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ACOUSTIC DOPPLER VELOCITY PROFILERS: APPLICATION TO TURBULENT FLOW IN HYDRAULIC OPEN CHANNEL AND LAKES

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ABSTRACT

Velocity and turbulence are important hydrodynamic parameters. Consequently, many instruments, working on a variety of principles, have been developed for their measurement. Among them the acoustic velocity profiler (ADVP) has a unique combination of advantages:
- it can take instantaneous complete velocity profiles with a resolution of turbulence scales.
- it is non-intrusive
- it can work reliably in the presence of sediment transport.

We have tested its feasibility for hydraulic laboratory research [2,3] based on hardware systems and signal processing algorithms which we have developed and improved since. Promising results were found despite some recent comments by [7] to the contrary.

1. ADVP application in open channel flow

1. 1 Monostatic ADVP

In a monostatic mode, one single acoustic transducer is used to emit and receive acoustic waves. In order to verify the validity of the measurements made by a monostatic ADVP, the results obtained are compared either to proven measurement techniques and to the known distribution laws for the flow parameters. Investigating stationary open channel flow over rough and smooth beds good agreement was found for all laws for the distribution of mean velocities and turbulence parameters [8,5]. It has thus been shown that the ADVP is a bona fide research tool capable of resolving turbulence scales in open channel flow. Its application to steep open channel flow is described in [10].

However the determination of turbulence parameters with this system is limited to uniform or very gradually varying flow. It is impossible to apply it to more rapidly accelerating or decelerating flows which are often encountered in rivers and lakes.

1. 2 Bistatic ADVP

Recently we have therefore extended the ADVP-technique to a system which is capable to determine instantaneous profiles two or more velocity components with resolution of turbulence scales.

A pulse of sound waves is emitted only from a central transducer (Fig. 1a): As in the monostatic mode this transducer can also work as a receiver of the backscattered sound waves. Additional transducers placed around the emitter will serve as receivers for the backscattered waves coming from same pulse of sound waves. For convenience and ease of signal extraction, these receivers which have to be inclined towards the central emitter are normally placed symmetrically around the emitter. In that case any sound waves which are backscattered from a certain volume in the central beam will have the same time of flight to all the surrounding receivers. One pair of opposingly inclined receivers is sufficient for the determination of two instantaneous velocity components. An additional pair in a plane perpendicular to the first one will allow to determine all three velocity components instantaneously. For simplicity this system is aligned here with the direction of the mean flow (the along axis flow in an open channel). In this case the two velocity components under consideration are the horizontal velocity u and the vertical velocity v. The emitted sound beam from which the velocity profile is determined is vertical with respect to the channel bottom. This is an advantage over the monostatic system where the profile has to be taken along an inclined sound beam. Details about the signal processing and the determination of the instantaneous velocities are given in [8].

For the evaluation of the possibilities and limits of this system, the measurements made in an open channel with smooth bed with the bistatic ADVP are compared with those obtained simultaneously by a monostatic ADVP and also with available distribution laws for uniform flow conditions. For the two components of the mean velocity, excellent agreement between the two systems is found (Fig. 1b); the profiles correspond to those predicted for open channel flow [5]. For the turbulence parameters, good agreement is found for distribution of the variance of the horizontal and the vertical components as well as for the Reynold's stress profiles (Fig. 1c) over most of the water depth. As with all measuring techniques, surface roughness prevents reliable measurements near the free surface. Near the channel bed the results from the bistatic ADVP tend to diverge from the theoretically predicted profiles. This is mainly due to the large Doppler angle and the unfavourable volume size in this region. Improvements can be expected from beam localization of the emitter beam and a change in transducer geometry.

The above results show that the bistatic ADVP has good potential in turbulent open channel flow investigations. In particular, its capability to take instantaneous simultaneous profiles of two velocity components greatly reduces the measurement time. Furthermore it gives the possibility to obtain insight into flow phenomena which have been difficult to investigate before. As an example we present the flow around a cylinder (Fig. 2). The mean flow pattern has been obtained with nine measurements only. Turbulence profiles have identified zones of accelerated and decelerated flow around the cylinder [1]. The second example shows the distribution of the instantaneous velocity vectors in uniform flow after the mean velocity vectors have been subtracted (Fig. 3). When these vectors are plotted for the highest resolution (profiles taken at 1000 Hz, averaged over 16 consecutive profiles) the temporal and spatial variability but also some structure is visible. This structure becomes more evident when the same data are averaged over 128 consecutive profiles. It is seen that the whole water column is organized in a sequence of alternating upward and downward jets. This may be the result of secondary flow structures [9]. We are further investigating this aspect.

2 ADVP applications in lakes

We have applied the monostatic ADVP to stratified geophysical flow in the Lake of Geneva. In the first study the transducer was gimbals mounted to point vertically upwards and placed on the lateral slope of the lake bottom near the depth of the thermocline [4]. In the presence of critical internal waves a complex profile of the vertical velocity was observed (Fig. 5). The shear which can be calculated from this profile indicates that the instabilities cannot be explained by a thermal structure. Instead, a particle laden turbidity current must be present. The vertical variability of the intensity of the backscattered signal supports this conclusion.

In the second study the instrument was lowered on a cable with constant speed (10 cms^{-1}), clamped to a high resolution CTD which provided information on the temperature profile and a check on the fall velocity via its pressure sensor. The simultaneous multigate profiling capacity and thus the possibility to establish short time series (of about 10 s duration) at any depth give new insight which cannot be obtained with any other instrument. The vertical velocity fluctuation amplitude is directly linked to the mean stratification in the water column. In layers of strong temperature gradients, even if they are only several cm thick, the amplitude of the vertical velocity fluctuations is strongly reduced. The turbulence intensity is larger and more homogeneous below the thermocline (the layer 5 to 15 m) in the constant N layer. Turbulence scales have been calculated from the vertical velocity data and the corresponding N-profile (Fig. 4b). In the thermocline of Lake Geneva the vertical turbulence scale is about 0.5 to 1 m. In the other parts of the water column (down to about 45 m depth) the turbulence appears closer to isotropic and the turbulence scale is about 2 m or more. These scales correspond well to the Thorpe scales which have been obtained from instabilities of the temperature profiles.

3. Conclusions and outlook

The Acoustic Doppler Velocity Profiler has been evaluated for its use in boundary layer flow conditions in open channel flows and in the field. From the analysis it is apparent that the ADVP hardware and the software algorithms applied to the extraction of the velocity vector are well suited for the analysis of turbulent flow characteristics. Without the need for a calibration procedure, mean vertical and horizontal water velocities and hydraulic parameters are effectively measured by the ADVP. Measurements can be taken rapidly with a degree of accuracy better than most conventional in situ sensors which at the same time can significantly modify the local flow conditions by intruding into the flow. The ADVP is easier to operate than laser velocimeters and essentially provides instantaneous velocity profiles instead of point measurements. Compared to existing instrumentation, the ADVP profile measurements take only a small fraction of the time for the same resolution. Furthermore, since ADVP profile measurements are taken simultaneously under the same flow conditions, the resultant profiles are found to be smoother than those taken in sequence by existing instruments.

In rivers and lakes, where typical values of sampling frequencies needed for correctly studying turbulence are about 10 Hz, ADVP systems of the type discussed here seem to be the most appropriate instrument. In this context the nature and the effect of the acoustic targets should be further investigated. Indeed, the presence of particles in low to medium concentration in the flow does not influence the acoustic system at all, a great advantage over the LDA. Therefore the pulse-to-pulse coherent technique presented here appears to be a rather promising tool in field studies. In the laboratory the presence of particles, its concentration and the variance may be investigated by exploiting the backscattering intensity information provided by the ADVP at the same time. This information, combined with the instantaneous velocity profile may be used for detailed studies of sediment transport.

In conclusion, the high frequency ADVP is a valuable tool for hydraulic research. More sophisticated techniques for beam focalization, data acquisition and signal processing may have to be further investigated before the optimal configuration and the range of application of a high frequency ADVP designed for hydraulic research can be determined. These developments or beam scanning techniques can extend the capabilities of the acoustic systems to further the understanding of the turbulent water flows.

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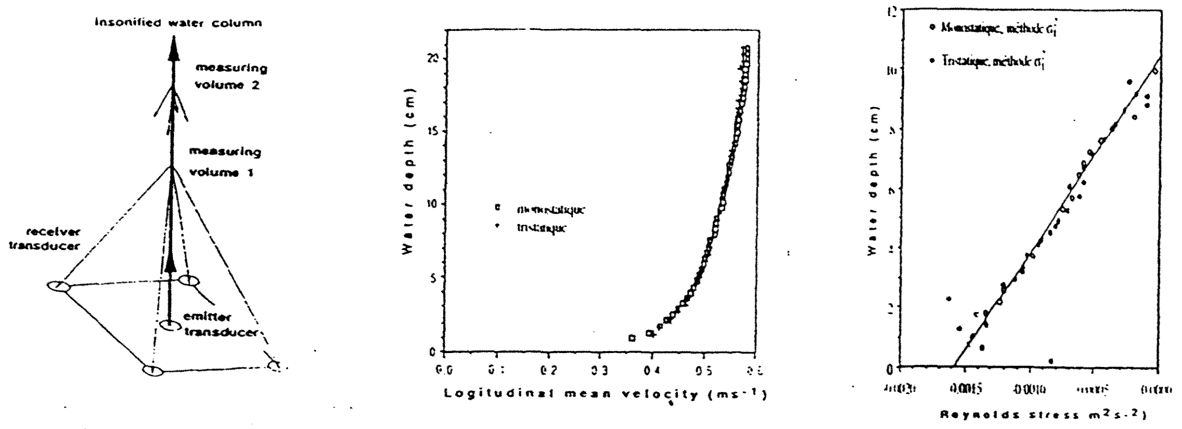

Fig. 1 Bistatic Acoustic velocity profiler: a: Measurement layout; b: Horizontal mean velocity profile; c: Reynold's stress profile.

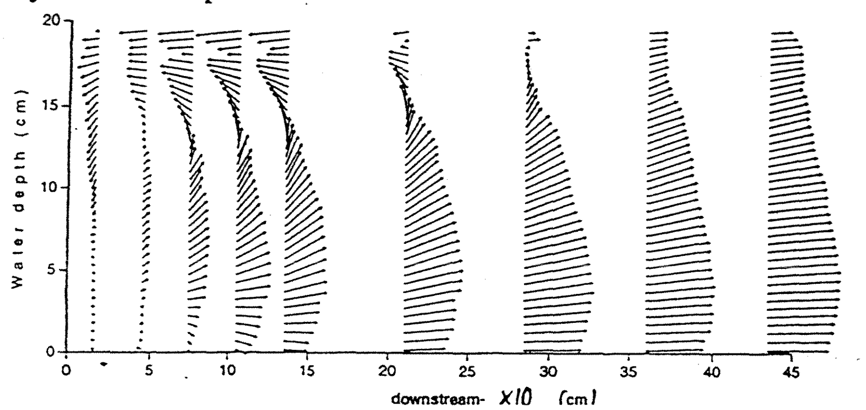

Fig. 2 Mean flow behind a vertical cylinder. Cylinder at x=0 cm, diameter D= 15 cm; Re= 87000

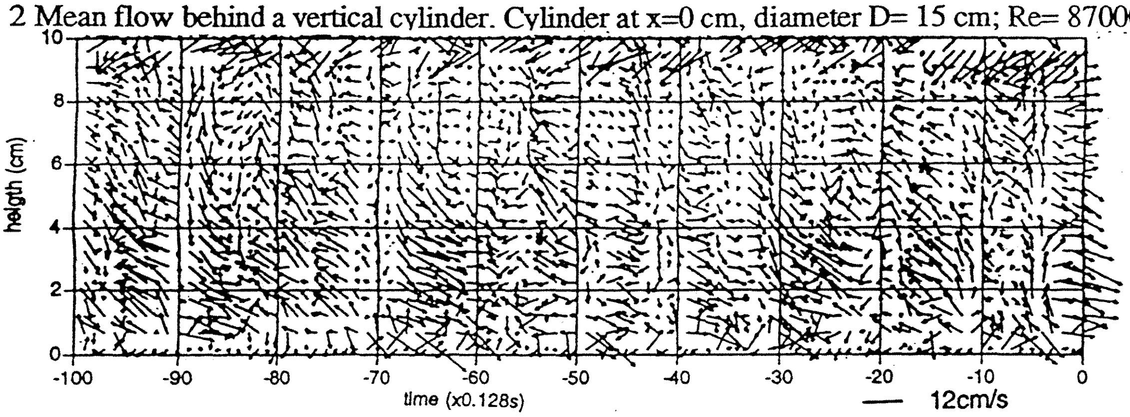

Fig. 3 Time series of 2D velocity fluctuations

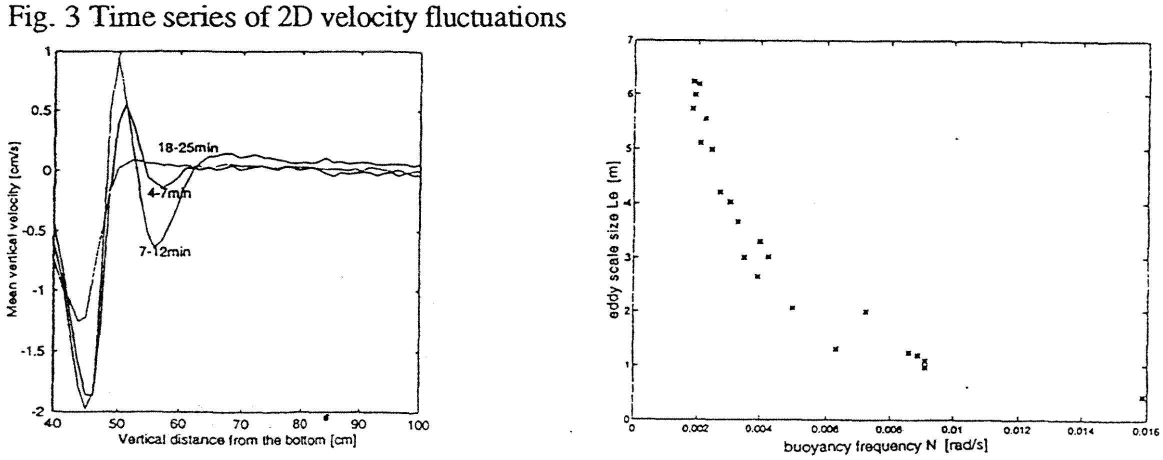

Fig. 4 Results from the stratified Lake of Geneva (taken in July); a: Mean vertical profiles in the bottom boundary layer (depth 29 m) b: Turbulence scales in the open water in the depth range: 2 m to 45 m.