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RELATIVE PERFORMANCE OF THREE ACOUSTIC FLOW METERS

P. Engel, K. Wiebe and E. Fast

NWRI CONTRIBUTION 91-112

[Relative performances of three acoustic...

MANAGEMENT PERSPECTIVE

The Water Survey of Canada is pursuing a hydrometric instrumentation development program which will lead to enhanced automation of its data acquisition activities. Of the two main activities, the measurement of stage and discharge, the latter requires by far the larger amount of manual input. To reduce the requirement for human intervention in remote areas, the acoustic method of unattended flow measurement is being evaluated. Successful development of an acoustic flow meter for long term, unattended deployment, will produce significant savings in the national flow measurement program of the Water Survey of Canada. This report presents the results of the comparison of three makes of acoustic flow meters. The information provides important input for Water Survey of Canada in their meter selection process.

Dr. J. Lawrence
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PERSPECTIVE-GESTION

La Division des relevés hydrologiques du Canada poursuit un programme de mise au point d'instruments hydrométriques qui permettra d'accroître l'automatisation de ses activités d'acquisition des données. Parmi les deux grandes activités, la mesure du niveau et la mesure du débit, la dernière est celle qui de loin exige le plus de travail manuel. Afin de réduire l'intervention humaine dans les régions éloignées, la méthode acoustique automatique de mesure du débit est en cours d'évaluation. La mise au point d'un débitmètre acoustique en vue d'une mise en place automatique à long terme permettra de réaliser d'importantes économies au niveau du programme national de mesure du débit de la Division des relevés hydrologiques du Canada. Le présent rapport contient les résultats d'une étude comparative de trois marques de débitmètres acoustiques. Les informations obtenues sont importantes pour la Division des relevés hydrologiques du Canada pour le choix des appareils.

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SUMMARY

Tests were conducted on three different makes of acoustic flow meters. The relationship for the computation of flow velocity using the "time of flight method" was developed from theoretical considerations. Dimensional analysis was used to develop a dimensionless meter performance ratio K_m and this was found to be a function of the Mach number $\frac{V_c}{C}$ (V_c = the speed of the towing carriage, C = the speed of sound in water) only. Analysis of the test data shows that all three meters have an uncertainty in the mean value of K_m of less than 0.5% when $\frac{V_c}{C} > 7 \times 10^{-4}$. For Values of $\frac{V_c}{C} < 7 \times 10^{-4}$, the uncertainty in the value of K_m increases sharply for all three meters. For values of $\frac{V_c}{C} > 4 \times 10^{-4}$ the performance of all three meters tends to be virtually independent of the Mach number. When $\frac{V_c}{C} < 4 \times 10^{-4}$, the performance of the three meters is strongly dependent on the Mach number. The overall performance of the Affra meter is better than that of the Stork 1500 MMK1 and the Accusonic meters.

RÉSUMÉ

Trois marques de débitmètres acoustiques ont été soumis à des essais. Le rapport pour le calcul de la vitesse du débit à l'aide de la "méthode du temps de vol" a été établi à partir de considérations théoriques. L'analyse dimensionnelle a été utilisée pour développer un rapport de rendement adimensionnel K_m de l'appareil, et cette valeur est une fonction du nombre de Mach V/C (V_0 = la vitesse du chariot mobile, C = la vitesse du son dans l'eau) seulement. D'après l'analyse des données d'essai, on a relevé, chez les trois appareils, une incertitude au niveau de la valeur moyenne de K_m inférieure à 0,5 % lorsque $V_0/C > 7 \times 10^{-4}$. Pour des valeurs de $V_0/C < 7 \times 10^{-4}$, l'incertitude au niveau de la valeur de K_m augmente brusquement dans le cas des trois appareils. Dans le cas de $V_0/C > 4 \times 10^{-4}$, la performance des trois appareils a tendance à être pratiquement indépendante du nombre de Mach. Lorsque $V_c/C < 4 \times 10^{-4}$, la performance des trois appareils est fortement dépendante du nombre de Mach. La performance générale de l'appareil Affra est supérieure à celle des appareils Stork 1500 MMK1 et Accusonic. Les résultats des essais montrent que l'on peut obtenir à peu près la même précision avec des débitmètres acoustiques qu'avec des courantomètres de type Price.

TABLE OF CONTENTS

RELATIVE PERFORMANCE OF THREE ACOUSTIC FLOW METERS

by

P. Engel, K. Wiebe and E. Fast

INTRODUCTION

The Water Survey of Canada, through private industry, is in the process of developing a reliable, low power, low cost, ultrasonic flow meter to measure river discharge in remote areas. Tests on three newly developed prototypes of acoustic flow meters have been conducted in a towing tank jointly by the Water Survey of Canada and the National Water Research Institute (Engel, and Fast 1988; Engel, Fast and Wiebe 1990; Engel, Fast and Todd 1990). The data were used to compare the performance of the three meters in measuring the speed of the towing carriage. The results are presented in this report. The work was conducted in the Hydraulics Laboratory of the National Water Research Institute.

MEASUREMENT PRINCIPLE

The measuring principle applied is the "time of flight method" which has been successfully applied with many acoustic flow meter systems. In this method sound pulses are transmitted through the water between two opposing transducers, say A and C, in both directions as shown in Figure 1. Proper installation of the transducers allows the determination of the mean flow velocity at the elevation of the acoustic path, by measuring the travel times of the sound pulses moving in both directions along a path of known length and diagonal orientation to the flow as shown in Figure 1.

If the time of travel for the sound pulse from A to C is designated by t_{AC} and on the return from C to A by t_{CA} , then for zero flow one obtains

$$t_{AC} = t_{CA} = \frac{L}{C} \tag{1}$$

where: L = the length of the acoustic path in metres (m) and C = the velocity of sound in water which, depending on water temperature varies between 1400 m/s and 1500 m/s. If there is a flow as shown in Figure 1, the travel time of the sound pulse from A to C will be smaller than from C to A. These times are given as

$$t_{AC} = \frac{L}{C + V_A cos\theta} \tag{2}$$

and

$$t_{CA} = \frac{L}{C - V_A cos\theta} \tag{3}$$

where V_A = the flow velocity measured by the meter, θ = the angle of alignment of the transducers with the flow and L is the shortest distance between the transducers. These variables are shown in Figure 1. If one now assumes that the velocity of sound C is the same for both pulses, the flow velocity can be obtained from equations (2) and (3) as

$$V_A = \frac{L}{2cos\theta}[\frac{1}{t_{AC}} - \frac{1}{t_{CA}}] \tag{4}$$

The two sound pulses are transmitted simultaneously, thereby assuring transmission through water having the same temperature and thus the same speed of sound. The two transit times are individually measured using acoustic pulses with unique signatures. Each individual flow measurement is automatically computed and checked by a computer using the established values of L and θ. A measurement is rejected when the measured flow velocity or velocity of sound does not lie between predetermined upper and lower limits. Direct digitalization and the programming of "time windows" for the reception of the pulse signals greatly improves the reliability and accuracy of the measurements.

DIMENSIONAL ANALYSIS

The performance of a flow meter can often be best characterized by developing a performance coefficient, the behaviour of which can be used to compare different meters over their operating range. For a given flow meter, the measured time difference between acoustic pulses travelling in opposite directions Δt, should depend on the towing speed V_c, the length of the acoustic path L, the angle of orientation θ and the speed of sound in water C. This can be expressed in a functional form by writing

$$\Delta t = f[V_c, L, \theta, C] \tag{5}$$

where f denotes a function unique to a particular flow meter. Using the Buckingham Π theorem equation (5) can be written in dimensionless form as

$$\frac{\Delta t C^2}{2V_c L\theta} = F[\frac{V_c}{C}, \theta] \tag{6}$$

where F denotes another function unique to a particular instrument. The difference in the time of travel Δt can be expressed as

$$\Delta t = t_{CA} - t_{AC} \tag{7}$$

Combining equations (2), (3) and (7) and observing that $V_c << C$, one obtains

$$\Delta t = \frac{2LV_A cos\theta}{C^2} \tag{8}$$

By combining equation (6) and (8), after replacing θ with the equivalently valid parameter $cos\theta$, one obtains

$$\frac{V_A}{V_c} = F[\frac{V_c}{C}, cos\theta] \tag{9}$$

The dependent dimensionless variable in equation (9) can be considered to be the flow meter performance ratio, say K_m and the variable $\frac{V_c}{C}$ is the Mach number. Finally, K_m should be independent of the angle of orientation θ and therefore, the parameter $cos\theta$ can be removed from the function F in equation (9), resulting in the test relationship

$$K_m = F[\frac{V_c}{C}] \tag{10}$$

For an ideal flow meter, the value of K_m should have a value of 1.0. Any departure from this value of 1.0 is a measure of the performance of the flow meter and/or the effect of the environment in which the meter is operating.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Towing Tank

The towing tank used to test the meter is constructed of reinforced concrete, is founded on piles and is 122 metres long and 5 metres wide. The full depth of the tank is 3 metres, of which 1.5 metres are below ground level. Normally, the water depth is maintained at 2.7 metres. Concrete was chosen for its stability and to reduce possible vibrations and convection currents.

At one end of the tank there is an overflow weir. Waves arising from towed current meters and their suspensions are washed over the crest, thereby reducing wave reflections. Parallel to the sides of the tank perforated beaches serve to dampen lateral surface wave disturbances.

Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tonnes and travels on four precision machined steel wheels. The carriage is operated in three overlapping speed ranges:

0.005 m/s-.06 m/s
0.05 m/s-0.60 m/s
0.50 m/s-6.00 m/s

The maximum speed of 6.00 m/s can be maintained for 12 seconds. Tachometer generators connected to the drive shafts emit a voltage signal proportional to the speed of the carriage. A feedback control system uses these signals as input to maintain constant speed during tests.

The average speed data for the towing carriage is obtained by recording the voltage pulses emitted from a measuring wheel. This wheel is attached to the frame of the towing carriage and travels on one of the towing tank rails, emitting a pulse for each millimeter of travel. The accuracy of the measuring wheel is checked regularly by comparing its output over a distance of one meter against a calibrated metal bar, one metre in length (Quantum, 1981). Time is measured to an accuracy of 0.001% with a crystal clock which is calibrated with a standard clock at the National Research Council of Canada. Any errors in the computed towing carriage speed due to the measurement of time are therefore insignificant. The pulses and measured time are collected and processed to produce an average towing speed with a micro computer data acquisition system. Analysis of the towing speed variability by Engel (1989), showed that for speeds between 0.2 m/s and 3.00 m/s, the error in the mean speed was less than 0.15% at the 99% confidence level. Occasionally, these tolerances are exceeded as a result of irregular occurrences such as voltage "spikes" in the data transmission system of the towing carriage. Tests with such anomalies are automatically aborted.

Transducer Suspension and Alignment

Each of the three meters was tested by suspending the two transducers with cylindrical rods, having a nominal diameter of 2.54 cm (1"), attached to the end of a cantilevered beam which was clamped to the deck of the towing carriage as shown schematically in Figure 2. The transducers were set at a depth between 0.5 m and 0.7 m which was sufficient to avoid any surface effects while at the same time minimizing the drag on the vertical suspension rods. The drag on the rods was further reduced by fitting plastic fairings over the submerged lengths. The beams and suspension rods were sufficiently braced to keep mechanical vibrations at a minimum. The test set-up shown in Figure 2 resulted in a suitable alignment of the transducer pairs for each flow meter. The towing carriage with a typical test set-up is shown in Figure 3. Data for the test conditions for the three flow meters are given in Table 1. The suspension configurations are within the operating limits of the meters and do not affect their performance.

Test Procedure

The test procedure consisted of towing the suspended transducers through the water at pre-set constant speeds. As the towing carriage traveled along the tank, pairs of acoustic pulses were collected continuously with the corresponding flow meter's data acquisition system. Tests were conducted at towing speeds of 0.2 m/s, 0.6 m/s, 1.00 m/s, 1.60 m/s, 2.00 m/s, 2.60 m/s and 3.00 m/s. Values of V_A and V_c were computed, the water temperature recorded and values of the speed of sound C obtained from standard tables.

All tests were conducted so that sampling of the acoustic pulses always began when the carriage passed the same pre-determined location in the towing tank in order to keep all characteristics unique to the towing carriage system constant. The tests were always made after sufficient time, usually from 4 to 10 minutes, had passed to allow disturbances in the water to subside. At the end of the waiting period the typical average measured residual velocity was of the order of 0.005 m/s and the general direction was toward the head end of the tank (ie: opposite to towing direction). This meant that the meter would sense the towing velocity plus the net residual velocity. Several tests with potassium permangenate crystals dropped into the stilled water, while the towing carriage was at rest, confirmed this behavior.

Ten tests, at the selected towing speeds, were conducted on one of each of three makes of flow meters; the "Affra", the "Stork 1500 MMK1" and the "Accusonic" by Engel and Fast (1988), Engel, Fast and Wiebe (1990) and Engel, Fast and Todd (1990) respectively. Values of $\overline{K}_m$ and $\frac{V_c}{C}$ were computed and are given in Tables 2, 3 and 4. The mean of K_m was used as the performance indicator to ensure that towing tank effects were kept to a minimum.

DATA ANALYSIS

Mean Performance of the Flow Meters

The behaviour of the flow meters was examined by plotting values of $\overline{K}_m$ as a function of $\frac{V_c}{C}$ in Figure 4 in accordance with the principles embodied in equation (10). The plotted points were connected by straight lines to facilitate the analysis. The plot shows that for $\frac{V_c}{C} > 4 \times 10^{-4}$, the Affra meter gives by far the best results because its values of $\overline{K}_m$ are virtually equal to the ideal value of 1.0. Over the same range of $\frac{V_c}{C}$, the Stork meter tends to consistently-under estimate the true velocity by 1% to 1.5% and the Accusonic meter under-estimates the true velocity by 2% to almost 3%. Considering that tests procedures were the same for all three meters, the difference in the mean performance must be attributed to the meters themselves. For values of $\frac{V_c}{C} < 4 \times 10^{-4}$, the performance of all three meters is very dependent on $\frac{V_c}{C}$. This sensitivity of $\overline{K}_m$ to $\frac{V_c}{C}$ suggests that at very low velocities, the difference in the time of travel of the acoustic pulses, as given by equation (7), may be sufficiently small to cause some difficulties for the instruments in resolving the velocities V_A. Efforts should be made to conclusively determine the reasons for the meters' behaviour at velocities less than 0.6 m/s (ie: $\frac{V_c}{C} < 10^{-4}$).

Uncertainty in the Mean Value of the Meter Performance Ratio

The true mean of the meter coefficient K_m at each towing velocity can be expected to lie within the range

$$\mu_K = \overline{K}_m \pm \frac{t_K S_K}{\sqrt{n-1}} \tag{11}$$

where μ_K = the true mean value of K_m, $\overline{K}_m$ = the mean of n tests, t_K = the confidence coefficient from Student's "t" distribution at $(n-1)$ degrees of freedom (Spiegel 1961), S_K = the standard deviation and n = the number of tests at a particular velocity for a given meter (ie: n = 10). Equation (11) can be made dimensionless by dividing both sides by $\overline{K}_m$. In addition, by noting that the coefficient of variation, say, $C_{vK} = \frac{S_K}{\overline{K}_m}$, one obtains

$$\frac{\mu_K}{\overline{K}_m} = 1 \pm \frac{t_K C_{vK}}{\sqrt{n-1}} \tag{12}$$

The quantity $\frac{t_K C_{vK}}{\sqrt{n-1}}$ in equation (12) represents the relative uncertainty in the mean of the meter performance ratio obtained for n different calibrations of the same meter and is expressed as

$$E_m = \frac{100 t_K C_{vK}}{\sqrt{n-1}} \tag{13}$$

where E_m is the relative uncertainty in the mean of the performance ratio of a particular meter at a given velocity in percent. Values of E_m at the 95% confidence level were computed for each flow meter and are given in Tables 2, 3 and 4. The original data are too extensive to be included in this report and can be obtained upon request.

It has been shown in equation (10) that K_m is a function of the Mach number $\frac{V_c}{C}$. Similarly, E_m can be expressed in a similar functional form as

$$E_m = \Phi[\frac{V_c}{C}] \tag{14}$$

where Φ is another function.

Values of E_m were plotted as a function of $\frac{V_c}{C}$ for all three flow meters in Figure 5. The plotted points were again connected by straight lines to facilitate the analysis. The plot shows that for values of $\frac{V_c}{C} < 7 \times 10^{-4}$, values of E_m decrease rapidly for all three meters as $\frac{V_c}{C}$ increases. The Stork meter has the largest values of E_m and exhibits the greatest rate of decrease. The Affra meter has the second highest values of E_m but only slightly greater than those of the Accusonic meter with their rate of decrease being quite similar but less than that for the Stork meter. In the range $7 \times 10^{-4} < \frac{V_c}{C} < 11 \times 10^{-4}$ the rate of decrease in E_m is very small for all three meters a $\frac{V_c}{C}$ increases. Once again the values of E_m are greatest for the Stork meter while for the other two meters these values are virtually equal but slightly lower. Finally, for $\frac{V_c}{C} > 11 \times 10^{-4}$, the behaviour of the Stork and the Accusonic meters is quite similar with values of E_m tending to increase gradually as $\frac{V_c}{C}$ increases. In contrast to this, values of E_m for the Affra meter tended to decrease gradually as $\frac{V_c}{C}$ increased to about 17×10^{-4} and then increased again gradually with further increase in the Mach number.

In general, all three meters had an uncertainty in $\overline{K}_m$ of less than about 0.5% for $\frac{V_c}{C} > 7 \times 10^{-4}$, with the Affra meter giving the lowest values and therefore the best results. However, for $\frac{V_c}{C} < 7 \times 10^{-4}$, all three meters exhibited considearble uncertainty in $\overline{K}_m$ and this increased sharply as $\frac{V_c}{C}$ decreased, to values in excess of 2.4% for the Stork meter, 1.3% for the Affra meter and 0.9% for the Accusonic meter at $\frac{V_c}{C} \cong 1 \times 10^{-4}$. Efforts should be made to improve the performance of the acoustic flow meters at velocities less than 0.6 m/s.

CONCLUSIONS

Carefully conducted tests on three different makes of acoustic flow meter have given rise to the following conclusions:

The performance of the three flow meters is virtually independent of the Mach number for values of the latter greater than 4×10^{-4}.

For values of the Mach number greater than 4×10^{-4} the Affra meter tends to give perfect results, whereas the Stork meter tends to under- estimate the true velocity by about 1% to 1.5% and the Accusonic meter tends to under-estimate the true velocity by about 2% to 3%.

For values of the Mach number less than 4×10^{-4}, the performance of all three meters tends to be dependent on the Mach number. This behaviour is symptomatic of some inherent difficulty for the meters to resolve low flow velocities. Further investigation is required to overcome this problem.

The uncertainty in estimating the true velocity increases rapidly for all three flow meters as the Mach number decreases, when the Mach number is less than 7×10^{-4}. The greatest uncertainty in this range of the Mach number occurs for the Stork meter reaching a value of about 2.5% and the least uncertainty was obtained with the Accusonic meter, reaching a value 0.9% when the Mach number is 1×10^{-4}.

For Mach numbers greater than 7×10^{-4}, the uncertainty in determining $\overline{K}_m$ was less that 0.5% for all three meters, but the Affra meter was the most accurate, having values of E_m always less than 0.2%.

The three flow meters can be ranked in order of their ability to estimate the true flow velocity as follows: 1.) Affra, 2.) Stork 1500 MMK1 and 3.) Accusonic.

ACKNOWLEDGMENT

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REFERENCES

Spiegel, M.S. 1961. Theory and Problems of Statistics, Schaum Outline, Schaum Publishing Company, New York, New York, U.S.A.

Quantum 1981. Calibration Certificate No. 167-140, February. Quantum Dimensional Metrology Laboratory, Burlington, Ontario.

Engel, P. and E. Fast 1988. Evaluation of the AFFRA Acoustic Flow Meter, Phase II. Contract Report, Research and Applications Branch, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6.

Engel, P. 1989. Preliminary Examination of the Variability in the Towing Carriage Speed. NWRI Contribution 89 -89, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6.

Engel, P., E. Fast and K. Wiebe 1989. Towing Tank Tests of the Stork 1500 MMK1 Acoustic Flow Meter. NWRI Contribution 90-105, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6.

Engel, P., E. Fast and J. Todd 1990. Towing Tests of the ACCUSONIC Acoustic Flow Meter. NWRI Contribution 90-142, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6.

TABLE 1
Test Conditions for the Three Flow Meters

L [m]	θ [$degr.$]	d [m]	C [m/s]	Meter Make
9.25	21.1	0.5	1472	Affra
10.00	20.0	0.6	1479	Stork 1500 MMK1
7.99	24.3	0.7	1480	Accusonic

L = the length of the acoustic path between transducers
θ = the angle of orientation of acoustic path with the flow
d = the depth of transducers below the water surface
C = the speed of sound in water during the tests

TABLE 2
Data Summary for the Affra Flow Meter

V_c [m/s]	$\frac{V_c}{C}$ [10^4]	$\overline{K}_m$ [o]	S_K [o]	E_m [%]	n
0.20	1.36	0.9740	0.0161	1.268	10
0.60	4.08	1.0038	0.0074	0.555	
1.00	6.79	1.0052	0.0024	0.180	
1.60	10.87	1.0030	0.0021	0.158	
2.00	13.59	-	-	-	
2.60	17.66	0.9997	0.0010	0.075	
3.00	20.38	0.9992	0.0024	0.181	

V_c = the towing carriage speed in m/s
C = the speed of sound in water in m/s
$\overline{K}_m$ = the mean performance ratio for the meter
S_K = the standard deviation of K_m
E_m = the uncertainty in $\overline{K}_m$ at the 95% level
n = the number of samples in each test (n =10)

TABLE 3
Data Summary for the Stork 1500 MMK1 Flow Meter

V_c [m/s]	$\frac{V_c}{C}$ [10^4]	$\overline{K}_m$ [o]	S_K [o]	E_m [%]	n
0.20	1.35	0.9914	0.0305	2.365	10
0.60	4.06	0.9913	0.0097	0.737	
1.00	6.76	0.9886	0.0033	0.252	
1.60	10.82	0.9877	0.0027	0.206	
2.00	13.52	0.9882	0.0034	0.259	
2.60	17.58	0.9861	0.0046	0.351	
3.00	20.28	0.9891	0.0062	0.477	

V_c = the towing carriage speed in m/s
C = the speed of sound in water in m/s
$\overline{K}_m$ = the mean performance ratio for the meter
S_K = the standard deviation of K_m
E_m = the uncertainty in $\overline{K}_m$ at the 95% level
n = the number of samples in each test (n =10)

TABLE 4
Data Summary for the Accusonic Flow Meter

V_c $[m/s]$	$\frac{V_c}{C}$ $[10^4]$	$\overline{K}_m$ $[o]$	S_K $[o]$	E_m [%]	n
0.20	1.35	1.0017	0.0122	0.918	10
0.60	4.05	0.9809	0.0050	0.384	
1.00	6.76	0.9776	0.0025	0.193	
1.60	10.81	0.9758	0.0022	0.170	
2.00	13.51	0.9764	0.0036	.0278	
2.60	17.57	0.9752	0.0030	0.232	
3.00	20.27	0.9731	0.0051	0.395	

V_c = the towing carriage speed in m/s
C = the speed of sound in water in m/s
$\overline{K}_m$ = the mean performance ratio for the meter
S_K = the standard deviation of K_m
E_m = the uncertainty in $\overline{K}_m$ at the 95% level
n = the number of samples in each test (n =10)

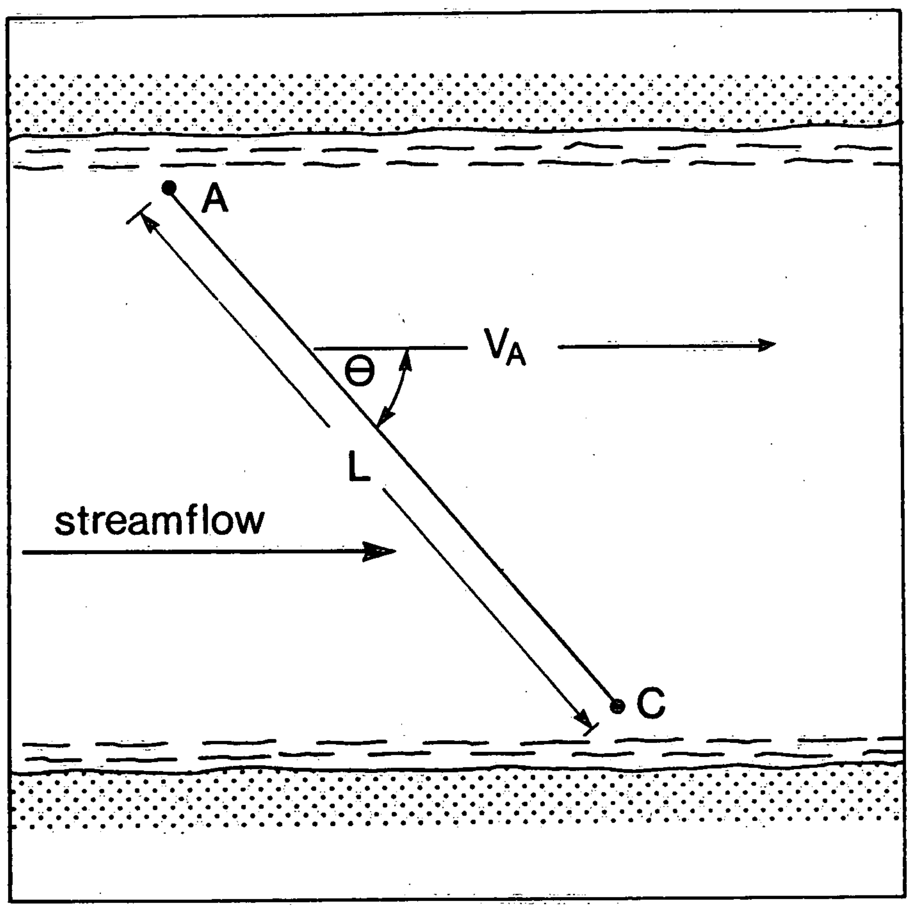

Figure 1 DEFINITION DIAGRAM FOR ACOUSTIC FLOW METER OPERATION

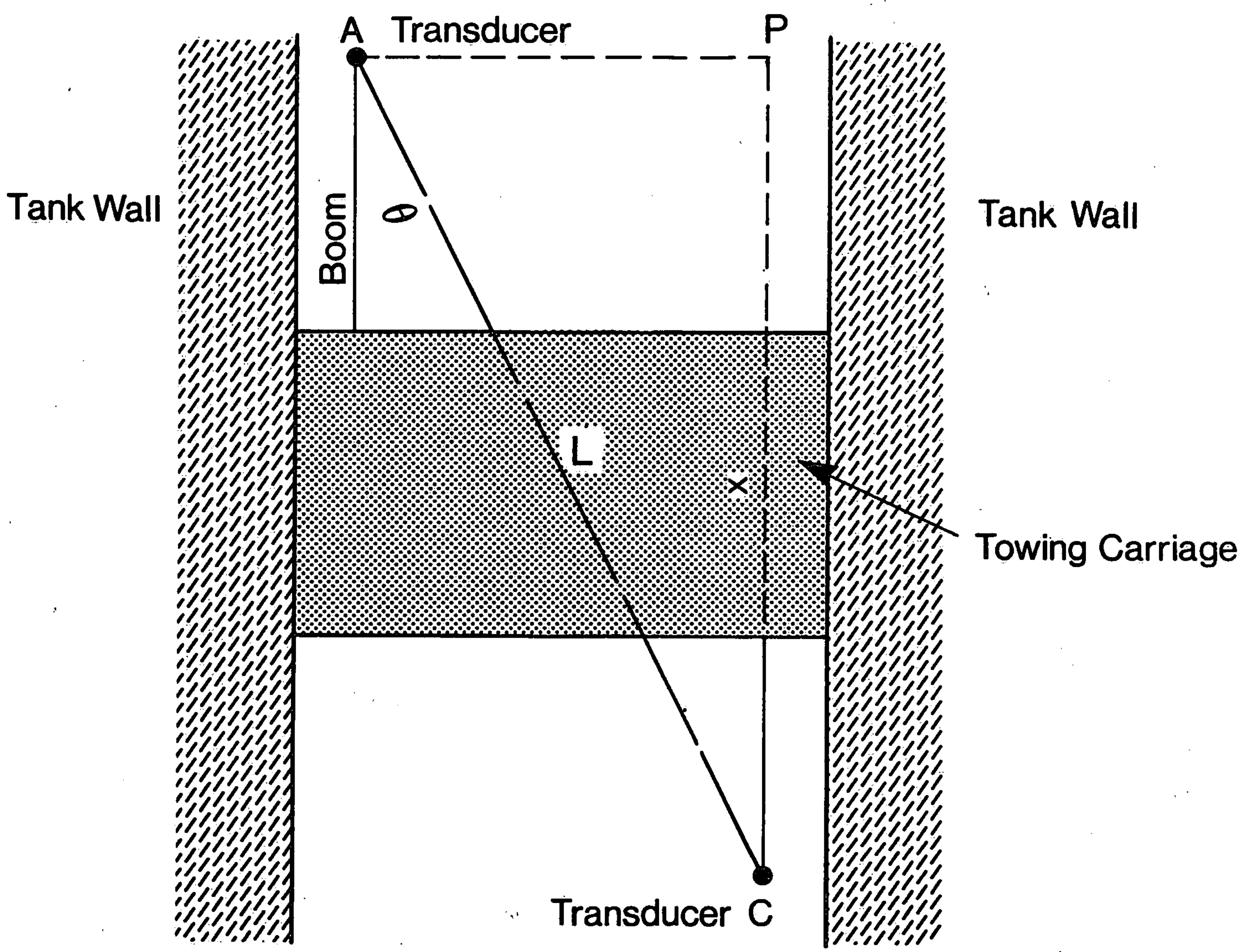

FIGURE 2. Length Measurements

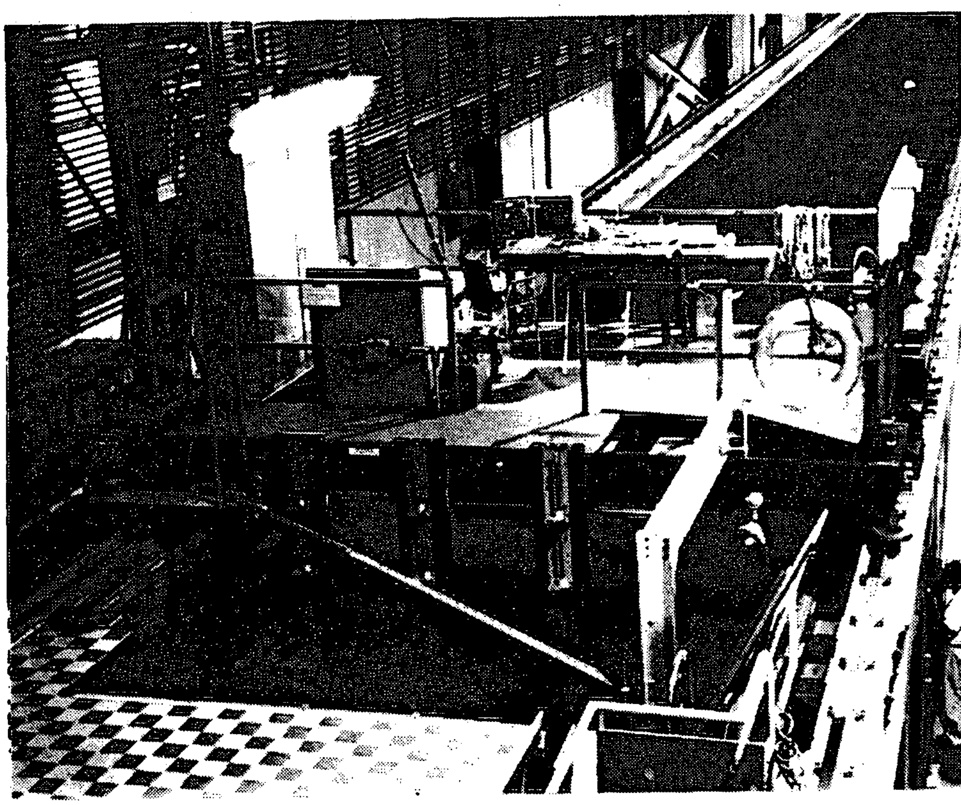

Figure 3 Towing Carriage and Suspension of Rear Transducer

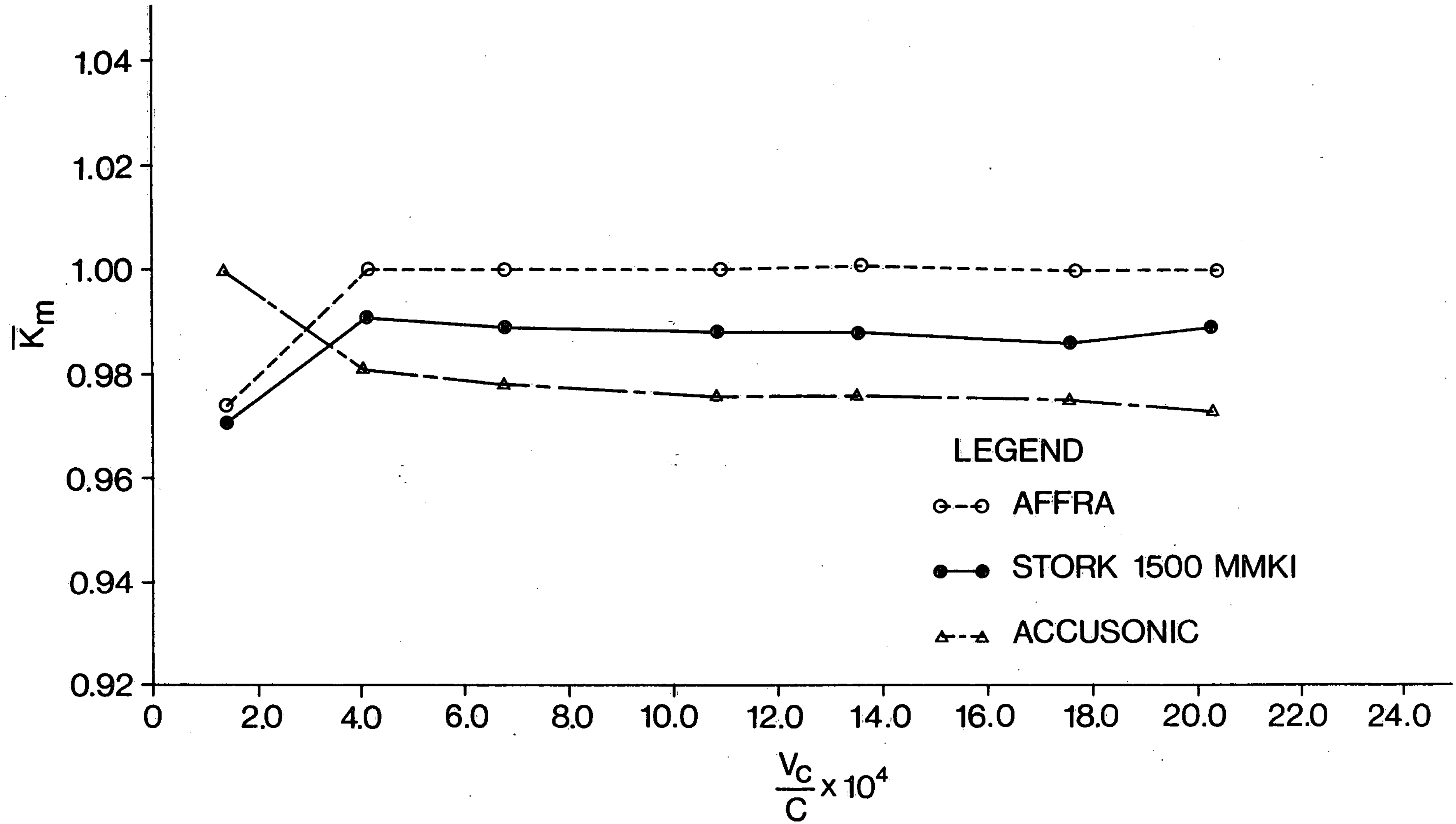

Figure 4 Mean performance of three flow meters tested

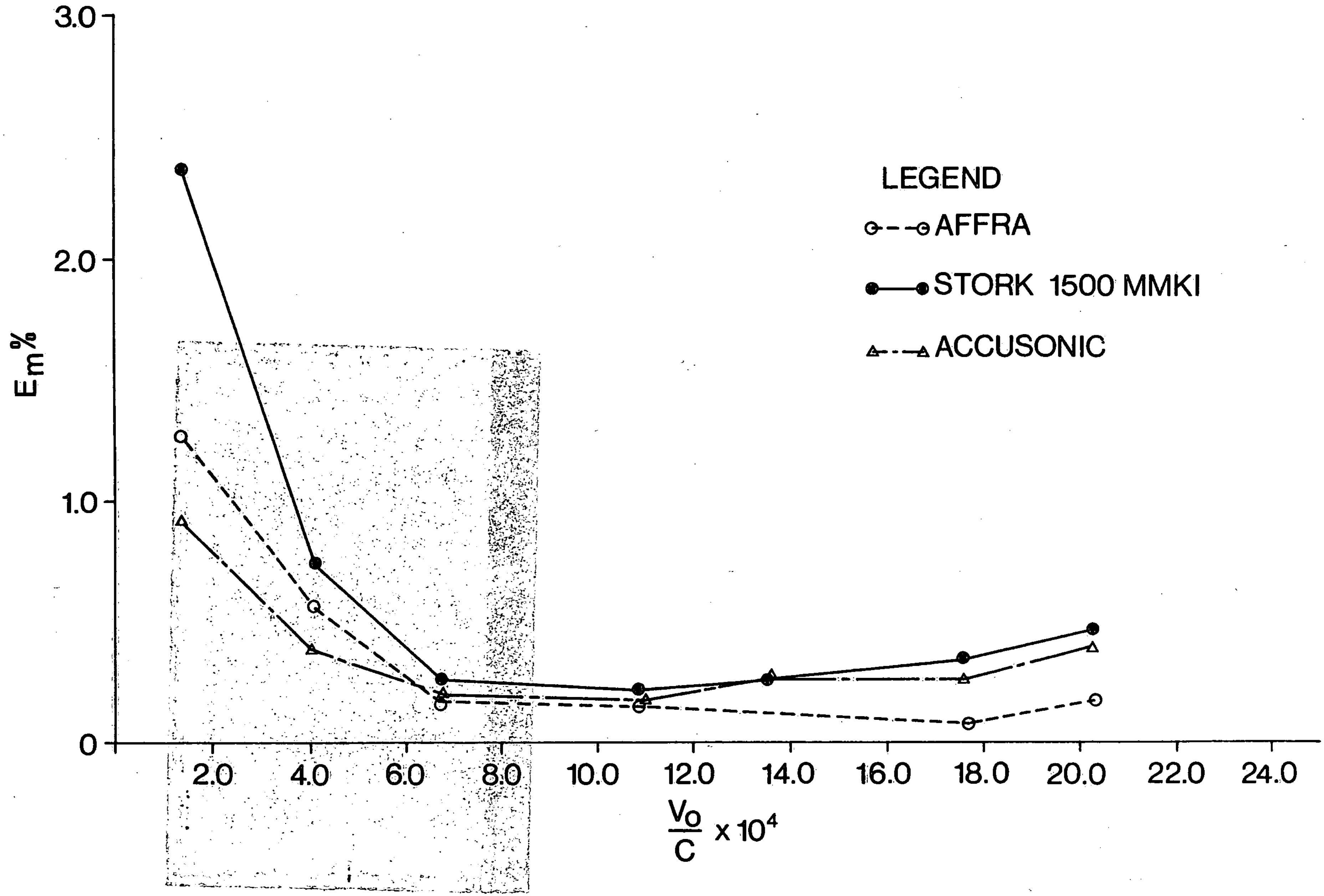

Figure 5 Uncertainty in the mean calibration for three flow meters.

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