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EFFECT OF WINTER SOUNDING WEIGHT ASSEMBLIES ON THE PERFORMANCE OF THE PRICE CURRENT METER

by

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MANAGEMENT PERSPECTIVE

Over the years different types of sounding weight suspensions for the Price current meter have been developed for measurement of stream flows under ice cover. These suspension assemblies have been designed to be sufficiently compact to permit deployment through the 20 cm diameter hole drilled through the ice. Unfortunately, improvements in meter deployment have been made at the expense of hydrodynamic performance of the suspension assembly. In this report the effects of the three types of sounding weight suspensions used by the Water Survey of Canada for flows under ice cover have been identified. The results lead the way toward a better understanding of the factors which contribute to the response of the Price current meter.

This work was conducted by the Research and Applications Branch of the National Water Research Institute for the Water Survey of Canada.

PERSPECTIVE DE GESTION

Au fil des ans, divers types d'attaches munies de poids ont été mises au point pour les courantomètres Price en vue de mesurer l'écoulement sous une couche de glace. Ces attaches ont été conçues de façon à être suffisamment compactes pour pouvoir être utilisées dans des trous de 20 cm de diamètre forés dans la glace. Malheureusement, les améliorations des possibilités d'utilisation des courantomètres se sont produites aux dépens de la performance hydrodynamique des attaches. Les auteurs présentent ici les effets des trois types d'attaches munies de poids utilisées par la Division des relevés hydrologiques du Canada pour mesurer l'écoulement sous la glace. Les résultats permettront de mieux comprendre les facteurs qui influent sur la réponse du courantomètre Price.

La présente étude a été réalisée par la Direction de la recherche et des applications de l'Institut national de recherche sur les eaux pour la Division des relevés hydrologiques du Canada.

SUMMARY

Calibrations of the Price current meter with three different types of sounding weight suspensions were conducted. The meter suspensions are used for the measurement of flows in rivers with a solid ice cover. The effect of the suspensions on the meter response was identified and found to be strongly dependent on the flow velocity. The test results indicate that mathematical expressions could be developed to define the effect of the suspension assemblies. Once such expressions have been defined for each suspension type, general calibration equations can be developed.

RÉSUMÉ

Les auteurs ont procédé à l'étude du courantomètre Price équipé de trois divers types d'attaches munies de poids. Les attaches servent lors de la mesure de l'écoulement des cours d'eau recouverts de glace. L'effet des attaches sur la réponse du courantomètre a été déterminé; on a montré que cet effet dépendait grandement de la vitesse de l'écoulement. Les résultats de l'essai indiquent que des expressions mathématiques pour définir l'effet des attaches pourraient être formulées. Les auteurs ont élaboré une expression mathématique pour représenter l'effet de chacun des types d'attaches; il est possible de formuler des équations d'étalonnage générales.

TABLE OF CONTENTS

1.0 INTRODUCTION

The Water Survey of Canada (WSC) is in the process of reviewing measurement standards and methods of flow measurement in rivers with ice cover. A major thrust of this effort will be a carefully designed flow measuring program at selected, representative, existing hydrometric stations.

Flow measurements are made with the Price current meter, which, depending on conditions, may be suspended into the flow using one of three winter weight assemblies. It is known that the presence of the sounding weight affects the performance of the meter rotor, however, information on such effects with winter weights is very limited. It was shown by Engel and Dezeeuw (1984), that when the Price meter was used with standard Columbus Sounding weight suspensions, the response of the meter could be significantly affected by the presence of the weights. In addition it was shown that current meter calibrations are unique for a given type of suspension configuration. This means that careful attention must be given to the calibrations of current meter assemblies that are going to be used for the experimental flow measurement program.

The WSC presently uses three types of winter sounding weights, namely, the NACA, the Pancake and the Slush-N-all. In order to investigate the effect of these sounding weights on the performance of the current meters, some preliminary tests were conducted in the towing tank of the National Water Research Institute (NWRI) in Burlington, Ontario. The results are presented in this report.

This report was prepared to provide information to the Committee for the Measurement of Flow Under Ice of the WSC.

2.0 ANALYTICAL CONSIDERATIONS

There are basically two types of suspensions that are used with the Price current meter, namely, rod suspension and cable suspension. When the rod suspension is used there is only one way that the meter is attached to the standard steel calibration rod with circular cross-section having a diameter of 20 mm. In this case the meter is mounted ahead of the free end of the steel rod, is virtually free from any peripheral effects and the calibration curve should give a good representation of the behaviour of the meter itself.

When sounding weights are used, the flow around the meter is affected by the proximity and the shape of the weight. In addition, because the meter is fixed rigidly into the weight assembly, there is no provision for the meter to maintain a proper horizontal alignment similar to that obtained when the Columbus type weights are used with the model 622AA Price meter. The resulting vertical misalignment due to downstream deflections of the meter-weight assembly, causes the meter to under-register the true velocity of the flow (Engel and Dezeeuw, 1979). As a result of the effects induced by the sounding weight, one can expect a significant difference in the response of the meter with rod suspension and weight suspension. The difference in the meter response can be revealed by considering separately the calibration equations for the meter with rod and weight suspension.

2.1 Calibration Equation For Rod Suspended Meter

It has been shown by Engel (1989), that the calibration equation for a rod suspended Price meter can be considered to be composed of a frictionless linear component and a non-linear component which accounts for the frictional properties of the meter. The calibration equation can be expressed as the sum of these two components and is given by

$$V_R = AN + V_o e^{-kN} \qquad (1)$$

where V_R = the average flow velocity measured with the rod suspended meter, N = the rate of rotation of the meter rotor in revs/s, V_o = the threshold velocity of the rotor, and A and k are coefficients.

2.1.1 The coefficient A

The coefficient A represents the slope of the linear frictionless component and is given by

$$A = \left[\frac{K + 1}{K - 1}\right]\frac{D}{\pi} \qquad (2)$$

where K is a dimensionless coefficient which reflects the drag characteristics of the conical elements of the meter rotor, D = the effective diameter of the rotor as shown in Figure 1, and π = 3.14.... It can be seen from equation (2) that the slope of the frictionless component of the calibration equation depends primarily on the shape and orientation of the conical elements of the rotor as well as its effective diameter. Physically, A represents the equivalent pitch of the rotor which is defined as the distance through which the meter must be towed to achieve one complete revolution of the rotor. The size of the pitch is an indicator of the sensitivity of the meter. In comparing two meters, the meter having the smaller pitch has the greater sensitivity.

2.1.2 The threshold velocity V_o

Theoretically, the threshold velocity is the maximum velocity for which the meter rotor will remain stationary. In other words, it is the flow velocity at which the rotor is on the verge of the beginning of rotation. For this critical condition it was shown by Engel (1989), that the threshold velocity can be expressed as

$$V_o = \frac{bT_o}{\sqrt{\rho\gamma}\; D^{7/2}} \qquad (3)$$

dictates the rate at which the non-linear component of equation (1) approaches the linear component. For a given value of V_o, the component with the largest value of k will have the largest rate of decline.

The rate of change of the non-linear component reflects the rate of change of the resistance in the meter. Therefore, one can expect that a meter with a high static resistance torque T_o will have a smaller value of k than a meter for which T_o is smaller. Since the threshold velocity is directly proportional to T_o, then k should be directly related to V_o. Therefore an increase in V_o should be reflected by an increase in k.

2.2 "Least Squares" Fit of Rod Suspended Calibration Equation

An optimized fit of equation (1) to the calibration data can be obtained by ensuring that the sum of the squared deviations between the observed values of velocity and their estimated values are as small as possible (Stanton, 1961). Mathematically, this is expressed as

$$S = \sum_{i=1}^{n} (V_i - AN_i - V_o e^{-kN_i})^2 \qquad (4)$$

where S = the sum of the squared deviations, n = the total number of data pairs of V_i and N_i and i = the i'th data pair in the range from 1 to n. For the sake of simplicity the subscript i is dropped and its presence is taken for granted. The sum S is a minimum for the conditions

$$\frac{\partial S}{\partial A} = \frac{\partial S}{\partial V_o} = \frac{\partial S}{\partial k} = 0 \qquad (5)$$

where T_o = the static resistance torque in the meter at the onset of rotor rotation, ρ = the density of the fluid (ie: usually water), γ = the specific weight of water and b is a dimensionless, experimental coefficient.

The most important variable affecting the threshold velocity is the static resistance torque T_o. According to equation (3), one can expect that the threshold velocity will increase as the resistance T_o increases. Clearly, for best performance, T_o should be kept as small as possible. In the case of the Price meter, the dependence of the threshold velocity on the static resistance torque has significant implications. The standard Price meter has "cat-whisker" electrical contact brushes which form part of the pulse signal generator circuit. The overall value of T_o is strongly dependent on how snugly these contact brushes are set. It is therefore important that the adjustments and settings made at the time of meter calibration are maintained during use in the field.

Equation (3) also shows that the threshold velocity is inversely proportional to the rotor diameter. Therefore, for a given resistance T_o, the threshold velocity can be significantly decreased by a small increase in the effective diameter D.

The effect of fluid density on the threshold velocity can be seen in Figure 2 in which data for calibrations of a Price meter in both air and water are plotted as V vs. N. It is quite clear that the threshold velocity for the meter when the fluid is air is much larger than when the fluid is water. Fortunately, changes in the density of water, as a result of temperature changes are small relative to the density differences between air and water. As a result density changes of the water normally encountered do not affect the response of the meter rotor significantly.

2.1.3 The effect of k

The exponent kN in equation (1) is dimensionless and therefore k has the units of s/rev. Physically, k is a decay constant, the magnitude of which

which results in a set of linear equations from which A and V_o can be expressed in terms of the third coefficient k. The values of A and V_o are given by

$$A = \frac{(\Sigma Ve^{-kN}) - Vo(\Sigma e^{-2kN})}{(\Sigma Ne^{-kN})} \qquad (6)$$

and

$$V_0 = \frac{(\Sigma NV)(\Sigma Ne^{-kN}) - (\Sigma N^2)(\Sigma Ve^{-kN})}{(\Sigma Ne^{-kN})(\Sigma Ne^{-kN})-(\Sigma N^2)(\Sigma e^{-2kN})} \qquad (7)$$

The solution of equations (6) and (7) requires a trial and error procedure. A value of k is initially assumed and values of A and V_o are computed. These initial values of A and V_o and the assumed value of k are then used to solve for the sum S in equation (4). Additional values of k are chosen and the process is repeated until the value of k which gives the minimum value of S has been found. The minimum value of k together with the corresponding values of A and V_o provide the best fit of equation (1) to the calibration data.

Data from Engel (1989) are plotted for a typical rod suspended winter Price meter in Figure 3. Superimposed are the "least squares" fits of equation (1). The figure clearly shows the excellent agreement between the calibration data and the fitted curves. Therefore the fitted curves will be used as the reference calibration against which calibrations for the meters with winter weight suspensions will be compared.

2.3 Effect of Sounding Weights

In order to determine the effect of the winter weight suspensions, the total calibration equation is considered to be composed of the frictionless and frictional components of the meter itself and a component which accounts for the effect of the sounding weights. Recalling that the calibration equation of the rod suspended meter virtually reflects the response of the meter itself, then the calibration equation for meters with weight suspensions may be expressed as

$$V_s = AN + V_o e^{-kN} + F(N) \qquad (8)$$

V_s = velocity obtained with the meter-weight assembly and F(N) is a function of N which accounts for the meter response component as a result of the presence of the sounding weights and all other terms have already been defined. It is clear from equation (8) and examination of equation (1), that the component F(N) can be determined as the difference

$$F(N) = V_s - V_R \qquad (9)$$

where V_R = the velocity obtained from the calibration equation for the rod suspended meter. The behaviour of F(N) can be examined using data of calibrations with winter weight suspensions conducted in the towing tank at the National Water Research Institute.

3.0 EXPERIMENTAL EQUIPMENT

3.1 Meter Suspensions

Each of the three winter sounding weights was fitted with a Price winter type meter. The three types of sounding weights are given in Figures 4,5 and 6.

The NACA weight weighs about 8 Kg in air and has been found to be stable in flows of 2 m/s. The Pancake weight weighs about 16 Kg in air and has been found to be stable in flows up to 2.5 m/s. The Slush-N-All weighs about 16 Kg, however there are no reports on the velocity to which it is limited.

3.2 Towing Tank

The towing tank used to conduct the calibration tests on the winter meters and their suspensions, 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 strength, stability and to reduce possible vibrations and convection currents.

At one end of the tank is an overflow weir. Waves arising from the 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.

3.3 Towing Carriage

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

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

The maximum speed of 600 cm/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.

3.4 Towing Speed

The average speed data for the towing carriage is obtained by recording the voltage pulses emitted from the 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 millimetre of travel. 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 20 cm/s and 300 cm/s, the error in the mean was less than 0.15% at the 99% confidence level. Occasionally, these tolerances are exceeded as a result of irregular occurrences such as "spikes" in the data transmission system of the towing carriage. Tests with such anomalies are automatically abandoned.

3.5 Rate of Revolution of the Meter Rotor

The Price meter is equipped with a contact closure mechanism which gives a voltage pulse for each complete revolution of the rotor. The pulses generated by the rotor are transmitted to a data acquisition module which begins counting the revolutions after the first pulse has been received. This ensures that all puses counted represent complete revolutions. In order to obtain the rate of rotation of the rotor in revolutions per second, time is measured simultaneously with the counting of the revolutions using a crystal clock.

4.0 EXPERIMENTAL PROCEDURE

4.1 Meter Preparation

Prior to testing, each meter underwent the following inspection:

a) the pentagear was checked to ensure that it was operating freely;

b) the contact wire was cleaned and adjusted for tension to provide a good contact;

c) all moving parts were lubricated.

Following the inspection the meters were hung in a wind tunnel where they were spun for two hours to ensure that all moving parts were "run-in".

4.2 Towing Tests

At the beginning of the tests a winter type Price meter was secured in the meter mounts of each of the three types of winter sounding weights. The assembly was suspended with the standard steel cable from the rear of the towing carriage at a depth of about 1m below the water surface. This depth was chosen to avoid surface effects and to allow for the upward deflection of the meter-sounding weight assembly due to the drag forces exerted by the water. Tests were conducted for towing speeds from 20 cm/s to 250 cm/s. Each time the meters were towed, care was taken that steady conditions prevailed when measurements of velocity and revolutions of the rotors were recorded. The length of the waiting time between successive tows of the meters was in accordance with criteria established by Engel and Dezeeuw, (1977) or better. For each test, the towing speed, revolutions of the meter rotors and type of sounding weight were recorded. Water temperature was not noted because temperature changes during the tests were small and therefore do not affect the meters significantly (Engel, 1976). The data from these tests are given in Tables 1, 2 and 3.

5.0 DATA ANALYSIS

5.1 Overall Meter Response

The data in Tables 1,2 and 3 were used to compute values of N/V and these were plotted as N/V vs. V in Figures 7 for the Slush-N-All, Pancake and Naca sounding weights respectively. The plot gives a relative comparison of the meter response in the presence of the different weights. The rating with the NACA sounding weight gives the largest values of N/V for velocities greater than 20 cm/s. When velocities are greater than 50 cm/s, values of N/V decrease gradually from a value of 1.46 to a value of 1.41 at 250 cm/s. The decline in the values of N/V is an indication that in this velocity range the meter calibration usually given as V vs. N is not linear. As velocities decrease from 50 cm/s, values of N/V decrease with the rate of decrease increasing as velocities decrease. The behavour of the meter with the Slush-N-All and the Pancake weight assembly is quite similar for velocities greater than 40 cm/s. In both cases the decline in N/V as velocities increase is less than that obtained with the NACA weight, indicating less non-linearity in the V vs. N relationship. For velocities less than about 50 cm/s, the performance obtained with the Slush-N-All weight is better than that obtained with the Pancake and the NACA weights. However, the observed variations in N/V at these low velocities may be partly due to differences in frictional effects because different meters were used with each weight. Nevertheless, considering that the meters were tested at velocities ranging from 20 cm/s to 250 cm/s, the frictional effects can be considered to be small. This uncertainty can be removed during any additional tests by using a single meter with each of the three sounding weights.

5.2 Comparisons with Calibrations of Rod Suspended Meter

The meter response with the three different sounding weight suspensions was compared by plotting values of N/V for the data in Tables 1,2 and 3, together with the curve of Figure 3 for a rod suspended meter, in Figures 8,9 and 10. The plots show that when the Pancake and the Slush-N-All weights are used, values of N/V are lower than those obtained with the rod suspension over the full range of velocities tested. This means that the presence of these sounding weights causes a reduction in the rate of rotation of the meter rotor for a given velocity. In the case of the NACA weight values of N/V coincide with the solid curve for velocities between 45 cm/s and 120 cm/s. Outside of this velocity range values of N/V are lower although the deficit is less than that observed with the other two sounding weights except when the velocity is 20 cm/s for which N/V is slightly larger than that obtained with the Pancake weight.

In Figure 12, the effect of the Pancake weight causes F(N) to decline initially for values of N from about 0.24 to 0.70. Thereafter, F(N) increases continuously, with the rate of increase increasing until a value of N = 1.4 has been reached. For values of N greater than this the rate of increase of F(N) is approximately constant and similar to that observed with the Slush - N - All weight. Values of F(N) reach a value of about 16 when N = 3.44.

In Figure 13, the shape of the F(N) function is much flatter than observed with either of the other two sounding weights. In addition, the predominantly non-linear segment of the curve extends over a wider range, with F(N) decreasing in the range of N from 0.24 to 1.0 and then increasing until at N = 1.6 the rate of change becomes approximately constant. Thereafter, F(N) increases to a value of about 8.6 when N =3.44.

In all three cases F(N) increases approximately linearly for values greater than about 1.4 in the case of the Slush-N-All and Pancake weights and 1.6 in the case of the NACA weight. The increase in the values of F(N) is partly due to the deflection caused by the drag of the flow on the suspended meter-weight assembly and partly due to changes in the flow field around the sounding weight as the flow velocities increase.

When the meter is deflected by the flow, its axis of rotation departs from the true vertical position because its longitudinal, streamwise axis is depressed below the horizontal plane. It has been shown by Engel and Dezeeuw (1979) that such a vertical misalignment causes the meter to under-register the true velocity. This measurement deficit increases with the velocity of the flow because, as a result of the increased drag, the deflection of the meter-weight assembly increases. In addition, the presence of the sounding weight and structural components designed to protect the rotor from ice impact damage, affect the flow field around the meter rotor (Engel, 1983; Kulin, 1977). As a result, secondary flows in the vicinity of the rotor are created and their intensity increases with the velocities of the main flow. These secondary flows affect the rate of rotation of the rotor.

The effect of the weights on the total calibration is also clearly revealed by the trend in the plotted data points relative to the solid curve for the rod suspended meter. The greatest similarity in trend is observed in Figure 8 between the solid curve and the Slush-N-All data. The plotted points suggest a smooth curve which exhibits some of the basic tendencies of the solid curve complemented by a component which tends to depart gradually from the solid curve towards higher and lower velocities. In the case of the data for the pancake weight in Figure 9, the similarity in trend with the solid curve is considerably less. The plotted data exhibit a sharp point of change in slope at a velocity of about 40 cm/s with N/V decreasing towards higher and lower velocities. Finally, examination of Figure 10 reveals a smoother transition of N/V from low to high velocities for the data obtained with the NACA weight suspension. The trend inherent in the plotted data is quite similar to that of the solid curve for veocities between 45 cm/s and 120 cm/s. For velocities outside of this range, the trend in the plotted data progessively departs from that displayed by the solid curve.

5.3 Separation of the Sounding Weight Effect

The effect of the sounding weights was revealed by an evaluation of F(N) in equation (3). Essentially, F(N) represents the difference between the velocity measured when the meter is used with a given sounding weight and the standard rod. Values of F(N) for the the Slush-N-All, Pancake and NACA weights are given in Tables 4, 5 and 6 respectively.

Values of F(N) for the three sounding weight assemblies were plotted as a function of N in Figure 11, 12 and 13. Examinations of these plots shows that, except for secondary variations, F(N) appears to be a characteristic function of N for each type of sounding weight. Smooth curves were fitted to the plotted points in order to further accentuate this functional tendency. In the case of the Slush-N-All weight the smallest effect on the meter response occurs at the lowest rate of rotation. Thereafter, F(N) increases slowly as N increases with the rate of increase increasing until when $N = 1.4$, the rate of increase becomes approximately constant, with F(N) reaching a value of about 17 when $N = 3.44$.

In the case of the Slush-N-All and the Pancake weights, the effects of meter deflection and distortion of the uniform flow field both contributed to the observed values of F(N) that were larger than those obtained with the NACA weight. This is most likely due to the fact that the NACA weight suspension provides the least interference with the main flow because the meter mount is the least intrusive of the three types of suspension systems.

5.4 Additional Test Requirements

The test results have shown that the effect of the sounding weights on the current meter response can be isolated and represented as a distinct functional component. In order to determine the consistency of the weight effect component for each of the types of weights used, it is necessary to conduct additional calibration tests. Tests should be conducted using only one current meter with five different weights of each type. This will ensure that any differences in F(N) will be due only to the sounding weight and any variabilty due to different current meters will be eliminated. The tests should consist of two parts: 1.) calibration of the meter with the corresponding weight suspension and 2.) calibration of the meter with rod suspension. In each case, values of F(N) can then be determined and their variability examined for the five weights of each type. The results can be used to establish the mathematical form for the F(N) vs. N relationship in order to arrive at a total single calibration equation for Price current meters with sounding weights used for flow measurements in rivers with ice cover.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 The response of a Price current meter with sounding weight suspension can be divided into three separate component: 1.) linear frictionless component, 2.) non linear frictional component and 3.) effect due to the presence of the sounding weight.

6.2 The effect of the sounding weight can be isolated as the difference in response of the meter with sounding weight suspension and rod suspension.

6.3 The effect on meter response was unique for each sounding weight type. The sounding weights can be ranked in the order of least effect on meter response as follows:

1. NACA
2. Pancake
3. Slush - N - All

The NACA weight has the smallest effect on the meter response because there is less interference by the meter mount and the weight.

6.4 The F(N) vs. N relationships for each type of weight show that it should be possible to develop mathematical expressions for these relationships. Once such expressions have been defined, general calibration equations for the Price meter in accordance with equation (8) for each type of sounding weight can be developed.

6.5 It is recommended to conduct further tests using a single current meter with five sounding weights of each type. This will make it possible to determine the variability in the F(N) vs. N relationships. The results will further contribute to the development of a calibration equation.

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TABLE 1

TEST DATA FOR SLUSH - N - ALL SUSPENSION

V cm/s	N rev/s
20.00	0.259
25.12	0.335
30.07	0.411
35.07	0.480
40.03	0.550
45.00	0.627
50.11	0.697
55.08	0.770
60.04	0.832
70.91	0.990
80.47	1.125
90.51	1.257
100.54	1.393
120.72	1.668
150.48	2.076
210.81	2.888
251.27	3.428

TABLE 2

TEST DATA FOR PANCAKE SUSPENSION

V cm/s	N rev/s
20.04	0.239
25.05	0.318
30.07	0.387
35.08	0.461
40.00	0.546
45.01	0.623
55.03	0.770
60.00	0.837
70.84	0.989
80.70	1.130
90.63	1.261
100.59	1.404
120.53	1.680
150.46	2.087
180.69	2.498
210.64	2.894
251.14	3.443

TABLE 3

TEST DATA FOR NACA SUSPENSION

V cm/s	N rev/s
20.04	0.249
25.05	0.338
30.11	0.426
35.08	0.497
40.10	0.572
45.06	0.650
50.05	0.730
55.03	0.808
60.00	0.880
70.84	1.037
80.70	1.178
90.63	1.327
100.59	1.467
120.53	1.757
150.46	2.172
180.69	2.576
210.64	2.993
251.14	3.549

TABLE 4

Values of F(N) FOR SLUSH - N - ALL SUSPENSION

V_s cm/s	N rev/s	V_R cm/s	F(N) cm/s
20.00	0.259	18.36	1.64
25.12	0.335	23.49	1.63
30.07	0.411	28.63	1.78
40.03	0.550	38.03	2.00
45.00	0.627	43.25	1.75
50.11	0.697	48.00	2.11
55.08	0.770	52.95	2.13
60.04	0.832	57.16	2.88
70.91	0.990	67.89	3.02
80.47	1.125	77.07	3.40
90.51	1.257	86.06	4.45
100.54	1.393	95.32	5.22
120.72	1.668	114.06	6.66
150.48	2.076	141.89	8.59
210.81	2.888	197.32	13.49
251.27	3.428	234.20	17.07

TABLE 5

Values of F(N) FOR PANCAKE SUSPENSION

V_s cm/s	N rev/s	V_R cm/s	F(N) cm/s
20.04	0.239	17.01	3.03
25.05	0.318	22.34	2.71
30.07	0.387	27.00	3.07
35.08	0.461	32.01	3.07
40.00	0.546	37.76	2.24
45.01	0.623	42.98	2.03
55.03	0.770	52.95	2.08
60.00	0.837	57.50	2.50
70.84	0.989	67.83	3.01
80.70	1.130	77.41	3.29
90.63	1.261	86.33	4.30
100.59	1.404	96.07	4.52
120.53	1.680	114.88	5.65
150.46	2.087	142.64	7.82
180.69	2.498	170.69	10.00
210.64	2.894	197.73	12.91
251.14	3.443	235.22	15.92

TABLE 6

Values of F(N) FOR NACA SUSPENSION

V_s cm/s	N rev/s	V_R cm/s	F(N) cm/s
20.04	0.249	17.69	2.35
25.05	0.338	23.69	1.36
30.11	0.426	29.64	0.47
35.08	0.497	34.44	0.64
40.10	0.572	39.52	0.58
45.06	0.650	44.81	0.25
50.05	0.730	50.23	-0.18
55.03	0.808	55.53	-0.50
60.00	0.880	60.42	-0.42
70.84	1.037	71.09	-.025
80.70	1.178	80.68	0.02
90.63	1.3.27	90.82	-0.19
100.59	1.467	100.36	0.23
120.53	1.757	120.13	0.40
150.46	2.172	148.44	2.02
180.69	2.576	176.01	4.68
210.64	2.993	204.49	6.15
251.14	3.549	242.46	8.68

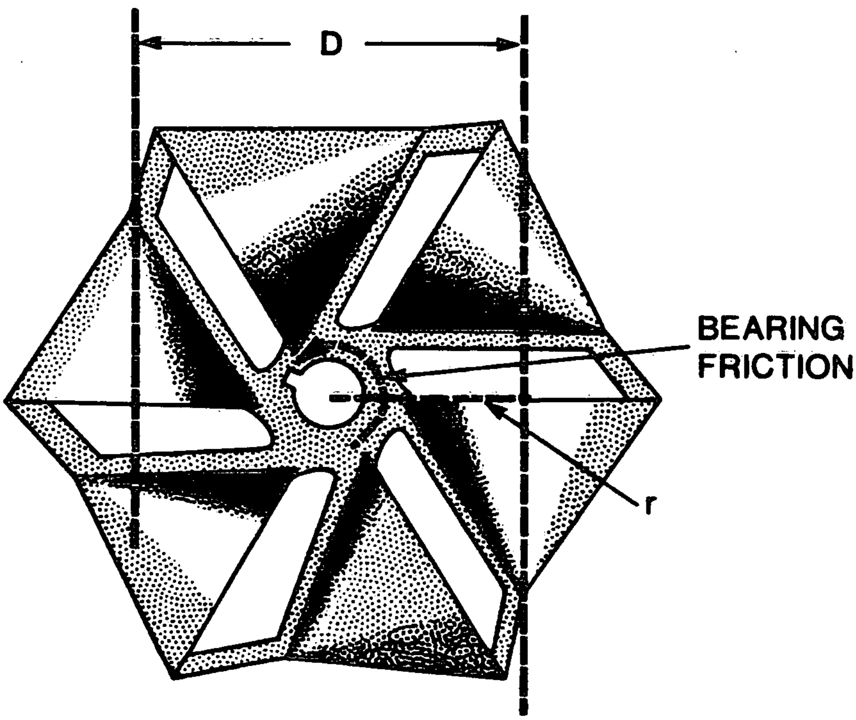

FIGURE 1. TYPICAL PRICE METER ROTOR

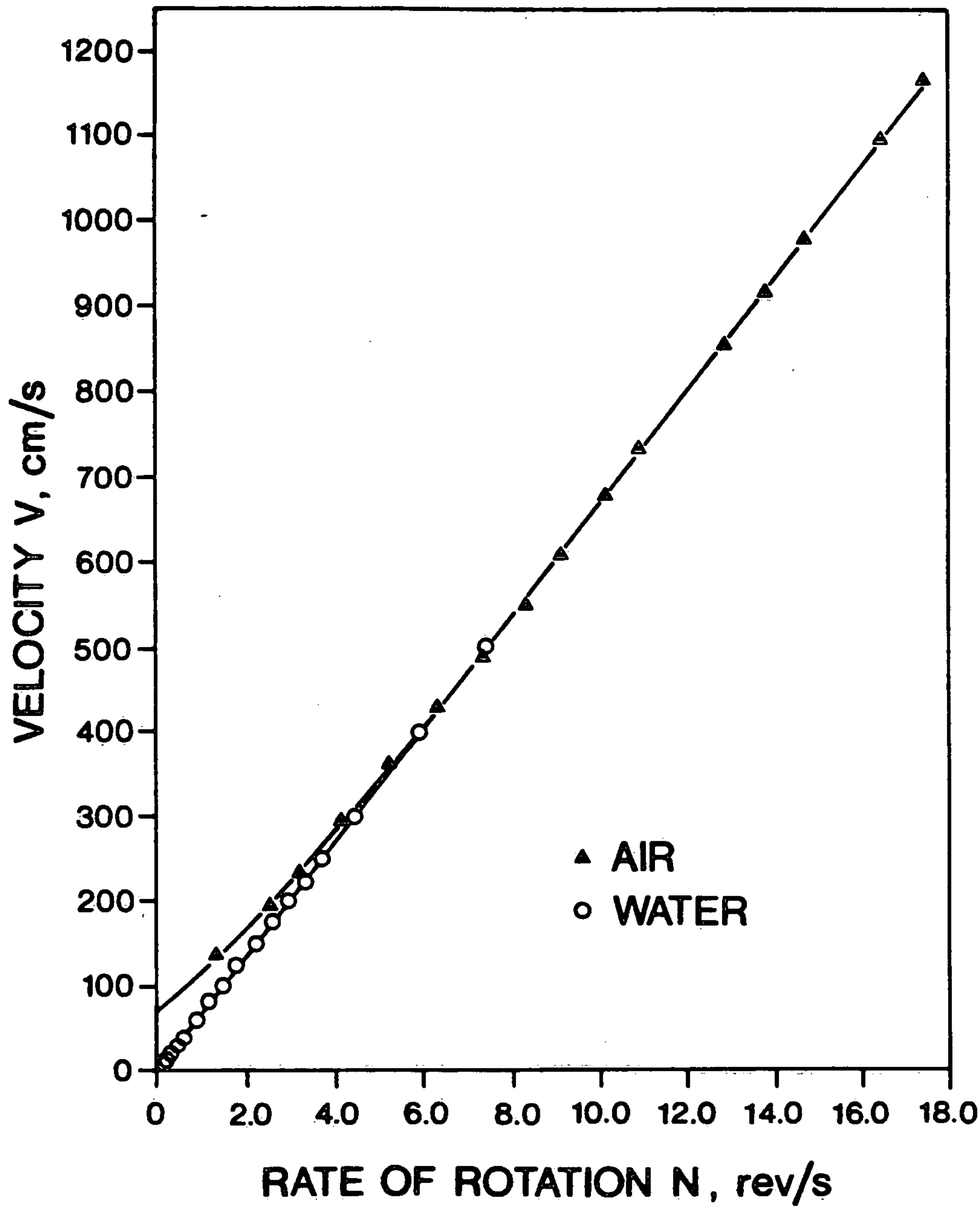

FIGURE 2. CALIBRATION CURVES FOR PRICE METER IN AIR AND WATER (Engel, 1976)

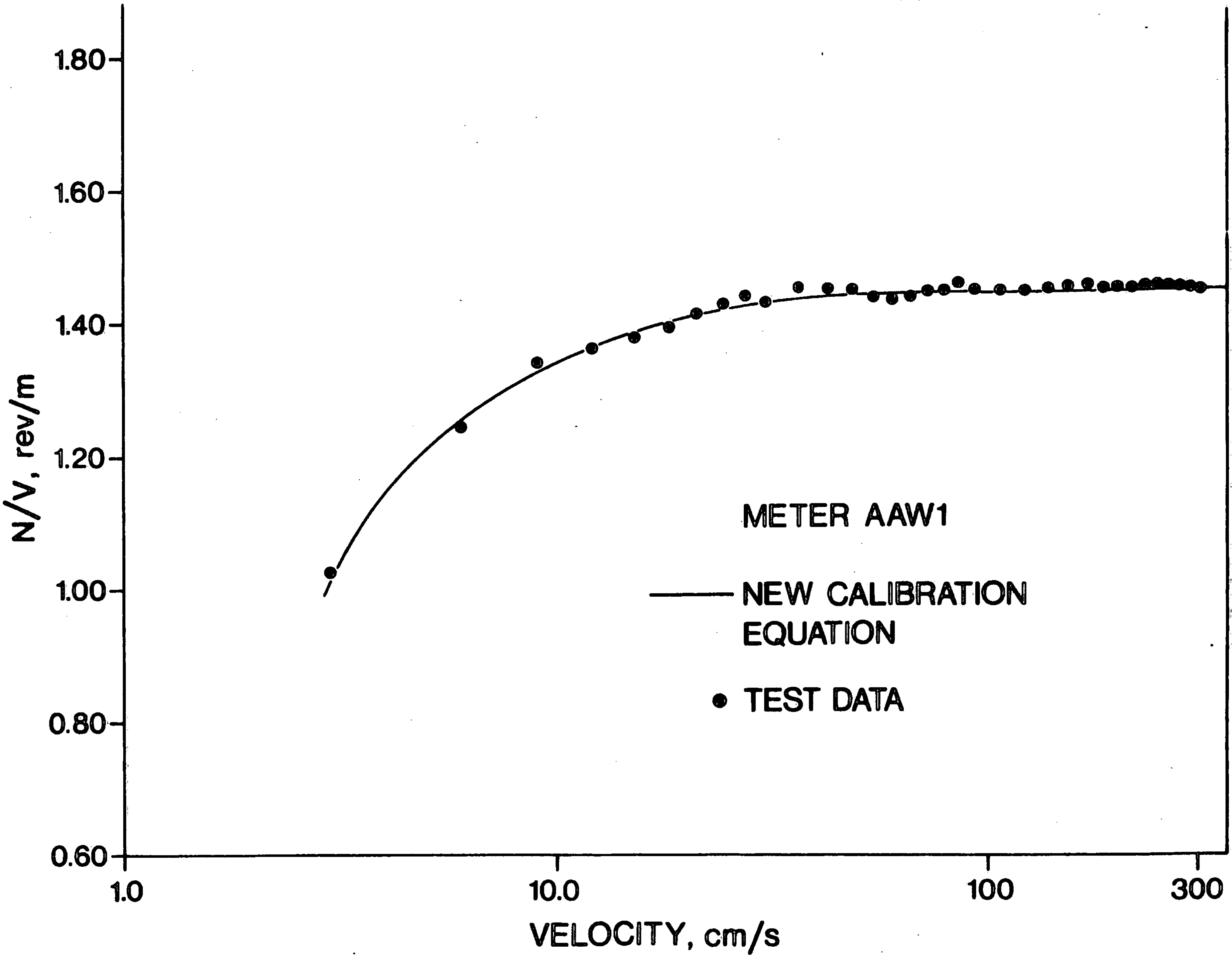

FIGURE 3. CALIBRATION FOR ROD SUSPENDED METER (Engel, 1989)

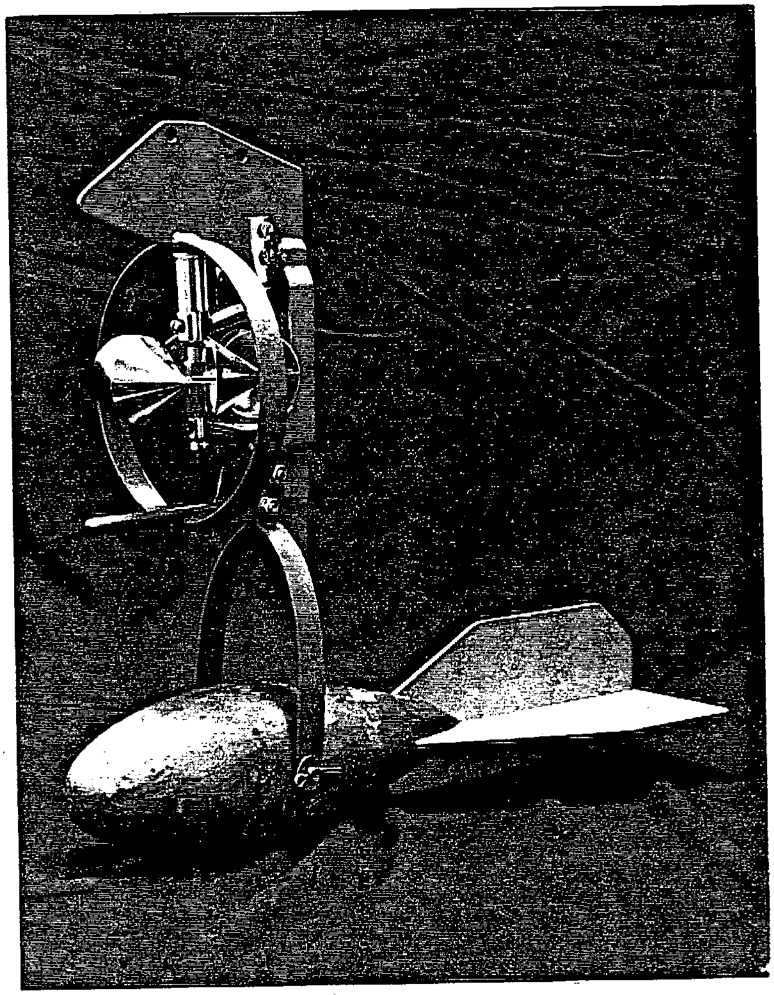

FIGURE 4. SLUSH-N-ALL SOUNDING WEIGHT

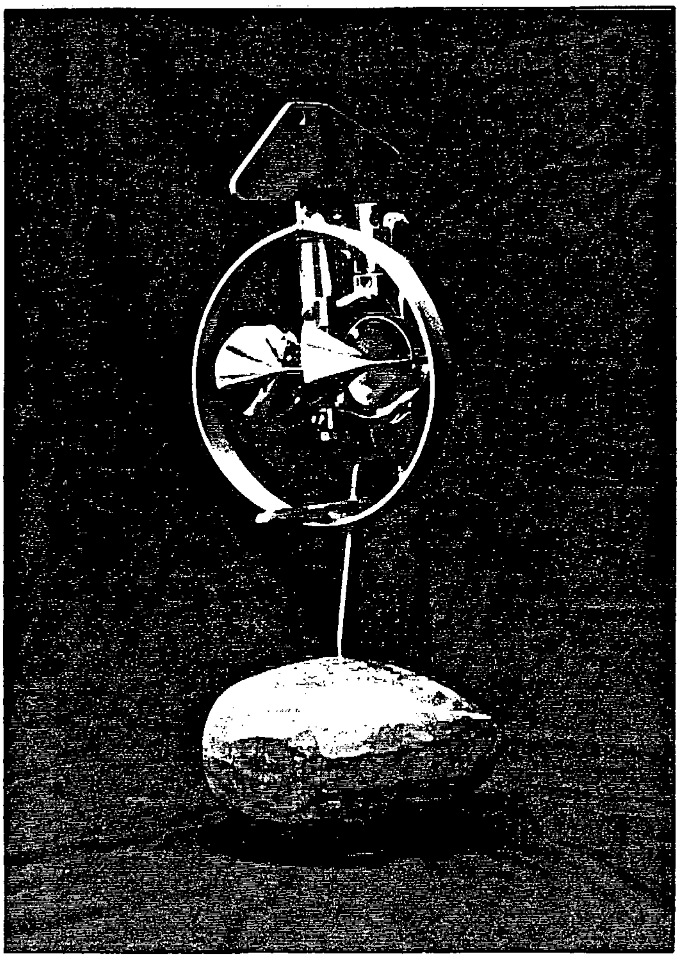

FIGURE 5. PANCAKE SOUNDING WEIGHT

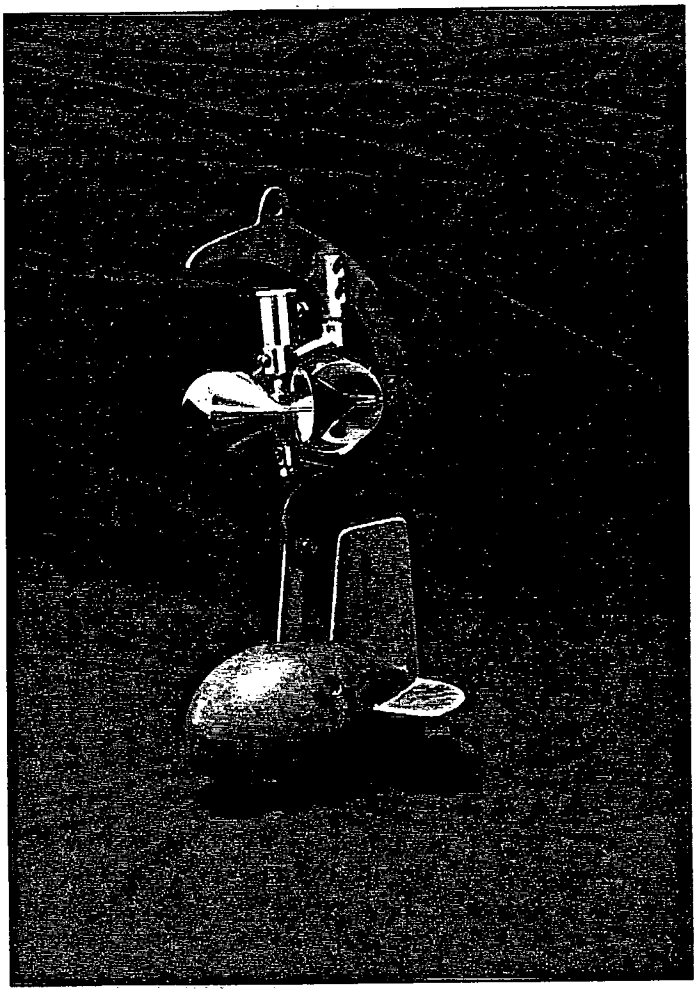

FIGURE 6. NACA SOUNDING WEIGHT

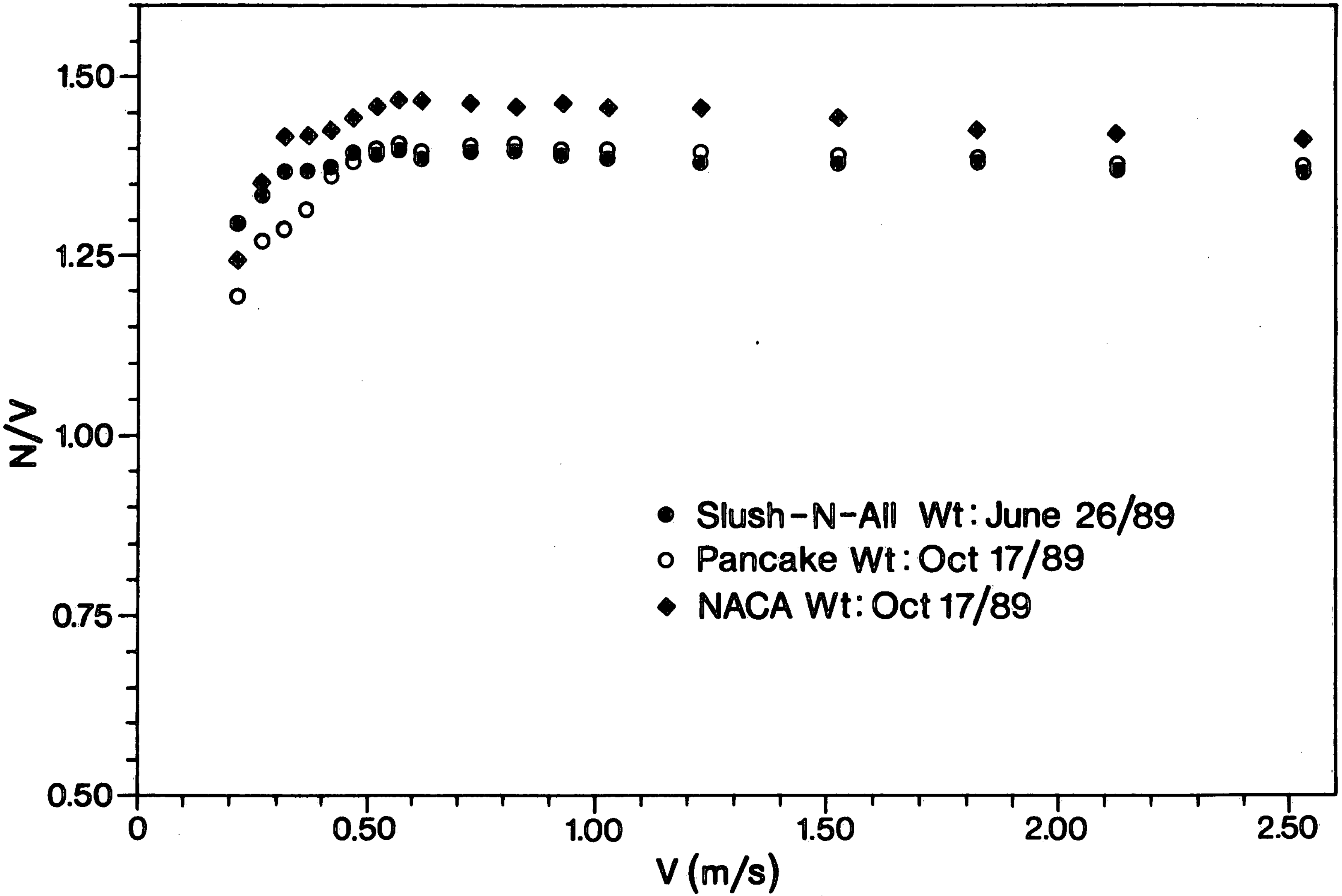

FIGURE 7. RESPONSE CURVES WITH THREE SUSPENSIONS TESTED

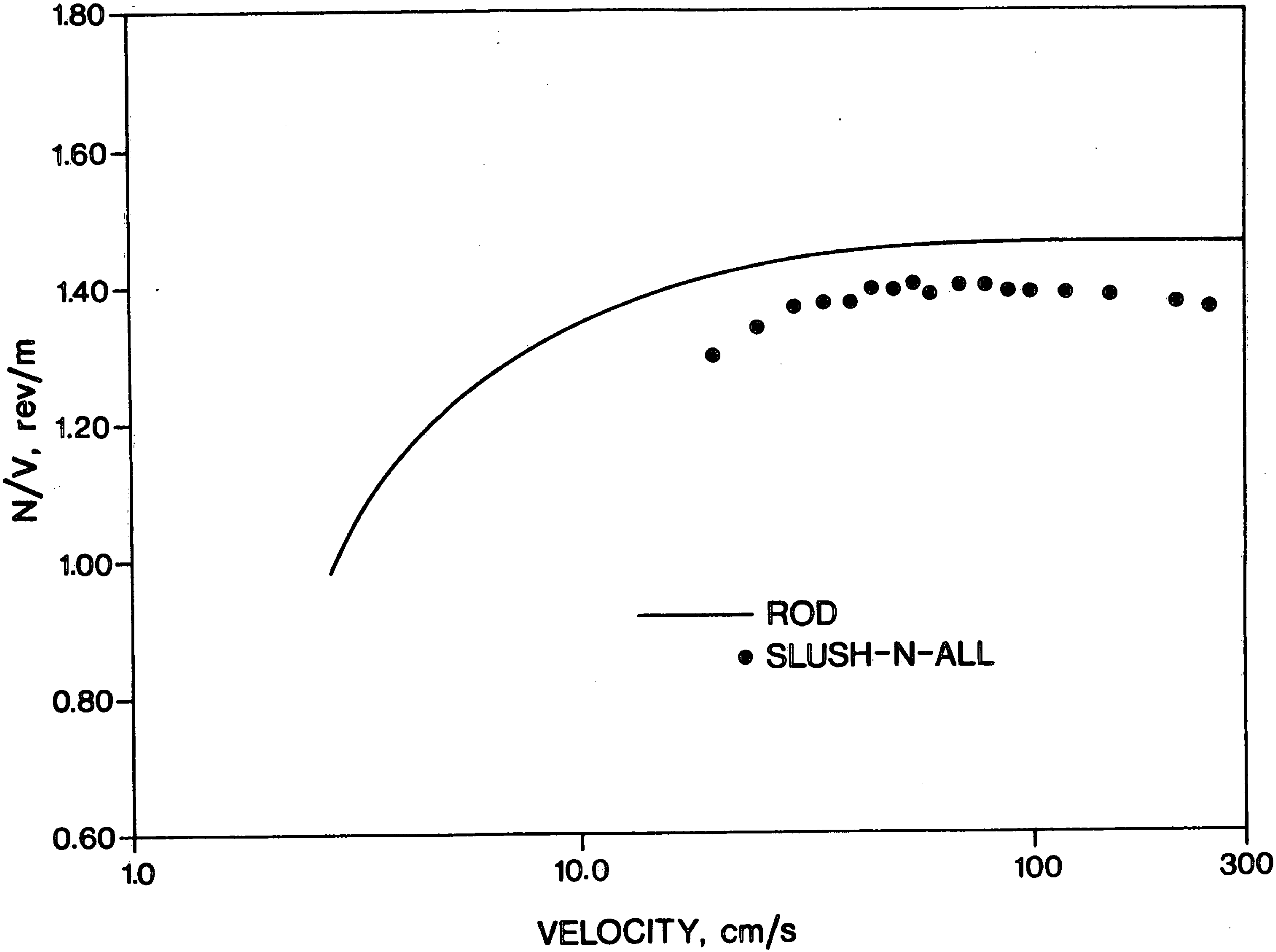

FIGURE 8. RESPONSE OF METER WITH ROD AND SLUSH-N-ALL SUSPENSION

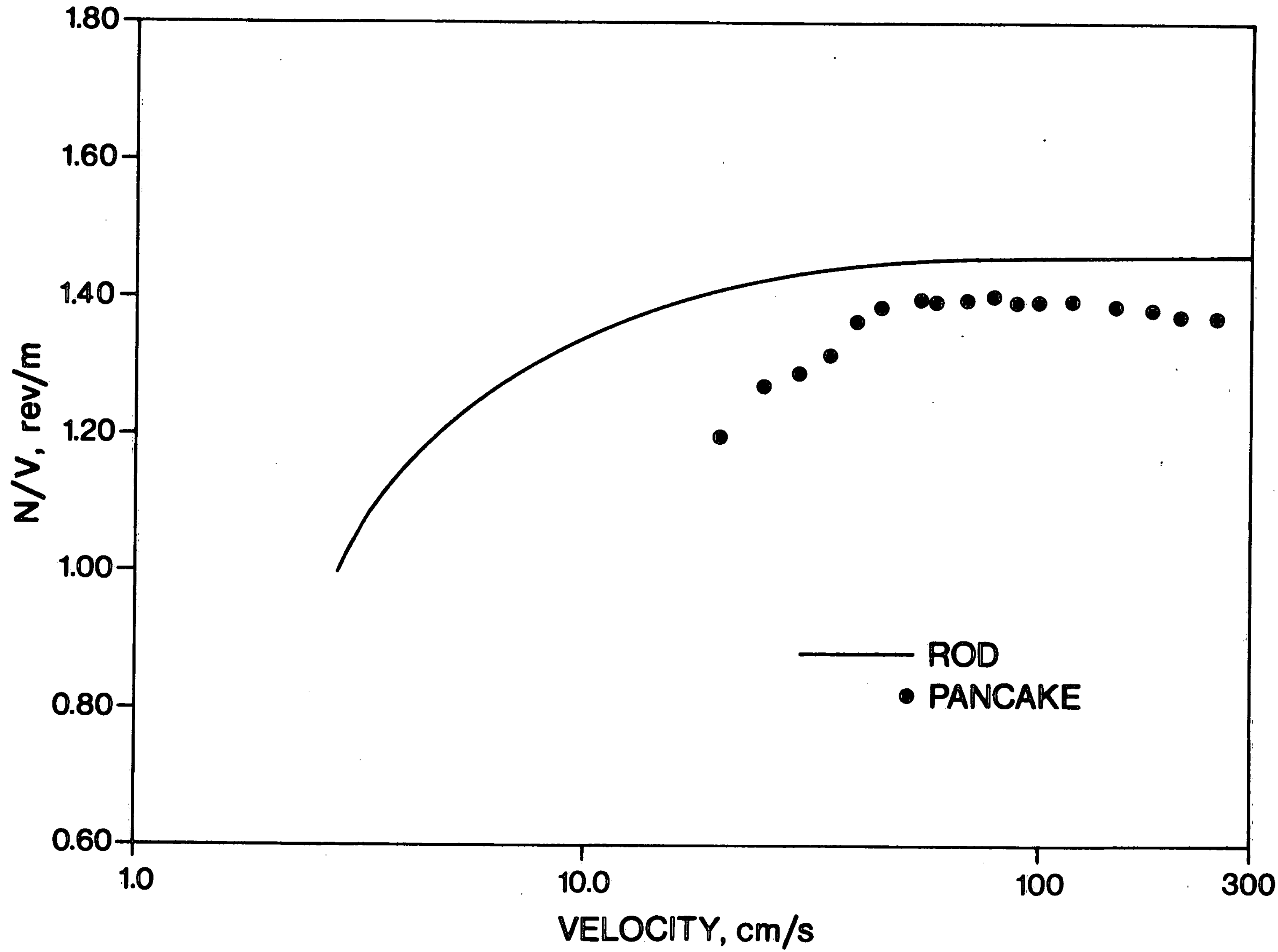

FIGURE 9. RESPONSE OF METER WITH ROD AND PANCAKE SUSPENSION

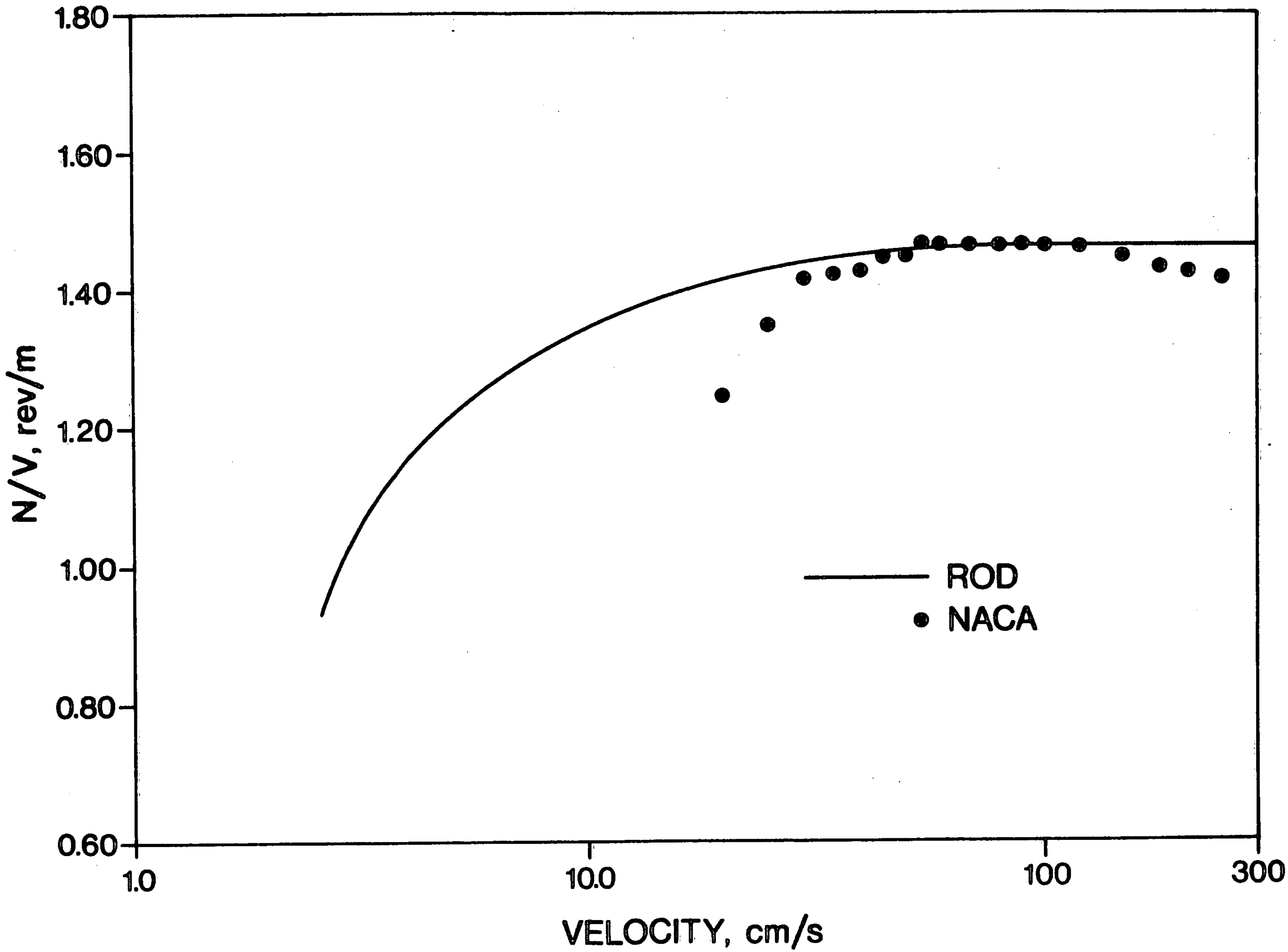

FIGURE 10. RESPONSE OF METER WITH ROD AND NACA SUSPENSION

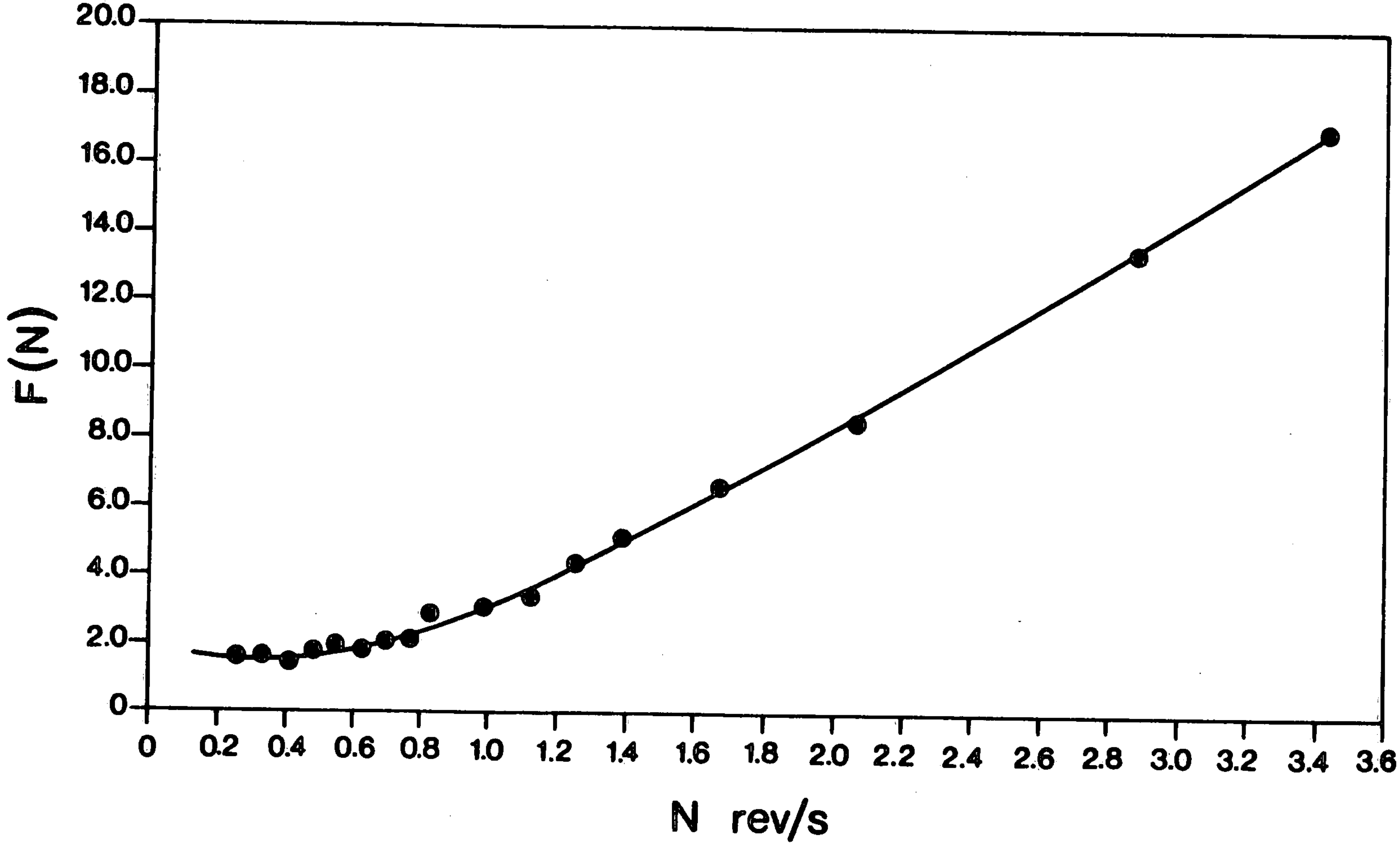

FIGURE 11. EFFECT OF SLUSH-N-ALL WEIGHT

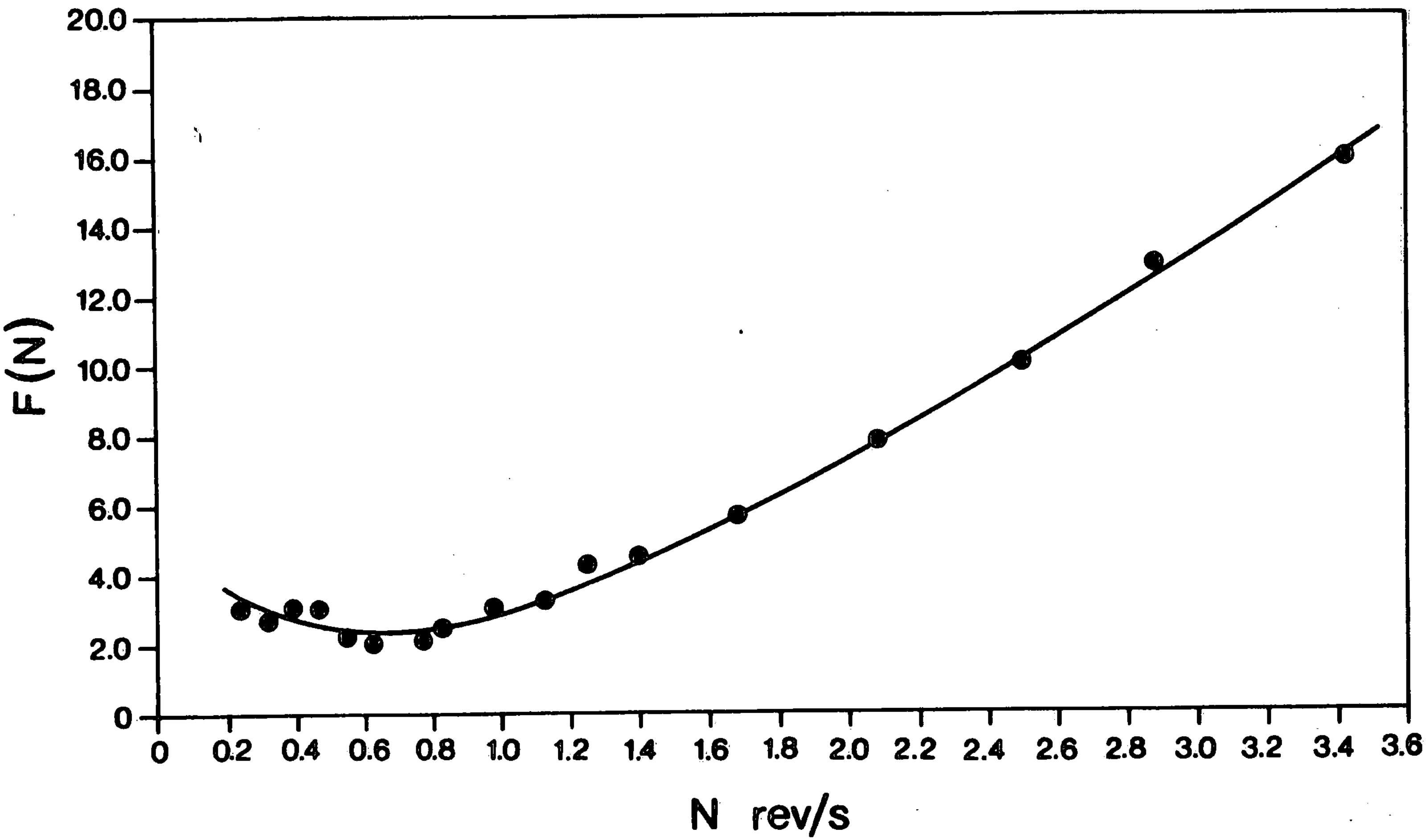

FIGURE 12. EFFECT OF PANCAKE WEIGHT

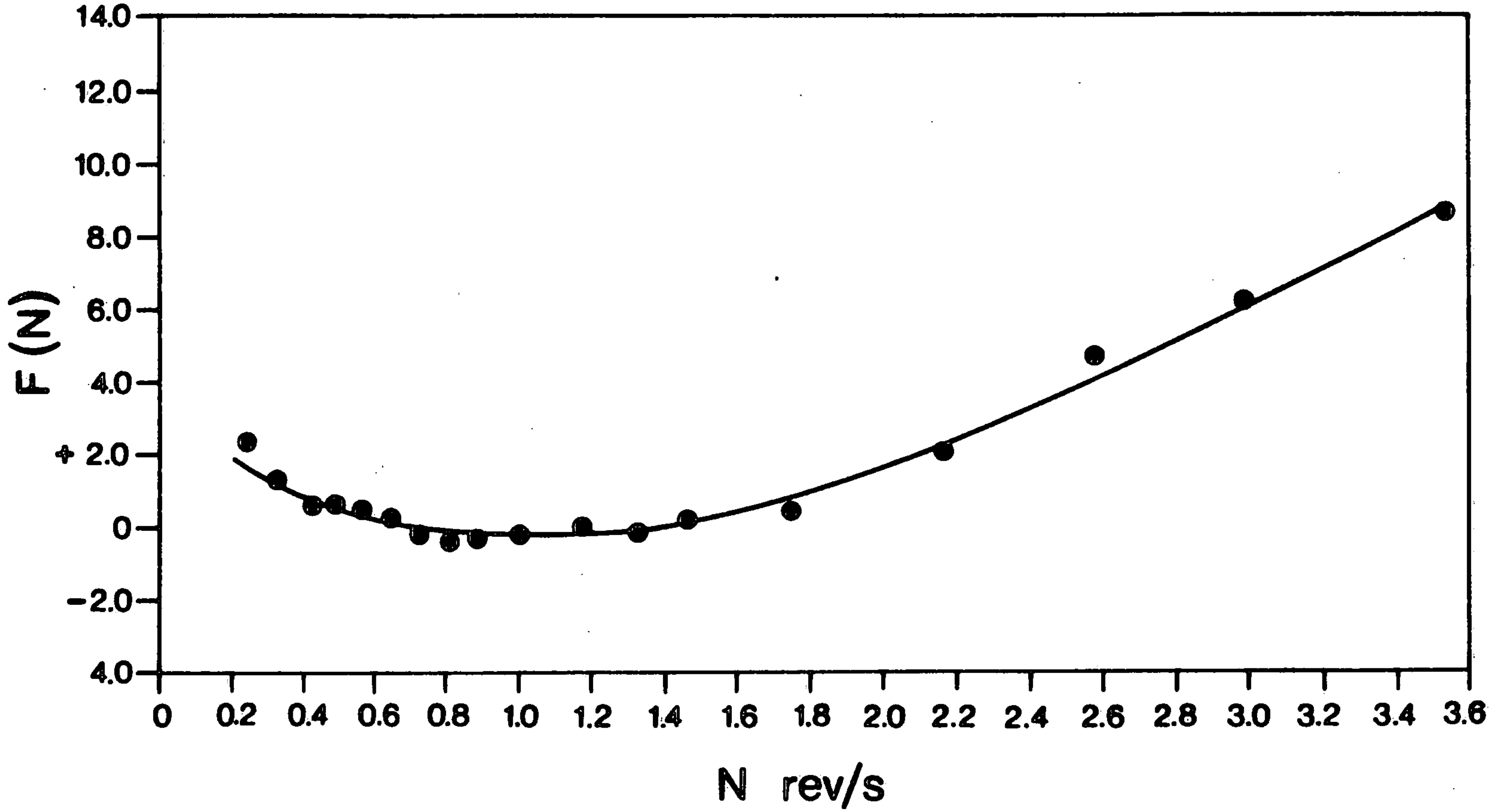

FIGURE 13. EFFECT OF NACA WEIGHT