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USE OF BALANCES IN ANEMOMETRY

M.J.F.P. PLUIJM, T.H.J.J. VAN DER HAGEN, C.H. MASSEN

Department of Technology, University of Technology, Eindhoven (The Netherlands)

ABSTRACT

In 1957 it were Poulis e.a. (ref.1) who pointed out that moving-coil ammeters could well serve as instruments for the measurement of horizontal forces. This idea has been widely applied to a great variety of purposes. In the present paper the application to the measurement of small air velocities is described. Thereto a vane is mounted on the pointer of a moving-coil-meter. The forces exerted on the vane allow for the detection of air velocities down to the mm/s range. This means that the method can be used supplementary to the commonly used types of anemometers, the detection limits of which are of the order of 5 cm/s.

INTRODUCTION

Until now, there are many commercial air velocity meters available, such as Pitot-tubes, hot-wire anemometers, Laser-Doppler anemometers and cup-anemometers (ref.2). Their detection limit is of the order of 5 cm/s which is insufficient for some applications. An apparatus covering velocities down to the mm/s range would be a welcome supplement to the commonly used types of anemometers. Possible applications of such an instrument are:

- Rooms with dust-free and sterile atmosphere, e.g. operating rooms in hospitals.
- Supervision of windcalm rooms, e.g. laboratoria.
- Investigations of the influence of indoor climate on men; fluctuations of low air flow play an important part in the sensation of draught (ref.3).

THEORY

Generally the drag on a body in an air flow can be described by:

$$F = \tfrac{1}{2}\rho A v^2 C_d \tag{1}$$

where ρ is the density of the air,
A is the cross-sectional area of the body perpendicular to the flow,
v is the velocity of the air and
C_d is the drag-coefficient.

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C_d however is dependent on the velocity as well as the shape of the body as is illustrated in Fig.1 (ref.4), in which

$$Re = v.L.\ \rho/\eta \qquad (2)$$

with L the characteristic length of the vane and
η the kinematic viscosity of the air.

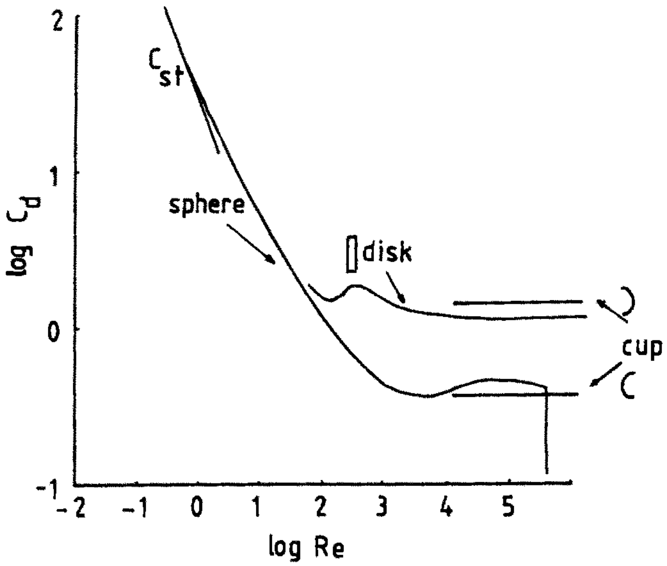

Fig.1: Coefficient of drag. vs. Reynolds number for axisymmetric bodies (ref.4)

As is shown in Fig.1 for Re < 50 the dependence of C_d on the shape is of minor importance.

MEASURING DEVICE

In order to measure the velocity of the air flow, the force exerted on a vane placed in this air flow, is measured. This force produces a displacement of the vane originally at rest. In order to prevent such displacements from influencing the measured force, a compensating force is introduced, which can be measured with precision.

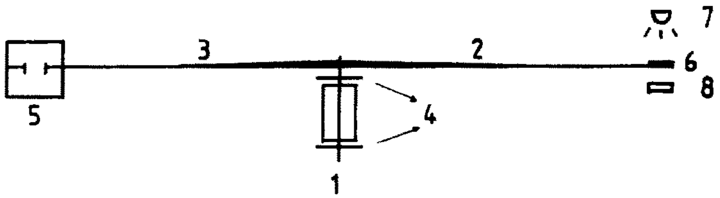

Fig.2: Schematic representation of the measuring device. For explanation of the symbols, see text.

An ordinary moving coil amperemeter serves as our balance. On top of its vertical axis of rotation (1) there are two horizontal beams (see Fig.2). One of these beams is the original pointer of the amperemeter (2) and the other (3) is fixed in a straight line with the original one. The meter is kept in balance by two spiral springs (4). At the far end of the second beam a rectangular vane (5) is fixed. At the other far end a small strip of metal (6) is fixed. Above this strip an infra-red Gallium-Arsenide (λ = 940nm) light emitting diode (LED) (7) is placed, which casts its light on the strip. Under the strip two identical Silicon photodiodes (Siemens type BPW 34) (8) are placed adjacently.

First the LED and the photodiodes are placed in such a way that the diodes catch the same amount of light, so the output signal of the combination of diodes is zero. After that the strip is positioned above the diodes in such a way that zero voltage is achieved. In case of non-zero air velocity, a force will be exerted on the vane, the vertical axis will rotate and the shadow on the photodiodes will no longer be spread symmetrically over the two cells. The output voltage V_{out} will either be positive or negative, dependending upon the direction of the wind. By sending a current through the coil of the amperemeter, the resulting Lorentzforce can serve as retro-active force. In order to put the beam in its original position the magnitude of the Lorentzforce (the current) has to be adjusted which involves a feedback system, leading to equilibrium of mechanical moments.

In our measuring device the ampere meter is placed in a hollow sphere (diameter 8 cm), except for the vane and the beam it is fixed upon.

EXPERIMENTAL SET-UP

The problem in constructing an experimental set-up, which can create velocities down to the mm/s range, is that one cannot measure these velocities. One has to rely on the theory which forecasts the velocity at a certain place at a certain time at given boundary conditions. A simple extrapolation from higher velocities, where calibration is possible, is not quite satisfactory and may lead to errors. In this paper we describe the method for creating small air velocities, called the pushing aside method.

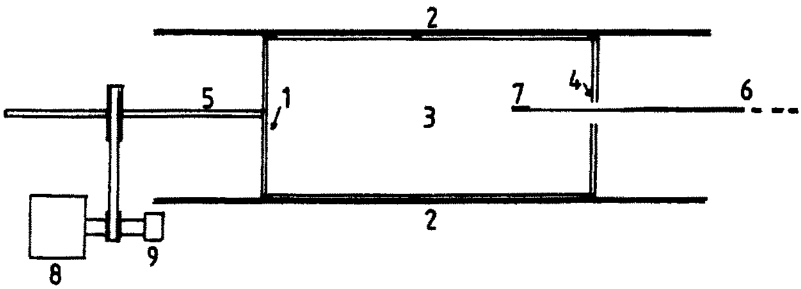

Fig.3: Experimental set-up. For explanation of the symbols, see text.

A circular piston (diameter 30 cm) (1) is moved in a cylindrical tube (PVC, length 3 m) (2) with constant velocity (see Fig.3). However, as a consequence of the conditions on the edges where the velocity is zero, whirls can occur in the neighbourhood of the piston. This problem can be solved by creating a situation in which all edges have the same velocity v. In order to cope with this problem a second tube (3) is fixed on the piston and on the other opening of this tube a second piston (4) is fixed. The air in this closed tube will move with constant velocity v. The velocity- and pressurewaves will travel with the speed of sound, so the air in the tube will almost instantaneously have the speed of the cylindrical tube.

The orginal PVC tube now serves as a support. On the left piston (see Fig.3) a bar (5) is fixed and from a construction of several wheels the rotations of the motor are transformed into a horizontal motion of the piston. In the second piston a small hole is made (diameter 3 cm) through which a 2 m long metal conical bar (6) is placed, which is fixed to the nearby wall. At the other end of the bar a small plateau is fixed on which the meter is placed (7).

With this experimental set-up velocities are produced in the range of 2.5 mm/s to 130 mm/s. The velocity of the tube (v_t) is determined by means of a tacho-generator (9), measuring the number of revolutions per second of the motor (8). Both the output voltage of the ampere meter (V_{out}), and the output-voltage of the tacho-generator (V_{tacho}) are sampled by a computer (DEC/LSI-11) with an accuracy of 2.5 mV and a sampling frequency which can be chosen between 200 and 1000 Hz. All signals are stored digitally.

EXPERIMENTS AND RESULTS

Experiments have been performed with the equipment described. As measure for the air velocity the output voltage V_{out} of the feedback system is used. In order to make comparison with the data of Fig.1 possible, we introduce a new coefficient C' which is defined as:

$C' = V_{out}/\frac{1}{2}\rho A v_t^2$

In Fig.4 C' is plotted as a function of Re on a double log-scale. The values of Re are obtained by taking v_t as the air velocity. Three different series are shown corresponding to three different rectangular vanes of 1.00, 2.25 and 4.00 cm^2. In this figure the measurement inaccuracies are also indicated. Also the data of C_d of a circular disk (see Fig.1) are presented here by the line drawn.

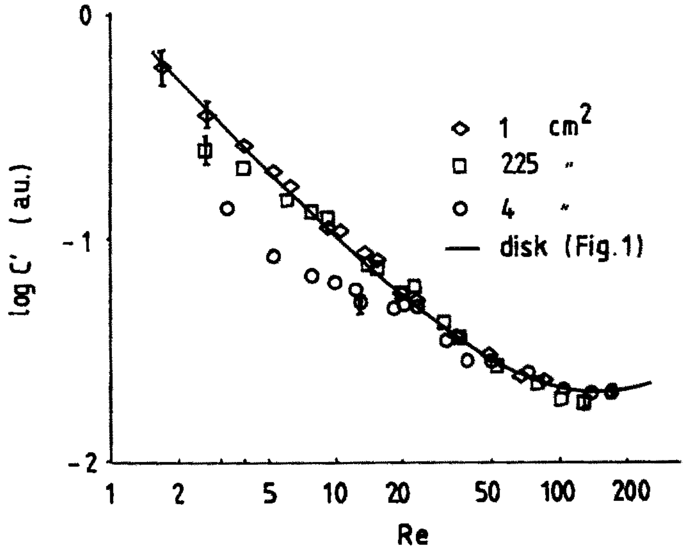

Fig.4: C' plotted as a function of Reynolds. I represents the measurement inaccuracy.

DISCUSSION AND CONCLUSION

From Fig.4 we see that for Re > 20 the dependence of C' on Re is very similar to the dependence of Cd on Re. It has to be mentioned here that the values of Cd and C' differ by a constant, yet unknown factor which only results in a vertical translation of C' in Fig.4. The line drawn for C_d here is chosen such that it coincides with the value of C' as Re = 20 and A = 1 cm^2. At Re < 20 we find that C' becomes dependent upon the area of the vane used, which is not found in the line drawn (C_d). This discrepancy may well be due to the presence of our meter which in our construction happens that the bigger the vane, the smaller the distance to our sphere. This may lead to smaller air velocities and so smaller values of V_{out}. The measurement inaccuracies indicated in Fig.4, are mainly caused by the mechanical vibrations of the meter brought about by the construction.

As a conclusion we can state that the anemometer described above is sufficiently sensitive for measuring air velocities from 130 mm/s to 1 mm/s. Future experiments will be focussed on optimizing both the facilities for attaining air velocities as well as the geometry of the meter.

REFERENCES

1 J.A. Poulis, L.J. Poldervaart and P. Teunissen, The measurement of small forces by means of a moving coil meter with an application to magnetic susceptibility measurements, Appl.Sci.Res., Section B, Vol.6 (1957), 124-128.
2 E.O. Doebelin, Measurement systems, Application and design, McGraw-Hill (1983), chapter 7.
3 B.W. Oleson, Draught and Air Velocity Measurements, DISA-information 24 (1979), 30-35.
4 J.A. Roberson e.a., Engineering Flind Mechanics, Houghton Mifflin Comp. (1975), chapter 11.