Mechanics

Aerodynamics and hydrodynamics

Measuring air resistance

LD Physics Leaflets

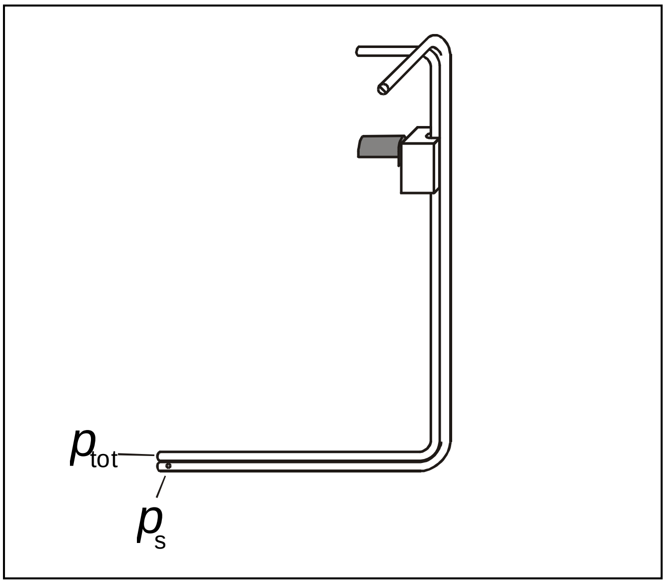
P1.8.6.2

Drag coefficient c_W: relationship between air resistance and body shape – Measuring the wind speed with the precision manometer

Objects of the experiment

- To verify that the aerodynamic drag depends on the object's shape.
- To verify that the aerodynamic drag depends on the flow velocity.
- To measure the drag coefficients of some typical object shapes.

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



Principles

The aerodynamic drag coefficient c_w is depending on the object's shape and can have great influence on the air resistance.

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

$$F = c_w \cdot A \cdot p_d \qquad \text{(I)}$$

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:

$$p_d = \frac{\rho}{2} v^2 \qquad \text{(II)}$$

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

In the experiment described here resistance bodies of different shape 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:

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

Therefore the flow velocity v can be determined by:

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

Remark: The experiment is closely related to P1.8.6.1 where the aerodynamic drag is determined depending on flow velocity and the object's cross-sectional area.

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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 Precision manometer 373 10

1 Stand base, V-shaped, small 300 02
1 Saddle base 300 11
1 Stand rod, 47 cm, 12 mm Ø 300 42

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 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.

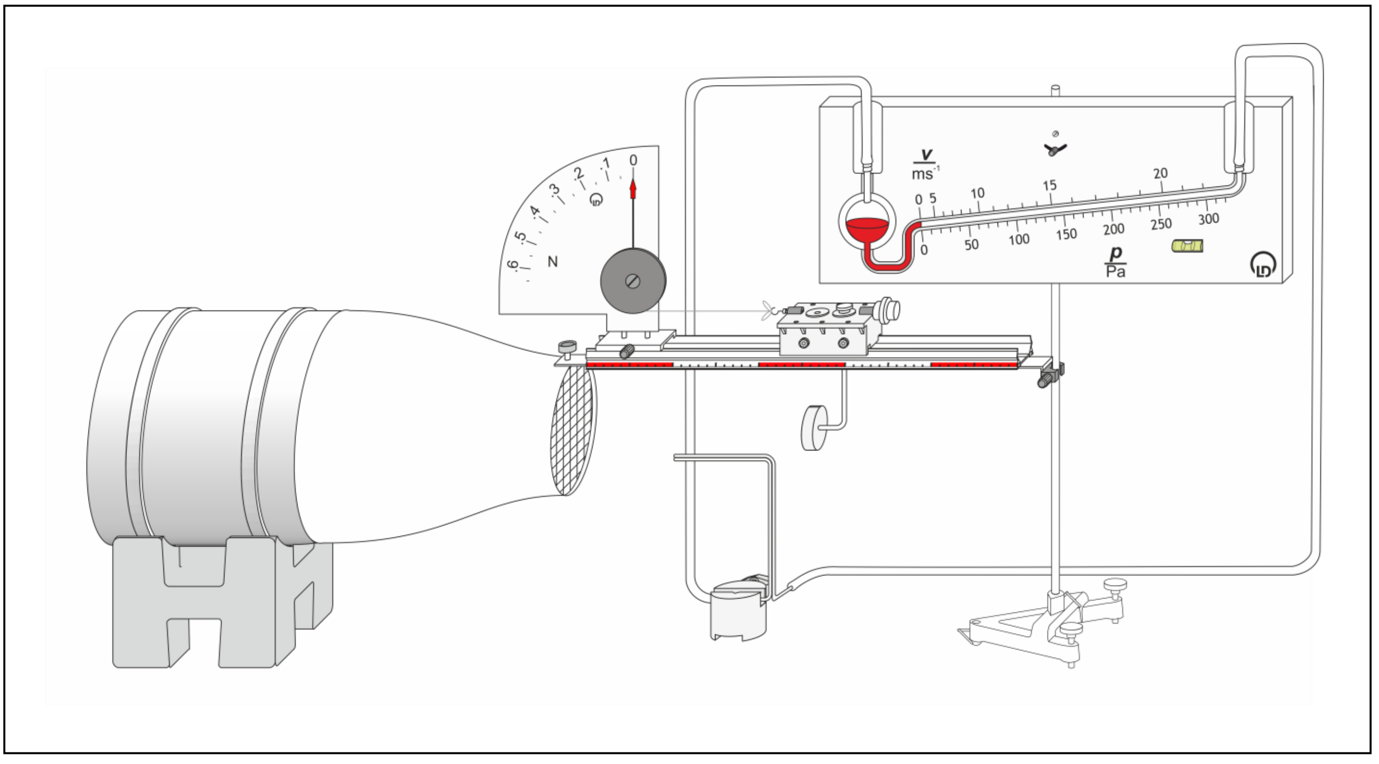
– Align the precision manometer exactly horizontal. If needed, refill the reservoir for manometer fluid.
– Connect the hose of the precision manometer to the precision manometer's tube attachment nipple for high-pressure (left).
– Connect the other end of the hose to the Prandtl pressure probe outlet for p_{tot} (see Fig. 1).
– In the same way, connect the precision manometer's tube attachment nipple for low-pressure (right) 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 all 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 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 10, 373 13 and 373 075.

Fig. 2: 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 dynamic pressure p_d reaches approx. 60 Pa (flow velocity v approx. 10 m/s).

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.

- Read off the dynamic pressure p_d and the flow velocity v shortly after reading off the aerodynamic drag F. Note all values in a table.
- 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 create a new table column. Mount another resistance body with Ø 56 mm (round disk, hemisphere dish, sphere, streamlined body reverse, streamlined body) and repeat these 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 dynamic pressure p_d reaches approx. 60 Pa (flow velocity v approx. 10 m/s).

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.

- Read off the dynamic pressure p_d shortly after reading off the aerodynamic drag F and 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 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. Mount another resistance body with Ø 56 mm (round disk, hemisphere dish, sphere, streamlined body reverse, streamlined body) and repeat these steps.

Remark: To record more than the 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#6" in the drop down menu for "y-axis". Do the same for tables "F(p_d)" and "c_w(v)".*

Measuring example

Fig. 3: Aerodynamic drag F as function of the flow velocity v for one of the five resistance bodies (round disk, Ø 56 mm). The solid line corresponds to a fit of a norm parabola: $y = D\,x^2$.

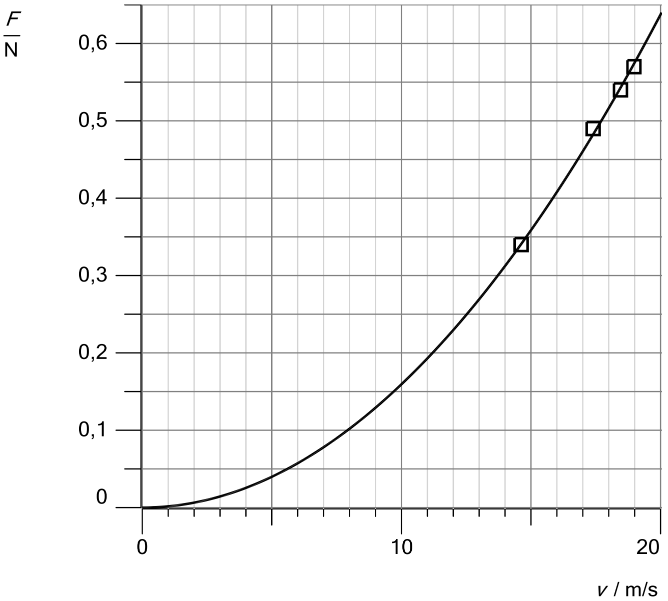
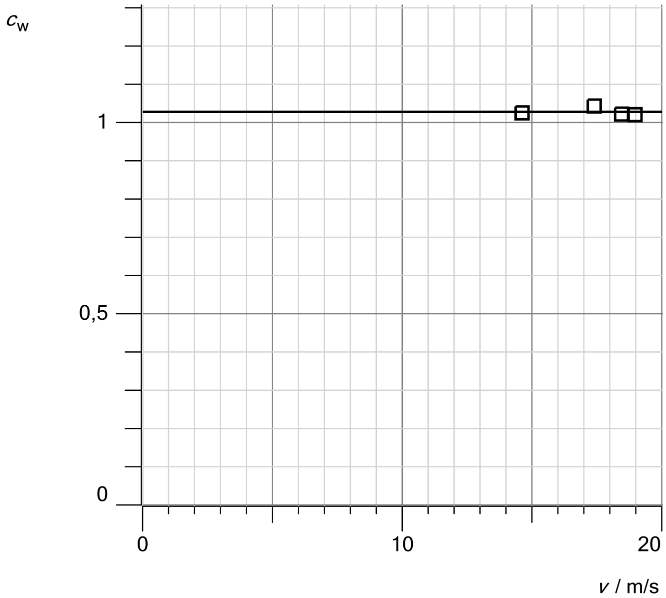


Fig.4: Drag coefficient c_W as function of the flow velocity v for the resistance body round disk, Ø 56 mm. The solid line indicates the average value.



CASSY Lab 2 can visualize and calculate the average value for the drag coefficient c_w automatically:

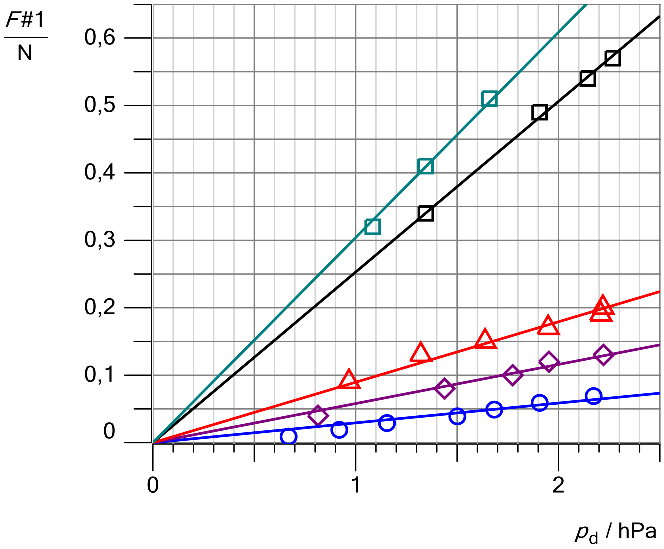
- Right click one measuring point in table "$c_w(v)$" and select "*Draw Mean*"
- Drag the left mouse button over all measuring points of the series. A mean line will appear.
- Right click the mean line, choose "*Set Marker*" and select "*Text (Alt+T)*". A text like *"$c_w = 1.028 \pm 0.005$"* will appear.

Tab. 1: Aerodynamic drag F, flow velocity v and drag coefficient c_w for the resistance body round disk, Ø 56 mm.

$\frac{F}{\mathrm{N}}$	$\frac{v}{\frac{\mathrm{m}}{\mathrm{s}}}$	c_W
0.34	15.0	1.03
0.49	17.8	1.04
0.54	18.9	1.02
0.57	19.4	1.02

Evaluation and Results

Fig. 5: Aerodynamic drag F as function of the dynamic pressure p_d for the five resistance bodies with Ø 56 mm (**round disk**, sphere, streamlined body, streamlined body reverse, hemisphere dish). The solid lines correspond to straight lines through origin: y = B x



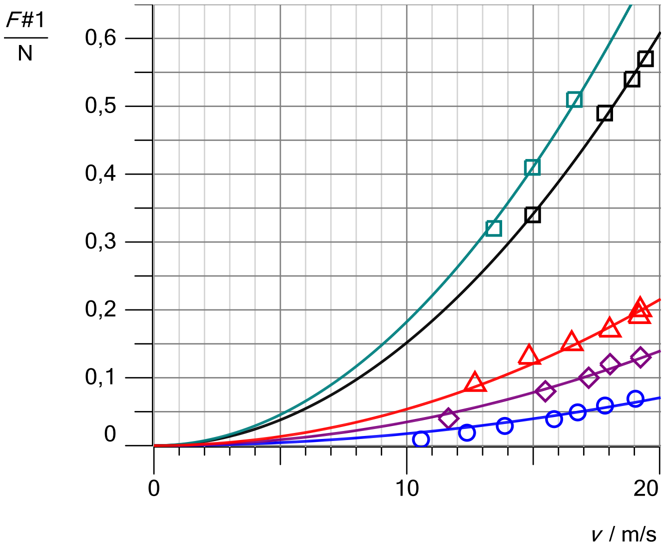
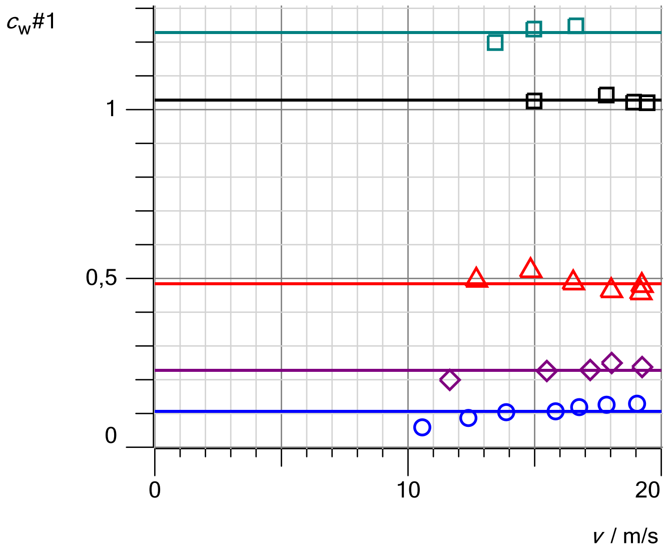


Fig. 6: Aerodynamic drag F as function of the flow velocity v for the five resistance bodies with Ø 56 mm (**round disk**, sphere, streamlined body, streamlined body reverse, hemisphere dish). The solid curves correspond to norm parabolas: y = D x²

Fig. 7: Drag coefficient c_W as function of the flow velocity v for the five resistance bodies with Ø 56 mm (**round disk**, sphere, streamlined body, streamlined body reverse, hemisphere dish). The solid lines indicate the average values.



Equation (I) can be rearranged:

$$c_W = \frac{F}{A \cdot p_d}$$

Substituting the dynamic pressure p_d with equation (II) leads to

$$c_W = \frac{2}{\rho} \cdot \frac{F}{A \cdot v^2} \quad .$$

Only resistance bodies with the same cross-sectional area A were chosen:

$$A = \pi \left(\frac{0.056\ \text{m}}{2} \right)^2 = 0.0025\ \text{m}^2$$

The drag coefficients c_W are relatively constant for flow velocities $v > 10$ m/s (see Fig. 7). The aerodynamic drag F for a streamlined body is less than 1/10 compared to a hemisphere dish.

Tab. 2: Average drag coefficients $\overline{c_W}$ for five resistance bodies with Ø 56 mm.

Resistance body shape	$\overline{c_W}$
hemisphere dish	1.23
round disk	1.03
sphere	0.37
streamlined body reverse	0.23
streamlined body	0.11

Remark: Great caution is required when comparing the measuring results with literature values. Aerodynamic behavior of differently scaled models can differ significantly. Even recent literature often neglects the principles of model building.