AerE 344 class notes

Lecture # 04  Pressure Measurement Techniques and Instrumentation

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Sources/ Further reading:
Tropea, Yarin, & Foss, “Springer Handbook of Experimental Fluid Mechanics,” Part B Ch 4
Measurement Techniques for Thermal-Fluids Studies

Thermal-Fluids measurement techniques

Intrusive techniques
- Pitot probe
- hotwire, hot film
- thermocouples
- etc ...

Non-intrusive techniques
- Laser Doppler Velocimetry (LDV)
- Planar Doppler Velocimetry (PDV)
- Particle Image Velocimetry (PIV)
- etc...

particle-based techniques
- Laser Induced Fluorescence (LIF)
- Molecular Tagging Velocimetry (MTV)
- Molecular Tagging Therometry (MTT)
- Pressure Sensitive Paint (PSP)
- Temperature Sensitive Paint (TSP)
- Quantum Dot Imaging
- etc ...

molecule-based techniques

Velocity, temperature, density (concentration), etc...
Pressure Measurements

- Pressure is defined as the force that acts normal to an area.
  - The pressure on the surface will increase if you increase the force or reduce the area
  - Pressure is a scalar
  - The net force on a fluid element due to pressure is zero except when there are pressure gradients
  - Pressure is isotropic

\[ P = \frac{F_n}{A} = \frac{dF_n}{dA} \]
Classical Pressure Measurements

$$P_{gauge} = P_{absolute} - P_{amb}$$

Manometer

Gage Pressure $\Delta P = P - P_0 = \rho gh$
Deadweight gauges:

- High accuracy
- Usually used for the calibration of other instruments
- Uses mass and length standards traceable to NIST
- Uncertainty is within 0.01–0.05% of the reading
Elastic-element gauges:

- Contain an elastic elements that deform under pressure and create linear or angular displacement.
- The displacement is either displayed on a dial by means of purely mechanical linkages or transformed to an electric signal that can be displayed or recorded.
- They usually used for monitoring supply pressure.

**Cross-sectional shape**
- Curved Bourdon tube
- Twisted Bourdon tube
Electrical Pressure Transducers

- Transducer: a device that translates a signal (usually a physical quantity) into a different kind of signal (usually electronic).
- These devices provide an output signal that can be linearly or nonlinearly dependent on the absolute pressure or a pressure difference.
- They can be categorized as:
  - Molecular transducers, where applied pressure or force produces a change (on the molecular level) of the electrical property of material.
    - Piezo-electric material such as quartz crystal: change in internal dipole moments of the molecules of the crystal when the pressure or force is applied.
  - Parametrical transducers, where the gross electrical parameter (resistance, inductance, capacitance) is altered by applied force.
    - Variable-capacitance transducer
Wall Pressure Measurements

- Make a small orifice (pressure tap) facing the flow.
  \[ \Delta p = P_m - P > 0 \]
- Machining small hole could be difficult
- \( d = 0.5\sim3.0\text{mm} \) in practice
- \( l/d = 5 \sim 15 \) is common used
- Potential effect on the wall roughness
- Streamline curvature/recirculation in cavity
- Effects of unsteady shock wave, and shock-boundary-layer interactions for transonic and supersonic flows
- Alternate solution: PSP method to be introduced later

\[ p_w = p_{mw} - \Pi \tau_w \]
\[ \Pi = \frac{\Delta p}{\tau_w} = f \left( \frac{d_s u_T}{v}, \frac{d_s}{D}, M, \frac{l_s}{d_s}, \frac{d_c}{d_s}, \epsilon \right) \]
For an unsteady flow, the dynamic response of a pressure acquisition system is a key issue!

- Dynamic response of the pressure transducers
- Dynamic response of the connection tubing – tradeoff between volume of tubing and flow resistance

Remote connection
- Dynamic response is low
- Spatial resolution is high

Cavity mounting
- Dynamic response is good
- Spatial resolution is high

Flush mounting
- Dynamic response is high
- Spatial resolution is low
Pressure Measurements inside Flow Field

• Non-intrusive technique is unavailable for direct pressure measurements
  – Based on N-S equation to calculate pressure field using the measured (PIV) velocity field.
• Static probe: for static pressure measurements
• Pitot probe: for total pressure measurements
• Pitot-static probe: for static and total pressures measurements (velocity measurements)
• Multi-hole probe: velocity direction information
Pressure Sensitive Paint (PSP) technique

- Composition of Air: 78.08% N₂, 20.95% O₂, 0.93% Ar, 0.03% CO₂, 0.002% Ne, plus lesser amounts of Methane, Helium, Krypton, Hydrogen, Xenon.
- The pressure of air can be determined if the partial pressure of oxygen (i.e. oxygen concentration) can be measured.
- PSP works via Oxygen-quenched luminescence
- A typical pressure sensitive paint is comprised of two main parts: an oxygen sensitive fluorescent molecule and an oxygen permeable binder
Applications of PSP Technique

PSP measurement result

PSP combined with PIV
Applications of PSP Technique

Rotating PSP/TSP on 22” Fan Model

GRC 9’x15’LSWT

Rotating PSP/TSP

Temperature

Pressure

Boundary Layer Control Tests in the 1’X1’SWT

Methods using suction and blowing for boundary layer enhancement
PSP Technique for Low Speed Applications

PSP measurements of a 2002 Ford Thunderbird

\[ V_{_{\infty}} = 50 \text{ m/s} \]
AerE344 Lab #03: Pressure Sensor Calibration and Measurement Uncertainty Analysis

- **Task #1:** Pressure Sensor Calibration experiment
  - A pressure sensor – Setra pressure transducer with a range of +/- 5 inH2O
    - It has two pressure ports: one for total pressure and one for static (or reference) pressure.
  - A computer data acquisition system to measure the output voltage from the manometer.
  - A manometer of known accuracy
    - Mensor Digital Pressure Gage, Model 2101, Range of +/- 10 inH2O
  - A plenum and a hand pump to pressurize it.
  - Tubing to connect pressure sensors and plenum

- **Lab output:**
  - Calibration curve
  - Repeatability of your results
  - Uncertainty of your measurements
Calibration Curve

\[ y = a + bx \]

Max dev: 30.4, \( r^2 = 0.998 \)

\( a = 13.2, \ b = 240 \)

Voltage (V)
Pressure (Pa)

Experimental data
curve fitting
AerE344 Lab #03: Pressure Sensor Calibration and Measurement Uncertainty Analysis

- Task #2: velocity profile measurements of a Wind tunnel
  - A Setra manometer to be used with a Pitot-static probe.
  - A Pitot-static probe mounted to a traverse for measuring velocity profiles in the wind tunnel.
  - A thermometer and barometer for observing ambient lab conditions (for calculating atmospheric density).
  - A computer with a data acquisition system capable of measuring the voltage from your pressure transducer.

- Lab Output
  - Velocity profiles across the wind tunnel test section.
  - FORMAL LAB REPORT (see website for details)
  - Word and LaTeX templates: http://arc.aiaa.org/page/authorresources

\[ p_0 = p_{stat} + \frac{1}{2} \rho V^2, \text{ (Bernoulli)} \]
\[ V = \sqrt{\frac{2(p_0 - p_{stat})}{\rho}} \]
Velocity profile in the Bill James wind Tunnel

![Graph showing velocity profile in the Bill James wind Tunnel. The x-axis represents position (mm) ranging from 0 to 0.9, and the y-axis represents velocity (m/s) ranging from 0 to 10. The graph shows a nearly constant velocity across the range of positions.]