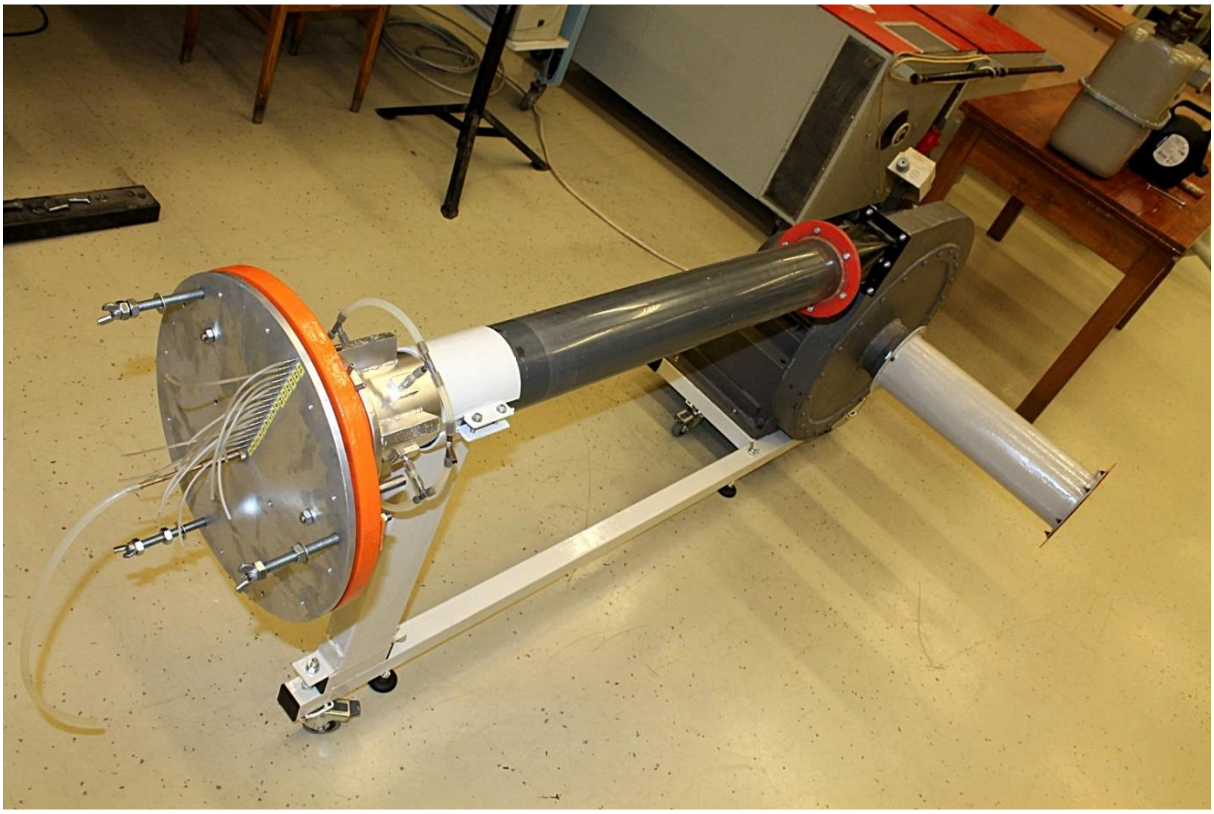


M13

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 A_1 and A_2 cross-sections (diffuser) in the direction of the A_2 cross-section, where the flow velocity is lower and the static pressure is higher, i.e. they flow towards the pressure growth. The work required

for this is covered by the decrease in the flow kinetic energy. According to the Bernoulli equation, this decrease is exactly equal to the increase in pressure. In reality, part of the kinetic energy is used to cover losses. Friction particularly has an effect along the pipe walls. The kinetic energy of the particles flowing here, which slow down due to the wall's shear stress—especially in the case of a suddenly expanding diffuser with a large opening angle—is insufficient to cover the work required by the pressure increase resulting from the deceleration of the fluid flowing farther from the wall. As a result, the particles flowing along the wall slow down, the **boundary layer thickens**, and eventually they stop, or even flow back, forming a separation zone along the wall. The layers flowing further inward do not continue to follow the expanding direction of the pipe wall and separate from it. This phenomenon is **called boundary layer separation**, and the pressure loss caused by it is known as separation loss.
Due to the thickening of the boundary layer and the separation, the actual flow cross-section increases less than would be expected based on the geometry of the diffuser.
In slowly expanding diffusers, the pressure increase falls short of the value calculated from the Bernoulli equation mainly due to **wall friction**, while in rapidly expanding diffusers, this shortfall is mainly due to **separation loss.**
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.

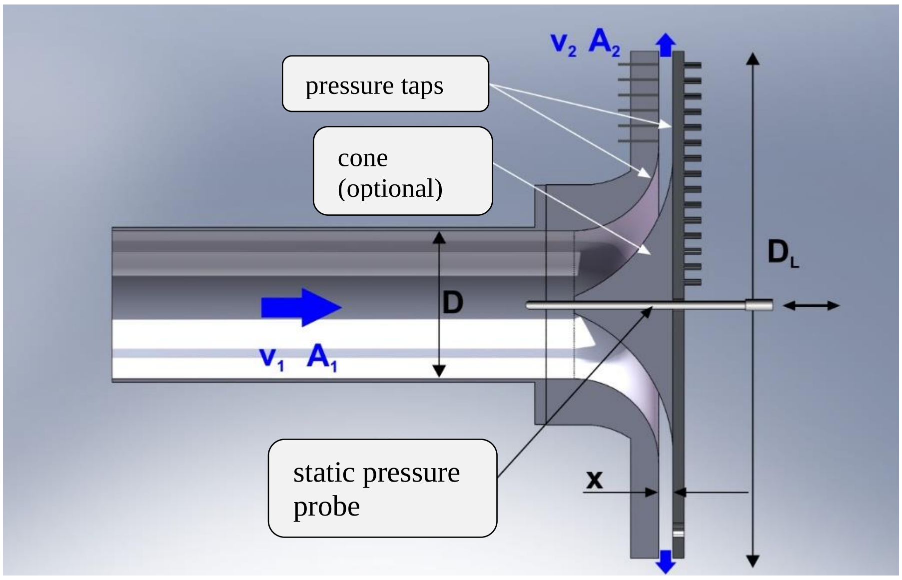


Figure 1: Sheet diffuser measurement facility

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. The sheet diffuser gap size can be set using the three bolts. Pay attention to move the bolts together so that the diffuser plates remain parallel! Diffuser efficiency can be improved using a cone that can be attached using an M5 bolt. Please don **NOT** use it during the measurement!

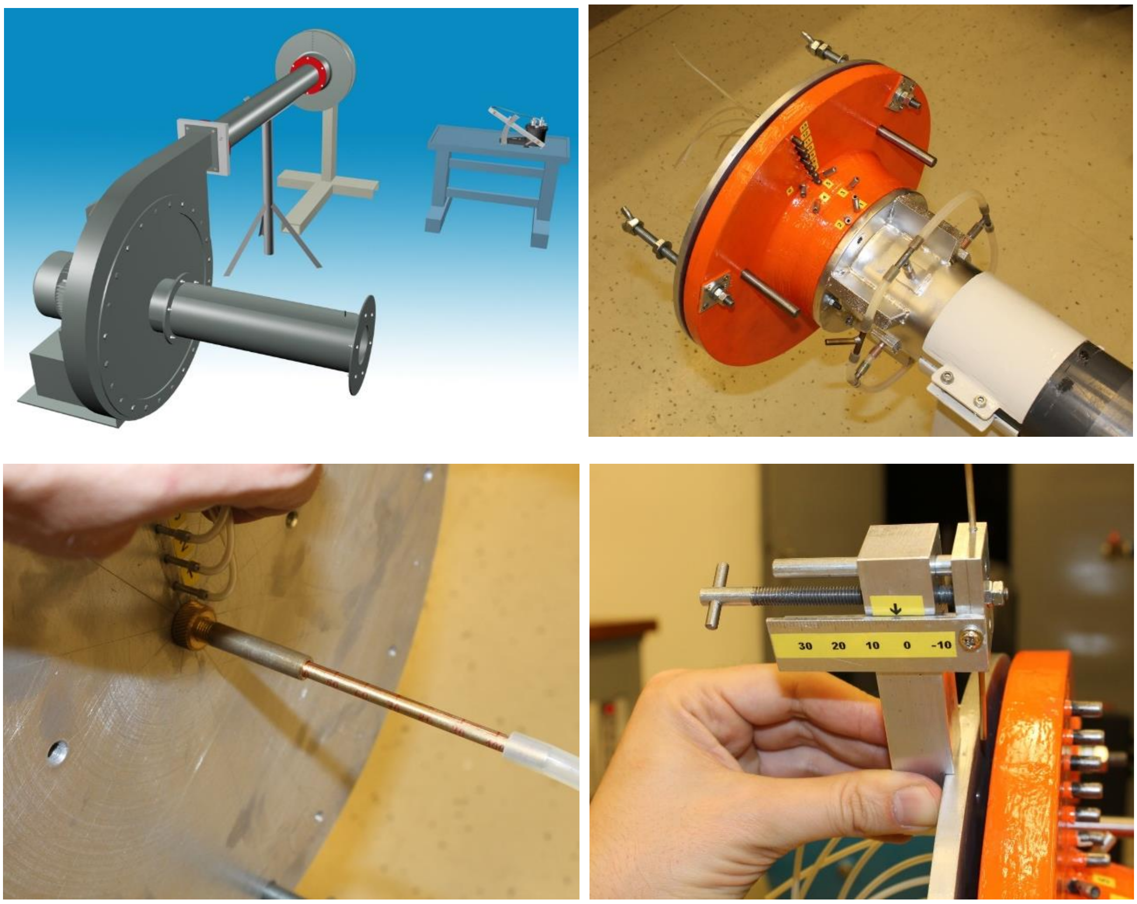


Figure 2: Measurement setup (top left); the sheet diffuser (top right); static pressure measurement on the axis (bottom left); outflow velocity measurement using the Pitot probe (bottom right)

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 $A_1<A_2$. This can be adjusted after calculating x_{min} ($A_1=A_2$) in the beginning of the measurement. During the measurement the distance x is to be changed from x_{min} (the rounded up integer value) by Δx=1 mm to set-up 15 different A_2 cross-sectional sheet diffusers.
IMPORTANT! The x distance should be changed by Δx=1 mm (or maximum 1.5 mm) till x = 20 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:

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

So the diffuser efficiency is:

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

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

4. Measurement process

General data

During the measurement the dimensions of the diffuser have to be recorded. Pressure tap positions can be read from the DWG file [3] available on the course web page.

The precise measurement of x gap size is very important; therefore it has to be carried out using a calliper in four radial positions for each setting. Three bolts are to be turned by the same amount to ensure that the diffuser plates are parallel to each other.

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.

Determination 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:

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

The change in gap size and the resulting pressure change might affect the operating state of the fan; therefore the volume flow rate has to be measured for every gap size.

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

13 pressure taps on the inner side and 15 on the outer side of the diffuser allow the measurement of pressure distributions inside the diffuser. Besides them, there is a static pressure probe in the diffuser axis.

Pressure distributions have to be recorded as specified by the measurement task. These profiles provide useful information about different flow phenomena: separations, stagnation points etc.

Outflow symmetry

In case of a symmetric setting on a given radius no flow properties change along the circumference. This is to be checked in one measurement case, i.e. one gap setting. The outflow velocity profile has to be measured along the diffuser circumference using the Pitot probe and its stand using 60° steps. Pay attention to set the Pitot probe in the middle of the outflow cross section!

5. Measurement evaluation, report

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.

Error calculation

The error of the diffuser efficiency measurement is to be calculated using the following steps.

The diffuser efficiency:

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

The absolute error:

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

The relative error is:

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

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

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

$X_2=\Delta p_{or}$,	and the error of orifice measurement is	$\delta\Delta p_{or}=2$ Pa
$X_3=D$,	and the error of diameter measurement is	$\delta D=1$ mm
$X_4=D_L$,	and the error of diameter measurement is	$\delta D_L=1$ mm
$X_5=d$,	and the error of diameter measurement is	$\delta d=1$ mm
$X_6=x$,	and the error of longitude measurement is	$\delta x=0.2$ mm

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.

Advice for creating the report

- Do not give too many digits in the tables! The written digits should correspond to the measurement error.
- Use the „X-Y" diagram type, in which case the software treats the X axis as numbers, too, and not as labels. Otherwise the software shows different step sizes as equal!
- Pressure distributions should be drawn as a function of e.g. radial distance [mm], not number of measurement point!
- Measurement points should be connected by straight lines on the diagrams.
- Add error bars to the efficiency curve!
- Please pay attention to create nice figures (correct number of digits on axes, axis title and dimension, appropriate line and point style etc.)

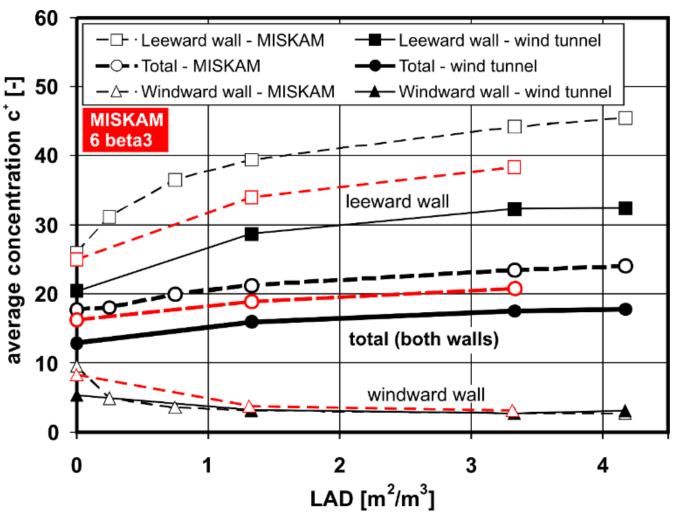


Figure 3: An example for a properly formatted diagram

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, 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.
- 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.
- The students should consult with their instructor before submitting the report.

Literature

[1] LAJOS, Tamás: Az áramlástan alapjai (Hungarian), Műegyetemi Kiadó, Budapest 2005
[2] Departmental Web Site: www.ara.bme.hu
[3] BSc_M13_pressure_tap_positions.DWG

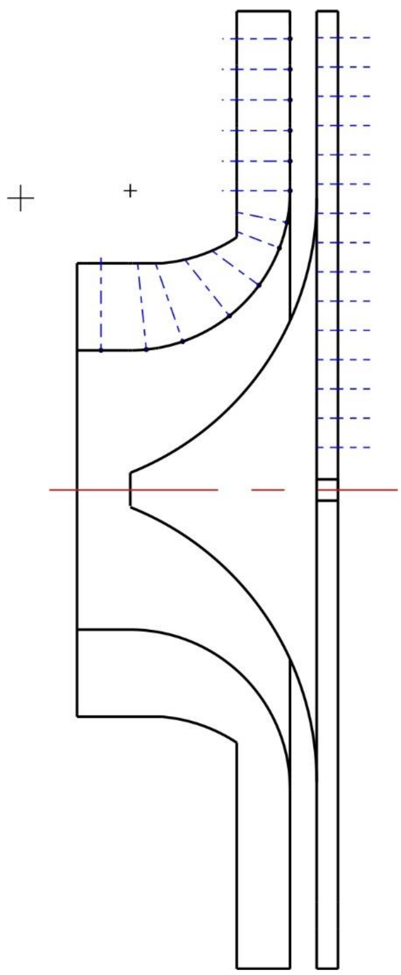
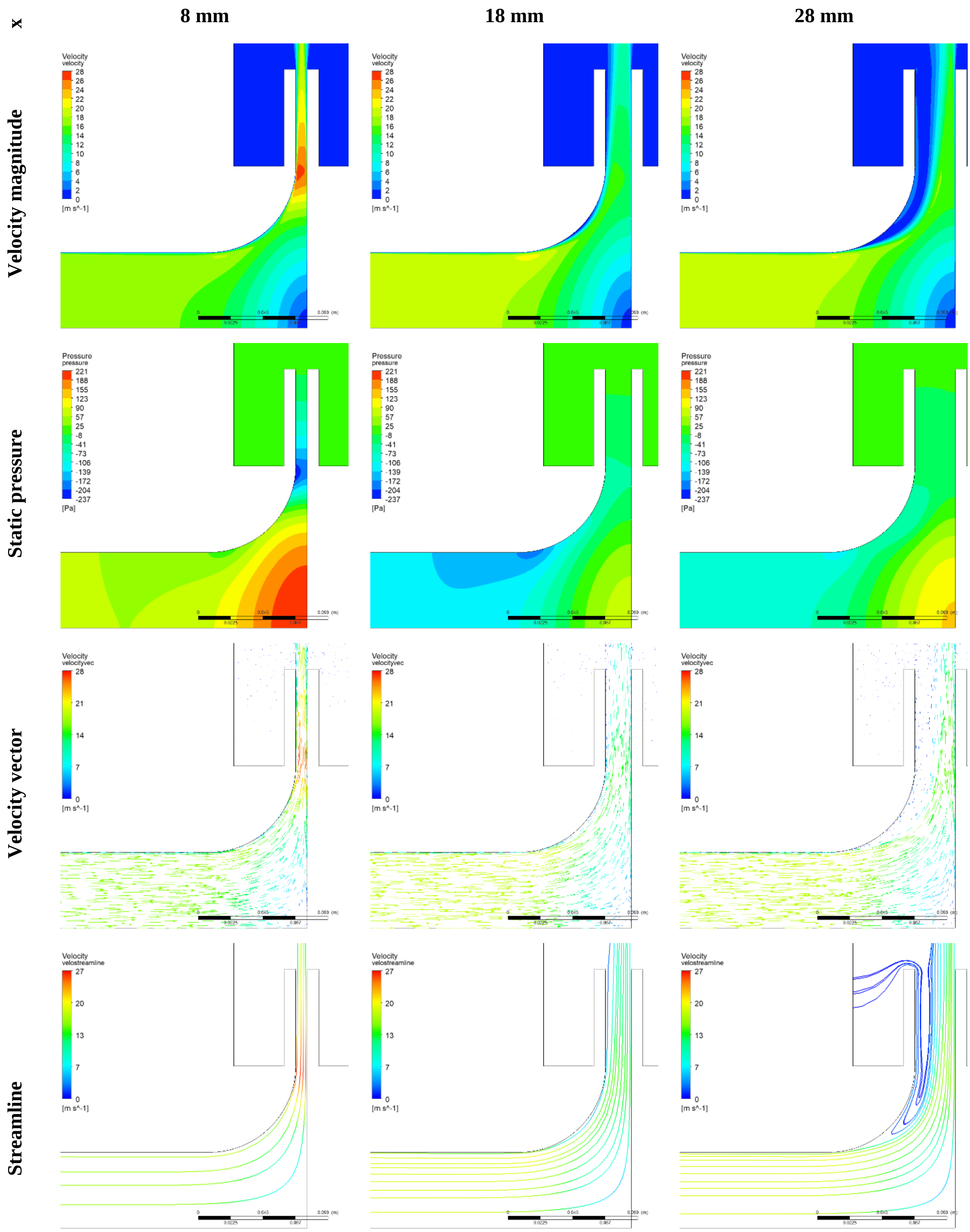


Figure 4: Contents of BSc_M13_pressure_tap_positions.DWG


x
8 mm
18 mm
28 mm
Velocity magnitude
Static pressure
Velocity vector
Streamline
Velocity
velocity
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
[m s^-1]
Pressure
pressure
221
188
155
123
90
57
25
-8
-41
-73
-106
-139
-172
-204
-237
[Pa]
Velocity
velocityvec
28
21
14
7
0
[m s^-1]
Velocity
velostreamline
27
20
13
7
0
[m s^-1]