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PRELIMINARY TESTS ON AN ACOUSTIC CURRENT METER DEVELOPED BY NEIL BROWN INSTRUMENT SYSTEMS INC

by

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This report describes the results of some tests made in the IOS towing tank on an acoustic current meter loaned for a short period by Neil Brown Instrument Systems Inc.

The principles on which the current meter is based are discussed in Lawson, Brown et al., 1976. Essentially, a measurement is made of the differential travel time of acoustic signals travelling with and against the fluid flow. There are a number of ways of achieving this. The present sensor operates in a continuous wave (c.w.) mode at about 1.6 MHz and detects phase difference. The use of a heterodyning technique (which preserves phase information) enables the measurement to be made at a low frequency (~ 30 Hz), with consequent advantage in reduced power requirement. The technique contrasts with that of direct measurement of transit time difference, adopted in the instrument described by Gytre (1975) which achieves a time resolution of 10^{-10} sec. Some tests on this sensor are described in Collar and Gwilliam (1977).

The appearance of the c.w. instrument loaned to IOS is shown in Figs. 1(a) and (b). The transducers are mounted on short arms projecting from a central housing and the acoustic path is directed via a reflector to minimize wake effects. The instrument, which is self contained and equipped with batteries for one year's continuous operation, is intended for use in a mooring line, the tension being taken by four titanium rods. Although the output is normally recorded internally as vector averaged N-S, E-W flow components, the instrument loaned to IOS allowed the voltage analogues of flow along the two current meter axes to be recorded externally. Thus, direction sensing (by fluxgate compass) is not included in the present measurements.

A number of tests - described below - were made in steady, near laminar flow conditions. Although less extensive than those described for the pulsed acoustic sensor (Gytre, 1975), due to lack of time, they have been conducted in an identical manner, and reference should be made to Collar and Gwilliam (1977) for experimental details. The reader is, however, warned against making direct comparisons of noise levels: the pulsed meter had a 10 Hz bandwidth defined by output filters, while the present instrument has a 1 Hz cut off. Another, but minor, difference is that all present measurements represent the mean of 300 samples at a 10 Hz rate, rather than the 200 samples taken previously.

Finally, since the tests were made we have become aware of a similar evaluation by Appell (1977) of three of these instruments. Our results are reasonably consistent with these.

RESULTS

Linearity at Constant Speed

The current meter was mounted in an upright position at the end of a vertical tubular spar, clamped to the towing carriage, and towed at constant speed. Runs were made with each axis aligned in turn along the tank. Vibration of the spar was insignificant at speeds below 1 m/sec. An unweighted linear regression has been applied to each set of data and the deviations from linearity are shown plotted against indicated carriage speed in Fig. 2. The actual outputs from the transverse axes, scaled by the appropriate calibration factor, also are plotted against towing speed in Fig. 3.

A separate set of measurements was made with the spar rotated by 45° to produce approximately equal outputs from each axis at constant speed. A similar treatment of these data yielded the residuals shown in Fig. 4.

The residual distributions in Figs. 2-4 show that the output from axis 1 is more consistent than that of axis 2. The reason for the erratic departures from linearity in axis 1 is not known, but it is thought to be associated with the current meter rather than the external buffer and logging system. (This was checked using a series of constant voltage inputs: departures from the regression line were within the equivalent of ±1 mm/sec).

In fig. 3(a) the output from axis 1 is indicative of the inaccuracy of alignment of axis 2 of the c.m. along the tank ($\sim 0.5^{\circ}$). With axis 1 aligned longitudinally (fig. 3(b)), axis 2 produces a positive output regardless of flow direction, further suggesting a fault condition in this channel. When flow is incident between the axes (Fig. 4) the distribution of axis 2 residuals is again erratic. Note also that there are differences in sensitivity between positive and negative flow directions. The reason for this is unknown.

Fluctuations occurred in sensor output at all speeds, but increasing generally with increasing speed. To indicate the degree of uncertainty thereby introduced in mean values, 95% confidence limits are shown in Figs. 2, 3, 4. The dependence of this 'noise' on speed is shown by plotting the standard deviations ($\sim$ 300 samples) in sensor outputs and carriage speed against mean carriage speed in Fig. 5. Note that the current sensor noise always exceeds a level attributable directly to fluctuations in carriage speed. The quantisation noise arising from the sampling method is small: 0.04 cm/s in the carriage speed determinations, and 0.07 cm/sec in each of the current meter channels. Residual flows also add uncertainty to the measurements. A settling time of 15-20 minutes was usually allowed between runs; this reduced uncertainty to an estimated ±3 mm/sec.

Azimuth response - directional response in horizontal plane with current meter mounted vertically

These measurements were made at 10° intervals at a speed of 20 cm/sec. As before, the mean of at least 300 samples was taken at each angle of incidence. The vector magnitude response is shown in Fig. 6, and the outputs for each axis as a function of incidence angle are compared with the ideal sine and cosine functions in Fig. 7. The variation of noise level with flow incidence angle is given in Fig. 8.

When testing the pulsed acoustic current meter, it had been found that the wakes from the reflector support cage had a significant effect in azimuth response and noise level. The present instrument has a similar form of construction but, surprisingly, shows no clear periodic changes in response attributable directly to flow obstruction by the tension bars.

Using expressions derived by Schlichting (1955), a rough calculation suggests that ~5% reduction in apparent sensitivity might be expected at azimuth angles of 45°, 135°, 225° and 315°.

There is, however, a correlation between angular position and noise level: minimum noise occurs when the axes are aligned either in or transverse to the flow direction. The maxima at intermediate positions are attributed to the wakes from the tension bars.

Tilt response

Measurements were made at 20 cm/sec with the instrument inclined to the vertical at angles between $\pm 30^{\circ}$. The tilt response is important since the instrument is generally not gimballed, but inserted directly in the mooring. Tilt angle was measured using a hand held inclinometer with an estimated settling accuracy within $\pm 2^{\circ}$. Two sets of observations were made: firstly with azimuth angle nominally zero; one axis was inclined along the tank but tilted through angle ϕ and should therefore read V $\cos\phi$. The other axis was therefore directed transversely and should give ideally zero output. The procedure was then repeated with the flow bisecting the angle between axes (i.e. azimuth = 45°). Both sets of results were normalised to the output at $\phi = 0^{\circ}$ and are plotted in Figs. 9(a) and (b) with the ideal cosine response for comparison. The plot also includes some points extracted from the tilt response documented by NOIC (Appell, 1977).

In both 9(a) and (b) the output appears to fall more rapidly than the ideal cosine when the instrument is tilted. For one direction of flow the data accord well with those of Appell. In the other direction, however, the NOIC response is closer to the cosine function.

Stability

Insufficient time was available to evaluate zero stability systematically. However measurements were made of the current meter output when the instrument had been stationary in the towing tank for periods exceeding twelve hours. Potassium permanganate dye was used to detect residual flow: this was $\lesssim 3$ mm/sec. The outputs from each axis are tabulated below.

Day No.	Axis 1 (mV)	Axis 2 (mV)
1	2.6±0.1	1.3±0.2
6	1.3	5.2
8	-4.8	-4.7

(4.08 mV = 1 cm/sec)

CONCLUSIONS

Lack of time has not permitted as comprehensive an evaluation as is desirable.

In particular, we would have liked to check the zero stability more thoroughly. On the evidence so far this appears marginal for a number of applications. Also, we have not been able to make any successful dynamic tests.

The linearity of the instrument is good if judged on the output of the better axis. A fault in the other axis may have produced increased scatter in output. Our measurements also show a departure from the vertical cosine response by <10% for tilt angles between $\pm 30^{\circ}$.

Overall the performance appears broadly comparable with that of the pulsed acoustic system prior to its recent modifications. At present, however, the c.w. sensor has one advantage in a lower power requirement.

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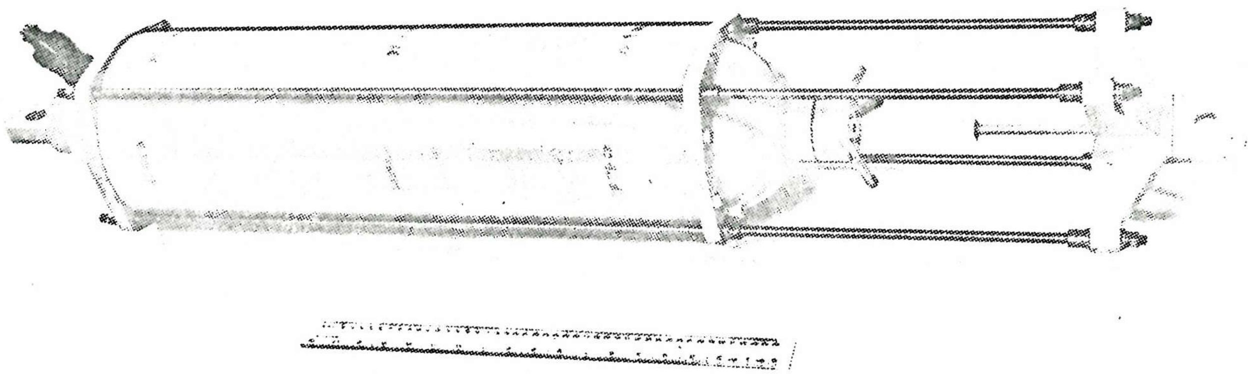

Figure 1. General view of current sensor.
(Acoustic path via reflector shown for one axis by broken line).

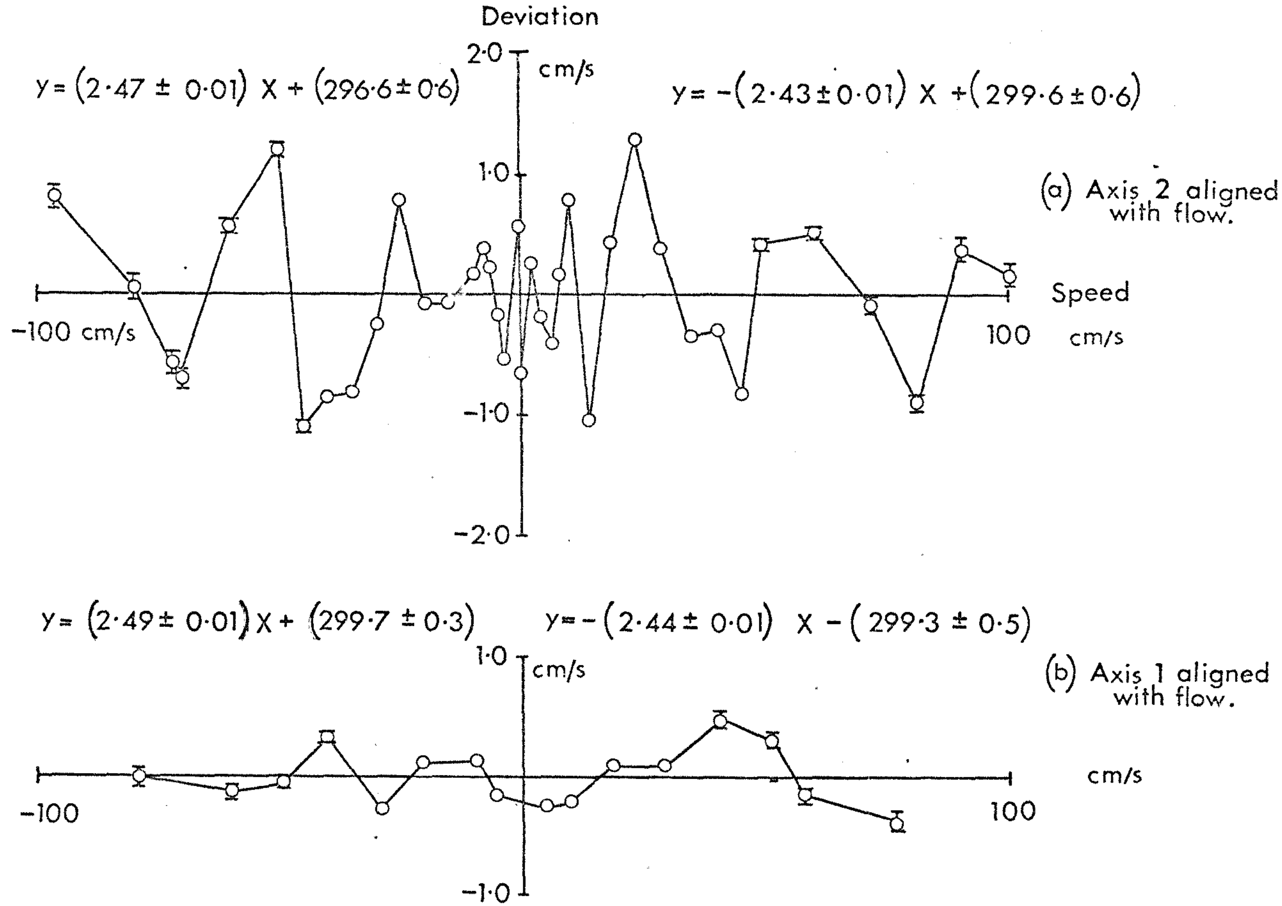

Figure 2. Deviation from linearity plotted against towing speed.

(a) Axis 1 in tow direction.

(b) Axis 2 in tow direction.

Note: Error bars denote 95% confidence limits (300 samples). Ordinate has been multiplied by fitted calibration factor to give cm/s units. Y is c.m. output expressed in arbitrary units. X is carriage speed in cm/s.

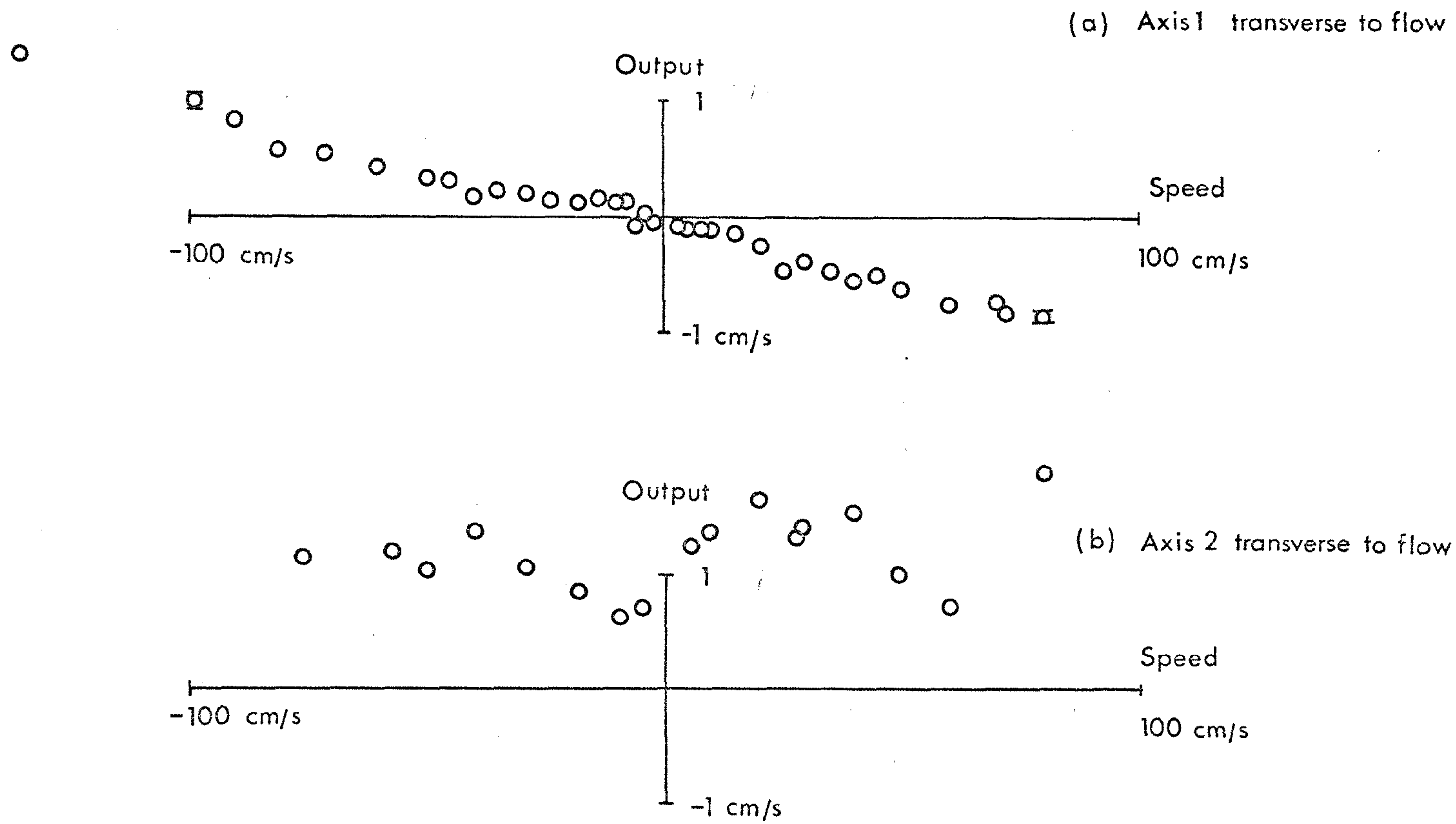

Figure 3. Outputs from transverse axes plotted against towing speed.
(a) Axis 1 transverse to flow.
(b) Axis 2 transverse to flow.

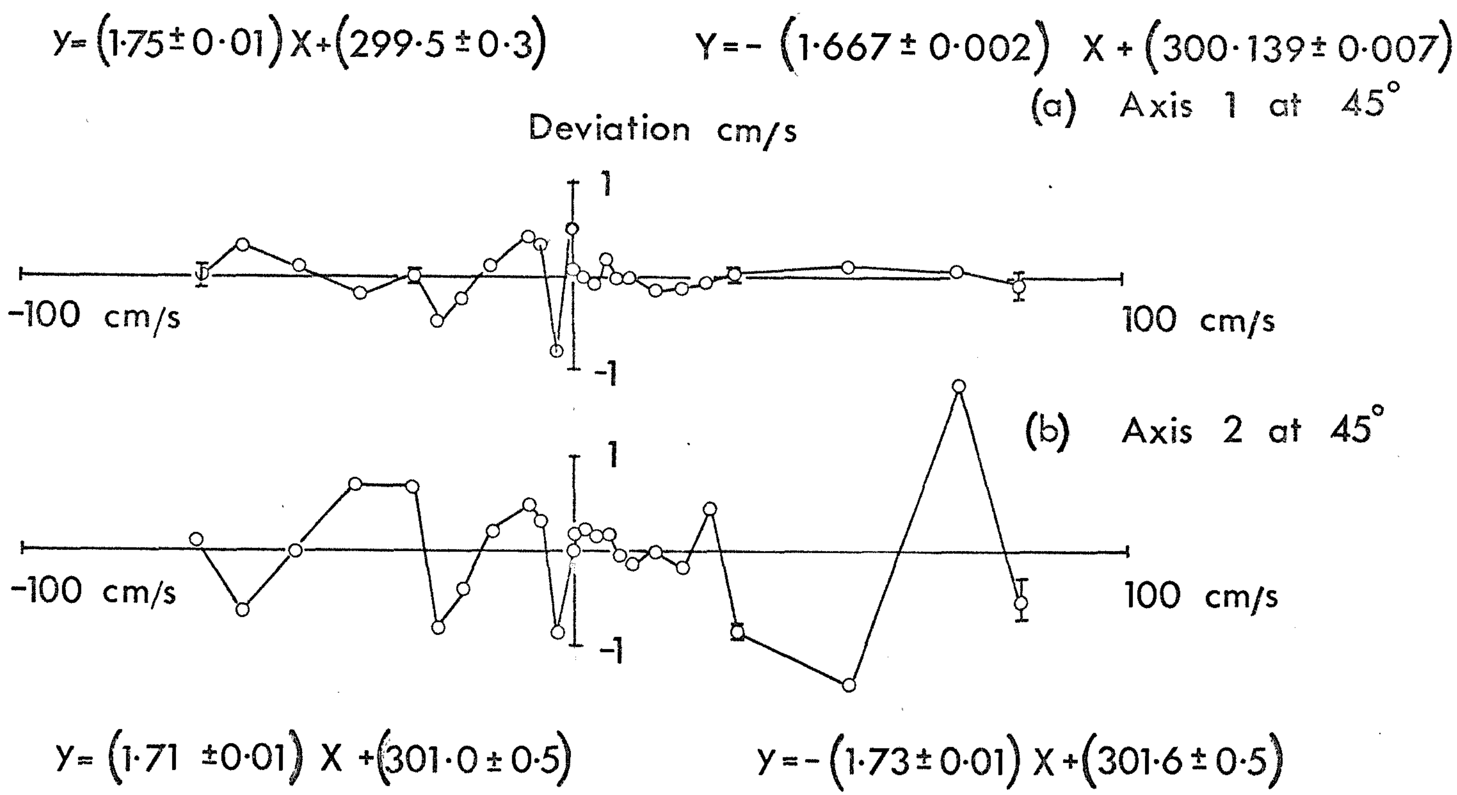

Figure 4. Deviation from linearity plotted against towing speed. Both axes aligned at 45° to towing direction.

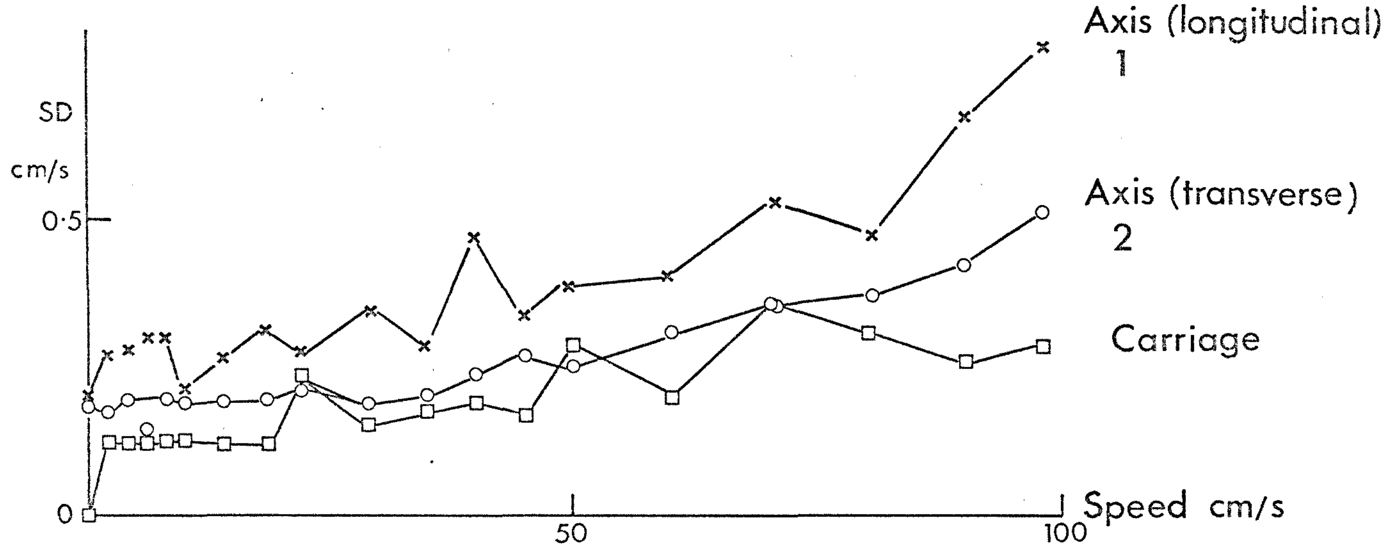

Figure 5. Variation of standard deviation of current sensor output with mean speed of tow.

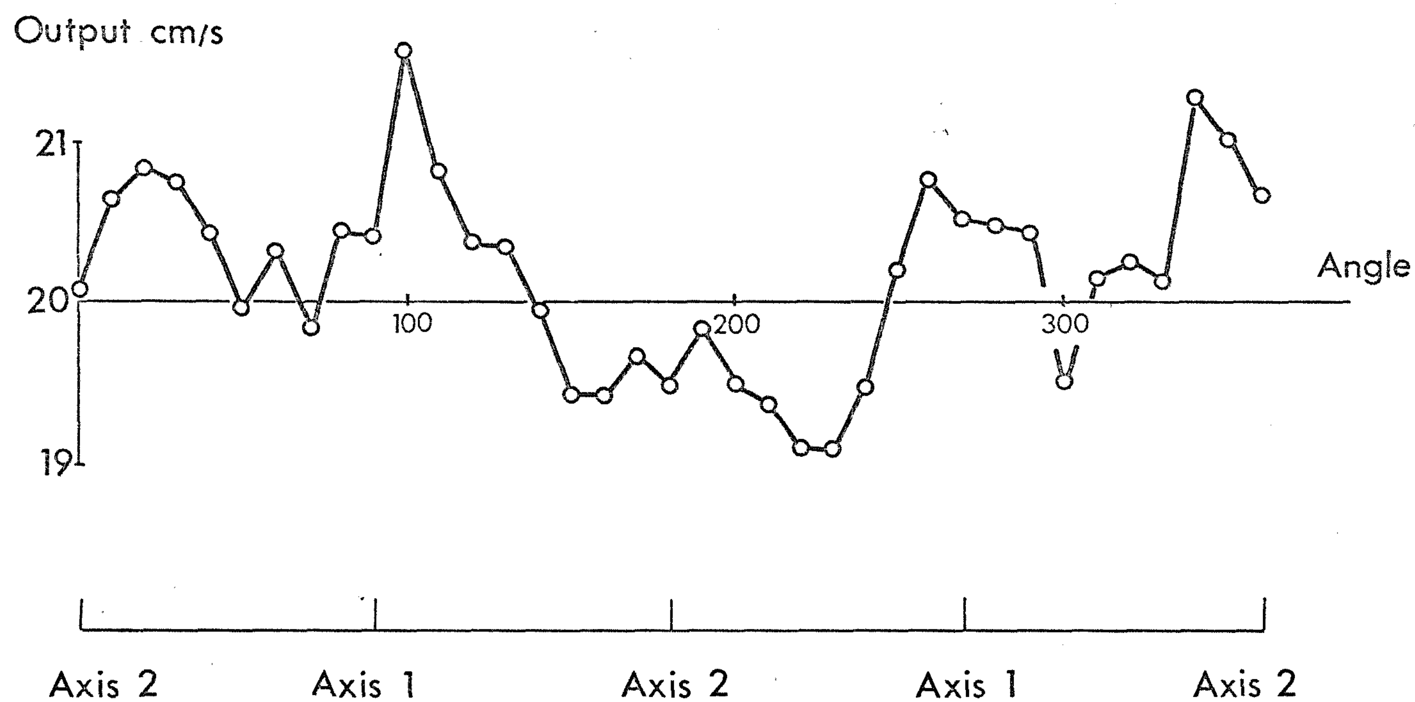

Figure 6. Response of vertically mounted current sensor to steady flow in horizontal plane at 20 cm/s. (Modulus of vector resultant of axes 1 and 2 outputs).
Axis 1 colinear with flow at 90°, 270°.
Axis 2 colinear with flow at 0°, 180°.
95% confidence limits are generally within size of plotted symbol.

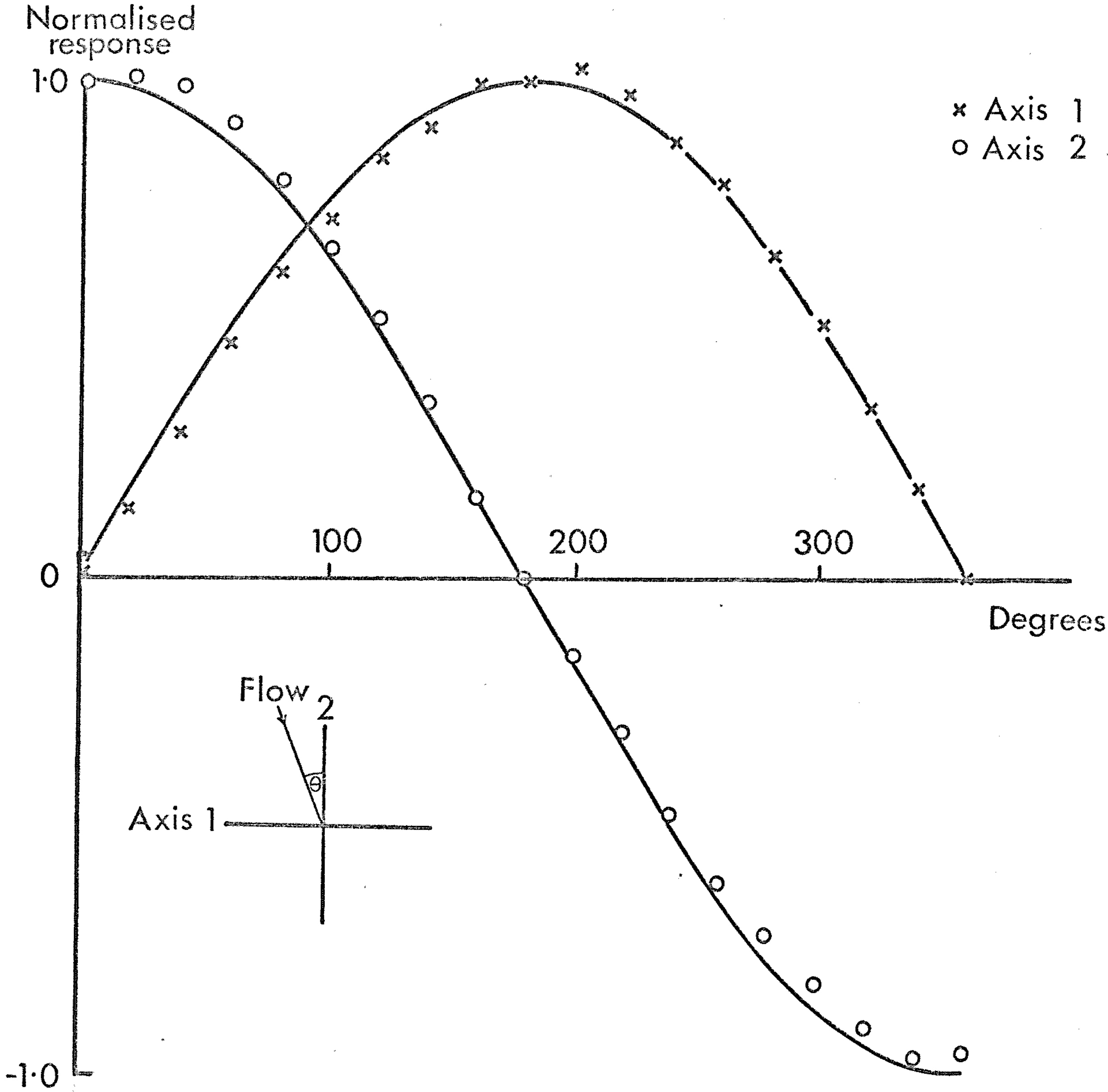

Figure 7. Axes 1 and 2 outputs plotted individually as functions of flow incidence angle in horizontal plane. Speed = 20 cm/s. Solid curves are sine, cosine functions.
95% confidence limits are generally of same order as size of plotted symbol.

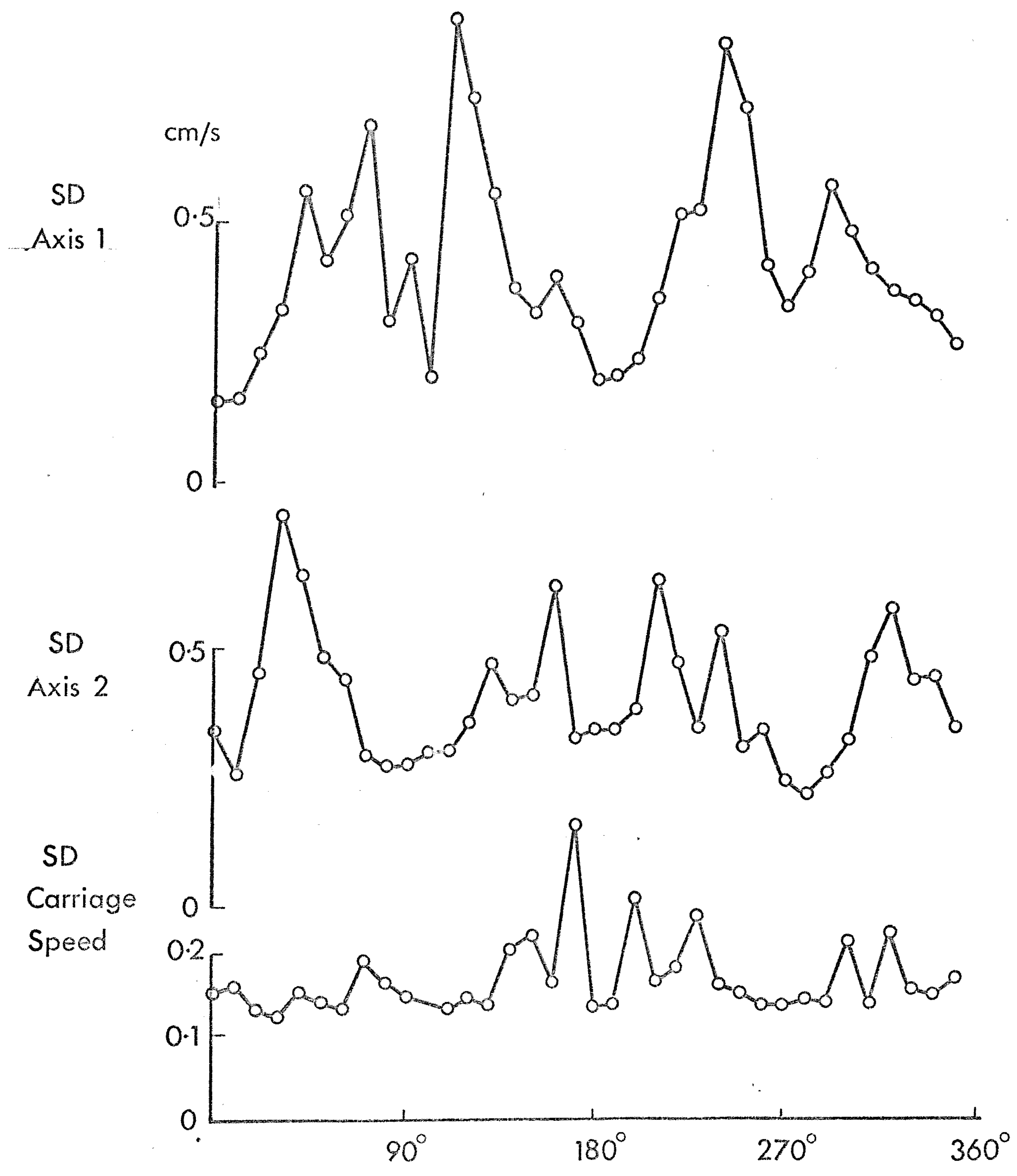

Figure 8. Standard deviations from mean outputs (figure 7) plotted against horizontal azimuth angle.

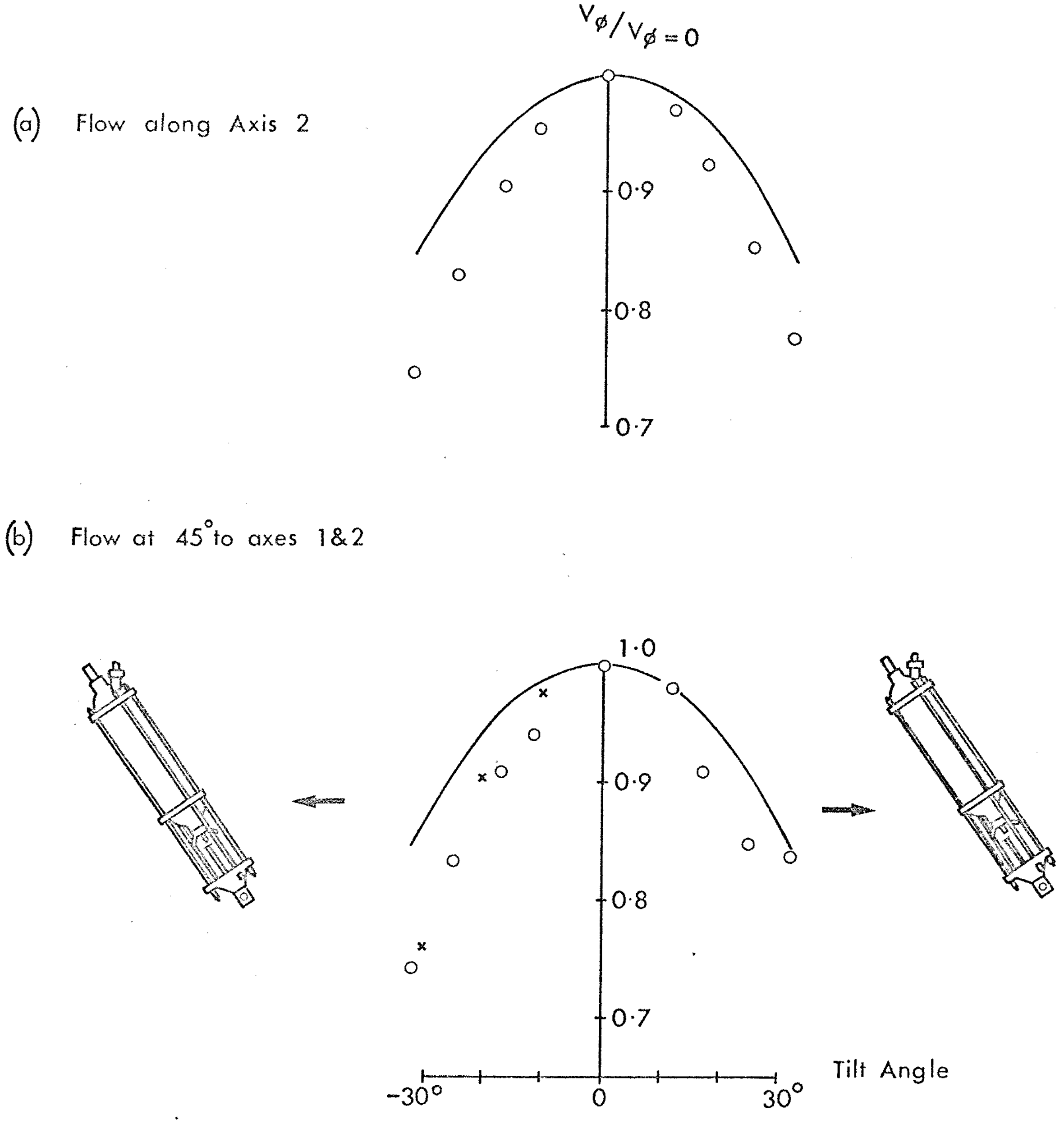

Figure 9. Response of towed current sensor tilted from vertical at a fixed angle, ϕ. Speed = 20 cm/s.

(a) Azimuth $\theta = 0^{\circ}$.

(b) Azimuth $\theta = 45^{\circ}$.

95% confidence interval generally lies within size of plotted symbol. In addition, uncertainty in residual flow contributes possibly ±0.03.

Solid line - ideal cosine response.

Open circles - measured response.

Crosses - points extracted from (Appell, 1977).