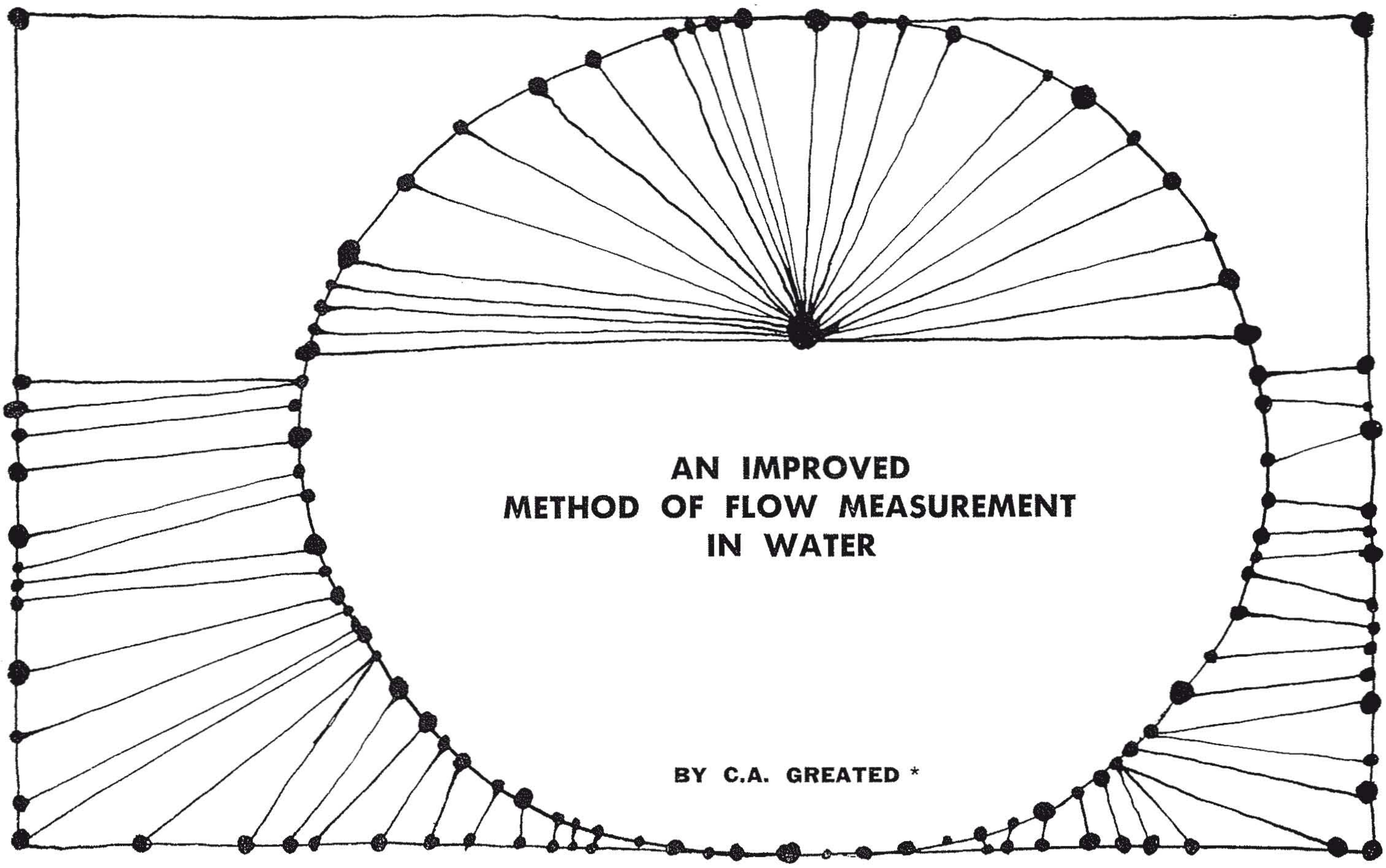

# AN IMPROVED METHOD OF FLOW MEASUREMENT IN WATER

BY C.A. GREATED *

## Introduction

Hot film anemometry has been used extensively for flow measurement in water and other liquids but the method has many serious drawbacks, among these being calibration drift and bubble formation on the film. Recently a number of investigators [1, 2, 3, 5, 7] have reported flow measurements by observation of the Doppler shift in scattered laser light from tiny particles in the fluid. This paper describes a system of flow measurement using this principle, developed by the author for turbulence studies in water and polymer solutions. It gives an output directly proportional to the instantaneous velocity in the direction of flow and can be used for measurements of both mean velocities and turbulence statistics in the same way as the output from a hot film anemometer.

The apparatus is quite simple and cheap to construct and gives results for water which are more consistent but in close agreement with those obtained from hot films. The method also eliminates the need for calibration and being purely optical has the further advantage that the flow is not disturbed by the introduction of measuring probes.

## Apparatus

The complete apparatus is shown in Figure 1. A number of different optical configurations are possible using mirror systems, but the one shown here (Fig. 2) using a mask with two parallel slits as a beam splitter (proposed by Rudd [6]) is especially simple to align as it uses only a single lens system.

Light from a 1mW He-Ne laser is spread by lens $L_1$ and lens $L_2$ is adjusted to give a parallel beam of light which is split by the two equal slits in the mask M. Lens $L_3$ is then used to focus the beams at the measuring point in the fluid and lens $L_4$ collects the light and focuses it onto a photodiode P. It is important to ensure that the lenses are free from aberration and that the side walls of the channel are reasonably flat, plane perspex or glass being ideal.

In this case flow measurements were being made in a 90 cm long rectangular channel of cross-section 6 cm $\times$ 5 cm with flow speeds of the order 25 cm/sec. The channel walls were constructed from 5 mm thick perspex sheet.

## Fringe model

The signal observed at the output to the photodiode is best explained by the Fraunhofer diffraction theory. Light from the two slits causes a pattern of interference fringes to be formed at the focus, perpendicular to the flow direction and particles in the fluid moving across the fringes cause varying amounts of light to be cut off, resulting in a frequency proportional to the axial velocity.

The volume over which the fringes extend is essentially diamond shaped in plan and is very small,

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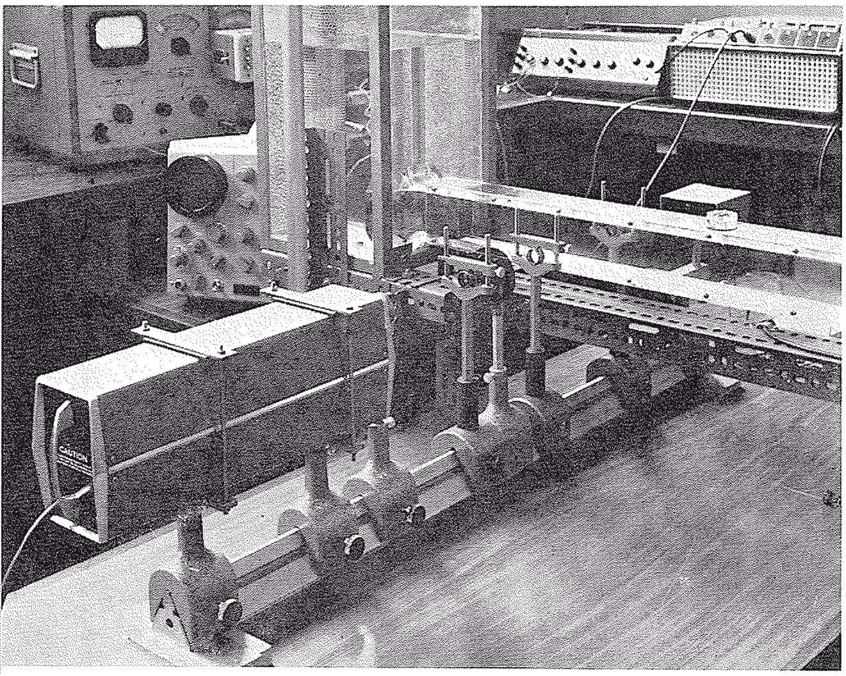
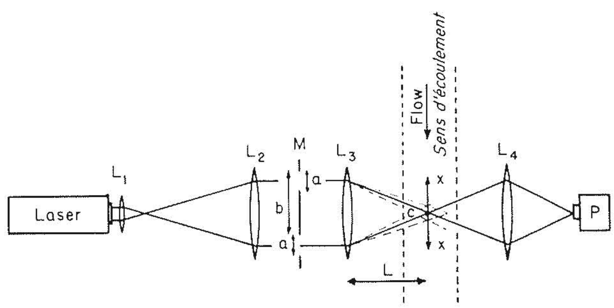
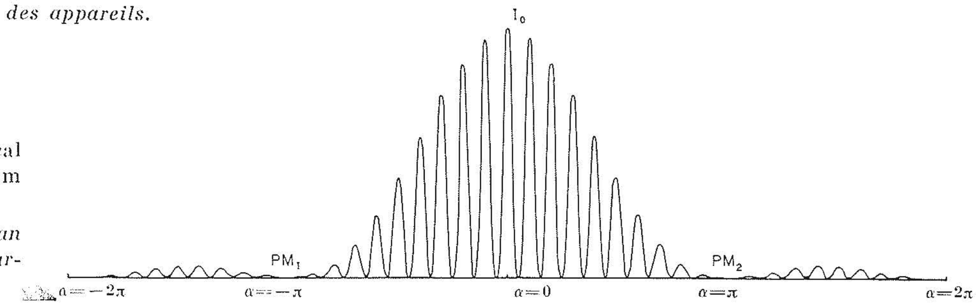


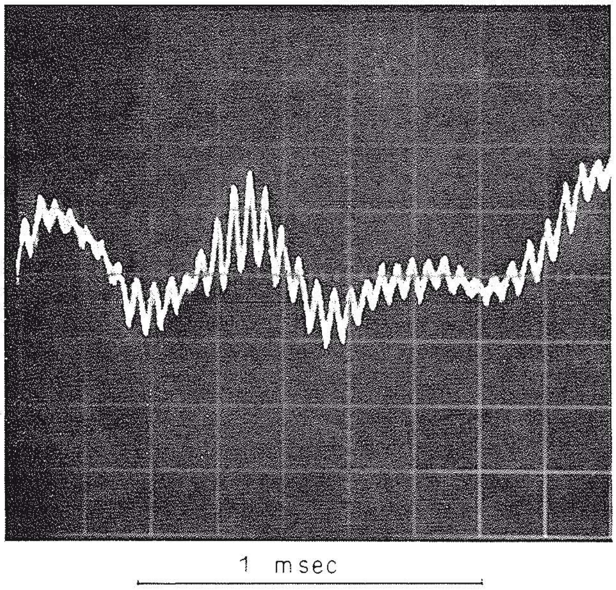
**1/** Complete apparatus. / *Vue d'ensemble des appareils.*



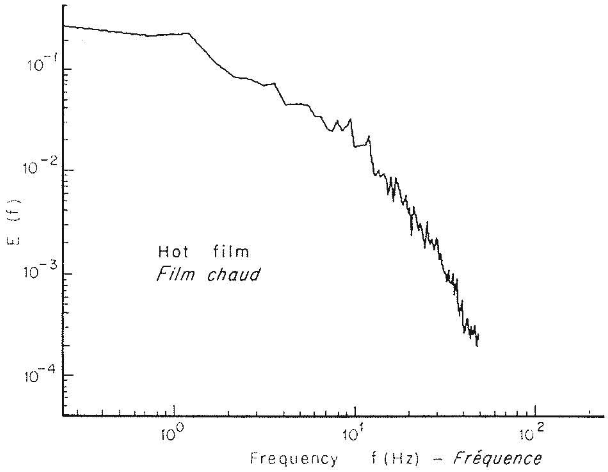

**2/** Optical configuration. / *Schéma optique.*

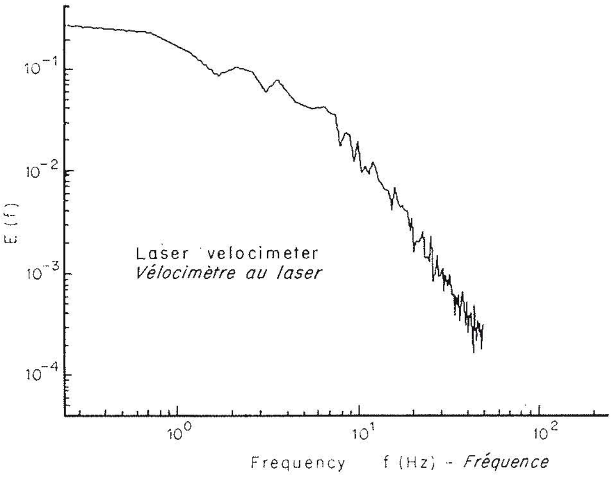
**3/** Distribution of intensity in the focal plane of $L_3$ for $b/a = 10$, computed from $I = I_0 (\sin^2 \alpha/\alpha^2) \cos^2 (\alpha b/a)$.
*Répartition des intensités dans le plan focal de $L_3$ avec $b/a = 10$, calculée à partir de $I = I_0 (\sin^2 \alpha/\alpha^2) \cos^2 (\alpha b/a)$.*




**4/** Oscilloscope record of photodiode output.
*Oscilloscopie de la puissance de sortie de la photodiode.*




**5/** Normalised power spectral density distributions of the axial velocity component, recorded with a hot film anemometer and laser velocimeter under the same flow conditions. Curves are the direct outputs from the computers on-line graph plotter. r.m.s. turbulence level = 4.4 %.
*Répartition de densité spectrale de puissance normalisée de la composante de vitesse axiale, mesurée à l'aide d'un anémomètre à film chaud et d'un vélocimètre à laser, pour les mêmes régimes d'écoulement. Les courbes proviennent directement du traceur de courbes couplé à l'ordinateur.*

typically 0.01 mm $\times$ 0.1 mm $\times$ 1 mm. The intensity of light in the focal plane of $L_3$ at a distance $x$ from the centre of the focus C (Fig. 2) is given by:

$$I = I_0 \frac{\sin^2 \alpha}{\alpha^2} \cos^2 \left(\frac{\alpha\, b}{a}\right)$$

where:

$$\alpha = \frac{\pi\, a x}{\lambda L}$$

Here:

$\lambda$ = wavelength of the laser light;
L = focal length of lens $L_3$;
$b/a$ = ratio of slit spacing to slit width;
$I_0$ = light intensity at C.

This is neglecting bending of the rays as they pass through the channel walls and into the water and a correction factor, dependent on the particular set-up used, must be applied if absolute values of velocity are required without calibration. The first term ($\sin^2 \alpha/\alpha^2$) represents the total amount of light diffracted from a single slit and is the envelope of the intensity curve. The second term is the result of the interference between the light from the two separate slits and determines the number of fringes under the envelope. Figure 3 shows the intensity distribution for $b/a = 10$, i.e. 19 fringes between the principal minima ($PM_1$ and $PM_2$) of the diffraction pattern.

A typical signal at the photodiode output is shown in Figure 4 and it can be seen that it contains the Doppler frequency, which is proportional to the axial velocity and inversely proportional to the fringe spacing, together with frequencies of order $b/a$ times lower corresponding to the single slit diffraction term.

The best results were obtained with $b/a$ close to 10 as the signal to noise ratio was then small, while on the other hand there was good separation between the single slit diffraction frequency and the Doppler frequency. In the author's investigations small quantities of talcum powder were added to the water to give a fine distribution of particles a few microns in size, although the particles present in ordinary tap water are sufficient to give a strong signal. Particle size is an important factor in determining the most suitable fringe spacing as clearly the largest particles should not be greater than the distance between the principal minima of the diffraction pattern and this imposes a limit on the resolution of the system.

## Analysis of signal

The electrical circuitry required for analysing the photodiode signal is quite simple and is described in detail in [4]. A high-pass filter is used to separate the Doppler signal from the low frequency components and a frequency demodulation circuit is then used to convert frequencies to voltages. These are recorded on magnetic tape and can be analysed in the same way as hot film anemometer results.

Observations of frequency spectra of axial velocity made in a number of flow situations showed that there was close agreement between results obtained using this method and those recorded with hot film probes. Figure 5 shows typical spectra using both methods under the same flow conditions in the channel previously described. They were computed digitally from the tape recordings using band widths of 0.5 Hz. For r.m.s. turbulent intensity levels the laser method gave results consistent to within 5 % which was a considerable improvement over hot film techniques, where readings can be strongly influenced by any calibration drift.

## Conclusions

The system of flow measurement described here overcomes many of the difficulties normally associated with velocity measurements in water. It is considerably more versatile than hot film anemometry and other techniques which employ a measuring probe or propeller and it can be used in liquids of varying density and non-Newtonian fluids such as polymer solutions. This should prove a useful tool for experimental investigations in hydraulics and it is possible that it could be adapted for certain field measurements.

## Acknowledgements

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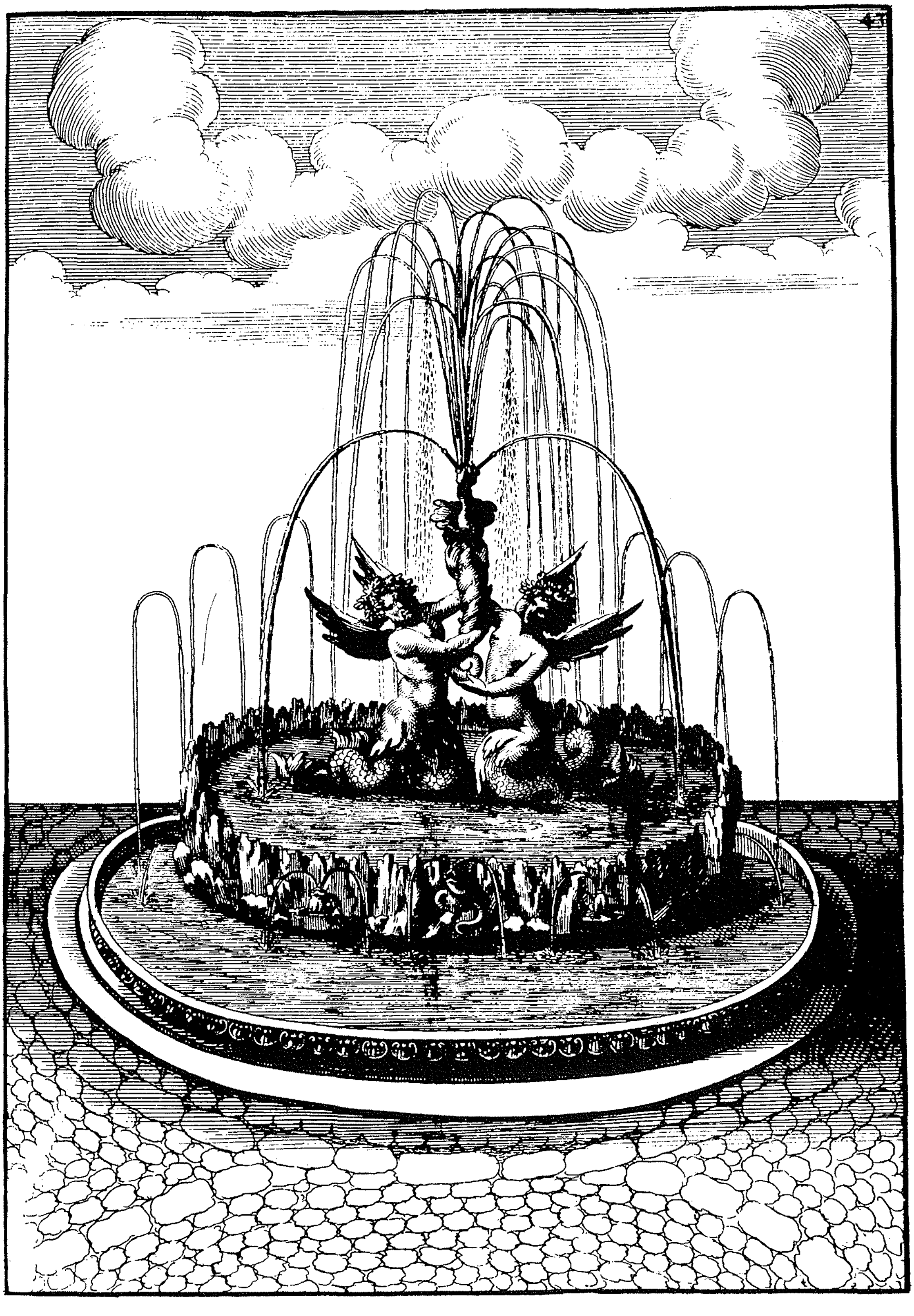

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