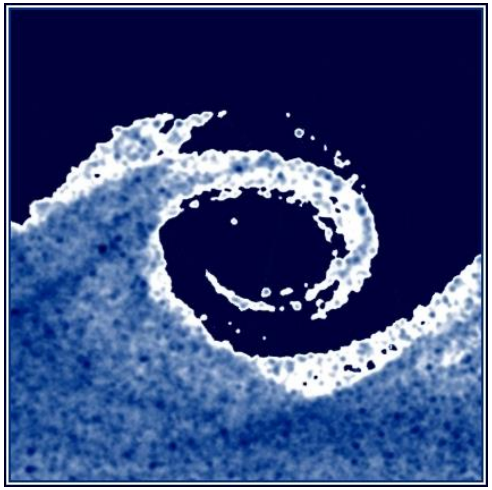


Budapesti University of Technology and Economics

Department of Fluid Mechanics

www.ara.bme.hu

Pre-measurement class I.

Dr Josh DAVIDSON, josh.davidson@gpk.bme.hu

If you have any questions, contact me!

2023

General information

- Department webpage: www.ara.bme.hu
- Student information page: www.edu.gpk.bme.hu

  (test scores, report and presentation upload etc.)
- Subject webpage:http://www.ara.bme.hu/neptun/BMEGEATAG11/ENGLISH_course/
- Laboratory webpage (materials, control tools): www.ara.bme.hu/lab

- **Schedule**
  - 1st occasion (2nd week): general info, measurement uncertainty
  - 2nd occasion (4th week): measurement equipment, methods
  - 3rd occasion (6th week): presentation of the measurents + **lab test (online)**
  - 4th occasion (8th week): measurement A
  - 5th occasion (10th week): SPRING BREAK, NO MEASUREMENT
  - 6th occasion (12th week): measurement B
  - 7th occasion (14th week): presentations of measurements A and B

General information

Measurement groups:

- 4 people in each group
- For the two different measurement occasions (A,B), 2 members of the group are leading while the other 2 are assisting
- The leaders prepare one report and one presentation for their measurement (same number of points will be given for the 2 people)
- For each measurement a subtask is assigned. The members of the groups and the subtasks will be on the webpage

Group #	Name	Neptun		Meas. Nr.	Task
1	Pedro Pascal	ABC123	Leaders of meas. A	M12	C
	Bella Ramsey	BAC231			
	Donald Glover	CAB321	Leaders of meas. B	M10	D
	Bryan Henry	BCA213			

Preparing for the laboratory measurements

- In preparing for the laboratory measurements, all members of the measurement group must read the syllabus (downloadable from the webpage: www.ara.bme.hu/lab) and understand the measurement which is to be made.
- A **hand written** outline of the measurement is prepared by the leaders before the beginning of the measurement, containing the following:
    - The measurement group's 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
    - Tables for documenting the measured and calculated values, including atmospheric conditions (e.g. atmospheric pressure and temperature, etc.)
    - The equations which are necessary in order to complete the measurement and the associated calculations, leaving room for verification calculations
    - Millimeter paper needs to be brought to the laboratory measurements

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. Unprepared groups will have to repeat the measurement.
- 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 micro manometer.
- During the measurement, department personnel supervising the measurements will assign a task to each group. The task will be to draw a graph of some measured values on the millimeter paper, in order to check the correctness of the measurement and the understanding of the measured results.

After the laboratory measurement

- A measurement report must be produced from the measured data
- Laboratory calculations must be checked utilizing the department’s online evaluation tools.

  www.ara.bme.hu/lab

  - **Use of the control tools is mandatory**. The control tools only evaluate whether the equations were applied properly.
    - There is no limit as to the number of attempts which can be made, but the attempts are logged, and can be taken into account when giving grades. (fair use policy)
    - In previous semesters each measurement had students who were able to complete the calculations correctly upon their first attempt.
  - **Once the calculations are correct**, a code is provided to the student.
    - **This code must be included on the laboratory report cover**.
    - The number of attempts, and the calculation error [%], as compared to the expected calculated value, will be taken into consideration when grades are assigned.

After the laboratory measurement

- Example:

Calculations are not accepted. Please check your data and try again!
Number of attempts: 1.

Measured and evaluated measurement data

* Atmospheric pressure:	99600	[Pa]	
* Lab. temperature:	21.8	[°C]	
Inflow coefficient:	skip	[-]	
The diameter of the tube:	skip	[mm]	
The diameter of the impeller:	skip	[mm]	
Lab. temperature:	skip	[K]	
Density of air:	skip	[kg/m^3]	
* Kinematic viscosity of air:	0.000015	[m^2/s]	Accepted!
Error of pressure-difference measurement:	skip	[Pa]	
Error of the temperture measurement:	skip	[K]	
Error of atmospheric pressure measurement:	skip	[Pa]	

The values for only one operating point should be given

* Number of revolution:	2500	[1/min]	
* Pressure difference measured at the inlet orifice:	385	[Pa]	
* Total pressure increase produced by the fan:	417	[Pa]	
* Flowrate:	0.43387	[m^3/s]	Accepted!
* Effective power:	205.7	[W]	Inaccurate calculation result!
* Flow coefficient:	0.1221	[-]	Inaccurate calculation result!
* Pressure coefficient:	0.358	[-]	Accepted!
* Absolut errof of the effective power:	1.1763	[W]	Inaccurate calculation result!
* Relative errof of the effective power:	0.0572	[-]	Inaccurate calculation result!

- 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

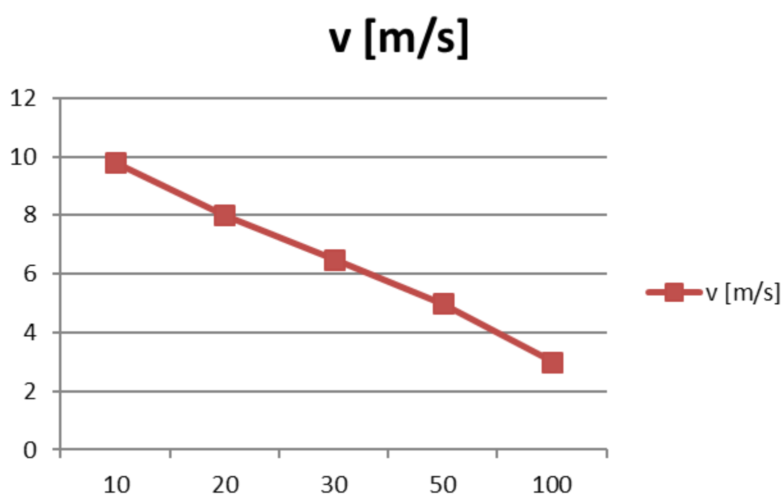
- After the calculations are accepted, the reports must be submitted through the Faculty moodle: www.edu.gpk.bme.hu
- Reports must be submitted **by midnight of the 2nd Sunday following the measurement**
- Consultations:
  - The faculty members grading the reports will provide consultation opportunities for each measurement they are grading. You can ask for consultation in email.
  - The name of the instructor responsible for each measurement can be found on the website: www.ara.bme.hu/lab

After the laboratory measurement

- Requirements of laboratory reports (can also be found at www.ara.bme.hu/lab)
  - The cover of the laboratory report must be downloaded from the web site.
  - The lab report can only be 8 pages long plus the required report cover and mandatory annex
  - The report should contain the following:
    - Code (proving that the calculations are right) on the cover
    - Short description of the measurement, data of the measurement device
    - The subtask
    - Equations
    - The measured and calculated data in tables
    - Uncertainty calculations
    - Necessary diagrams with error bars
    - Interpretation of the measurement results
    - Bibliography
    - The hand-written measurement plan, filled in during the measurement as an annex (in scanned form)

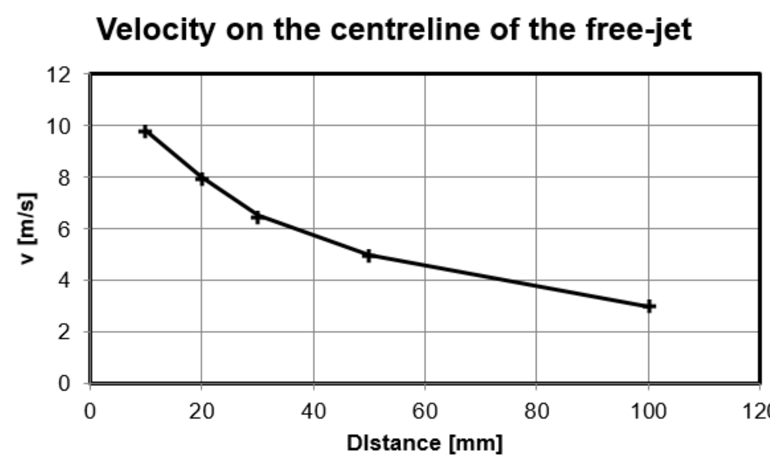
After the laboratory measurement

- Beside the report the Excel file containing the calculations should also be submitted
- The type of the diagrams should be XY plot, use of the line plot is FORBIDDEN! (the distance on the X axis will not be proportional)



Incorrect (and ugly)

(the values on the X axis are only labels)



Correct

(the values on the X axis are numbers)

After the laboratory measurement

- Incorrect (and ugly) diagram

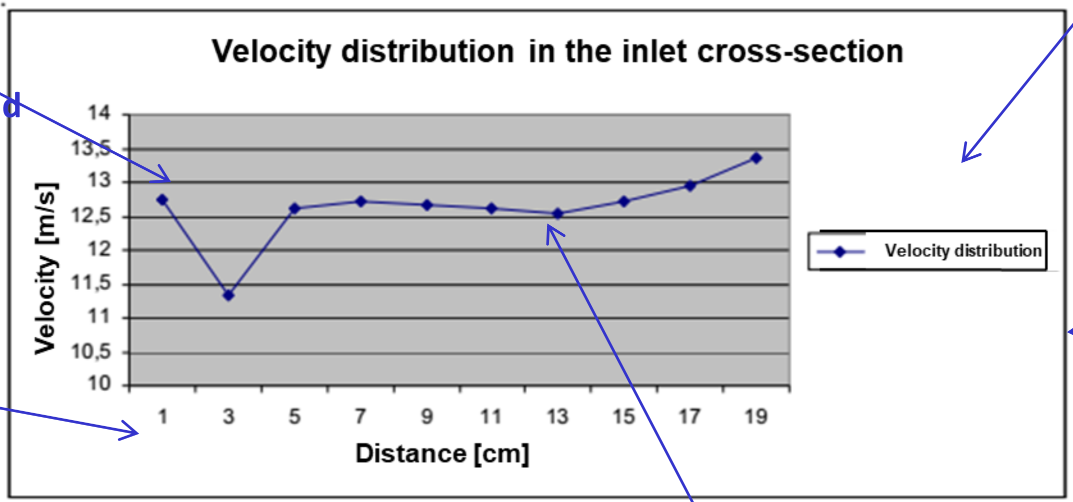
Unnecessary legend, thus the diagram is small

The coloring of the curve is unnecessary

Why is the background gray?

Bad diagram type

The border is unnecessary



There are no errorbars

After the laboratory measurement

- Nice diagram

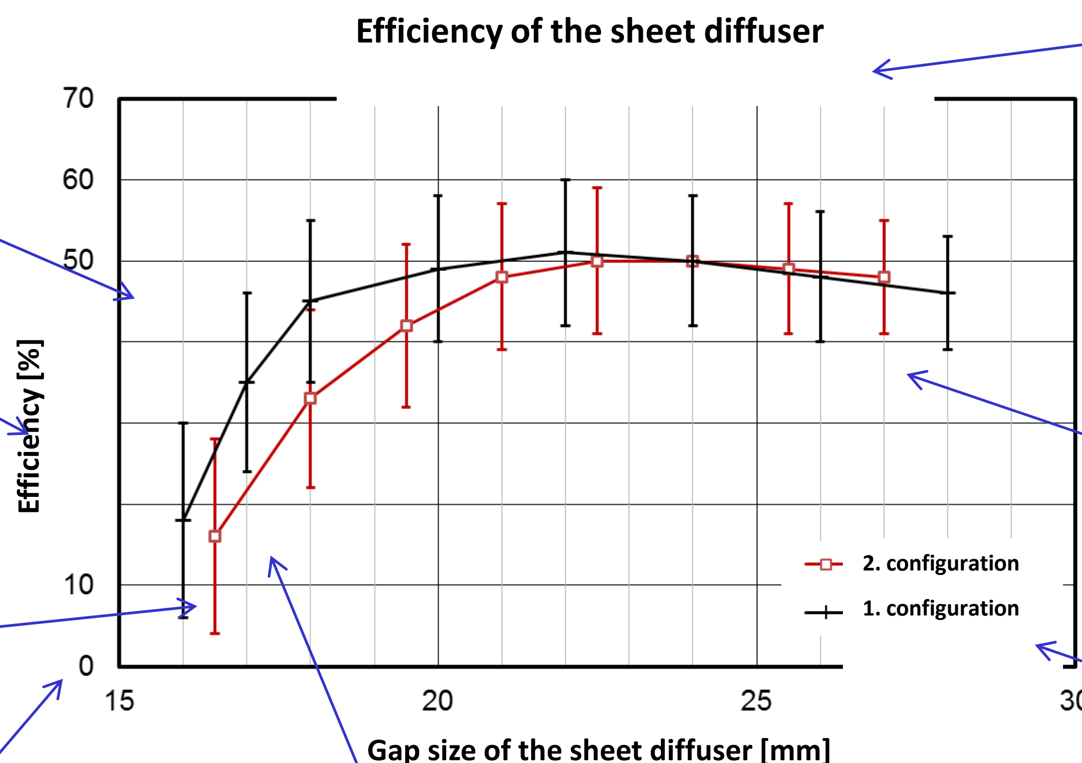


Figure 3. The efficiency of the sheet diffuser as a funcion of gap size for the two measured configurations

Title (not necessary, instead caption can be used at the bottom)

Boundary: 1.5-2 pt, grid lines: 0.5 pt.

Axis name and [dimension]

Readable letter size

Error bars

Minimal number of conrasting colors

Meaningful legend

The axis starts from 0 (not autoscale)

Points connected with sraight lines
(We are indicating that they belong together, and not an interpolation between them. Not even necessary.)

The diagram is not miniature, it utilizes well the width of the page

After the laboratory measurement

- The report should be logical and „nice”
    - Justified form
    - Equations are created with the equation editor and not copied in as a picture
    - Diagrams are uniform
    - Hand made figures should be avoided (use: photos, CAD softwares…)
- The file extension of the report should be PDF
- A mandatory annex to the 8 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
- The name of the file should be in the following form:
    - Lastname1_neptun1_lastname2_neptun2_Mx_deadline.zip
    - Example: Pascal_ABC123_Ramsey_BAC231_M12C_20230507.zip

After the laboratory measurement

- ALL LABORATORY REPORTS NEED TO BE ORIGINAL AND MADE BY THE LAB GROUP! ANY GROUP SUBMITTING WORK WHICH WAS NOT SOLELY PRODUCED BY THE GROUP, WITHOUT CITING THE APPROPRIATE SOURCE, WILL BE REPORTED TO THE DEAN'S OFFICE AND THE ETHICS COMMITTEE IN ACCORDANCE WITH THE CODE OF STUDIES (CoS/TVSZ)
- The deadline for the submition of the report is **midnight of the 2nd Sunday following the measurement**
- The reports are evaluated within 2 working days, and a message is sent to the student through moodle 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, however in this case you can only receive the **80%** of the maximal points.
- The report is **accepted** if the received points reach the **40%** of the maximal points
- The accepted report can also be improved once for better points until next Sunday
- An accepted report is a criterion for the presentation (info will be provided later)

Late submission and make up

- Sanctions for late submission
    - -20%
    - Extra fee will be charged
    - The report must be submitted by Friday 4 pm on the 14th week! (this is very severe delay)
- Retake of the lab test:
    - 3 chances
    - Re-retake: oral (you have to contact your seminar instructor)
- Late presentation:
    - During the „repeat exam period”
    - Additional fee

Presentation (more info later)

- The template for the presentations, which is also an example for a typical presentation, can be downloaded from the webpage.
- You may use the departmental template, but don't need to
- 8 minutes
- The measurement has to be summarized.
- The personal measurement assignment has to be presented and explained.
- The measurement set-up and the used equipment has to be presented.
- Error calculations has to be presented.
- The evaluation of the results has to be presented.
- The results have to be shown
- The conclusions and results have to be summarized.
- (Suggestions for the improvement of the measurement)
- Try to make it unique and interesting!

Checklist

At the measurement:

- In preparing for the measurement (hand written measurement plan): assignment, neptun code, name, documentation, personal assignment, mm paper, signature.
- The laboratory instructor checks your preparedness with 1 or 2 questions
- Record atmospheric conditions (p_0, T_0) before and after the laboratory
- Calibrate to the Betz micro manometer
- You can ask questions from any of the laboratory instructors at the laboratory session, but it is advised to ask from the one leading your measurement
- Check the list of supplies in your measurements box. The box will be opened and closed by the laboratory instructor. The laboratory instructor will provide manometers, and will replace those which needs to be charged. Do not connect digital manometers to chargers!

After the measurement

- Consultations can be made with the appropriate instructor during consultation hours.
- Calculation results have to be checked www.ara.bme.hu/lab
- Once calculations are correct and the report is complete, submit the report: www.edu.gpk.bme.hu (pdf+xls)
    - zip name = Lastname1_neptun1_lastname2_neptun2_Mx_deadline.zip

Determining the uncertainty of the results (error calculation) I.

- **Absolute error** (measurement uncertainty): the region where the measurement data is located with 95% confidence
- Notation if the measured data is *X*: δX
- The **correct specification of the measurement data** in this case: $X \pm \delta X$
- **Relative error:** $\delta X / X$
- In case of a **calculated quantity (*R*)** the error propagates, and the following equation is used:

$$R = R(X)$$

$$\delta R = \frac{\partial R(X)}{\partial X} \cdot \delta X$$

Example

Measurement uncertainty of an inclined manometer

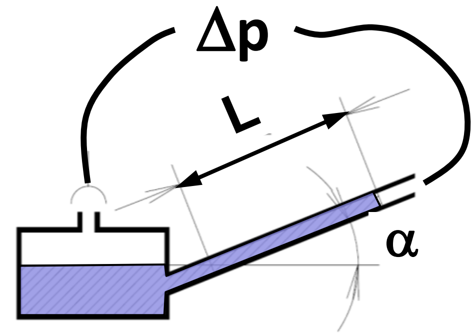
$\Delta p = \rho \cdot g \cdot L \cdot sin(\alpha)$

$\delta L = \pm 8mm$

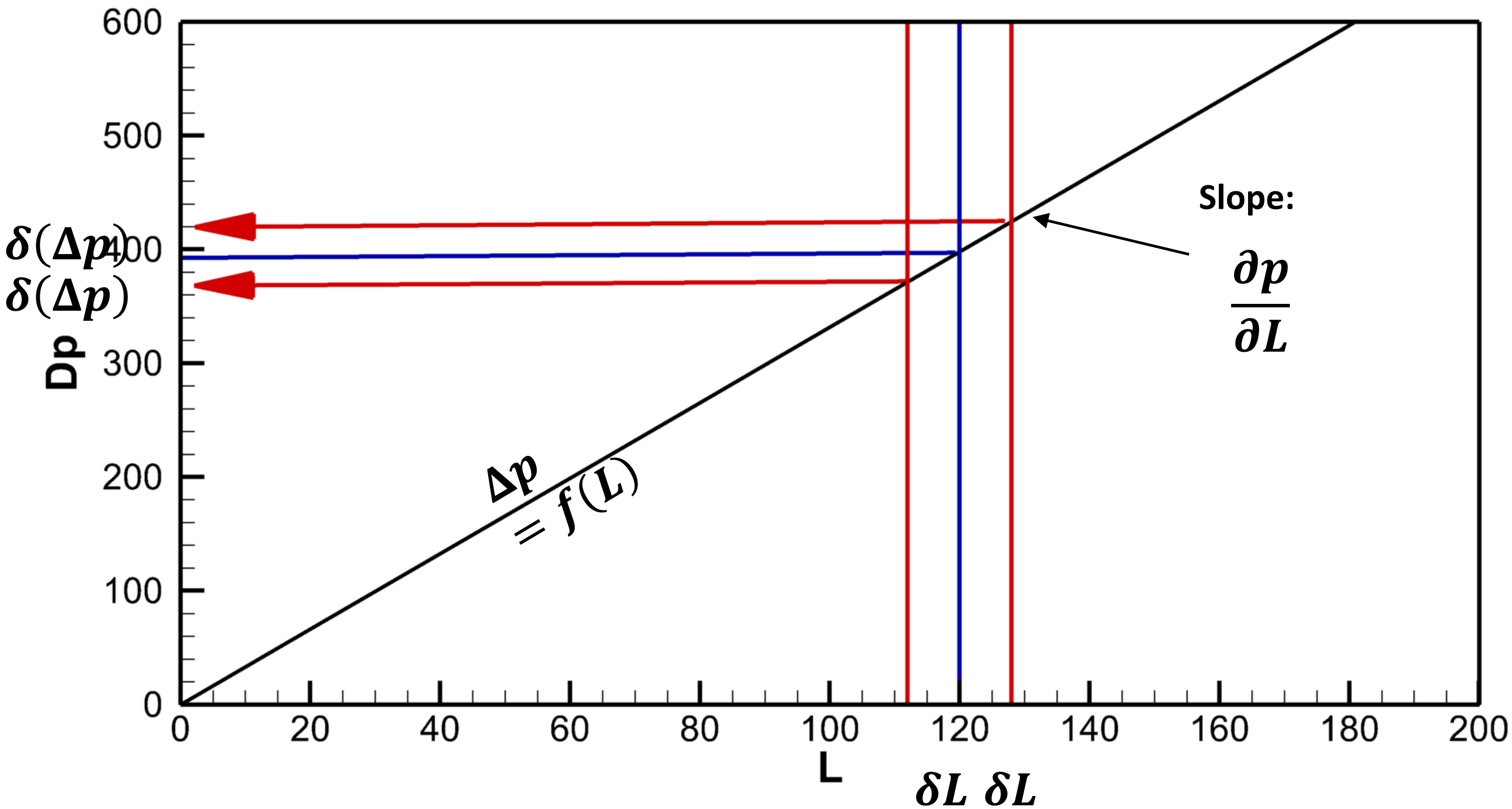
$\delta(\Delta p) = ?$

ρ=800 kg/m³, α = 25°

$$\delta(\Delta p) = \frac{\partial p}{\partial L} \cdot \delta L$$



$\Delta p = \rho_m \cdot g \cdot L \cdot \sin(\alpha)$



Multiple measured quantity

- **In case of more, independently measured variables :**

$$R = R(X_1, X_2, ..., X_n)$$

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

Why aren't we taking the sum of the errors?

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

Because the errors are **random,** they can be smaller and larger than the expected value. Thus, they can both increase and decrease the value of the calculated quantity. Consequently, the resulting error (caused by multiple measured quantities with errors) will be smaller than the sum of the errors caused by the individually measured quantities.

Example

Measurement uncertainty of an inclined manometer

$\Delta p = \varrho \cdot g \cdot L \cdot sin(\alpha)$

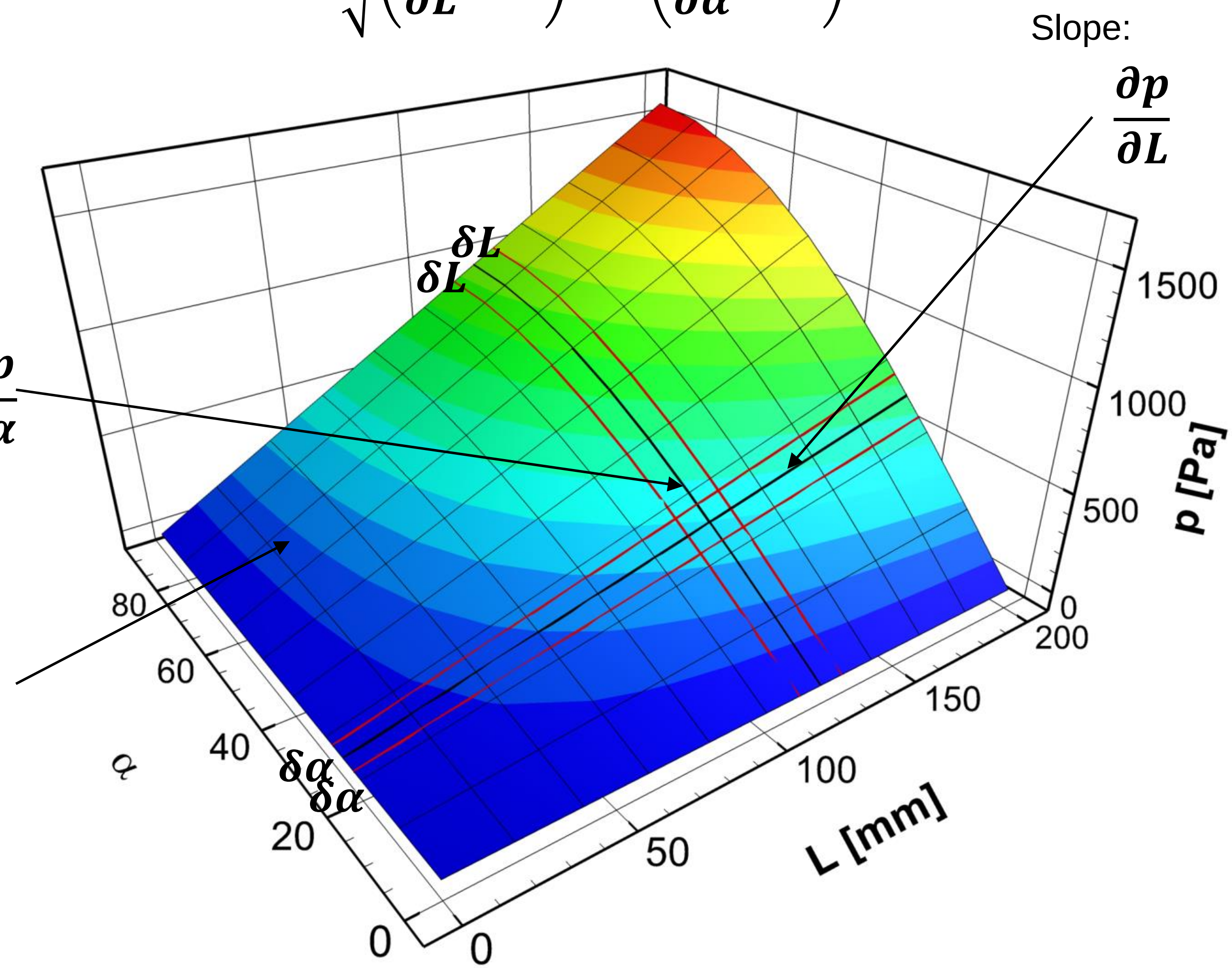
$\delta L = \pm 8\,mm$

$\delta\alpha = \pm 3°$

$\delta(\Delta p) = ?$

ρ = 800 kg/m³,
L = 120 mm
α = 25°

$$\delta(\Delta p) = \sqrt{\left(\frac{\partial p}{\partial L}\cdot\delta L\right)^2 + \left(\frac{\partial p}{\partial \alpha}\cdot\delta\alpha\right)^2}$$



Slope: $\frac{\partial p}{\partial \alpha}$

$\Delta p = f(L, \alpha)$

Determining the uncertainty of the results (error calculation) II.

Example: Velocity measurement uncertainty

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

Atmospheric conditions experienced in the lab:
p_0 =1010hPa ; T=20°C (293K);
Specific gas constant of air
R=287 J/kg/K

$$v = \sqrt{\frac{2}{\rho_{air}} \cdot p_d} = 28.47 \frac{m}{s}$$

$$\rho_{air} = \frac{p_0}{R \cdot T} = 1.2 \frac{kg}{m^3}$$

$$\Bigg\} \quad v = \sqrt{\frac{2}{p_0} \cdot p_d RT} \quad \Longrightarrow \quad v = f\left(T, p_0, p_d, const.values\right)$$

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 a EMB-0XY digital manometer: δp_d=2Pa

More info: Vad & Lukács, Advanced Flow Measurements lecture note, Chapter 2.3 Dynamic pressure

Determining the uncertainty of the results (error calculation) III.

Example: Velocity measurement uncertainty

Typical calculation of absolute error:

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

$R = v$

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

$$v = \sqrt{\frac{2}{p_0} \cdot p_d R T}$$

$$\frac{\partial v}{\partial T} = \sqrt{\frac{2}{p_0} p_d R} \cdot \frac{1}{2} \cdot T^{-\frac{1}{2}} = 0.0486 \frac{m}{s \cdot K}$$

$$\frac{\partial v}{\partial p_0} = \sqrt{2RTp_d} \cdot \frac{-1}{2} \cdot p_0^{-\frac{3}{2}} = 1.4 \cdot 10^{-4} \frac{m}{s \cdot Pa}$$

$$\frac{\partial v}{\partial p_d} = \sqrt{\frac{2}{p_0} RT} \cdot \frac{1}{2} \cdot p_d^{-\frac{1}{2}} = 0.0293 \frac{m}{s \cdot Pa}$$

Determining the uncertainty of the results (error calculation) IV.

Example: Velocity measurement uncertainty

The absolute uncertainty of the velocity measurement:

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

$$\delta v = 0.0567 \quad \frac{m}{s}$$

The relative uncertainty of the velocity measurement:

$$\frac{\delta v}{v} = 0.002 = 0.2\%$$

The result of the velocity measurement:

$$v = 28.457 \pm 0.0567 \quad \frac{m}{s}$$