Department of Fluid Mechanics

Pre-measurement class I.
Csaba Horváth

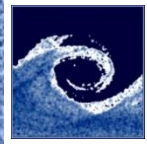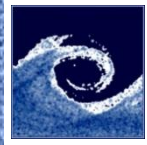| M1 – M2 | Várhegyi Zsolt | varhegyi@ara.bme.hu |
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2013.

General information

- Department webpage: **www.ara.bme.hu**

- Student information page: **www.ara.bme.hu/poseidon**

  (materials, test scores, etc.)

- Schedule: 1 pre-measurement class + 1 measurements (A and B) + 1 presentations
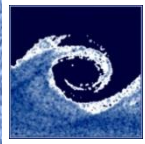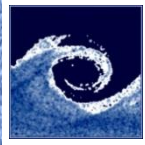
General information

- The measurement reports are due on the second Sunday following the measurement, at midnight. A faculty member will correct the report within 2 days and send a message to the student, through the Poseidon network, to let them know if the report has been accepted, corrections need to be made, or if the measurement needs to be repeated. If corrections need to be made, the students can consult the faculty member. The corrected reports need to turned in by the third Sunday following the measurement, at midnight.

Measuring pressure differences (measuring Δp)

- Provides the basis of many measurements (e.g. velocity, volume flow rate)

- For a fluid medium, pressure differences can be measured between two points

- It is often measured with regard to a reference value (atmospheric pressure, static pressure in a duct)

- Tools which can be applied

    - U tube manometer

    - Betz manometer

    - Inclined micro manometer

    - Bent tube micro manometer

    - EMB-001 digital handheld manometer

Measuring Δp / U tube manometer I.

- Pipe flow

- Butterfly valve

- Average of the pressure measured on the pressure taps around the perimeter
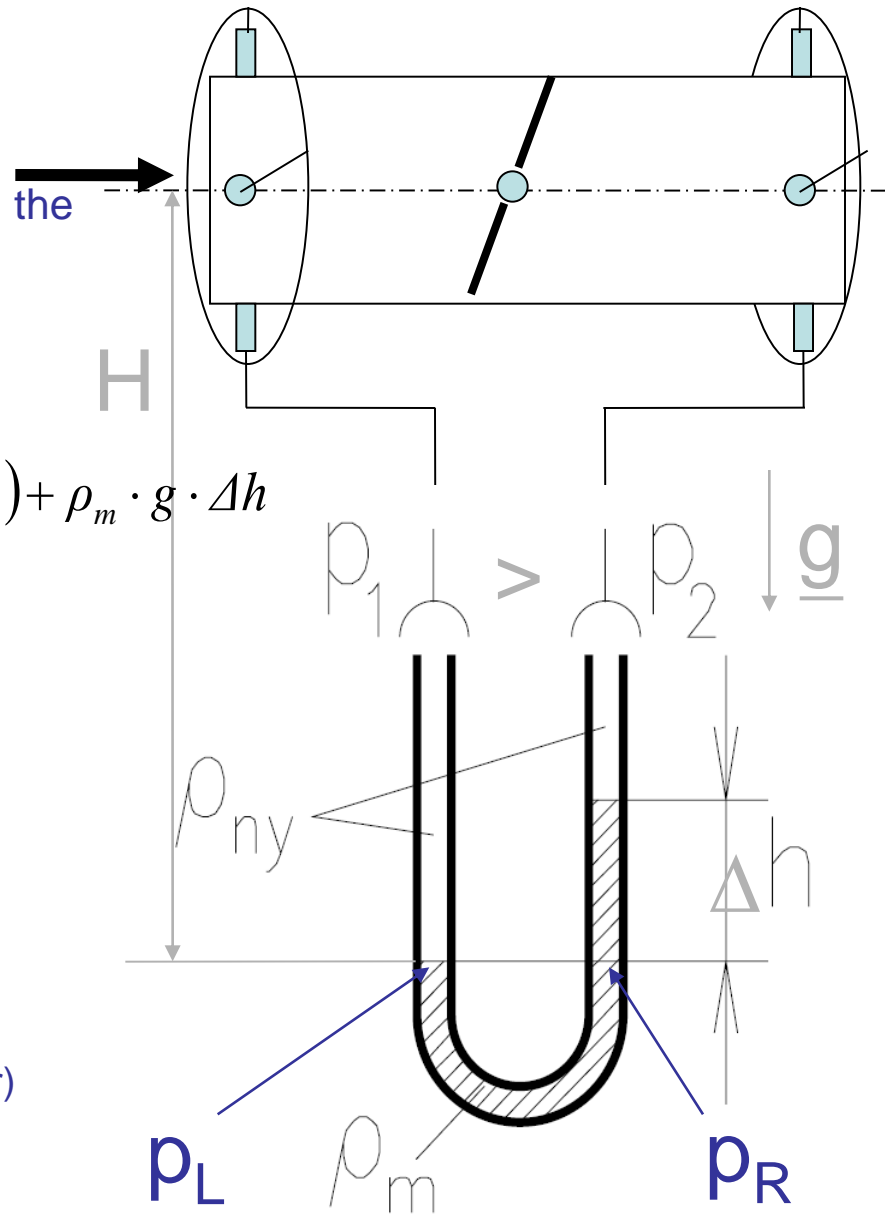
The manometers balance equation:

$$p_L = p_R$$

$$p_1 + \rho_{ny} \cdot g \cdot H = p_2 + \rho_{ny} \cdot g \cdot (H - \Delta h) + \rho_m \cdot g \cdot \Delta h$$

$$p_1 - p_2 = (\rho_m - \rho_{ny}) \cdot g \cdot \Delta h$$

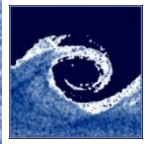Can be simplified if

$$\rho_{ny} << \rho_m$$

(e.g. if the measured fluid is air

and the measurement fluid is water)

$$p_1 - p_2 = \rho_m \cdot g \cdot \Delta h$$

Notice that

$$\Delta p \neq f(H)$$

H

p_1 > p_2 g

ρ_{ny}

Δh

p_L ρ_m p_R

The manometers balance equation:

$$\Delta p = \left(\rho_m - \rho_{ny}\right)g\Delta h$$

Density of the measuring fluid ρ_m (approximately)

$$\rho_{Hg} \approx 13600 \frac{kg}{m^3}$$ mercury

$$\rho_{water} \approx 1000 \frac{kg}{m^3}$$ water

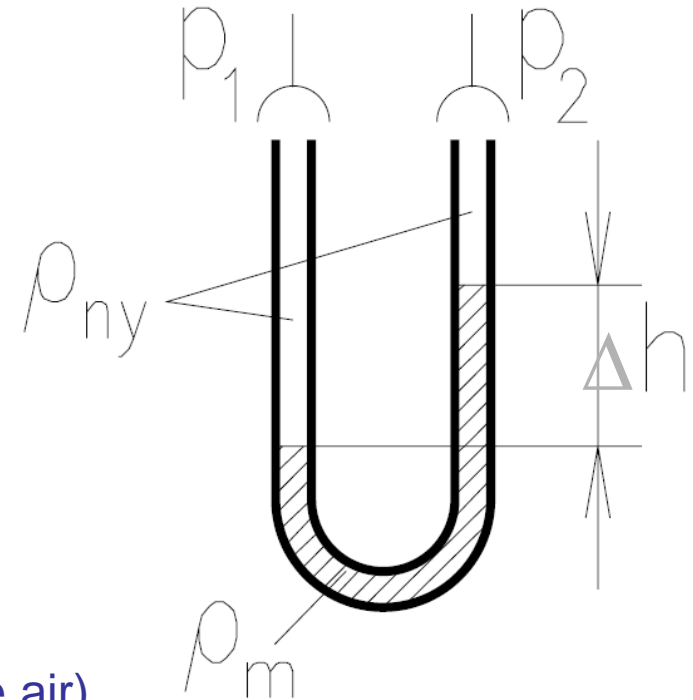$$\rho_{Alcohol} = 830 \frac{kg}{m^3}$$ alcohol

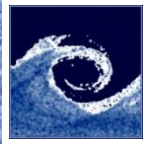Density of the measured fluid: ρ_{ny} (For example air)

$$\rho_{air} = \frac{p_0}{R \cdot T} = 1.19 \frac{kg}{m^3}$$

$p_{levegő} = p_{air}$ atmospheric pressure [Pa] ~$10^5 Pa$

R - specific gas constant for air 287[J/kg/K]

T - atmospheric temperature [K] ~293K=20°C

Example: the reading: $\Delta h = 10mm$

The accuracy ~1mm: The absolute error:

$$\delta(\varDelta h) = \pm 1\,mm$$

How to write the correct value with the absolute error(!)
$$\Delta h = 10mm \pm 1mm$$

The relative error:

$$\frac{\delta(\varDelta h)}{\varDelta h} = \frac{1\text{mm}}{10mm} = 0.1 = 10\%$$

Disadvantages:

• Reading error (take every measurement twice)

• Accuracy~1mm

• For a small pressure difference, the relative error is large

Advantages:

• Reliable

• Does not require servicing

## Measuring Δp / upside down U tube micro manometer

The manometer's balance equation

$$p_1 - p_2 = (\rho_v - \rho_l) \cdot g \cdot h$$

Since in most cases liquid (e.g. water) filled lines are measured using upside down U tube manometers, the measurement fluid in these cases is usually air, and therefore the density ratio is (1.2/1000), and therefore the $-\rho_l$ (density of air) can be neglected.

The advantage of this measuring device is that when it is used for liquid filled systems, air can be used instead of mercury in order to improve the accuracy of the relative error of the readings!
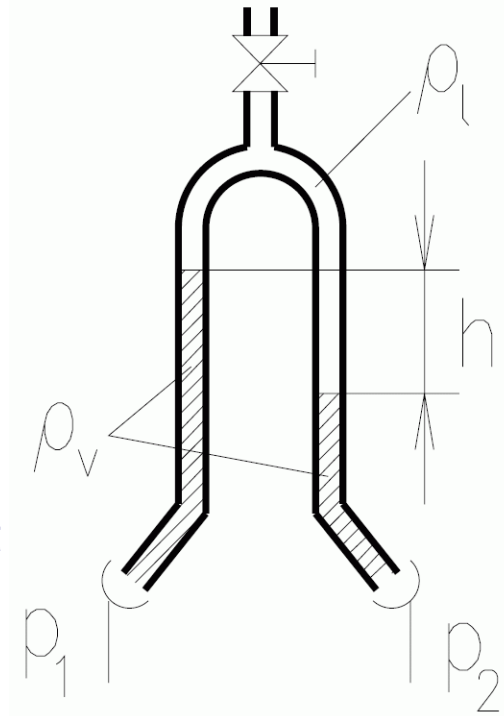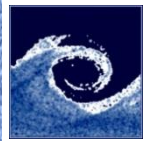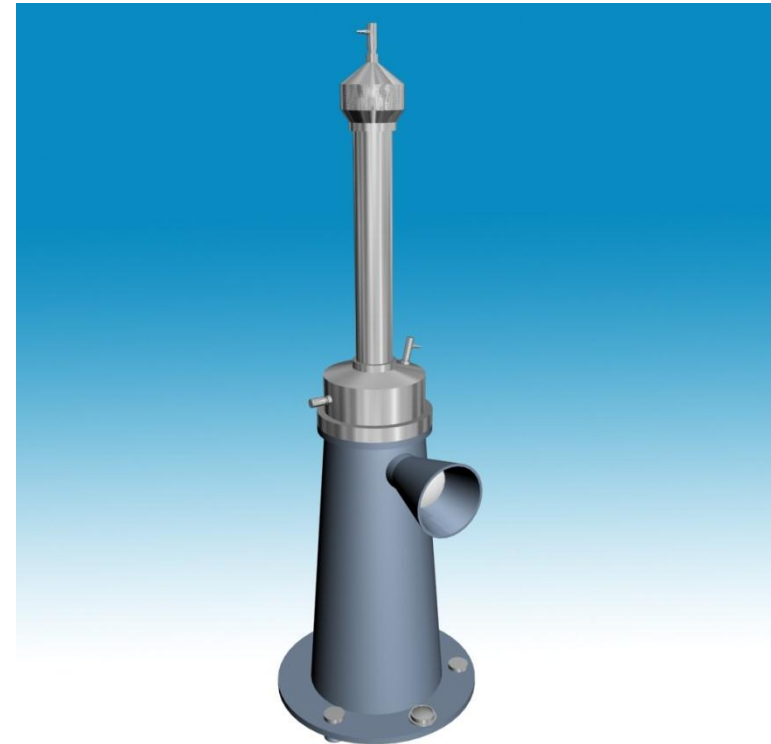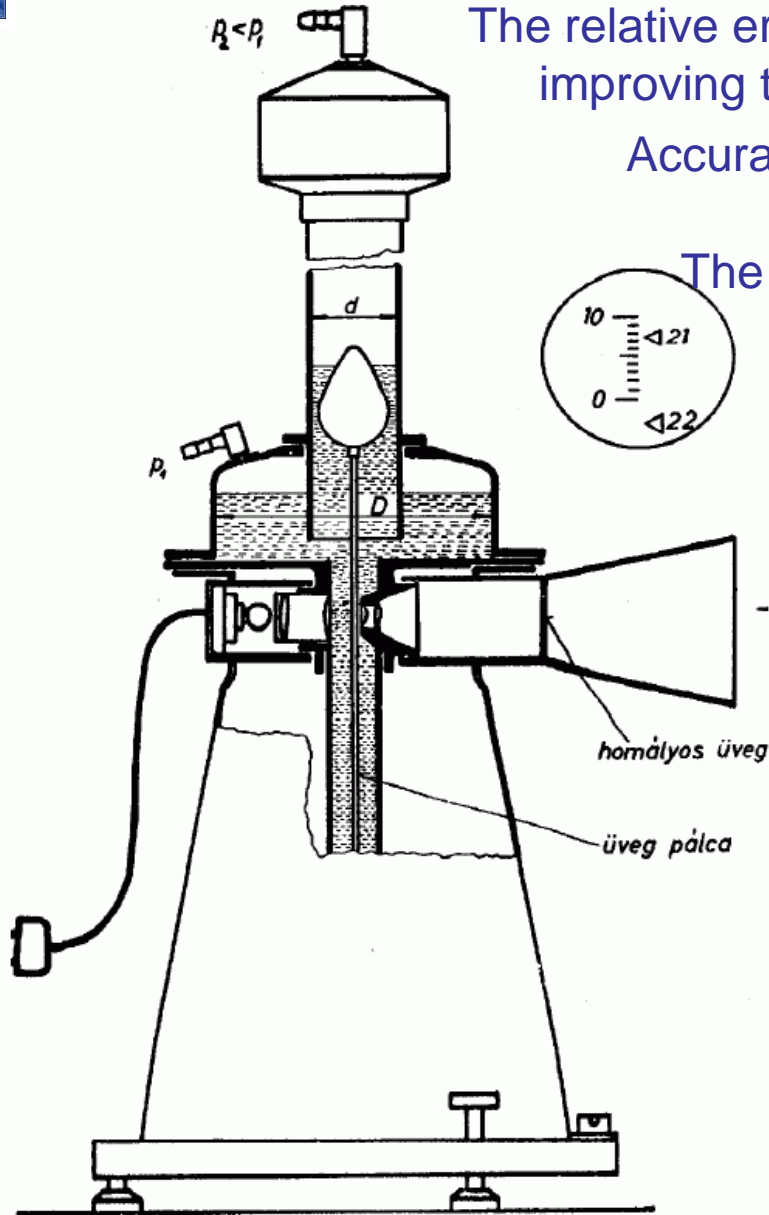
The relative error is reduced using optical tools, therefore improving the accuracy.
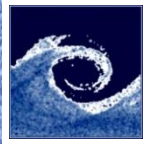
Accuracy ~0,1mm: The absolute error is:

$$\Delta h = 10mm \pm 0.1mm$$

The relative error:

$$\frac{\delta(\Delta h)}{\Delta h} = \frac{0.1mm}{10mm} = 0.01 = 1$$

homályos üveg

üveg pálca

The manometers balance equation

$$p_1 - p_2 = \rho_m \cdot g \cdot \Delta h$$

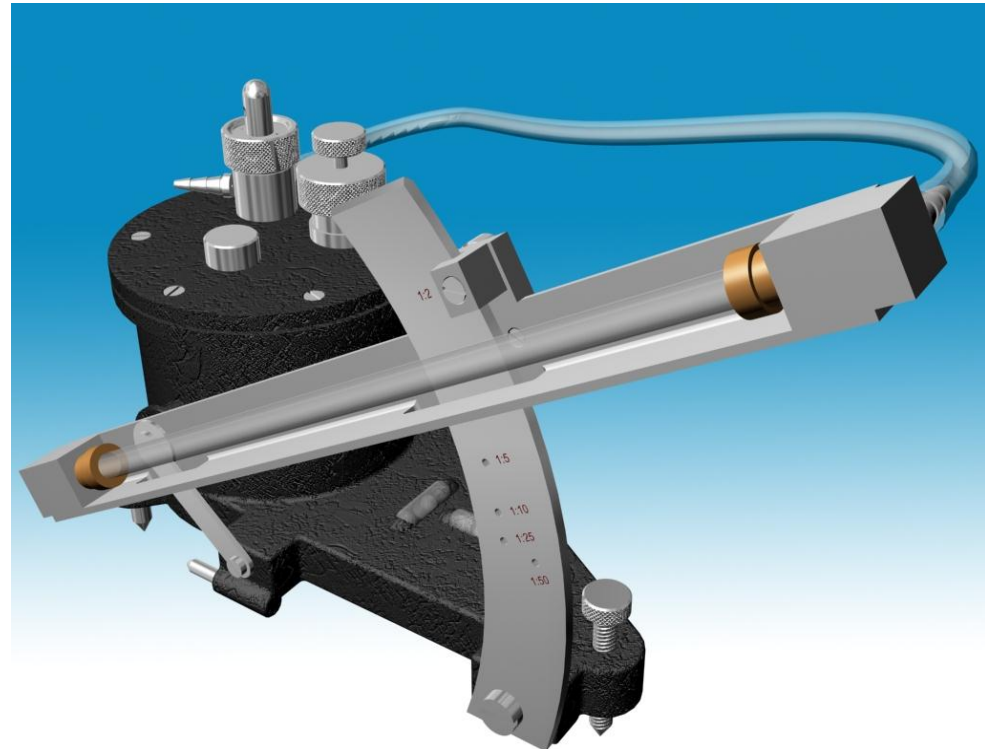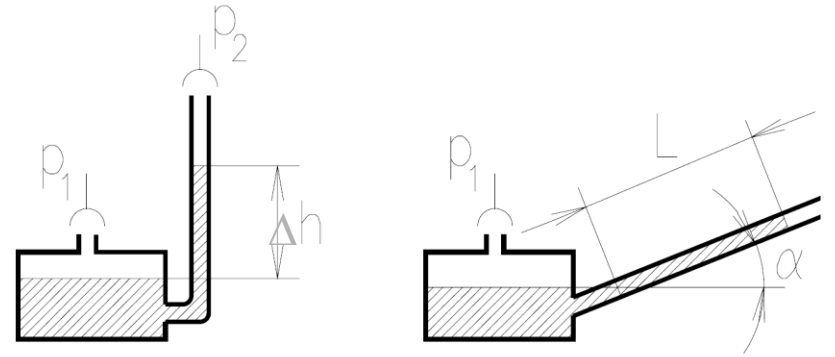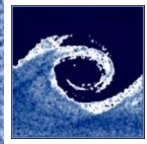$$\Delta h = L \cdot \sin\alpha$$

Accuracy: $\delta L \sim \pm 1mm$,

Relatív error in the case of $\alpha = 30°$

$$\frac{\delta L}{L} = \frac{\delta L}{\dfrac{\Delta h}{\sin\alpha}} = \frac{1mm}{\dfrac{10mm}{\sin 30°}} = 0.05 = 5\%$$
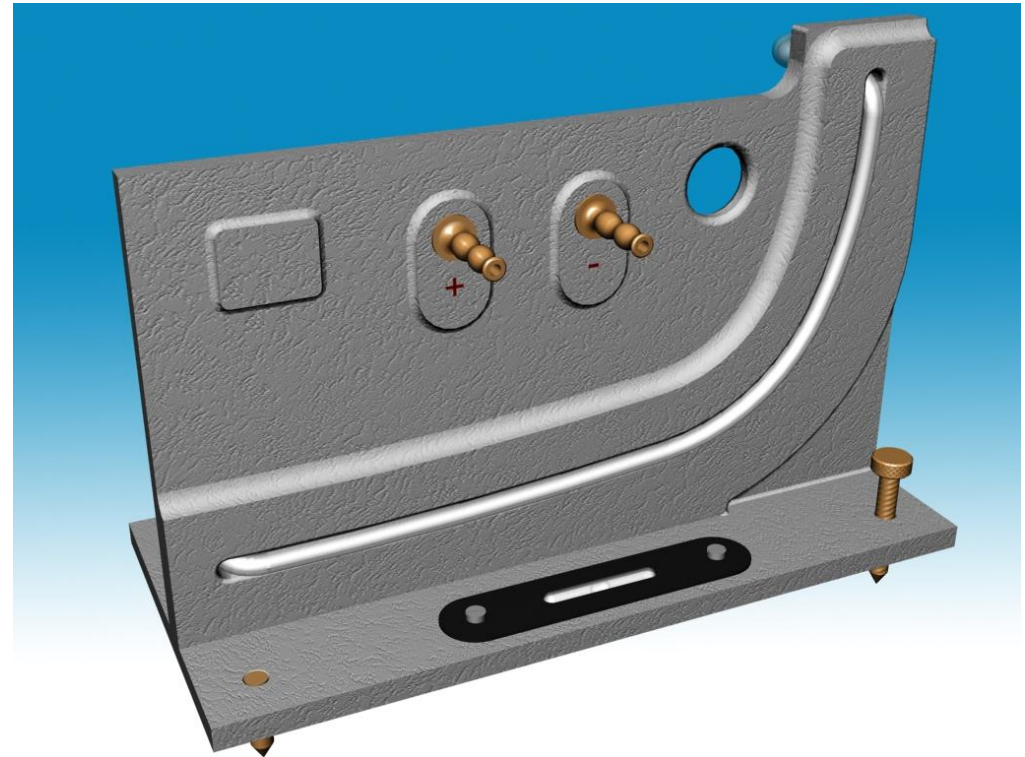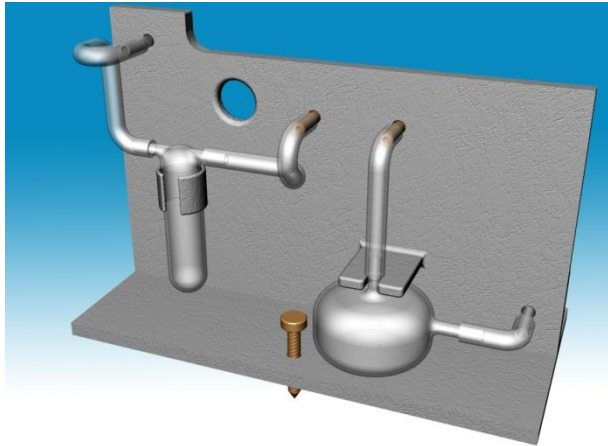
The relative error is a function of the inclination angle - $f(\alpha)$ - It is characterized by a changing relative error.
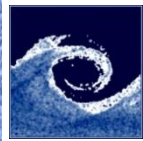
Measuring Δp / bent tube micro manometer

Is characterized by a
   constant relative error
   and a nonlinear scale

List of buttons to be used during the measurements
On/Off   Green button
Factory reset   „0" followed by the „STR Nr
Changing the channel   „CH I/II"
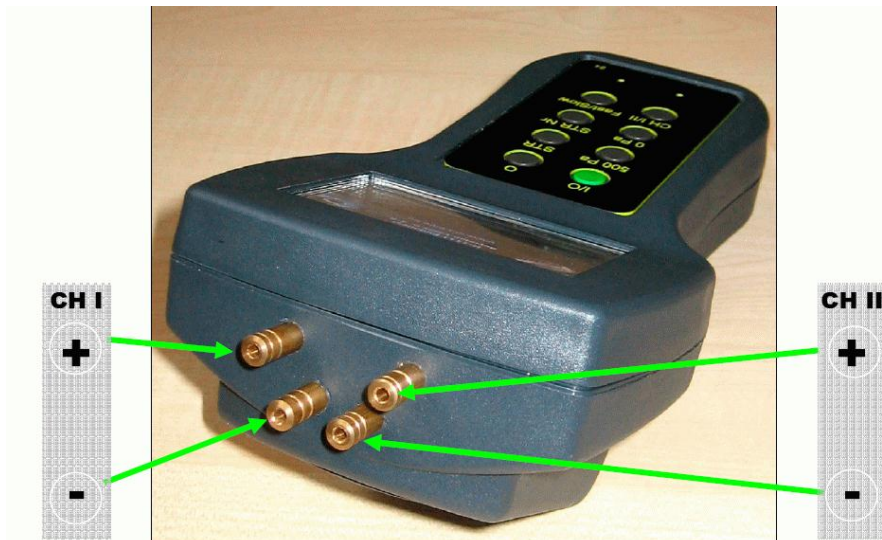Setting 0 Pa   „0 Pa"
Averaging time(1/3/15s)   „Fast/Slow" (F/M/S)

Measurement range:

$$\Delta p = \pm 1250 Pa$$

Measurement error:

$$\delta \Delta p = 2 Pa$$
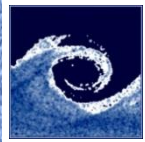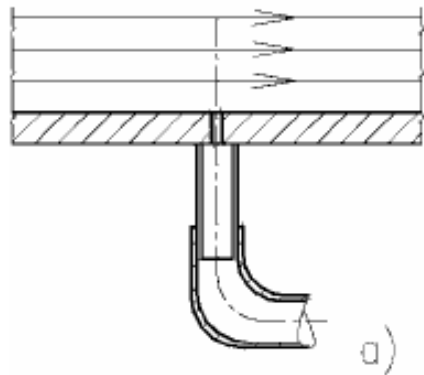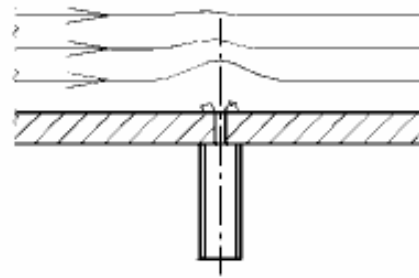
When measuring pressures we need the streamlines to be
parallel and straight
 In this case the pressure is not changing perpendicularly
 to the streamlines
 (The normal component of the Euler equation)
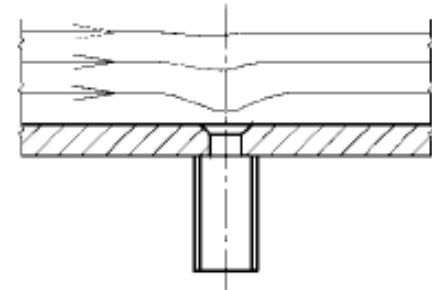
a) Correct b) c) Incorrect
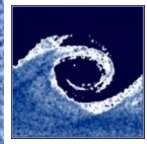
Velocity measurement devices

- Pitot tube/probe

- Pitot-static (Prandtl) tube/ probe
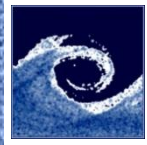
Velocity measurement / Pitot tube/probe

Pitot, Henri (1695-1771), French engineer.

Determining the dynamic pressure:

$$p_d = p_ö - p_{st}$$

$p_ö$ = p_t the pressure measured in the stopped fluid (total pressure)
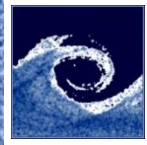
p_{st} the pressure acting on a surface which is parallel to the flow (static pressure)

$$p_d = \frac{\rho_{ny}}{2} \cdot v^2$$

Determining the velocity:

$$v = \sqrt{\frac{2}{\rho_{ny}} \cdot p_d}$$
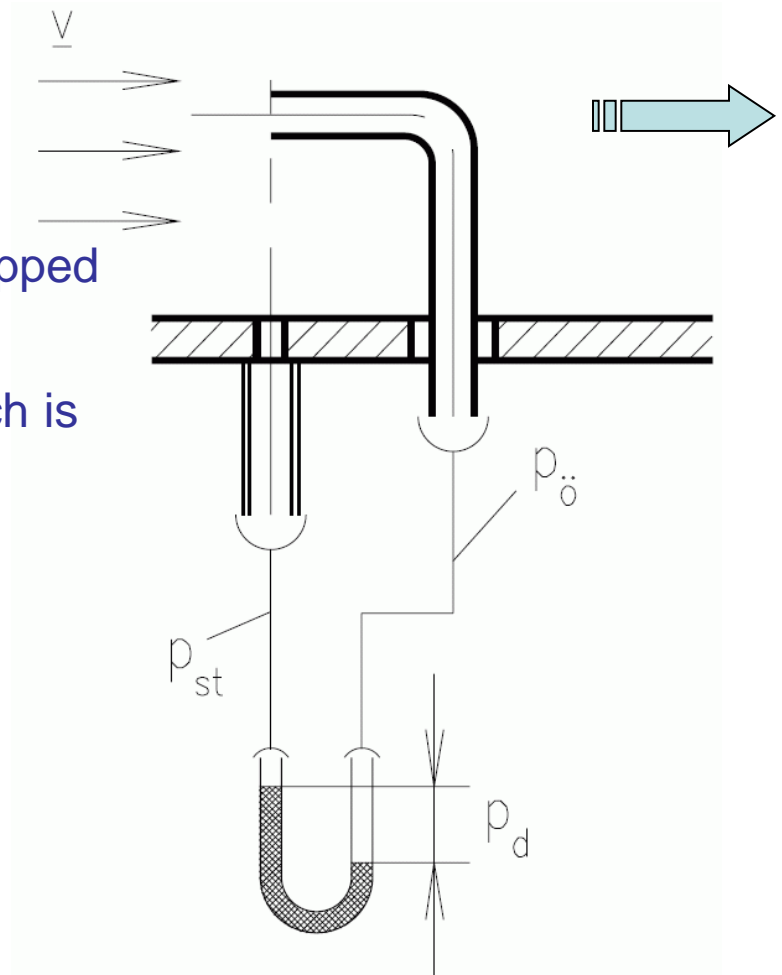
Velocity measurement / Pitot-static (Prandtl) tube/probe

Prandtl, Ludwig von (1875-1953), German fluid mechanics researcher
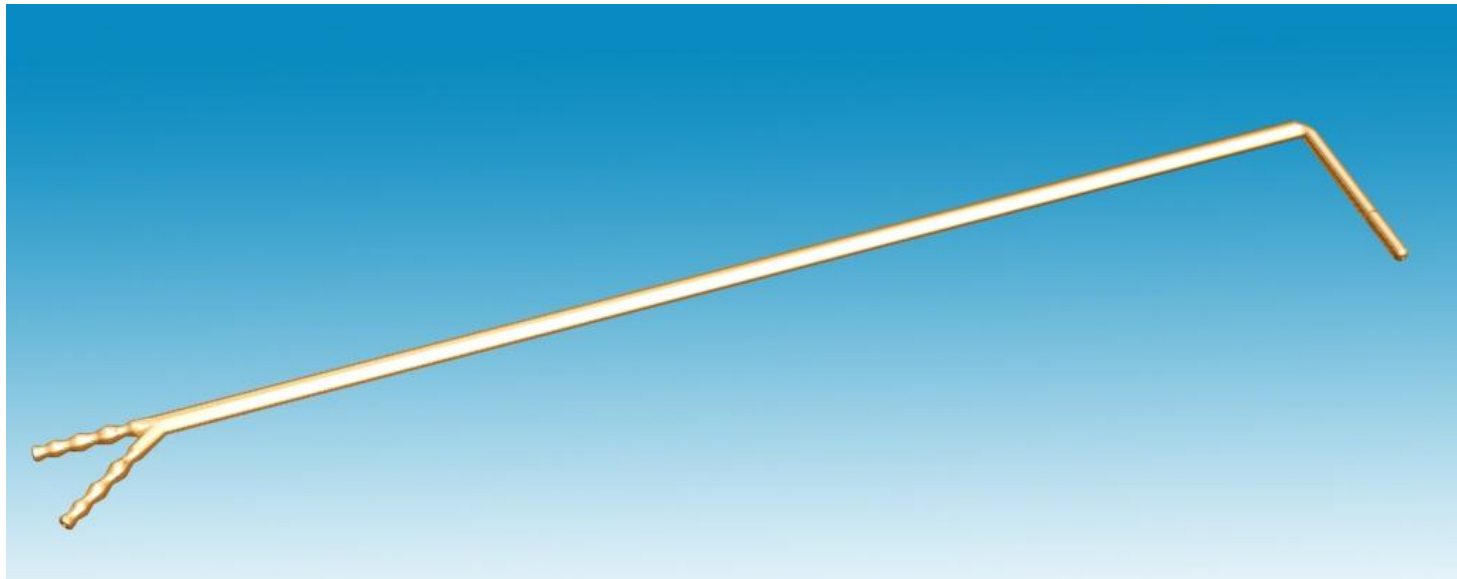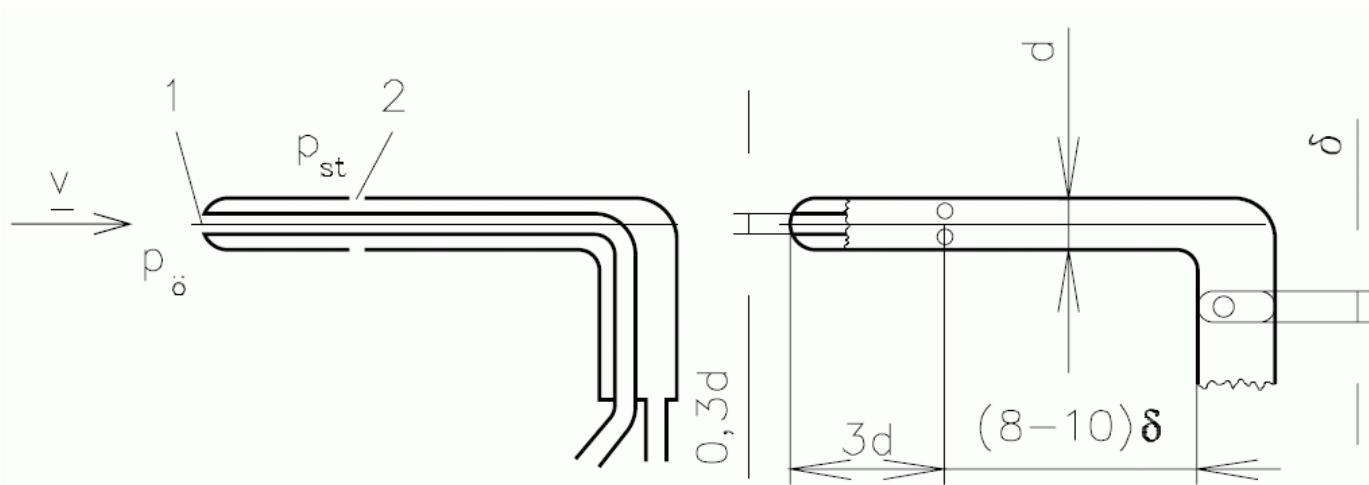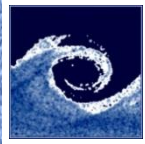
Measuring volume flow rate

- Definition of volume flow rate

- Measurement method based on velocity measurements in multiple points

  - Non-circular cross-sections

  - Circular cross-sections

    - 10 point method

    - 6 point method

- Pipe flow meters based on flow contraction

  - Venturi flow meter (horizontal/inclined axis)

  - Through flow orifice (contraction ratio, iteration)

  - Inlet orifice

  - Inlet bell mouth
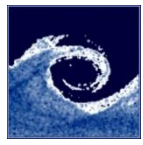
Very important: the square root of the averages ≠ the average of the square roots(!)

Example: Measuring the dynamic pressure in multiple points and calculating the velocity from it

$$v_i = \sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_i} \qquad\qquad v_1 = \sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_1}$$

1.	2.
3.	4.

$$\bar{v} = \frac{\sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_1} + \sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_2} + \sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_3} + \sqrt{\frac{2}{\rho_{ny}} \cdot \Delta p_4}}{4} \neq \sqrt{\frac{2}{\rho_{ny}} \cdot \frac{\Delta p_1 + \Delta p_2 + \Delta p_3 + \Delta p_4}{4}}$$

Correct   Incorrect

$$q_v = \int_A \underline{v} \cdot \underline{dA} \approx \sum_{i=1}^{n} v_{m,i} \cdot \Delta A_i$$

Assumptions:

$$\Delta A_1 = \Delta A_2 = \Delta A_i = \frac{A}{n}$$

$$q_v = \Delta A_i \cdot \sum_{i=1}^{n} v_{m,i} = \frac{A}{n} \cdot \sum_{i=1}^{n} v_{m,i} = A \cdot \bar{v}$$

•The velocity profile is assumed to be a 2nd order parabola
•Steady flow conditions
•Based on Pitot-static (Prandtl) tube measurements of the dynamic pressure
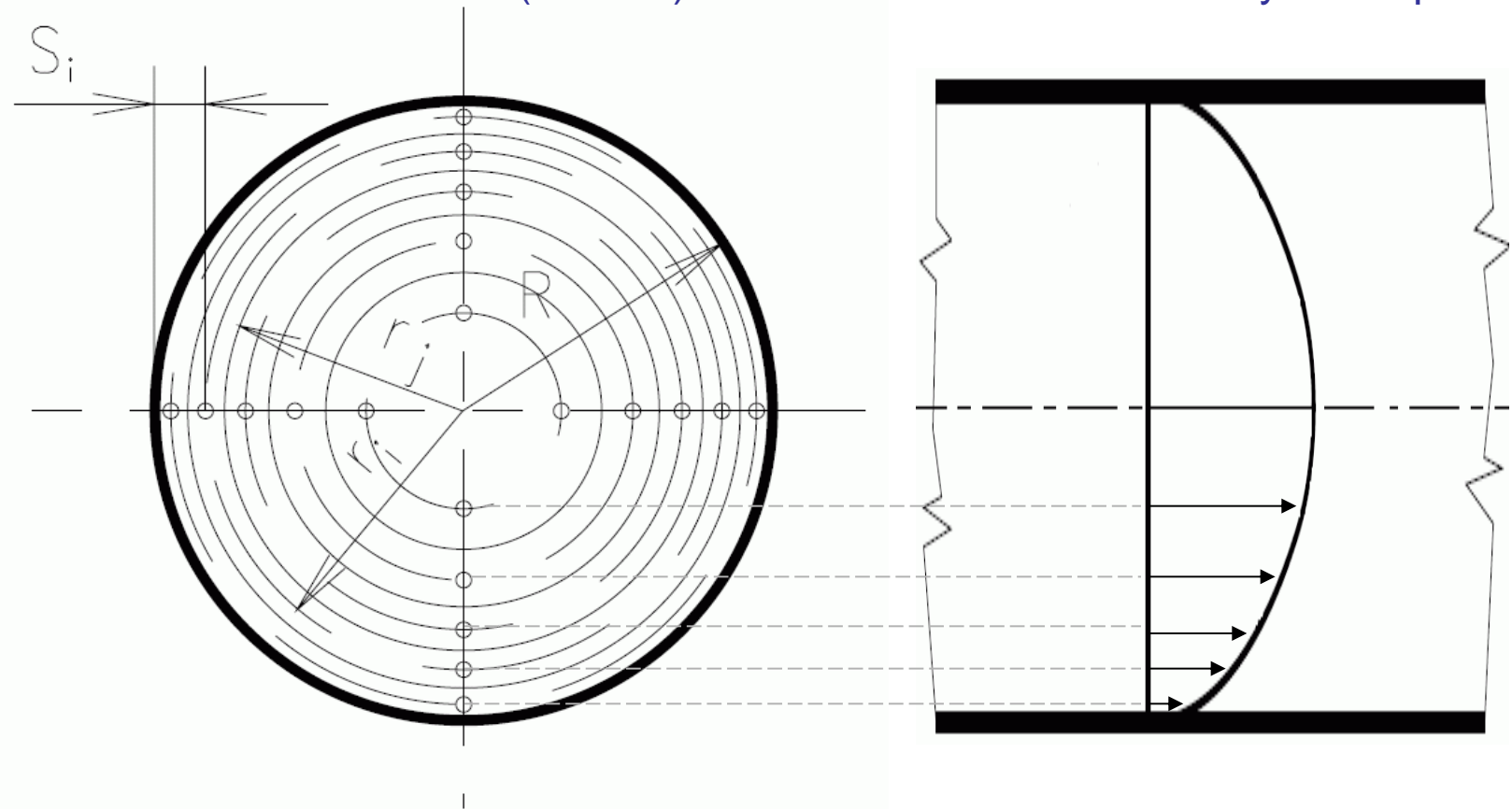
This is a standardized procedure, and the measurement point are given in the standard (MSZ 21853/2):
S_i/D= 0.026, 0.082, 0.146, 0.226, 0.342, 0.658, 0.774, 0.854, 0.918, 0.974

$$q_v = A \cdot \frac{v_1 + v_2 + \ldots + v_{10}}{10}$$

Assumptions:

$$A_1 = A_2 = \ldots = A_{10}$$

The advantage of this method, as compared to methods based on flow contraction, is that the flow is not disturbed greatly, and therefore the operation point of the system is not altered as well as that it is easy to execute the measurements.

The disadvantage is that the error can be much larger with this method. For long measurements it is also hard to keep the flow conditions constant. (10 points x 1.5 minutes = 15 minutes)
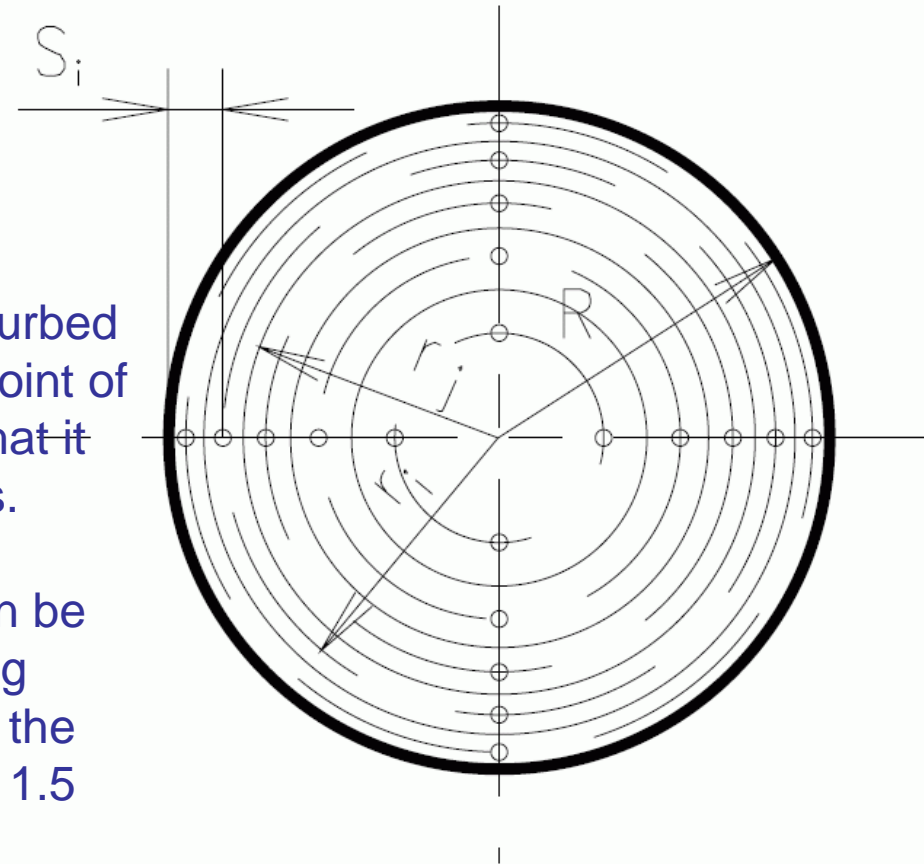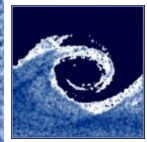
If compressibility is negligible (ρ=constant):

$$q_v = v \cdot A = cont. \qquad [q_v] = \frac{m^3}{s}$$

$$q_v = v_1 \cdot A_1 = v_2 \cdot A_2$$

Bernoulli equation (ρ=const., U=const., no losses):

$$p_1 + v_1^2 \cdot \frac{\rho_{ny}}{2} = p_2 + v_2^2 \cdot \frac{\rho_{ny}}{2}$$

$$v_1 = \sqrt{\frac{(\rho_m - \rho_{ny}) \cdot g \cdot \Delta h}{\frac{\rho_{ny}}{2} \cdot \left[\left(\frac{d_1}{d_2}\right)^4 - 1\right]}} = \sqrt{\frac{\Delta p}{\frac{\rho_{ny}}{2} \cdot \left[\left(\frac{d_1}{d_2}\right)^4 - 1\right]}}$$

A_1

A_2

H

p_1 p_2

ρ_{ny}

ρ_m

Δh
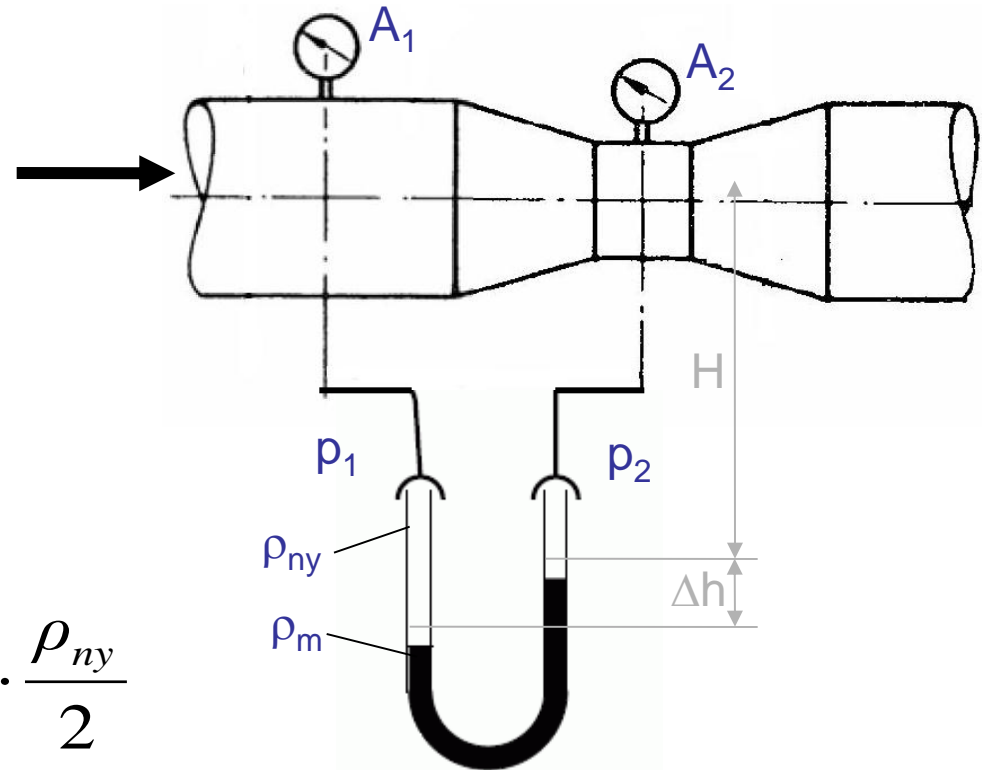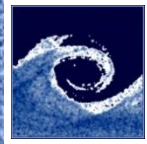
Standard orifice - pressure difference
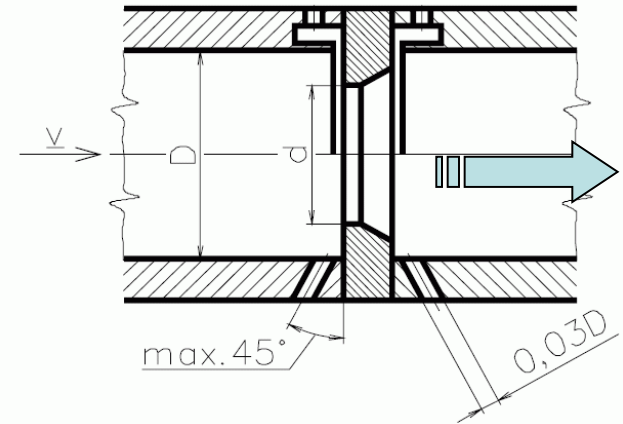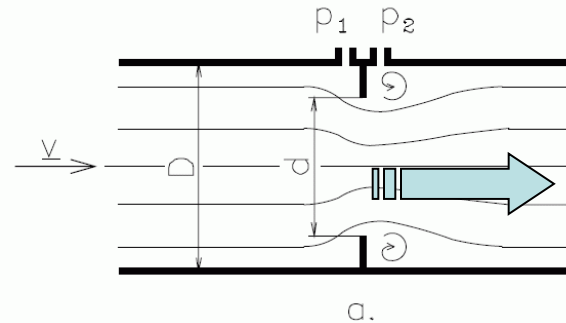
$$q_v = \alpha \cdot \varepsilon \cdot \frac{d_{or}^2 \cdot \pi}{4} \cdot \sqrt{\frac{2\Delta p_{or}}{\rho}}$$

$\beta = d/D$ Cross-section ratio

d [m]   Diameter of the smallest cross-section

D [m]   Diameter of the pipe upstream of the orifice

$Re_D = Dv/\nu$ Reynolds number's basic equation

v [m/s]   The average velocity in the pipe of diameter D

ν [m²/s]   kinematic viscosity

p_1 [Pa]   The pressure measured upstream of the orifice

p_2 [Pa]   The pressure measured downstream of the orifice

ε Expansion number ($\varepsilon=\varepsilon(\beta,\tau,\kappa)\sim 1$ since for air, the change in pressure is small)

α Contraction ratio, $\alpha=(\beta,Re)$ (When used according to the standard)

κ Heat capacity ratio or Isentropic expansion factor

$\tau=p_2/p_1$ Pressure ratio

Not a standard contraction – pressure difference

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

$$\alpha = 0.6$$
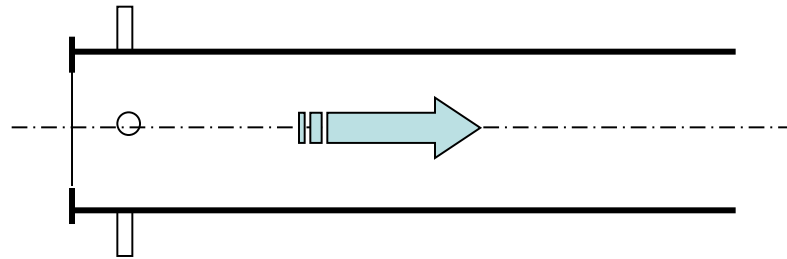
$$q_v = k \cdot \frac{d_{or}^2 \cdot \pi}{4} \cdot \sqrt{\frac{2\Delta p_{or}}{\rho}}$$
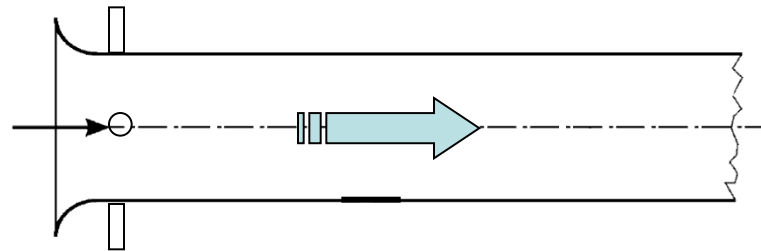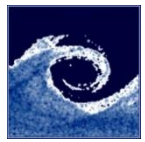
Example: Pipe volume flow rate uncertainty

Dynamic pressure measured using a Pitot-static (Prandtl) tube:
p_d =486.2Pa

Atmospheric conditions experienced in the lab:
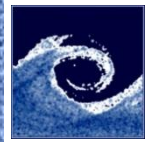p =1010hPa ; T=20°C (293K);
Gas constant of air
R=287 J/kg/K

$$v = \sqrt{\frac{2}{\rho_{air}} \cdot \Delta p_d} \qquad \rho_{air} = \frac{p_0}{R \cdot T}$$

$$v = \sqrt{\frac{2}{p_0} \cdot \Delta p_d RT}$$

$$v = 28.45 \quad \frac{m}{s} \qquad \rho_{air} = 1.2 \frac{kg}{m^3} \qquad v = f(T, p_0, \Delta p_d, const.values)$$

Quantities having uncertainties (X_i):
The measurement uncertainty of the atmospheric pressure
comes from the error arising when reading the scale δp_0=100Pa
The measurement uncertainty of the atmospheric temperature
in the lab, δT=1K
The pressure measurement uncertainty arising when making a
measurement using a Pitot-static (Prandtl) probe and the
following digital manometer (EMB-001) $\delta(\Delta p_i)$=2Pa
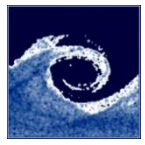
Example: Pipe volume flow rate uncertainty

Typical absolute error

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

$R = v$

$X_1 = T; X_2 = p_0; X_3 = \Delta p_d$

$(\delta p,\ \delta T,\ \delta(\Delta p_d))$
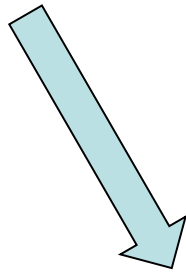
$$\frac{\partial v}{\partial T} = \sqrt{2R} \cdot \frac{1}{2} \cdot T^{-\frac{1}{2}} \cdot \frac{1}{\sqrt{p_0}} \cdot \sqrt{\Delta p_d} = 0{,}00366\,\frac{m}{s \cdot K}$$

$$\frac{\partial v}{\partial p_0} = \sqrt{2R} \cdot \sqrt{T} \cdot \frac{-1}{2} \cdot p_0^{-\frac{3}{2}} \cdot \sqrt{\Delta p_d} = 1{,}4 \cdot 10^{-4}\,\frac{m}{s \cdot Pa}$$

$$\frac{\partial v}{\partial \Delta p_d} = \sqrt{2R} \cdot \sqrt{T} \cdot \frac{1}{\sqrt{p_0}} \cdot \frac{1}{2} \cdot \Delta p_d^{-\frac{1}{2}} = 0{,}029\,\frac{m}{s \cdot Pa}$$
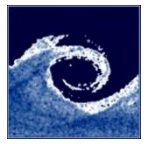
Example: Pipe volume flow rate uncertainty

The absolute uncertainty of the velocity measurement:

$$\delta v = \sqrt{\left(\delta T \cdot \sqrt{\frac{2R}{p_0} \Delta p_d} \cdot \frac{1}{2} \cdot T^{-\frac{1}{2}}\right)^2 + \left(\delta p_0 \cdot \sqrt{2 \cdot R \cdot T \cdot \Delta p_d} \cdot \frac{-1}{2} \cdot p_0^{-\frac{3}{2}}\right)^2 + \left(\delta(\Delta p_d) \cdot \sqrt{\frac{2 \cdot R \cdot T}{p_0}} \cdot \frac{1}{2} \cdot \Delta p_d^{-\frac{1}{2}}\right)^2}$$

$$\delta v = 0.05977 \ \frac{m}{s}$$

The relative uncertainty of the velocity measurement:

$$\frac{\delta v}{v} = 0.0021 = 0.21\%$$

The result of the velocity measurement:

$$v = 28.45 \ \pm 0.05977 \ \frac{m}{s}$$

Downloadable materials

www.ara.bme.hu/poseidon

english

login ->username: neptun code (lower case letters), password: NEPTUN CODE (capital letters)

„Egyéb tantárgyinformációk"

BMEGEATAG01 (AG11 or AM06) ->english

Or www.ara.bme.hu

In english

Download

„Tantárgyak"

BMEGEATAG01 (AG11 or AM06) ->english
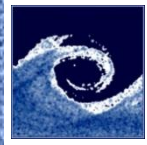
Preparing for the laboratory measurements

- In preparing for the laboratory measurements, all members of the measurement group must understand the measurement which is to be made.

- The poseidon network needs to be checked, in order to find out which measurement assignment is assigned to the group (e.g. M03/c).
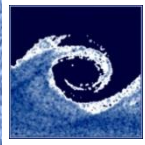
Preparing for the laboratory measurements

- Millimeter paper needs to be brought to the laboratory measurements

- A hand written outline of the measurement needs to be prepared by the lab leader. This outline should contain the following:

  - The measurement groups information (names, neptun codes, leaving a space for checking attendance)

  - Space where the measurement supervisor can sign each page.

  - A list of the instruments which will be used during the measurement, leaving room for the serial numbers, which will be documented during the measurement

  - A table for documenting the measured and calculated values (e.g. pressure, temperature, etc.)

  - The equations which are necessary in order to complete the measurement and the associated calculations, leaving room for verification calculations.

During the laboratory measurement

- At the beginning of the laboratory the hand written outline will be checked by the instructor supervising the measurement, and questions will be asked in order to determine whether the group is prepared for the measurement.

  - If the group is unprepared, they will be sent away

- During the laboratory the faculty member supervising the laboratory session will evaluate the groups preparedness by asking questions regarding the measurement and evaluating the properness of the measurement by conducting sample calculations with the groups as well as having them graph certain values. If the group is deemed unprepared, they will be sent away.

- The measurements need to be completed during the allotted time.

- The proper calibration of the digital manometer needs to be assessed during the laboratory measurement, with the help of the Betz micromanometer.

- During the measurement, department personnel supervising the measurements will assign a task to each group, by which some values measured during the laboratory measurement will be drawn on the millimeter paper, in order to check the correctness of the measurement and the understanding of the measured results. If the task can not be completed in a satisfactory manner, the measurements must be repeated.

After the laboratory measurement

- A measurement report must be produced

- For those laboratory measurements for which the laboratory evaluation control tools are prepared, the calculations must be checked and accepted by the system.

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  - Use of the control tools is mandatory, when these tools are available.

  - The control tools assess whether the calculations were executed correctly.

  - If the calculations were deemed invalid, they must be repeated, and the control tools must be used again, to see if the answers are correct.

    - There is no limit to the number of attempts which can be made, but the attempts are logged, and can be taken into account when giving grades.

  - Once the calculations are correct, a code is provided to the student, which must be included on the laboratory report cover.
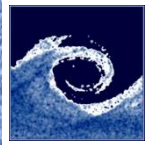
- Example:

Sajnos a számítása helytelen. Kérjük ellenőrizze a bevitt adatokat és próbálja
Próbálkozások száma: 7.

* Beszívóelemen mért nyomásesés (3. térfogatáram):	300	[Pa]
* Mérőperemen mért nyomásesés (1. térfogatáram):	400	[Pa]
* Mérőperemen mért nyomásesés (2. térfogatáram):	500	[Pa]
* Mérőperemen mért nyomásesés (3. térfogatáram):	600	[Pa]

Származtatott mérési adatok

Hőmérséklet:	kihagy	[K]	
* Levegő sűrűsége:	1.18	[kg/m^3]	Elfogadva!
* Levegő kinematikai viszkozitása:	1.507e-5	[m^2/s]	Elfogadva!

Kalibráció (1. térfogatáram)

Mérőperem átfolyási tényező, C (1. lépés):	0.6	[-]	Elfogadva!
Térfogatáram (1. lépés szerint):	kihagy	[m^3/s]	
Sebeség (1. lépés szerint):	kihagy	[m/s]	
* Reynolds-szám (1. lépés szerint):	30e3	[-]	Pontatlan számítási eredmény!
Mérőperem átfolyási tényező, C (2. lépés):	kihagy	[-]	
* Mérőperem átfolyási tényező, C (végleges):	0.65	[-]	Elfogadva!
* Térfogatáram (végleges):	0.025	[m^3/s]	Pontatlan számítási eredmény!
* Beáramlási tényező:	1.8	[-]	Pontatlan számítási eredmény!

Kalibráció (2. térfogatáram)

Mérőperem átfolyási tényező, C (1. lépés):	0.6	[-]	Elfogadva!
Térfogatáram (1. lépés szerint):	kihagy	[m^3/s]	
Sebeség (1. lépés szerint):	kihagy	[m/s]	
* Reynolds-szám (1. lépés szerint):	31e3	[-]	Elfogadva!

- It is not mandatory to fill out the grey cells..

- If the program deems the calculations incorrect, then it might be useful to fill out these cells, in order to help one find the source of the error.
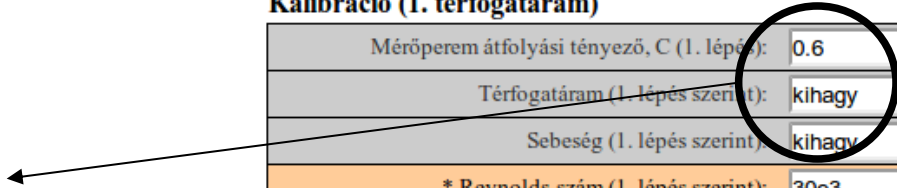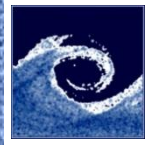
After the laboratory measurement

- After the calculations are accepted (where applicable), the reports must be submitted through the poseidon network
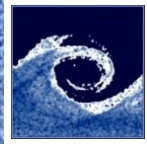
- Reports must be submitted by midnight of the second Sunday following the measurements.
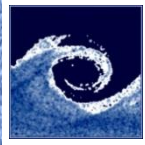
After the laboratory measurement

- Consultations:

    - The faculty members grading the reports will provide one consultation opportunity per week at a given time.

    - The measurement groups can also come to the laboratory to consult with the supervisors overseeing the given measurements during the last 15 minutes of any regular measurement session.

- Extent of lab reports

    - The cover of the laboratory report must be downloaded from the webpage.

    - The lab report can only be 6 pages long plus the required report cover and mandatory annex

    - A mandatory annex to the 6 pages needs to contain the following:

        - A scanned copy of the hand written notes which were signed upon completion of the laboratory measurement, and which contain all the tables of all the data which was recorded.

    - The uploaded zip file must contain an excel file in which the calculations were made and the pdf of the laboratory report.

•ALL LABORATORY REPORTS NEED TO BE ORIGINAL AND MADE BY THE LAB GROUP! ANY MEASUREMENT LEADERS SUBMITTING WORK WHICH WAS NOT SOLELY PRODUCED BY THE GROUP, WITHOUT CITING THE APPROPRIATE SOURCE, WILL HAVE TO FACE THE CONSEQUENCES OF THEIR ACTIONS!

•The reports are evaluated within 2 days, and a message is sent to the student through the poseidon network informing the student whether the report was accepted or not. If the report is unacceptable, there is one opportunity to resubmit the report by the following Sunday at midnight.

•Please note that in some cases the reports need to be submitted earlier in order to make sure that presentations can be presented when needed.

Presentation

- The template for the presentations, which is also an example for a typical presentation, can be downloaded from the webpage.

- 8 minutes

- The measurement needs to be summarized.

- The personal measurement assignment needs to be presented and explained.

- The measurement stand and the used equipment needs to be presented.

- Error calculations need to be presented.

- The evaluation of the results needs to be presented.

- The results need to be shown

- The conclusions and results need to be summarized.