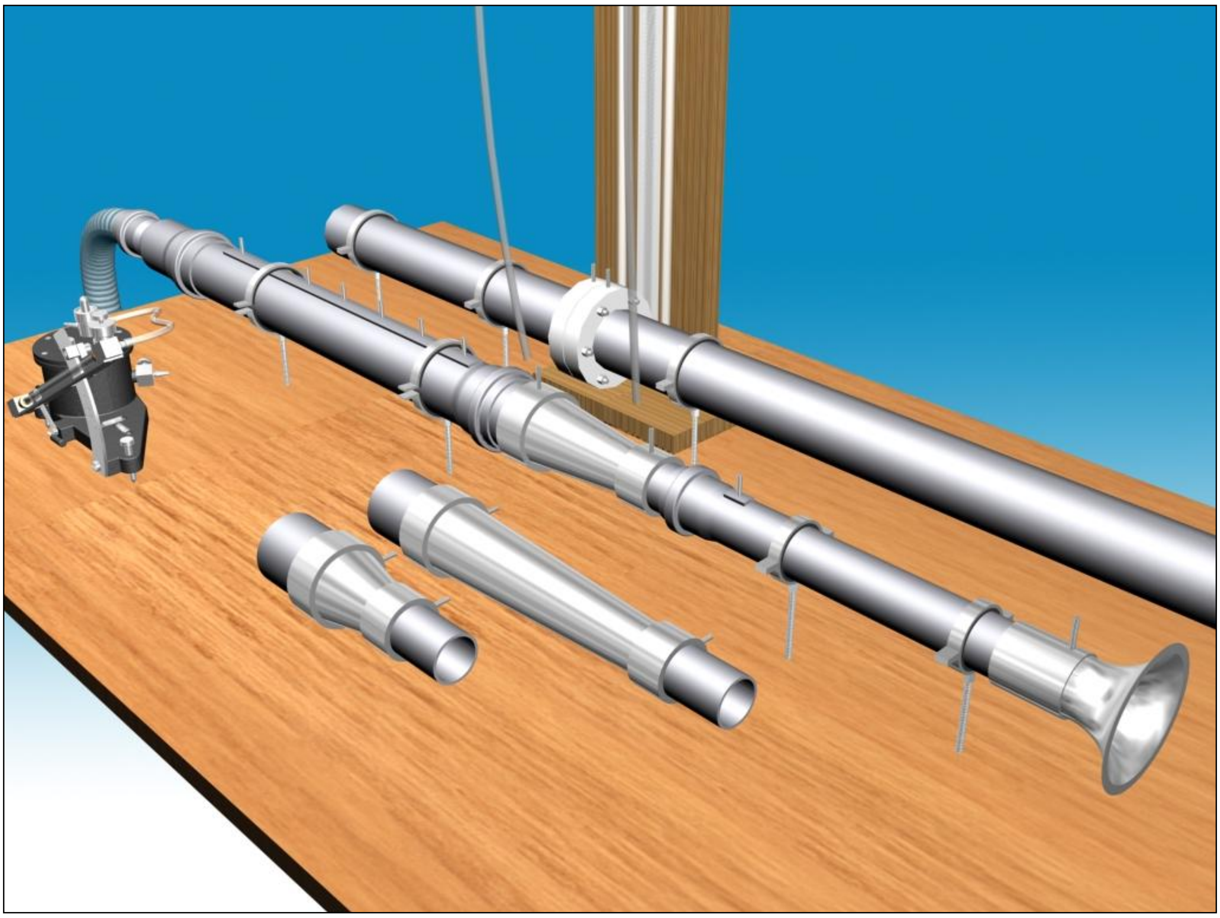


M9

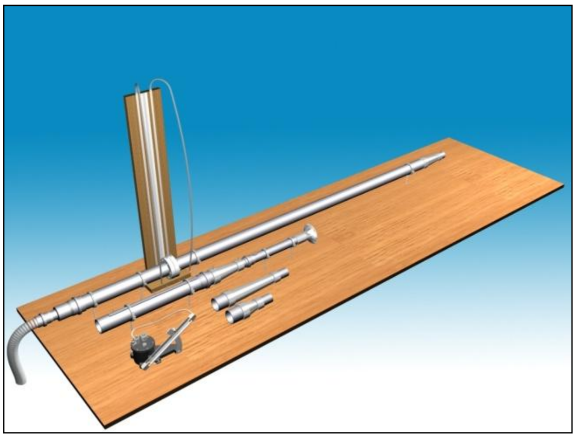
DETERMINATION OF THE CHARACTERISTICS OF A DIFFUSER

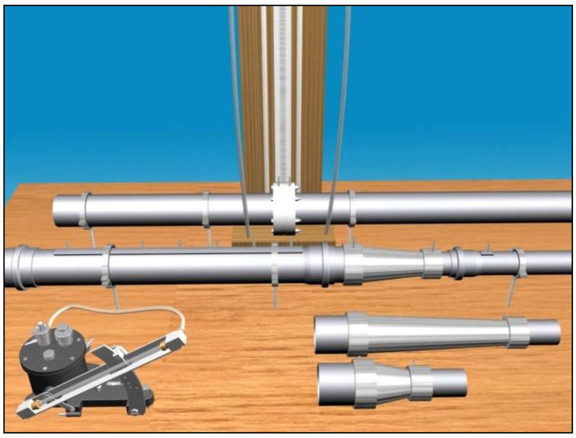
1. The aim of the measurement:

During the laboratory measurements the diffuser efficiency (η_{diff}) needs to be determined. The efficiency needs to investigated as a function of the diffuser angle (φ) and the volume flow rate (q_V), with the results being plotted in diagrams. Three different diffusers with angles of 6°, 15°, and 30°, and one Borda-Carnot element can be built into the measurement set-up. The length of the flow straightener section following the built in elements can be varied as well as the volume flow rate passing through the system.

2. Description of the measurement set-up

The sketch of the measuring device can be seen in Figure 1. We calibrate the inlet orifice plate (5) with the help of a built in standardized orifice plate (6) and the use of the upper, so-called calibration section (7). After the calibration of the inlet orifice plate (5), it has to be built into the lower measurement section after which the actual measurement can begin.





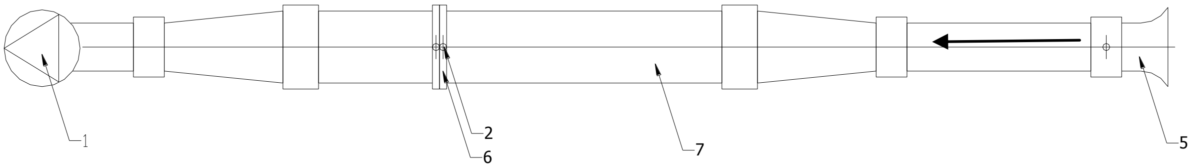


Figure 1: Calibration section

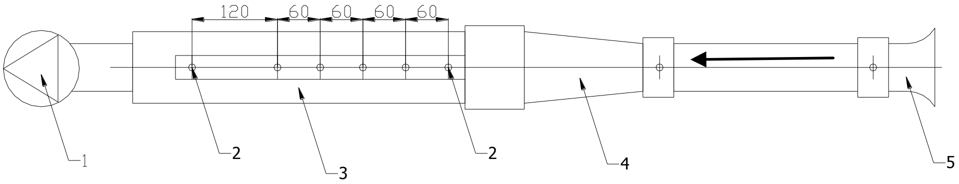


Figure 2: Measurement device for the diffuser efficiency

INLET ORIFICE PLATE CALIBRATION

The air is delivered into the device via a radial fan built into the table (1) which is connected to the calibration section (7). With the use of the standardized orifice plate (6), we can determine the flow number of the inlet orifice plate, by measuring the pressure difference on the standard built-in orifice plate and the inlet orifice plate simultaneously. Volume flow rates can be calculated using the standard orifice plate, and then it can be substituted into the equation describing the inlet orifice plate, where the only unknown variable will be the flow number. A calibration diagram can be constructed if the corresponding pressure differences are recorded and displayed in a diagram.

DIFFUSER EFFICIENCY MEASUREMENT

The suction tube of the fan, as well as the inlet orifice plate, has to be connected to the measurement section (3). We attach the diffusers to be measured (4) between the measurement section and the inlet orifice plate. The flow rate can be calculated based on the pressure differences, with the help of the calibration diagram recorded previously.

The efficiency of the diffuser can be calculated from the increase of pressure measured on the pressure taps before and after the diffuser with an inclined micro manometer or pressure transducer. There are many pressure taps on the measurement section after the diffuser in order to avoid the measurement of the pressure in the separated flow.

3. The theory of the measurement

The variables in the next theoretical definitions are always average variables applied to pressures and velocities in entire cross sections. Cross section ‘1’ is the diffuser entry cross section, while cross section '2' is the diffuser exit cross section (the cross section leading to the measurement section).

What does it mean, and how do we define which diffuser is good?

We use a diffuser if we want to establish a cross section expansion between two sections with two different cross-sections (A1/A2 cross-section expansion). The expansion should be established with the lowest possible loss of total pressure. The diameter expansion could be achieved with sudden increase in diameter (a Borda-Carnot element) with a large separation loss, or the other extreme would be an expanding tube with large wall friction losses. With regard to the given flow, the best possible solution should to be between the two, and hence a diffuser with the lowest loss (an optimal opening angle, best efficiency) (see table 1 below).

DIAMTER EXPANSION SOLUTION	Diffuser opening angle	REASON FOR PRESSURE LOSS IN THE SYSTEM		RATE OF EFFICIENCY
		separation	Wall friction	
Borda–Carnot component (sudden increase in diameter)	180°	BIG	-	BAD
Diffuser	$0° < \varphi < 180°$	LITTLE	LITTLE	MAXIMUM
Infinite expanding tube section	~ 0°	-	BIG	BAD

Table 1.

Note: The experience shows that a diffuser with a diffuser angle of greater than 40º has the same amount of losses as a Borda-Carnot element.

For the characteristics of a diffuser, we define the rate of efficiency of a diffuser:

$$\eta_{diff} = \frac{(p_2 - p_1)_{val.}}{\frac{\rho}{2} \cdot \left(v_1^2 - v_2^2\right)},$$

which relates the actual increase in pressure $(p_2 - p_1)_{val}$ to the ideal increase in pressure $(p_2 - p_1)_{id.}$, where there is no loss and which can be calculated with a simple Bernoulli equation:

$$(p_2 - p_1)_{id.} = \frac{\rho}{2} \cdot \left(v_1^2 - v_2^2\right),$$

The diffuser efficiency is the ratio of the actual (measured) and the ideal pressure increase.

The other characteristic, which is used to characterize components (valves, angles, etc), is the ζ loss factor, which can be determined in case of a diffuser with following equation:

$$\zeta_{diff.} = \frac{\Delta p'_{diff}}{\frac{\rho}{2} \cdot v_1^2} = \frac{(p_2 - p_1)_{id.} - (p_2 - p_1)_{val.}}{\frac{\rho}{2} \cdot v_1^2}.$$

The pressure loss in the diffuser is divided by the dynamic pressure at the inlet. Of course, there is a close relationship between the efficiency and the loss factor, which is the following: (on the right side of the equation using $v_1 \cdot A_1 = v_2 \cdot A_2$ continuity.)

$$\zeta_{diff.} = (1-\eta_{diff})\cdot\left[1-\left(\frac{v_2}{v_1}\right)^2\right] = (1-\eta_{diff})\cdot\left[1-\left(\frac{A_1}{A_2}\right)^2\right]$$

Cross-sections “1” and “2” are the cross-sections upstream and downstream of the diffuser, respectively. The upstream measurement point is easily given, since the upstream effects of the diffuser can be neglected in the present case.

Which should be the downstream “2” cross-section is a harder question though. How far downstream does the diffuser still influence the flow?

Why is this question brought up? Why can’t the first point after the diffuser be used? It is because a disturbance in the flow is brought about by the separation flow. When a fluid goes though a section of pipe where the cross-section is increasing, and therefore the pressure is increasing in the downstream direction, it is expected that the flow will separate from the wall and will only reattach after a certain distance. During this separation the velocity of the fluid is decreasing while its pressure is increasing. If we graph the measured static pressure difference as a function of the distance from the exit of the diffuser, it can be seen that the maximum static pressure difference does not occur at the exit of the diffuser, but slowly increases. The pressure is therefore still increasing after the separation zone. We do our calculations with the pressures which can be found in the beginning of the horizontal section of the graph.

Since the different diffusers have different size separation zones at different volume flow rates, the “2” cross-section needs to be found separately for every measurement.

4. The process of the measurement

Calibration of the inlet orifice plate

The volume flow rates during the measurements will be given by the inlet orifice. The equation of the flow rate of the inlet orifice plate is the following:

$$q_v = k\frac{d_i^2\pi}{4}\sqrt{\frac{2}{\rho_1}\Delta p_i}$$

where

k	flow factor
d_i	inner diameter of inlet orifice plate
ρ_1	density of air
Δp_i	pressure drop measured on the inlet orifice plate

The flow factor of the inlet orifice plate can be determined with the calibration tube (figure 1). The calibration tube contains a standardized orifice plate, on which we can measure the flow rate with a standard method. During calibration we have to measure the pressure drop of the standard orifice plate and the inlet orifice plate at different flow rates. The flow rate can be deduced from the pressure drop of the standard orifice plate, which compared to the pressure drop of the inlet orifice plate determines the flow rate in the equation. The determination of the flow factor should be done at three volume flow rates, after which the three results need to be compared. Since the measurement set-up can be set to only small Reynolds numbers (Re) the dependency on the Re cannot be seen and the three values will be similar. Taking the average of the three values for the flow factor, we can now make measurements with the inlet orifice.

Note:
In general, the calibration procedure would require the creation of a calibration diagram from the measurement results. In this case the measured data would always be compared to the diagram to find the actual value of the measured results. This was not necessary in this case, since the calibration could be limited to the one constant's value.

The formula to calculate the flow rate of the standard orifice plate:

$$q_v = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{d^2\pi}{4} \sqrt{\frac{2}{\rho_1}\Delta p}$$

where

C	Flow coefficient
β	Measured relation of the cross-section of the inner brim to the diameter of the pipe (here β=0,6587)
ε	Compressibility factor (ε=1, since the change in the pressure of the fluid is small)
d	Hole diameter of the measurement brim (here d=38.8mm)
Δp	Pressure drop on flow through orifice

Formula to calculate flow coefficient *C*:

$$C = 0.5961 + 0.0261\beta^2 - 0.261\beta^8 + 0.000521\left(\frac{10^6\beta}{Re_D}\right)^{0.7} + (0.0188 + 0.0063A)\beta^{3.5}\left(\frac{10^6}{Re_D}\right)^{0.3} + 0.011(0.75-\beta)\left(2.8 - \frac{D}{0.0254}\right)$$

where

$Re_D = \frac{vD}{\nu}$ [-] The Reynolds number calculated with the diameter before the brim (here D=58,9mm)

$$A = \left(\frac{19000\beta}{\mathrm{Re}_D}\right)^{0,8}$$

Since the Reynolds number is dependent on the velocity, and the velocity is dependent on the flow coefficient, which is again dependent on the Reynolds number, it is advisable to use iteration to complete the task. The flow coefficient in the first iteration cycle shall be C=0.6. We shall determine the flow rate at the given flow number, the velocity before the standard orifice plate, the Reynolds number, and finally we shall determine the flow coefficient. From here the cycle starts all over again, and we calculate the flow rate with the new flow coefficient, the velocity, etc. The results converge swiftly and after 2 or 3 iteration cycles we receive the actual results (we can consider the solution converged if the relative difference between the substituted C and the calculated C value is below 1-2%).

1. step
$C' \rightarrow q_V' \rightarrow v' \rightarrow Re_D' \rightarrow C''$
2. step
$C'' \rightarrow q_V'' \rightarrow v'' \rightarrow Re_D'' \rightarrow C'''$
etc.

Pressure drop and velocity

v_1 and v_2 velocities can be calculated with the volumetric flow rate measured with the inlet orifice plate:

$$\mathrm{v}_1 = \frac{4 \cdot q_v}{d_{in}^2 \cdot \pi} \qquad \mathrm{v}_2 = \frac{4 \cdot q_v}{d_{out}^2 \cdot \pi}$$

We have to measure the pressure drops between the pressure tap before the diffuser (p1) and the pressure taps of the so called measuring section (p2). From the pressure drop and the velocity we can calculate the efficiency (η_{diff}).

5. Checking and comparing the results with data from the literature:

The geometrical data of the diffusers has to be recorded during the measurement. The measured velocities and pressure values have to be shown in tables and diagrams. (The diagrams should show the pressure as a function of the distance from the outlet of the orifice.) After the measurements the efficiencies (η_{diff}) and the loss coefficients of the diffusers have to be determined. The results need to be presented in tables and diagrams. (The diagrams should be made so that the effects of the changing volume flow rate and the different diffuser designs can easily be seen. For example x axis: volume flow rate, y axis: efficiency. In this way every diffuser element provides one curve on the diagram.)

Error calculation:
The diffuser efficiency and the absolute error calculation:

$$\eta_{diff.} = \frac{\Delta p_{real}}{\Delta p_{id}}$$

Expressed with the measured values:

$$\eta_{diff.} = \frac{\Delta p_{real}}{\left[1 - \left(\frac{d_{in}}{d_{out}}\right)^4\right] \cdot k^2 \cdot \Delta p_i}$$

absolute error:

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

relative error:

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

where X_i are the measured values and the related errors:

$X_{1,2}=d$ $\delta d=0.001\mathrm{m}$

$X_{3,4}=\Delta h$ $\delta\Delta h=0.001m$

Or:

$X_{3,4}=\Delta p$ $\delta\Delta p = 2\ Pa$

The calculated errors need to be applied to the results in the tables and the diagrams.

(ex. $\eta_{diff.}$ =#±0.1)

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 group.
- 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, date 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.