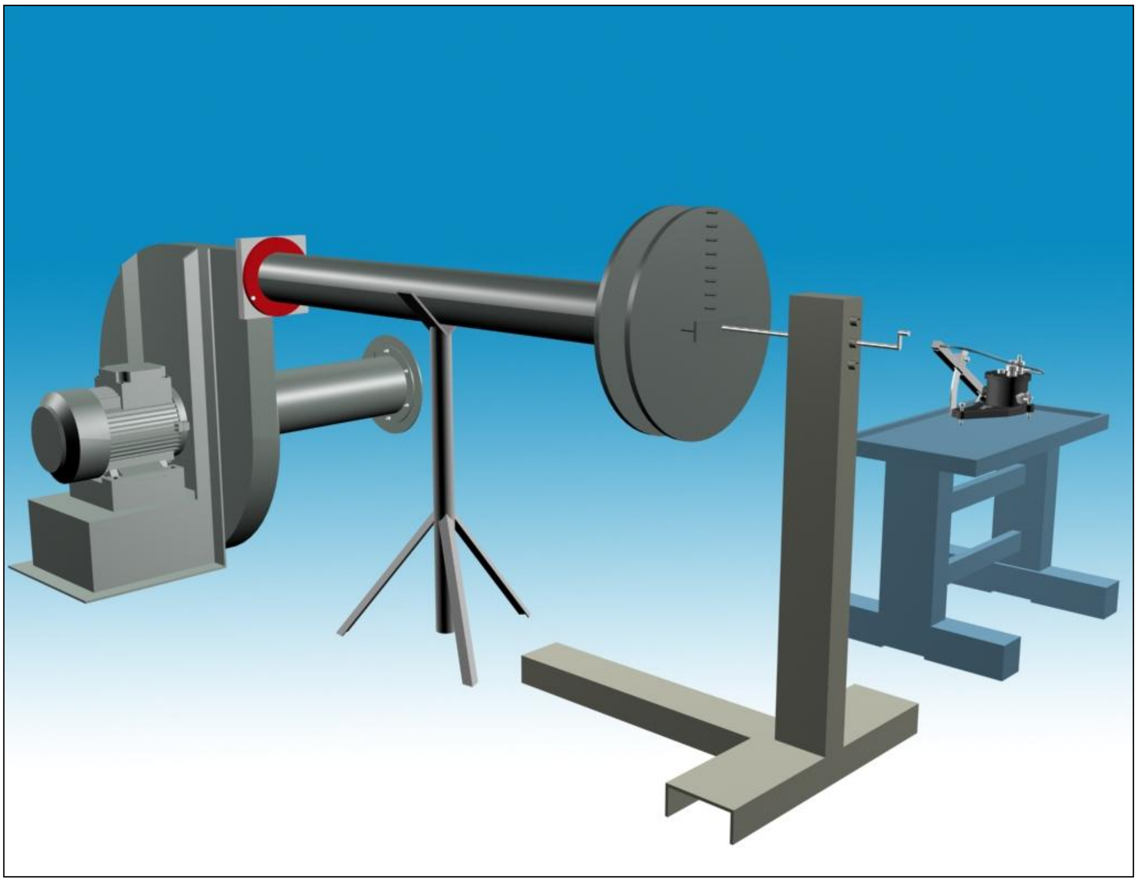


M13

MEASUREMENT OF SHEET DIFFUSER PROPERTIES

1. Theoretical background

In the Bernoulli-equation (if we do not consider the change of the force field, in frictionless and stationary cases):

$$p+\frac{\rho}{2}v^2=const.$$

The first term of the equation is static pressure, the second is dynamic pressure. Therefore the Bernoulli equation suggests that the dynamic pressure of a fluid flowing in a pipeline can be increased by decreasing the static pressure and that a maximal pressure can be obtained by decreasing the dynamic pressure to zero. This is the stagnation point pressure or draught pressure.

In real flows there are losses. While for the acceleration of the flow, i.e. increasing velocity at the expense of a pressure loss can be carried out in a confuser resulting in small losses, decreasing the velocity can be only be obtained with fairly large losses. There were and still are research projects on decreasing these losses as much as possible. In the case of pipelines, the simplest structure is a diffuser with which the velocity can be decreased and the pressure increased in the streamwise direction.

In the diffuser the fluid particles are flowing in the widening pipe connecting the A1 and A2 cross-sections (diffuser) in the direction of the A2 cross-section, where the flow velocity is lower and the static pressure is higher, i.e. they flow towards the pressure growth. The energy for this is covered by the kinetic energy. According to the Bernoulli-equation this decrease is equal to the pressure growth. In real fluids a part of the kinetic energy covers the losses and friction has the most significant effects near the pipe wall. The kinetic energy of the particles, here slowing down because of the wall shear stress, – especially by the suddenly widening diffuser- is not enough for the energy necessary for the pressure growth induced by the slowing down of the particles further from the wall. Therefore the particles near the wall are slowing down. They may stop or even flow back. In this case a separation zone develops next to the wall. The inner particles do not follow the widening shape of the pipe and separate from the wall. This phenomenon is called boundary layer separation, and the pressure loss induced is separation loss.
The separation loss can be explained as when the real flow cross-section is widening less than the diffuser geometry would suggest. In case of rapidly widening diffusers that is the main reason why the pressure growth is less than calculated by the Bernoulli-equation.
Streamwise widening cross-sections can also be obtained by draining the fluid to a radial channel bordered by two circular sheets. This structure is the sheet diffuser. This is one of the ways to form air-jets in ventilation systems.

The aim of the measurement:
In the laboratory measurements the efficiency of the sheet diffuser fixed at the end of the pipe in Figure 1 will be defined. The x distance between the plane of the outflow element and the sheet of diameter D_L influences the A_2 outflow cylindrical shell cross-section. During the measurement the diffuser efficiency must be measured as a function of the distance x, and the maximum efficiency must be found.

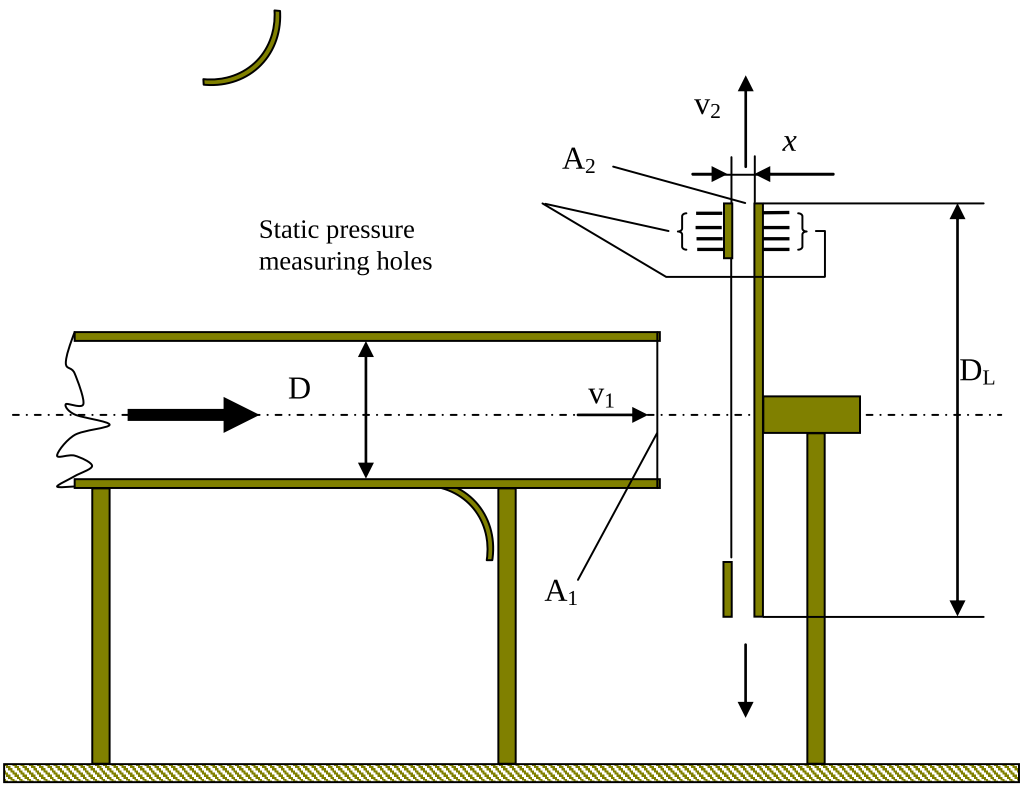
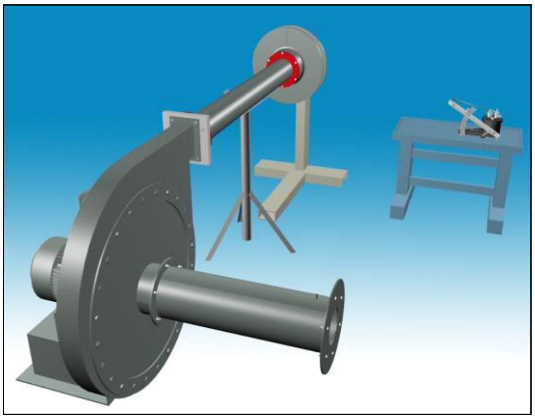
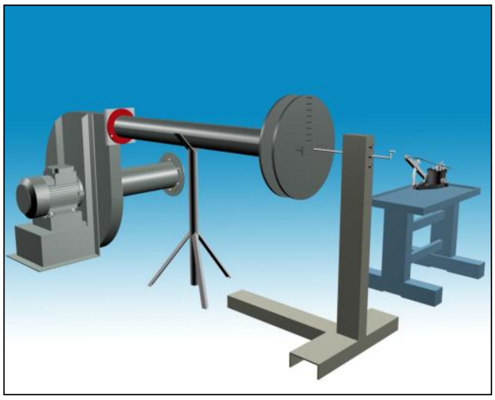


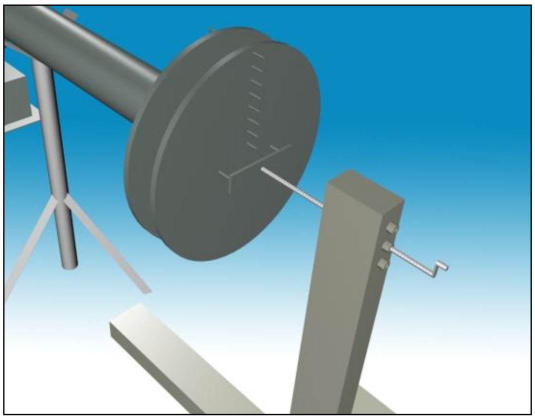
Figure 1: Sheet diffuser measurement facility

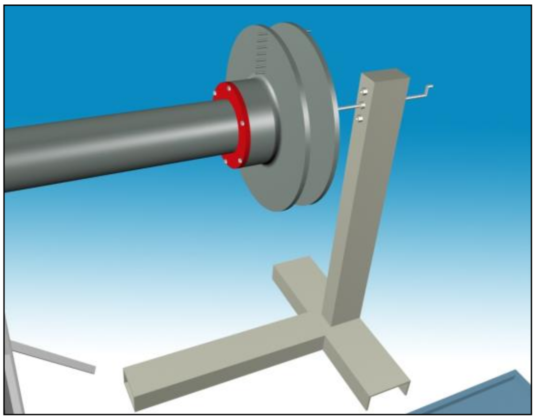
2. Description of the measurement facility

The sheet diffuser is connected to a pipeline located at the delivery side of a radial fan. At the suction side of the fan there is an inlet orifice to measure the volume flow rate. The v_1 and v_2 velocities can be defined by this with the help of the cross-sectional area.









3. Theory of the measurement

In the previous figures the flow takes place between cross-sections A_1 and A_2 in the diffuser. A_1 is the circular cross-section of the pipe, A_2 is a cylindrical shell characterized by a diameter D_L and distance x. The facility works as a diffuser if $A1<A2$. This can be adjusted after calculating x_{min} ($A_1=A_2$) in the beginning of the measurement. During the measurement the distance x must be changed from x_{min} (the rounded up integer value) by Δx=1mm to set-up 10 different A_2 cross-sectional sheet diffusers.
IMPORTANT! The x distance should be changed by Δx=1mm (or maximum 1.5 mm) otherwise with greater intervals the maximum efficiency will be difficult to define from the data.

In cross-sections A_1 and A_2 neither the pressure nor the velocity is constant (neither in space nor in time). Due to the temporal fluctuation occurring when reading the measurement devices, temporal averaging must be carried out. In case of the EMB-001 type digital pressure manometer, three averaging periods can be chosen (F/M/S, see the manometer's user manual).
In the following deductions the average pressures and velocities are presented.

How to define diffuser performance?

A diffuser efficiency will be defined, which compares the real pressure growth, $(p_2\text{-}p_1)_{real}$, to the pressure growth in an ideal case, which can be calculated from the Bernoulli-equation, $(p_2\text{-}p_1)_{id}$. This ratio is called diffuser efficiency.
The Bernoulli-equation between cross-sections “1” and “2” is:

$$(p_2 - p_1)_{id} = \frac{\rho}{2}(v_1^2 - v_2^2)$$

So the diffuser efficiency is:

$$\eta_{diff} = \frac{(p_2 - p_1)_{real}}{\frac{\rho}{2}(v_1^2 - v_2^2)}$$

During the measurements the quantities in the above equations must be measured at several x positions of the diffuser sheet, then $\eta_{diff.}$ must be calculated and plotted against the distance x to evaluate the results.

4. Measurement process

Definition of flow velocity by volume flow rate measurements

v_1 and v_2 velocities can be calculated from the pressure measured by the orifice plate at every diffuser setting, i. e. at every distance x. It is advisable to use the digital pressure manometer. To define the volume flow rate, the pressure of the pressure outlet at the inlet orifice must be compared to the atmospheric pressure, with this Δp_{or} the volume flow rate of the device can be calculated:

$$q_V = \alpha \cdot \varepsilon \frac{d^2 \cdot \pi}{4} \sqrt{\frac{2 \cdot \Delta p_{or}}{\rho}}$$

where „d" is the inner diameter of the orifice. $\alpha = 0.6$ in case of a suction orifice. (ε=1)
The velocity in cross-section”1” entering the diffuser is:

$$v_1 = \frac{q_V}{A_1} = \frac{4 \cdot q_V}{D^2 \cdot \pi}$$

where D is the inner diameter of the pipe at the suction side of the fan. The average velocity of the air leaving the sheet diffuser is:

$$v_2 = \frac{q_V}{A_2} = \frac{q_V}{D_L \cdot \pi \cdot x}$$

Measurement of the real pressure difference:

The p_1 pressure can be measured in the sidewall static pressure measurement point in cross-section A_1, while p_2 pressure is the atmospheric pressure p_0, since the outlet of the sheet diffuser enters the atmosphere at p_0. Thus it is enough to measure p_1 as compared to the atmospheric pressure and the result is the real pressure difference.

Measurement of the diffuser sidewall pressure distribution

There are several pressure outlets along the radius of the sheet to allow the measurement of changes in the diffuser. In case of the diffusers with different geometries, flow patterns must also be investigated at different x positions. Two different geometries can be measured. In one case, the D_L sheet is plane, while in the other there is an addition installed on the sheet following the diffuser geometry and thus evening the flow cross-section. During the measurement the pressure distribution will be measured on one of the geometries, on the pressure outlets along the radius of the sheet. The pressure distribution must be measured and plotted in each arrangement, by which the location and size of the separation can be defined.

Assuming a symmetric arrangement along the periphery of the sheet on a certain radius the flow is theoretically not changing. In a typical arrangement this must be verified by measurement. For this reason the outlet velocity along the outlet cross-section must be measured by Prandtl tube every 15-30˚. If there is a significant difference between the outlet velocities along the periphery, the diffuser geometry must be checked, since in this case the measured static pressure along one radius of the sheet is not characteristic of the flow for the entire sheet. (The flow pattern is changing along the periphery).

During the measurement it is advisable to use the digital pressure manometer. During the calculations the density of the air ρ, can be defined by the air properties:

$$\rho = \frac{p_0}{R \cdot T}$$

where p_0 is the barometric pressure, $R = 287 \frac{J}{kg \cdot K}$ and T is the actual temperature of the air in K.

5. Measurement evaluation and comparing the data to the literature:

The geometrical data of the diffuser must be recorded accurately. The measured velocity and pressure values must be given in tables and diagrams.
In the measurement evaluation, the diffuser efficiency as a function of the distance between diffuser sheets and the evenness of the flow as a function of the circumferential angle must be given for one diffuser set-up. The pressure distribution along the radius of the sheet and the diffuser must also be plotted for each setting. With the help of this the flow pattern between the diffuser and the sheet can be implied.

6. Error calculation:

The error calculation must be carried out on the diffuser efficiency as follows:

The diffuser efficiency is:

$$\eta_{diff} = \frac{\Delta p_{real}}{\Delta p_{id}} = \frac{\Delta p_{\mathrm{real}}}{\frac{\rho_{air}}{2}(v_1^2 - v_2^2)} = \frac{\Delta p_{real}}{\alpha^2 d^4 \Delta p_{or}\left(\frac{1}{D^4} - \frac{1}{16 D_L^2 x^2}\right)}$$

The absolute error is:

$$\delta\eta_{diff.} = \sqrt{\sum_{i=1}^{n}\left(\delta X_i \cdot \frac{\partial \eta_{diff.}}{\partial X_i}\right)^2}$$

The relative error is:

$$\frac{\delta \eta_{diff.}}{\eta_{diff.}} = ?$$

where X_i is the measured quantity and the related measurement error:

$X_1 = \Delta p_{real}$, and the error of measurement is $\delta\Delta p_{real}$=2Pa

$X_2=\Delta p_{or}$,	and the error of orifice measurement is	$\delta\Delta p_{or}$=2Pa
$X_3=D$,	and the error of diameter measurement is	δD=1mm
$X_4=D_L$,	and the error of diameter measurement is	δD_L=1mm
$X_5=d$,	and the error of diameter measurement is	δd=1mm
$X_6=x$,	and the error of longitude measurement is	δx=1mm

7. Diagrams:

- Diffuser efficiency and loss factor as a function of distance x (absolute and relative error should also be plotted).
- Outflow velocity as a function of circumferential angle.
- Pressure distribution on the radius of the sheet and the diffuser.

Remember that during the labs:

- Before turning any measurement device on or in general during the lab, make sure that safe working conditions are ensured. The other participants have to be warned of the starting of the machines and of any changes that could endanger the members of the lab.
- The atmospheric pressure and room temperature should be recorded before and after every measurement..
- The measurement units and other important factors (e.g. data sampling frequency, data of calibration) of every recorded value of the applied measurement devices should be recorded.
- Type and construction number of the applied measuring instrument should be included in the final report.
- Checking and harmonizing of the units of the recorded values with those used in further calculations.
- Manometers should be calibrated if necessary.
- The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
- If inlet or outlet tubes are to be assembled with fans, connections should be airtight as escaping/entering air can significantly modify the measurement results