CE 3105 Laboratory Report

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CE 3105 Fluid Mechanics Laboratory

Lab X

Calibration of a Pitot Tube Using a Wind Tunnel

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1 Calibration of a Pitot Tube Using a Wind Tunnel

Objective: The objective of this experiment is to calibrate a Pitot tube by measuring the dynamic pressure in a wind tunnel at varying airspeeds. The experiment will compare the velocity determined by the Pitot tube to the known airspeed from the wind tunnel and provide a calibration curve for the Pitot tube.[1]

2 Background/Theory:

A Pitot tube measures the velocity of a fluid (in this case, air) by comparing the total pressure at the stagnation point with the static pressure in the flow. The difference between these pressures, known as the dynamic pressure, is used to calculate the airspeed using Bernoulli's equation:

$$V = \sqrt{2 \times \frac{\Delta P}{\rho}} \tag{1}$$

where:

V is the airspeed (m/s),
ΔP is the difference between total and static pressures (Pa),
ρ is the air density (kg/m^3).

The purpose of this experiment is to calibrate the Pitot tube by comparing the measured airspeed (using the Pitot tube and Bernoulli's equation) to the actual airspeed set by the wind tunnel.

[1] This example provides a generic outline. Adapt your report to reflect the specific equipment and procedures available in your lab. Pay careful attention to environmental conditions as they significantly affect fluid density and, consequently, your results. Some laboratory experiments will have substantially more complex data collection steps.

3 Materials and Equipment:

- Pitot tube
- Wind tunnel (with variable airspeed control)
- Differential pressure transducer
- Data acquisition system (DAQ) connected to pressure transducer
- Barometer (to measure atmospheric pressure)
- Thermometer (to measure ambient air temperature)
- Calculator or software for data analysis
- Safety goggles

4 Experimental Setup:

1. Wind Tunnel Setup:

   Securely mount the Pitot tube in the test section of the wind tunnel, ensuring that the tube's tip is aligned with the airflow direction. The Pitot tube should be positioned at the center of the airflow to avoid boundary layer effects.

2. Pressure Measurement System:

   Connect the Pitot tube to the differential pressure transducer. Ensure that the total pressure tap (stagnation pressure) is connected to the positive side of the transducer and the static pressure tap to the negative side.

3. Data Acquisition:

   Connect the pressure transducer to the data acquisition system (DAQ). Calibrate the DAQ system according to the manufacturer's specifications to ensure accurate pressure readings. The DAQ will record the pressure difference, ΔP, at various wind speeds.

4. Environmental Conditions:

   Measure the ambient air temperature and barometric pressure to calculate air density, ρ. Use the following equation to compute air density:

   $$\rho = \frac{P}{R \cdot T} \tag{2}$$

   where:

   - P is the atmospheric pressure (Pa),
   - R is the specific gas constant for dry air $(287\ \frac{J}{kg} \cdot K)$, and
   - T is the absolute temperature (K).

5 Procedure:

1. Start the Wind Tunnel:
   - Turn on the wind tunnel and set it to the lowest airspeed (e.g., 5 m/s).
   - Record the differential pressure, ΔP, using the DAQ system.
   - Note the wind tunnel's airspeed from its control system as the reference velocity.
2. Increase the Wind Speed:
   - Gradually increase the airspeed of the wind tunnel in increments (e.g., 5 m/s increments) up to the maximum speed of the wind tunnel.
   - For each speed increment, record the differential pressure, ΔP, from the DAQ system.
3. Repeat Measurements:
   - At each airspeed, take at least three readings of ΔP to ensure consistency and accuracy. Compute the average ΔP for each airspeed.
4. Shutdown:
   - After collecting data for all airspeeds, shut down the wind tunnel and disconnect the Pitot tube from the system.

6 Data Collection:

Collect ΔP at 5 m/s speed increments to populate a data table similar to Table 1 below. [2]

Table 1: Wind Tunnel Settings and Pitot Tube Pressure Drop

Wind Tunnel Airspeed (m/s)	Measured ΔP (Pa)	Calculated Airspeed (m/s)
5	15	4.87
10	60	9.75
15	135	14.61
20	240	19.48
25	375	24.35

[2] Your data should be for every measurement, so there will be at least 3 measurements per windspeed. Perfom the indicated avaerging in the data analysis section of the report!

7 Data Analysis:

1. Calculate the Airspeed: Use the measured ΔP values and the air density, ρ, to compute the airspeed using Bernoulli's equation:

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

   Example calculation: For $\Delta P = 15\ Pa$, assuming $\rho = 1.225\ kg/m^3$:

   $V = \sqrt{2 \times \frac{\Delta P}{\rho}} V = \sqrt{2} \times \sqrt{\frac{15}{1.225}} = 4.87\ m/s$

8 Results

```
Enter b0 value 0
Enter b1 value 1.27
Enter b2 value 0.5
```

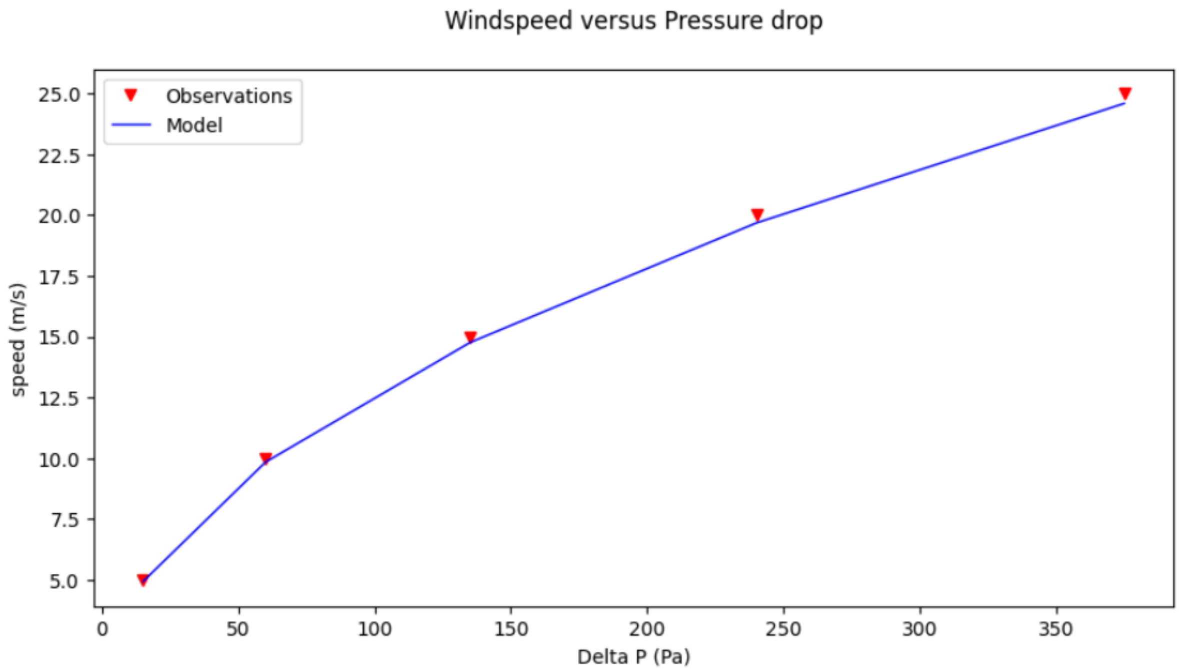

Figure 1: Measured airspeed vs. Pressure Drop. Markers are observations, line is fitted model (calculated airspeed using above equations).

The model used is[3]

$$V_{mod} = 0.0 + 1.27 \times (\Delta P)^{0.5} \tag{3}$$

[3] This model is identical to the Bernoulli equation representation.

1. Compare to Reference Velocity: Compare the calculated airspeed from the Pitot tube with the wind tunnel's reference airspeed. Plot a calibration curve of measured airspeed vs. reference airspeed.

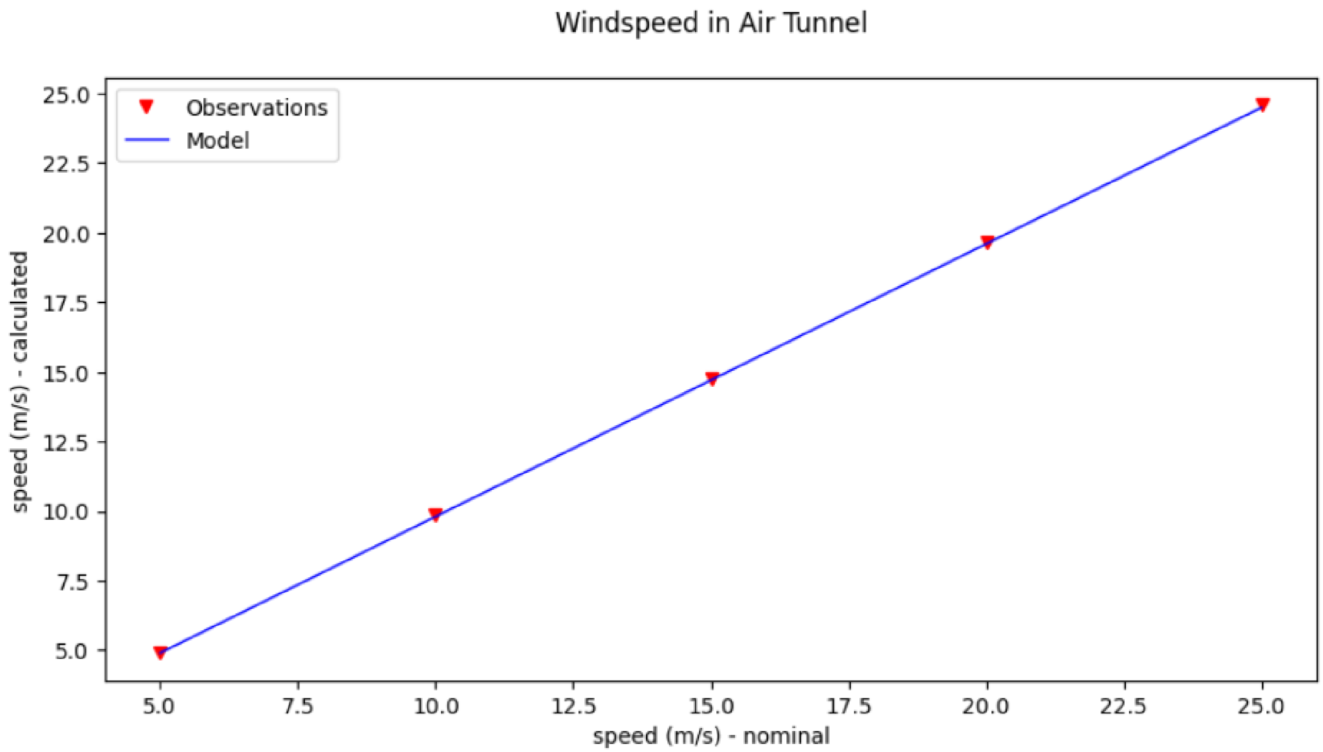

Figure 2: Reference airspeed vs. Pitot airspeed. Markers are observations, line is calibration curve.

The model used is

$$V_{pitot} = 0.0 + 0.98 \times (V_{nominal}) \tag{4}$$

2. Calibration Curve: Use the data to create a plot (e.g., in Excel or Python) with the reference airspeed on the x-axis and the calculated airspeed on the y-axis. Ideally, the points should lie on the 1:1 line, but any deviations will indicate a correction factor for the Pitot tube calibration. Figure 2 is a plot of nominal windspeed and Pitot tube airspeed - the solid line is the calibration curve.

9 Interpretation & Engineering Judgment:

In this section, interpret your results:

- Compare the calculated airspeed values to the reference airspeeds from the wind tunnel.
- Discuss any discrepancies between the two measurements. Were they consistent? Did the Pitot tube require calibration?
- Discuss potential sources of error (e.g., alignment of the Pitot tube, calibration of the pressure transducer, or air density variations).

10 Conclusions:

Bullet list of the 2–4 takeaways that answer the objective(s). Include recommended next steps.

- The calculated airspeed values are/are not consistent with the reference airspeeds from the wind tunnel.
- Discuss potential sources of error (e.g., alignment of the Pitot tube, calibration of the pressure transducer, or air density variations).
- Suggest improvements to the experimental setup or procedures that could reduce error in future experiments.

References

Holman, J.P., 2012. Experimental Methods for Engineers, 8th Ed. https://mech.at.ua/HolmanICS.pdf

Gupta, R.S. 2017. Hydrology and Hydraulic Systems 4th ed. Waveland Press, Inc. ISBN 978-1-4786-3091-3 888p.

Cleveland, T. G. 2024. Engineering Hydrology Instructor's Notes and Selected Readings to accompany CE-3354, Department of Civil, Environmental, and Construction Engineering, Whitacre College of Engineering. http://54.243.252.9/ce-3354-webroot/

11 Appendices

Scripts to Generate Plots

```
import matplotlib.pyplot as plt
def make2plot(listx1,listy1,listx2,listy2,strlablx,strlably,strtitle):
    mydata = plt.figure(figsize = (10,5)) # build a square drawing canvass from figure c
    plt.plot(listx1,listy1, c='red', marker='v',linewidth=0) # basic data plot
    plt.plot(listx2,listy2, c='blue',linewidth=1) # basic model plot
    plt.xlabel(strlablx)
    plt.ylabel(strlably)
    plt.legend(['Observations','Model'])# modify for argument insertion
    plt.title(strtitle)
    plt.show()
    return

def linear(b0,b1,x):
    '''
    linear data model, b0,b1 are parameters
    return y = b0+b1*x
    '''
    linear=b0+b1*x
    return(linear)

def quadratic(b0,b1,b2,x):
    '''
    quadratic data model, b0,b1 are parameters
    return y = b0+b1*x+b2*x^2
    '''
    quadratic=b0+b1*x+b2*x**2
    return(quadratic)

def powerlaw(b0,b1,b2,x):
    '''
    power law data model
    return y = b0 + b1*x**b2'''
    powerlaw=b0+b1*x**b2
    return(powerlaw)

def residue(list1,list2,list3):
    '''
```

```
    compute residues
    list3 = list1 - list2
    return residuals in list3
    '''
    if len(list1)!=len(list2) or len(list1)!=len(list3):
        print('Lists unequal length, undefined operations')
        return
    for i in range(len(list1)):
        list3[i]=list1[i]-list2[i]
    return(list3)



ytable = [5,10,15,20,25] # nominal windspeed
xtable = [15,60,135,240,375] #pressure drop in pitot tube


# Fit a data model - power-law model
b0=float(input('Enter b0 value'))
b1=float(input('Enter b1 value'))
b2=float(input('Enter b2 value'))
# build a data model
modelYYY = [] # empty list
for i in range(len(xtable)):
    modelYYY.append(powerlaw(b0,b1,b2,xtable[i]))
# Plotting results
make2plot(xtable,ytable,xtable,modelYYY,'Delta P (Pa)','speed (m/s)','Windspeed versus P

# build a data model
modelZZZ = [] # empty list
for i in range(len(ytable)):
    modelZZZ.append(linear(0,0.98,ytable[i])) # fitted velocity pitot vs velocity nomina
make2plot(ytable,modelYYY,ytable,modelZZZ,'speed (m/s) - nominal','speed (m/s) - calcula
```