USE OF TOW TANKS TO STUDY SENSITIVE CURRENT METERS

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Abstract- **The importance of accurate calibration of current sensors has increased as current sensors have become more sensitive, and as scientists study turbulence and mixing in boundary layers. Current sensors are often calibrated in tow tanks. This paper discusses and presents some measurements of some of the complexities of calibration in tow tanks. Residual convective currents cause a noise floor in calibration. Sensor wakes cause gain errors and increase the ambient turbulence if not dissipated before a successive measurement is made in the same water. Proximity to surfaces can affect the velocity gain of current sensors. Density stratification in water and the internal waves it allows add complexity to measuring slow flows. Strumming of current meter mounts greatly increases the velocity noise of current meters.**

Measurements of velocities in current sensor wakes are compared with far-field turbulent wake models to characterize how long one must wait between tank tows in order for wakes to dissipate. Wake velocities caused by sensors that looked like they would leave two-dimensional wakes, in fact, decayed as velocities in three-dimensional wakes. Three-dimensional wake velocities dissipate more rapidly than two-dimensional wakes velocities, reducing the time required to wait between measurements in tow tanks.

INTRODUCTION

Turbulence and turbulent transport have become areas of increasing interest in the oceanographic community and are active areas of research. Fundamental to this research is the ability to accurately measure turbulent flow statistics such as dissipation and transport (Reynolds Stress, the turbulent transport of momentum). Accurate measurements of these quantities in boundary layers is difficult. Any current meter whose measurement volume is local to the sensor can have its accuracy compromised by having its wake advected back into the measurement volume by waves or other recirculating currents. Acoustic-travel time, acoustic-travel phase, mechanical, and electromagnetic current sensors measure current local to the sensor. The scientist needs to know how much of a current meter's output is real and how much is an artifact of the meter's flow disturbance. Much of this needed calibration can be done by towing the meter through still water in a tow tank.

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The application of a current meter determines what tests are required to characterize its measurement accuracy. A current meter solely used to measure mean flow in a constant flow environment, only needs its linearity and cosine response (response from different flow directions) calibrated. A current meter in waves, however, may rectify some of the off-axis flow and have a bias. A current meter used to measure mean flow in a wave environment (or on a mooring excited by waves), also needs its wave bias measured [1]. A current sensor used to measure mean and turbulent quantities in a boundary layer, requires its gain, cosine response, wave bias, and self noise spectra to be measured.

In the earlier days of mechanical current meters, the propeller stopped when the current dropped below one to two centimeters per second. Tank currents of a couple of millimeters per second were ignored. Newer current meters such as acoustic-travel time meters are linear through zero and have the potential of accurately measuring very slow velocities. The Benthic Acoustic Stress Sensor (BASS) [2] current meter, for example, has an electronic noise standard deviation of 0.0095 centimeters per second. The sensor can now measure the small convective velocities in a bucket. Conversely these small convective velocities in a bucket, or larger convection in a tow tank, can limit the accuracy of calibration of sensitive current meters. The accuracy of acoustic travel time current meters is limited by disturbance to the flow by the sensor for all but very slow velocities.

Facilities that can be used to calibrate current sensors include: tow tanks where the meter is dragged through still water, flumes where a meter is held fixed and water flows past, and tanks with wavemakers where waves radiate past a fixed current meter. Both flumes and tanks with wave makers have nonuniform residual flows that are hard to characterize accurately. Without accurate knowledge of the flow, accurate calibration of current meters in the flow is not possible. It is easy to buy accurate off the shelf carriage velocity sensors. Tow tanks can simulate waves by moving the sensor in a circular path relative to the carriage. Most current meter calibrations are performed in tow tanks. This paper will focus on complications in calibrating a current meter in a tow tank.

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WATER MOTION IN A TOW TANK

A problem in calibrating current meters in tow tanks is that the water is never perfectly still. Tank water can have velocity from wakes of earlier tows, surface gravity waves and seiches from earlier disturbances, internal gravity waves and seiches from earlier disturbances, and convection from unequal heating, cooling, air currents on the surface, or unequal evaporation from the surface.

Typical convection velocities in a tank that, has not been disturbed for over an hour, are of order three millimeters per second for a tank one meter deep by 1.2 meters wide by twenty meters long. Fig 1 shows a typical velocity trace in an undisturbed tank. Larger tanks have larger velocities but the velocity is not linear with tank size. These velocities are rarely an issue for propeller current meters that do not turn below one to two centimeters per second. Newer current meters do measure these velocities and these velocities in turn limit the accuracy of calibrating current sensors. One independent check of convection currents is to drop a crystal of permanganate dye in the tank and observe the water motion by the distortion of the dye streak.

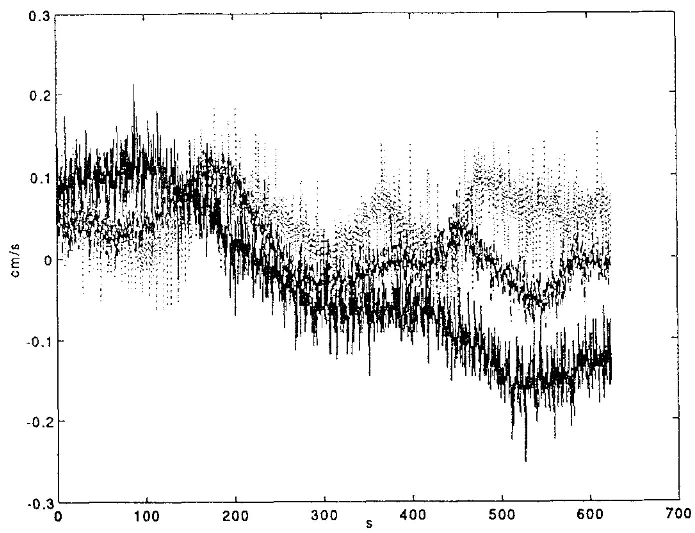

Fig. 1. Typical convective velocity in an undisturbed tank. Three orthogonal components of velocity are shown.

Current meters that measure current local to the instrument change the flow in their measurement volume. When a current sensor is dragged through water it pushes on the water and that will cause a wake and can create surface gravity and/or internal waves. Seiches are waves that slosh the water of the tank and can take a long time to damp out. Fig. 2 shows a seiche seventy minutes after the last disturbance to the tank. This seiche was the second surface gravity mode and was not noticeable to the eye. It can be argued that this seiche would not have significantly affected a calibration, but it does show that waves can take a long time to dissipate. Surface and internal seiches should be avoided, when possible, because they take a long time to dissipate.

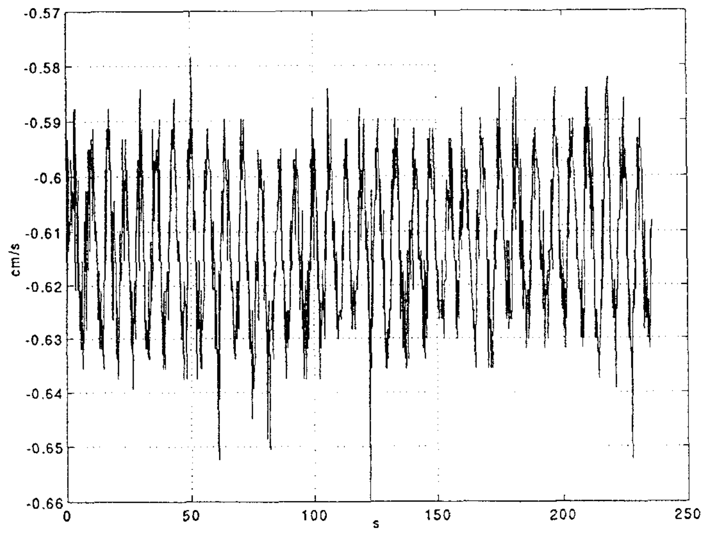

Fig. 2. Velocity trace of tank seiche 70 minutes after tank disturbance. This period agreed with the second mode of the tank.

CURRENT METER WAKES

Towing a current sensor in a tow tank leaves a wake. This section will compare the decay of observed wakes with two-dimensional and three-dimensional far-field wake models. Most of these tests were made with a BASS sensor (Fig. 3) mounted on a spacer cage that looks a lot like a sensor cage to the flow. A typical sensor output is shown in Fig. 4. The sensor initially recorded still water, was towed down a tank, left still, and then towed back. After the carriage stops, the sensor wake is seen to catch up to the stopped sensor and then slowly dissipate. A person running a calibration needs to know how long to wait before running the next test.

The turbulent wake models to be compared to the data are the two-dimensional and three-dimensional (circular) wake models in Schlichting [3] pp. 729-734. Schlichting assumes a wake in a constant flow measured a distance x downstream of the object and assumes Prandtl's mixing length theory. The predicted wake width and core velocity anomaly are shown in (1) and (2) for two-dimensional and three-dimensional wakes. In these equations, b is the wake width, β is an entrainment coefficient, C_D is the drag coefficient, x is the distance downstream, A is the cross-sectional area, U_∞ is the objects

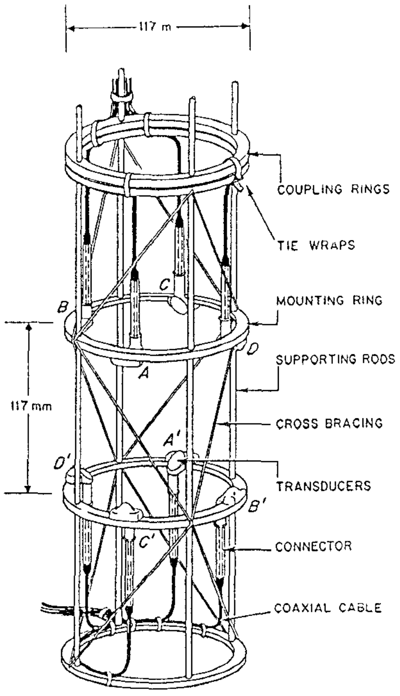

Fig. 3. Typical BASS sensor cage.

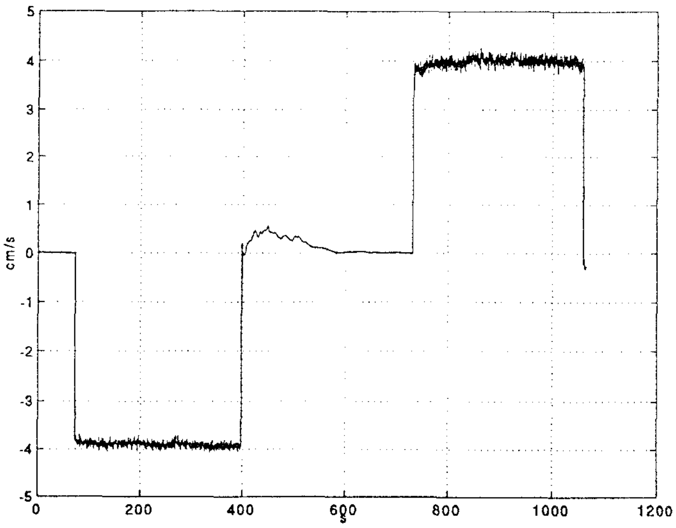

Fig. 4. Typical BASS velocity record from calibration in a tow tank. The sensor wake advects past the sensor after the tow stops.

velocity, u_1 is the core velocity, and d is the width of the two-dimensional object. I assume that the carriage stops quickly, that the wake catches up to and envelops the still sensor. After the wake catches up to the sensor, time t can be used as a surrogate for distance downstream x. For the two model wakes, the core velocity should scale as in (3). The three dimensional circular wake dissipates faster than the two dimensional wake, as it proportionally has more volume of fluid around it to entrain.

$2D$	$3D$	
$b \sim (\beta C_D d x)^{\frac{1}{2}}$	$b \sim (\beta C_D A x)^{\frac{1}{3}}$	(1)
$\frac{u_1}{U_\infty} \sim \left(\frac{C_D d}{\beta x}\right)^{\frac{1}{2}}$	$\frac{u_1}{U_\infty} \sim \left(\frac{C_D A}{\beta^2 x^2}\right)^{\frac{1}{3}}$	(2)
$u_1 \sim t^{-\frac{1}{2}}$	$u_1 \sim t^{-\frac{2}{3}}$	(3)

Although the BASS sensor and spacer cage appeared to be a shape whose wake would be primarily two-dimensional, like the wake of a cylinder, the velocity of the wake it left decayed as a three-dimensional wake. The wake velocity after stopping the tow carriage is shown in Fig. 5. The wake decay most

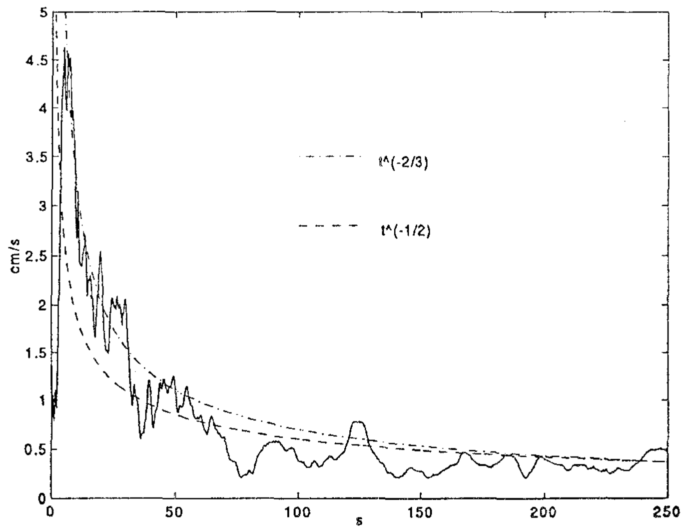

Fig. 5. Wake of BASS decay compared to $t^{-1/2}$ and $t^{-2/3}$.

closely follows $t^{-2/3}$ which is good as the wake decays more quickly than a two-dimensional wake allowing less time to be required between tow tank runs. Similar data are shown in Fig. 6. of a vorticity sensor's velocity output [4]. The geometry of

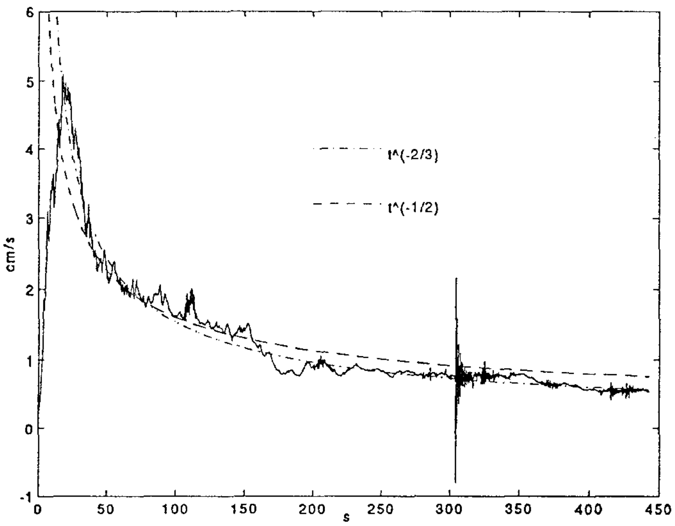

Fig. 6. Wake of vorticity sensor measuring velocity compared to $t^{1/2}$ and $t^{2/3}$.

the sensor, again, suggested that the wake would be primarily two-dimensional, but the wake velocity was found to decay as in a three-dimensional wake. As a rule of thumb, the wake velocity at the stopped sensor reached a peak approximately ten seconds after the carriage stopped and had decayed to seven percent of its peak after ten minutes. There is not much point in waiting for the wake velocity to decay significantly below the residual convective velocities in the tank.

MODELING PARAMETERS

Parameters that can affect current-meter performance are proximity to a surface, stratification, and mount compliance. Proximity to a surface can change the current-meter gain because a nearby surface can restrict flow around a sensor forcing more flow through it. Towing a BASS sensor parallel to a tank bottom and 2.5 centimeters off the bottom can increase the sensor gain by 8.4 percent. Towing a BASS sensor parallel to and 3.8 centimeters below the surface increased the sensor gain by an average of 3.8 percent, for Froude numbers from 0.09 to 0.72. These tows were much closer to the surfaces than would happen in a normal deployment and show the largest error from not taking surface proximity into account. If the sensor is calibrated as it is deployed, this will not result in an error.

Stratification of a flow can affect current meter performance by providing the density gradient to support internal waves. If a current sensor is towed at a speed comparable to potential internal wave phase velocities, the towed sensor can create significant internal waves. Internal waves have vorticity in the density stratified layer. Fig. 7. shows a set of tows of a vorticity sensor measuring velocity [4] at different speeds in a strongly temperature stratified tank. The temperature difference over one meter of depth was three degrees Centigrade. This stratification was stronger than is common in geophysical flows, but can occur. The slow tows show significant variation in velocity over a slow time scale. For faster tows, this variation decreased and disappeared. Towing at a speed much faster than the fastest internal wave speed should be like towing in a less stratified tank. If significant stratification is expected on a deployment, calibrating the current meter at the same internal Froude number will result in no error.

For most calibrations, we mix out any tank stratification, and let the tank settle before making any sensitive or slow calibrations.

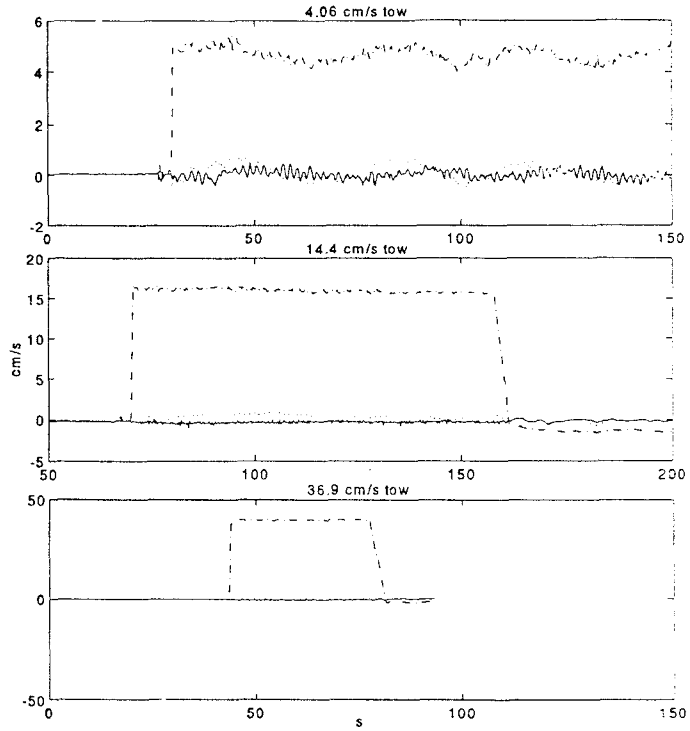

Fig. 7. Velocity output of current sensor towed at different speeds in strongly stratified water.

Any time strumming can occur, compliance of the current meter mount can influence current meter performance [5]. When strumming occurs, the measured velocity noise greatly increases. Our tests, however, have not found a measurable change in mean gain. Fig. 8. shows the results of towing, at different speeds, a vorticity sensor measuring velocity [4]. The largest structure in the sensor is a long cylinder with a diameter of about 3.8 centimeters. The top graph shows the mean measured velocity along the direction of carriage motion, velocity across tank, and vertical velocity while the lower graph

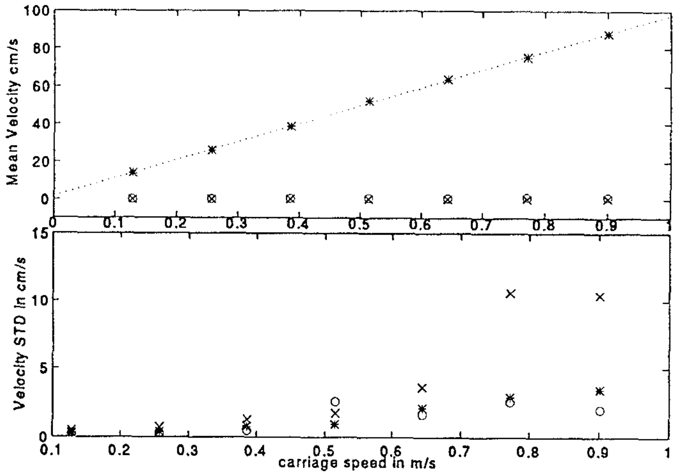

Fig. 8. Mean velocity output in top graph. Velocity noise in lower graph.

shows the standard deviation of velocity in these directions for these tows. Since the tows were through still water, the lower graph measures velocity noise. Above 0.6 meters per second carriage speed, the sensor mount started to strum, and above 0.75 meters per second, the strumming was very strong. The lower graph shows the big jump in velocity noise perpendicular to the long cylinder. The upper graph, however, shows no significant change in velocity gain along the flow direction. As the drag coefficient of a cylinder can triple in strong strumming, it was not anticipated that the velocity gain would stay constant. If a current meter is mounted on a strumming mooring, it is doubtful that turbulence in the frequency range of the strumming, will be measurable. To calibrate the velocity-noise level of a current meter in a strumming environment, the strumming also must be reproduced.

CONCLUSIONS

Tow tanks are handy for calibrating current sensors. The water, however, is not perfectly still. The operator must wait for the tank water to settle down between runs. The parameters of surface proximity, stratification, and mount compliance or motion need to be the same for a careful calibration. Production of waves should be avoided in the tank as waves can take longer to dissipate than wakes. Finally, the temptation to tow slowly should be resisted unless required; the proportion of noise increases and the results are more sensitive to stratification.

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