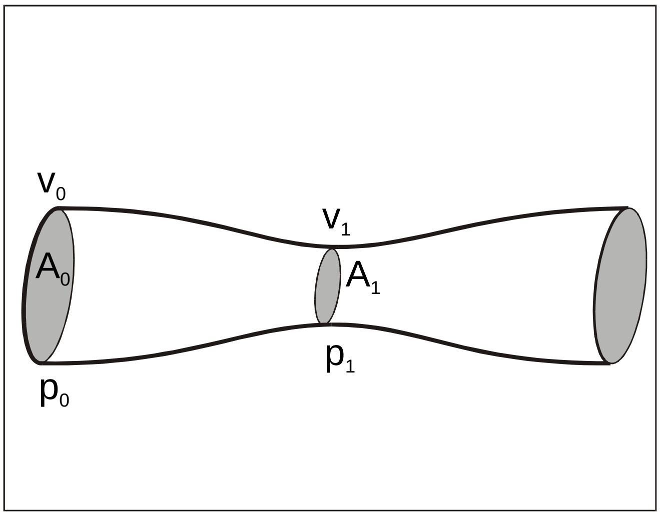
Verifying the Bernoulli equation – measuring with the precision manometer

Objects of the experiment

- To verify the total pressure remains constant
- To verify that the product of the cross-section and the square root of the dynamic pressure is constant
- To verify the Bernoulli equation

Fig. 1: Bernoulli equation schematically: cross sectional areas A_0 and A_1, flow velocity v_0 and v_1, static pressure p_0 and p_1



Principles

Bernoulli's law states the relationship between static pressure p and flow velocity v, whereby the following applies to a frictionless, horizontally flowing stream through a stationary flow between two points labeled with indices 0 and 1 (Fig. 1):

$$p_0 + \frac{\rho}{2} v_0^2 = p_1 + \frac{\rho}{2} v_1^2 \qquad \text{(I)}$$

p_0, p_1: static pressure

v_0, v_1: flow rate

ρ: density of the flow medium

In particular, equation (I) states that the total pressure p_{tot} has the same value everywhere:

$$p_1 + \frac{\rho}{2} v_1^2 = p_{tot} = \text{const} \qquad \text{(II)}$$

In the experiment described here, air flows through a wind tunnel whose cross-section decreases progressively in the direction of flow. Due to the incompressibility of air (which can always be assumed at the given flow rates) the flow velocities v_0 and v_1 at two different locations in the wind tunnel with cross-sectional areas A_0 and A_1 are given by the continuity equation:

$$v_0 \, A_0 = v_1 \, A_1 \qquad \text{(continuity equation)} \qquad \text{(III)}$$

The Bernoulli's equation (II) allows to eliminate v_1 in equation (III). By rearranging we obtain:

$$\sqrt{\Delta p} \cdot A_1 = \sqrt{\frac{\rho}{2}} \cdot v_0 \cdot A_0 \qquad \text{(IV)}$$

with

$$\Delta p = p_{tot} - p_1 \qquad \text{(V)}$$

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Apparatus

1 Wind tunnel 373 12
1 Suction and pressure fan 373 04
1 Pressure head 373 13
1 Measurement trolley 373 075
1 Precision manometer 373 10
1 Leybold multiclamp 301 01

The dynamic pressure Δp is determined by measuring the pressure difference. The cross-sections are stated at the various measuring points in the wind tunnel.

Safety notes

Mind the safety notes in the instruction sheet of the suction and pressure fan.

Before removing the protective grid or the nozzle:

- pull out the mains plug
- wait for at least 30 seconds until the rotor comes to a complete stop.

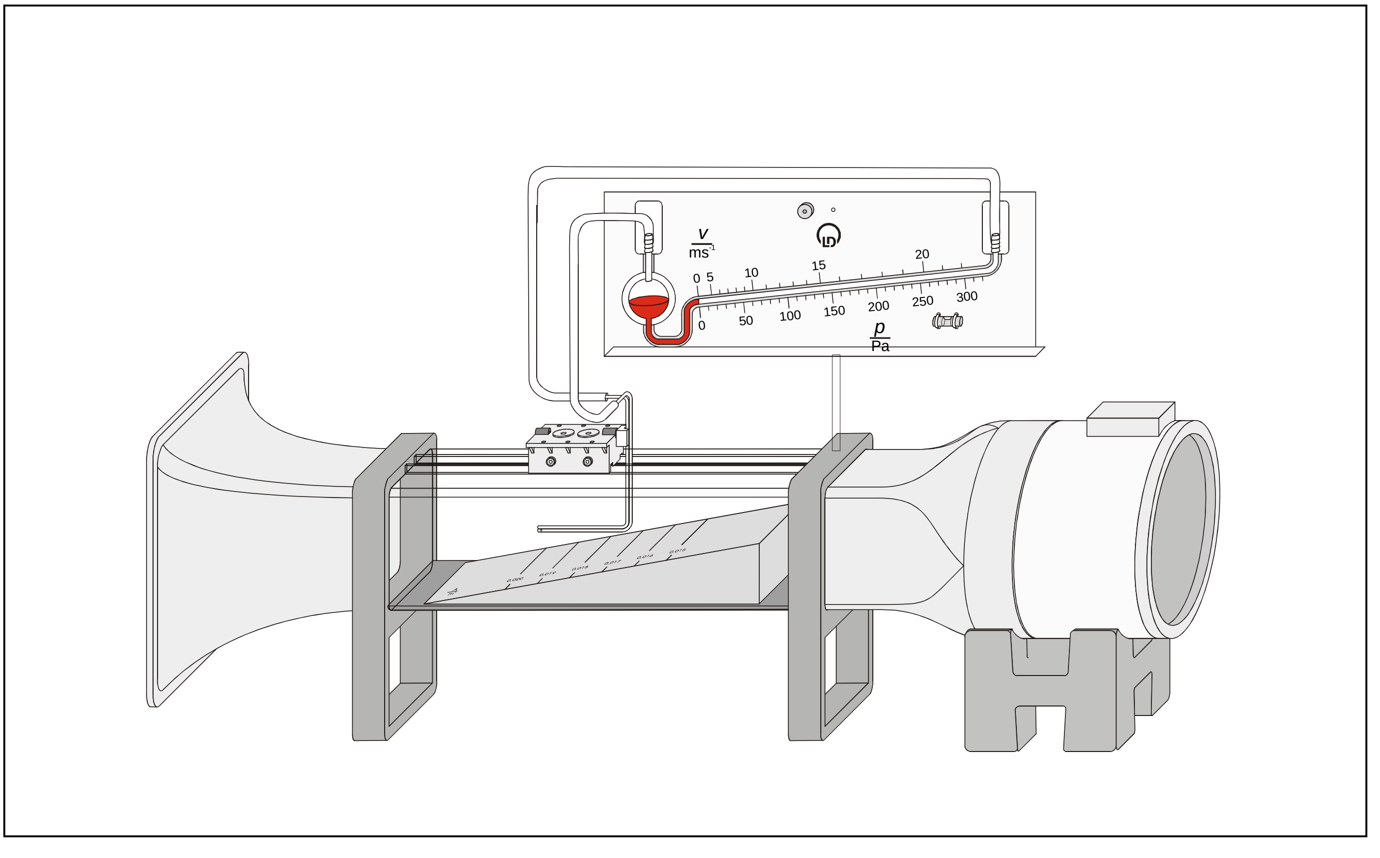
Mind the safety note in the instruction sheet of the precision manometer 373 10

Setup

Assemble the wind tunnel and the fan as shown in Fig 2. Insert in the fan into the outlet nozzle so that the air is drawn through the wind tunnel during the experiment. Ensure a clearance of approx. 1 m in front of the suction nozzle and behind the fan so that the air can be drawn into the wind tunnel without any turbulence.

- Mount the smoothing screen on the inlet.
- With the aid of the four screws secure the Bernoulli ramp underneath the plexiglass canopy so that the ramp height increases in the direction of flow.
- Mount the sealing strip (included in the equipment for the wind tunnel) on the sliding rails.
- Guide the pressure probe carefully bent section first, through the foam rubber seal of the sealing strip and secure the trolley.
- Push the probe down fully to the stop so that it reaches a position approx. 2 cm higher than the highest point of the ramp.
- Mount the precision manometer to the wind channel as shown in Fig. 2.
- Connect the total pressure probe by means of a hose to the nipple (left side) of the precision manometer.
- Connect the static pressure probe by means of a hose to the nipple (right side) of the precision manometer.

Fig. 2: Experimental setup with precision manometer schematically.



Carrying out the experiment

- Place the measurement trolley at with end of the pressure head at the position F.
- Read off the pressure difference from the precision manometer.
- Repeat the measurement for the positions "A" to "E".
- Repeat this measurement procedure several times and calculate the mean average.

Note: The experiment may also be performed for different speeds of the fan.

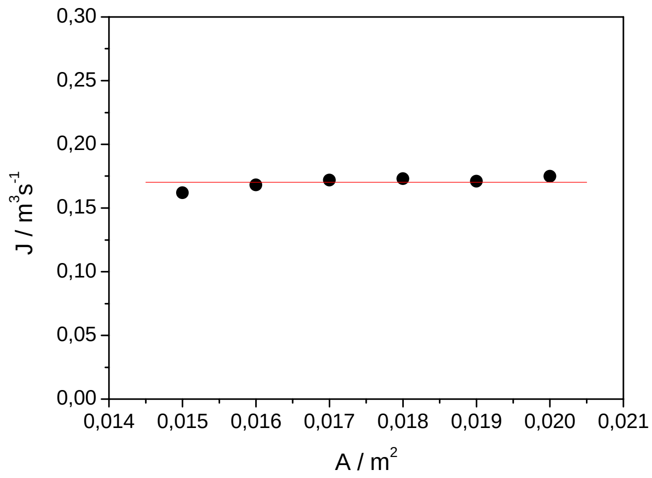


Fig. 3: Volume flow J as a function of the cross section A. The solid lines correspond to the mean average in accordance with continuity equation (III).

Measuring example

Table 1: Pressure difference Δp (mean average over 3 measurement series) at the positions A to F.

position	$\frac{A}{m^2}$	$\frac{\Delta p}{Pa}$
A	0.020	47
B	0.019	51
C	0.018	57
D	0.017	63
E	0.016	68
F	0.015	75

Evaluation and results

Table 2: Flow velocity v and volume flow J evaluated from the pressure difference Δp of table 1 at the positions A to F.

position	$\frac{v}{m/s}$	$\frac{J}{m^3/s}$
A	8.74	0.175
B	9.02	0.171
C	9.63	0.173
D	10.12	0.172
E	10.52	0.168
F	11.04	0.162

The flow velocity $v = \sqrt{\frac{2\cdot\Delta p}{\rho}}$ increases with decreasing cross-section A.

The volume flow $J = v\cdot A$ is constant over the entire decreasing cross-sectional area (Fig. 3). Thus the predictions based on the Bernoulli's equation (I) are verified quantitatively.

Supplementary information

Additionally, the total pressure can be measured along the progressively decreasing cross section. Therefore the hose is connected to the total pressure head only (see instruction sheet of precision manometer 373 10).

The result of the measuring the total pressure is depicted in Fig. 4. The measurement verifies that the total pressure remains constant over the entire measurement section.

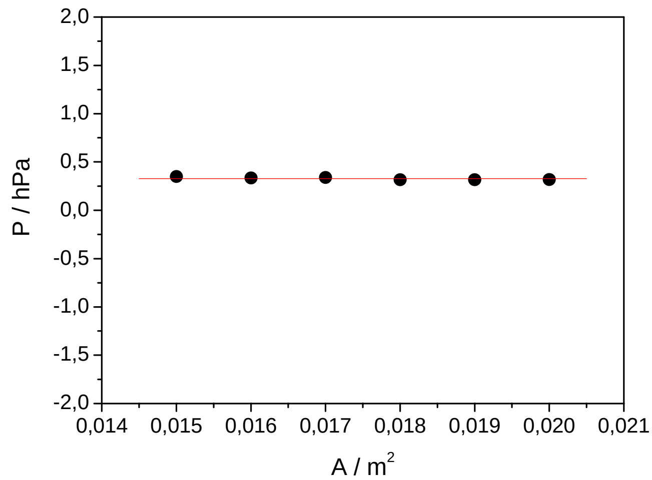


Fig. 4: Total pressure as function of the cross section A. The solid line corresponds to the mean value.

Additionally the static pressure can be investigated. An example measurement is given in supplementary information of leaflet P1.8.7.4.