Technical Memorandum

To: T.A. Cody Gonzalez, Prof. Sherif Hassaan

From: Kevin Naraki Kim Wong, Triet Ho, Josue Guerrero, Devrajsinh Mayurdhvajsinh Zala, Matthew Valencia, Noah Palanjan, Tristan Reyes, Vanessa Abigail Renderos, Yonghao Huo, Xuanqi Zang.

Subject: Lab 1 Flow Speed in Wind Tunnel Experiment

Due Date: October 17, 2024

Date of Experiment: October 10, 2024

Abstract:

The purpose of this wind tunnel test is to determine the flow characteristics and uniformity within UCI's low-speed wind tunnel. Key flow properties, including velocity and angle of attack, were measured using instruments such as the Pitot-static tube and yaw probe. The objective was to experimentally measure the velocity distribution and flow angle within the wind tunnel's test section. Dynamic and total pressures were determined using the Pitot-static tube, while flow misalignment was measured with the yaw probe.

The experiment involved simulating airflow across a range of velocities and angles of attack, utilizing both static pressure taps and measurement probes. The Pitot-static tube provided velocity data by measuring pressure differentials. The yaw probe identified flow misalignment by comparing measurements in erect and inverted positions. The results indicate that both instruments exhibit limitations in accuracy at higher angles of attack but provide complementary data for characterizing the wind tunnel's flow profile.

Introduction:

A wind tunnel consists of three main components: the nozzle, the test section, and the diffuser. Air is drawn from the surrounding area through the converging nozzle into the test section which is designed with solid walls to isolate the airflow from external disturbances. After passing through the test section, the air exits back into the surrounding area via the diffuser. The wind tunnel used in this study can achieve a maximum velocity of 35 m/s when the test section is empty; however, the presence of objects in the test section reduces the maximum achievable speed due to flow disturbances and drag effects.

The primary objective of this experiment is to measure flow velocity and angle of attack in the test section using pressure differential measurements. A Pitot-static tube is employed to determine velocity by measuring both the total (stagnation) pressure and static pressure. The relationship between dynamic pressure and velocity is described by Bernoulli's equation as expressed:

$$\Delta P = \frac{1}{2}\rho V^2 \qquad \text{(Equation 1)}$$

Where ΔP is the dynamic pressure (difference between total and static pressure), is the air density, and V is the flow velocity. By rearranging equation 1, we may calculate the velocity:

$$V = \sqrt{\frac{2\Delta P}{\rho}} \qquad \text{(Equation 2)}$$

In equation 2, V is the velocity, ΔP is the dynamic pressure, and is the air density.

In addition to velocity measurements, a yaw probe is used to measure the flow angle - critical for assessing the alignment of the airflow. The yaw probe contains multiple pressure taps positioned at intervals along the probe to measure pressure differences indicating the flow direction. By adjusting the probe until the pressure difference between taps equals zero, the flow angle is determined. This method aids in identifying flow misalignment angles or uncertainties in the flow direction.

An outline for the memorandum is structured as follows: The procedure section will outline the experimental setup and procedures used to collect data. Results section will present the experimental results including plots of velocity profiles and flow angles. The discussion section will include a discussion of the accuracy of data collected, discrepancies (if applicable) and limitations of the equipment. A question section will answer questions addressed in the lab manual and finally a summary section will summarize critical results and provide a clear understanding of the experiment.

Procedure:

1) Schematic of the experimental setup

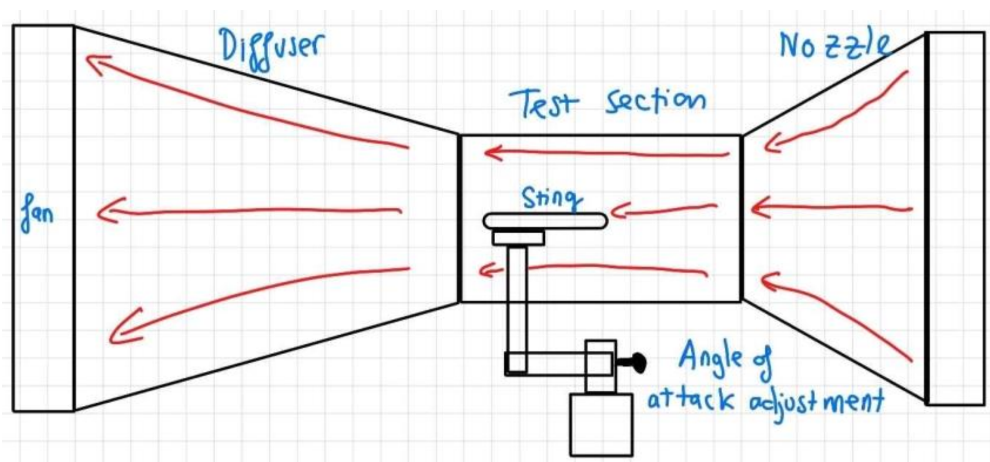

Figure 1. Wind Tunnel Block Diagram

2) Experiment equipment

Equipment	Description
Pitot-static tube	Measures flow speed in the wind tunnel by sensing dynamic and static pressure.
Setra Pressure Transducer	Captures differential pressures to determine flow characteristics.
Yaw Probe	Determines flow angle by measuring pressure difference.
Digital Level	Sets the Pitot-static tube horizontally for alignment with the flow.
Hygrometer, Barometer, and Thermometer	Measures environmental conditions such as humidity, total pressure, and temperature.
NI 9205 Data Acquisition	Digital data acquisition module to convert analog signals from sensors.
Depth Gauge	Measures the distance of the tip of the pitot-static tube to the wall

3) Summary of lab procedures

a) Use relative humidity, total pressure, and temperature to calculate the density of humid air.

b) Calibrate the pressure transducer device by zeroing the Setra pressure transducer before collecting measurements.

c) Place the digital level on the floor of the wind tunnel test section and record the reading to ensure proper alignment

d) Insert the Pitot-static tube into the wind tunnel and connect it to the Setra pressure transducer.

e) Adjust the wind tunnel speed until the LabView program reads a velocity of 30 ± 0.5 m/s.

f) Rotate the Pitot-static tube clockwise in 2 degree increments until a sudden drop in dynamics pressure is noted. Record both the dynamic pressure and total pressure for each angle. Repeat the process counterclockwise.

g) Adjust the Pitot-static tube angle until the total pressure reading reaches its maximum.

h) Adjust the wind tunnel speed to 2 m/s. Record the dynamic pressure and velocity from the Pitot-static tube and the static pressure taps on the wind tunnel (while the other pressure port is open). Repeat the measurements at velocities of 5, 10, 15, 20, 25, 30, and 35 m/s.

i) Adjust the wind tunnel speed to 30 m/s. Replace the Pitot-static tube with the yaw probe in the "erect" position. Rotate the yaw probe clockwise in 1 degree increments up to +10 degree. Record the yaw pressure difference, Δp_{yaw}. Repeat the process counterclockwise.

j) Repeat step (i) with the yaw probe in the "inverted" position.

k) Replace the yaw probe with the Pitot-static tube and adjust the wind tunnel speed to 30 m/s. Adjust the Pitot-static tube until it touches the near wall of the test section.

l) Adjust the length of the pitot-static tube in 1 mm increments for the first 2 cm. Record the velocity and transverse distance. After traversing 2 cm, move the pitot-static tube in 4-cm intervals until it is 2 cm away from the far wall.

m) Turn off the wind tunnel. Record the approximate downstream distance and measure the height and width of the test section.

Results:

(1).

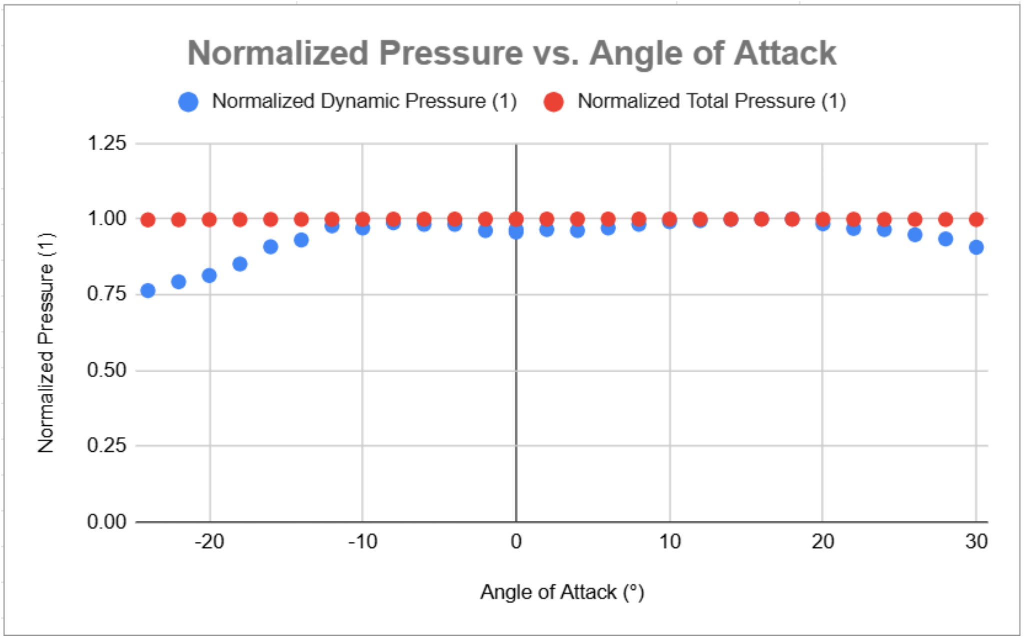

Figure 2: The plot shows how normalized dynamic pressure and normalized total pressure vary with different angle of attack

(2).

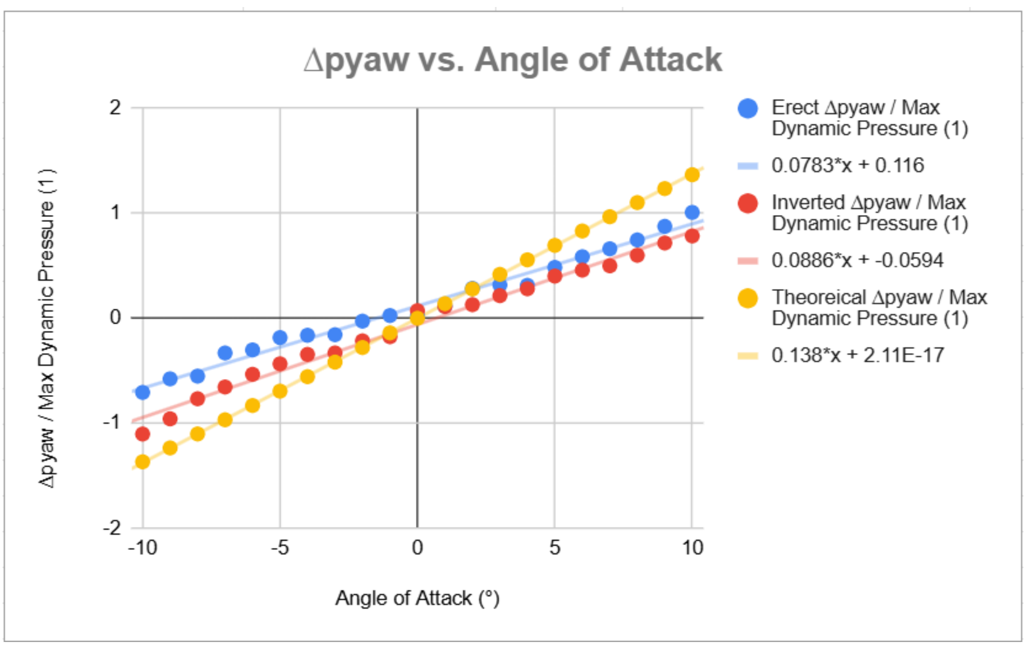

Figure 3: The plot shows the trend of Δpyaw variance with angle of attack. The erect Δpyaw / max dynamic pressure, inverted one and theoretical one follows a similar trend.

(3).

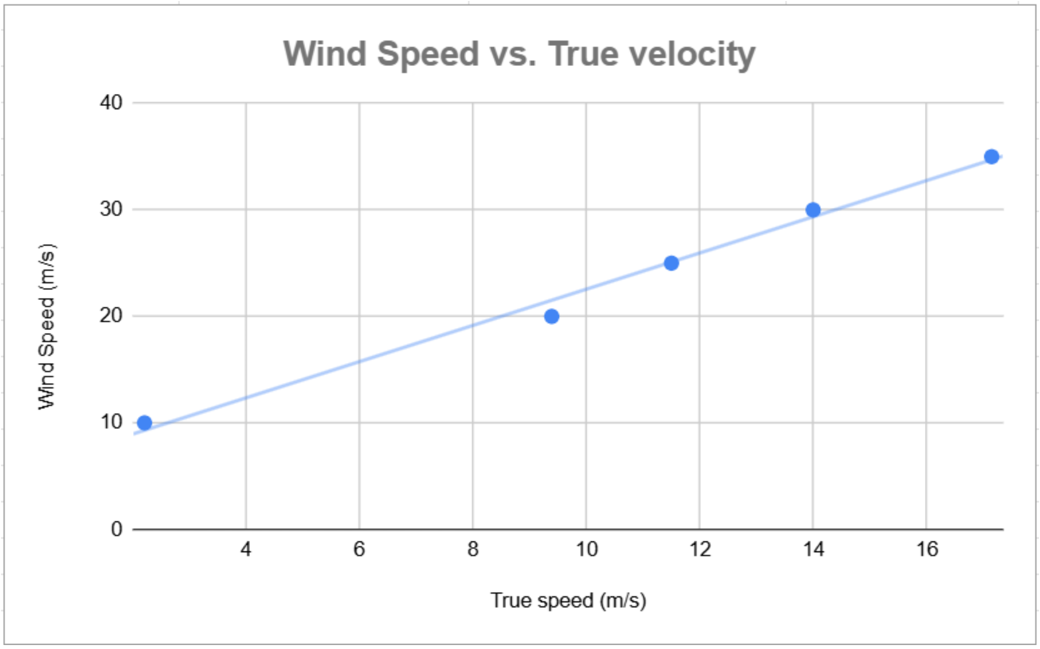

Figure 4: The plot shows the relationship between true velocity calculated from the measured pressure and the wind speed

(4).

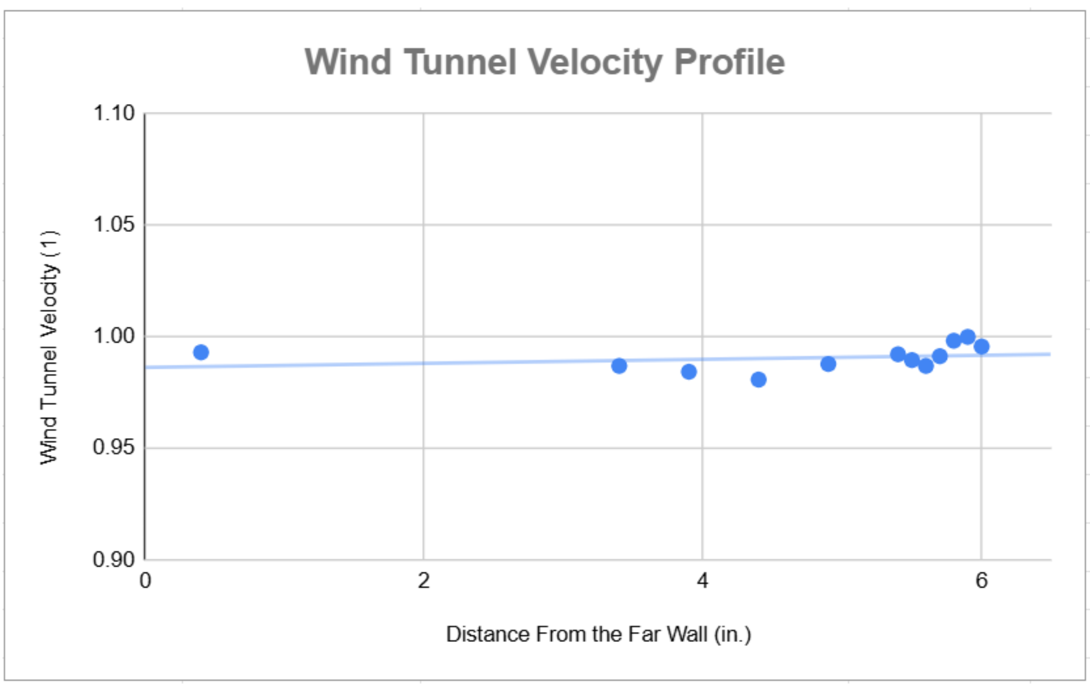

Figure 5: The plot shows that the relationship between wind tunnel velocity and the increasing distance from the far wall

(5).

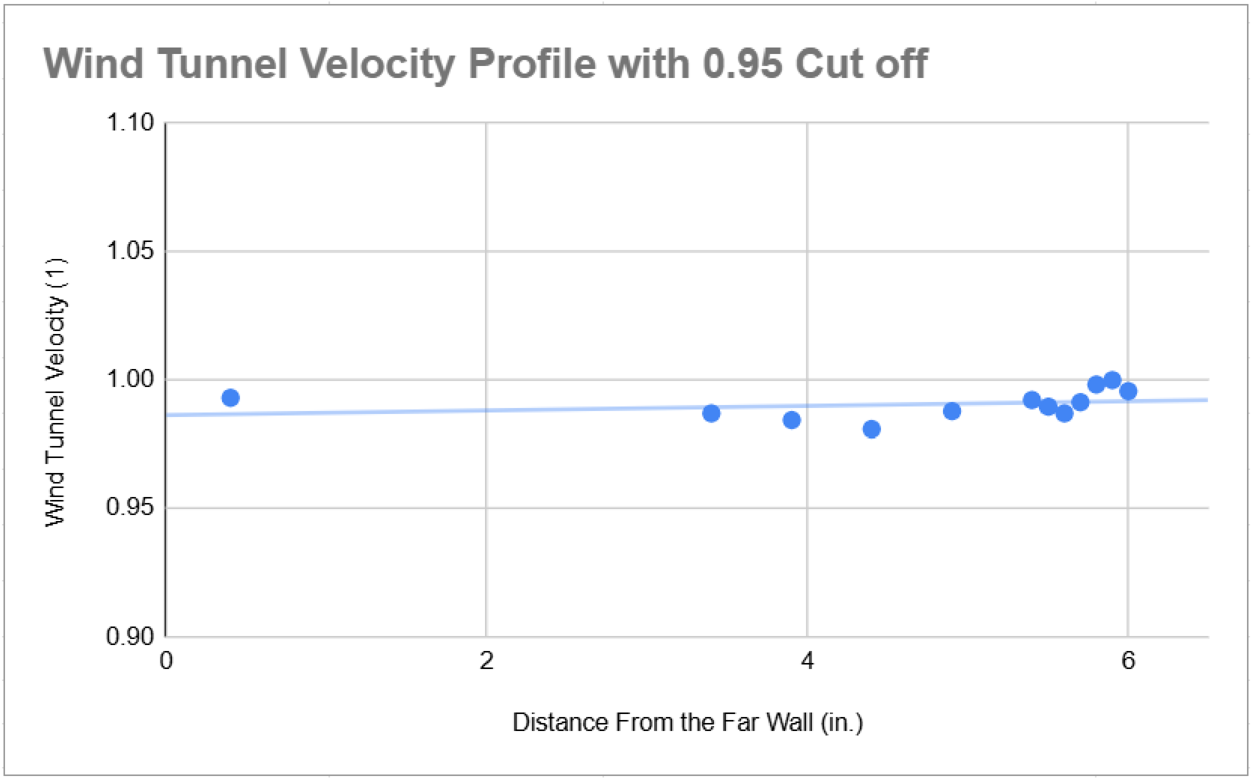

Figure 6: The plot shows the relationship between wind tunnel velocity profile with 0.95 cut off and the distance from the far wall. Basically, there is no significant difference from the original one.

Discussion:

For Figure 1, the normalization of dynamic and total pressures was performed using the maximum dynamic pressure per the lab manual. Normalizing both by maximum dynamic pressure results in two flat lines: one on top for the total pressure and one at the bottom for the dynamic pressure. The total pressure remained a flat line as expected due to energy conservation. The flat line of dynamic pressure also results from the difference between total and dynamic pressure and the limited resolution of the figure. Our findings conclude that the velocity decreases with increasing angle, which reduces dynamics pressure.

In Figure 2, the yaw probe determined the alignment of the wind tunnel flow relative to the test section floor. Ideally, they should align. However, in real-life conditions, discrepancies occur in the experimental process. For example, the yaw probe records an angle value where $\Delta p_{yaw} = 0$, which indicates an alignment is met. On the erect position, the angle measured was -1.48° while the inverted position measured 0.67°. The misalignment would, therefore, be calculated as 0.81°; a minor error would still suggest a reliable analysis.

Figure 3 shows the trend of normalized yaw pressure difference (Δp_{yaw}/Max Dynamic Pressure) as a function of angle of attack (°), comparing erect, inverted, and theoretical conditions. The erect configuration increases from approximately -0.71 at -10° to 1.01 at 10°, while the inverted configuration follows a similar trend but slightly lower, ranging from -1.10 at -10° to 0.78 at 10°. This difference, especially at higher angles, likely arises from minor calibration inconsistencies or probe alignment differences that become more pronounced with the angle. The theoretical values, calculated at angles (β_1 vs. β_2), exhibit a steeper increase, representing idealized behavior without real-world factors like flow disturbances or instrument misalignments. At higher angles, theoretical values diverge more noticeably from measured values, potentially due to boundary layer effects or turbulence. Despite these slight deviations, particularly in the inverted setup, the alignment of trends across erect, inverted, and theoretical conditions suggests that the setup effectively captures flow angle variations, emphasizing the importance of calibration and precise probe alignment for improved accuracy.

Figure 4 depicts the velocity profile within the wind tunnel. The wind velocity will increase near the wall, indicating a turbulent flow. Our calculations for Reynolds number of 82,263 confirm our assumption of turbulent flow above the 4,000 threshold. As shown in Figure 5, the velocity begins at zero (the start of the wall) and quickly increases to its maximum - the turbulent boundary layer. These observations of turbulent flow effects were noted in higher angles of attack.

Questions:

1) Based on the yaw measurements in the "erect" and "inverted" positions, determine the misalignment or instrument error of the alignment block.

From Figure 2, the normalized yaw pressure difference in the "erect" position is:

Normalized, $$\Delta P_{yaw} = 0.0783 * \propto \ + 0.116 \qquad \text{(Equation 3)}$$

$$0 = 0.0783 * \propto \ + 0.116$$

"Erect" Angle of attack at zero Normalized,

$$\Delta P_{yaw} = -\frac{0.1160}{0.0783} = -1.48°$$

From Figure 2, the normalized yaw pressure difference in the "inverted" position is:

Normalized,

$$\Delta P_{yaw} = 0.0886 * \propto \ -0.0594$$

$$0 = 0.0886 * \propto \ -0.0594$$

where α is the Angle of Attack.

“Inverted” Angle of attack at zero Normalized,

$$\Delta P_{yaw} = \frac{0.0594}{0.0886} = 0.67°$$

“Erect” Angle of attack at zero Normalized Δpyaw and “Inverted” Angle of attack at zero Normalized Δpyaw are supposed to have the same magnitude, but they do not.

Misalignment of instrument = |-1.48| - |0.67| = 0.81°

2. Based on the Pitot tube measurements as a function of angle, determine the flow angle relative to the tunnel floor.

From Figure 1, dynamics pressure is maxed out at angle of attack of 16°, the angle of the flow is 16° relative to the tunnel floor.

3. Based on the yaw probe measurements, determine the angle of the flow relative to the tunnel floor.

The angle of the flow relative to the tunnel floor is

$$\frac{\text{Erect} \propto + \mathit{Inverted} \propto}{2} = \frac{1.48+0.67}{2} = 1.075° \qquad \text{(Equation 4)}$$

where α is the Angle of Attack.

4. Determine the maximum misalignment possible for the Pitot tube so that the velocity will be within 1% of the value indicated when the probe is aligned with the flow. Do you think that you can obtain the required alignment by “eye”, or do you need an alignment aid?

An alignment aid will be required to gather data more accurately, as the angle of misalignment and the observed change in velocity are both relatively minor. With a pitot maximum misalignment of approximately [-1.48°, 0.67°], the velocity can be absorbed within 1% by the intervening of the erect and inert yaw probe values. Because of this, as previously said, assistance will be needed, as the angle is narrow and "eye" alignment is not practical.

5. Determine the maximum difference between the velocity measured by means of the Pitot tube and the velocity using the static taps at the wind tunnel inlet. Determine the velocity range where the velocity measured using the static taps is within 1% of the corresponding velocity measured using the Pitot tube.

According to the percentage of the difference, the maximum difference (21.5%) occurs when the pitot tube speed is 1.903m/s. From the table below, all of the calculated differences are greater than 4%. Therefore, there is no velocity range where the velocity measured using static taps is within 1%.

Table 8: Speed from pitot tube and speed from static probe

Static Calibration		
Speed from pitot tube(m/s)	Speed from static probe(m/s)	|Static - Pitot|/Pitot (100%)
29.99	31.42	4.551241248
27.6	28.85	4.332755633
25.29	26.46	4.421768707
22.42	23.46	4.433077579
20.63	21.84	5.54029304
18.08	19.48	7.186858316
14.64	15.79	7.283090564
10.03	10.82	7.3012939
4.603	5.132	10.30787217
1.903	2.424	21.49339934

6. Explain any differences between the theoretically (i.e., potential flow) and experimentally determined Δpyaw vs angle of attack curves. (In future labs, you will use an uncertainty analysis to guide your answer, but for now, just give some qualitative reasons.)

The theoretical Δp_{yaw} vs. angle of attack curves assume ideal flow conditions, such as inviscid, incompressible flow with no disturbances, leading to a symmetrical response around an angle of attack of zero. On the other hand, the experimental data, even after adjusting for some equipment inaccuracies, has real-world factors like compressibility, turbulence, and boundary layer effects.

7. Based on the length from the nozzle exit/test section entrance to the measurement plane of the Pitot-static tube, calculate the Reynolds Number of the flow and state if the flow is laminar or turbulent?

$$Re = \frac{\rho V D}{\mu} = \frac{1.255*30.48*0.4}{18*10^{-5}} = 82263 \qquad \text{(Equation 5)}$$

Where ρ is the density of air, V is the flow velocity, D is the length from the test section entrance to the measurement plane, and μ is the viscosity of air.

The calculated Reynolds Number is 82263, which is greater than 4000 therefore, it is turbulent flow.

8. Based on the velocity profile near the wall (plotted for data reduction question 7), does the profile show a turbulent boundary layer or a laminar Boundary layer. Is this consistent with the Reynolds Number calculated in question 7?

The profile shows a turbulent boundary layer because velocity is already around the maximum value near the boundary layer. This is consistent with the Reynolds Number calculated in question 7 because the Reynold number = 82,263 > 4,000, which is the threshold for turbulent flow.

Summary:

This experiment's purpose was to determine the flow characteristics within the wind tunnel and evaluate the alignment of instruments relative to the airflow. Measurements focused on total pressure, dynamic pressure, and the angle of flow. The Pitot tube measures the pressure difference to determine velocity, while the yaw probe detects flow misalignment by sensing pressure differences at various angles.

From the results, the flow within the wind tunnel behaves predictably in terms of pressure changes and velocity as a function of angle. Discrepancies were observed between theoretical predictions and experimental results due to real-world factors such as turbulence and misalignments in the positioning of the probe. The experiment demonstrated the effectiveness of the Pitot tube measuring flow speeds but highlighted the sensitivity of yaw probe measurements to precise alignment. The data gathered in this lab concludes that flow measurements require careful calibration and alignment for accurate readings. Precision in instrument alignment is essential to improve the accuracy of each measurement while addressing the effects of turbulence.

References:

[1]. MAE 108 Laboratory Manual

Signature box

Kevin Naraki Kim Wong	
Triet Ho	
Josue Guerrero	
Devrajsinh Mayurdhvajsinh Zala	
Matthew Valencia	
Noah Palanjan	
Tristan Reyes	
Vanessa Abigail Renderos	
Yonghao Huo	
Xuanqi Zang	

Appendices:

Appendix 1: Sample computations

This section will include sample computations that were done to reduce the data down to the final results.

Figure 1 calculations:

$$\text{Normalized dynamic pressure} = \frac{\text{Dynamic pressure } \cancel{[Pa]}}{\text{Max dynamic pressure } \cancel{[Pa]}} \quad [1]$$

$$\text{Normalized total pressure} = \frac{\text{Total pressure } \cancel{[Pa]}}{\text{Max total pressure } \cancel{[Pa]}} \quad [1]$$

Figure 2 calculations:

$$\text{Normalized } \Delta P_{yaw} = \frac{\Delta P_{yaw} \ \cancel{[Pa]}}{\text{Max dynamic pressure } \cancel{[Pa]}} \quad [1]$$

$$\beta_1 = \text{Angle of attack} + 45°$$

$$\beta_2 = \text{Angle of attack} - 45°$$

$$\text{Theorical normalize pressure} = 1 - 4(\sin\beta)^2$$

$$\text{Theorical normalize } \Delta P_{yaw} = \Delta \text{ Theorical normalize pressure}$$

Figure 3 calculations:

$$\text{Dynamic pressure} = \frac{1}{2}\rho V^2 = \text{Total pressure} - \text{Static pressure} = \Delta P$$

$$\Rightarrow V = \sqrt{\frac{2\Delta P}{\rho}}$$

Figure 4 calculations:

$$P_{dynamic} = \text{Dynamic pressure} = \frac{1}{2}\rho V^2$$

$$\Rightarrow \quad V = \sqrt{\frac{2 P_{dynamic}}{\rho}}$$

$$\text{Normalized velocity} = \frac{V}{V_{max}}$$

Appendix 2: Experimental data

The following chart shows recorded data from the experiment.

Table 1: Dynamic pressure and total pressure difference(P0-Pa) from Setra pressure transducer (clockwise)

Angle(°)	Dynamic pressure (Pa)	Stagnation pressure (Pa)	pressure diff
0.00	555	103680	-35
2.00	560	103682	-33
4.00	558	103683	-32
6.00	563	103684	-31
8.00	570	103682	-33
10.00	575	103679	-36
12.00	577	103674	-41
14.00	579	103668	-47
16.00	580	103654	-61
18.00	580	103648	-67
20.00	571	103634	-81
22.00	562	103612	-103
24.00	560	103600	-115
26.00	550	103580	-135
28.00	542	103555	-160
30.00	526	103540	-175

Table 2: Dynamic pressure and total pressure difference(P0-Pa) from Setra pressure transducer (clockwise)

Angle(°)	Dynamic pressure (Pa)	Stagnation pressure (Pa)	pressure diff
0.00	560	103687	-28
-2.00	558	103687	-28
-4.00	570	103683	-32
-6.00	570	103684	-31
-8.00	573	103665	-50
-10.00	563	103647	-68
-12.00	567	103630	-85
-14.00	540	103591	-124
-16.00	527	103558	-157
-18.00	494	103515	-200
-20.00	472	103493	-222
-22.00	460	103458	-257
-24.00	443	103421	-294

Table 3: Dynamic pressure and velocity from the LabView Program for the velocities 5, 10, 15, 20, 25, 30, and 35 m/s

Wind Speed (m/s)	Dynamic Pressure (Pa)	Total Pressure (Pa)	Static Pressure (Pa)	True Velocity (m/s)
5	15.3125	14	9	2.857142857
10	61.25	54	51	2.213133341
15	137.8125	134	125	3.83325939
20	245	255	201	9.389529557
25	382.8125	385	304	11.49977817
30	551.25	545	425	13.99708424
35	750.3125	745	565	17.14285714
30	551.25	555	n/a	n/a

Table 4: Variance of Δpyaw (erect) with increasing angle of attack (clockwise)

Angle(°)	Δpyaw (erect)
0	14
1	67
2	165
3	184
4	182
5	281
6	340
7	384
8	433
9	508
10	585

Table 5: Variance of ∆pyaw (erect) with increasing angle of attack (counterclockwise)

Angle(°)	∆pyaw (erect)
-1	15
-2	-16
-3	-91
-4	-94
-5	-107
-6	-175
-7	-192
-8	-320
-9	-335
-10	-410

Table 6: Variance of Δpyaw (inverted) with increasing angle of attack (clockwise)

Angle(°)	Δpyaw (inverted)
0	42
1	65
2	75
3	125
4	163
5	233
6	266
7	290
8	348
9	416
10	455

Table 7: Variance of Δpyaw (inverted) with increasing angle of attack (counterclockwise)

Angle	Δpyaw (inverted)
-1	-102
-2	-125
-3	-192
-4	-200
-5	-252
-6	-310
-7	-380
-8	-445
-9	-556
-10	-640

Table 8: Speed from pitot tube and speed from static probe

Static Calibration		
Speed from pitot tube(m/s)	Speed from static probe(m/s)	|Static - Pitot|/Pitot (100%)
29.99	31.42	4.551241248
27.6	28.85	4.332755633
25.29	26.46	4.421768707
22.42	23.46	4.433077579
20.63	21.84	5.54029304
18.08	19.48	7.186858316
14.64	15.79	7.283090564
10.03	10.82	7.3012939
4.603	5.132	10.30787217
1.903	2.424	21.49339934