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Effects of Aeration on the Performance of an ADV

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Abstract

Using acoustic Doppler velocity meters (ADV's) to collect field data can be hampered by the air-water flow mixtures that are often present in and around the vicinity of many hydraulic structures. The flow fields near weirs, spillways, gate structures, fish screens, fish ladders, pumping plants and powerplants are just a few examples where significant air entrainment can and does occur. ADV manufacturers warn their users of the detrimental effects of attempting measurements in bubbly flows. However, no significant data exists for evaluating how much air is too much or what the relative drop in accuracy is with increase in air concentration. Experience using the probes has shown that air bubbles in the flow causes a drop in the reported correlation value and general increases in noise level. A simple study evaluating the effect of air concentration on ADV performance was conducted in Reclamation's Water Resources Research Laboratory (WRRL). In the study, a porous stone attached to a compressed air supply was used to generate bubbles in a channel of flowing water. Simultaneous measurements by the ADV probe and an air concentration probe were collected. Data were collected for a single velocity and variable air concentration. ADV performance was evaluated using standard parameters reported by the ADV during the measurement process.

Introduction

Recent developments in acoustic technologies now provide the engineer and scientist means to measure local water velocities for both laboratory and field experimentation. Acoustic Doppler velocity meters (ADV's) provide a relatively portable, 3-dimensional velocity measurement tool (Kraus, N.C. et al, 1994) that can be used in place of traditional velocity measurement devices such as: pitot tubes, propeller-type current meters, and electromagnetic current meters. The benefit of using an ADV is that they measure 2- or 3-dimensional velocity components in a small measurement volume (0.2036 cm^3) about 5 cm (10 cm for the field models) away from the probe head. In addition, with data collection occurring at up to 25 Hz, statistical treatment of the data provides improved estimates of the mean velocity and allows the user to quantify turbulent properties of the flow field.

Acoustic measuring devices take advantage of the fluid properties and in particular the sonic velocity in order to measure and compute the fluid velocity. Water has a reasonably constant sonic velocity at a given state of water quality. However, presence of air bubbles in the flow, even in small concentrations greatly affects the speed of sound through water. Very small bubbles can act as seed material and actually increase the signal to noise ratio and correlation values. However, the buoyancy properties of even small air bubbles can affect the true water velocity readings by inducing larger vertical velocities since the bubbles do not follow the streamlines of the flow. As the air concentrations increase and bubble sizes increase, correlation values drop dramatically as the acoustic signals used by the probe are absorbed and reflected by the two-phase flow mixture resulting in undesirable performance.

The Problem

There are currently two manufacturers of ADV's, Sontek and Nortek. The two probes are almost identical. Each manufacturer warns their users about taking measurements in aerated flows. They recommend using only data points that have correlation values above 70. In many measurement situations, only a small percentage of the data set may satisfy a criterion of correlation greater than 70. This is especially true for aerated flows. Can the indicated mean velocity be useful at lower correlation values and if so, how small can the correlation be before the data are totally unusable?

The Experiments

A simple experiment to examine the affects of aeration on ADV performance was setup in Reclamation's Water Resources Research Lab (WRRL). Using an existing acrylic-walled flume, a 3-dimensional Sontek probe and an air concentration probe were located along the centerline of the flume. The measurement location was selected which had a velocity of about 1 m/s at the test section. Just upstream from the test section, a linear porous diffuser was installed on the flume bottom (figure 1). The diffuser was connected to the lab air system. A pressure regulator provided adjustment of supply pressure and airflow rate.

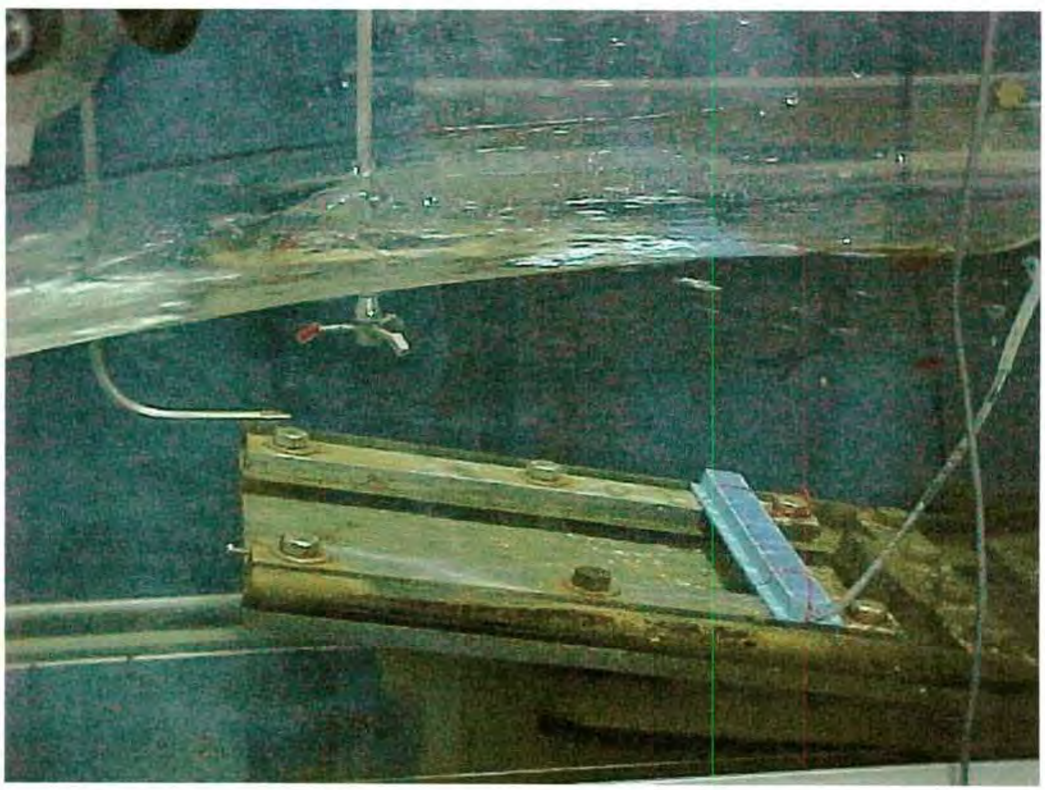


Figure 1: View of measurement location showing: Sontek probe, air concentration probe, and linear porous diffuser attached to air supply (no air flow).

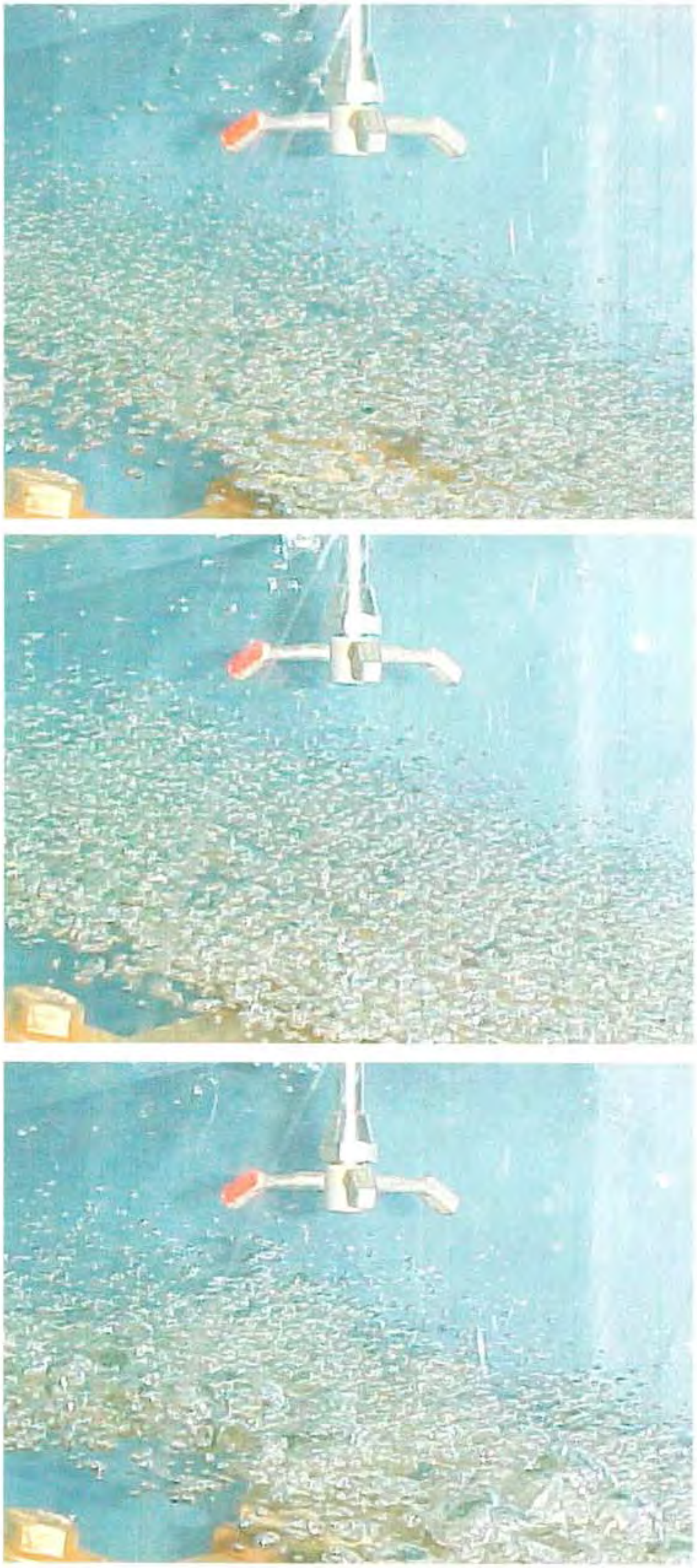
After some initial experimentation, it was decided to limit the scope of the studies due to many variables that could not easily be controlled. I set one discharge, yielding a single streamwise velocity (about 1 m/s) and located the measurement point at the approximate center of the water prism. I then varied the air concentration by adjusting the pressure regulator on the supply system. For each setting, we took a velocity record of 3000 samples at 25 Hz, and an air concentration record of 819,200 samples at 5000 Hz. The Sontek system included a 3D down-looking probe with a splash-proof box. The air concentration probe is one of Reclamation's design and details can be found in Matos and Frizell (1998).

Results

Experiments were performed with a constant velocity and air concentrations varying from 0 – 3.61 percent. The air concentration was adjusted by varying the supply pressure to the porous diffuser. Bubble size varied with the change in supply pressure, with the bubble size increasing with increases in pressure. Figure 2 shows a series of photographs depicting the range of air concentrations tested in this study.

a) Air concentration 0.01%

b) Air concentration 0.10%



c) Air concentration 0.59%

d) Air concentration 1.46%

e) Air concentration 3.61%

Figure 2: Photographs showing the range of air concentrations studied.

The air concentrations are determined by relating the void fraction to the percent of air in the flowing water by volume. Very tiny bubbles (< 0.1 mm) cannot be detected by the air concentration probe so only results with bubbles sizes greater than this were reported. The mean streamwise velocity as a function of air concentration for a variety of correlation filtering conditions is shown in figure 3.

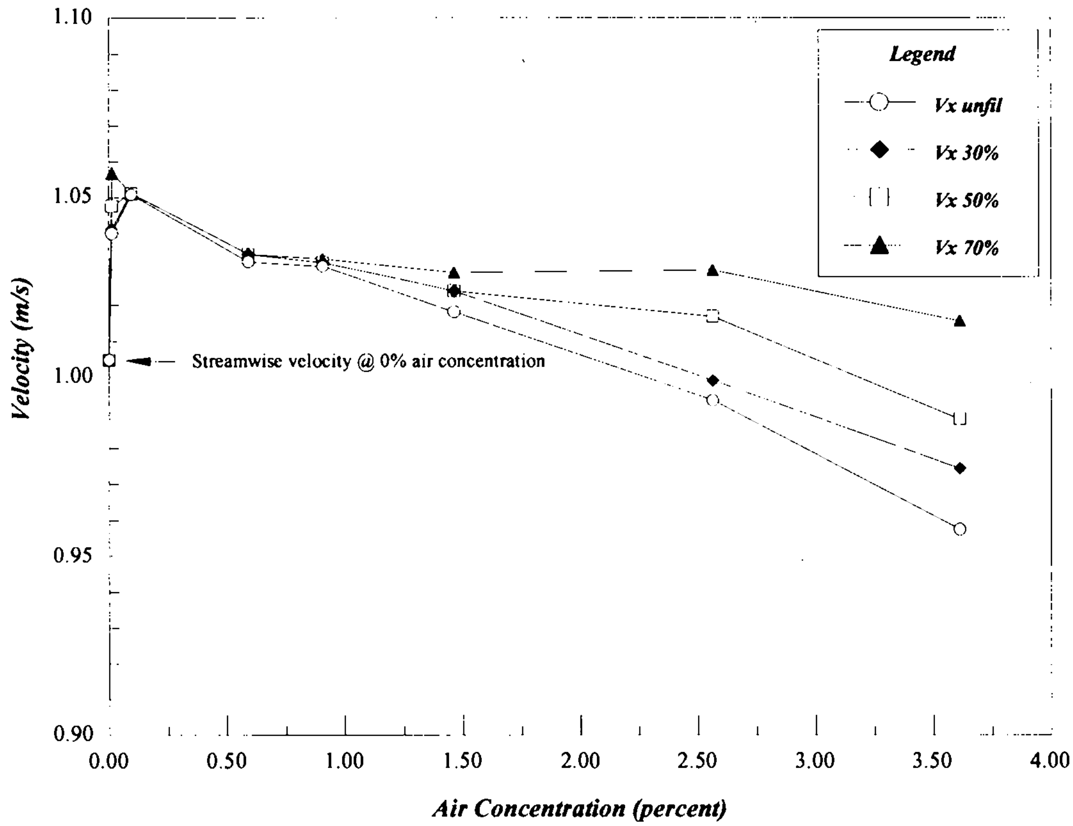


Figure 3: Mean streamwise velocity as a function of air concentration passing the measurement volume. Unfil, 30-, 50-, and 70-percent refer to the correlation critera used to filter the data.

The cross channel and vertical velocities were also measured for each condition. The cross-channel velocity was essentially 0 m/s and did not vary with an increase in the air concentration. The vertical velocity components revealed a significant increase in the vertical velocity component at even the smallest air concentration. This vertical component appears to be related to the bubble trajectories through the measurement volume. Buoyancy of the air bubbles affects the local velocities, even when the air bubbles are too large to be considered seed material. Figure 4 shows the induced vertical velocities as a function of the air concentration.
In addition to velocities and correlation, the Sontek software also reports several other parameters that can be of interest. The signal-to-noise ratio (SNR) and relative signal strength (AMP) can sometimes give additional information to the user such as relative particle concentrations. In the presence of air bubbles, the signal strength becomes very large and is nearly uniform over the air concentration range tested. The increase in signal strength does not include an increase in the noise level as the SNR followed the same trend as the AMP function, figure 5. These parameters do not appear to be a good indicator of air concentration.

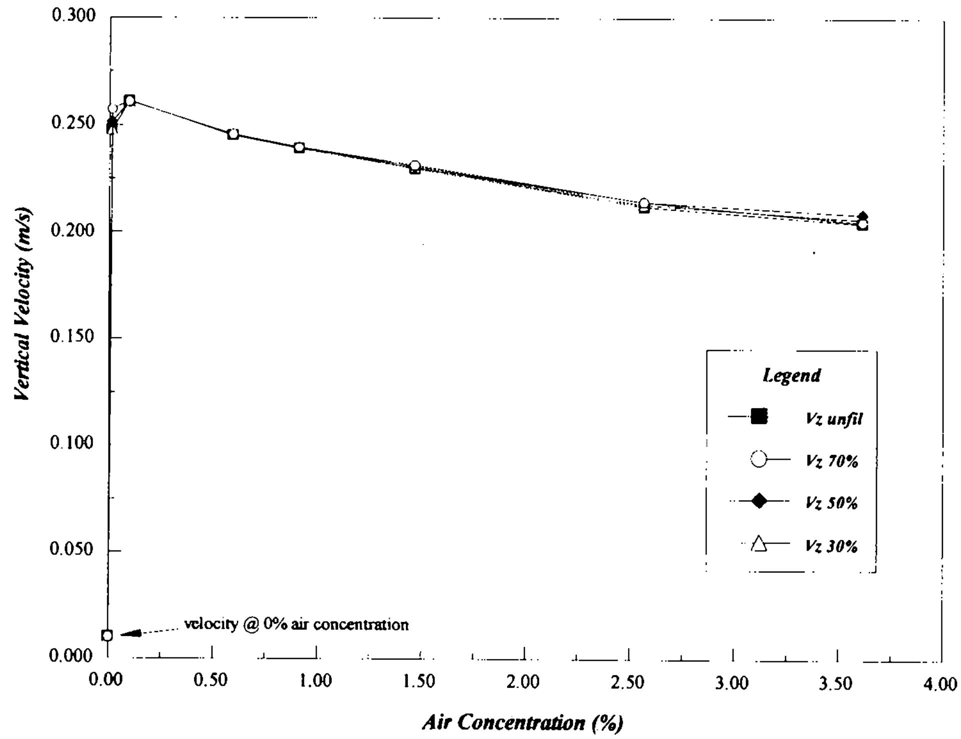


Figure 4: Mean vertical velocity as a function of air concentration. Unfil, 30-, 50-, and 70-percent refer to the correlation criteria used to filter the data.

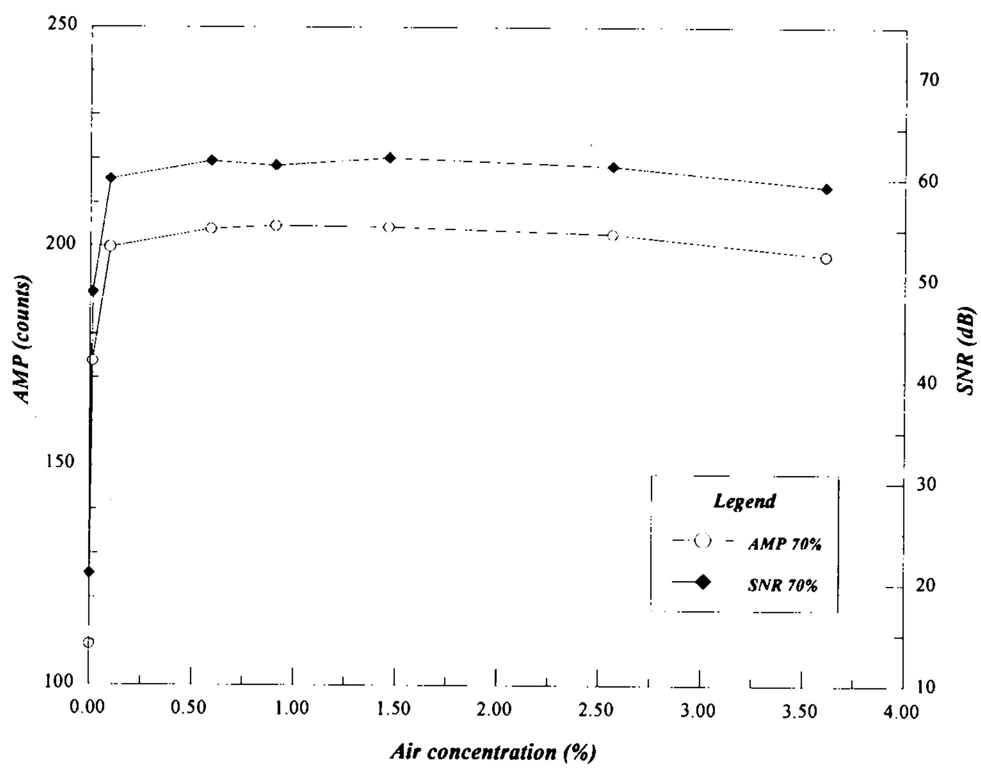


Figure 5: AMP and SNR values as a function of air concentration. Note similar shape reflecting increase in the signal strength without an increase in noise.

Discussion

Air bubbles even in small concentrations can greatly affect the accuracy of velocity measurements taken with an ADV. Figures 3 and 4 reveal significant differences in streamwise and vertical velocity components even at concentrations around 0.01-percent. Manufacture's specifications for the equipment used in this experiment, report a velocity bias of ±0.5-percent under recommended operating conditions. Buoyancy effects are noticeable with even very small air bubbles in a relatively swift moving streamwise velocity (1 m/s). Other researchers have shown that a plume or cloud of bubbles rises at two to three times the velocity of a single bubble in stagnant water [Wood 1991]. However, even moderate cross flow velocities quickly reduce the bubble-rise velocities to the order of magnitude of the slip velocity of a single bubble. It is important to note that these vertical velocities are on the order of 0.2 to 0.25 m/s.

Another generalized effect of increasing the air concentration is the resulting drop in the sonic velocity (Falvey 1990). The ADV relies on the sonic velocity in order to perform accurate measurements. Sontek provides user input for temperature and salinity values that effect the sonic velocity. However, air concentration greatly affects the sonic velocity and in turn, data returned by the ADV – such as sensed distance from the measurement volume to a fixed boundary (figure 6).

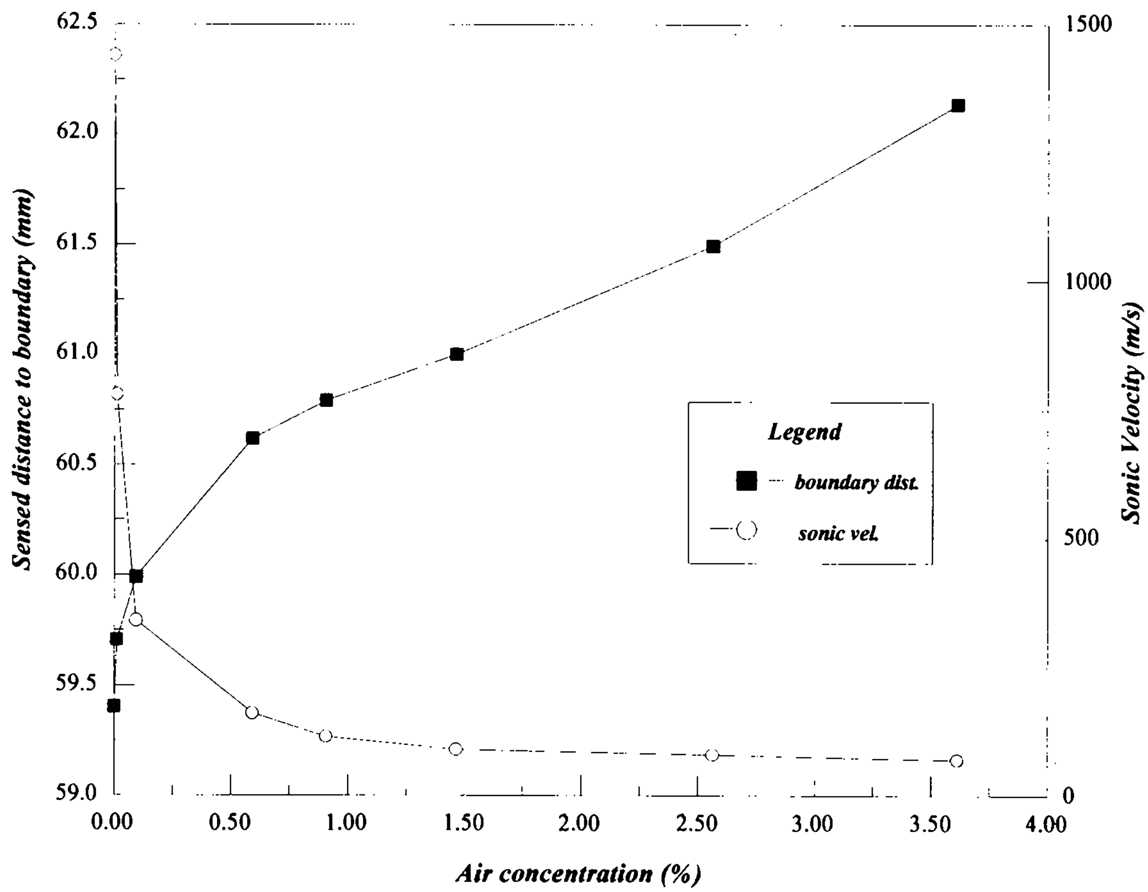


Figure 6: Sensed boundary distance as a function of air concentration. Also shown is the speed of sound in water as a function of air concentration.

During the course of this set of experiments, several interesting phenomena were observed. Since we were unable to uniformly distribute the air bubbles through the entire water prism, we positioned the probe so that the measurement volume was centered within the bubble plume. In making this adjustment, it was noted that when the measurement volume is on the edge of the bubble plume, use of the ADV is not possible. Correlation values are very low and the probe appears to have difficultly in sensing the fixed boundary. Once the measurement volume was within the bubble plume or even below the plume, operation of the ADV was possible.

The induced local velocities caused by the bubble plume were easily noted in the vertical component, however they also appeared in the streamwise component. Roughly a 5-percent increase in streamwise velocity was measured for very small air concentrations. The use of correlation filtering at the 70-percent level increased the consistency of the streamwise velocity data which remained within 2- to 3-percent of the unaerated velocity measurement for all but the smallest of air concentrations. Different levels of correlation filtering did not show much difference up to an air concentration of about 1- percent, above that level the variations in the data grew quickly.

Performance of acoustic Doppler velocimeters is significantly affected by the presence of air bubbles in the water. Even small concentrations of air can induce large differences in the flow field from that of an unaerated measurement. Air bubbles in the size range of 0.5-5 mm do not follow flow streamlines for velocities up to 1 m/s. The bubble plume induces a vertical velocity component due to the buoyancy effects. The ADV does relatively good at measuring the bubbles' slip velocity as it rises through the fluid. No strict criteria for use of velocity data as a function of correlation filtering can be recommended.

References

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