Single-beam Acoustic Doppler Profiler and co-located Acoustic Doppler Velocimeter flow velocity data

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Abstract

Acoustic Doppler Profilers (ADPs) are routinely used to measure flow velocity in the ocean, enabling multi-points measurement along a profile while Acoustic Doppler Velocimeters (ADVs) are laboratory instruments that provide very precise point velocity measurement. The experimental set-up allows laboratory comparison of measurement from those two instruments. Simultaneous multi-point measurements of velocity along the horizontal tank profile from Single-Beam Acoustic Doppler Profiler (SB-ADP) were compared against multiple co-located point measurements from an ADV. The data-set of this first time comparison has been made available. Measurements were performed in the FloWave Ocean Energy Research Facility at the University of Edinburgh at flow velocities between 0.6 m/s and 1.2 m/s. This data-set contains a) time series of raw SB-ADP uni-directional velocity measurements along a 10 m tank profile binned into 54 measurements cells and b) ADV point measurements of three-directional velocity time series recorded in beam coordinates at selected locations along the profile. Associated with the velocity data are instrument generated quality data, metadata and user-derived quality flags. This data-set provides multiple contemporaneous velocity measurements along the tank profile, relevant for correlation statistics, length-scale calculations and validation of numerical models simulating flow hydrodynamics in circular test facilities.

1 Introduction

Knowledge of flow hydrodynamics in test tanks is critical to conducting scaled tank testing for the offshore renewable energy sector as flow conditions directly influence turbine loads and generated power [1, 2]. Flow measurement in test tanks is typically performed using point measurement techniques such as Laser Doppler Velocimetry (LDV) or Acoustic Doppler Velocimetry (ADV)[3, 4, 5, 6, 7].

Doppler technology based instruments estimate velocity using the Doppler shift in frequency between transmitted and return signals which results from back scattering by water-borne particulates. The Doppler shift between the transmitted and received pulse depends on the flow velocity, assuming that the particulates are moving at the same speed as the water. In the test tank environment, the scatterers comprise glass micro-beads with neutral buoyancy.

Acoustic Doppler Profilers (ADP) capture multiple, virtually simultaneous, measurements along a profile and were originally designed for operation in environments such as open oceans, coastal waters and rivers. ADPs typically comprise multiple transducers mounted in a divergent configuration. Each transducer transmits and receives acoustic pulses to measure radial velocities along each acoustic beam. Recent increases in the carrier and sampling frequencies of ADPs has enhanced their potential for use at tank scales.

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In this paper we apply a profiling instrument in the context of tank testing, namely a Nortek 1 MHz single-beam acoustic Doppler profiler (SB-ADP). The single-beam ADP described herein provides a uni-directional velocity component measurement. The use of a single beam reduces insonification of the tank outwith the zone of interest, reduces beam reflection at the tank sides, floor and water surface and eliminates measurement uncertainty associated with divergent beams.

The study compared velocity profiles measured by the SB-ADP with co-located ADV velocity measurements at a range of typical tank operating velocities. The complete comparison is presented in Jourdain de Thieulloy et al. [8]. The associated data set is available in the DataShare repository of the University of Edinburgh. The data set contains SB-ADP data for nominal tank flow velocities of 0.6 ms$^{-1}$, 0.8 ms$^{-1}$, 1.0 ms$^{-1}$ and 1.2 ms$^{-1}$, and ADV data acquired at four locations along the profile for tank nominal tank flow velocities of 0.6 ms$^{-1}$, 1.0 ms$^{-1}$ and 1.2 ms$^{-1}$. ADV point measurements at nominal tank flow speed of 0.8 m/s were collected during the SuperGen Marine tidal array project [9] and are available in [10]. The SB-ADP configuration generated 54 simultaneous measurements of uni-directional velocity over a 10 m profile.

2 Material and methods

The Nortek SB-ADP (Figure 1), is a variant of the Nortek Signature 1000 AD2CP [11]. SB-ADP measurements were compared against a Nortek Vectrino Profiler ADV [12] configured in non profiling mode.

The component of flow velocity captured by the SB-ADP is the radial flow velocity along the acoustic beam formed by the sound waves. In the configuration presented in Figure 2 the SB-ADP acoustic beam points into the flow, directly measuring the stream-wise flow velocity component $u$. The profile is binned into a number of along-beam range cells by time-gating the reflected acoustic signal [13]. Hence, the SB-ADP can provide next to simultaneous velocity measurement of the $u$-component of the flow, reporting a velocity in each measurement cell along the profile. The ADV provides a measurement of 3-dimensional velocity over a small sample volume (1 -4.5 cm$^3$). Instrument specifications are contained within [14] and [15]. Table 1 details the instruments settings utilised during the experiments with further detail in the metadata (Sec. 3). Calibration of both instruments was performed by the manufacturer and certificates supplied.
Figure 1: SB-ADP set-up with the tank floor lifted up.

Table 1: Instruments characteristics during experiments

| Instrument type       | Model            | Abbreviation | Operating Frequency (MHz) | Sample Rate (Hz) | Cell size (cm) |
|-----------------------|------------------|--------------|---------------------------|------------------|---------------|
| Acoustic Doppler Profiler | Nortek Single-beam | SB-ADP      | 1                         | 16               | 20            |
| Velocimeter           | Nortek Vectrino Profiler | ADV      | 10                        | 100              | 0.4           |

2.1 Experimental set-up

The test set-up schematic is illustrated in Figure 2. A Cartesian coordinate system is used to locate the instruments in the tank, with origin at the tank centre on the floor \((x_t, y_t, z_t) = (0, 0, 0))\), \(z_t\) vertically upwards and \(x_t\) pointing into the main flow direction. Instrument coordinates with reference to the tank centre are provided in Table 2. A translated coordinate system \((x, y, z)\), originating at the SB-ADP transducer is used to facilitate analysis of the velocity measurements along the profile.

The SB-ADP was mounted on a floor bolted stand with sufficient structure stiffness to avoid vibration of the system. Laser alignment verified that the acoustic beam lay parallel to \(x_t\) of the tank coordinate system. The SB-ADP theoretical acoustic beam is represented in Figure 2 as a cone of 2.9° width, binned into measurement cells. The ADV was mounted onto the gantry which can be moved along the \(x_t\)-axis of the tank to capture successive point measurements within the sample volumes of the SB-ADP. The gantry positions are recorded with millimetre precision. The ADV flexible head was used to enable sampling at the same location in the \(z\)-axis as the SB-ADP. The flexible head was mounted on a rigid beam with a kite structure to minimise vibration. To reduce acoustic interference, the ADV was removed from the water.
while the SB-ADP was measuring. ADV locations along the profile are displayed in Table 3 with reference to both the tank centre and the SB-ADP. Note that ADV data at multiple locations within the tank are available in [10].

![Diagram of the test set-up showing the SB-ADP pointed into the flow, and its theoretical acoustic beam binned into measurement cells. The ADV is mounted on an x-adjustable gantry, enabling ADV point measurements to be made within successive SB-ADP measurement cells [8].](image)

| Instrument | Coordinates (m) | $x_t$ (m) | $x$ (m) |
|------------|-----------------|-----------|---------|
| SB-ADP     | -2.98 -0.545 1.00 | A -2.181 | 0.799  |
| ADV        | variable see Table 3 -0.545 1.00 | B -0.774 | 2.206  |
|            |                  | C 1.019  | 3.999  |
|            |                  | D 3.013  | 5.993  |

Table 2: Instrument coordinates with reference to the tank centre.

Table 3: ADV locations along the profile with reference to the tank centre ($x_t$) and to the SB-ADP ($x$).

2.2 Test conditions

Repeatability of test conditions within the tank was ensured by application of identical tank settings. All tests were run at a flow direction of -180° to the $x_t$ axis. No waves were generated and paddles were locked up, resulting in a tank depth of 2 m. The measurement period was defined as 2 minutes, longer than the stationarity period of the flow defined in [16]. Changes made to tank nominal flow velocities were performed with sufficient time between changes for
the flow to settle. Table 4 provides an overview of the flow speeds recorded by the SB-ADP along the tank profile and by the ADV at locations A,B,C and D.

Table 4: Tank conditions measured by the SB-ADP and the ADV

| Flow speed (ms$^{-1}$) | Impeller speed (rpm) | SB-ADP | ADV  |
|-----------------------|----------------------|--------|------|
|                       |                      | Profile | A    |
| 0.6                   | 73                   | X       | X    |
| 0.8                   | 96                   | X       |      |
| 1.0                   | 120                  | X       | X    |
| 1.2                   | 144                  | X       | X    |

3 Data

The data-set is available as a zip-file provided by the authors via the Datashare service of the University of Edinburgh. It contains netCDF (Network Common Data Form) files, a machine independent format. The individual file naming convention is defined as follows:

- ADV_[Flow speed][Location].nc
- SBADP_[Flow speed].nc

Where “ADV” and “SBADP” are the type of instrument, and [Flow speed] and [Location] are as listed in Table 4.

The netCDF file contains metadata, data and flags as shown in Table 5, where * refers to characteristics exclusively applicable to the SB-ADP data file and ** refers to characteristics exclusively applicable to the ADV data file, otherwise the characteristics are applicable to both instrument files. If relevant, data dimensions are written in []; $N_{data}$ refers to the number of samples recorded during the 2 minute measurement period and $N_{bin}$ refers to the number of measurement cells (only relevant for the SB-ADP data).

Quality control flags have been added to each individual sample collected by both instruments. Flag values have been set to either 0 where the raw data point has passed the corresponding quality control, or 1 where the data point has failed quality control. A despiking algorithm [17, 18] was applied to all data using the phase-space method based on Goring and Nikora [19]. A correlation threshold of 70% was implemented, where correlation is a statistical measure of similarity in the received signal with respect to time. Data associated with correlations lower than 70% were flagged as failing quality control. SB-ADP data had an extra quality control flag, as an increase of amplitude in the returned signal with distance in one or more cells along the profile, is indicative of an anomaly in the recorded data [11]. Measurement cells where anomalies have been detected have been flagged as failing the quality control test. Future investigation will reduce the sources of error to improve the accuracy of the SB-ADP measurement in laboratory environment.

| Instrument Specification |
|--------------------------|
| Instrument type          |
| Model                    |
| Firmware Version         |
| Number of beams          |
| Carrier Frequency (Hz)   |
| Position                 |

5
| Test location                          |
|---------------------------------------|
| Coordinates reference system         |
| X coordinates (m)                     |
| Y Coordinates (m)                     |
| Z Coordinates (m)                     |

**Clock**

| Time (s) BST                                      | [Ndata X 1] |

**Environment**

| Pressure (dbar)*                                 | [Ndata X 1] |
| Pressure Offset* (dbar)                           | [Ndata X 1] |
| Temperature (Celsius)                              | [Ndata X 1] |
| Salinity                                           | [Ndata X 1] |
| Speed Of Sound in water                           | [Ndata X 1] |

**Tank settings**

| Tank nominal flow velocity (m/s)                  |
| Tank speed setting (rpm)                           |
| Tank flow direction                                |
| Tank wave setting                                  |

**Instrument orientation**

| Pitch* (°)                                        |
| Roll* (°)                                         |
| Heading* (°)                                      |

**Instrument configuration**

| Number of bins                                      |
| Bin size (m* or 0.1mm**)                            |
| Bin start** (0.1mm)                                |
| Blanking distance*                                  |
| Sample rate (Hz)                                    |
| Transmitted power (dB)                              |
| Probe calibration matrix **                         |

**Quality data**

| Amplitude of the returned echo beam 1 (dB)         | [Ndata X nbin] or [Ndata X 1]** |
| Ping to ping correlation of the returned echo beam 1 (%) | [Ndata X nbin] or [Ndata X 1]** |
| Signal to noise ration beam 1** (dB)               | [Ndata X 1]**                    |
| Amplitude of the returned echo beam 2** (dB)       | [Ndata X 1]**                    |
| Ping to ping correlation of the returned echo beam 2** (%) | [Ndata X 1]**                    |
| Signal to noise ration beam 2 ** (dB)              | [Ndata X 1]**                    |
| Amplitude of the returned echo beam 3** (dB)       | [Ndata X 1]**                    |
| Ping to ping correlation of the returned echo beam 3** (%) | [Ndata X 1]**                    |
| Signal to noise ration beam 3 ** (dB)              | [Ndata X 1]**                    |
| Amplitude of the returned echo beam 4 ** (dB)      | [Ndata X 1]**                    |
| Ping to ping correlation of the returned echo beam 4** (%) | [Ndata X 1]**                    |
| Signal to noise ration beam 4 ** (dB)              | [Ndata X 1]**                    |

**Velocity data**

| Velocity beam 1* (m/s)                             | [Ndata X nbin] |
| Velocity along X** (m/s)                           | [Ndata X 1] |
| Velocity along Y** (m/s)                           | [Ndata X 1] |
Velocity along $Z1^{**}$ (m/s) $[Ndata \times 1]$
Velocity along $Z2^{**}$ (m/s) $[Ndata \times 1]$

**Data quality flags**

| Flag from phase-space threshold | $[Ndata \times nbin]$ or $[Ndata \times 1]$** |
|--------------------------------|------------------------------------------|
| Flag correlation $>70\%$        | $[Ndata \times nbin]$ or $[Ndata \times 1]$** |
| Flag anomaly detected*          | $[Ndata \times nbin]$ or $[Ndata \times 1]$** |

Table 5: Structure of the netCDF files containing metadata and data, where * refers to variables that only apply to the SB-ADP and ** only to the ADV.

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