Mechanics

Aerodynamics and hydrodynamics
Measuring air resistance

LD
Physics
Leaflets

P1.8.6.4

Measuring the air resistance as a function of the wind speed – Measuring the wind speed with a pressure sensor and CASSY

Objects of the experiment

■ To verify that the aerodynamic drag increases with one object's cross-sectional area.

■ To verify that the aerodynamic drag increases with the flow velocity.

Fig. 1: Prandtl pressure probe for measuring the static pressure p_s and the total pressure p_{tot}.

p_{tot}

p_s

Principles

The air resistance or aerodynamic drag F is defined as the friction caused force component in direction of flow or against one object's direction of movement:

$$F = c_w \cdot A \cdot p_d \tag{I}$$

The drag coefficient c_w is constant for low Mach numbers. The area A denotes the maximal cross-sectional area of the object in direction of the flow. The dynamic pressure p_d is depending on the flow velocity v:

$$p_d = \frac{\rho}{2} v^2 \tag{II}$$

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

In the experiment described here three resistance bodies (round disks) are placed in the air flow and the aerodynamic drag F is measured for different flow velocities v.

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:
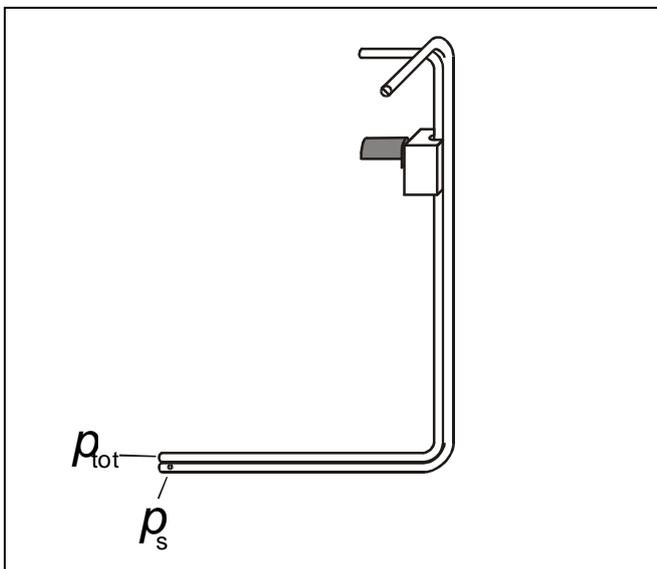
$$p_d = p_{tot} - p_s \tag{III}$$

Therefore the flow velocity v can be determined by:

$$v = \sqrt{\frac{2}{\rho} \cdot (p_{tot} - p_s)} \tag{IV}$$

Remark: The experiment is closely related to P1.8.6.5 where the aerodynamic drag is determined depending on the object's shape.

Apparatus

1	Suction and pressure fan	373 041
1	Open aerodynamics working section	373 06
1	Prandtl pressure probe	373 13
1	Sector dynamometer, 0.65 N	373 14
1	Aerodynamics accessories 1	373 071
1	Measurement trolley for wind tunnel	373 075
1	Sensor-CASSY 2	524 013
	or	
1	Mobile-CASSY	524 009A
	or	
1	Pocket-CASSY 2 Bluetooth	524 018
1	CASSY Lab 2	524 220
1	Pressure sensor S, ±70 hPa	524 066
1	Stand base, V-shaped, small	300 02
1	Saddle base	300 11
1	Stand rod, 25 cm, 12 mm Ø	300 41

Additionally required: 1 PC with Windows XP or higher

Safety notes

Mind the safety notes in the instruction sheets 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 shown in Fig 2. Place the pressure side of the suction and pressure fan facing towards the open aerodynamics working section. Ensure a clearance of approx. 1 m in front of the suction side and behind the open aerodynamics working section.

– Plug the pressure sensor S, ±70 hPa into Input A of Sensor-CASSY 2 (Fig. 2) or into the Mobile-CASSY (Fig. 4).
– Connect the 3 mm hose coming out of pressure connection p_1 (top) of pressure sensor S to the 5 mm hose delivered with the Prandtl pressure probe.
– Connect the other end of the 5 mm hose to the Prandtl pressure probe outlet for p_{tot} (see Fig. 1).
– In the same way, connect pressure connection p_2 (bottom) of the pressure sensor S to the p_s outlet of the Prandtl pressure probe (see Fig. 1).

Remark: Not mixing up the connections of the hoses is crucial since the relative static pressure p_s will be negative in the air stream.

– Make sure the precision metal rail is horizontal and exactly parallel to the direction of flow.
– Assemble the measurement trolley as shown in Fig. 2, using the smallest resistance body (round disk, Ø 40 mm) first and place it on the precision metal rail. The 50 g counterweight is crucial for exact measuring results.
– Connect the sector dynamometer's cord for the transfer of force to the hook of the measurement trolley so that the cord is approx. horizontal. Check if the cord wines closely around the spring casing with groove for the cord.
– Slide the measurement trolley away from the sector dynamometer so that the cord is almost stressed.

Remark: For further hints refer to instruction sheets 373 13, 373 041, 373 075 and 524 066.

Fig. 2: Experimental setup with Sensor-CASSY 2.
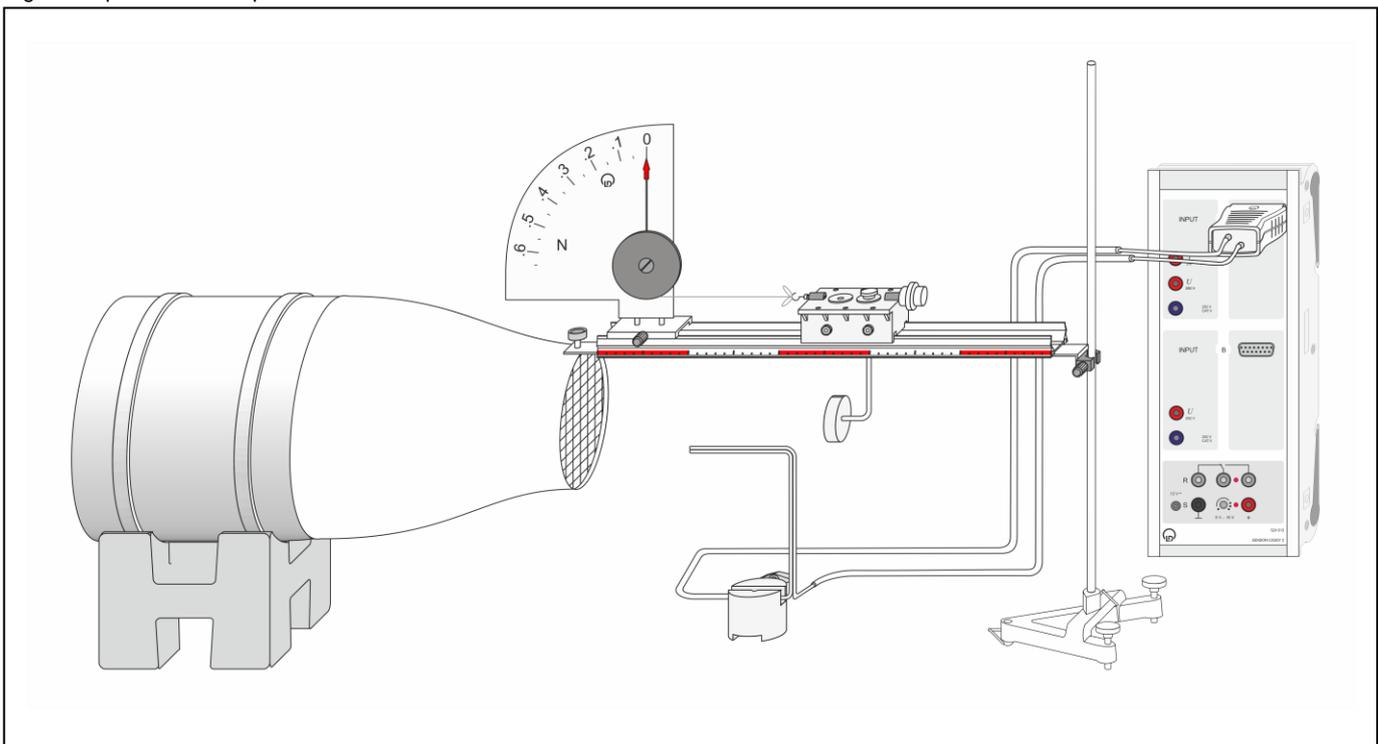
Carrying out the experiment

– If not yet installed, install the software CASSY Lab 2 and open the software.

a) Measuring with Sensor-CASSY 2

– Load the settings in CASSY Lab 2.

– The connected pressure sensor S should be displayed if Sensor-CASSY 2 is powered on and connected to the computer via the USB port.

– Activate the connected pressure sensor S at Input A by clicking ⬜.
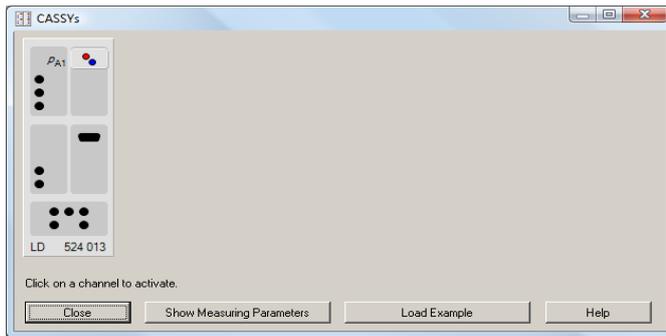
Remark: Further details about connecting sensors to Sensor-CASSY 2 can be found in the CASSY Lab 2 manual or in the web help.

– Reset the pressure sensor S by clicking →0← in the "*Settings*" pane when "*relative pressure p_{A1}*" is marked.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 sector dynamometer shows more than 0.01 N for the aerodynamic drag *F*.

Remark: For minimizing measurement errors due to friction: Push the measurement trolley a little against the direction of flow. Release the measurement trolley again. When the sector dynamometer's pointer stopped oscillating, first check if the cord is still in the groove of the spring casing. Repeat this step several times for estimating a good average value.

– Type the sector dynamometer's value in the CASSY Lab 2 column for the aerodynamic drag *F* (left side of the window).

– To record the belonging flow velocity *v* with CASSY Lab 2 click ⏱ shortly after reading off *F*.

– Slowly increase the speed of the suction and pressure fan until the flow velocity *v* shows approx. 2 m/s more.

– Repeat the last steps until the sector dynamometer, 0.65 N comes close to its maximum.

– To record another resistance body click the drop down menu #1 ▼ and select the next measurement series. Exchange the resistance body (round disks: Ø 40 mm, Ø 56 mm and Ø 80 mm) and repeat these steps.

Remark: For the reset button →0← to appear in the ✴ "Settings" pane "relative pressure p_{A1}" has to be marked in the submenu of "CASSYs". It is recommended to press the reset button →0← before each series of measurements.

b) Measuring with Mobile-CASSY

*Remark: To record the pressure values automatically, follow the instructions as described in **a**).*

– Switch on Mobile-CASSY with the ⬛ key.

– Open the main menu by pressing the ⬛ key again.

– Select the submenu "Quantities" by using the arrow keys, △ or ▽, and enter the submenu using the right ⬛ key.

– Go to submenu "p" using the right ⬛ key.

– Choose "Compensate Offset" and set the pressure to zero by pushing the right ⬛ key.

– Press the ⬛ key and then the left ⬛ key to display the current pressure value.

Remark: It is recommended to zero the pressure values before each series of measurements. For further hints on using Mobile-CASSY (524 009A) refer to the instruction sheet.

– 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 sector dynamometer shows more than 0.01 N for the aerodynamic drag *F*.

Remark: For minimizing measurement errors due to friction: Push the measurement trolley a little against the direction of flow. Release the measurement trolley again. When the sector dynamometer's pointer stopped oscillating, first check if the cord is still in the groove of the spring casing. Repeat this step several times for estimating a good average value.

– Load the settings in CASSY Lab 2.

– Read off the belonging pressure p_d shortly after reading off the aerodynamic drag *F*. Type both values in table "*F(p_d) [manu.]*" (left side of the window). The flow velocity *v* will be calculated automatically in table "*F(v)*".

– Slowly increase the speed of the suction and pressure fan until the dynamic pressure p_d is approx. 30% higher.

– Repeat the last steps until the sector dynamometer, 0.65 N comes close to its maximum.

– To record another resistance body click the drop down menu #1 ▼ and select the next measurement series. Exchange the resistance body (round disks: Ø 40 mm, Ø 56 mm and Ø 80 mm) and repeat these steps.

Remark: To record more than the three prepared measurement series open "Measurement" in the menu bar and select ⬚ "Append new Measurement Series". Select table "F(v)" and click ⏱ once. Open the ✴ "Settings" pane and mark "F(v)" in the submenu "Displays". Push the button "Add new Curve" and select "F#4" in the drop down menu for "y-axis". Do the same for "F(p_d)".

Measuring example

Fig. 3: Aerodynamic drag *F* as function of the dynamic pressure p_d for the smallest resistance body (round disk, Ø 40 mm). The solid line corresponds to a fit of a straight line through origin: y = B x.
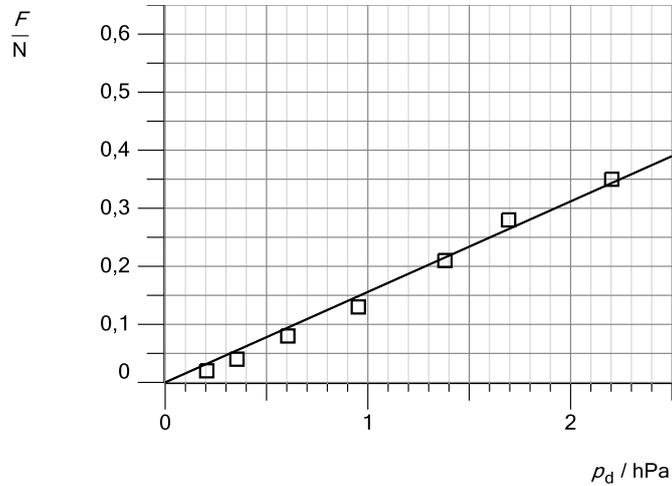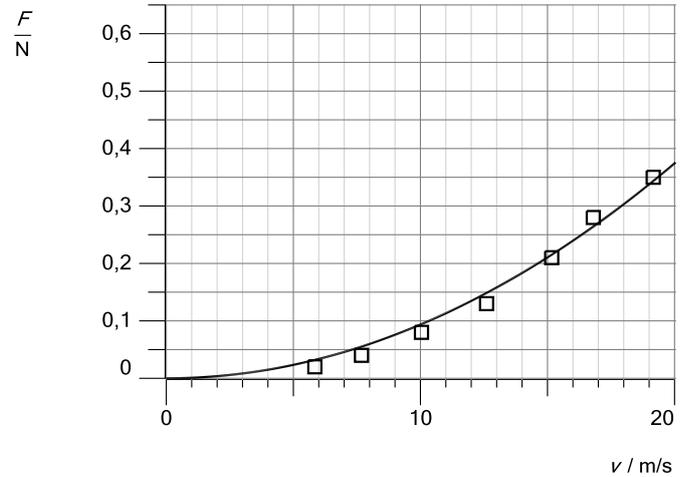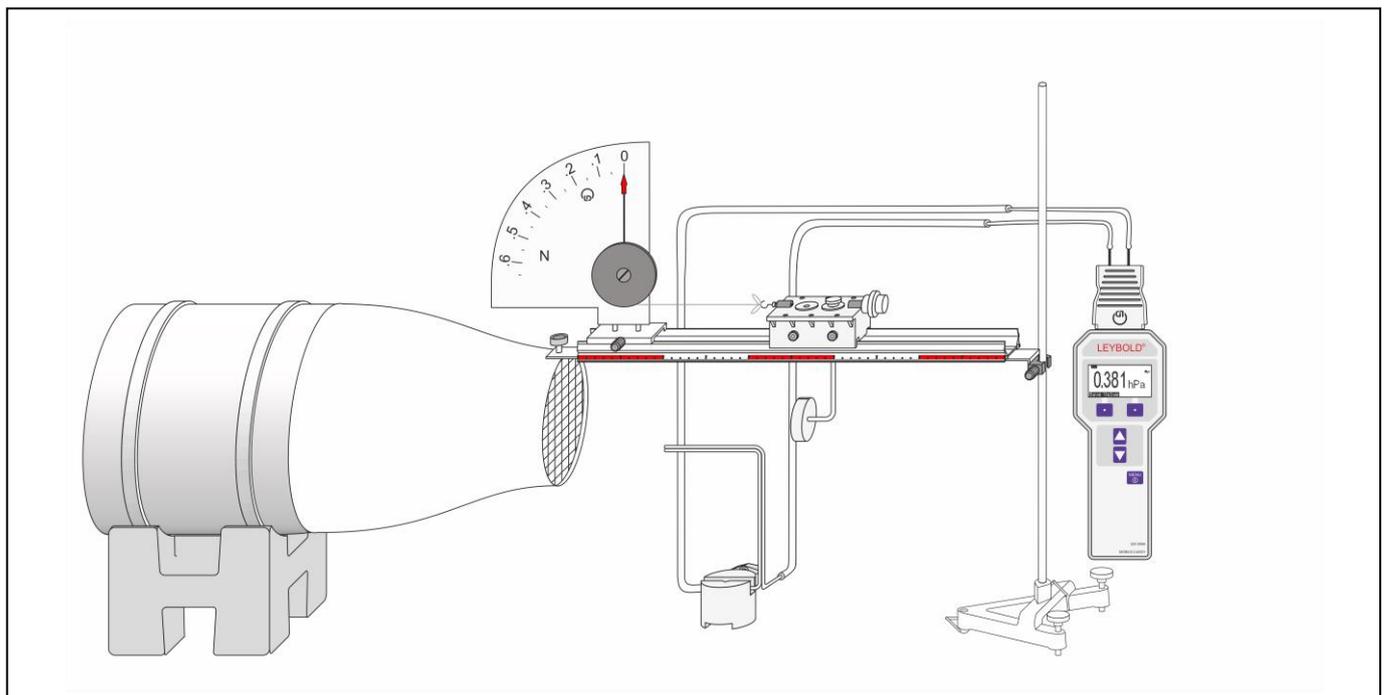

Fig. 5: Aerodynamic drag *F* as function of the flow velocity *v* for the smallest resistance body (round disk, Ø 40 mm). The solid curve corresponds to a fit of a norm parabola: $y = C x^2$.

Tab. 1: Dynamic pressure p_d, flow velocity *v* and resulting aerodynamic drag *F* for the smallest resistance body (round disk, Ø 40 mm).

$\dfrac{p_d}{\text{hPa}}$	$\dfrac{v}{\frac{\text{m}}{\text{s}}}$	$\dfrac{F}{\text{N}}$
0.205	5.8	0.02
0.354	7.7	0.04
0.605	10.0	0.08
0.953	12.6	0.13
1.380	15.2	0.21
1.694	16.8	0.28
2.203	19.2	0.35

Fig. 4: Experimental setup with Mobile-CASSY.

Evaluation and Results

Fig. 6: Aerodynamic drag F as function of the dynamic pressure p_d for three resistance bodies (round disks: **Ø 40 mm**, Ø 56 mm, Ø 80 mm) with different cross-sectional areas. The solid lines correspond to a fit of straight lines through origin: y = B x.
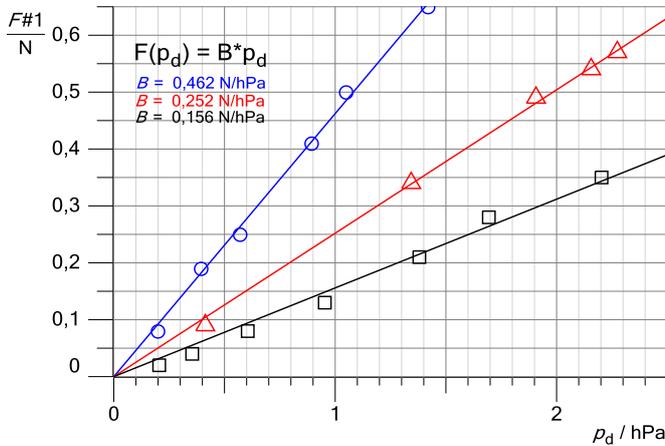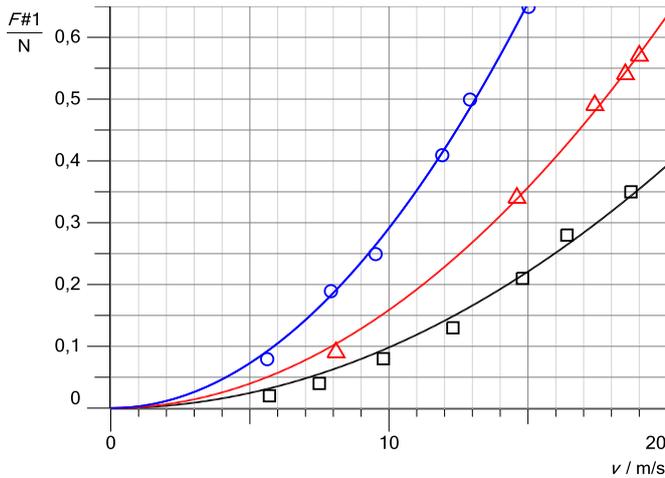
$\frac{F\#1}{N}$

$F(p_d) = B*p_d$

$B = 0{,}462$ N/hPa
$B = 0{,}252$ N/hPa
$B = 0{,}156$ N/hPa

p_d / hPa

Fig. 7: Aerodynamic drag F as function of the flow velocity v for three resistance bodies (round disks: **Ø 40 mm**, Ø 56 mm, Ø 80 mm) with different cross-sectional areas. The solid lines correspond to a fit of norm parabolas: y = C x^2.

$\frac{F\#1}{N}$

v / m/s

When the cross-sectional area A of the resistance body doubles the aerodynamic drag F doubles, too (e.g.: In Fig. 6 at $p_d = 0.8$ hPa the best-fit functions cross approx. **0.1 N**, 0.2 N and 0.4 N):

$F \propto A$

Therefore the measuring results confirm equation (I).

Substituting the dynamic pressure p_d in equation (I) leads to:

$F = c_w \cdot A \cdot \frac{\rho}{2} v^2$ (V)

The aerodynamic drag F increases with increasing flow velocity v. The relation appears to be quadratic. The best-fit functions are norm parabolas (Fig. 7):

$F \propto v^2$

Therefore the measuring results confirm equation (V).

Supplementary information

Furthermore, the function F(A) may be determined by exchanging the three resistance bodies at one constant flow velocity v, respectively dynamic pressure p_d.

With the CASSY Lab 2 software it is possible to determine the function F(A) for any flow velocity v or dynamic pressure p_d even if the measuring points were not recorded with one common flow velocity, respectively dynamic pressure p_d:

– Select one series of measurements by clicking on its first or last measuring point in the diagram pane for F(p_d).

– Right click the selected measuring point, select f(x) "*Fit Function*" and click ✓"*Straight Line through Origin*".

– Drag with held left mouse button over all measuring points of the series. The selected fit function appears automatically.

– Right click on the created fit function, select ➕ "*Set Marker*" and click ABC "*Text (Alt+T)*". A text like "*A = 0.0156 N/hPa*" will appear. At this point the cross-sectional area A should not be confused with the mathematical scaling factor A. Renaming it to B is recommended here.

– Repeat these steps for the other series of measurements.

This analysis delivered the mathematical scaling factor B for each series of measurements.

From equation (I) follows that the mathematical scaling factor B is defined here as

$B = c_w \cdot A$.   (VI)

When the cross-sectional areas A are known the the drag coefficients c_w can be calculated and hence the values for function $F(A)$ for any dynamic pressure p_d:

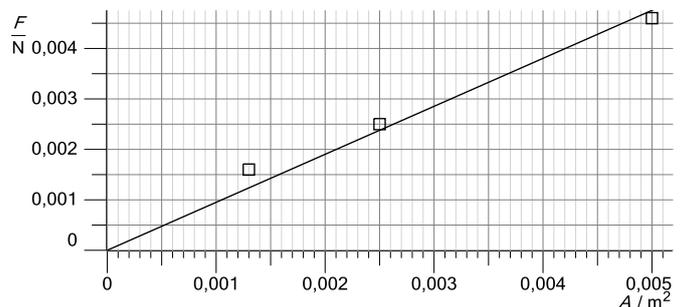| $\dfrac{B}{\frac{N}{Pa}}$	$\dfrac{A}{m^2}$	c_w	$\overline{c_w}$
0.00462	0.0050	0.9	
0.00252	0.0025	1.0	1.1
0.00156	0.0013	1.2	

$\frac{F}{N}$

A / m^2

Fig. 8: Aerodynamic drag F of round disks as function of the cross-sectional area A. The values were calculated from the fit functions of all three series of measurements for p$_d$ = 1 Pa.

The slope of $\overline{F(A)}$ is $\overline{c_w} \cdot p_d$. When choosing $p_d = 1$ Pa (not hPa) the slope of $\overline{F(A)}$ simplifies to $\overline{c_w}$.

Remark: The aerodynamic drag coefficient c$_w$ is directly determined in P1.8.6.5.