VCE Physics

Examples of causes of uncertainty

Determining the causes of uncertainty is not always easy.

Consider the following extended example of the measurement of wind speed in an investigation of its effect on the rate of cooling of a model house. The wind speed is measured by a handheld digital anemometer, in which a tiny fan is rotated by the moving air. The displayed windspeed value is derived from the rotational speed of this fan. In a constant wind speed, repeated measurements by the anemometer may show slightly different values, indicating ‘random errors’. A possible cause is slight variations in friction between the fan axle and its bearing. Friction is never truly constant even in carefully controlled conditions due to irregularities of the surfaces at the nano- and atomic scale. This variation in friction will be more evident at low speeds. Turbulence at higher speeds will cause the airflow across the fan blades to be irregular, possibly also contributing to random errors.

The amount of friction at any instant might be affected by whether the fan axle is truly parallel to the wind direction or not. If not parallel, there could be an extra force (compared to the ideal wind direction along the fan axis) acting on the fan blade and hence affecting the friction between fan and axle. Further, if the axle is not perfectly horizontal, then the normal force on the fan by the axle, spread across the bearing surfaces, will no longer be perpendicular to the bearing surface – might this affect the friction? In the previous paragraph, friction was assumed to be a cause of random errors. However, these two further effects, of wind direction and axle orientation, each have a systematic aspect. They may be able to be minimised by better control. Whether these two effects make a significant contribution can only be evaluated by a further investigation.

So, for instance, if the orientation of the anemometer axle was controlled within say 2 degrees of horizontal and the wind direction was horizontal within 2 degrees, then all the friction-related effects could be lumped together and considered ‘random’, and their effects covered by considering the variations only, without further knowledge of the details. (The *GUM* does not use the terms ‘random’ or ‘systematic’ errors. Rather,   
if the source of error can be treated by statistics only, it is termed a ‘Type A’ error. It means that the effect is completely ‘random’. Any systematic errors require further knowledge of the measuring system.)

For a good quality instrument, it is expected that its specifications would cover all causes both random and systematic.

The main systematic effect is simply to do with how the instrument’s reading relates to the actual (true) windspeed. The manufacturer will aim for a balance between cost and accuracy. As an example, the specifications of a medium-priced (around $140) handheld anemometer on sale in Melbourne in 2022 gives its operating range as 0.4 to 30.0 m/s and its ‘accuracy’ is ± (3.0% + 0.2 m/s). It simply will not respond reliably to an airspeed less than 0.4 m/s (1.4 kph) due to friction on the axle. At a low wind speed of, say,   
2 m/s, the ‘uncertainty’, as given by ‘accuracy’, is estimated as (0.06 + 0.2) m/s or 0.3 m/s to 1 significant figure. This is mainly determined by the 0.2 m/s contribution which could be an estimate of the unpredictability of friction at low speeds or possibly because of the limited resolution of the frequency detector used to determine rotational speed. At a higher speed of 24 m/s, the uncertainty is 0.9 m/s, being dominated by the 3.0% term.

‘Accuracy’, such as in this example specification, is understood to include both systematic and random effects. In mass-manufactured instruments, the design will be a trade-off between the cost of improving quality with the price a customer is happy to pay for their requirements. In the manufacturer’s quality control it is possible that selected instruments are tested at two or more known windspeeds to ensure that the readings are within the stated ‘accuracy’. It is likely that variations between individual instruments arise as a result of the manufacturing tolerances of the fan, axle and bearing. For an individual instrument, a small imperfection in the plastic fan, such as a rough leading edge, might cause a systematic variation of the rotational speed with wind speed compared to the intended design. The systematic errors can only be known by doing a calibration using an instrument with better specifications.

The experimental method is also important. If the anemometer is placed in wind (from a fan) which is directed towards the model house, how much does the anemometer (and hand or retort-stand holding it) affect the speed of the wind onto the house itself? Or, if the anemometer is placed to the side of the house to avoid impeding the flow, is the windspeed there the same as onto the house itself? Is the fan that generates the wind, providing a constant windspeed for the time required for the cooling measurement to be completed? Or does it vary with varying mains AC voltage?