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by

P. Engel and C. DeZeeuw

UNPUBLISHED REPORT
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P. Engel and C. DeZeeuw

Hydraulics Research Division
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
May 1978

TABLE OF CONTENTS

REFERENCES

ACKNOWLEDGEMENTS

FOREWORD: MANAGEMENT PERSPECTIVE

Price current meters rotate about a vertical axis which should make them fairly insensitive to the orientation of the supporting frame with respect to the current direction. Provided the axis of the meter frame remains within 10 to 15° of the current vector, the meter will measure the current velocity within ±1% of the time value. It is therefore important that where the meter is held by a rod that it be correctly aligned with the mean current direction. For accurate measurements through the ice, efforts should be made to equip the meter with alignment vanes. Alternatively, when there are severe conditions, several readings could be taken at different orientations of the meter with the most correct value being the greatest recorded.

T. M. Dick
Chief
Hydraulics Research Division
National Water Research Institute
Canada Centre for Inland Waters

AVANT-PROPOS: PERSPECTIVE - GESTION

Les moulinets Price tournent autour d'un axe vertical qui doit leur permettre d'être assez insensibles à l'orientation de l'armature de soutien quant à la direction du courant. Si l'axe de l'armature du moulinet se situe toujours entre 10 et 15° du vecteur formé avec le courant, le moulinet peut mesurer la vitesse du courant dans une période de ±1 p. 100 du temps. Il est donc important, là où le moulinet est retenu par une perche, qu'il soit correctement aligné avec la direction moyenne du courant. Pour obtenir des mesures exactes à travers la glace, il faut s'efforcer d'équiper le moulinet d'ailettes d'orientation. Une autre solution consiste, dans de mauvaises conditions, à effectuer plusieurs lectures pour des positions différentes du moulinet et de retenir la valeur enregistrée la plus importante comme value la plus exacte.

T. M. Dick
Chef
Division des recherches hydrauliques
Institut national de recherche sur l'eau
Centre canadien des eaux intérieures

SUMMARY

Tests were conducted to study the performance of the Price 622AA current meter when placed at a horizontal angle to the direction of flow. Results indicate that the behaviour of the meter is unsymmetrical for misalignment to the left and the right. In this respect, the Price meter should not be allowed to deviate from true alignment with the flow by more than 10° to the left and 15° to the right so as not to exceed errors due to alignment by one percent.

It was also found that the Price meter has a very poor cosine response and cosine components of the measured velocity should not be computed for angles greater than ±10°.

The effect of the tail fin in increasing errors is insignificant for misaligned meters and can be neglected for practical purposes.

RÉSUMÉ

Des essais ont été effectués afin d'étudier le rendement du moulinet Price 622AA lorsqu'il est placé horizontalement dans la direction du courant. Les résultats indiquent que le comportement du moulinet est asymétrique s'il s'écarte vers la gauche et la droite. À cet égard, il faut éviter que le moulinet Price s'éloigne de plus de 10° vers la gauche et 15° vers la droite de la véritable ligne d'alignement avec l'écoulement et ce, afin de ne pas faire d'erreurs de plus de 1 pour cent à cause de l'alignement.

On s'est également aperçu que le moulinet Price avait une réaction très faible de cosinus et que les éléments cosinus de la vitesse mesurée ne devraient pas être calculés pour des angles supérieurs à ±10°.

L'effet de la dérive n'a aucune importance en ce qui concerne l'augmentation des erreurs dans le cas de moulinets s'écartant de l'alignement et on peut l'omettre à toutes fins pratiques.

LIST OF NOMENCLATURE

E_{Δ} = Difference in error when using fin and no fin, in percent

E_n = Error obtained without using tail fin, in percent

E_t = Error obtained when using tail fins, in percent

E_{θ} = Error in cosine response

N_o = Revolutions/sec for standard calibration

N = Revolutions/sec for oblique calibrations

V_o = Towing speed for standard calibration

θ = Horizontal angle of alignment

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Current velocities in a river, lake or other body of water are measured by placing the current meter into the flow and recording the rate of rotation of the rotor. The relationship between the linear current velocity and the rate of revolution of the meter rotor is normally determined by calibrating the meter in a towing tank.

It has been observed that Price meters give erroneous readings when they are not aligned parallel to the current in the horizontal plane, given that alignment in the vertical plane is true. This discrepancy has also been noted to differ for the same angles left and right from true alignment. Such behaviour can result in measurement errors particularly when current meters are used with rod suspensions. Therefore, this study was conducted to assess the behaviour of the Price meter under these conditions.

Some tests on the effects of horizontal alignment have been made by Grindley (1971). He conducted his experiments with the stabilizing fins attached to the meter. However, the Price meter is often used without fins and thus the present tests were conducted in this mode. The data will thus yield information on the meter's behaviour and how this is affected by the presence of the tail fins when the meter is not alligned parallel to the flow.

This report is one in a series of seven, investigating the performance characteristics of the Price current meter. The results are intended to show only the performance tendency of the meter and as such do not provide information suitable for angular correction coefficients. Such information can only be obtained by exhaustive repetitive tests using many meters and is beyond the scope of this report. The experiments for this report were conducted under study number HRD 78 050.

2.0 EQUIPMENT AND APPARATUS

2.1 Meter Suspension

Two Price 622AA type current meters number 1-061 and 1-179 were used in these tests. The meters were drawn at randum from inventory and used with a 20 mm diameter solid steel rod assembly fastened to the rear of the towing carriage as shown in Figure 2.1.

2.2 Towing Tank

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

At one end of the tank is an overflow weir. Waves arising from towed current meters and their suspensions are washed over the crest, reducing wave reflections. Parallel to the sides of the tank, perforated beaches serve to dampen lateral surface wave disturbances. The large cross-section of the tank also inhibits the generation of waves by the towed object.

2.3 Towing Carriage

The carriage is 3 metres long, 5 metres wide, weight 6 tons and travels on four precision machined steel wheels.

The carriage is operated in three overlapping speed ranges:

0.5 cm/sec - 6.0 cm/sec
5.0 cm/sec - 60 cm/sec
50 cm/sec - 600 cm/sec

In all speed ranges, the constant speed is well within a tolerance of ±1% of the mean. The maximum speed of 600 cm/sec can be maintained for 12 seconds within the specified tolerance. 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 the constant speed within the specified tolerance.

2.4 Data Acquisition Module

For contact closure meters, such as the Price 622AA, the pulses generated by the meter rotor are transmitted to a data acquisition module in the control room. Four channels are provided since four meters may be calibrated simultaneously.

A permanent record of velocity and distance is provided by a digital printout in the control room. For contact closure meters, the number of revolutions of the meter rotor and time are also recorded on the printout. The printer can be engaged for several printing intervals from 1 to 10 seconds. The velocity and position of the carriage can also be monitored continuously on a visual display in the control room.

Time is measured with a crystal clock. The basic clock frequency is obtained from a 10 MHz oscillator contained within the frequency counter used to measure velocity. This frequency is divided down to provide a continuous 1 KHz clock which is used for overall synchronization purposes. The KHz clock is further divided down to provide a clock frequency of 100 Hertz which is used for the measurement of the elapsed time between successive current meter pulses.

3.0 EXPERIMENTAL PROCEDURE

3.1 Meter Preparation

Prior to testing, each meter underwent the following inspection:

(a) the pentagear was checked for binding
(b) the contact wire was cleaned and adjusted for tension to provide good contact
(c) all moving parts were lubricated

Following the inspection, the meter was hung in a wind tunnel where it was spun for two hours to ensure that all moving parts were "run in".

3.2 Towing Tests

In each test, the meter was attached to the rod suspension as shown in Figure 3.1 (a) and lowered into position 30 cm below the water surface. This depth was chosen to avoid surface effects and to create a minimum of drag on the steel rod and thus eliminate undue vibrations. The alignment of the meter with the direction of tow was measured with a protractor as shown in Figure 3.1 (b). In all cases, the suspended meter was placed near the centreline of the towing tank in accordance with test conditions set out by Engel (1977).

A tow of the meter with the towing carriage at a preset speed for a fixed angle of alignment was defined as a test. To begin a set of tests, the meter was set at the desired angle of alignment. The meter was then towed at different speeds, resulting in a total of 20 tests from a speed of 6 cm/s to 300 cm/s. Each time the meter was towed, care was taken that steady state conditions prevailed when measurements were recorded. The lengths of the waiting time between successive tests were in accordance with criteria established by Engel and DeZeeuw (1977) or better. For each test, the towing speed, revolutions of the meter rotor, time and angle of alignment were recorded. Water temperatures were not noted since temperature changes during the tests were small and do not affect the meter significantly (Engel, 1976).

Tests were conducted for alignment parallel to the longitudinal axis or the towing tank and angles of 10°, 15°, 20°, 30° and 40° to the left (LT) and right (RT). Angles to either left or right were defined as the direction which the longitudinal axis of the meter makes with the longitudinal axis of the towing tank, as shown in Figure 3.2.

The tests for angles of 15° and 30° left and right were conducted with meter 1-719 whereas tests for the remaining angles were made with meter number 1-061. For each meter a separate calibration curve was made for true alignment in order to compare the relative behaviour of these two meters.

The data for all the tests are given in Table 3.1 for angles turned to the left and Table 3.2 for angles turned to the right.

4.0 DATA ANALYSIS

4.1 Preliminary Considerations

In order to assess the performance of the Price meter, tests for oblique alignments were compared with the calibration for true alignment parallel to the direction of tow. The latter are called standard calibration and the tests for angles other than at 0^{o} are referred to as oblique calibrations.

Since two meters were used, namely, number 1-179 and 1-061, their standard calibrations were examined first. Values of N_o/V_o (N_o=revolutions/s, V_o=towing speed in cm/s) were plotted versus V_o for each meter in Figure 4.1. Here the subscript o denotes the angle of 0^{o}. This method of plotting was chosen because it best shows the characteristics of the meter calibration (Dickenson, 1967; Grindley, 1971; Engel, 1976). The values of N_o/V_o for both meters are virtually constant for speeds greater than 60 cm/s, whereas for speeds less than 60 cm/s, N_o/V_o varies strongly with speed. The data also show that the two meters over most of the tested speed range behave quite similarly. There are some small differences in the speed range from about 30 cm/s to 220 cm/s in which values of N_o/V_o for meter number 1-061 are slightly higher. In the speed range from 30 cm/s to 60 cm/s, the calibration of both meters is quite erratic and this condition prevails also for speeds less than 30 cm/s, although to a lesser degree. The erratic behaviour has to be attributed for the most part to the hydro-dynamic properties of the Price meter since the required waiting times between successive tows were carefully observed (Engel, DeZeeuw, 1977). In addition, the accuracy of the towing carriage is well within the variance of N_o/V_o indicated for speeds less than 60 cm/s.

Although the difference between the two calibration curves is quite small, the oblique calibrations were always compared with the meter with which they were carried out. In other words, for angles of 15^{o} and 30^{o} to left and right, comparisons were made with the standard calibration of meter 1-179. For the remaining angles, the standard calibration for meter 1-061 was used.

4.2 Effect of Misalignment on Meter Response

Values of N_Θ/V_o (subscript Θ denotes alignment angle Θ) were computed and are given in Table 4.1 for angles turned to the left and Table 4.2 for angles to the right. The values of N_Θ/V_o were then plotted versus V_o for angles to the left on Figure 4.2 and on Figure 4.3 for angles turned to the right. Superimposed on these figures were the corresponding standard calibration equations. This arrangement afforded a direct visual comparison between the oblique and standard calibrations over the full range of speeds tested.

In order to facilitate the comparison, average curves were sketched through the plotted points. This effectively reduced the analysis to consideration of the dominant deterministic response of the meter by removing the random component. These average curves were then used to assess the behaviour of the meter for the different conditions tested. Such a procedure was considered to be justified within the scope of this report.

Because of the shape of the N/V_o versus V_o curves, the analysis was conducted by considering separately the portion of the curve for speeds greater than 60 cm/s and that for speeds less than 60 cm/s.

4.2.1 Meter response for speeds greater than 60 cm/s

When the curves in Figure 4.2 for angles turned to the left are examined, it is noted that the oblique response is always slower than the standard. This response deficiency becomes greater as the angle increases from 0^o through 30^o LT. When the angle is 40^o LT, the departure from the standard curve has decreased.

For angles turned to the right in Figure 4.3, when the angle is 10^o RT, there is virtually no difference from the standard curve. For angles of 15^o, 20^o, 30^o and 40^o RT, the departure from the standard curve increases respectively.

In order to obtain a better appreciation of the variation of the meter response with alignment, values of N/V_o were plotted versus Θ for fixed values of V_o. Since for values from V_o=60 cm/s to 300 cm/s values of N/V_o are on the average taken to be constant, then the variation of N/V_o versus Θ in this speed range is given by one curve. This curve is given in Figure 4.4.

The shape of the curve in Figure 4.4 clearly shows the variations in the behaviour of the Price meter for different angles of alignment. From the overall shape of the curve, it is at once apparent that the meter responds differently for angles turned to right and left of $\Theta=0^o$. This difference is due to the interference effected by the yoke and rod support of the meter. When the meter is turned to the right, the direction of movement of the water is with the direction of motion of the rotor cups as they move past the yoke. When the meter is turned to the left, this effect is reversed.

With reference to the value of N_o/V_o at $\theta=0^o$ (i.e. standard calibration) values of N_θ/V_o are always lower except in the range of the angle from $\theta=0^o$ to 10^o RT. For angles between these values, the smooth curve indicates a tendency for values of N_θ/V_o to be slightly larger than the standard value. At the angle of $\theta=10^o$ RT, $N\ /V_o$ is equal to N_o/V_o. For angles greater than 10^o RT, there is a steady decline in the N_θ/V_o values below the standard values. On the other hand, for angles turned to the left, the variation of N_θ/V_o with θ assumes the shape of an S curve with an initial decline in N_θ/V_o values, through a point of inflection when $\theta \approx 15^o$ LT and continuing to decrease until $\theta \approx 30^o$ LT. Thereafter, there is a smooth rise in N_θ/V_o values up to the last tested angle of 40^o LT.

In order to define the magnitude in the response changes of the meter, the differences between oblique and standard calibrations from the average curves in Figure 4.2 and 4.3 were computed. These differences expressed as percent with respect to the standard calibration given by $(N_\theta-N_o)/N_o \times 100\%$ are presented in Table 4.3 for angles turned to the left and Table 4.4 for angles turned to the right.

The percent differences were plotted in Figure 4.5 versus the angle to both left and right. The average curve, which is of course similar in shape to that of Figure 4.4, clearly shows the magnitudes of error in measuring velocity which can be incurred when the meter is not properly aligned with the flow. For angles from 0^o to 10^o RT, the difference appears to reach to a value of the order of about 0.2 percent, which is an over registration and well within the tolerances of a normal meter calibration. However, it is possible the difference in this range is also zero. For angles greater than 10^o RT, the meter always underregisters which means that it always will measure a velocity less than the actual. This discrepancy increases rapidly with increase in the angle and reaches a value of about -11% when the angle is 40^o RT. For angles turned to the left, the percent differences are always negative and increase to a value of -4.5% when the angle is 30^o LT. For angles greater than 30^o LT, the differences decrease to about -2.8% when $\theta=40^o$ LT.

The error in measuring the towing speed with towing carriage used in these tests is ±1% at all speeds. In order to stay within this limit, it can be seen from Figure 4.5, that the Price meter should not be allowed to deviate from true alignment ($\theta=0^o$) by more than 10^o LT and about 15^o RT. This observation applies for velocities greater than 60 cm/s.

4.2.2 Meter response for speeds less than 60 cm/s

For speeds less than 60 cm/s, Figures 4.2 and 4.3 show that there is a distinct variation of values of N/V_o with V_o for all curves. In addition, contrary to the behaviour of the meter for speeds greater than 60 cm/s, the differences between the oblique and standard curves are generally not constant except for the case when $\theta=10^\circ$ RT for which both curves are coincident. Instead, the non-linear, oblique curves approach the standard curve and merge at low values of V_o. There is no definable relationship between angle of alignment and the value of V_o at which the curves merged. This may largely be due to the relatively large variance in the data in the low speed range and the consequent subjectivity in sketching the average curves.

When the meter response was plotted as N/V_o versus θ for constant V_o, because of the behaviour of N/V_o for speeds less than 60 cm/s, a separate curve resulted for each value of V_o. The family of curves thus generated provides a convenient way of making a relative assessment of the meter's behaviour at low speeds. Such curves for values of V_o=6 cm/s, 12 cm/s, 18 cm/s and 30 cm/s are given in Figure 4.4 together with the curve for speeds greater than 60 cm/s.

The general shape of the curves is very much the same as that for the curve representing the high speeds. However, as the speed is reduced, the curves for angles to the left become sharper around their minimum value of N_θ/V_o and this minimum also tends to move from a value of $\theta\approx 30^\circ$ at 60 cm/s to $\theta\approx 20^\circ$ at 6 cm/s. This indicates that the effect of the meter yoke is most pronounced at very low speeds and that this effect becomes less pronounced as the speed V_o approaches 60 cm/s after which it remains fixed. When angles are turned to the right, the curves are smooth and generally their shapes are smooth and continuous with no abrupt changes in slopes.

In order to define the magnitude of the response changes, percent differences were again computed and these can also be found in Tables 4.3 and 4.4. The percent differences were plotted versus θ for fixed speeds of 6 cm/s, 12 cm/s, 18 cm/s and 30 cm/s in Figure 4.6. The curves show that for low speeds, namely 6 cm/s to 18 cm/s, in order to maintain an error not exceeding ±1%, the meter may be turned as far as about 17.5% RT and 15° LT. When the speed is up to 30 cm/s, the allowable angle for an error of ±1% is still 17.5° RT but is reduced to 10° LT. Outside of this range of angles, the percent differences vary rapidly with the alignment and becomes as high as -11% for angles turned to the right when $\theta=40^{\circ}$ RT and -9% for angles turned to the left when $\theta \approx 20^{\circ}$ LT.

Generally, the behaviour of the meter, as indicated by the shape of the curves, tends to approach that observed for speeds greater than 60 cm/s.

4.3 Angular Response of the Price Meter

When a meter is held at some angle θ to the direction of the flow, the angular response of the meter is defined as its ability to measure the cosine component of the velocity. This response is often referred to as the "cosine" response. Some horizontal axis type meters, notably the Ott C-31, can be fitted with propellers which are designed to give full cosine response for a specific angle over its full operating speed range. The Price meter, however, does not do this because of its construction. Indeed, if the rotor were completely isolated from the interfering effects of the yoke and suspension, it would be completely insensitive to direction. In this ideal situation, the question of alignment and cosine components would be totally meaningless. However, as shown in Section 4.2, the meter yoke does affect the flow field around the rotor and thus its response and this varies with the angle of alignment. Therefore, it is of interest to know what error would result if one were to assume that the Price meter measures the cosine component and use this fact to determine the total velocity.

In the case of perfect cosine response, the relationship between the response of a meter when aligned with the flow and that when aligned at an angle is given by

$$N_{\theta} = N_{o} \cos \theta \qquad \text{...4.1}$$

The difference incurred in assuming equation 4.1 can be obtained from

$$E_{\theta} = \frac{N_{\theta} - N_{o} \cos \theta}{N_{o} \cos \theta} \qquad \text{...4.2}$$

where: E_{θ} = the difference at a given angle θ.

Values of E_{θ} were computed for speeds of 6 cm/s, 12 cm/s, 18 cm/s, 30 cm/s and greater than 60 cm/s. These are given in Table 4.5 for angles turned to the left and Table 4.6 for angles turned to the right. The data for V_o=12 cm/s, 30 cm/s and V_o> 60 cm/s were plotted as E_θ versus θ in Figure 4.7. A smooth curve was fitted through the data for V_o> 60 cm/s and this shows that for the high speeds the difference in the cosine response increases positively for increases in θ for angles both left and right. The increase in E_θ with increase in θ is relatively slow for angles up to 15° left and right. Thereafter, the increase in E_θ is more rapid, increasing more quickly and reaches higher values when angles are to the left, attaining a value of about 28% at θ=40° LT compared with about 16% at θ=40° RT.

Values of E_θ for speeds of 12 cm/s and 30 cm/s generally follow the same pattern as those for V_o> 60 cm/s, except in the region of $\theta \approx 20°$ LT. This behaviour is in line with that noted in Section 4.2. Toward the larger values of θ, the difference appeared to increase as the speed V_o decreased. In general, the data in Figure 4.7 indicates that for an angle less than 10° LT and 10° RT the accuracy of assuming a cosine response for the Price meter is within 1%.

4.4 Effect of the Tail Fin on Meter Response

Grindley (1971) conducted tests with the Price meter for angles to the left and right of true alignment. His tests were conducted by attaching the tail fins to the yoke as shown in Figure 4.8. The meter was then attached rigidly to a hanger bar, rectangular in cross-section, which was then attached to a device on the towing carriage which permitted the turning of any desired horizontal angle. The data presented by Grindley (1971) covers a speed range from 25 cm/s to 100 cm/s. Although the meter attachment of the present tests differs from that used by Grindley, it is felt that the major difference between the two sets of data is due to the effect of the tail fins. Data from Grindley (1971) are given in Table 4.7 for angles turned left and Table 4.8 for angles turned to the right.

Using the data from Grindley (1971), the percent error in the meter response for a speed of V_o=100 cm/s and 25 cm/s was compared with that from the present tests for speeds of V_o>60 cm/s and 25 cm/s respectively. The two sets of data for the higher speeds were plotted in Figure 4.9 and for the lower speeds in Figure 4.10. Smooth curves were sketched through the plotted points.

Figure 4.9 shows that for high speeds (V_o> 60 cm/s) the difference between the two curves is small for angles turned to the right. Slightly larger negative errors are incurred when the tail fin is used for angles greater than 15° RT, whereas slightly larger positive errors are incurred when the angle is between

0° and 10° RT. There is virtually no difference when θ=10° RT. For angles to the left, once again when tail fins are used, the negative errors are slightly larger, up to an angle of about 17° LT. For angles between 17° LT and 40° LT, the negative errors are less with the difference reaching a maximum of about 1.8% at an angle around 25° LT. This again shows that in this range of alignment the Price meter is most sensitive to orientation and suspension.

Figure 4.10 shows that at lower speeds (i.e. V_o=25 cm/s) the relative effect of the fins is much the same as that observed at the higher speeds. The maximum difference between the two curves is slightly greater at around 2% when θ about 25° LT. The error incurred when using tail fins is also slightly larger for angles turned to the right but is also in the same direction.

In order to show the effect of the tail fins more directly, the difference in the error obtained with and without using tail fins at a given alignment were plotted in Fgure 4.11 for speeds greater than 60 cm/s and at 25 cm/s. The error difference is defined as

$$E_\Delta = E_t - E_n \qquad \text{...4.4}$$

where:
E_Δ = difference in error when using fin and no fin
E_t = error obtained when using fins
E_n = error obtained without using fins

The values of E_Δ were plotted versus θ. The distribution of the values of E_Δ clearly shows the magnitude of the influence of the tail fins on the Price meter. When the towing speed is greater than 60 cm/s, the difference E_Δ is less than 1% in most cases. Values of E_Δ are only equal to or greater than ±1% in the range of alignment from around 22° LT to 37° LT. When angles are turned to the right, the value of E_Δ exceeds 1% only after the angle has exceeded a value of about 37° RT.

In the case when the towing speed is only 25 cm/s, the shape of the E_Δ distribution in Figure 4.11 has a similar shape, but offset to the right for angles to the left and offset to the left for angles to the right. Values of E_Δ exceed the 1% value in the range of angles from 16° LT to about 36° LT and from 17° RT to 27° RT as well as for angles greater than 33° RT.

The two curves in Figure 4.11, therefore, indicate that within a calibration accuracy of ±1% the effect of the tail fin is not significant except for the values of angles indicated above. The effect of the tail fins is felt more at lower speeds and becomes less noticeable as speed increases to about 60 cm/s. Thereafter, the effect remains constant.

5.0 CONCLUSIONS

5.1 The behaviour of the Price meter is unsymmetrical when not properly aligned with the direction of the flow. This is due to the interference created primarily by the meter yoke and to a lesser degree by the meter suspension.

5.2 In order to keep the error in measuring velocity due to alignment within ±1%, the Price meter must not be allowed to deviate from true alignment by more than 10° LT and about 15° RT for speeds greater than 60 cm/s. The Price meter is slightly less sensitive to alignment at lower speeds. When the speed is 6 cm/s, in order not to exceed a 1% error, the allowable range of misalignment is from 15° LT to 17.5° RT.

5.3 When the Price meter is placed obliquely into the flow, the meter will measure a speed which is greater than the expected cosine component of the true velocity. This error in cosine response increases for increases in angle of alignment both left and right attaining a value of 28% at $\theta=40^\circ$ LT and 16% at $\theta=40^\circ$ RT. In general, this behaviour holds true at low speeds as well as high speeds. For an angle of less than 10° LT and 10° RT, the accuracy of assuming true cosine response is within 1%.

5.4 The presence of the tail fin has a small effect on meter performance for angles turned to the right tending to increase the measurement error by less than 1% for angles up to 37° RT. The effect of the tail fin is more pronounced for angles turned to the left where its use reduces the measurement error for angles from 12° LT to 40° LT with a maximum reduction of about 2% when $\theta \approx 30^\circ$ LT at speeds greater than 60 cm/s. For lower speeds, the magnitudes of the error reduction are about the same, but the maximum of 2% occurs for angles between 20° LT and 30° LT.

ACKNOWLEDGEMENTS

The writers wish to express their appreciation to Mr. C. Bil, Mr. B. Leaney and Mr. J. Dalton who conducted the tests and performed some of the computations.

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TABLE 3.1 TEST DATA FOR ANGLES LEFT

V_o cm/s	N_o rev/s	N_o * rev/s	N_Θ rev/s				
			$\Theta=10^o$	$\Theta=15^o$*	$\Theta=20^o$	$\Theta=30^o$	$\Theta=40^o$
6	.079	.079	.077	.050	.074	.079	.097
12	.166	.169	.140	.166	.157	.159	.169
18	.257	.256	.251	.254	.238	.243	.263
24	.342	.344	.340	.340	.323	.326	.347
30	.426	.447	.425	.424	.403	.428	.430
36	.532	.529	.529	.524	.514	.506	.514
42	.615	.618	.613	.603	.598	.591	.601
48	.699	.711	.697	.694	.685	.678	.694
54	.788	.799	.782	.782	.775	.764	.770
60	.887	.890	.884	.862	.860	.852	.857
84	1.241	1.250	1.234	1.220	1.217	1.195	1.202
108	1.603	1.614	1.591	1.569	1.558	1.538	1.555
132	1.959	.1976	1.938	1.920	1.909	1.880	1.898
156	2.313	2.340	2.292	2.275	2.247	2.223	2.255
180	2.672	2.692	2.638	2.619	2.591	2.564	2.603
204	3.034	3.052	2.981	2.968	2.937	2.942	2.956
228	3.400	3.402	3.339	3.312	3.283	3.265	3.313
252	2.758	3.775	3.706	3.663	3.642	3.614	3.671
276	4.125	4.134	4.062	4.010	3.995	3.943	4.039
300	4.488	4.507	4.409	4.374	4.355	4.310	4.376

* Data for Meter No 1-719

TABLE 3.2

TEST DATA FOR ANGLES RIGHT

V_o cm/s	N_o rev/s	N_o * rev/s	N_Θ rev/s				
			$\Theta=10^\circ$	$\Theta=15^\circ$*	$\Theta=20^\circ$	$\Theta=30^\circ$	$\Theta=40^\circ$
6	.079	.079	.081	.079	.078	.075	.071
12	.166	.169	.165	.169	.163	.155	.151
18	.257	.256	.275	.255	.251	.238	.227
24	.342	.344	.349	.342	.335	.321	.307
30	.426	.447	.450	.442	.423	.401	.386
36	.532	.529	.538	.527	.519	.488	.470
42	.615	.618	.625	.609	.609	.569	.550
48	.699	.711	.710	.706	.696	.653	.625
54	.788	.799	.808	.793	.786	.729	.711
60	.887	.890	.887	.883	.869	.829	.783
84	1.241	1.250	1.246	1.232	1.220	1.156	1.105
108	1.603	1.614	1.598	1.591	1.570	1.487	1.425
132	1.959	1.976	1.958	1.946	1.927	1.813	1.743
156	2.313	2.340	2.302	2.300	2.267	2.152	2.051
180	2.672	2.692	2.650	2.654	2.607	2.478	2.361
204	3.034	3.052	3.037	3.022	2.955	2.814	2.696
228	3.400	3.402	3.370	3.359	3.306	3.151	3.019
252	3.758	3.775	3.765	3.757	3.667	3.484	3.347
276	4.125	4.134	4.122	4.082	4.016	3.804	3.660
300	4.488	4.507	4.434	4.439	4.369	4.168	3.986

* Data for Meter No. 1-719

TABLE 4.1

COMPUTED REVOLUTIONS/METER FOR ANGLES LEFT

V_o cm/s	$\frac{N_o}{V_o}$ rev/m	$\frac{N_o}{V_o}$ * rev/m	N_θ/V_o rev/m				
			$\theta=10^\circ$	$\theta=15^\circ$	$\theta=20^\circ$	$\theta=30^\circ$*	$\theta=40^\circ$
6	1.31	1.31	1.27	1.33	1.22	1.32	1.61
12	1.38	1.41	1.16	1.38	1.30	1.32	1.40
18	1.42	1.42	1.39	1.41	1.32	1.35	1.45
24	1.42	1.43	1.41	1.42	1.34	1.36	1.44
30	1.42	1.49	1.41	1.41	1.34	1.43	1.43
36	1.47	1.47	1.47	1.45	1.43	1.41	1.43
42	1.46	1.47	1.46	1.44	1.42	1.41	1.43
48	1.45	1.48	1.45	1.45	1.43	1.41	1.44
54	1.46	1.48	1.45	1.45	1.43	1.41	1.43
60	1.48	1.48	1.47	1.44	1.43	1.42	1.43
84	1.47	1.49	1.47	1.45	1.45	1.42	1.43
108	1.48	1.49	1.47	1.45	1.44	1.42	1.44
132	1.48	1.50	1.47	1.45	1.44	1.42	1.43
156	1.48	1.50	1.47	1.46	1.44	1.42	1.44
180	1.48	1.50	1.46	1.45	1.44	1.42	1.44
204	1.49	1.50	1.46	1.45	1.44	1.44	1.45
228	1.49	1.49	1.46	1.45	1.44	1.43	1.45
252	1.49	1.50	1.47	1.45	1.44	1.43	1.46
276	1.49	1.50	1.47	1.45	1.45	1.43	1.46
300	1.49	1.50	1.47	1.46	1.45	1.44	1.46

* Data for Meter No. 1-719

TABLE 4.2 COMPUTED REVOLUTIONS/METER FOR ANGLES RIGHT

V_o cm/s	$\frac{N_o}{V_o}$ rev/m	$\frac{N_o}{V_o}$ * rev/m	N_θ/V_o rev/m				
			$\theta = 10^\circ$	$\theta = 15^\circ$	$\theta = 20^\circ$	$\theta = 30^\circ$*	$\theta = 40^\circ$
6	1.31	1.31	1.34	1.32	1.29	1.25	1.18
12	1.38	1.41	1.37	1.41	1.35	1.29	1.26
18	1.42	1.42	1.52	1.42	1.39	1.32	1.26
24	1.42	1.43	1.45	1.42	1.39	1.34	1.28
30	1.42	1.49	1.50	1.47	1.41	1.34	1.29
36	1.47	1.47	1.49	1.46	1.44	1.35	1.30
42	1.46	1.47	1.49	1.45	1.45	1.35	1.31
48	1.45	1.48	1.48	1.47	1.45	1.36	1.30
54	1.46	1.48	1.49	1.47	1.45	1.35	1.32
60	1.48	1.48	1.48	1.47	1.45	1.37	1.30
84	1.47	1.49	1.48	1.47	1.45	1.38	1.31
108	1.48	1.49	1.48	1.47	1.45	1.38	1.32
132	1.48	1.50	1.48	1.47	1.46	1.37	1.32
156	1.48	1.50	1.47	1.47	1.45	1.38	1.31
180	1.48	1.50	1.47	1.47	1.45	1.38	1.31
204	1.49	1.50	1.49	1.48	1.45	1.38	1.32
228	1.49	1.49	1.48	1.47	1.45	1.38	1.32
252	1.49	1.50	1.49	1.49	1.45	1.38	1.33
276	1.49	1.50	1.49	1.48	1.45	1.38	1.33
300	1.49	1.50	1.48	1.48	1.46	1.39	1.33

* Data for Meter No. 1-719

TABLE 4.3 ERRORS IN MEASURING FLOW SPEED FOR ANGLES LEFT

V_o cm/s	$\frac{\Delta N}{N_o}$ %				
	$\Theta=10^o$	$\Theta=15^o$	$\Theta=20^o$	$\Theta=30^o$	$\Theta=40^o$
6	0.00	0.00	-8.71	-0.92	.00
12	0.00	0.00	-6.60	-3.77	.00
18	0.00	-1.13	-4.69	-3.97	-0.43
24	-0.98	-1.26	-3.93	-4.06	-0.84
30	-0.83	-1.59	-3.47	-4.21	-1.04
36	-0.21	-1.78	-3.17	-4.25	-1.38
42	-0.75	-2.04	-3.08	-4.48	-1.98
48	-0.95	-2.10	-2.99	-4.40	-2.25
54	-0.81	-2.36	-2.85	-4.51	-2.24
60	-0.95	-2.55	-2.91	-4.50	-2.43
84	-1.01	-2.94	-2.63	-4.61	-2.36
108	-1.01	-2.94	-2.63	-4.61	-2.36
132	-1.01	-2.94	-2.63	-4.61	-2.36
156	-1.01	-2.94	-2.63	-4.61	-2.36
180	-1.01	-2.94	-2.63	-4.61	-2.36
204	-1.01	-2.94	-2.63	-4.61	-2.36
228	-1.01	-2.94	-2.63	-4.61	-2.36
252	-1.01	-2.94	-2.63	-4.61	-2.36
276	-1.01	-2.94	-2.63	-4.61	-2.36
300	-1.01	-2.94	-2.36	-4.61	-2.36

TABLE 4.4 ERRORS IN MEASURING FLOW SPEED FOR ANGLES RIGHT

V_o cm/s	$\frac{\Delta N}{N_o}$ %				
	$\Theta = 10^{\circ}$	$\Theta = 15^{\circ}$	$\Theta = 20^{\circ}$	$\Theta = 30^{\circ}$	$\Theta = 40^{\circ}$
6	0.00	0.00	-2.25	-4.73	-10.51
12	0.00	0.00	-2.68	-6.16	- 9.79
18	0.00	0.00	-2.28	-6.73	-10.53
24	0.00	0.00	-1.96	-7.34	-10.80
30	0.00	-0.55	-1.46	-7.46	-10.63
36	0.00	-0.69	-1.24	-7.54	-10.74
42	0.00	-0.95	-1.30	-7.75	-10.81
48	0.00	-0.95	-1.50	-7.91	-10.88
54	0.00	-1.08	-1.63	-8.08	-10.86
60	0.00	-1.07	-2.03	-8.05	-11.01
84	0.00	-1.40	-2.03	-7.82	-11.05
108	0.00	-1.40	-2.03	-7.75	-11.05
132	0.00	-1.40	-2.03	-7.75	-11.05
156	0.00	-1.40	-2.03	-7.75	-11.05
180	0.00	-1.40	-2.03	-7.75	-11.05
204	0.00	-1.40	-2.03	-7.75	-11.05
228	0.00	-1.40	-2.03	-7.75	-11.05
252	0.00	-1.40	-2.03	-7.75	-11.05
276	0.00	-1.40	-2.03	-7.75	-11.05
300	0.00	-1.40	-2.03	-7.75	-11.05

TABLE 4.5 DIFFERENCE IN COSINE RESPONSE FOR ANGLES LEFT

V_o cm/s	E_Θ %				
	$\Theta=10^{o}$	$\Theta=15^{o}$	$\Theta=20^{o}$	$\Theta=30^{o}$	$\Theta=40^{o}$
6	1.27	3.95	-2.67	14.71	31.15
12	1.23	3.75	0.00	10.42	30.95
18	1.61	2.45	0.30	10.91	29.90
30	.71	2.15	1.10	10.64	29.31
60	.69	0.81	3.30	10.59	27.79

TABLE 4.6 DIFFERENCE IN COSINE RESPONSE FOR ANGLES RIGHT

V_o cm/s	E_Θ %				
	$\theta=10^{o}$	$\theta=15^{o}$	$\theta=20^{o}$	$\theta=30^{o}$	$\theta=40^{o}$
6	1.27	3.95	4.00	10.29	18.03
12	1.23	3.75	3.87	7.64	18.25
18	1.61	3.67	3.78	7.73	16.49
30	1.65	3.58	4.93	6.92	16.62
60	1.49	2.32	4.32	6.98	16.47

TABLE 4.7 DATA FROM GRINDLEY (1971) FOR ANGLES LEFT

V_o cm/s	$\frac{\Delta N}{N_o}$ %				
	$\theta=10^o$	$\theta=15^o$	$\theta=20^o$	$\theta=30^o$	$\theta=40^o$
25	-1.17	-	-1.91	-2.47	-0.78
100	-1.47	-	-2.57	-2.81	-2.16

TABLE 4.8 DATA FROM GRINDLEY (1971) FOR ANGLES RIGHT

V_o cm/s	$\frac{\Delta N}{N_o}$ %				
	$\theta=10^o$	$\theta=15^o$	$\theta=20^o$	$\theta=30^o$	$\theta=40^o$
25	+0.36	-	-3.29	-7.53	-12.45
100	+0.78	-	-3.56	-8.15	-12.61

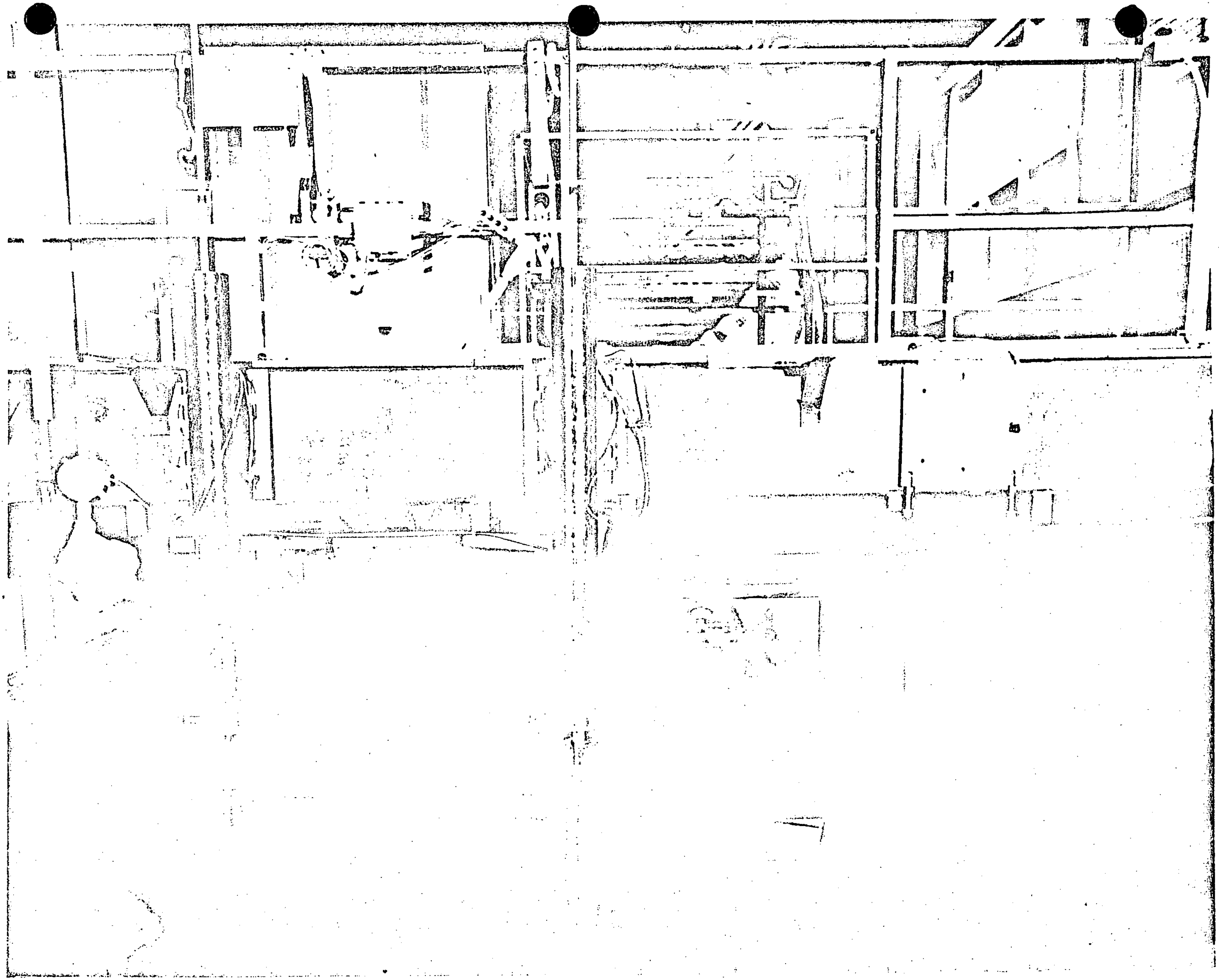


FIGURE 2.1 METER SUSPENDED AT REAR OF TOWING CARRIAGE

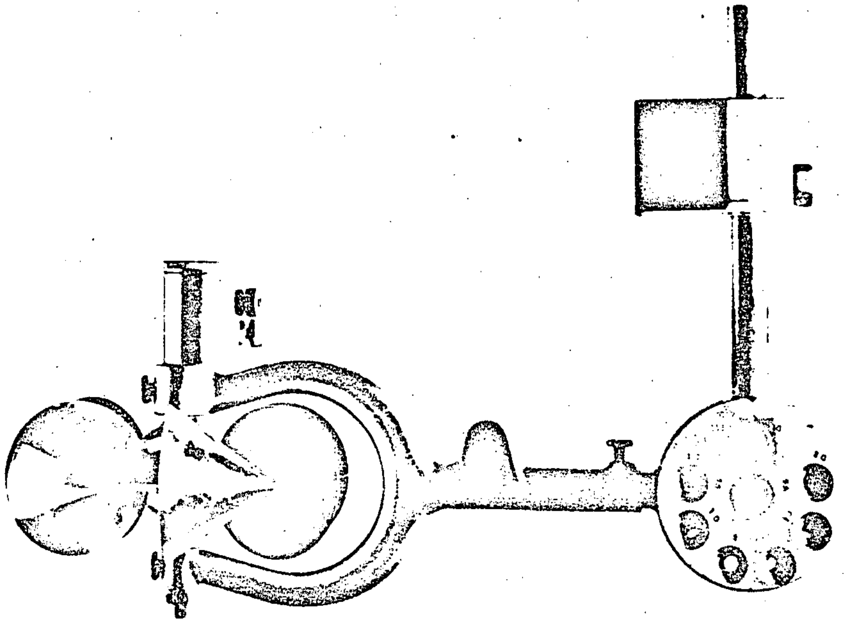


FIGURE 3.1(a) METER ATTACHMENT TO SUSPENSION ROD

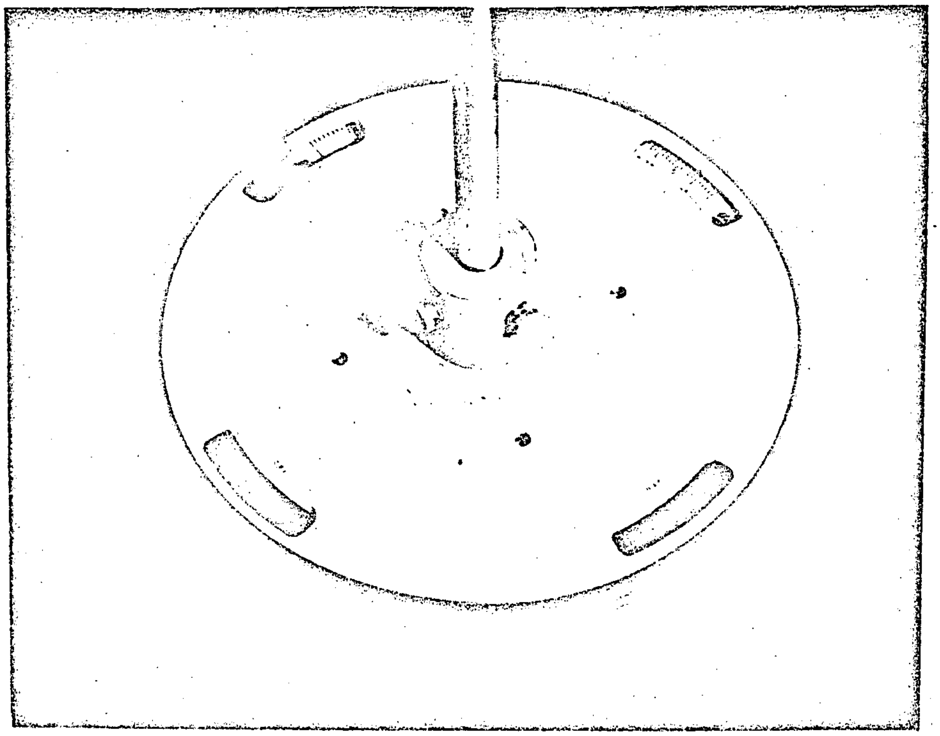


FIGURE 3.1(b) PROTRACTOR FOR HORIZONTAL ANGLES

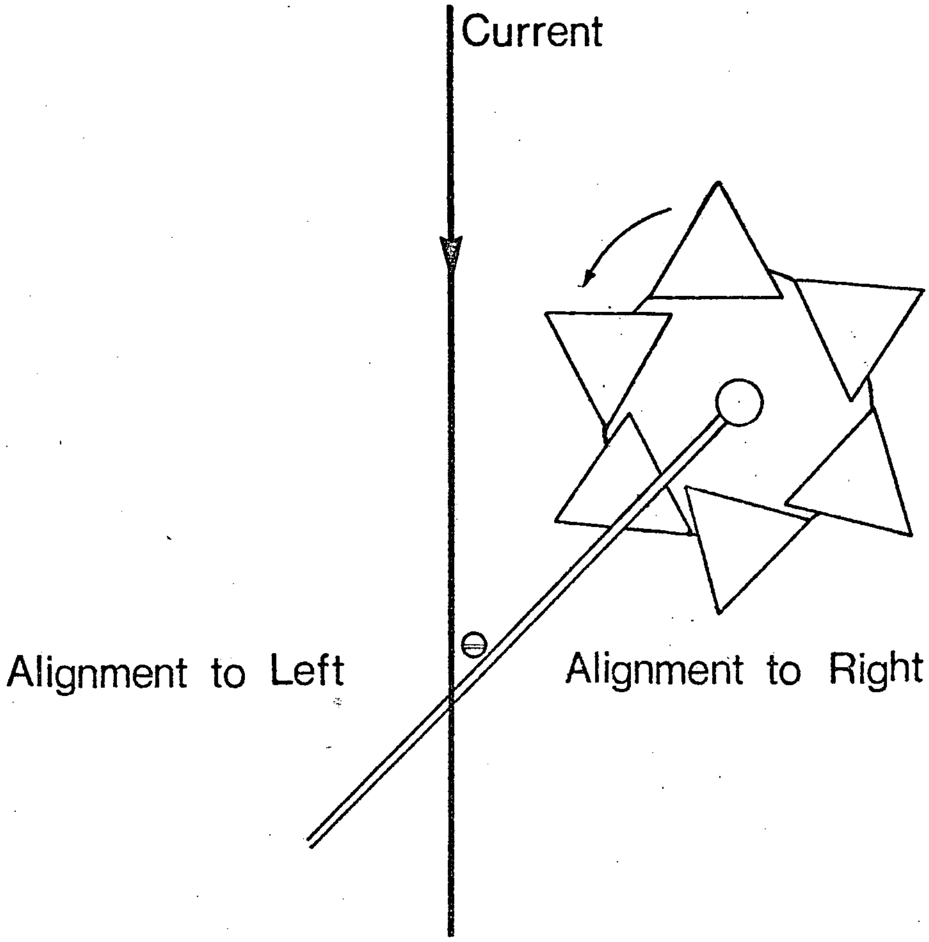


FIGURE 3.2 ALIGNMENT DEFINITION FOR PRICE METER

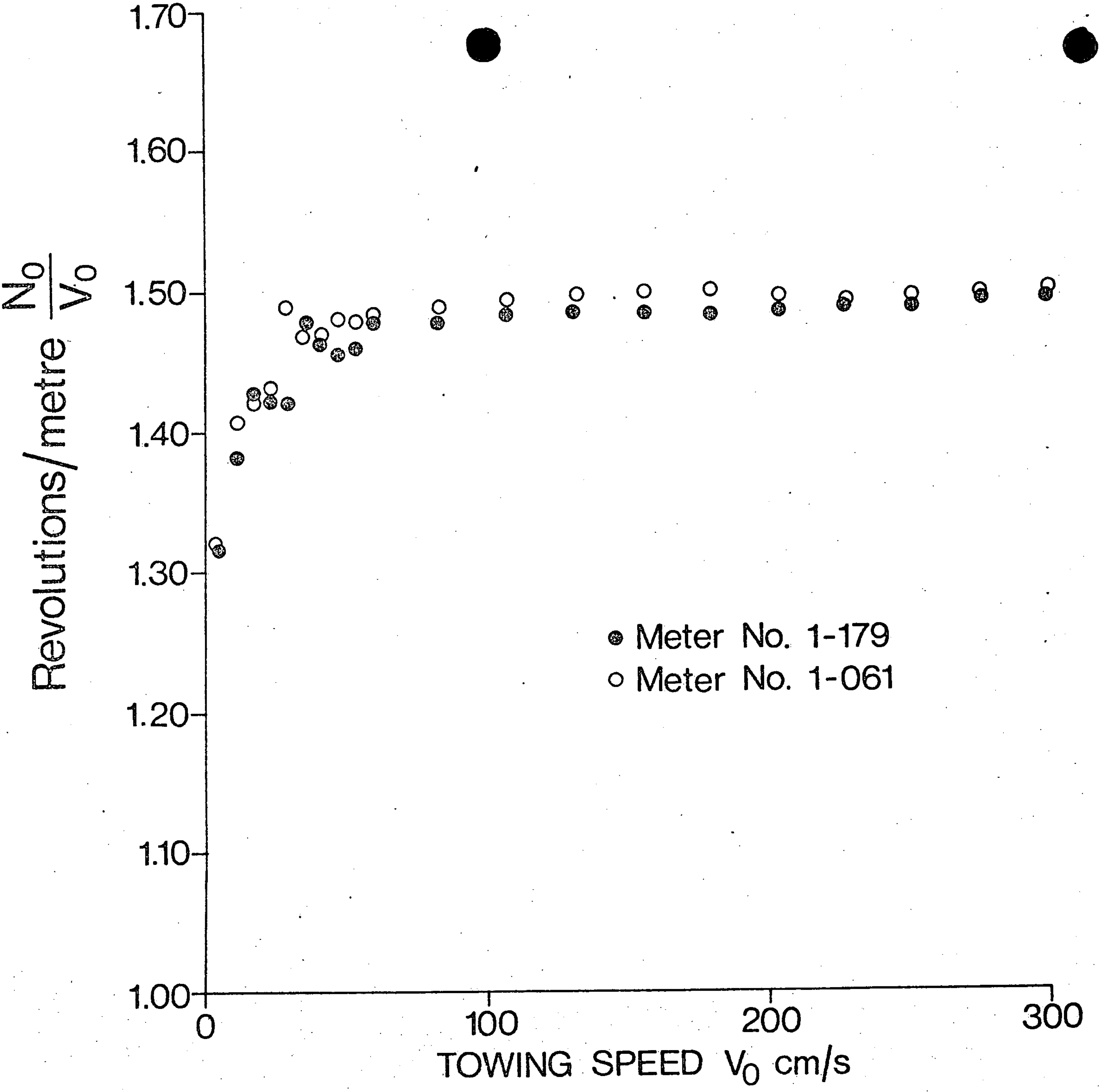


FIGURE 4.1 STANDARD CALIBRATION CURVES

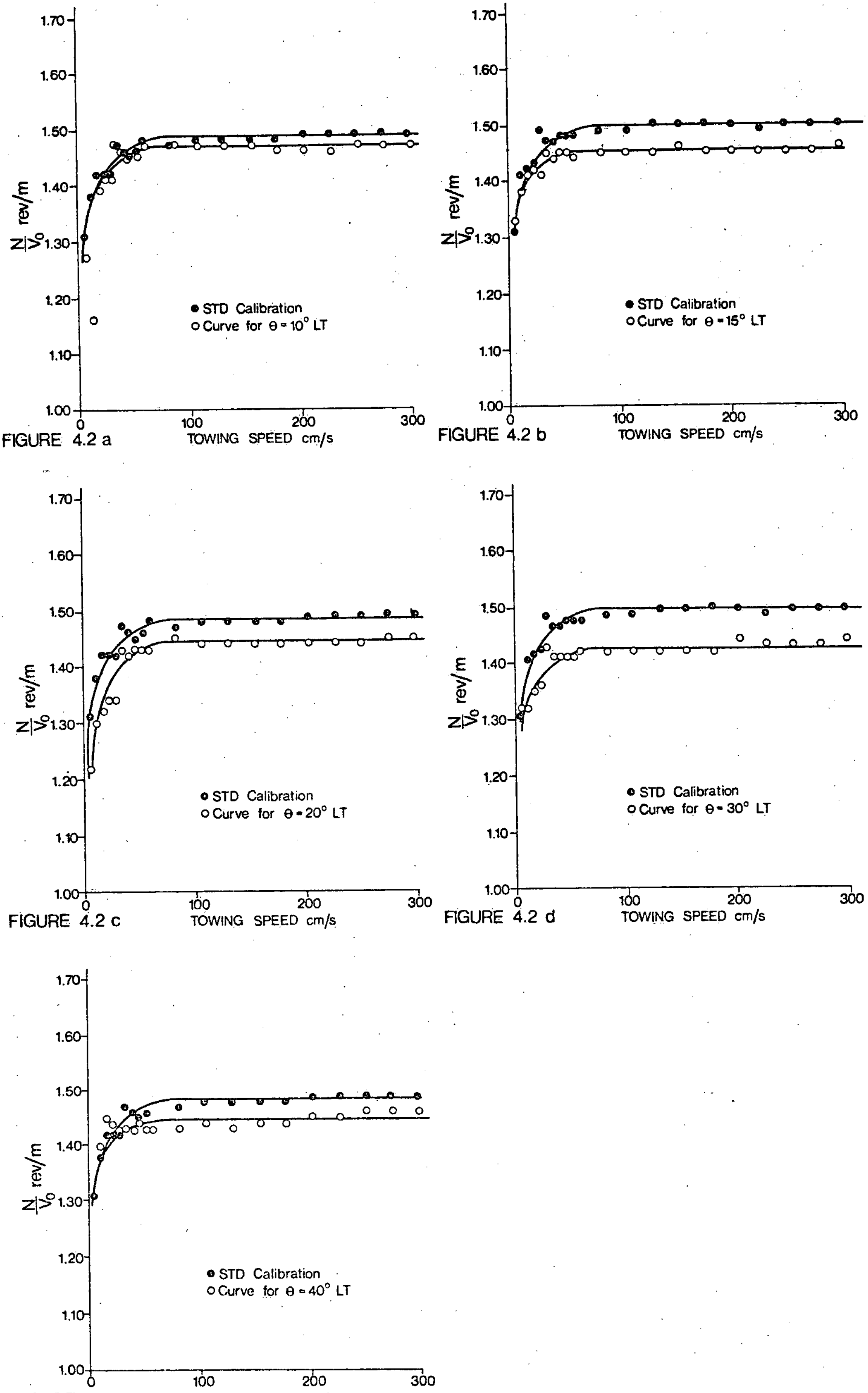


FIGURE 4.2 a

FIGURE 4.2 b

FIGURE 4.2 c

FIGURE 4.2 d

FIGURE 4.2 e

FIGURE 4.2 BEHAVIOR OF CURRENT METER AT DIFFERENT ANGLES OF ALIGNMENT TO THE LEFT

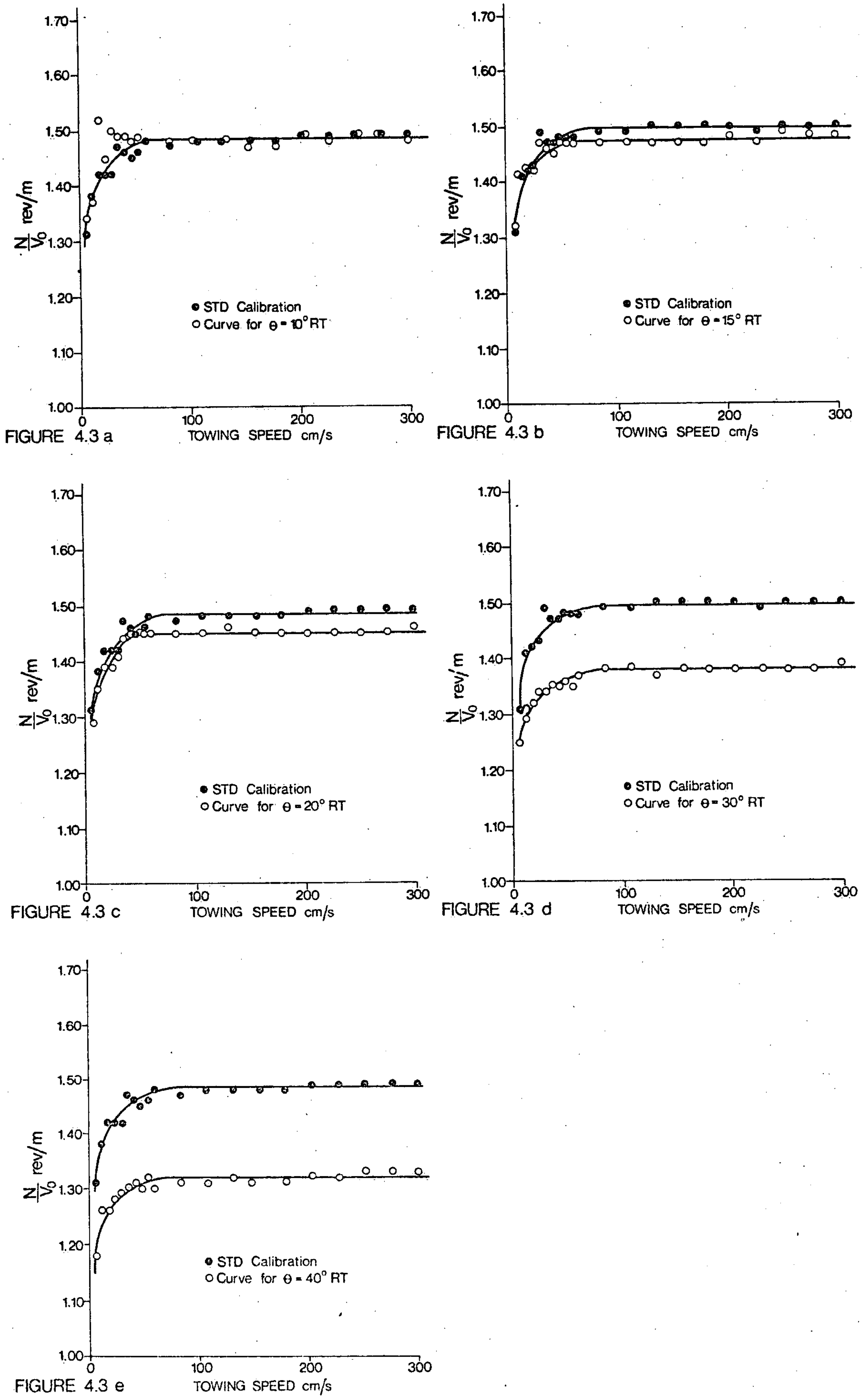


FIGURE 4.3 a

FIGURE 4.3 b

FIGURE 4.3 c

FIGURE 4.3 d

FIGURE 4.3 e

FIGURE 4.3 BEHAVIOR OF CURRENT METER AT DIFFERENT ANGLES OF ALIGNMENT TO THE RIGHT

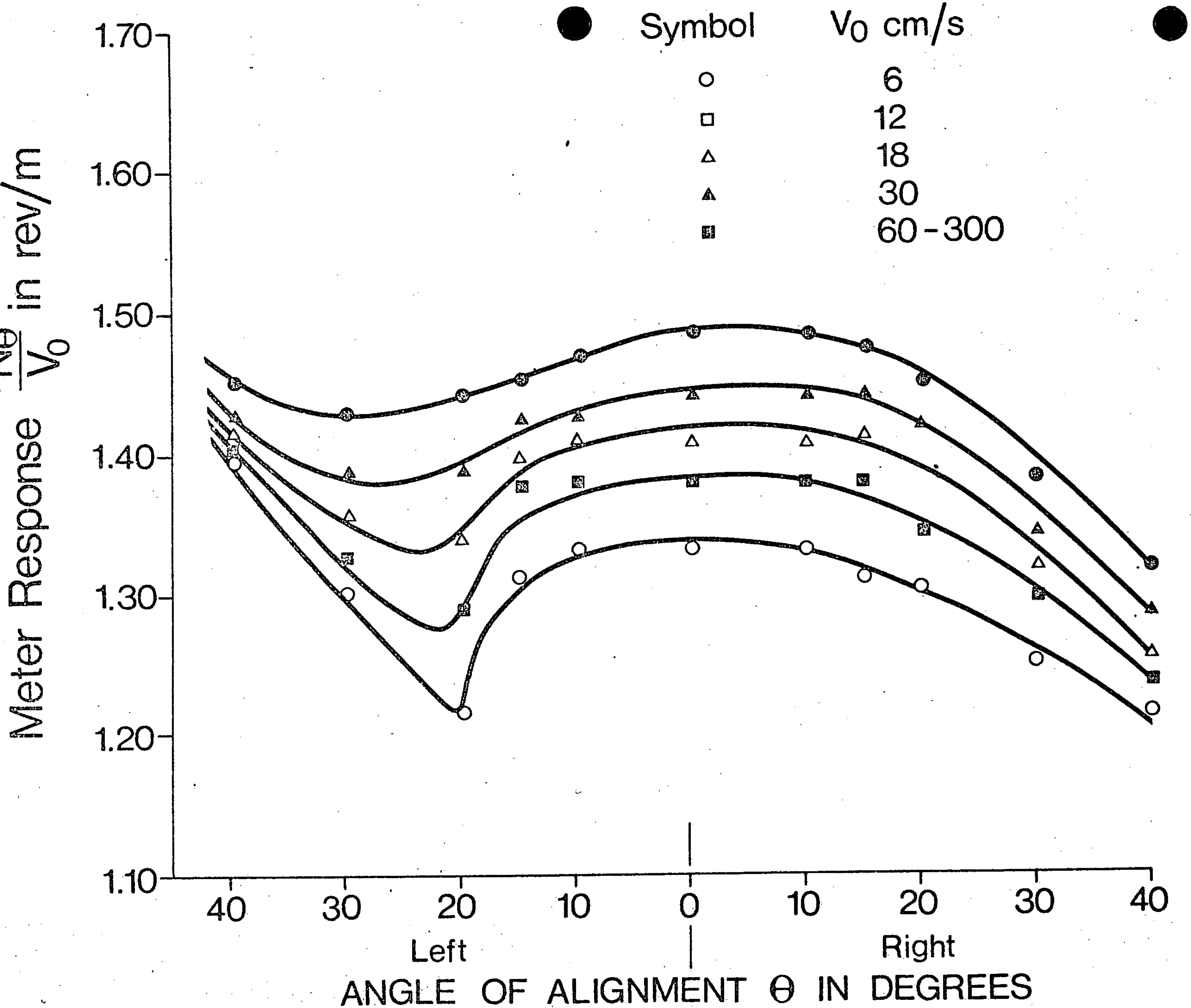


FIGURE 4.4 VARIATION OF METER RESPONSE WITH ALIGNMENT FOR CONSTANT SPEED

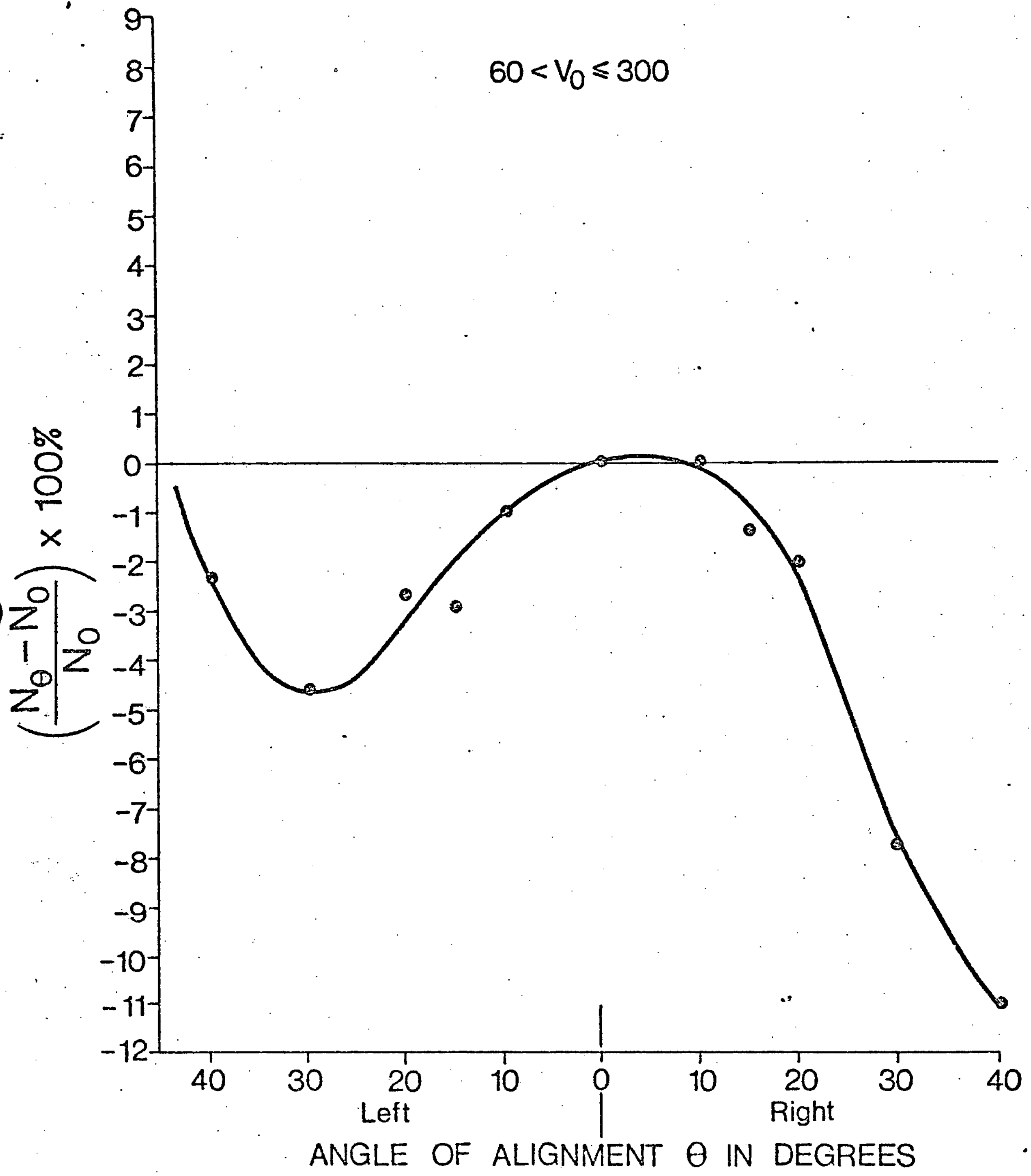


FIGURE 4.5 VARIATION OF PERCENT ERROR WITH ALIGNMENT FOR SPEEDS GREATER THAN 60 cm/s

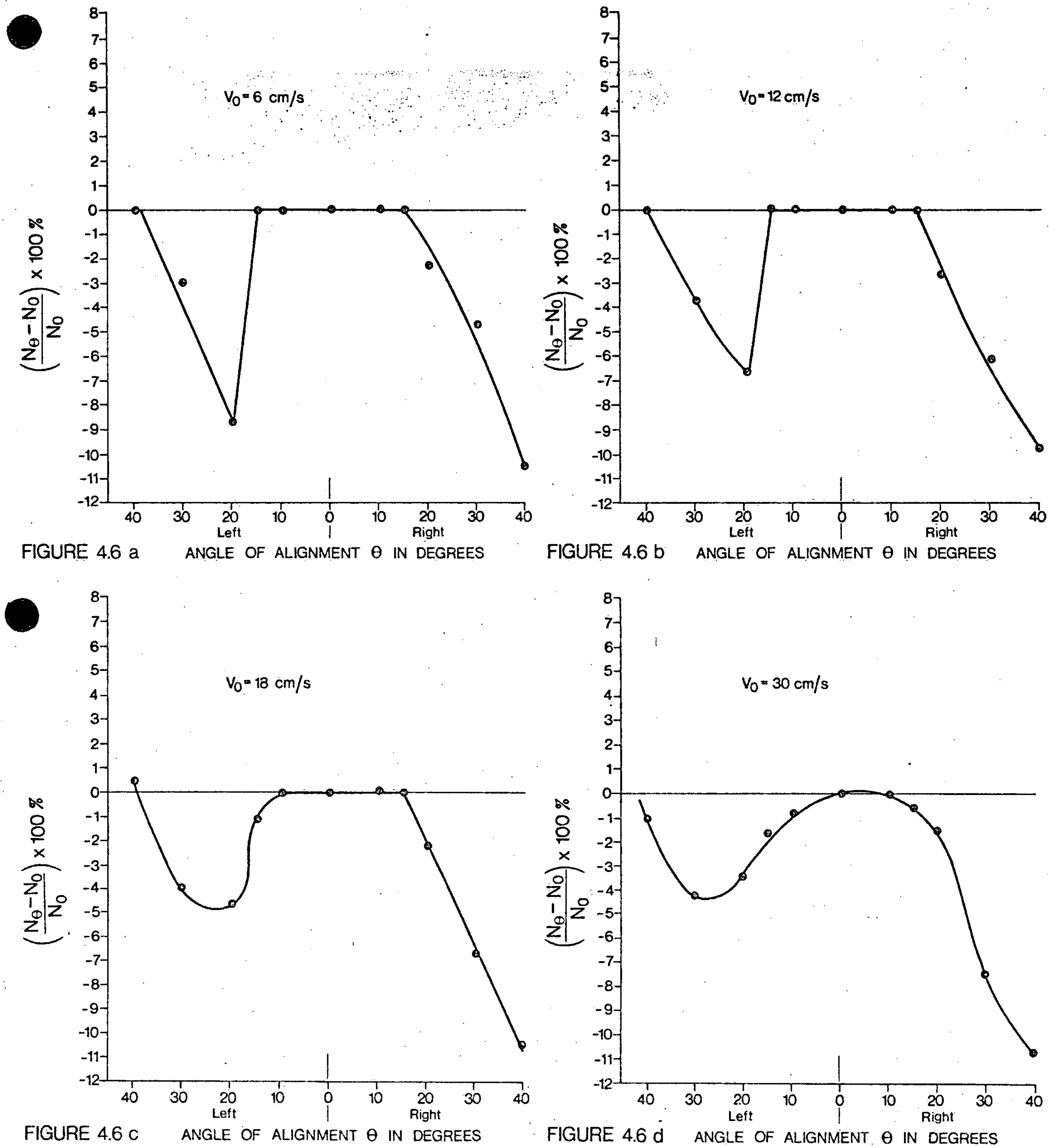


FIGURE 4.6 a

FIGURE 4.6 b

FIGURE 4.6 c

FIGURE 4.6 d

FIGURE 4.6 VARIATION OF PERCENT ERROR WITH ALIGNMENT FOR FIXED SPEED

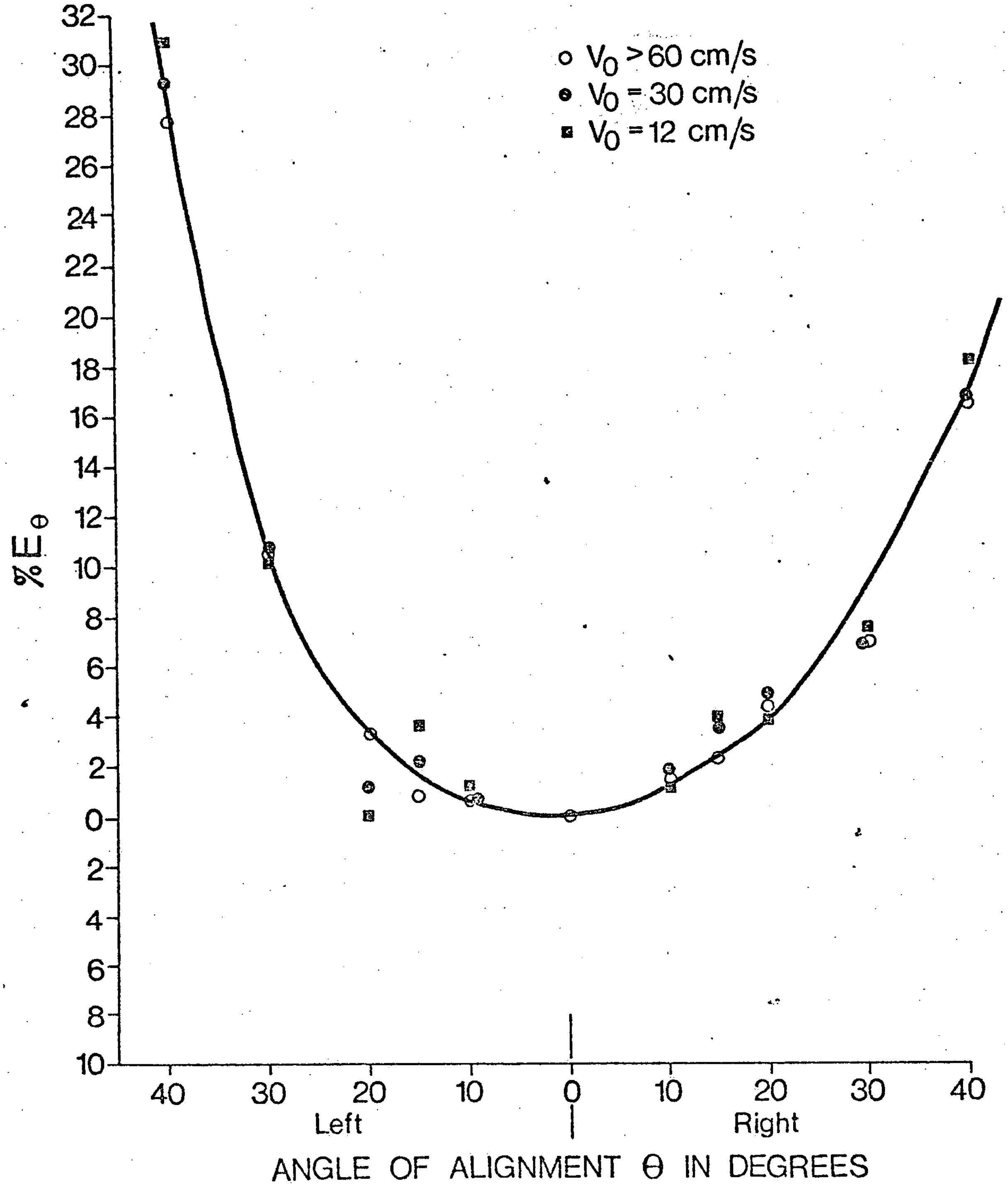


FIGURE 4.7 DIFFERENCE IN COSINE RESPONSE FOR VARIOUS SPEEDS

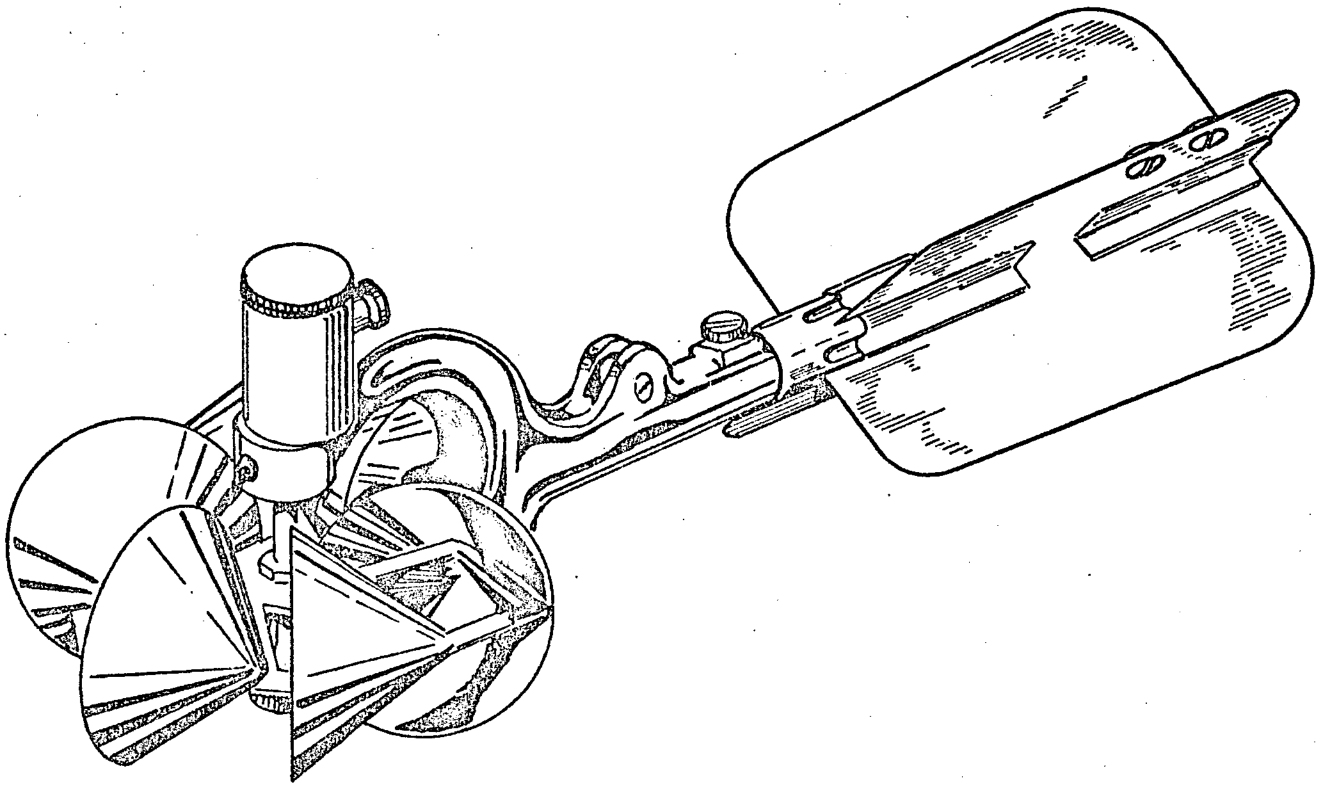


FIGURE 4.8 PRICE METER WITH TAIL FIN

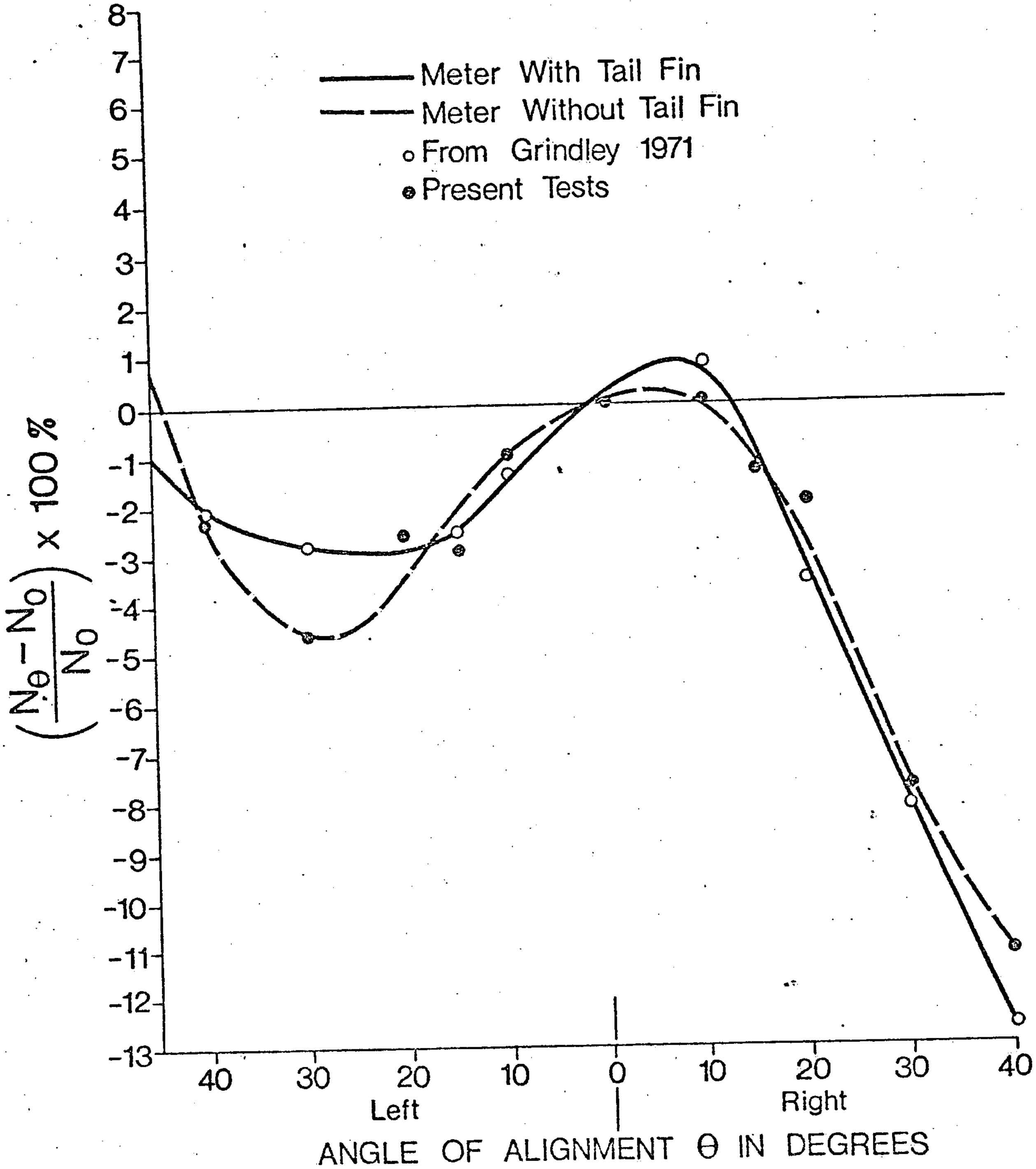
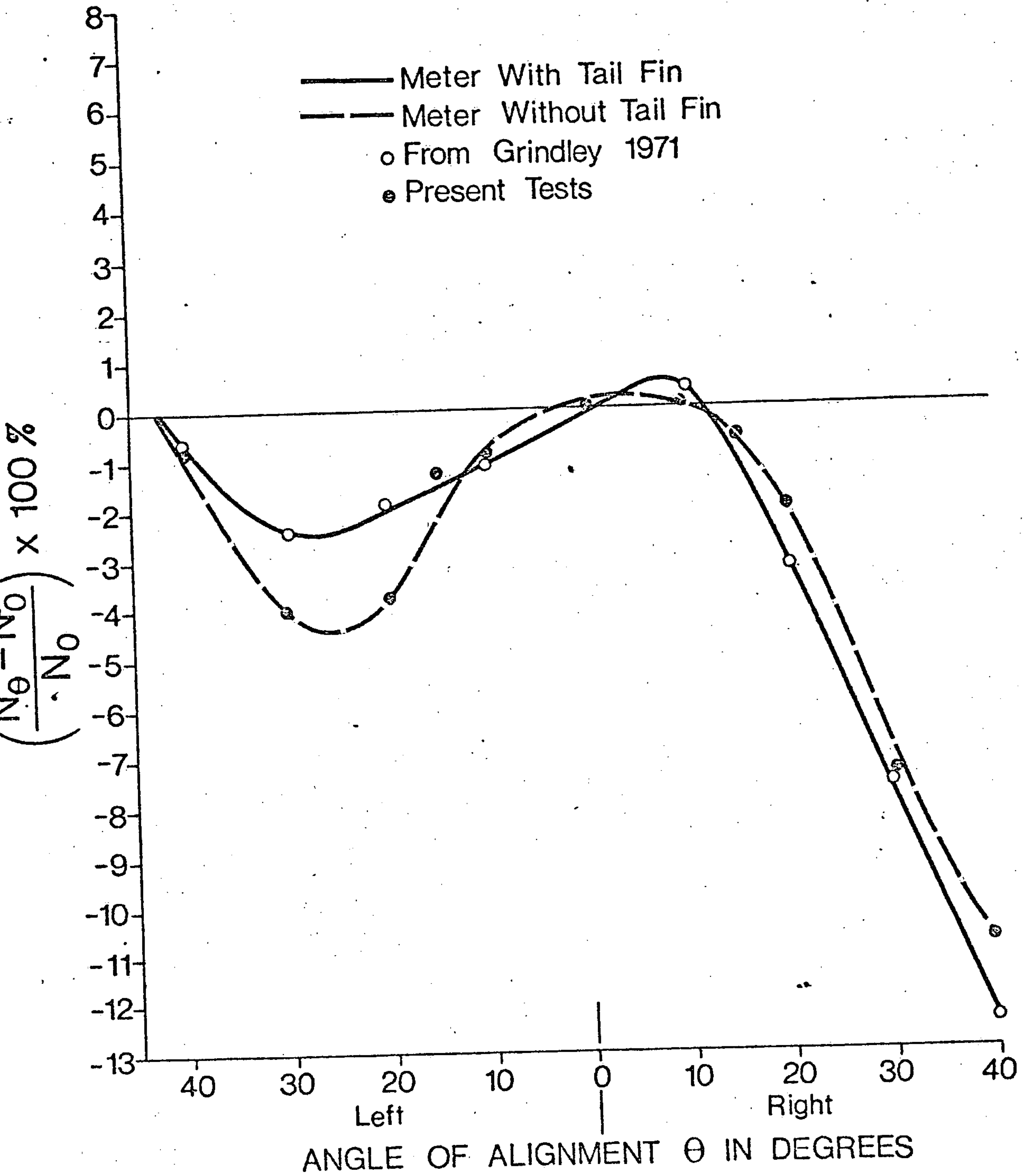


FIGURE 4.9 EFFECT OF TAIL FIN WHEN TOWING SPEED IS GREATER THAN 60 cm/s



IGURE 4.10 EFFECT OF TAIL FIN WHEN TOWING SPEED IS 25 cm/s

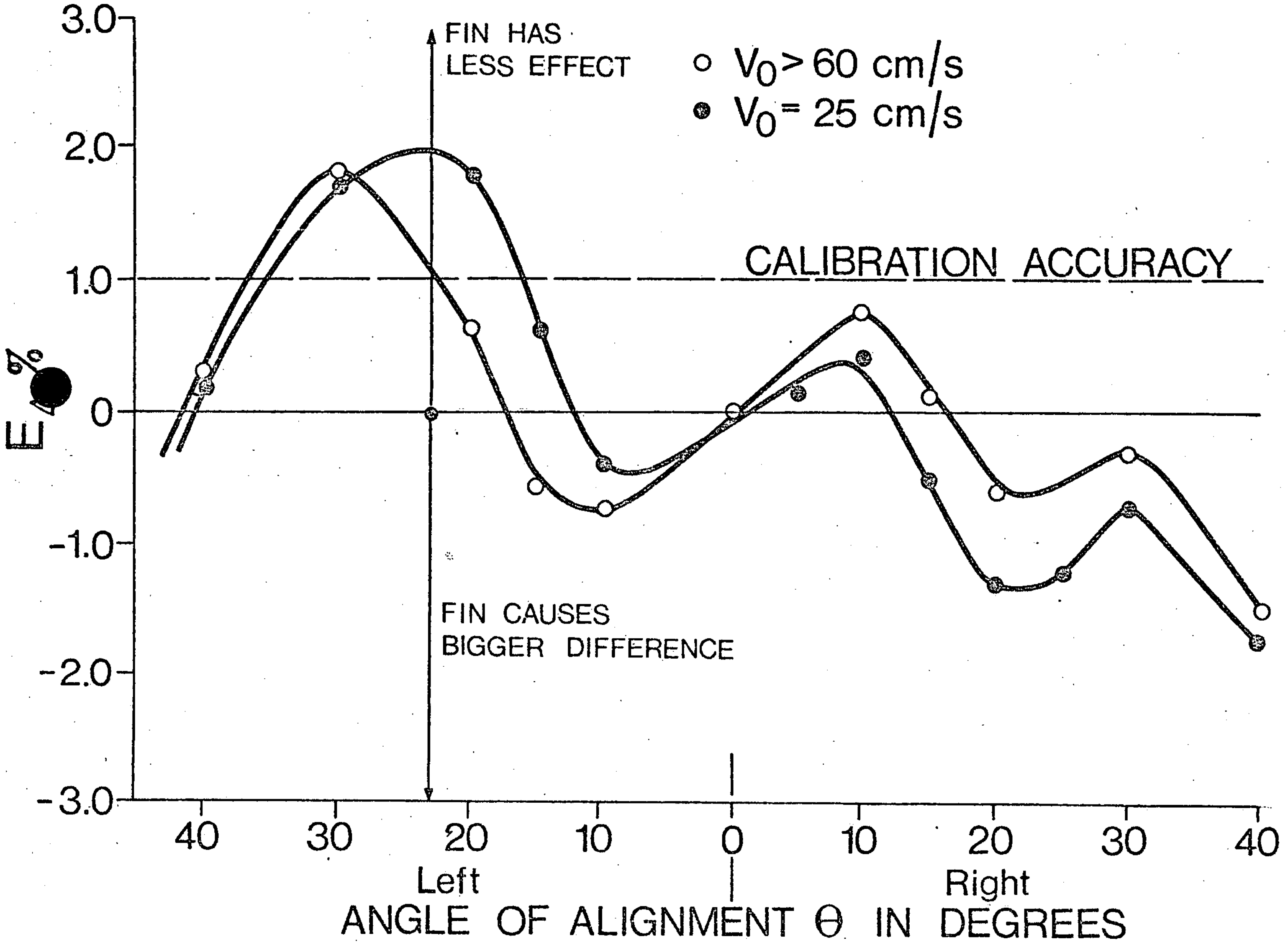


FIGURE 4.11 DISTRIBUTION OF E_Δ