AOE 3054
Measuring Velocity and Pressure in Fluid Flows

• Relevant to experiments 3 and 7, senior lab
• See Barlow et al., “Low Speed Wind Tunnel Testing” for more info
AOE 3054 - Class 10
Measuring Velocity and Pressure in Fluid Flows

• Why?
• What characteristics should measurement devices have?
• Pressure measurement techniques
  – Transducers (Manometer, diaphragm, piezo-electric)
  – Probes (Tap, standard, other devices)
• Velocity measurement techniques
  – Pitot-static probe
  – Hot-wire anemometry
  – Laser Doppler anemometry
Why Measure Pressure or Velocity?

- to understand the flow (to enable prediction)
- to evaluate the performance of a device
- to evaluate the likely effects of the flow
- to obtain other information (e.g. lift, drag)

= flow problem diagnosis and resolution

What Characteristics Should Measurement Devices Have?

- e.g. velocity measurement in a turbulent flow of 40m/s with scales as small as 1mm = dynamic response of 40kHz needed
Flows can be dynamic...
Pressure measurement - *Transducers*

A. Manometer

- Inclined manometer
- Multi-tube manometer

\[ p_2 \quad h \quad p_1 \]

\[ p_{\text{atm}} \quad p_1 \quad p_2 \quad p_3 \ldots \]
Pressure measurement - *Transducers*

B. Piezo-electric, Piezo-resistive

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- 
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![Piezo-electric transducers](image)

Crystal

\[ p_1 \rightarrow p_2 \]

Charge Amplifier or Bridge Circuit and Amp

\[ V_{\text{out}} \]

C. Diaphragm Type

- Measures - \( p_2 - p_1 \propto d \)
  
  Transducer is described as *Differential*, if \( p_2 \) comes from flow
  
  *Absolute*, if \( p_2 = 0 \) (vacuum), *Gage*, if \( p_2 = p_{\text{atm}} \),
  
  *Reference*, if \( p_2 = \) some reference pressure

- Accuracy/limitations/response - Depends on technique
  
  used to sense diaphragm deflection (see next slide)
C. Diaphragm Type

Methods for sensing diaphragm deflection

1. LVDT
   - Accuracy/limitations –
   - Dynamic response –

   Iron core slides in and out of transformer changing coupling between coils and therefore output AC voltage

   Ametec AM747X LVDT transducer
   Ranges from 30 to 6000psig

   Honeywell A-5 4-arm strain gage transducer. Ranges from 0.5 to 30000psia

2. Strain gage
   - Accuracy/limitations -
   - Dynamic response -

   Strain gages wired as arms of Wheatstone-bridge circuit sense deflection
C. Diaphragm Type

Methods for sensing diaphragm deflection

3. Capacitance (microphone)
   - Accuracy/limitations - Diff. in capacitance between diaphragm and two sides varies with deflection
   - Dynamic response -

http://www.setra.com/

Setra Model 239
Ranges 0.15" H₂O to 10psid
No dynamic response

Bruel and Kjaer Model 4938
0.25" diameter mike
Dynamic response from 4Hz to 70kHz
Pressure measurement - *Probes*

A. Pressure Tap / Flush mount

- Tube to transducer (poor response)
- Microphone: small cavity = good response
- Flush ‘Kulite’ piezo: good response
Example

Instrumented Blade

- NACA 0012, 2’ chord, 6’ span
- 96 Sennheiser KE 4-211-2 microphones
- Signal conditioning for each microphone (operating circuitry, signal amplifiers) inside blade to minimize interference. 64-channel, 16-bit data acquisition at 56kHz
- Chordwise resolution - 1%c near leading edge
- Spanwise spacing - 1%c to 96%c
Pressure measurement - Probes

B. The Static Probe
- Measures -
- Accuracy -
- Dynamic response -

to transducer

C. Other Devices
Velocity measurement

The Pitot-Static Probe

- Measures -

- Accuracy/Limitations -
  -
  -
  -

- Dynamic response -

\[ U \]
Velocity measurement

The Pitot-Static Probe

Pitot static misalignment errors
Example

F-15B/Flight Test Fixture: an aerodynamics and fluid dynamics research test bed at NASA Dryden Flight Research Center (Edwards, California).

Rake of Pitot probes for measuring velocity at different heights in a/c boundary layer
Velocity measurement

The Yaw Probe

- Typically one central hole and 4 or 6 surrounding on a conical or hemispherical probe tip.
- Each hole connected to a separate transducer.
- Requires extensive calibration varying independently all 3 velocity components.
- Diameter variable, typically 3mm

See [http://www.aeroprobe.com/products.html](http://www.aeroprobe.com/products.html) for real examples

- Measures -
- Accuracy/Limitations -
  -
  -
  -
  -
- Dynamic response -
Velocity measurement

Hot-Wire Anemometry - Probes

Basic Single-Sensor Probe
(measures $U$)

- Measures -

- Accuracy/Limitations –

Basic Two-Sensor Probe
(measures $U$ and $V$)

5 micron tungsten sensor wire (resistance proportional to temperature)

Hot-wire rake in the German-Dutch Wind Tunnel (DNW)
Velocity measurement

Hot-Wire Anemometry - Operation

Constant temperature operation  Op Amp feedback holds wire resistance constant (and thus temperature constant) – see the ‘golden rules’ in the Electronics Review class. Voltage required to do this increases with velocity according to

- Dynamic response -

Velocity measurement

*Laser Doppler Anemometer*