Measurement of air flow rates in ducts by velocity measurements: an overview

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Context

- Evaluation of air flow in duct by velocity measurements
  - Measurement of local velocity(ies)
  - Representative value of the mean velocity from the shape of the velocity profile
Measurement of local velocity(ies)

- **Pitot tube (Prandtl tube)**
  - Measurement of a differential pressure
  - Velocity range depends on pressure range
  - $V_{\text{min}} > \sim 3 \text{ m/s}$

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

- **Thermal anemometer**
  - Sensitive to pressure and temperature conditions
  - Fragile
  - $V_{\text{min}} > \sim 0.1-0.3 \text{ m/s}$
Measurement of local velocity(ies)

- **Vane anemometer**
  - Small size ($\varnothing \approx 16$ mm)
  - Start threshold $V_{\text{min}} > \sim 1$ m/s

Measurement of local velocity(ies) in ducts

- **Measurement in the duct**
  - On several diameters
  - At different positions
Position of the measurement points

- **ISO 3966** (circular & rectangular ducts), “reference method”
  - Turbulent flow
    - For any disturbances: 20D/5D (80D/20D)
  - Expected uncertainty: 2% flow rate

- **EN 12599**, **Pr EN 16211**, **NF X 10-113** (ISO 7145)

On site measurement

- **ISO 3966**
  - Time consuming method
  - Straight lengths not always available
  - Low uncertainty not always needed

**Question:** what would be the method uncertainty if

- Another method is used
- A lower number of local velocities is measured
- The distance from the disturbances is smaller
Circular ducts (Bonthoux et al.)

- Experimental conditions
  - DN 200 (Re \( \approx \) 200000)
  - 2 x 10 points + 1 point at the center
  - Different disturbances
    - At 1D, 4D, 10D, 45D

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Circular ducts (Bonthoux et al.)

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  - DN 200 (Re \( \approx \) 200000)
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Circular ducts (Bonthoux et al.)

Figure 2. Profile of velocity $U/U_d$ for an elbow (velocity axis covers a $U/U_d$ from 0.7 to 1.3).

- Maximum measured error (whatever the disturbance is)

Figure 4. $E$ as a function of the points scheme

Figure 3. $E$ as a function of $L/D$
RECTANGULAR DUCTS
(Caré et al.)

- Disturbances
  - 1 elbow
  - 2 coplanar elbows
  - 2 non coplanar elbows

- Rectangular ducts shape
  - Shape factor (Length/Width) < or > 4

Expected maximum method uncertainty
Circular duct

<table>
<thead>
<tr>
<th>Exploration scheme</th>
<th>Number of diameters</th>
<th>Expected method uncertainty (%)</th>
<th>L/D : Upstream distance from disturbances</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4</td>
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<tr>
<td>ISO 3966 [1]</td>
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<td>6</td>
<td>3</td>
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<td>7</td>
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<tr>
<td>EN 12599 [3]</td>
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<td>2</td>
<td>3</td>
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<td>1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Non standardised method</td>
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<td>8</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>
Expected maximum method uncertainty

Rectangular duct (Length/Width < 4)

<table>
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<tr>
<th>Exploration scheme</th>
<th>Number of traverses (points)</th>
<th>Expected method uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 3966 [1]</td>
<td>5 (25)</td>
<td>5  3  1</td>
</tr>
<tr>
<td></td>
<td>1 (5)</td>
<td>39 9 8</td>
</tr>
<tr>
<td>EN 12599 [3]</td>
<td>2 (6)</td>
<td>11 10 8</td>
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<tr>
<td></td>
<td>1 (3)</td>
<td>38 26 19</td>
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<tr>
<td>Non standardised method</td>
<td>2 (9)</td>
<td>14 16 10</td>
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<tr>
<td></td>
<td>1 (5)</td>
<td>62 25 17</td>
</tr>
</tbody>
</table>

- To achieve an acceptable measurement uncertainty
  - Circular duct: 5%
  - Rectangular duct: 10%

- It is necessary to
  - Choose a suitable method
  - Measure away from disturbances and/or Increase number of measurement points

- Time consuming
Circular ducts (Caillou et al.)

- One measurement in the middle of the cross-section
  - ISO 7145
  - Simple,
  - The result must be corrected with the “pipe factor” coefficient

![Diagram showing velocity distribution](U = U_c / 0.85)

- Velocity at
  - centre: U_c
  - flow: U_d

Pipe factor vs relative distance from an elbow

Pipe factor vs Reynolds number
Conclusion

- Evaluation of flow rate in duct by velocity profile
  - Compromise between Time & Method uncertainty
    - Circular & Rectangular ducts
  - Additional components of uncertainty
    - Instrument uncertainty
    - Knowledge of the inside duct section
    - Uncertainty of the positioning of the instrument inside the duct
    - Measurement procedure and expertise

Thank you for your attention

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