0.000453305 | 8.5 | 0.06 | 0.00047026 | -0.004 | -1.69513E-05 | 2.27E+05 |
| 900 | 12.12 | 0.082 | 0.000450727 | 12.5 | 0.085 | 0.00045301 | -0.003 | -2.28661E-06 | 2.76E+05 |
| 1050 | 16.87 | 0.102 | 0.000402798 | 17 | 0.118 | 0.00046242 | -0.016 | -5.96206E-05 | 3.25E+05 |
| 1200 | 22 | 0.151 | 0.000457253 | 22.5 | 0.158 | 0.00046782 | -0.007 | -1.05649E-05 | 3.71E+05 |
| 1350 | 28.57 | 0.2 | 0.000466361 | 29 | 0.202 | 0.00046404 | -0.002 | 2.32055E-06 | 4.23E+05 |



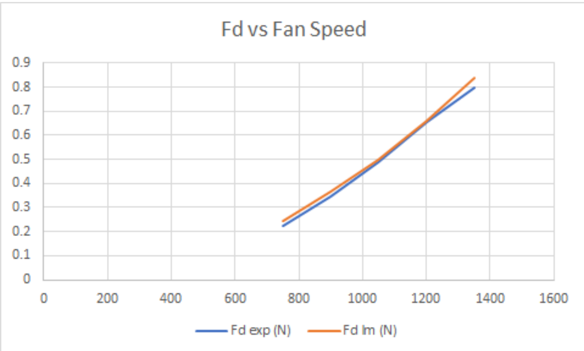


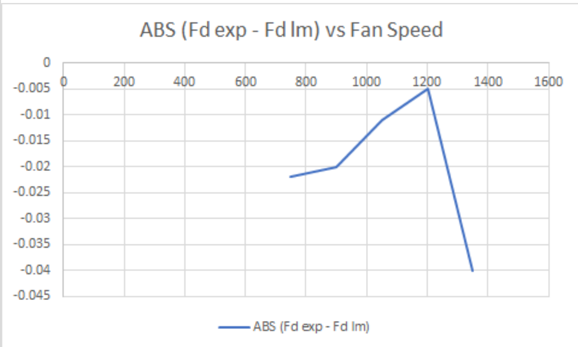



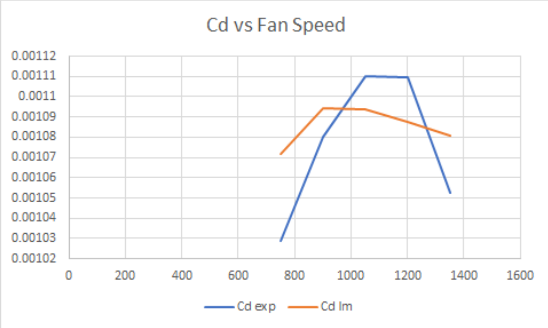



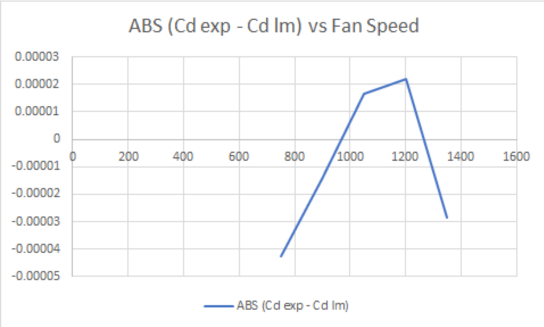

Rectangular Wedge Facing Forward:

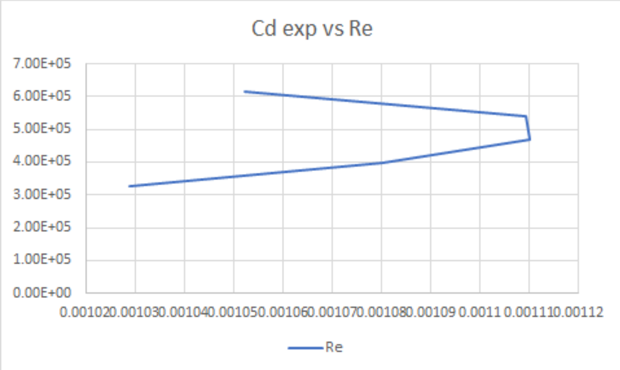
| Rectangular Wedge Facing Forward | Lenght (in) | 5.18 | Thick (in) | 0.21 | Width (in) | 0.89 | Area (in) | 4.63 | Dh (in) |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 7.11 | 0.223 | 0.001028943 | 7.5 | 0.245 | 0.00107167 | -0.022 | -4.27265E-05 | 3.27E+05 |
| 900 | 10.54 | 0.347 | 0.001080052 | 11 | 0.367 | 0.00109453 | -0.02 | -1.44818E-05 | 3.99E+05 |
| 1050 | 14.45 | 0.489 | 0.001110189 | 15 | 0.5 | 0.00109354 | -0.011 | 1.66491E-05 | 4.67E+05 |
| 1200 | 19.46 | 0.658 | 0.001109275 | 20 | 0.663 | 0.00108753 | -0.005 | 2.17489E-05 | 5.42E+05 |
| 1350 | 24.94 | 0.8 | 0.001052324 | 25.5 | 0.84 | 0.00108067 | -0.04 | -2.83508E-05 | 6.13E+05 |



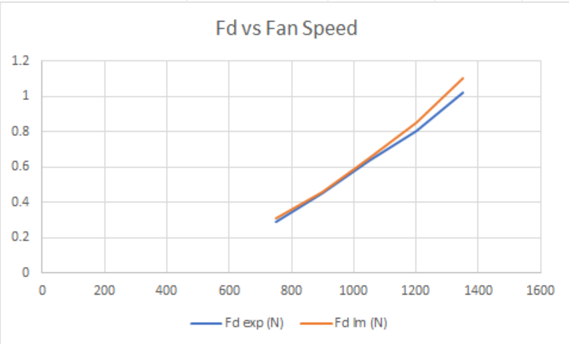


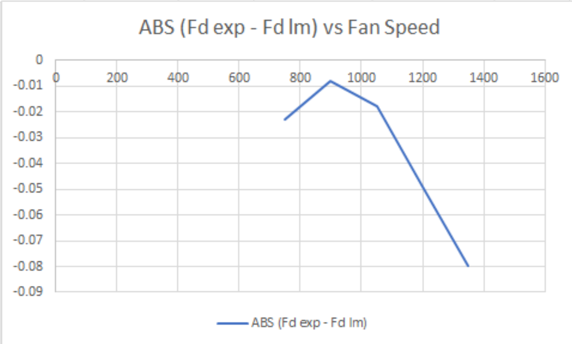



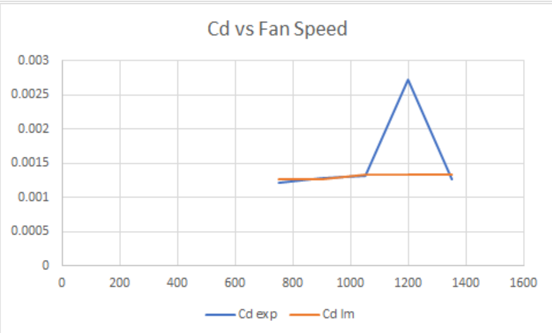



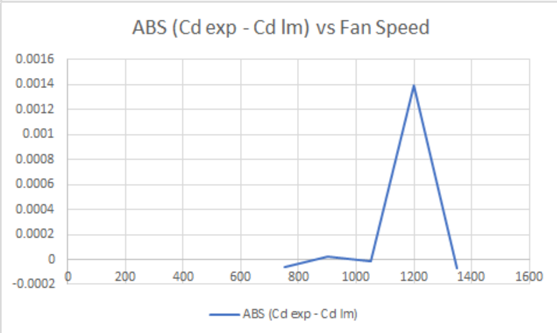

## Rectangular Wedge Facing Rearward

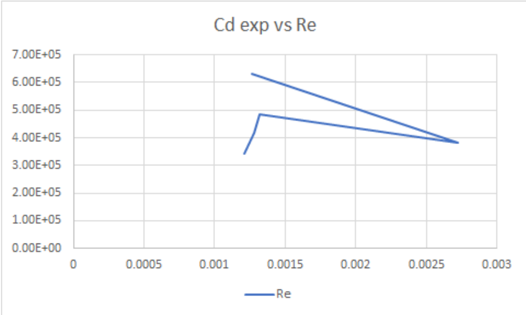
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rectangular Wedge Facing Rearward | Lenght (in) | 5.18 | Thick (in) | 0.21 | Width (in) | 0.89 | Area (in) | 4.63 | Dh (in) | 1.52 |
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re | |
| 750 | 7.8 | 0.287 | 0.0012071 | 8 | 0.31 | 0.00127124 | -0.023 | -6.41403E-05 | 3.43E+05 | |
| 900 | 11.56 | 0.452 | 0.001282734 | 12 | 0.46 | 0.00125757 | -0.008 | 2.51628E-05 | 4.18E+05 | |
| 1050 | 15.7 | 0.632 | 0.001320606 | 16 | 0.65 | 0.00133275 | -0.018 | -1.21456E-05 | 4.87E+05 | |
| 1200 | 9.65 | 0.801 | 0.002723085 | 21 | 0.85 | 0.00132787 | -0.049 | 0.001395215 | 3.81E+05 | |
| 1350 | 26.42 | 1.02 | 0.001266553 | 27 | 1.1 | 0.00133655 | -0.08 | -6.99961E-05 | 6.31E+05 | |






As we can see depending on geometry in which the air flows through, the drag will either increase or decrease. That is why cars or airplanes are built in such a way that the shape helps reduce the most drag possible.

## II. Conclusions:

The goal of this experiment was first to learn the principle of pitot static probe for measuring wind tunnel airspeed, and then identifying the aerodynamic lift and drag forces which act on varying geometries. Direct comparison of the changes occurred due to differing dimensions were also done in the experiment. Various entrance shapes of tunnels such as square, rectangle, circle, and triangle were analyzed in the experiment with the help of a pitot static system. The results obtained in the experiment were illustrated with the help of various graphs for much better understanding. By using the air velocity, in Table-1 the values of volumetric flow rate and Reynolds's Number is calculated. The obtained values of Reynolds's Number show that the flow is completely turbulent for all the observations. The turbulent nature of the flow from the fan governs various other parameters in the experiment, so it is an important deduction.

Next we compared the experimental results with the use of graphs for various geometries one by one. Firstly in the sphere from Graph-1, one can see that the drag force was directly changing as the speed of the fan was increased. Also the experimental and theoretical values of forces were almost the same. In the next graph the values of drag coefficient shows a lot of variations with fan speed and the maximum drag coefficient obtained was 0.001165 at fan speed of 1200RPM.

In the geometry of the cylinder, the drag coefficient decreases with increase of Reynolds's Number and the maximum drag coefficient obtained was 0.000982384 at Reynolds's value of 184000.

For the geometry of Hemisphere facing forward and facing rearward, the graph of drag force V/s Speed was very similar, however the graph of drag coefficient showed a lot of variations. Next geometry that we analyzed was Rectangle Wedge forward and rearward facing geometries and expected results were obtained which can be shown in the graph. In this geometry also drag force increases with speed. Similar trends in the graph of drag coefficient V/s. fan speed.

Thus the experiment suggested that the drag and lift forces are dependent on the flow velocities of air. There might be some errors also in the experiment which could be eliminated using standard practices of performing the experiment. Thus we were successful in conducting the experiment with acceptable results

## References:


- Fig. 1) https://learn-us-east-1-prod-fleet01-xythos.s3.us-east-1.amazonaws.com/5cc0bc5a4bb1d/7749866?response-content-disposition=inline%3B%20filename%2A%3DUTF-8%27%27Wind%2520Tunnel%2520Experiments%2520%2528Experimental%2520Setup%2520and%2520Aligned%2520Theories%2529.pdf&response-content-type=application%2Fpdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20200409T000243Z&X-Amz-SignedHeaders=host&X-Amz-Expires=21600&X-Amz-Credential=AKIAZH6WM4PLTYPZRQMY%2F20200409%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=7a8a875a45891ad340283ca565b659cf722e0c828ab0b7a93f28c6a432ee27ac
- fig .2) Simmons, Matthew, Carlos Montalvo, and Sytske Kimball. "Wind Tunnel Tests of a Pitot-Static Tube Array to Estimate Wind Velocity." *arXiv preprint arXiv:1901.10600* (2019).
- Fig. 3) https://learn-us-east-1-prod-fleet01-xythos.s3.us-east-1.amazonaws.com/5cc0bc5a4bb1d/7749867?response-content-disposition=inline%3B%20filename%2A%3DUTF-8%27%27Wind%2520Tunnel%2520Lab%2520Manual%2520Data.pdf&response-content-type=application%2Fpdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20200409T205411Z&X-Amz-SignedHeaders=host&X-Amz-Expires=21600&X-Amz-Credential=AKIAZH6WM4PLTYPZRQMY%2F20200409%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=0cff4bb62755bdbd8dde4b6ae826131dff35702f49517d455591bb3f45bd24fc


Appendices:

Appendix A: Part A Calculations and Data

**Calculation for finding velocity:**

**Formula: V = 795√ΔP (For Air at 0.075 lb ft3 , 70°F, 29.92 inches of Hg Barometric Pressure)**

**Example: 795√7.62 mm = 2194.55 ft/min**

**Calculation for finding volumetric flow rate ($Vf$)**

**Formula:$Vf$ = $V$ = $V$ave *A**

**Example: 2194.55 ft/min * .444 = 974.38**

**Calculations for finding the Reynolds number:**

**Formula:Re = (ρ*Vave* Dh)/ µ**

**Example:(0.07489*2194.55* 0.667)/ 1.23E-05 = 148773.54**

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/ µ**

**Example: (0.07489*2194.55* 1)/ 1.23E-05 = 2.07E+05**

| Sphere | Diameter (in) | 1 | Area (in2) | 0.784 | Perimeter (in) | 3.14 | Dh (in) | 1 | |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 6.55 | 0.037 | 0.001094457 | 7 | 0.039 | 0.0011778 | -0.002 | -8.33477E-05 | 2.07E+05 |
| 900 | 9.25 | 0.055 | 0.001151875 | 10 | 0.059 | 0.00114308 | -0.004 | 8.79475E-06 | 2.46E+05 |
| 1050 | 13.72 | 0.074 | 0.001044901 | 14 | 0.078 | 0.00107928 | -0.004 | -3.43789E-05 | 2.99E+05 |
| 1200 | 17.45 | 0.105 | 0.001165753 | 18 | 0.108 | 0.00116224 | -0.003 | 3.51635E-06 | 3.38E+05 |
| 1350 | 23.11 | 0.134 | 0.001123256 | 23.5 | 0.137 | 0.00112953 | -0.003 | -6.27339E-06 | 3.88E+05 |

Appendix C: Cylinder Calculations and Data

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/ µ**

**Example: (0.07489*2194.55* 1.01)/ 1.23E-05 = 1.84E+05**

| Cylinder | Lenght (in) | 5.44 | Diameter (in) | 1.01 | Area (in2) | 5.48 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 5.08 | 0.18 | 0.000982384 | | 0.19 | | | | 1.84E+05 |
| 900 | 7.62 | 0.252 | 0.000916434 | | 0.276 | | | | 2.25E+05 |
| 1050 | 10.67 | 0.375 | 0.000974193 | | 0.39 | | | | 2.67E+05 |
| 1200 | 14.22 | 0.495 | 0.000964661 | | 0.51 | | | | 3.08E+05 |
| 1350 | 18.29 | 0.643 | 0.0009743 | | 0.65 | | | | 3.49E+05 |

Appendix D: Hemisphere Facing Forward Calculations and Data

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/ μ**
**Example: (0.07489*2194.55* 2.28)/ 1.23E-05 = 6.17E+05**

| Hemisphere Facing Forward | Radius (in) | 0.49 | Diameter (in) | 0.98 | Area (in2) | 2.28 | Perimeter (in) | 3.02 | Dh (in) |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 6.4 | 0.035 | 0.000364326 | 7 | 0.037 | 0.00035213 | -0.002 | 1.21938E-05 | 6.17E+05 |
| 900 | 9.86 | 0.05 | 0.000337828 | 10.5 | 0.054 | 0.00034262 | -0.004 | -4.7875E-06 | 7.66E+05 |
| 1050 | 13.23 | 0.072 | 0.000362556 | 14 | 0.076 | 0.00036165 | -0.004 | 9.06389E-07 | 8.87E+05 |
| 1200 | 18.44 | 0.093 | 0.000335988 | 19 | 0.096 | 0.0003366 | -0.003 | -6.16074E-07 | 1.05E+06 |
| 1350 | 23.47 | 0.121 | 0.000343459 | 24 | 0.124 | 0.0003442 | -0.003 | -7.42741E-07 | 1.18E+06 |

Appendix E: Hemisphere Facing Rearwards Calculations and Data

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/ μ**
**Example: (0.07489*2194.55* 2.28)/ 1.23E-05 = 2.27E+05**

| Hemisphere Facing Rearward | Radius (in) | 0.49 | Diameter (in) | 0.98 | Area (in2) | 2.28 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re |
| 750 | 8.23 | 0.056 | 0.000453305 | 8.5 | 0.06 | 0.00047026 | -0.004 | -1.69513E-05 | 2.27E+05 |
| 900 | 12.12 | 0.082 | 0.000450727 | 12.5 | 0.085 | 0.00045301 | -0.003 | -2.28661E-06 | 2.76E+05 |
| 1050 | 16.87 | 0.102 | 0.000402798 | 17 | 0.118 | 0.00046242 | -0.016 | -5.96206E-05 | 3.25E+05 |
| 1200 | 22 | 0.151 | 0.000457253 | 22.5 | 0.158 | 0.00046782 | -0.007 | -1.05649E-05 | 3.71E+05 |
| 1350 | 28.57 | 0.2 | 0.000466361 | 29 | 0.202 | 0.00046404 | -0.002 | 2.32055E-06 | 4.23E+05 |

Appendix F: Rectangular Wedge Facing Forward:

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/**

**Example: (0.07489*2194.55* 0.89)/ 1.23E-05 = 3.27E+05**

| Rectangular Wedge Facing Forward | Lenght (in) | 5.18 | Thick (in) | 0.21 | Width (in) | | 0.89 | Area (in) | 4.63 | Dh (in) |
|---|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re | |
| 750 | 7.11 | 0.223 | 0.001028943 | 7.5 | 0.245 | 0.00107167 | -0.022 | -4.27265E-05 | 3.27E+05 | |
| 900 | 10.54 | 0.347 | 0.001080052 | 11 | 0.367 | 0.00109453 | -0.02 | -1.44818E-05 | 3.99E+05 | |
| 1050 | 14.45 | 0.489 | 0.001110189 | 15 | 0.5 | 0.00109354 | -0.011 | 1.66491E-05 | 4.67E+05 | |
| 1200 | 19.46 | 0.658 | 0.001109275 | 20 | 0.663 | 0.00108753 | -0.005 | 2.17489E-05 | 5.42E+05 | |
| 1350 | 24.94 | 0.8 | 0.001052324 | 25.5 | 0.84 | 0.00108067 | -0.04 | -2.83508E-05 | 6.13E+05 | |

Appendix G: Rectangular Wedge Facing Rearward:

**Calculation for finding drag force:**

**Formula: FD = (CD*A* ρ)*(V^2/2g)**

**Calculation for finding Reynold Number:**

**Formula: Re = (ρ*Vave* Dh)/**

**Example: (0.07489*2194.55* 1.52)/ 1.23E-05 = 3.27E+05**

| Rectangular Wedge Facing Rearward | Lenght (in) | 5.18 | Thick (in) | 0.21 | Width (in) | | 0.89 | Area (in) | 4.63 | Dh (in) | 1.52 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fan Speed (RPM) | DP exp (mm of H2O) | Fd exp (N) | Cd exp | DP lm (mm of H2O) | Fd lm (N) | Cd lm | ABS (Fd exp - Fd lm) | ABS (Cd exp - Cd lm) | Re | | |
| 750 | 7.8 | 0.287 | 0.0012071 | 8 | 0.31 | 0.00127124 | -0.023 | -6.41403E-05 | 3.43E+05 | | |
| 900 | 11.56 | 0.452 | 0.001282734 | 12 | 0.46 | 0.00125757 | -0.008 | 2.51628E-05 | 4.18E+05 | | |
| 1050 | 15.7 | 0.632 | 0.001320606 | 16 | 0.65 | 0.00133275 | -0.018 | -1.21456E-05 | 4.87E+05 | | |
| 1200 | 9.65 | 0.801 | 0.002723085 | 21 | 0.85 | 0.00132787 | -0.049 | 0.001395215 | 3.81E+05 | | |
| 1350 | 26.42 | 1.02 | 0.001266553 | 27 | 1.1 | 0.00133655 | -0.08 | -6.99961E-05 | 6.31E+05 | | |