DEVELOPMENT OF A MODULAR ACOUSTIC VELOCITY SENSOR

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***Abstract*- We are developing a Modular Acoustic Velocity Sensor (MAVS), a three-axis current meter that measures the differential acoustic-travel time in a small measurement volume. The requirements of this sensor are: low cost, small size, high accuracy, good cosine response to current direction, lack of bias in a wave environment, ability to measure turbulence and the Reynolds stress, resistance to fouling, ability to measure near a boundary, and accuracy at low current speeds. The sensor is a derivative of the Benthic Acoustic Stress Sensor (BASS) which has been very successful at measuring currents, shear, and Reynolds stress. A first MAVS sensor prototype has been built and tested. The sensor was designed to reduce flow disturbance error when flows are steeper than thirty degrees from the horizontal.**

This paper describes performance measurements of the first prototype sensor. The sensor was towed in a tow tank to measure its accuracy and to characterize the vortex shedding noise inherent in any flow measurement made local to an ocean sensor. The first prototype was found to have better cosine response but more flow noise than BASS. A second prototype is now being built to have better cosine response than BASS and lower noise than the first prototype.

INTRODUCTION

This paper describes some aspects of the development of a small, low-cost current sensor. There is a need in the oceanographic community for a small, easy-to-use current sensor that can measure currents and turbulence. If the cost and size of the current sensor can be kept small enough, arrays of current sensors could be deployed to measure flow fields, not just the time series of current at one or two points. Measurement and understanding of organized structures, such as Langmuir cells, could benefit greatly from such an array. The requirements of this sensor are: low cost, small size, high accuracy, good cosine response to current direction (immunity to off axis flow and gain independent of attitude), lack of bias in a wave environment (no wave rectification), ability to measure turbulence and the Reynolds stress (the turbulent transfer of momentum), resistance to fouling (helped by no moving parts), ability to measure near a boundary, and accuracy at low current speeds (linear response through zero flow).

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We are developing a Modular Acoustic Velocity Sensor (MAVS), a three-axis current meter that measures differential-acoustic-travel time in a small measurement volume. The sensor is a derivative of the Benthic Acoustic Stress Sensor (BASS) which has been very successful at measuring currents, shear, and Reynolds stress (the turbulent transport of momentum)[1,2]. The goal of this development is to give oceanographers access to this technology in an affordable, easy-to-use form. A first MAVS prototype has been designed, built and tested. The sensor was designed to reduce the amount of labor required in its manufacture compared to a BASS sensor, and was designed to reduce flow disturbance error when flows are steeper than thirty degrees from the horizontal.

BASS has been a very successful development system. A BASS is a complete measurement system with three-axis velocity measuring sensors, compass, tilt meters, a data logger, and often some additional sensors of pressure, temperature, and turbidity. The BASS electronics are very sensitive and linear through zero flow with a forty picosecond electronic noise in measuring differential travel time and a 0.3 millimeter per second velocity resolution. The flow measurement has instantaneous response to velocity fluctuations making it ideal for measuring turbulence. There is no propeller that needs to be accelerated. A BASS sensor is pictured in Fig. 1. Acoustic current sensors are more resistant to fouling than mechanical current sensors.

In the development of a MAVS sensor, we wanted to improve three aspects over BASS; cost, zero offset changes, and cosine response to steep flows (flows more than thirty degrees above or below the horizontal). A BASS sensor requires a great deal of labor to build, thereby making it expensive. The MAVS sensor requires fewer labor-intensive potting steps of molding the

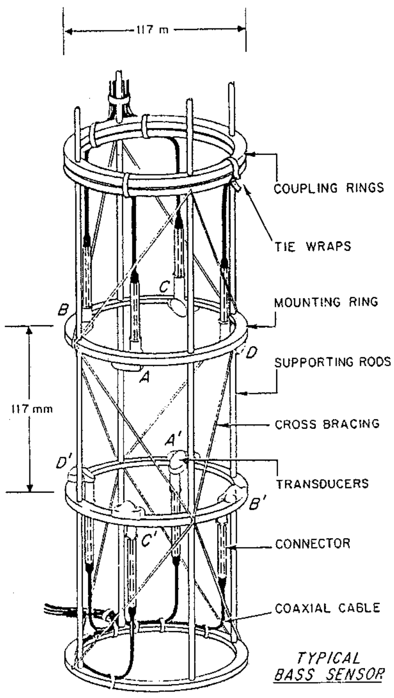

Fig. 1. Typical BASS sensor showing acoustic transducers, braced frame, and external electrical cables.

transducers and cables in polyurethane. MAVS is only a single velocity sensor that outputs a serial data stream to a user-supplied logger. Cable flexing effects the zero offset of the velocity measurements by slightly changing the cable capacitance [3]. When the cables are flexed or retied, the zero offset typically changes by one-third to one-half centimeter per second. In past BASS deployments, careful calibrations of the zero offsets are typically done after all the cables have been secured. The MAVS sensor uses internal wiring that does not flex and its zero offset should not change as much, avoiding the need to recalibrate the zero offsets.

The BASS sensor has been measured to have good cosine response for horizontal flows but imperfect cosine response for steep flows. Cosine response measures sensitivity to off-axis velocity and any changes in sensor gain with attitude relative to the flow. An ideal sensor measures the undisturbed flow which is independent of sensor attitude. The rings in the BASS sensor appear to partially obstruct flow that is steep causing the sensor to measure less than the undisturbed flow, when the flow is more than thirty degrees from the horizontal.

The first MAVS prototype was designed, built, tested, and is pictured in Fig. 2. It has internal, rigidly fixed

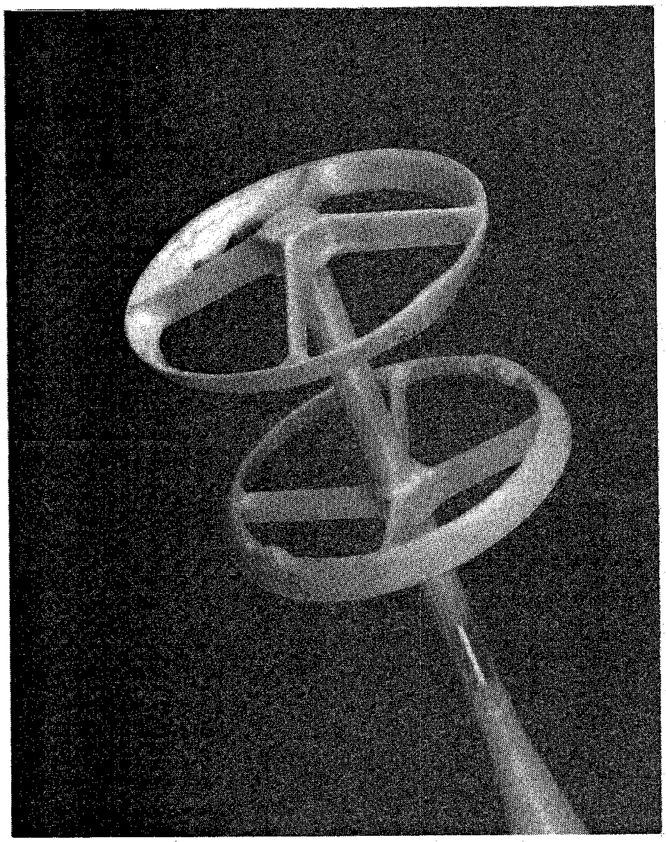

Fig. 2. First MAVS prototype sensor showing internal wiring,and streamlined cross sections for steep flows.

wires to reduce zero-offset changes. The structural rings holding the acoustic transducers have streamlined cross sections to reduce drag when the flow is forty-five degrees from perpendicular to the central tube, to reduce flow obstruction at this attitude, and to improve the cosine response. The geometry is simpler to make, as larger pieces of the sensor are moldable, to reduce labor and cost of production. The prototype uses four acoustic paths of ten centimeters to reduce sensor size, and is operated by modified BASS electronics. The central tube is large to allow use as the tension member in a mooring. The production version will use surface mount technology electronics to reduce the sensor electronics case size.

SENSOR PERFORMANCE CONSIDERATIONS

Error sources for an acoustic travel time current meter include:

·time average flow obstruction from wakes,

cosine response
- time varying disturbance from wakes, vortex shedding
- potential flow disturbance
- zero offset bias
- electronic nonlinearity
- electronic noise

These error sources have been described by [4,5]. The electronic noise is small with a standard deviation of 0.5 millimeters per second for the ten centimeter acoustic pathlength. Electronic nonlinearity is described in [6] and is less than 1.5 percent. Zero drift was described earlier in this paper and is reduced by rigidly securing the transducer cables. This paper focusses on degradation of velocity measurements caused by the various flow disturbance induced errors of the prototype sensor, and compares these to BASS. The prototype was towed through still water in a tow tank at various attitudes to measure the sensor's cosine response, linearity, and flow noise.

Vortex shedding from bluff structural members is a significant contributor to measured velocity noise. The dominant frequency of vortex shedding is given by

$$F_s \doteq \frac{0.2 \times v}{d} \qquad (1)$$

for cylinders [7]. F_s is the frequency in Hertz, v is the fluid velocity relative to the cylinder, and d is the cylinder diameter. Acoustic travel time measurement of flow velocity can be thought of as measuring a line integral of velocity along the acoustic path. If the acoustic path is downstream, and at an angle to the cylinder, the measured flow noise will scale with

$$velocity\ noise \propto \frac{v \times d}{L} \qquad (2)$$

In this equation L is the acoustic pathlength. If the structure upstream of an acoustic path is streamlined but stalled, its wake will also form a vortex street [8]. To reduce the measured flow noise associated with vortex streets caused by the sensor, the ratio of cylinder diameter to acoustic pathlength needs to be minimized. The pathlength can not be made large and still measure small scale turbulence. We want to minimize the cross-sectional thickness of the sensor structure that supports the acoustic transducers consistent with structural considerations of strength and stiffness to avoid Strouhal resonances. BASS uses a braced metal frame of small diameter rods to minimize flow noise, but this requires external electrical cables which are thicker than the structure cage rods. The BASS sensor has no undisturbed flow directions, but all horizontal flow directions are pretty good.

MEASURED SENSOR PERFORMANCE

This section compares the measured sensor performance of BASS and the first MAVS prototype for cosine response and flow noise. The MAVS and BASS sensor cages were towed through still water in a tow tank at many attitudes to measure the cosine responses. The symmetry of the sensors about the vertical axis (as shown in Figs. 1 and 2) requires the cosine response of each quadrant to be the same. Rotations of the flow about the vertical axis is called the longitudinal angle. The BASS sensor cosine response to rotations about the longitudinal axis is shown in Fig. 3 and MAVS in Fig. 4.

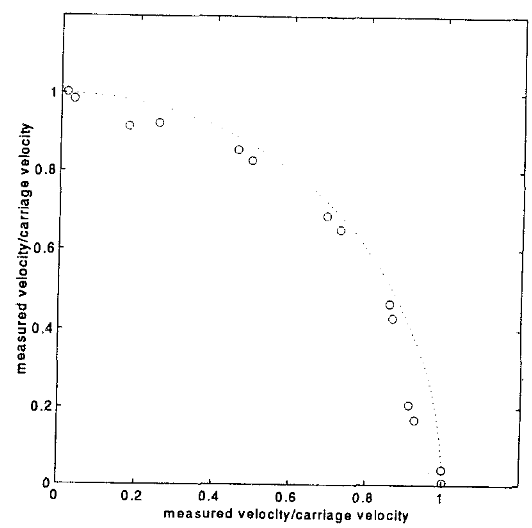

Fig. 3. BASS sensor cosine response to rotations about the longitudinal axis.

The longitudinal angle cosine response for both sensors is quite good. A typical BASS deployment on the ocean bottom sees mostly horizontal flows and its performance is good.

The measured cosine response of rotations about the axis perpendicular to both the longitudinal axis and the flow velocity, is shown for BASS in Fig. 5 and MAVS in Fig. 6. Rotations about the

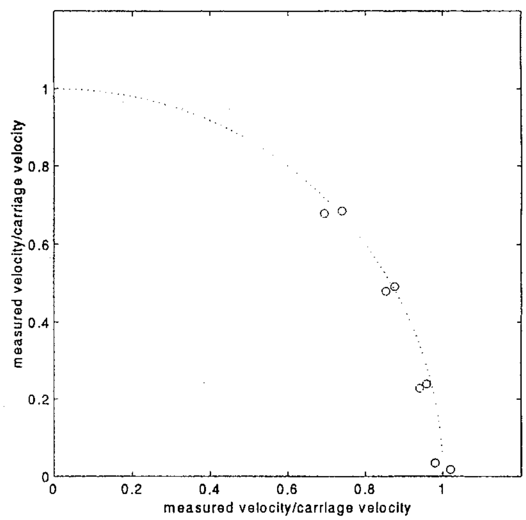

Fig. 4. MAVS sensor cosine response to rotations about the longitudinal axis.

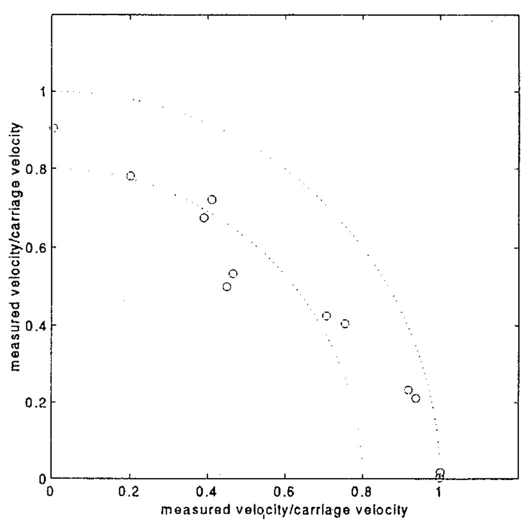

Fig. 5. BASS cosine response to rotations about the perpendicular axis.

third axis relative to the flow (the axis parallel to the flow velocity) has no effect. Rotations about the perpendicular axis is equivalent to varying the steepness of the current in Fig. 1. Again, due to the sensor symmetry about this axis only one quadrant needs to be plotted. The BASS cosine response to steep flows is thought to be impacted by the rings. Streamlining the rings for these steep angles in the MAVS sensor reduced the flow blockage and improved the sensor's cosine response.

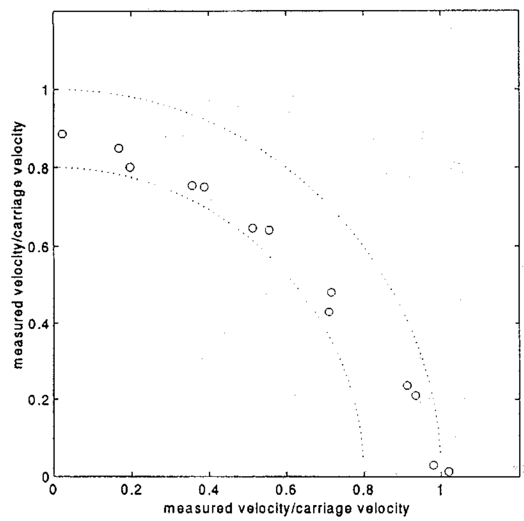

Fig. 6. MAVS cosine response to rotations about the perpendicular axis.

The measured flow noise for both BASS and MAVS is found to be largely linear with relative velocity, as expected. The noise levels of both sensors are plotted as a function of tow-carriage velocity in Fig. 7. The first

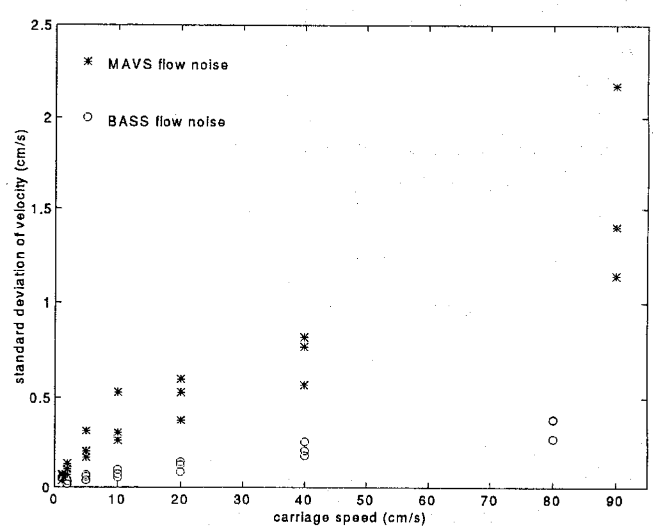

Fig. 7. Measured flow noise of BASS and MAVS sensors towed through still water.

MAVS prototype sensor has a larger cylinder-diameter-to-acoustic-pathlength ratio and its flow noise is much larger than BASS. The ratio of noise is consistent with the diameter over pathlength ratio of equation(2).

The power spectral densities of measured velocity, mutually perpendicular to the sensors' longitudinal axes and flow velocity, are shown in Fig. 8 for tows at two centimeters per second. The prominent noise peak frequencies for both sensors are consistent with equation (1) for vortices shed and the larger magnitude of the MAVS noise peak is consistent with equation (2). The MAVS spectral peak could be due to the wakes of both the central tube strut and the stalled streamlined rings. The wake frequencies from these two elements cannot be distinguished.

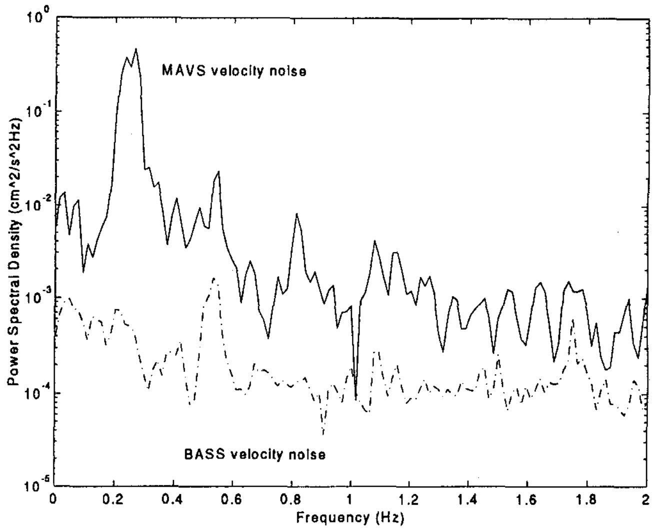

Fig. 8. Noise spectra of velocity in direction perpendicular to both tow velocity and axis of radial symmetry. Tows at two centimeter per second through still water.

CONCLUSIONS

The first MAVS prototype sensor was shown to have better cosine response to steep flow angles than BASS due to streamlining for these attitudes, but has much larger noise. Any acoustic travel time current meter, with a central strut large enough to take a mooring load, will not be good at measuring small scale turbulence due to its large ratio of strut diameter to acoustic pathlength. Streamlining a current sensor, if the user cannot control the sensor angle of attack, is problematic. The first prototype has too much flow noise to excel at measuring small scale turbulence.

FUTURE WORK

We are currently building the second MAVS prototype sensor with thinner structural members and of a geometry similar to BASS but with internal wiring. The rings have circular cross sections and smaller transducers than BASS. The acoustic pathlength was returned to the larger fifteen centimeters to reduce flow noise. We anticipate that the second MAVS prototype will have a better cosine response to steep flows than BASS, less flow noise than the first MAVS prototype, be less expensive to produce than BASS, and not need zero offset recalibration for normal use.

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