Mechanics

Aerodynamics and hydrodynamics

Measuring air resistance

LD
Physics
Leaflets

P1.8.6.3

Pressure curve on an airfoil profile – Measuring the pressure with the precision manometer

Objects of the experiment

- To measure an airfoil profile's pressure curve for different angles of attack.
- To determine the static pressure difference's stake in the aerodynamic lift.
- To qualify the aerodynamic lift explanation due to the Bernoulli principle.
- To develop a critical distance to apparently secured knowledge.

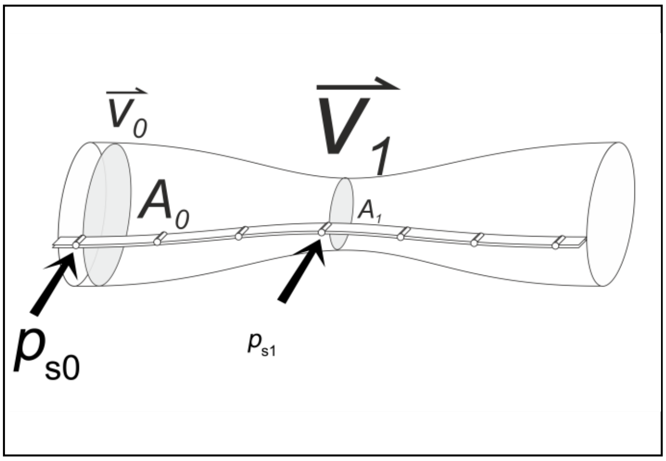
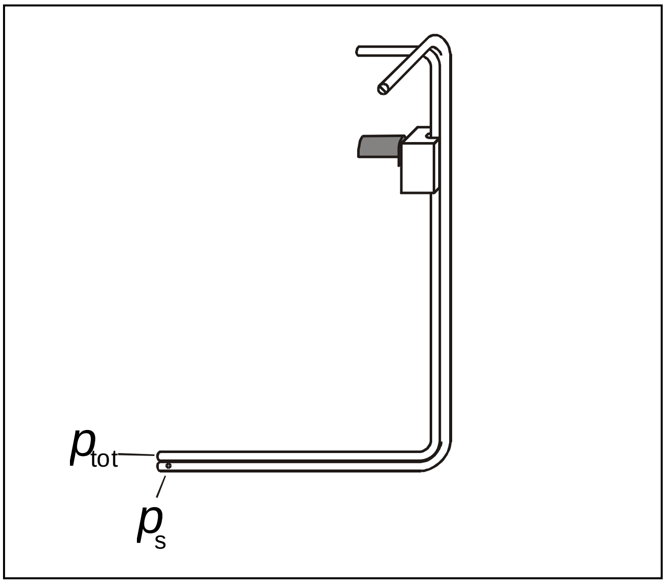


Fig. 1: Bernoulli principle: cross-sectional area A, flow velocity v, static pressure p_s. The font size indicates the absolute value of the physical quantity.

Fig. 2: Prandtl pressure probe for measuring the static pressure p_s and the total pressure p_{tot}.



Principles

For a long time in physics books, the aerodynamic lift has been explained with a decrease in pressure due to the Bernoulli principle. In this experiment the stake of the static pressure difference Δp_s in the aerodynamic lift F is verified quantitatively.

Bernoulli's law states the relationship between static pressure p_s and flow velocity v. The following equation applies to a friction-free, horizontally flowing stream through a stationary flow tube between two points labeled with indices 0 and 1:

$$p_{s0} + \frac{\rho}{2}v_0^2 = p_{s1} + \frac{\rho}{2}v_1^2 \qquad \text{(I)}$$

Density of the air: $\rho = 1.2\,\frac{\text{kg}}{\text{m}^3}$

The insufficient explanatory approach is phrased as follows: The air's longer path length on top of the airfoil results in a difference of static pressure Δp_s, which lifts up the airfoil.

Thus the theoretical aerodynamic lift F_T is defined via pressure and area:

$$F_T = A \cdot \Delta p_s \qquad \text{(II)}$$

Area of the airfoil profile: A

The flow velocity v is indirectly determined by a Prandtl pressure probe and a pressure sensor. Pointing in the direction of flow the Prandtl pressure probe measures the difference between the total pressure p_{tot} and the static pressure p_s:

$$p_d = p_{tot} - p_s \qquad \text{(III)}$$

Therefore the flow velocity v can be determined by:

$$v = \sqrt{\frac{2}{\rho} \cdot \left(p_{tot} - p_s\right)} \qquad \text{(IV)}$$

Remark: The experiment is closely related to P1.8.7.1, where the airfoil's aerodynamic lift is measured directly. P1.8.5.1 and P1.8.7.3 are closely related, too.

Apparatus

1	Suction and pressure fan	373 041
1	Open aerodynamics working section	373 06
1	Prandtl pressure probe	373 13
1	Airfoil model	373 70
1	Precision manometer	373 10
1	Stand rod 47 cm, 12 mm Ø	300 42
2	Stand base, V-shaped, small	300 02

Optional:

1	CASSY Lab 2	524 220

Additionally required: 1 PC with Windows XP or higher

Safety notes

Mind the safety notes in the instruction sheet of the suction and pressure fan.

Before removing the protective grid or the nozzle:

- Pull out the mains plug and
- Wait for at least 30 seconds until the suction and pressure fan comes to a complete stop.

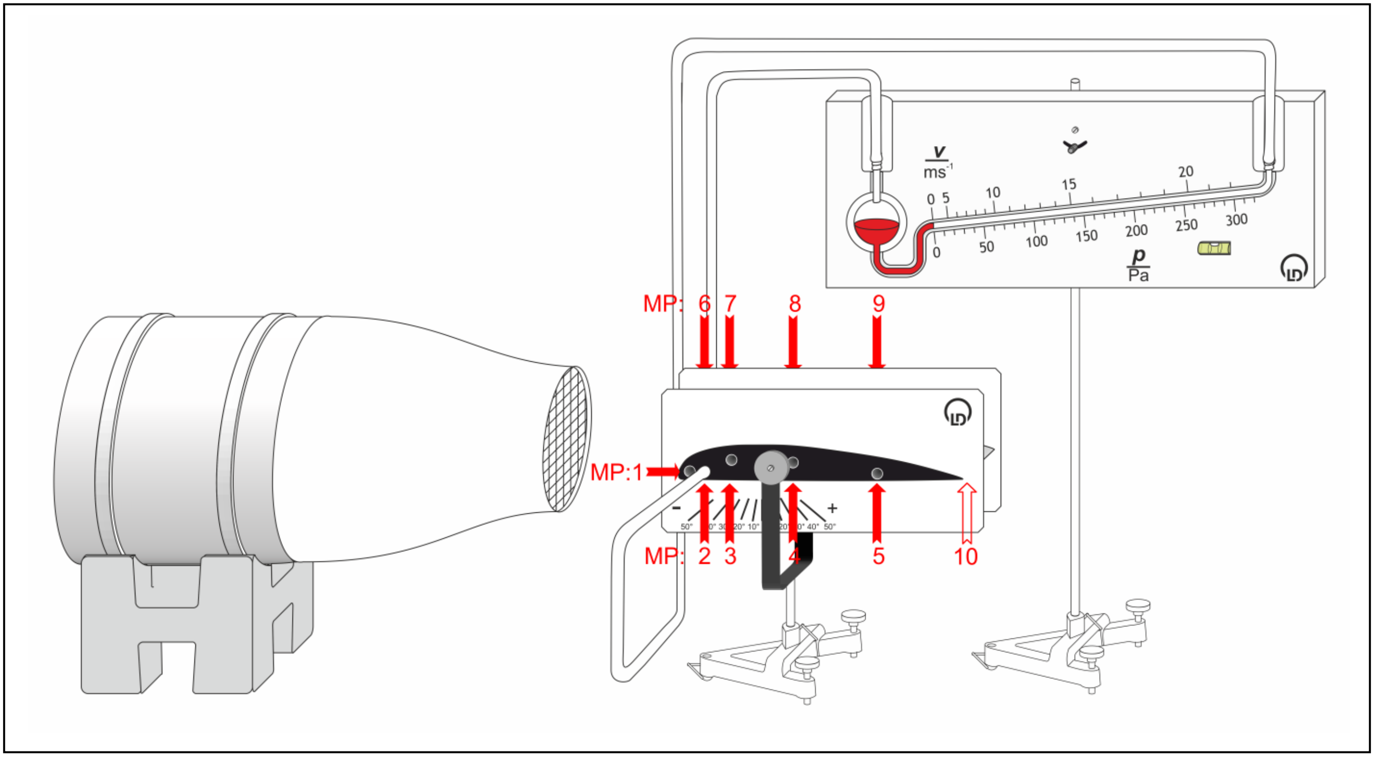
Setup

Assemble apparatus as in Fig. 3. Equip the suction and pressure fan with the big nozzle 150 mm Ø. Place the pressure side of the suction and pressure fan facing towards the airfoil model. Ensure a clearance of at least 1 m in front of the suction side and behind the airfoil model.

- Align the precision manometer exactly horizontal. If needed, refill the reservoir for manometer fluid.
- Connect the hose of the precision manometer to the precision manometer's tube attachment nipple for high-pressure (left).
- Connect the other end of the hose to the hose nipple and plug it into measuring point 6 of the airfoil model (see Fig. 3).
- In the same way, connect precision manometer's tube attachment nipple for high-pressure (left) with measuring point 2 of the airfoil model (see Fig. 3).
- Position the airfoil model approx. 10 cm in front of the nozzle with a stand base, V-shaped and adjust the angle of attack α = +10°.

Remark: Not mixing up the connections of the hoses is crucial since the static pressure difference Δp_s will be negative in the air stream. Further information in the instruction sheets 373 13 and 373 10.

Fig. 3: Experimental setup with the precision manometer.



Carrying out the experiment

a) Measuring without CASSY Lab 2

- Set the suction and pressure fan to its minimum speed (i.e. left limit position of fan control) and only then switch it on.
- Slowly increase the speed of the suction and pressure fan until the flow velocity v reaches approximately 5,6 m/s. Therefore connect the hoses preliminary with the Prandtl pressure probe as shown in Fig. 4 and set Δp = 19 Pa.

Remark: Detailed information for determining the flow velocity v is given in P1.8.5.3.

- Adjust the airfoil model‘s angle of attack to α = +10° and position it approx. 10 cm in front of the nozzle.
- At measuring points 1 and 10 (see Fig. 3) the difference in static pressure Δp_s is 0 Pa.
- Connect the hoses again with measuring points 2 and 6 of the airfoil model (as in Fig. 3) and note the belonging profile depth z:

MP	1	2; 6	3; 7	4; 8	5; 9	10
z	0%	15%	24%	43%	72%	100%

- Read off the static pressure difference Δp_s for measuring points 2 and 6, 3 and 7, … 5 at the precision manometer.
- For recording further angles of attack α create a new table column and repeat the previous steps.

b) Measuring with CASSY Lab 2

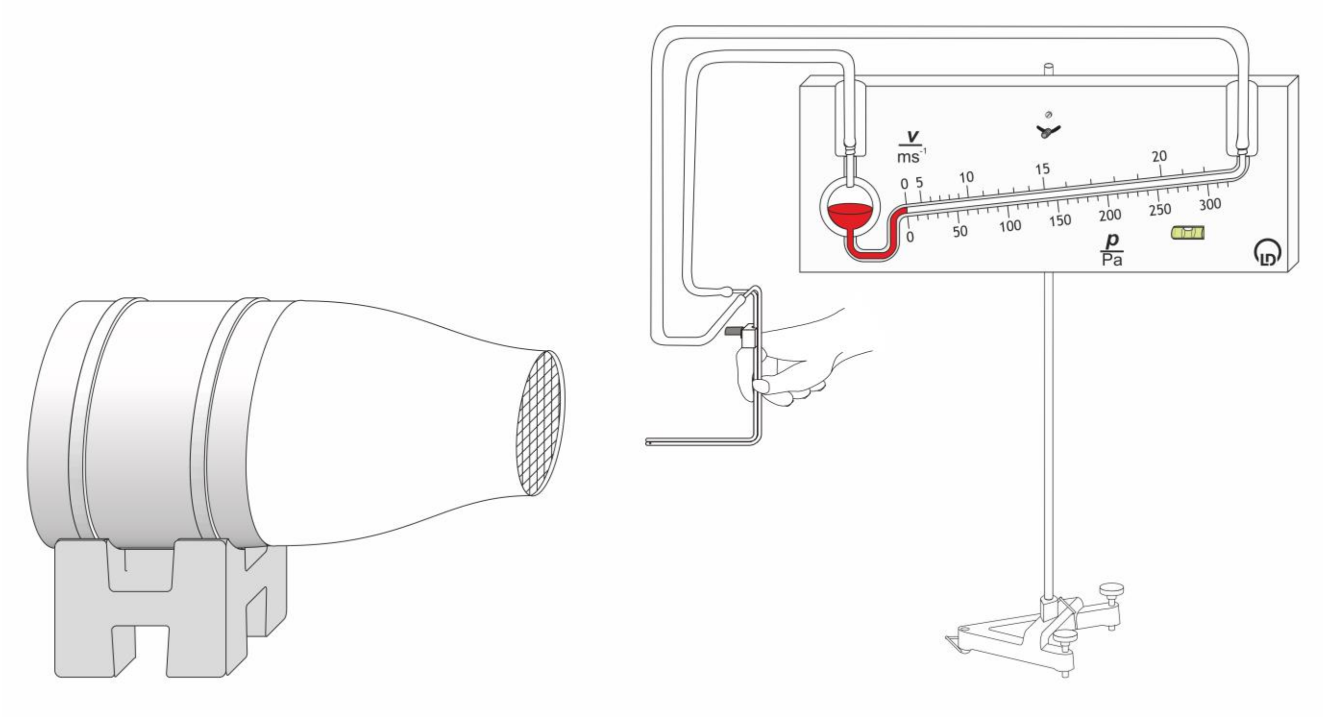
- If not yet installed, install the software CASSY Lab 2 and open the software.
- Load the settings in CASSY Lab 2.
- Set the suction and pressure fan to its minimum speed (i.e. left limit position of fan control) and only then switch it on.
- Slowly increase the speed of the suction and pressure fan until the flow velocity v reaches approximately 5,6 m/s. Therefore connect the hoses preliminary with the Prandtl pressure probe as shown in Fig. 4 and set Δp = 19 Pa.

Remark: Detailed information for determining the flow velocity v is given in P1.8.5.3.

- Adjust the airfoil model‘s angle of attack to α = +10° and position it approx. 10 cm in front of the nozzle.
- At measuring points 1 and 10 (see Fig. 3) the difference in static pressure Δp_s is 0 Pa.
- Connect the hoses again with the airfoil model. Read off the difference in static pressure Δp_s for measuring points 2 and 6, 3 and 7, … 5 and 9 and type the values in table “*p_s(z) [manu.]*“ together with be belonging profile depths z (see table on the left).
- For recording further angles of attack α click the drop down menu #1 ▾ and select the next series of measurements. Repeat the previous steps.

Remark: To record more than the prepared measurement series open “Measurement” in the menu bar and select “Append new Measurement Series”. Select table “Δp_s(z)” and click once. Open the *“Settings” pane and mark “Δp_s(z)” in the submenu “Displays”. Push the button “Add new Curve” and select “Δp_s#6” in the drop down menu for “y-axis”.*

Fig. 4: Measuring the wind speed v with a Prandtl pressure probe and equation (IV).



Measuring example

The profile depth z corresponds with the airfoil's measuring points. At the airfoil's leading edge (z = 0 %) and the tailing edge (z = 100 %) the difference in static pressure Δp_s equals 0 Pa.

	$\frac{\alpha}{°}$	20	10	0	-10	-20
MP	*z*	$\frac{\Delta p_s}{\text{Pa}}$				
1	0 %	**0**	0	0	0	0
6-2	15 %	**27**	16	4	-15	-14
7-3	24 %	**27**	20	12	-1	-4
8-4	43 %	**10**	7	5	2	-5
9-5	72 %	**4**	3	2	2	-4
10	100 %	**0**	0	0	0	0

Tab. 1: Static pressure difference Δp_s between downside and upside of the airfoil model for six different profile depths *z* and five angles of attack *α*.

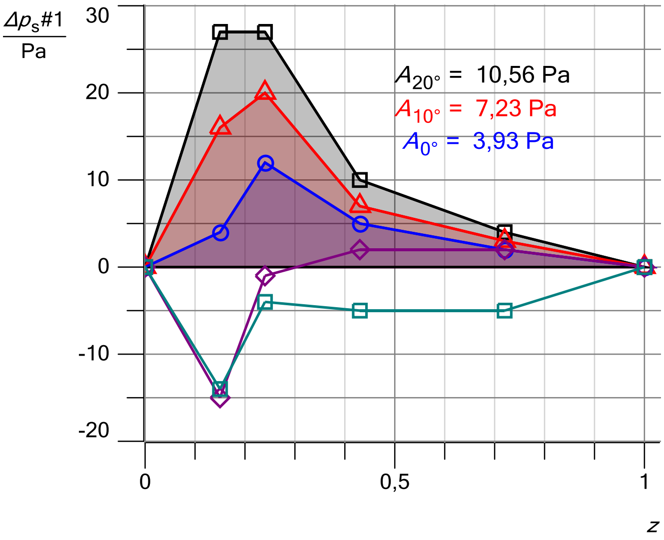


Fig. 5: Static pressure difference Δp_s as function of profile depth *z*.

Remark: CASSY Lab 2 can determine the area below the graph of Δps(z) automatically: Right click on one measuring point in the $\Delta p_s(z)$ diagram, select ∫dx "Calculate Integral" and click „Area to x-Axis". Drag the left mouse button over all measuring points of the series.

If the first or last measuring point of one measuring series is covered by others, first select an outstanding measuring point and drag the integral in one direction. Then double click the same measuring point again and drag the integral into the other direction.

Evaluation and results

The area $A_{10°}$ below the graph of $\Delta p_s(z)$ can be determined with CASSY Lab 2 automatically or calculated manually. E.g. for an angle of attack $\alpha = +10°$:

$$A_{10°} = \int_0^{100\%} \Delta p_s(z)\, \mathrm{d}z = 7.23\ \text{Pa} = \mathbf{7.23\ \frac{N}{m^2}}$$

Multiplying $A_{10°}$ with the airfoil model's width *b* and depth *z* (in meters, not %!) and considering the angle of attack $\alpha = +10°$ results in the theoretical aerodynamic lift F_T:

$$F_T = A_{10°} \cdot b \cdot z \cdot \cos(\alpha)$$

According to this Bernoulli principle based theory an airfoil as in P1.8.7.1 (similar shape, width *b* = 0.14 m, depth z =0.22 m) should produce an aerodynamic lift of:

$$F_T = 7.23\ \frac{\text{N}}{\text{m}^2} \cdot 0.14\ \text{m} \cdot 0.22\ \text{m} \cdot \cos(10°) = \mathbf{0.2\ N}$$

In contrast to this theory the measured aerodynamic lift F_M for the airfoil in P1.8.7.1 amounts to 2.1 N at an angle of attack $\alpha = +10°$ (see Tab. 2):

$$F_M = \mathbf{2.1\ N}$$

$\frac{v}{\frac{\text{m}}{\text{s}}}$	5.6							
$\frac{\alpha}{°}$	0	2	4	6	8	10	12	14
$\frac{F_M}{\text{N}}$	0.5	0.7	1.1	1.5	1.7	2.1	2.3	2.5

Tab. 2: Measuring results from P1.8.7.1: Measured aerodynamic lift F_M and angle of attack *α* at flow velocity *v* = 5.6 m/s.

The difference in static pressure Δp_s explains only approx. 10% of the measured aerodynamic lift!

Supplementary information

Often in this context, the lower pressure on the upside of the airfoil is wrongfully explained with rejoining airstreams at the tailing edge and the air's longer path length. This insufficient explanation survived even though Alexander Lippisch had already published contradictory pictures of pulsed smoke trails around airfoils in the early years of aviation. This pictures show that the two airstreams do not rejoin with each other:

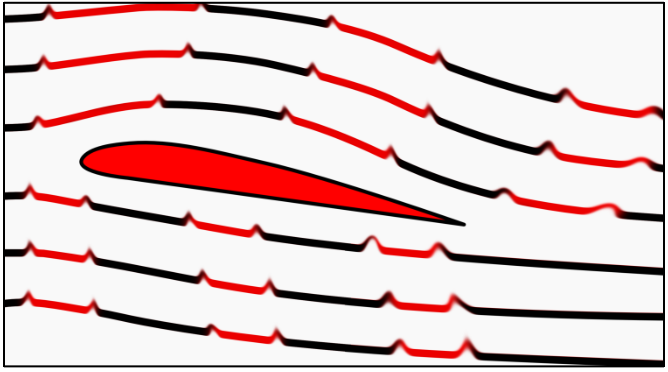


Fig. 6: Pulsed smoke trails around an airfoil, schematically.