Lift and drag

LEP 1.4.09

Related topics

Aerofoil, plate, induced resistance, frictional resistance, circulation, pressure, Bernoulli equation, angle of incidence, dynamic pressure, polar diagram.

Principle and task

A rectangular plate or an aerofoil in a stream of air experiences a buoyant force (lift) and a resistance force (drag). These forces are determined in relation to area, rate of flow and angle of incidence.

Equipment

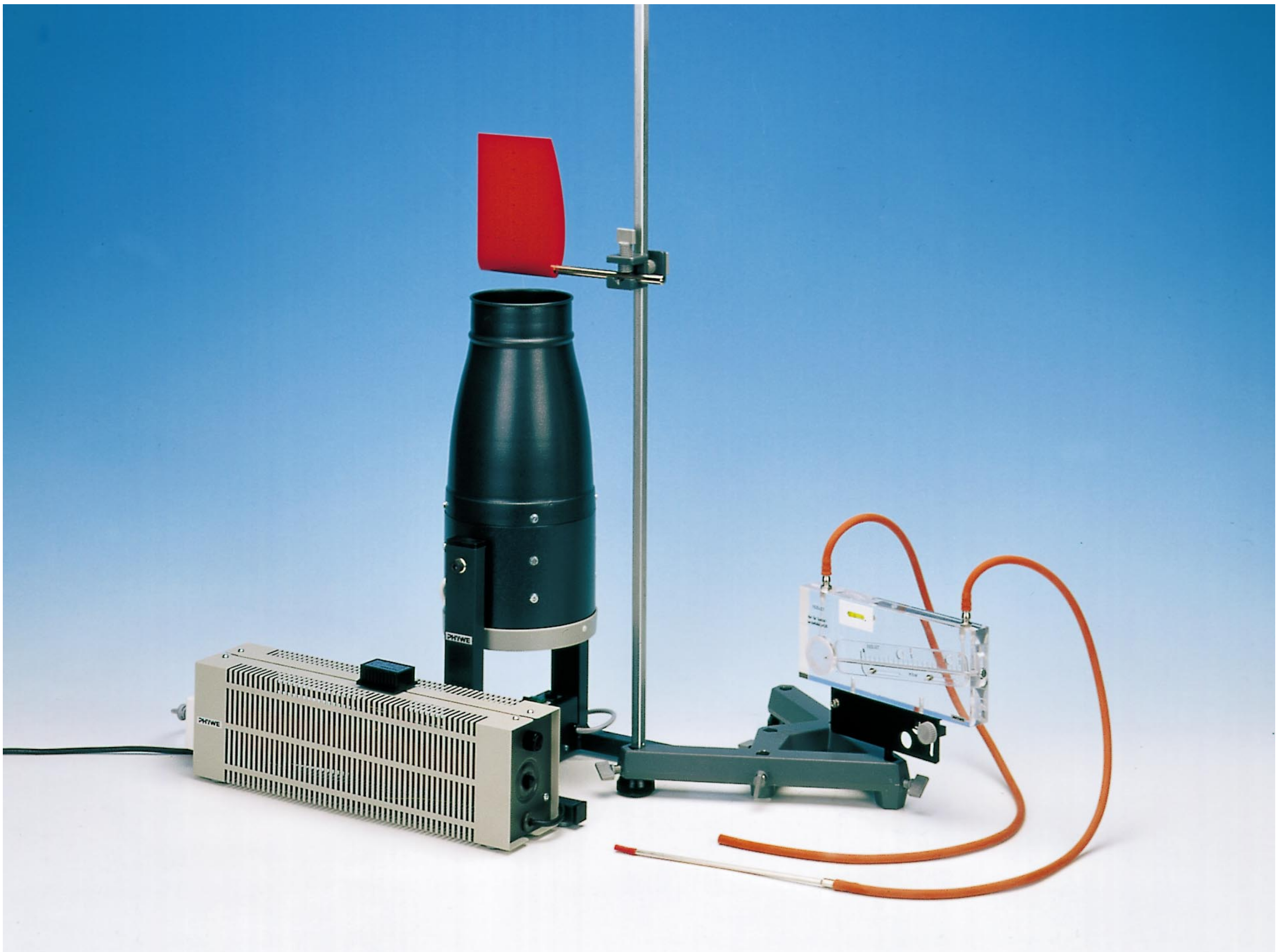
Aerodynamic models, set of 14	02787.00	1
Aerofoil model	02788.00	1
Pitot tube, prandtl type	03094.00	1
Pipe probe	02705.00	1
Precision manometer	03091.00	1
Holder with bearing points	02411.00	1
Double shaft holder	02780.00	1
Precision pulley	11201.02	1
Rheostat, 500 Ohm, 220 V	06111.93	1
Spring balance 0.1 N	03061.01	2
Blower, mains voltage 220 V	02742.93	1
Rheostat, 500 Ohm , 220 V	06111.93	1
Support base -PASS-	02005.55	1
Barrel base -PASS-	02006.55	1
Support rod-PASS-, square, l = 1000 mm	02028.55	1
Right angle clamp -PASS-	02040.55	4
Rod with hook	02051.00	2
Stand tube	02060.00	2
Rod, pointed	02302.00	1
Silk thread, 200 m	02412.00	1
Rubber tubing, i.d. 7 mm	39282.00	1

Problems

Determination of the lift and the drag of flat plates as a function of:

1. the plate area
2. the dynamic pressure
3. the angle of incidence (polar diagram)
4. Determination of the pressure distribution over the aerofoil for various angles of incidence.

Fig. 1a: Experimental set up for determining the lift and drag acting for determining the pressure distribution over the aerofoil.



Set-up and procedure

The dynamic pressure is measured with the Prandtl tube, and the air velocity is calculated from equation (2). The air velocity must be checked frequently.

The double shaft holder must be clamped loosely in the pivot points and adjusted horizontally and vertically. The rectangular plates are statically counterbalanced; it is convenient to use the pointed rod as a reference point. Since the anticipated lift and drag forces are very slight, the balance must be very carefully adjusted. Using the spring balances, the lift and (using the precision pulley) the drag are compensated and measured. If, after compensation, the plates do not return to equilibrium when deflected by hand, the double shaft holder is gripped too loosely in the pivot points (surface friction) or too tightly (squeezing effect), and must be corrected accordingly.

In the range between 27° and 35° approximately, pronounced turbulence occurs so that these angles of incidence are unsuitable for carrying out a test.

To measure the pressure distribution over the aerofoil (Fig. 1a) a piece of rubber tubing is slipped over the pipe probe. In order to obtain better contact with the measurement positions this tubing must be turned back at the contact point and moistened.

Theory and evaluation

The force $\vec{K}$ acting on a body around which air is circulating is:

$$\vec{K} = \int_A \vec{p} \, da \qquad (1)$$

where A is the lateral face of the body. The surface forces $\vec{p}$ are the normal and shearing stresses. These include the pressure p and the frictional forces. If the direction of the flow velocity v lies along the x direction, then K_x is the drag F_R and K_y is the lift F_A.

Equation (1) is more suitably expressed by the dynamic pressure due to the flow velocity:

$$q = \frac{\rho}{2} v^2 \qquad (2)$$

(ρ = density of the medium)

and by a typical area f_p , e.g. the plate area:

$$F_R = c_w \cdot f_p \cdot q$$

$$F_A = c_a \cdot f_p \cdot q.$$

Fig. 1b: Experimental set up for determining the lift and drag acting on the rectangular plate.

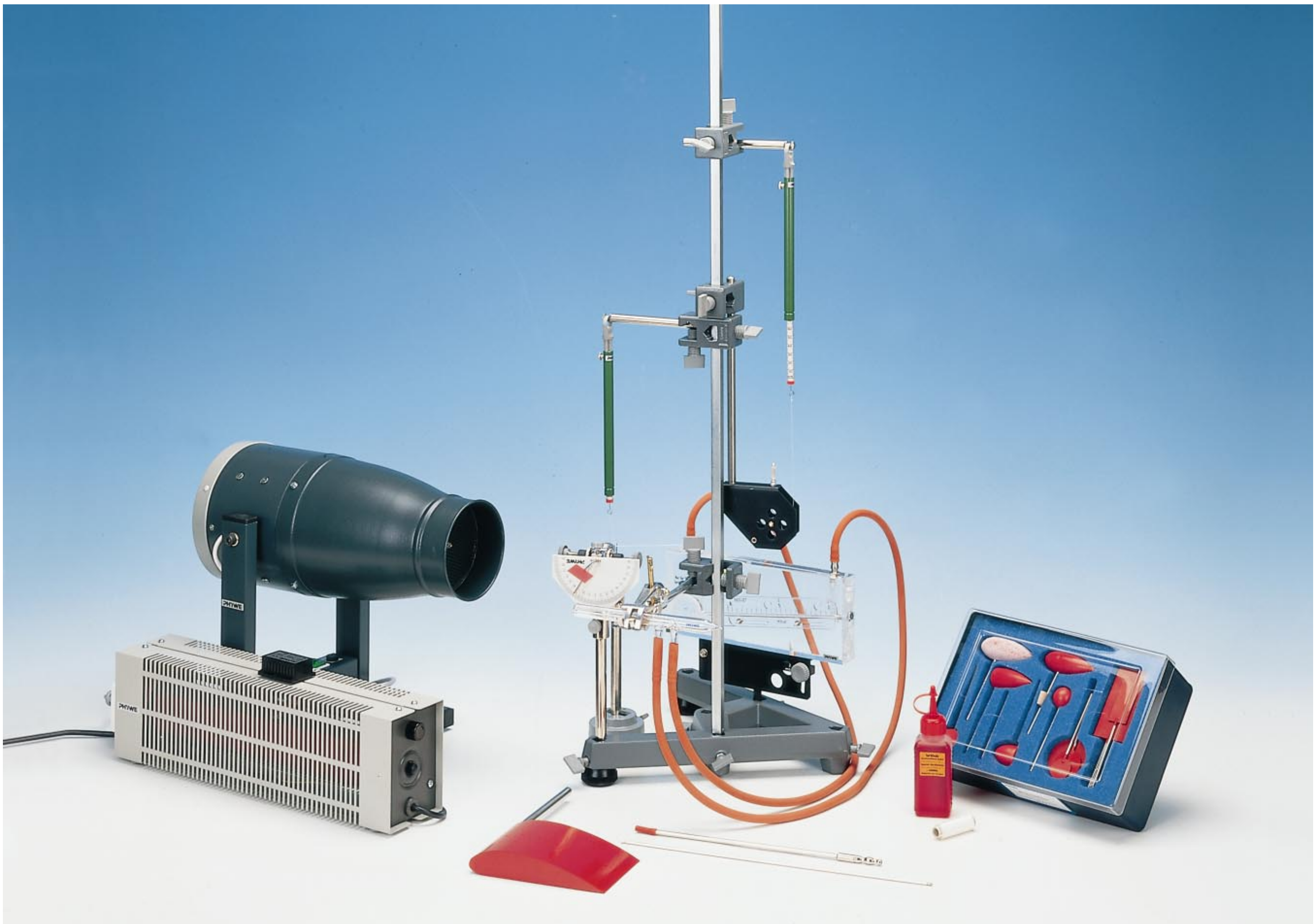


Fig. 2: Drag and lift in relation to dynamic pressure for an angle of incidence of 20° and a plate area of 17.5 cm^2.

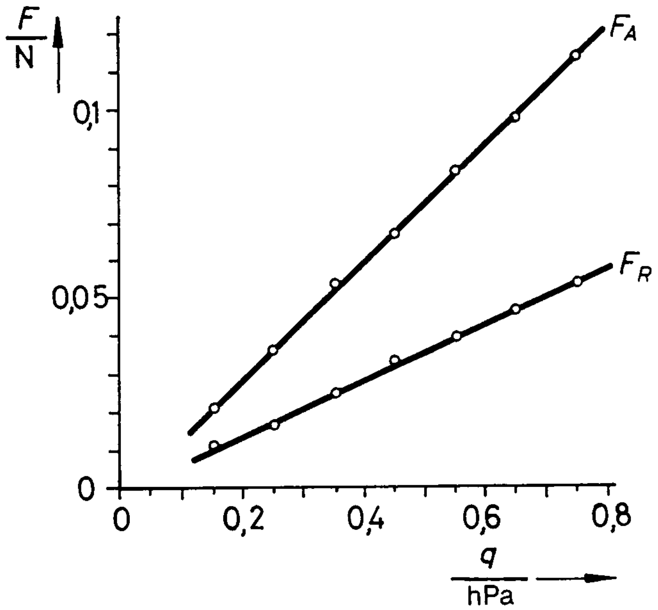
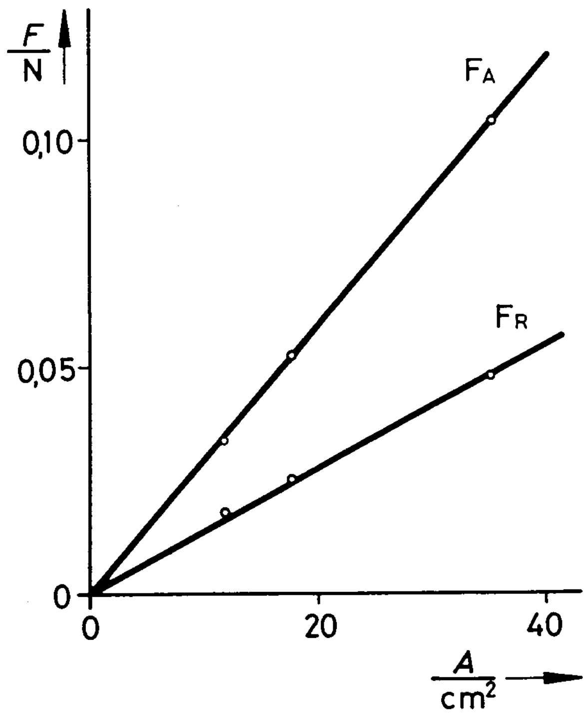


Fig. 3: Drag and lift in relation to the plate area for an angle of incidence of 20° and a dynamic pressure of 0.35 hPa.



For small angles of incidence α and for irrotational flow we have, for an aerofoil of infinite length,

$$c_w = 0$$

and c_a is approximately equal to

$$c_a = 2\pi \cdot (\alpha + \frac{2f}{t}),$$

where: t = chord, f = camber.

In the case of the finite aerofoil, a separation area is formed at the trailing edge if the angle of incidence is small. The turbulence produced induces a resistance (coefficient of resistance c_{wi}) which is related to the lift:

$$c_{wi} = \frac{C_a^2 \cdot \int_p}{\pi \cdot b^2},$$

where b is the distance between the supports.

Since a certain frictional resistance as well as the resistance due to partial separation of the flow still exist, the following is obtained

$$c_w = c_{wo} + \frac{C_a^2 \cdot \int_p}{\pi \cdot b^2}.$$

With larger angles of incidence, the flow changes from laminar to turbulent so that the drag increases and the lift decreases.

The lift is usually plotted against the drag (polar diagram).

Literature:

L. Prandtl, K. Oswatitsch, K. Wieghardt: Stromungslehre (Fluid dynamics). Braunschweig, Vieweg 1969.

H. Ashley, M. Landahl: Aerodynamics of wings and bodies. Reading, Addison Wesley 1965.

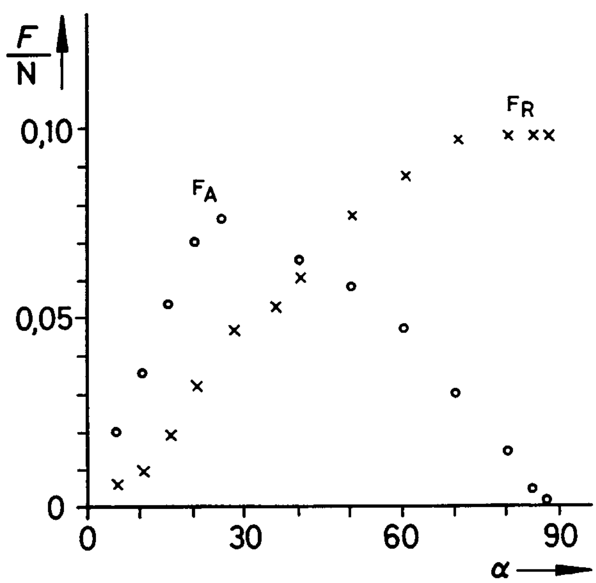


Fig. 4: Lift F_A and resistance F_R of a flat plate as a function of the angle of incidence.

Fig. 5: Lift F_A as a function of the drag F_R of a plate for different angles of incidence with a dynamic pressure of 0.25 hPa and a plate area of 35.1 cm^2.

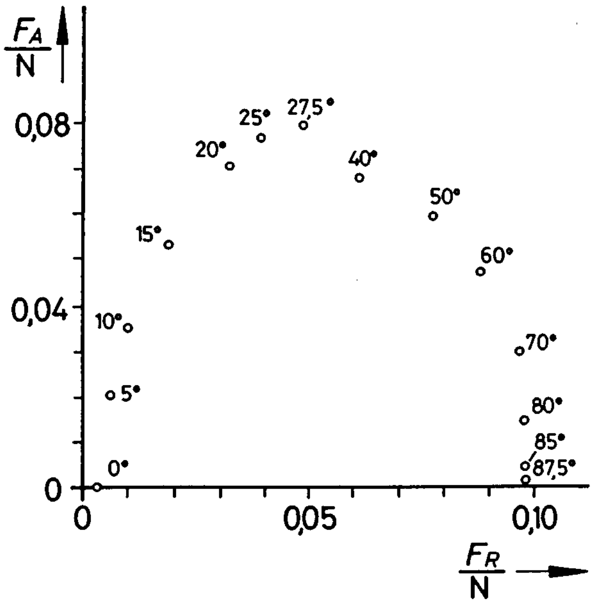


Fig. 6: Pressure distribution over the aerofoil for different angles of incidence with a dynamic pressure of 0.8 hPa
o = top side of the aerofoil,
x = under side of the aerofoil.