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A Portable Retractable ADCP Boom-Mount for Small Boats

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ABSTRACT: This paper describes the design, testing, and application of a portable and retractable shipboard acoustic Doppler current profiler (ADCP) boom-mount. The boom is specifically adapted for small fiberglass boats working with a minimal crew. The design permits the rapid collection of ADCP data on discontinuous transects which would be difficult or impossible using a large displacement hull vessel or with a towed vehicle. This capability is particularly useful in shallow wind-driven estuaries and in tidal channels where flow time scales are often on the order of several hours. Tests of the boom show that high quality ADCP data (as measured by percent good) can be obtained at boat speeds up to 4.0 m s^{-1} and that data quality depends on transducer depth. The utility of the retractable design is demonstrated with an 8 m boat on two nearly synoptic ADCP surveys of a shallow estuary. With minor modifications to accommodate different vessel geometries, the design could be readily adapted for use on similar vessels.

Introduction

Shipboard acoustic Doppler current profilers (ADCPs) are uniquely suited for measuring the horizontal and vertical velocity gradients commonly found in coastal and estuarine waters. Over the past decade they have become an indispensable tool for observational circulation studies and a variety of methods for mounting shipboard ADCPs have been developed. Early applications were on deep displacement research vessels where the ADCP was mounted directly into a hull sea chest (Joyce et al. 1982; Simpson 1986; Leaman et al. 1989) or transducer well (Murphy et al. 1992). Both the sea chest and transducer well installations are most appropriate for large vessels and continue to be implemented (e.g., Flagg et al. 1998). The large through-hull fittings, deep bilges, or external hull fairings required by these mounts are not readily adapted for use with small vessels and alternative mounting systems have evolved.

More recently, submerged towed vehicles (Kaneko et al. 1990; Hori et al. 1991; Spain and Fortin 1994; Munchow et al. 1995; Trump et al. 1995) have come into favor for open water measurements since they reduce the ADCP's exposure to surface disturbances and ship wakes. In shallow nearshore applications these vehicles are less effective since they exclude data from a significant portion of the upper water column and can impede ship maneuverability.

Small surface towed vessels (e.g., Valle-Levinson et al. 1998) have also been used as ADCP platforms, particularly with smaller ships. Most designs use a catamaran configuration towed alongside the ship and tethered to a spar. The shallow draft of surface-towed vessels permits measurement of much of the upper water column. Unfortunately, their use is limited to calm sea states due to their rapid pitch/heave/roll response which degrade ADCP data. When surveying multiple discontinuous transects, deployment and recovery of towed vehicles can also be prohibitively time consuming.

Boom-mounts offer an inherently more stable ADCP platform than surface-towed vehicles due to their direct connection to the comparatively larger ship (which cuts through small surface waves and has a damped pitch/heave/roll response for larger

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waves). Care must be taken to avoid hull and propeller induced bubble streams, and excessive turbulence around the boom itself (Colbourne et al. 1993). Previous boom-mounts have been used on large steel-hull research vessels and required permanent mounting apparatus, cumbersome deck hardware, or wire struts for support (Colbourne et al. 1993; Kolb 1995; Mathewson and Seim 1997). In addition, the high freeboard of these vessels required large boom structures that required ship's cranes for installation.

Until recently the use of shipboard ADCPs was limited to deep-water applications and large research vessels. Improvements in broadband acoustic technology (allowing smaller vertical bin sizes, decreased blanking distances, and increased precision) as well as advances in bottom-tracking and inexpensive precision navigation instruments (e.g., differential global positioning system, DGPS) have now made shipboard ADCP measurements in shallow water (<10 m) possible (e.g., Churchill et al. 1999). These shallow water applications use correspondingly smaller vessels and indeed practical access to many inshore areas of interest may only be gained by trailering a small boat. Often the vessel of choice is a high-speed planing fiberglass hull driven by an outboard motor. Working with this kind of vessel in shallow water presents unique challenges for mounting a shipboard ADCP and we found previous methods and designs could not meet these needs.

In particular, we required a mounting system that would: provide a stable platform for the ADCP, even in choppy seas; place the ADCP away from the hull slipstream to avoid air bubble contamination; be compact and lightweight enough to be easily installed and removed from the vessel by two people; readily allow the ADCP to be inserted into the water for data collection, and extracted to permit the vessel to rapidly steam to the next transect; fully retract into the vessel to avoid the risk of instrument damage while steaming between stations, docking, or while trailering the vessel; leave no permanent hardware on the deck which would interfere with other vessel uses when the ADCP was not needed; and be durable yet inexpensive to build and install. The remainder of this paper describes the design, testing, and application of a new boom-mount that addresses these requirements.

Materials and Methods

Boom Design

The boom consists of an L-shaped channel section that attaches to the deck and gunwale of the ship. The channel extends over the ship bulwarks and away from the hull slipstream. The boom end connects to a tubular arm which extends below the water surface to a flat plate where the ADCP is attached (Fig. 1). Boom length was chosen to extend away from the ship wake to avoid air bubbles which can degrade ADCP data (New 1992). The length was limited by concern that in rough sea states, a long moment arm would amplify ship motion and potentially overwhelm the ADCP's internal pendulum pitch/roll sensors. Outside the boat the channel section dips down toward the water to reduce the length of the vertical ADCP arm, reducing the twisting moment generated. Clearance above the water surface was maintained so small waves would not impact the boom. The cross-sectional surface area outside the boat was kept to a minimum so occasional large waves impacting the boom would not generate damaging forces on the connections to the fiberglass hull.

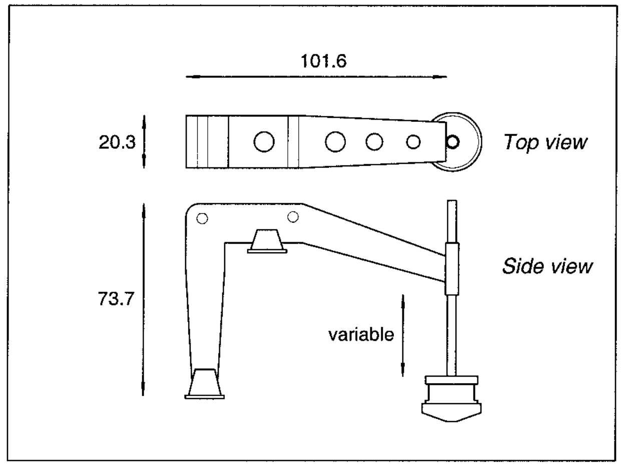

Fig. 1. Schematic drawing of boom design. Dimensions are shown in centimeters.

The boom was constructed of 316 stainless steel (which has exceptionally weak magnetic properties) to avoid biasing the ADCP's internal flux-gate compass. This material was chosen over marine grade aluminum (despite the extra weight) because it is more resistant to saltwater corrosion. The channel section was fabricated from flat plate parts cut from a 3/16 inch (4.7625 mm) sheet. The parts were cut using a high velocity abrasive water-jet. The side and bottom plates were welded to form a channel section, with plates capping each end. Two sections of 1 5/8 inch (41.275 mm) outside diameter (OD) schedule 40 stainless steel tubing were used inside the channel at stress points to increase stiffness and provide handholds. Cutout holes in the channel section were made with the water-jet to reduce weight. The resulting space-frame design yielded a light, compact, yet extremely rigid boom (Fig. 2a).

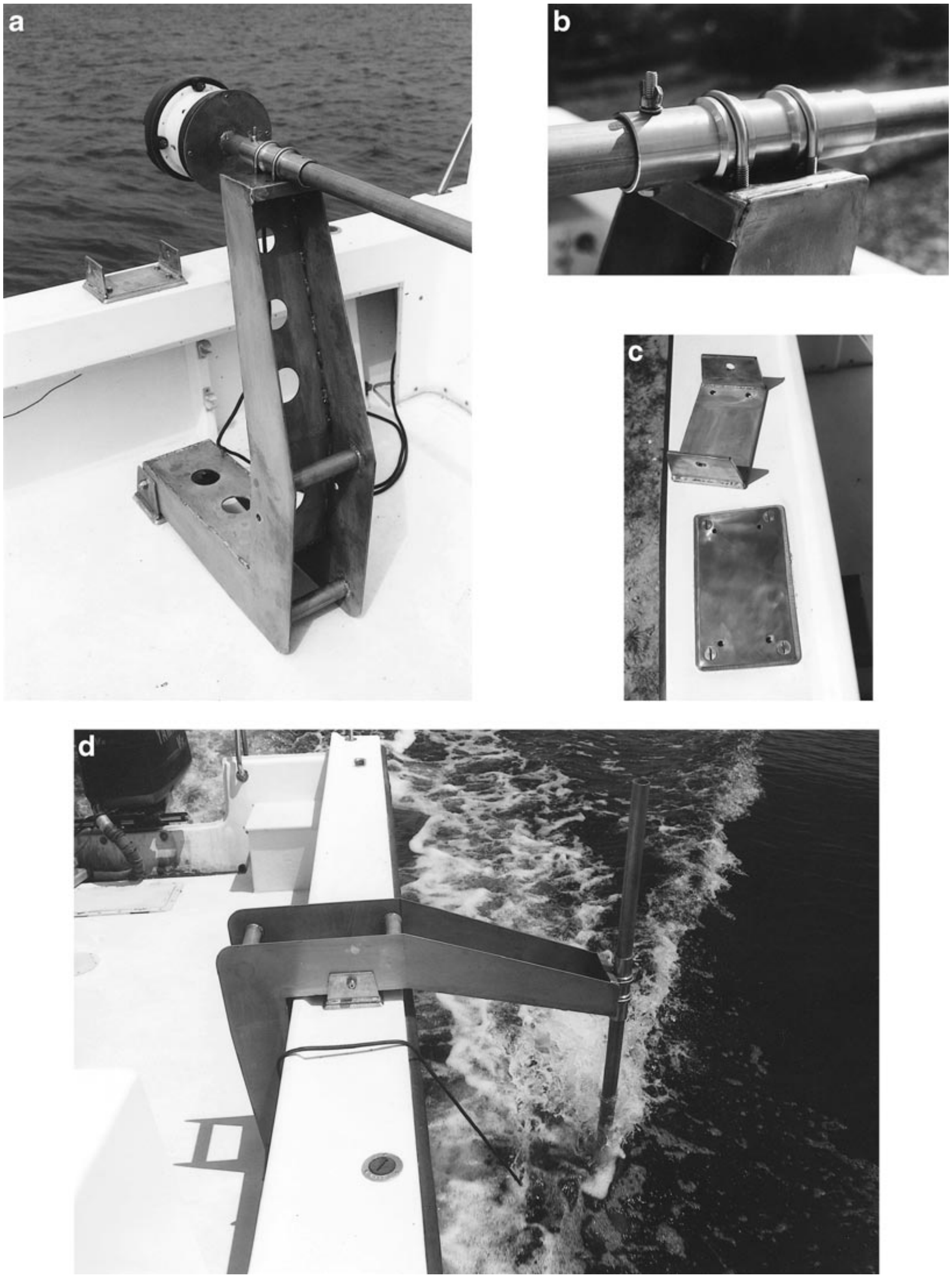

Fig. 2. (a) Photo of boom rocked into ship cockpit. The ADCP arm has been retracted to avoid risk of damage while in transit between stations or docking. (b) Photo of collar connecting boom and ADCP arm. Ridges in collar outside diameter were milled to seat U-bolts in position. Collar was milled flat on face adjoining the boom to resist rotation. (c) Photo of permanent gunwale plate and removable bracket. The boom attaches to the deck in the same way. (d) Photo of boom in data collection position while steaming at 3.5 m s^{-1}. The black data/power cable runs from the ADCP to an onboard laptop computer and power supply.

The ADCP itself is mounted on an arm made of 1 5/8 inch (41.275 mm) OD schedule 40 stainless steel tubing attached to the boom with a tubular collar (Fig. 2b). The arm slides through the collar to permit the ADCP transducers to be set at various depths as well as to retract the arm inside the boat while steaming between stations. The arm is secured into position with a single pin through the collar. The boom could readily be fitted with a hydrodynamic arm instead of the tubing to permit higher data collection ship speeds (e.g., Colbourne et al. 1993; Mathewson and Seim 1997). We opted to use small OD stainless steel tubing to simplify the design and reduce costs. An alternative low cost option that could improve arm hydrodynamics would be to use a short section of sailboat mast.

Regarding arm hydrodynamics, we note that in estuarine and coastal applications ping rate rather than ship speed is often the limiting ADCP data collection factor. With the present generation of ADCPs, multiple independent ADCP ensembles must be averaged together to obtain a usefully precise velocity measurement (see Gordon 1996). As ship speed is increased, ADCP data can become too sparse across a given horizontal segment to allow sufficient averaging for acceptable velocity precision. For example assuming a typical ADCP ping rate of 1 Hz, in order to resolve velocity gradients with horizontal length scales of order 100 m (such as across estuarine density fronts) ping rate can limit ship speeds to about 3 m s^{-1}. At these low speeds, the hydrodynamics of the arm are less critical and simple shapes may suffice. We note that the small pressure cases now used for direct reading ADCPs make less of a flow disturbance than older models and this reduces the need for a hydrodynamic arm to enclose the instrument.

Most research vessels are called to perform a wide range of tasks (e.g., hydrographic surveys, biological sampling, scientific diving). It is desirable to avoid installing equipment that will be in the way when not in use. For this reason, we designed a removable mounting system for the boom. Permanently mounted plates on the deck and gunwale were cut from 3/8 inch (9.5250 mm) 316 stainless steel, again using the water-jet. Plate corners were rounded, the edges beveled, and the mounting bolts countersunk to reduce tripping hazards when the boom is not installed. The plates were tapped with threaded holes for attaching removable brackets (Fig. 2c). The plates were mounted to the ship with 3/8 inch (9.5250 mm) bolts and 3M 5200 marine adhesive.

The finished boom weighs 63.0 lb (28.6 kg) and is easily handled by two people. The arm is mounted separately and weighs only 14.5 lb (6.6 kg). The ADCP itself weighs 15.0 lb (6.8 kg). Prior to attaching the boom, the removable brackets are bolted to the permanent deck plates and the boom is attached to each bracket with a single 5/8 inch (15.8750 mm) bolt. During a survey the brackets remain attached to the deck plates; the boom can be pivoted to rest inside the vessel cockpit by removing the gunwale attachment bolt and manually rocking the boom 90° inward. The arm holding the ADCP retracts as well and can be slid up to the boom connection point, leaving the entire apparatus safely within the cockpit (Fig. 2a). Arm adjustment also permits a range of working ADCP transducer depths: shallow when anchored on station, deeper underway and when adverse sea states dictate.

Once the design phase was complete, the total fabrication time was about 50 hr, plus a total of 10 hr for alignment and installation on the vessel. Total cost for materials and labor was about US$3,100. The use of abrasive water-jet technology reduced the cost and time associated with making irregularly shaped parts and avoided heat-related warpage that commonly occurs when cutting stainless steel using conventional methods. The use of 316 stainless steel over lower grades (e.g., 304) increased the cost, but seems worthwhile to avoid questions about the boom material biasing the ADCP's internal compass.

Field Tests

The boom was installed on the 8 m *R/V Parker,* a fiberglass hull, outboard driven vessel. This vessel provided a stable platform, yet had a draft of only 0.30 m giving minimal interference with the upper water column. The boom was mounted amidships to reduce the amount of pitch and roll the ADCP would experience. A direct reading 1,200 kHz RDI Workhorse broadband ADCP with bottom tracking capability was attached to the boom. Initial loading and installation of the boom requires 2 people about 10 min. In the field, the boom only needs to be extended and retracted for each transect which requires less than 2 min for 1 person. The monolithic construction yields a highly repeatable installation; only the depth of the transducer head is adjustable. Figure 2d shows the boom in data collection position while steaming at 3.5 m s^{-1}.

The performance of the boom was evaluated with a series of tests at different boat speeds and transducer depths. These tests were made over a 3-h period on the upper Neuse Estuary in eastern North Carolina, U.S. (Fig. 3). Depths in the upper estuary range from less than 1 m to 7 m. This reach of the estuary is often vertically and horizontally stratified, depending mostly on freshwater discharge and wind forcing. The astronomical tide is negligible with amplitude less than 5 cm (Luettich

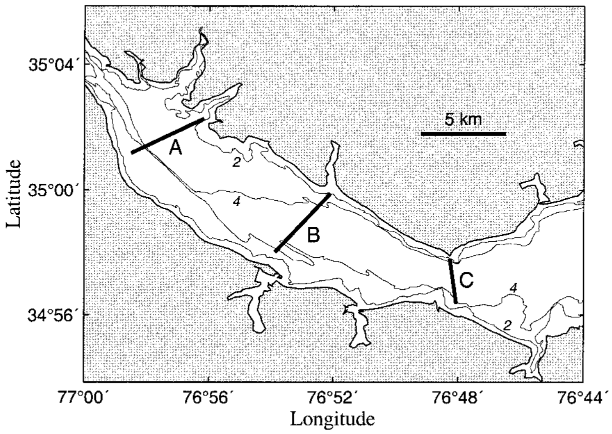

Fig. 3. Map of upper Neuse Estuary showing locations of ADCP transects. Depth contours are in meters.

TABLE 1. ADCP system configuration.

Acoustic frequency	1,200 kHz
Ping rate	0.85 Hz
Vertical bin size	0.25 m
Depth range	1.05–8.05 m
Single ping velocity standard deviation	10 cm s^{-1}
Velocity standard deviation for ensemble of pings (noise floor)	<2 cm s^{-1}
Navigation sampling rate	0.5 Hz
Navigation precision	1–4 m
Data acquisition software	RDI Transect version 2.85

et al. 1999). Repeated runs were made at 10 different boat speeds, each over the same short transect (the northern 400 m of Transect B on Fig. 3). Boat speeds ranged from 1.9 m s^{-1} to 4.3 m s^{-1}. For each speed we tested two different transducer depths, 25 and 50 cm, for a total of 20 tests. Wind during the tests was steady from the northwest at 10–15 knots with wave heights of 0.3 to 0.5 m.

Ship heading and speed were removed from the ADCP data using the ADCP's internal flux gate compass and bottom-tracking. The instrument's internal pendulum sensors were used to remove ship pitch and roll. An attractive feature of using a fiberglass boat and a non-magnetic boom is that the ADCP's internal compass and pendulum sensors can be used, rather than reverting to separate ship gyros. Position and navigation were obtained from a NorthStar 951XD DGPS. The ADCP and DGPS data were logged on a standard laptop computer. Table 1 details the ADCP configuration.

Results

Boom performance during the tests was assessed using percent good, a common measure of ADCP data quality (Gordon 1996; Flagg et al. 1998). For each run percent good profile data were horizontally and vertically averaged to yield a single summary test measure. Figure 4 shows these results as a function of boat speed. With the center of the ADCP transducers set 25 cm below the water surface, high quality data were obtained at boat speeds up to about 3.0 m s^{-1}. At higher boat speeds percent good rapidly decreases and above 3.5 m s^{-1} few usable data were obtained with this transducer depth. By setting the transducers deeper, at 50 cm below surface, high quality data were obtained up to 4.0 m s^{-1} (Fig. 4). At slightly higher speeds acceptable data were obtained, but quality became marginal by 4.3 m s^{-1}. Visual observations during the tests indicated that air bubble contamination (mostly from the hull) corresponded closely to decreases in percent good. The boom is sufficiently rigid that wire support cables were not needed at any of the tested speeds. These data acquisition speeds are comparable to those obtained with the boom-mounts of Colbourne et al. (1993) and Mathewson and Seim (1997) and the surface towed vehicle of Valle-Levinson et al. (1998), however, the retractable design of the present boom permits more rapid transit between survey transects as described below.

An additional test was conducted to demonstrate the new boom's capability to rapidly collect discontinuous transect data in a set of nearly synoptic surveys of the upper Neuse Estuary. Two ADCP surveys composed of three transects each were made on May 5, 1999 (see Fig. 3). Boat speed was nominally 3.5 m s^{-1} while collecting ADCP data and about 12 m s^{-1} while steaming between transects. The ADCP transducers were set at 0.50 m below surface. The ADCP configuration was the same as for the previous tests (see Table 1) and each transect yielded about 1 megabyte of data.

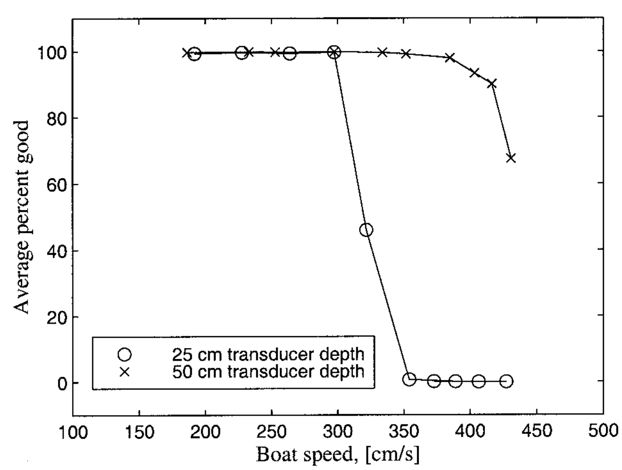

Fig. 4. Comparison of ADCP data quality at different boat speeds and transducer depths.

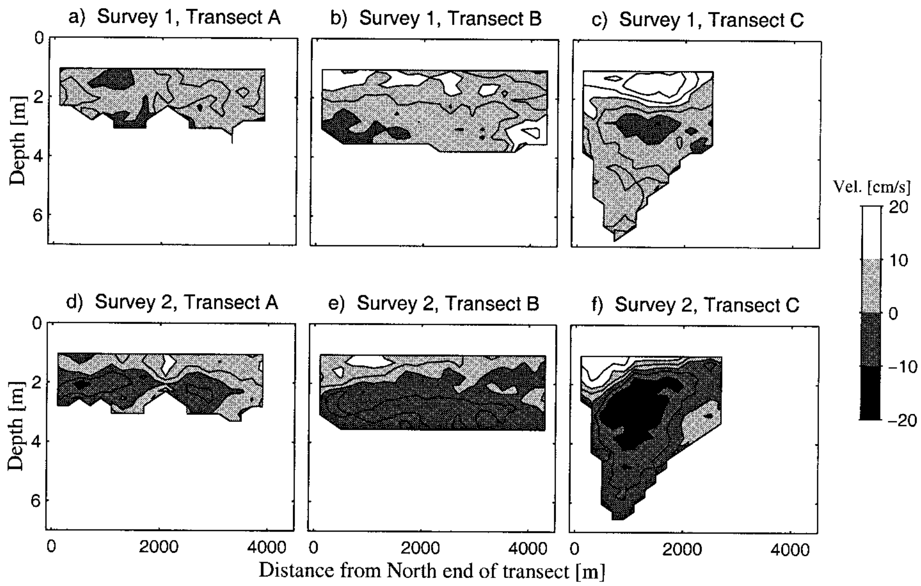

Fig. 5. Along-channel component of rotated ADCP velocities. Flow in the downstream direction is positive; the contour line interval is 5 cm s^{-1}.

Both surveys took about 1 h 40 min to complete, with a 3 h period between surveys. The first survey was preceded by and conducted under variable winds less than 5 knots. Winds began blowing from the southwest at 10–15 knots during the period between surveys and continued through the second survey. The surveys yielded two nearly synoptic views of the circulation: during calm conditions and under moderate wind forcing. The data were horizontally averaged into 200 m bins (representing a 60 s time-average) and rotated into along-channel and across-channel components (Figs. 5 and 6).

Along-channel Circulation

Measured along-channel velocities during survey 1 are contoured in Figs. 5a–c. Flow at transect C was mostly downstream but with marked vertical structure. Flow in the upper 2 m was fastest and rather uniform across the width of the estuary; be-

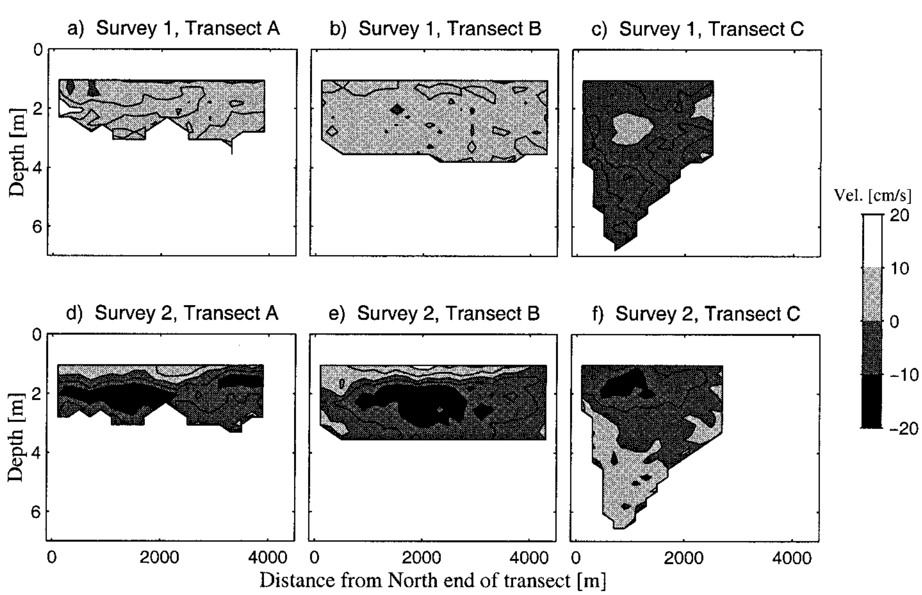

Fig. 6. Cross-channel component of rotated ADCP velocities. Flow toward the north end of each transect is positive; the contour line interval is 5 cm s^{-1}.

low 2 m the flow was also downstream but with a weak core moving upstream. Flow at transect B was also generally downstream, although the surface velocities were smaller. Along transect A the circulation was rather weak and less coherent. Marked vertical shear at C around 2 m depth was associated with vertical salinity stratification (the presence of a sharp halocline at this depth was observed in CTD data, not shown).

With southwest wind forcing during survey 2, circulation dramatically changed (Fig. 5d–f). Velocities increased and the vertical shear between the two layers intensified. The sharpest velocity increase was along C, presumably because this transect was along a natural constriction in the estuary. The lateral asymmetry along C was due to the northward component of the southwest wind driving the surface layer in a northeast direction, where it was confined by the shoreline geometry. The downstream surface flux was compensated by return flow at depth.

Cross-channel Circulation

Figures 6a–c show the cross-channel velocities from survey 1. Flow at C was predominantly southward. Cross-channel flows at A and B were nearly stagnant and in fact were near the noise floor of the ADCP (see Table 1).

As was seen in the along-channel circulation, the addition of wind forcing had a substantial effect on the flow (see Fig. 6d–f). Transect B was closely aligned with the wind direction; near surface flow was with the wind, while below 2 m flow was opposite the wind direction due to upwelling and downwelling of the surface layer. Circulation across A exhibited a similar pattern as at B. Velocities were smaller, presumably due to the correspondingly smaller fetch along A, and since B was more closely aligned to the wind direction. Cross-channel circulation at C was mostly southward, but the mechanism for this is not entirely clear. Given the strong vertical stratification, it is possible that there was a significant northward flow in the upper 1 m of the water column, which is not measured by the ADCP. The bathymetry and shoreline geometry may have also played a role in steering the lower layer southward.

Discussion

We successfully designed and tested a portable and retractable boom mount for a shipboard ADCP. The boom design is well suited for small fiberglass boats working with a minimal crew. Aside from two unobtrusive deck plates, the boom is entirely removable so as not to impede other vessel tasks when the boom is not in use. The design is durable, inexpensive, and straightforward to fabricate. With minor modifications to accommodate different vessel geometries, the design could be readily adapted for use on similar vessels.

Tests revealed that ADCP data quality was insensitive to boat speed and transducer depth at boat speeds less than 3.0 m s^{-1}. At higher boat speeds data quality rapidly decreased with the transducers set at 25 cm below surface. By setting the transducers to 50 cm depth, high quality data were obtained up to boat speeds of 4.0 m s^{-1}. These results suggest a trade-off between boat speed and the amount of the upper water column measured.

Surveys on the upper Neuse Estuary demonstrated the ability of the retractable design to rapidly collect ADCP data on discontinuous transects. These data would have been difficult or impossible to obtain using a deep displacement hull vessel or with a towed vehicle. Velocity data from these two surveys show the rapid spin-up of shallow water circulation. Only by rapidly covering a survey area can reasonably synoptic depictions of the flow field be obtained. This capability is particularly useful in shallow wind-driven estuaries and in tidal channels where flow time scales are often on the order of several hours.

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