8

Wind Speed and Direction

8.1 Introduction

Although airflow in the atmosphere is a three-dimensional velocity field, it is the horizontal component of its motion which is commonly measured, in part because the vertical component is generally much smaller. Measuring the horizontal air velocity ultimately determines the wind vector $\mathbf{V} = (u, v)$, where u is conventionally the west-to-east (*zonal*) component, and v the south-to-north (*meridional*) component. Often only the magnitude of the vector (i.e. the wind speed, which is usually given the symbol U) is measured, with the wind direction measured entirely independently. An instrument for measuring the wind speed is known as *anemometer*; the mechanical device turned by the wind to indicate the direction from which the wind is blowing is a *wind vane*.

With a fast-response wind sensor, rapid changes of speed and direction can be identified. Fluctuations on all time scales from fractions of a second upwards are present, although changes on timescales longer than about 30 min are not regarded as turbulence. Wind speed measurements spaced along a flow can also show a statistical correlation, when coherent structures or eddies are present.

Properties used to determine wind speed include the flow's kinetic energy (cup and propeller anemometers), pressure (tube, Pitot and pressure plate anemometers), cooling (hot wire or film anemometer) and the effective speed of sound in a moving reference frame (sonic anemometer).

8.2 Types of anemometer

8.2.1 Pressure plate anemometers

A simple anemometer is provided by the deflection of a vertically hanging plate oriented into the mean wind direction. The deflection of the plate to the vertical is proportional to the strength of the wind. Although an early experimental method,[1] the non-linear response and the directional response mean it is not widely used. A related technique, the deflection of a small weight or lightweight ball by the horizontal wind known as a 'telltale', has however been used as a sensor on the Phoenix Martian lander [71], with the measurement made using a video camera.

8.2.2 Pressure tube anemometer

A pressure tube anemometer measures pressure differences associated with a static and moving flow. An early design of this was the pressure tube anemometer of W.H. Dines[2] in 1892, which measured the small difference in pressure (see Chapter 7 for pressure measurement techniques) from a tube aligned to face the wind by a vane, and a further set of sensing holes exposed to the mean flow. The tube facing the wind determines the total stagnation pressure P_t, and the sensing holes the static pressure P_s.

The wind speed is derived from Bernoulli's principle as

$$\Delta P = P_t - P_s = \frac{1}{2}\rho U^2 , \quad (8.1)$$

where ρ is air density, P_t is the total pressure (from the orifice pointing directly into the air stream) and P_s the static pressure (from an orifice sensing the pressure of the moving air stream).

The pressure difference ΔP is measured using a differential manometer, and is small. For example, Equation 8.1 shows a wind speed of 1 m s^{-1} giving a pressure difference of ∼ 0.5 Pa. It is also apparent that the response is non-linear, with least sensitivity at low wind speeds.

A Pitot tube anemometer operates on the same principle, but uses a fixed direction sampling tube pointing towards the incoming flow. For a practical Pitot instrument, an extra 'form constant' should be included in Equation 8.1, although the sensor head is usually designed so that this constant is close to unity. With allowance for the form constant, a well-designed Pitot tube can be regarded as an absolute instrument. Pressure tube anemometers are therefore used for wind tunnel calibrations of other anemometers, but not normally in field measurements because of the directional sensitivity. The Dines pressure tube anemometer has seen long use because of its absolute mode of operation [72].

8.2.3 Cup anemometers

A typical cup anemometer[3] (Figure 8.1) has three conical or hemispherical collecting cups mounted at equal distances from a vertical shaft by equally spaced horizontal supporting arms.

The vertical shaft rotates on bearings arranged to cause as little mechanical loading as possible. The asymmetry of the cup arrangement ensures that the anemometer always rotates the same way irrespective of the direction of the incoming wind. The response characteristic of a cup anemometer is close to linear, and can be described by

$$\omega = k(U - U_0), \tag{8.2}$$

where ω is the angular rotation speed, U is the wind speed, U_0 is the starting speed for the anemometer and k a calibration constant. Typically, U_0 is about 2 m s^{-1} for large-cup anemometers used in a climatological station, but may be only 0.5 m s^{-1} for a light anemometer with good bearings as used in micrometeorology.

Figure 8.1 A three-cup anemometer used to measure the horizontal wind speed.

For small changes of wind speed, the response time constant τ of a cup anemometer is inversely proportional to the wind speed. The product τU is known as the *response length* as it corresponds to a run (or distance) of wind necessary for the instrument to respond, which is fairly independent of the actual wind speed. For a climatological station anemometer, the response length is about 10 m, while for a small lightweight anemometer, it may be only 2.5 m.

The output signal from a cup anemometer may be a voltage proportional to rotation speed (e.g. from a DC generator) or a series of electrical pulses generated by an optical or magnetic switch on the rotating shaft (Figure 8.2). The optical switch is particularly well suited to minimising the rotational load, and hence in obtaining a small starting speed. Both voltage and pulse outputs generally require some smoothing, which limits the time response of the measurement. At slow speeds for pulse output devices, reciprocal counting (timing the interval between pulses, rather than by determining the pulse rate), provides higher resolution of the rotation rate.

Figure 8.2 View of the optical shutter arrangement used in the lightweight cup anemometer of Figure 8.1. As the shaft rotates, a light beam between an optical source and electronic detector is regularly interrupted by the teeth on the shutter, generating a series of digital pulses at a rate which is proportional to the rotation speed.

8.2.4 Propeller anemometer

In contrast to a cup anemometer, a propeller anemometer provides a directional response, and, if the sensing propeller is made of lightweight material, it can be accelerated and decelerated rapidly by the wind. Examples of propeller anemometers are shown in Figure 8.3. These use a 'helicoidal' design of lightweight propeller, mounted on a shaft to drive a small DC generator [73]. If the anemometer shaft is inclined at a small angle θ to a steady air flow of speed U, the rotation rate of the shaft is expected to be given by

$$\omega = k(U - U_0)\cos\theta \,. \tag{8.3}$$

Figure 8.3 An array of three orthogonal propeller anemometers providing a rapid response to wind fluctuations, from which the wind direction can also be found. (A fast response thermometer is also mounted in the middle of the anemometer array.)

The starting speed is much lower than for most cup anemometers (typically 0.2 m s^{-1}), and response lengths correspondingly smaller (typically 1 m). Consequently, this type of anemometer is suitable for measuring turbulent fluctuations of air speed along one direction. Unfortunately, Equation 8.3 is only approximated for relatively small angles (typically less than 30^{o}), due to the effect of one blade interrupting the flow to another blade, known as blade sheltering. Consequently, if a propeller anemometer is only required to measure wind speed, then it is usually kept oriented along the direction of the wind with the aid of a wind vane.

A common application of the propeller anemometer is to measure turbulent fluctuations in the vertical component of the wind (often given the symbol *w*). If simultaneous measurements of temperature using a fast response thermometer are also made, their combination provides an estimate of the vertical transfer of heat (see Section 12.1.2). For this application, the anemometer is mounted with its axis vertical.

8.2.5 Hot sensor anemometer

A hot sensor anemometer determines the wind speed by the amount of cooling generated from a heated sensor. The sensor may be in the form of a fine wire (a hot wire anemometer) or the bead of a thermistor (a hot bead anemometer), to which a heating current is supplied. Two operating modes are possible; in one case by measuring the power needed to keep the sensor at constant temperature, or, in the other, by measuring the sensor's temperature with a constant supply of power.

In the case of a heated fine wire suspended in an airflow, the wire also operates as a thermometer, in that its resistance is proportional to its temperature. It can be kept at a constant temperature electronically by a feedback circuit, which varies the heating current to maintain a constant resistance (Figure 8.4). For this situation, the current supplied to the wire to keep its temperature constant will be determined only by the wire's cooling rate, and therefore provides the quantity to be measured. A general empirical relation between heating current and air speed, known as King's law, relates the voltage drop across the wire to wind speed by

$$V^2 = A + B\sqrt{U}. \tag{8.4}$$

Such a relationship is obviously non-linear, and shows that the sensitivity increases as a power law with decreasing wind speed. (The response of a practical sensor measured in a wind tunnel is shown in Figure 8.5.) Because such a sensor can be constructed to be small, the response can be rapid, so hot wire (or hot bead, or even a filament bulb with the glass envelope carefully removed [74]) anemometers are normally used to measure turbulence or details of flow structure over objects mounted in a wind tunnel. They are, however, sufficiently delicate that they are not well suited to field measurements, although the hot bead devices can be mounted in a protective head to increase their robustness. The response of the wire or bead is also directional, and therefore consistent alignment with respect to the flow is important if the directional response is not to contribute to the measurement.

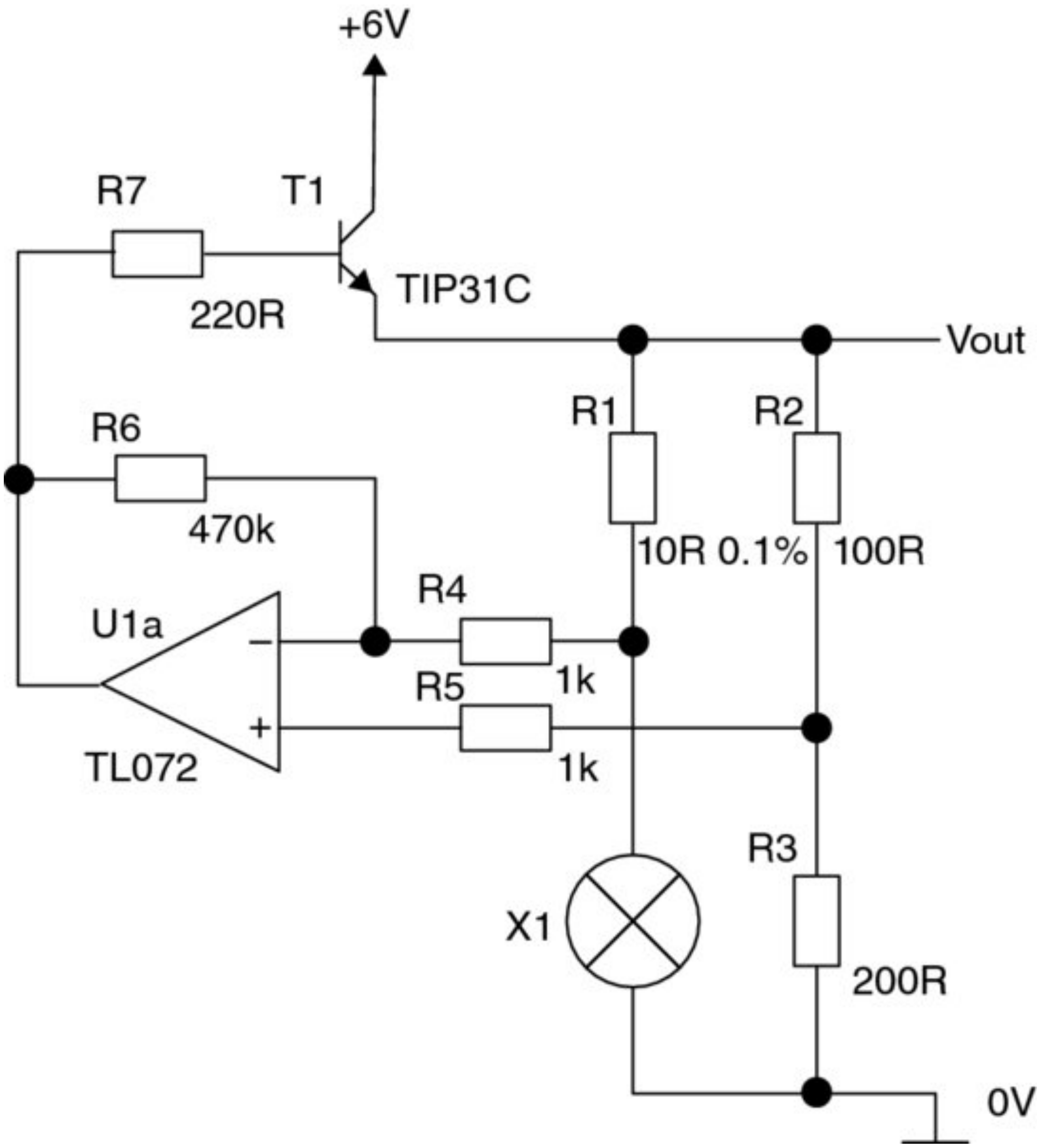

Figure 8.4 Principle of the electronic feedback system used to control a constant temperature hot wire anemometer. The hot wire anemometer sensing element (X1) has a filament lamp with the glass removed, a resistance which varies with temperature, and this forms a potential divider with R1. The mid-point voltage of this potential divider varies with the element's temperature, which varies in turn with the air flow. This mid-point voltage is compared (by differential operational amplifier U1a), with the reference voltage from a potential divider (R2 and R3), which is insensitive to the air flow. The difference voltage is amplified and used to bring the two mid-point voltages into agreement, by controlling the current supplied to both dividers by the transistor T1. This feedback stabilises the hot wire sensor temperature, with the excitation voltage of the potential dividers (V_{out}) providing the signal to be measured.

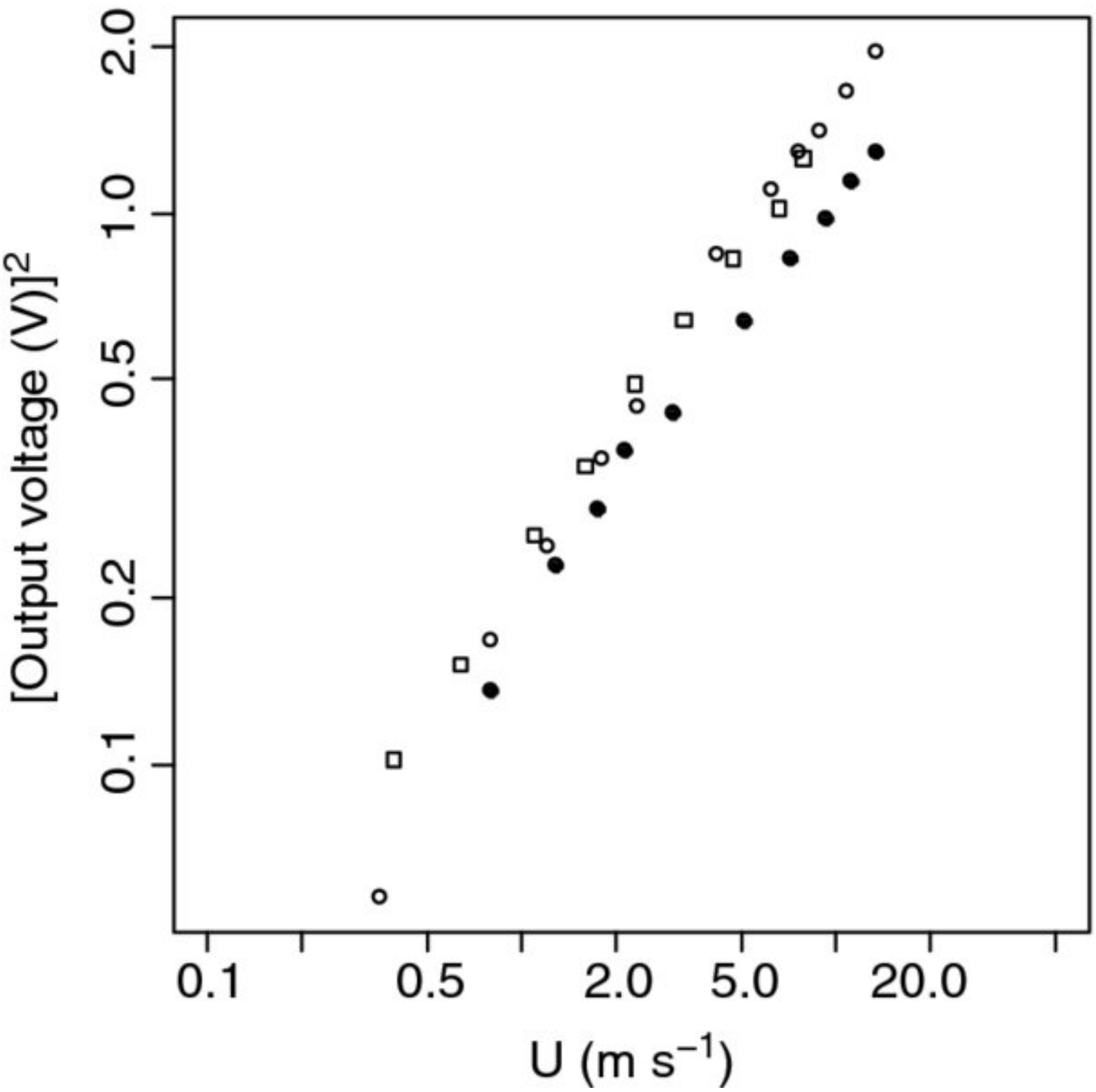

Figure 8.5 Measured wind speed response of a hot wire sensor, using the constant temperature control principle of Figure 8.4. Three similar sensors were used, each identified by different plot symbols, which demonstrates the need for individual sensor characterisation.

8.2.6 Sonic anemometer

The time of flight of a pulse of sound propagating in air provides a further method for sensing the wind speed. Ultrasound[4] can be readily generated and detected electronically, and is used for such measurements. In an ultrasonic anemometer, the flight time required for pulses of ultrasound to travel forwards and backwards between two fixed transducers A and B is measured (see Figure 8.6). The separation of the sensors is usually 10 to 20 cm, and as these measurements are electronic, they can be repeated rapidly, at typically 5 to 100 Hz, giving good accuracy and time response.

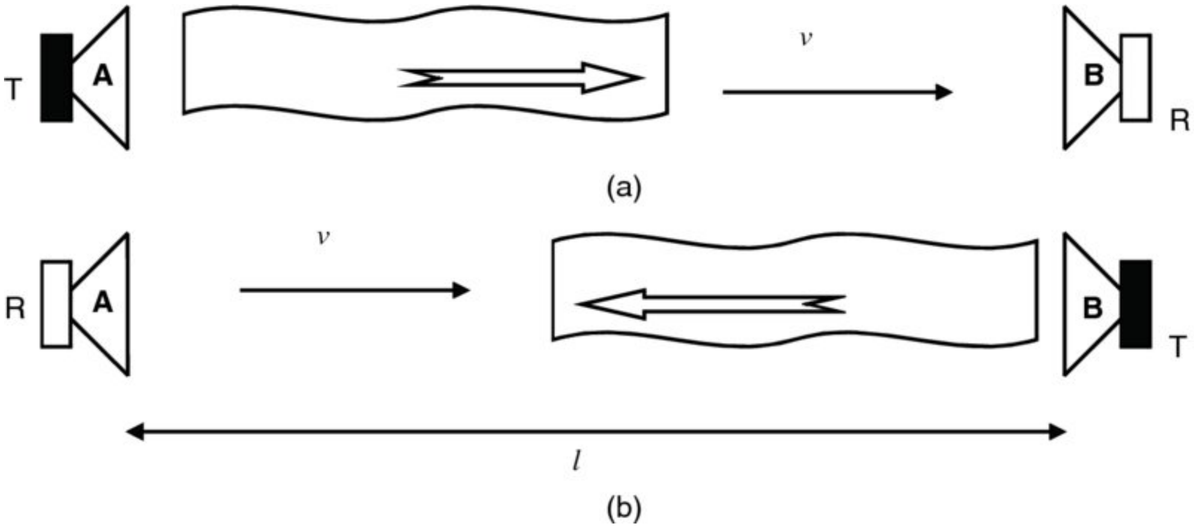

Figure 8.6 Conceptual arrangement of a one-dimensional sonic anemometer, with reversible transducers A and B spaced a distance *l* apart, each able to act as a transmitter (T) or receiver (R) of ultrasound. The pulse of ultrasound travels at the speed of sound and is propagated forwards (a) and backwards (b), encountering a wind speed *v* which adds or subtracts from the speed of sound accordingly.

If the flight time is t_1 from A to B

$$t_1 = \frac{l}{(c_s + v)}, \tag{8.5}$$

and t_2 from B to A,

$$t_2 = \frac{l}{(c_s - v)}, \tag{8.6}$$

where v is the component of wind travelling from A to B and c_s is the speed of sound.

Eliminating c_s gives

$$v = \frac{l}{2}\left\{\frac{1}{t_1} - \frac{1}{t_2}\right\}. \tag{8.7}$$

Alternatively, c_s can be found, which is strongly temperature-dependent. This variation is given by

$$c_s = \sqrt{\frac{\gamma R^* T}{M_r}}, \qquad (8.8)$$

where T is the air temperature, R^* the universal gas constant, M_r the relative molecular mass of air and γ the ratio of the specific heat capacities of air at constant pressure and volume, c_p/c_v. Inserting typical values for dry air (γ = 1.4, M_r = 0.029 kg mol^{-1} and R^* = 8.31 JK^{-1} mol^{-1}) gives c_s at room temperature (T = 298 K) as ∼346 m s^{-1}. If γ and M_r are assumed to be constant (i.e. considering the air to be dry), the *sonic temperature* T_s can also be defined from Equation 8.8 , such that

$$c_s^2 = \frac{\gamma R^*}{M_r} T_s \approx 403 T_s . \qquad (8.9)$$

This relationship forms the basis for sonic thermometry, where a measure of the air temperature is found from the speed of sound. However, a complication arises if the air is moist, as γ and M_r then need to be modified [75] to allow for the partial contribution of water vapour, giving

$$c_s^2 = 403T \left[1 + 0.32\frac{e}{p}\right], \qquad (8.10)$$

where e is the water vapour pressure and p the absolute pressure. This shows the relationship between the sonic temperature and air temperature, as

$$c_s^2 = 403T \left[1 + 0.32\frac{e}{p}\right]. \qquad (8.11)$$

For $e \ll p$, the sonic temperature becomes a good approximation to the air temperature.[5] Consequently, the humidity correction effect is usually neglected, particularly when using sonic thermometry to determine air temperature fluctuations. The difference between the air temperature and sonic temperature, if available very accurately, does, however, yield an acoustic method for measuring relative humidity [76].

Because of its rapid response, a sonic anemometer is well suited to the field measurement of turbulent fluctuations of wind velocity, and, as Figure 8.7 shows, in several directions simultaneously. After applying Equation 8.7, the three-dimensional velocity vector can be calculated with some data processing and trigonometric identities. The only significant disadvantages of this instrument are cost and management of the large volumes of data which can be quickly generated.

Figure 8.7 Ultrasonic anemometers mounted on masts. In the foreground is a two-dimensional device, and in the background a three-dimensional device. For the three-dimensional anemometer, the three pairs of transmitting and receiving transducers are towards the centre, with an outer support frame arranged to minimise disturbance to the flow.

8.3 Wind direction

Variations in wind direction can provide sensitive detections of changes in conditions, such as those associated with the passage of fronts, sea breezes or even solar eclipses [77]. These are complementary to other changes occurring which may be obscured by more substantial variations due to diurnal cycles.

Wind direction is conventionally defined as the bearing of a point from which the air is blowing, reckoned clockwise from north. This meteorological convention means that the wind direction is considered to be in the opposite direction to that of the vector describing the horizontal air velocity. Thus, for example, a 'south-westerly' wind would describe a wind direction of 225^{o}, but its vector direction would be 45°. A wind direction of 0° is sometimes used to signify calm conditions in databases as a null variable, as no wind direction is then defined.[6] It is important to identify when calm conditions affect wind vanes, as then the wind direction indicated merely refers to the last wind direction before the conditions became calm. In light winds inconsistent starting speeds of vane and cup anemometers may also cause uncertainties.

8.3.1 Wind vanes

For synoptic and climatological applications, wind direction is usually measured simply using a wind vane. Except for decorative versions (see, e.g. Figure 8.8), a wind vane usually consists of a flat vertical plate attached to a horizontal arm able to rotate on a vertical shaft. Such a device operates on the simple principle that the dynamic wind pressure P ($= 0.5\rho U^2$) causes a static force on a plate if the plate is not exactly aligned with the wind direction. The direction of the arm therefore becomes aligned with the wind direction.

Figure 8.8 Ornate weather vanes receive varying amounts of maintenance, and are unlikely to have low friction bearings. A combination of several devices provides more confidence in the direction indicated.

The response of a wind vane to changes in wind direction is limited by the need to damp the motion in order to avoid overshoot. It is theoretically possible to arrive at a critical damping factor, such that the vane responds quickly without overshooting. Practical designs allow slight overshoot with rapid damping of oscillations about the mean wind direction.

The direction of the arm of a mechanical wind vane can be determined by several methods:

i. from a mechanical switch with multiple contacts distributed regularly around the shaft;

ii. from an optical encoder giving a digital representation of measured angle; and

iii. from a precision potentiometer attached to the shaft, able to rotate continuously.

The principle of a potentiometer wind vane is shown in Figure 8.9. A potentiometer provides a fixed resistance between the two ends of a track of resistive material, and a movable contact (or wiper), which can be positioned anywhere between one end of the track and the other. If the two ends of the resistive track are connected across a fixed voltage supply, as the wiper moves from one end to the other, the voltage on the wiper will vary smoothly across the supply range from zero to its maximum value. For a track constructed in a circular form, this will provide an output voltage proportional to the amount of rotation, except for a small dead zone where the resistance track begins and ends.

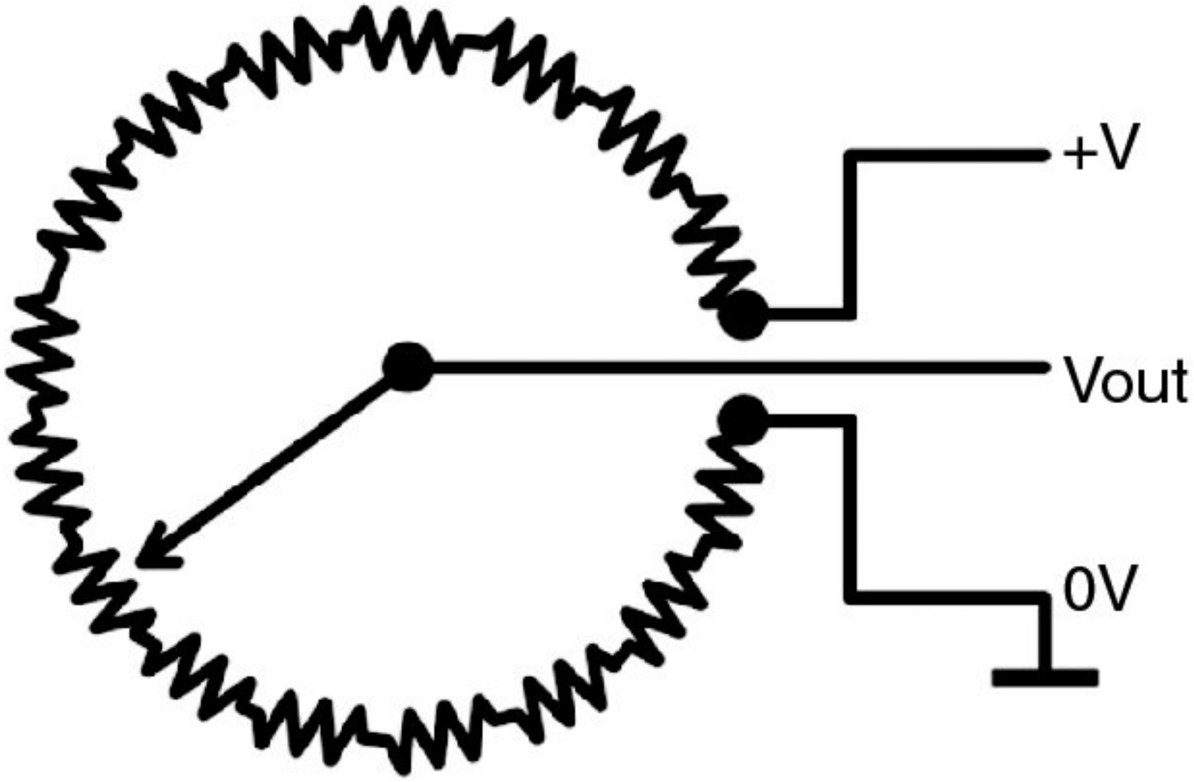

Figure 8.9 Principle of a potentiometer wind vane. Viewed from above (left hand side of diagram), the potentiometer wiper is free to rotate continuously for almost all the 360° of the resistance track, with a small dead zone necessary between the beginning and end of the track. When powered from a regulated supply, the voltage V_{out} at the wiper is proportional to the angular rotation.

Although this will provide an accurate measurement of the rotation, such an approach also requires that the orientation of the vane is already known or has been correctly installed to a standard configuration. For some circumstances where this cannot be assumed, such as on ocean buoys, a magnet may be used to orientate the direction measuring instrumentation, giving a self-referencing wind vane.

8.3.2 Horizontal wind components

An array of two or three directional instruments (Figure 8.3) or a multi-direction instrument (Figure 8.7) allows measurements of both wind speed and direction. Figure 8.10 shows a wind of speed U at a bearing θ from north, which can equivalently be expressed in terms of wind components u and v (in the west-east and the south-north directions respectively) by

$$u = -U \sin\theta , \tag{8.12}$$

and

$$v = -U\cos\theta\,. \tag{8.13}$$

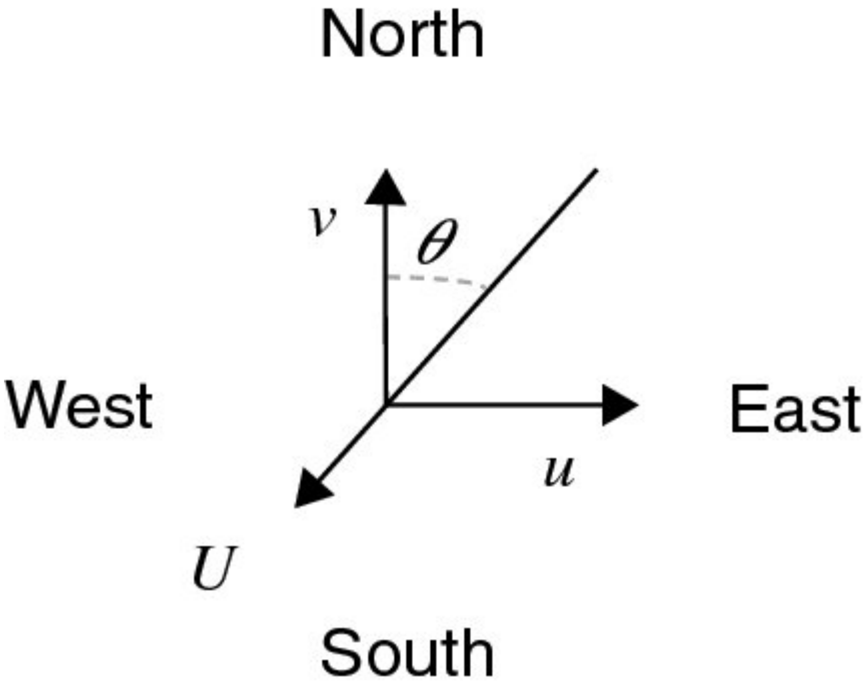

Figure 8.10 View from above of a horizontal wind of magnitude *U* blowing from the north-east, with a wind direction *θ* reckoned clockwise from north. The wind components in the west-east and south-north directions are *u* and *v* respectively.

Resolving the wind speed and direction into *u* and *v* or other wind speed components is essential if the wind direction needs to be averaged. This is because wind direction is a circular measure, and its value repeats as the wind direction passes through north. Consequently simple arithmetic averaging of wind direction may generate entirely the wrong direction.[7] The preferable method is to first derive wind speed components *u* and *v* for averaging, and then calculate the wind direction from the averaged components. The mean wind direction is given by $\tan^{-1}(v/u)$, although careful account of the quadrant in which the angle is returned is needed[8] especially as some inverse trigonometric function calculations only return angles in the range ±90°.

Figure 8.11 illustrates how the mean wind direction can be obtained on a day when the wind is northerly. Figure 8.11a shows the time series of the wind speed and direction, obtained using a wind vane and cup anemometer at 10 m. Clearly the wind direction is fluctuating around northerly, and although substantial changes are apparent in wind direction, generating lines between the top and bottom of the plot, the actual fluctuations in wind direction are small in terms of absolute change in angle. Figure 8.11b shows the two horizontal wind speed components calculated from the wind speed and direction in Figure 8.11a which are both single values and hence can be separately averaged and then the mean wind direction found from trigonometry. An alternative approach sometimes adopted is to extend the range of wind directions before the direction returns to zero. Figure 8.11c shows the wind direction in this way, to prevent the wind direction values beyond 360° resetting to 1°, instead allowing the wind direction to carry on increasing. This has the effect of removing the appearance of substantial wind direction fluctuations from the plot. It also makes it easier to evaluate the position of the mean value calculated from the averaged components in Figure 8.11b.

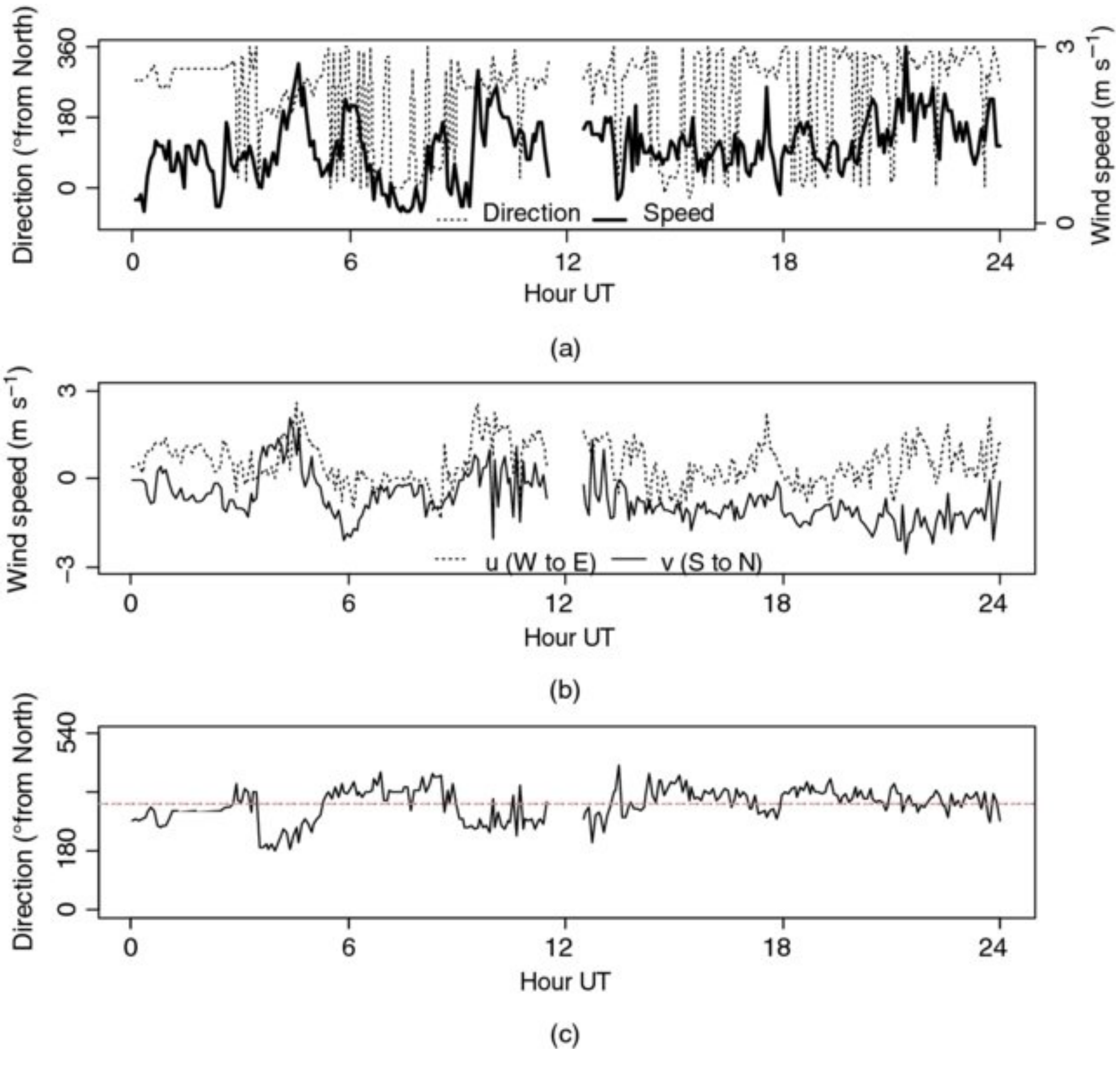

Figure 8.11 (a) Scalar wind speed and direction measured at 10 m at Reading, on a day with flow mostly around northerly (10 January 2013). (b) shows the calculated south-north and west-east components. (c) shows the wind direction recalculated from the wind components in (b), but offset to allow the wind direction in the first (NE) quadrant to be reported in the range 360° to 540°, with the calculated mean value also marked (dashed line).

8.3.3 Multi-component research anemometers

If three-dimensional wind speed measurements are required, the convention in micrometeorology is to adopt wind components which are aligned with the flow, rather than the fixed compass directions of the usual meteorological convention. These are known as stream-wise coordinates, but, confusingly, the related literature also tends to use the same symbols *u* and *v*. In the micrometeorological convention, a set of three velocities (**u**, **v**, **w**) is arranged so that **u** is along the mean wind direction, **v** is at right angles to the mean flow and **w** is close to the vertical direction. The horizontal wind speeds *u* and *v* are, respectively, along the mean flow (the stream-wise) direction and at right angles (the crosswise direction).

Because the wind direction is constantly changing, a set of three fixed anemometer positions will never be continuously aligned in the mean wind direction. Consequently, the stream-wise and crosswise wind speeds have to be obtained by calculation. These somewhat elaborate calculations are known as coordinate rotations, and serve to transform the measurements made in the fixed directions to a new coordinate frame based on the mean direction of the flow. The measurement directions are rotated so that the mean vertical wind component $\overline{w}$ is zero over the averaging period considered (typically 30 min), which ensures that the corrected vertical velocity is normal to the local stream surfaces. The mean crosswise component $\overline{v}$ will also be zero over the same period, but the mean stream-wise component $\overline{u}$ will be finite. The calculations required are summarised in Appendix B.

8.4 Anemometer exposure

For synoptic meteorology, wind speed and direction is conventionally measured at 10 m above the surface with the wind unobstructed in all directions. These can be achieved directly by using instruments mounted at that height (Figure 8.12) or by applying a correction to measurements made at the greatest height available. Use of such a correction is possible because, at an unobstructed site, the wind speeds measured at different heights vary with a known vertical profile (see also Figure 12.6).

Figure 8.12 Standard meteorological mast at Camborne Met Office, Kehelland, Cornwall, carrying anemometers and wind vanes.

8.4.1 Anemometer deficiencies

A key requirement in the operation of mechanical anemometers and wind wanes is that their bearings maintain low friction for minimal loading. Snow accumulations provide one source of obstruction which can affect cup anemometers, leading to a change in their calibration. At high wind speeds, the snow may fall out of the cups, but at low speeds the combination of low temperatures and clogged cups may even lead to the sensor freezing. Heated versions exist which can circumvent this problem but power is then required which may not be available at remote sites.

Figure 8.13 shows a comparison between the horizontal wind speed determined by cup and sonic anemometers at 10 m during snow. The wind speed measured by the cup is reduced during the snowfall. There is no simultaneous anomaly in a comparison between the wind direction determined from the same sonic anemometer data and the wind direction from a wind vane. This indicates that it is more likely to be the cup rather than the sonic anemometer which is affected by the snowfall.

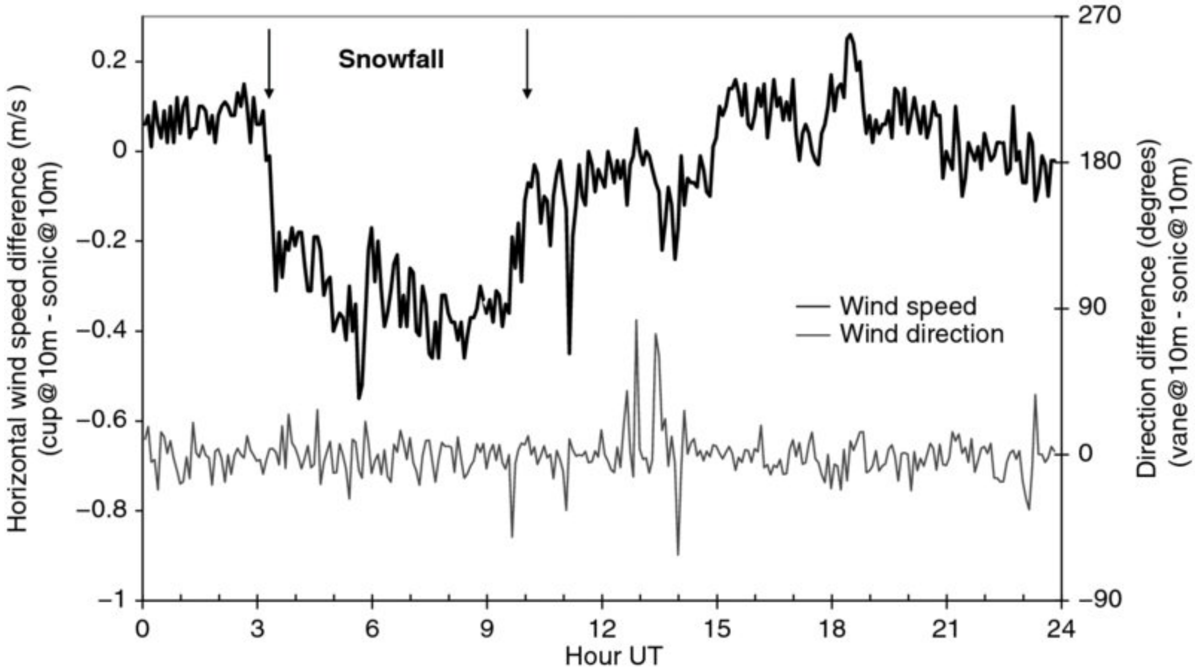

Figure 8.13 The effect of heavy snowfall (8 February 2007) on the difference between the 5-minute mean wind speed at 10 m measured by a cup anemometer and three-component sonic anemometer at Reading. The difference in wind direction determined by a wind vane and the same sonic anemometer is also shown (the mean daily wind speed was 2.5 m s^{-1}, standard deviation 1.2 m s^{-1}).

8.5 Wind speed from kite tether tension

Wind speed measurements immediately above the surface generally use meteorological towers or adjustable masts,[9] but tethered kites can also be used for wind speed measurements when conditions are changing and rapid deployment is needed, such as for monitoring flows in Antarctica. Some work has used kites as aerial instrument platforms or ‘skyhooks’, but it is also possible to use the kite itself as the sensor by measuring the tension in the tether line. This operates on the same principle as a wind vane, in that, for a flat plate, the wind force is approximately proportional to the square of the wind speed, which provides the tension in the tether. The tether tension can be monitored conveniently at the ground anchoring point.

A strain gauge can be used to measure the tension, but an important aspect of such measurements, as the tension variation is relatively small for a kite of modest dimensions, is to ensure that the instrumentation is not strongly influenced by temperature. In the kite wind-monitoring system shown in Figure 8.14, a measuring anchor ring was used with strain gauges mounted around it to monitor the distortion under tension [78].

Figure 8.14 A Rokkaku kite (flat area 2.3 m^2) with a tension-measuring sensor at the base of the tether, flown close to a sonic anemometer operating at 10 m.

Figure 8.15 shows the response obtained in the tether line tension, during which the mean wind speed was determined by a nearby sonic anemometer. The instantaneous tension in the tether line shows, approximately, a linear response to the instantaneous wind speed measurements. Some scatter arises from the comparison between the point measurement and area average obtained by the kite.

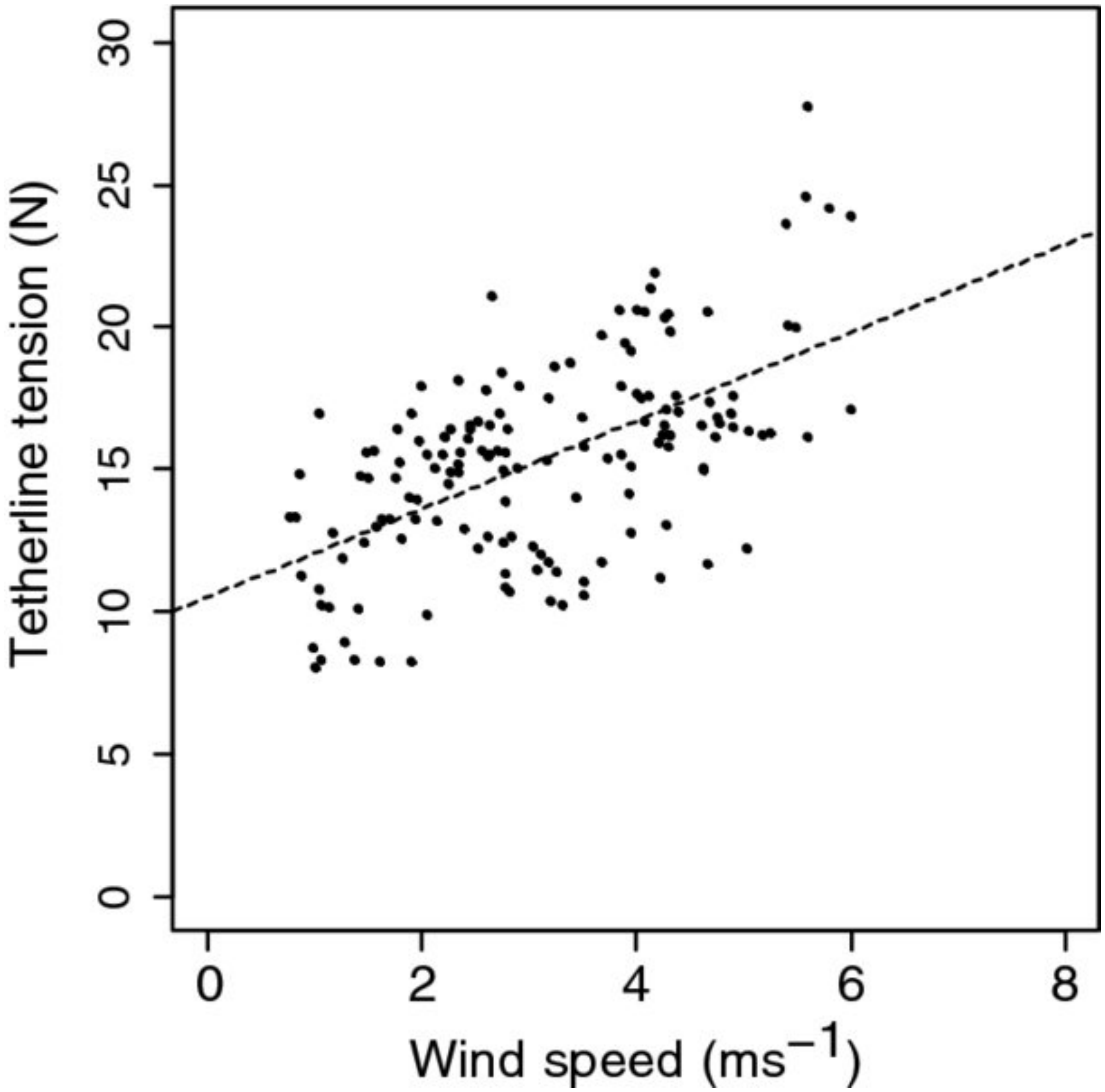

Figure 8.15 Response of the kite tether line tension to wind speed, for instantaneous (1-second sampling) measurements of tension and mean wind speed determined by a nearby sonic anemometer at 10 m. (An extrapolation to zero wind speed is marked to indicate the zero offset in tension.)

Notes

1 Such a method was proposed for meteorological use by Robert Hooke (1635–1703).

2 Beyond the pressure tube anemometer, William Henry Dines (1855–1928) is also known for his upper air recording work, using the meteograph.

3 A four-cup anemometer was developed in 1846 by John Robinson (1792–1882), director of Armagh Observatory.

4 Ultrasound is acoustic energy which has frequencies above the usual range of human hearing, such as sound in the frequency range ∼40 kHz to 100 kHz used for sonic anemometry.

5 The sonic temperature is similar to the *virtual temperature*, which is the temperature at which a sample of dry air would have the same density as a sample of moist air, for no associated change in pressure.

6 As discussed in Chapter 4, it is preferable to avoid assigning a real number to a data value which cannot be obtained, and instead to mark it as unavailable, to prevent erroneous results occurring in automated processing.

7 Consider, for example, averaging two wind directions when the wind is blowing from around north, of 10° and 350°. The arithmetic average of these two values is 180°, which represents a southerly wind, whereas the actual mean wind direction is 360°, i.e. northerly.

8 Some computer languages offer an inverse tangent function *atan2* which returns angles in the range ±180°, but note there are variations in calling conventions for the order of the arguments between different languages.

9 Hollow telescopic metal masts, which can be pumped up to achieve an extension to the height required, deflated afterwards for convenient transport, provide robust and transportable options for field work.