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Modular Acoustic Velocity Sensor - A Commercial Prototype

Measurement requires instrumentation but oceanographic research often is done with prototype instruments since the measurement produced by that instrument reveals processes that have general validity and only a few copies of the instrument will ever be needed. Sometimes, the measurement must be made frequently and in many places so that a production run of instruments is required. Commercial production is then appropriate. Successes in commercial transitions of instruments include the CTD, XBT, rosette sampler, and ADCP. These each produce measurements required by many research scientists, environmental engineers, and mission agencies including navies. The transition of a research tool to a commercial instrument is unfamiliar to most academics and is not always rewarding professionally or financially. But the correct solution to many measurement problems requires just such a transition to reduce the cost, increase the availability, and improve the reliability of the instrument in question.

The Benthic Acoustic Stress Sensor, BASS, developed from 1978 to 1981 and refined and improved continuously to 1996 became a candidate for such commercial production in 1993 as a result of NSF support to develop the instrument as a 3-D modular acoustic velocity sensor with manufacturability as well as measurement excellence the development target. Electronically, BASS was nearly ready for this transition, simply requiring updating of obsolete components and miniaturization through migration from DIP to surface mount packages. Several stages of board condensation occurred during the period of development, simplifying the miniaturization task. This resulted from improvements in FETs permitting elimination of the 12 volt logic level (FETs can now be switched with 5 volt levels where 12 volts was required formerly) and four layer boards that increased component density. But the real problem was the optimization of the sensor head, the flow intrusive element.

An excellent acoustic current meter has good cosine response in the vertical as well as in the horizontal. This means that flow at speed s measured with an acoustic axis at an angle θ to the flow direction should give a reading of $s*\cos(\theta)$ or, more generally, the resolved velocity vector from an array of acoustic axes should reflect the angle of the flow direction with respect to the principal coordinate axes of the sensor - u, v, and w - with $u=s*\cos(\theta)*\cos(\varphi)$, $v=s*\sin(\theta)*\cos(\varphi)$, and $w=s*\sin(\varphi)$ where φ is the angle of elevation of the flow direction from the horizontal plane and θ is the angle of the projection of the flow direction on the horizontal plane from the u direction. The $\cos(\varphi)$ part is the vertical cosine response. This is generally hard for a sensor to achieve if it has been optimized to have a good horizontal cosine response, the $\cos(\theta)$ part. To make a commercial instrument with wide utility, good response to both planes of rotation are desirable. Furthermore, the sensor should be free of cabling problems (zero offset dependent on cable dressing) and should be readily manufacturable. This seemed to be the place to start the development effort. The last well characterized current meter was the Davis-Weller VMCM and a commercial current meter to replace it should have equally well characterized response. Small, free of flow noise, cable tension carrying, robust, free of fouling, water proof, pressure insensitive, temperature insensitive, uv insensitive, and cheap were all characteristics desired if possible as well.

The freedom from sensitivity to cable dressing mandated that the conductors be buried in the sensor itself and potted through to the instrument housing. Mooring cable tension carrying required that a cage surround the sensor to carry tension or that the sensor have a tension carrying member pass through the center. Most of the other desired properties could be achieved by having the sensor injected plastic but there were stiffness constraints that were uncertain without metal or at least glass or graphite fiber in part of the sensor. While these constraints suggested a central strut of metal with injected plastic for the transducer supports, the requirement of good vertical cosine response meant that the transducers must be very small or the supports faired or both. The MAVS I prototype sensor is faired along the direction of the acoustic axis since only in that direction of flow is there a flow distortion problem. The transducers are small, 5 mm diameter for MAVS I vs 10 mm for BASS. The path length is 9.5 cm vs 15 cm for BASS. The transducers are glued into the plastic injected rings and the wires are run along the ring and covered with the same material as the transducers. There is still some problem getting a pressure resisting and water proof seal where the wires enter the central steel strut. But the vertical cosine response is good, within 15 % of perfect at its worst near 45º elevation. The cost of this benefit is that at all angles of flow, the wake of the sensor is greater because of the projected area of the fairing. This wake increases the flow noise fourfold over BASS at every speed. The cost of a cable tension carrying sensor with good vertical cosine response is a degradation of turbulence sensing capability.

The next target, after manufacturability of the sensor, was cost. Cost scales surprisingly well with volume. Since complexity remains as size is reduced, one might think that cost would remain fixed but it isn't so in commercial devices at large volumes of production. Parts costs decrease somewhat as component size decreases to a point. But the savings really result from handling, stocking, shipping, deployment, and lab bench costs where they scale with volume (or sometimes with weight). Logistics are a dominant part of the cost of medium scales of production and these are reduced if the devices are small. So miniaturizing MAVS was a target. Presently, the MAVS I design using standard BASS electronic circuits with DIP ICs is on a single four layer circuit card 11 1/2" long by 3 1/4" wide and there are few wire connections, only those to the transducers and the outside world. Construction of the board is about equal in difficulty to one of the harder boards of conventional BASS. Circuit costs are thus modest. Housing costs are again proportional to volume and the volume is 1/4 that of a conventional BASS (1/8 that of an earlier BASS). Closure of the housing and integration of the sensor to the housing is a concern and simple, corrosion free endcap retainers have been sought. Plastic may be the housing of choice for freedom from the requirement for surface treatment but aluminum is also satisfactory.

All prototype instruments and most limited production instruments require the user to be trained. In fact, the single major cost in such instruments is customer support by engineers. Part of this is customizing, part is training, and part is hand holding through early stages of familiarization with the instrument. Integrated circuits at $1.00 each are complex but have no customer support, only a data sheet. To reduce or eliminate the major cost of engineering support and customer service, the instrument must be simply described with a data sheet and must be primitive in its operation with fewer bells and whistles than a Timex watch. This means that the program running in MAVS must be what nearly every user can live with and must be easy to understand. The modular concept prevails here. A module can be used in a more complex system that is customized to the users need but itself is primitive. MAVS may simply spit out four digital words representing u, v, w, and θ. Alternatively, a second version may spit out five digital words including φ (tiltmeter added). This could be done every time a line to the MAVS is strobed or could be continuous at 10 Hz for the time the line is held high. Battery and logger are not included and this simplifies the engineering support. Power is low and tolerant, 5 ma at 14 to 25 volts while measuring, 2 ma standby, 0 ma if power is removed and comes on line 2 seconds after power is restored. This is almost so simple that no phone number need be supplied, just like an IC.

The part that is furthest from the academic subject of instrumentation is marketing. Yet there is a transition in manufacturing technique and thus cost between the 100 unit batch and the 1000 unit batch. I suspect there are other breaks near 100,000 and 10 M but I don't expect to learn about them. To move to the 1000 unit batch, marketing must be done. This involves confidence building, exposure, preparation of the marketplace, salesmen, advertising, and careful pricing. This is so far from most academics' experience that a commercial partner or licensee is desirable. Confidence is built by getting prototypes into the hands of knowledgeable and critical users who will certify a good instrument to their colleagues. Exposure requires that user communities see results derived from the instrument. Trade shows, technical magazines, and international expositions are opportunities to prepare the marketplace for a new product before it is being manufactured in commercial quantities. MAVS I, a commercial prototype is being shown at the General Oceanics booth at Oceanology International in Singapore in May 1997 and is being offered in response to a request for bid by a group of Korean customers who want a direct reading acoustic current meter. This is hoped to prepare the marketplace. G.O. has an international sales network so that when interest is generated in one sector of the market, the instrument can be sold in other markets soon after. As orders permit the batches to become larger, the cost may (or may not without care) drop and the price can be reduced. At this point, I will have achieved my goal of providing a new measurement capability, modular current sensors by the sixpack. Then benthic storms can be tracked as weather is tracked on land. Drifting instruments can measure turbulence as they measure temperature now. Nets, AUVs, benthic cameras can be equipped with current sensors as easily as temperature or pressure sensors. Inlets, streams, sewers, even large tanks can be instrumented with flow sensors to monitor fluid movement. Sloshing in aircraft fuel tanks can be detected. A good current meter is just over the horizon.