

AerE 344: Undergraduate Aerodynamics and Propulsion Laboratory

Lab Instructions

Lab #02: Wind Tunnel Calibration

Purpose:

- To learn the fundamentals of wind tunnel technology.
- To learn how to operate a low-speed wind tunnel.
- To learn how to use Bernoulli's equation for the low-speed wind tunnel calibration.
- To learn how to use a pitot-static probe for low-speed flow velocity measurements.

Instructor:

Dr. Hui Hu
Department of Aerospace Engineering
Iowa State University
Office: Room 2251, Howe Hall
Tel: 515-294-0094
Email: huhui@iastate.edu

In using the wind tunnel to conduct tests, it is essential to know the dynamic pressure of the flow in the test section. It is not practical to insert a pitot-static tube into the tunnel flow when the model is present because: (1). it would interfere with the model; (2). it would not give a true reading because of the effect of the model on it; and (3). it is sometimes impossible to do so. One solution to this problem is to make pressure measurements at two convenient points in the wind tunnel and then relate these measurements to the dynamic pressure in the test section. The two points used should not interfere with the test in the wind tunnel. In this test, the two points are approximately at the points A and E shown in Fig.1

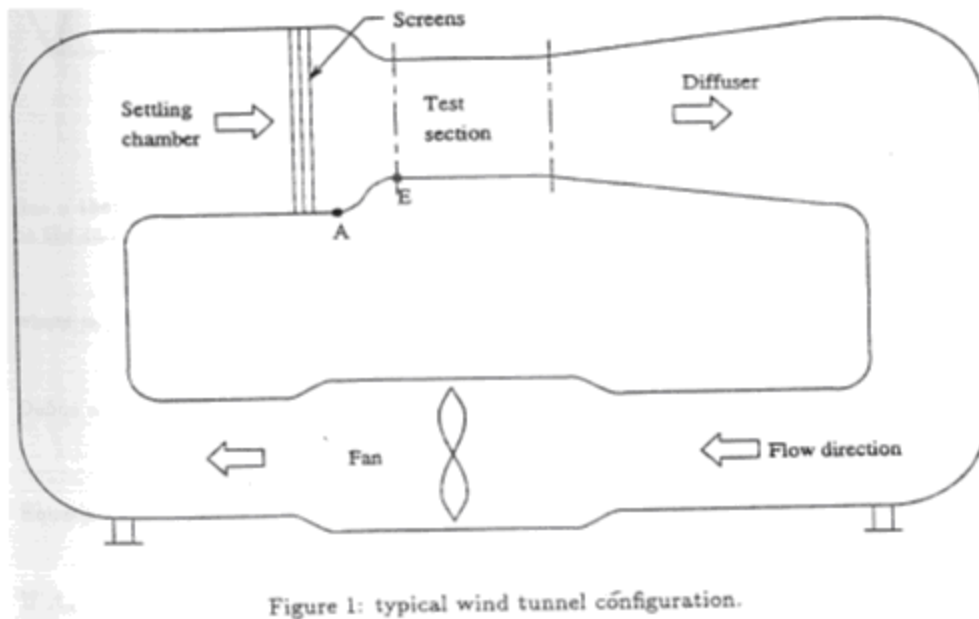


Figure 1: typical wind tunnel configuration.

The pressure difference between the points A and E, in theory, is linearly related to the dynamic pressure in the test section. The objective here is to obtain, by calibration, a relationship between the dynamic pressure in the test section and the pressure differential between the points A and E.

The required relationship can be obtained by applying Bernoulli's principle and mass conservation between different sections as shown in Fig.2. Under ideal conditions, the total pressure, P_0 , would be the same at the three stations and Bernoulli's equation could be written as

$$P_0 = p_A + q_A = p_E + q_E = p_T + q_T;$$

$$q = \frac{1}{2} \rho V^2 \text{ is called dynamic pressure.}$$

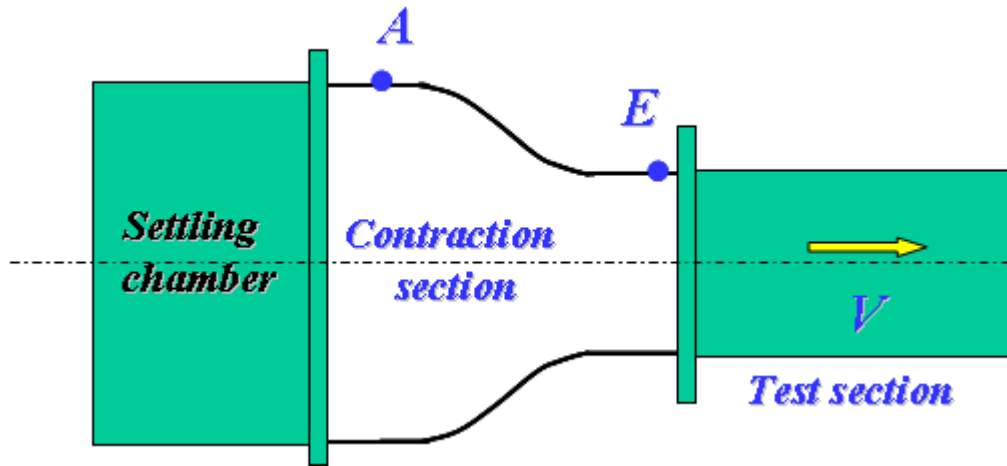


Fig. 2: Settling chamber and Test section of wind tunnel

But if there are losses from the boundary layers, screens, etc., then the total pressure will not be the same between the settling chamber and the entrance to the test section.

$$P_{0A} \neq P_{0E} \text{ in fact } P_{0A} > P_{0E}$$

$$\text{Where } P_{0A} = p_A + q_A = p_E + q_E + (P_{0A} - P_{0E}) \dots\dots\dots(1)$$

Define a total pressure loss coefficient by the relation

$$C_1 = \frac{P_{0A} - P_{0E}}{q_E}$$

Equation (1) can now be written as

$$p_A - p_E = q_E + C_1 q_E - q_A \dots\dots\dots(2)$$

If A_A , A_E and A_T are the areas of the different sections, then the conservation of mass principle can be written to relate the mass flow rates between the different sections as:

$$\rho_A V_A A_A = \rho_E V_E A_E = \rho_T V_T A_T$$

Low-speed flows can be treated as inviscid flows, i.e., $\rho_A = \rho_E = \rho_T$. The fluid density can be canceled from the above relation, therefore,

$$V_A A_A = V_E A_E = V_T A_T.$$

Squaring the above equation, and multiplying through by $\rho/2$ yields

$$\frac{1}{2} \rho_A V_A^2 A_A^2 = \frac{1}{2} \rho_E V_E^2 A_E^2 = \frac{1}{2} \rho_T V_T^2 A_T^2.$$

Letting $q_A = \frac{1}{2} \rho_A V_A^2$, $q_E = \frac{1}{2} \rho_E V_E^2$ and $q_T = \frac{1}{2} \rho_T V_T^2$ result in

$$q_A A_A^2 = q_E A_E^2 = q_T A_T^2.$$

From which $q_A = q_E \frac{A_E^2}{A_A^2}$ and $q_E = q_T \frac{A_T^2}{A_E^2}$

Define:

$$C_2 = \frac{A_E^2}{A_A^2} \quad \text{and} \quad C_3 = \frac{A_T^2}{A_E^2}$$

Hence :

$$q_A = C_2 q_E \dots\dots\dots(3)$$

$$q_E = C_3 q_T \dots\dots\dots(4)$$

Using (3) and (4) into equation (2) yields:

$$p_A - p_E = C_3 q_T + C_1 C_3 q_T - C_2 C_3 q_T = (1 + C_1 - C_2) C_3 q_T \quad (5)$$

Note: No assumptions have been made between E and T, i.e., $P_{0E} = P_{0T}$. Now, if $A_E = A_T$ then

$$C_3 = \frac{A_T^2}{A_E^2} = 1, \text{ and equation (5) reduces to } p_A - p_E = \Delta p = (1 + C_1 - C_2) q_T \text{ or } \Delta p = C q_T,$$

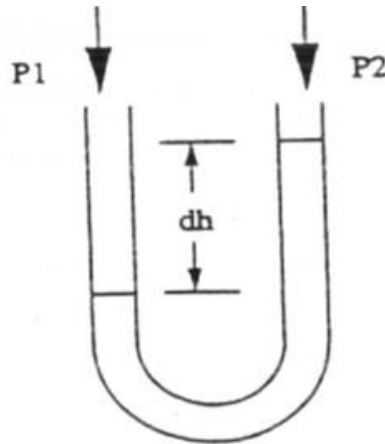
where C is determined by calibration. C_2 is determined by measuring areas. C_1 is calculated from $C_1 = C + C_2 - 1$.

$K = 1/C = q_T / \Delta p$ is defined as the wind tunnel calibration constant.

The wind tunnel can be run at various speeds, and the pressure differential $\Delta p = p_A - p_E$ can be read from static pressure ports located at the points A and E. The dynamic pressure in the test section, q_T , can be read from the pitot-static tube aligned with the centerline of the test section. Once the calibration constant K has been determined, then all that needs to be done in future tests is to measure the pressure differential ($\Delta p = p_A - p_E$) and then multiply this value by K to determine the dynamic pressure in the test section.

Calculating Pressure from Manometer Data

Always keep in mind that manometers only measure pressure differentials. Basic mechanism by which a manometer works is shown in the schematic below.

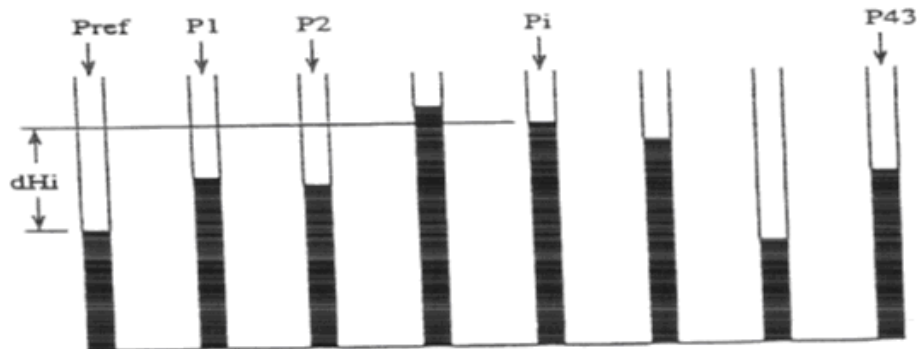


Here, there are two pressures exerted on both ends of the manometer tube. Using a simple vertical force balance, hydrostatic equation yields

$$p_1 = p_2 + \rho_f g \Delta h \dots\dots\dots(6)$$

Where ρ_f is the density of the fluid used in the manometer, not the air. Thus if p_2 is known, p_1 can be obtained. Or, frequently you need only to know the relative pressures, rather than absolute pressures ($p_1 - p_2$, where p_2 is some reference pressure, such as the pressure in the room, free stream, or stagnation pressure).

Now consider a bank of manometers as shown below.



This manometer configuration can be treated as nothing more than a number of individual manometers packed together. Though the fluid is shared among all the tubes, with a

sufficiently large reservoir, the interference between tubes can be neglected. For example, if you are interested in the pressure applied at the i -th tap, p_i , in the above figure, you can simply treat the reference tube (acted on by p_{ref}) and the i -th tube as a single manometer like the previous example.

Here the vertical height difference between the fluid levels of the reference and the i -th tubes are denoted by Δh_i , so always record the inclination angle. Using the hydrostatic equation,

$$p_{ref} = p_i + \rho_f g \Delta h_i \dots\dots\dots(7)$$

As you can see from Eq.7, if the fluid level of the i -th tube is higher than the reference level, the pressure, p_i , is lower than the reference pressure, p_{ref} .

Note that to obtain the absolute pressure at the i -th tube, you need the absolute reference pressure, p_{ref} . Since the pressure is typically ambient, or room pressure, one can use a barometer to obtain p_{ref} .

On the other hand, the gauge pressure, p_g , is the relative pressure with respect to the ambient pressure,

$$p_{g,i} = p_i - p_{ref} = p_i - p_{room} = -\rho_f g \Delta h_i$$

But keep in mind that the reference pressure can be anything. It is just that the room pressure is normally the easiest thing to measure, but not necessarily the easiest choice in a given aerodynamic analysis. It is therefore important to know what the reference pressure represents when using the hydrostatic equation.

$$p_i - p_{ref} = -\rho_f g \sin \theta_m [(h_i - h_{i0}) - (h_{ref} - h_{ref0})]$$

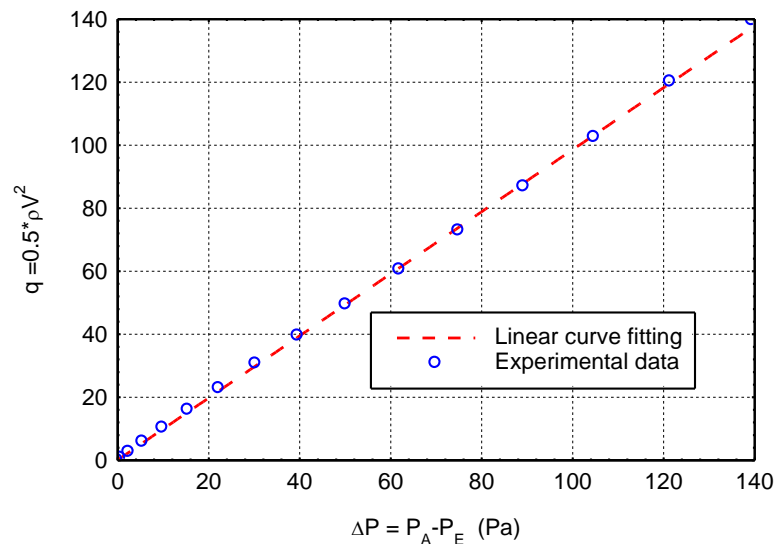
Data Sheet

#	Motor speed (Hz)	H _{ref}	H _A	H _E	H _{total}	H _{static}	T _{tunnel}
1	0						
2	5						
3	10						
4	15						
5	20						
6	25						
7	30						
8	35						
9	40						

2. Figures

(a). Please plot the relationship between the q_T and Δp .

1. Plot the actual points.
2. Plot the linear regression line of the data and find K. $K = q_T / \Delta p$.



(b). Please plot the flow velocity inside the test section of the wind tunnel as a function of the motor speed.

1. Plot the actual points.
2. Plot the linear regression line of the experimental data.
3. Find the equation of the linear regression.

Using the following equations to calculate P (pressure):

$$P_i - P_{ref} = -\rho_f g \sin \theta_m [(h_i - h_{i0}) - (h_{ref} - h_{ref0})]$$

p_{ref} : Atmospheric pressure