Introduction to Flow Rate and Velocity Measurement

There are numerous ways of measuring fluid flow rates or velocities. Some of these methods are focussed on measuring the total flow rate in a pipe or other device while others are designed to measure the flow velocity at a particular location in a flow. For convenience, we will refer to these respectively as internal and external meters. Some of the listed devices have the advantage of being inexpensive, some of being simple and rugged. Some have the advantage of having relatively slow response time so that they effectively average over time; but this may also mean they have the disadvantage of having a poor dynamic response. Some average over a larger spatial volume while others have a higher spatial resolution. Some of the methods are intrusive in that they disturb the flow they are measuring while others are non-intrusive. Consequently the experimenter needs to carefully consider all these limitations and/or advantages in choosing a particular flow rate or velocity instrument.

Here we list some of the most common flow rate or velocity measurement techniques with some of their individual characteristics:

[A] **Anemometers:** These are simple external devices (some of which are depicted in Figure 1) that rotate when placed in a fluid flow. The flow velocity is then obtained by measuring the rate of rotation (often by using a magnetic proximity sensor that monitors the passage of rotating components). They come in many geometric forms and are based on the fact that the drag on a rotating component is greater when the flow is impacting the component from one direction rather than from the opposite direction. They have the advantage of being simple, inexpensive and rugged but the disadvantage of having relatively poor spatial and temporal resolution. They also require adjustment of their orientation relative to the flow direction. They are also intrusive. Often they are used to estimate wind speed.

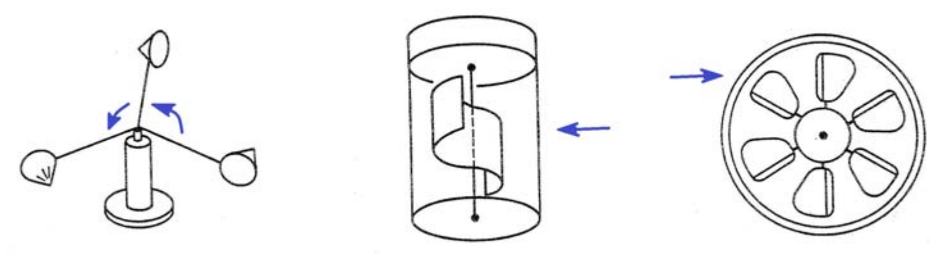

Figure 1: Various Anemometer Geometries.

[B] **Propeller Meter/Turbine Flow Meter:** Another form of external anemometer frequently used in water is the propeller meter that consists of a small propeller (of the order of $1cm$ in diameter) mounted on a free-wheeling shaft and on the end of support strut. The flow velocity is evaluated from the measured rotation rate. Again these are simple and inexpensive but intrusive devices and have relatively poor spatial and temporal resolution. They also require calibration.

The equivalent internal device is known as a turbine flow meter and is used in many applications, sizes and fluids including in cryogenic fluids where devices for pipe sizes up to $10cm$ are common. However, turbine flow meters have limited dynamic response and require calibration.

Another, somewhat similar internal device is the versatile and inexpensive *rotameter* that consists of a transparent vertical section of pipe with a gradually diverging cross-sectional area. A free bobbin floats in this section and rises to a level that corresponds to the flow rate. Calibrated graduations on the transparent housing allow the flow rate to be read directly. Clearly the calibration depends on the fluid density and therefore also on the prevailing pressure within the device.

[C] **Drag Disc:** Yet another form of external anemometer is the *drag disc* which consists of a small flat disc facing into the flow on the end of a support sting. The force on the disc is measured by means of strain gauges and converted to a velocity knowing the disc size and the fluid density. Often the device comes with a variety of disc sizes so as to cover a range of flow velocities. Such an anemometer has a better dynamic response than the above types but may be less robust.

[D] **Bernoulli Devices:** Many flow rate and flow velocity meters measure a pressure difference and derive the velocity from that pressure difference. Examples are the external Pitot tube (for example, used to measure aircraft flight speed) and the internal Venturi meter. Section (Kdcb) that follows details some of these devices.

[E] **Hot Wire and Hot Film Anemometers:** Another class of external fluid velocity anemometers utilizes the fact that the heat transfer from a small element will be roughly proportional to the fluid velocity over that element. The most common form of this anemometer is the hot wire anemometer which consists of a thin wire between two prongs at the end of a probe (see Figure 2). An electrical current runs through the wire whose electrical resistance is proportional to its temperature. The flow over the wire cools it and this cooling is greater the higher the fluid velocity. Consequently, by measuring the electrical conductivity of the wire one obtains a measure of the fluid velocity. Some

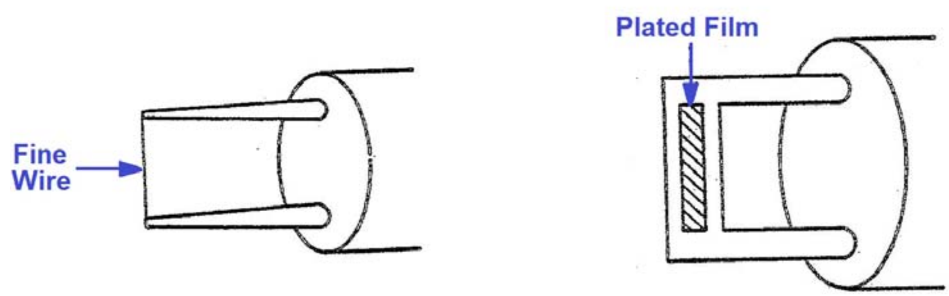

Figure 2: Hot-wire (left) and Hot-film (right) Anemometers.

versions utilize a hot-film rather than a fine wire to improve the robustness of the instrument. Hot-film or thin-film versions are frequently imbedded in a solid surface and used to measure the fluid shear rate at the surface; though the no-slip condition dictates zero fluid velocity at the surface, the heat transfer into the fluid is then governed by the gradient of the tangential velocity at the surface and the heat transfer is then proportional to the surface shear rate.

[F] **Electromagnetic Flowmeters:** An important set of instruments utilize electromagnetic effects in order to measure fluid flow rates and velocities. These instruments utilize the fact that a liquid flow that carries charge constitutes an electric current and in the presence of a magnetic field at right angles to that current will induce an electropotential gradient in the third perpendicular direction. The magnitude of that electropotential gradient will be proportional to the electric current and, therefore, by measuring the electropotential gradient one can obtain a measure of the liquid velocity. The details of these relations in the commonest manifestation of the electromagnetic flow meter are presented in Section (Kdcc). This instrument has two very advantageous properties. First, in a circular pipe configuration it transpires that the instrument measures the total volume flow in the pipe irrespective of the velocity profile of the flow in the pipe (provided that veloocity profile is axisymmetric). Second, it has the potential to measure unsteady flow rates up to frequencies of the order of hundreds of Hz.

These two advantages are coupled because oscillating flow rates at such high frequencies will lead to very complex velocity profiles.

Interestingly, electromagnetic flow measuring and sensing devices were first developed for use in medical contexts to sense the motion of blood and they are still used in that context today. Their primary limitation in a broader context is that the fluid must have a certain minimal electric conductivity in order for the device to be feasible. But, in the context of electrically conducting liquids (such as water or liquid metals) they are currently available in pipe sizes up to meters in diameter.

[G] **Laser Velocimeters:** Another class of instruments use focused laser light scattered off minute particles in the fluid to obtain measurements of the velocity of the fluid. Section (Kdcd) describes two such instruments, namely the Laser Doppler Velocimeter and the Laser Two-Focus Velocimeter. These instruments are primarily used to measure velocities at very well-defined locations in a flow. Consequently they have high spatial resolution. They also have excellent temporal resolution and are therefore ideal for mapping out complex turbulent flows.

[H] **Acoustic Doppler Velocimetry:** Yet another class of instruments use the Doppler shift that sound waves experience in a fluid flow in order to measure the fluid velocity. Examples of such instruments are detailed in Section (Kdce). Instruments exist that measure the flow rate in a pipe and that attempt to measure the fluid velocity at a discrete location in a flow. They can aslo measure flow rates or velocities up to quite high frequencies.

Because there are so many options, the experimenter needs to carefully consider the requirements of his/her particular experiment and make an informed choice of the most appropriate measuring device. Often several instruments may be needed, for example one for the measurement of the steady flow and one for the unsteady flow rates or velocities.