CHAPTER 115

WATER CURRENT METER FOR MEAN FLOW MEASUREMENTS[1]

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ABSTRACT

A drag-sphere water current meter with a 0 to 6 ft/sec range has been developed for velocity measurements of relatively steady flows A two-component strain-gage type force transducer is mounted within a 3 7-inch-diameter perforated drag sphere Drag force measurements are related to the flow velocity around the meter Several drag sphere configurations were tested in selecting the 336-hole pattern

Frequency response data have been recorded and evaluation tests were made with current meters deployed in an estuary Use of these current meters in studies of steady-state fluid processes and sediment responses is feasible They are simple, relatively inexpensive, and well suited to applications where several simultaneous measurements are needed to determine velocity profiles or map flow distributions

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[1] Contribution 358 of the Virginia Institute of Marine Science

INTRODUCTION

This water current meter was developed to satisfy the need for a relatively simple, inexpensive device to measure generally steady flows characterize certain nearshore waters The design is compatible with automatic data acquisition and reduction equipment in order that several meters can be deployed and monitored simultaneously This capability makes it feasible to determine and map the velocit distribution and/or profiles in the nearshore areas under study The meter (fig 1) employs strain-gage techniques to measure the force exerted on a submerged drag sphere over a flow velocity range of 0 to 6 ft/sec This drag force is then related to the flow velocity around the meter

Inman and Nasu [1] were perhaps the first to develop a drag force meter for measuring fluid flow in the nearshore environment Their device consisted of "a small flexible beryllium-copper rod with a sphere mounted on one end and the other mounted rigidly to support " Other efforts toward developing this type current meter are noted [2, 3, 4] in which the drag sphere or cylinders used were found to be subject to both an acceleration-dependent force and a fluid drag force Consequently, this type of current meter is suitable for use only if fluid accelerations such as those in oscillatory flow are of low magnitude relative to the mean flow velocity

DESCRIPTION OF THE CURRENT METER

The current meter (fig 1) consists of a two-component strain-gage force balance designed to fit within a 3 7-inch-diameter polyethylene drag sphere, similar to the anemometer developed by Reed and Lynch [5] The force balance is constructed of Armco 17-4 PH Steel, with a 1/2-inch-diameter mounting "sting" extending approximately 14 5 inches from the sphere A machined flat is located on the "sting" for alignment purposes

Each of two perpendicular force components is sensed by 4 active foil-type strain gages The meter is designed to be insensitive to moments or couples and detects only the forces exerted on the drag sphere The output signal is approximately 2 4 mv per volt for a one pound force The 0 to ±6 ft/sec velocity range of interest corresponds to an electrical signal of about 0 to ±18 mv for each component Support equipment for each meter consists of a regulated power supply for the 4 0 to 6 0 v input to each strain-gage bridge, and a recorder with two channels Strain-gage bridges used in this application are compensated for temperature variations over a suitable 100°F range A 3M product designated EC870 is used to waterproof the strain gages and wiring on these devices

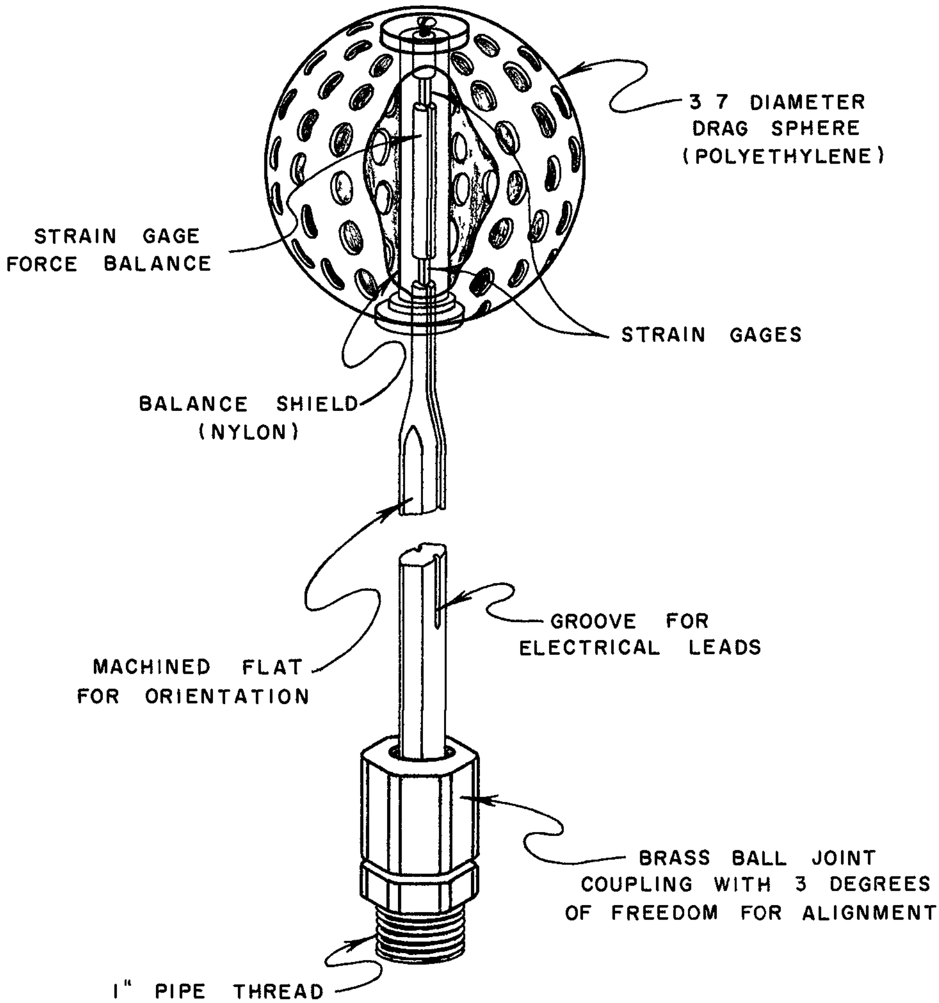


FIG 1 SCHEMATIC OF DRAG-SPHERE CURRENT METER

SELECTION OF THE DRAG SPHERE

Initial tow tank experiments with drag spheres were made in the Virginia Polytechnical Institute's towing basin at Blacksburg, Virginia Smooth spheres were found to be very unstable in the flow velocity range of interest (0 to 6 ft/sec) The smooth spheres oscillated very erratically in the lateral direction of perpendicular to the flow past the sphere, as observed in other studies [6, 7] Several methods of stabilizing sphere response were investigated, including various hole patterns, dimples, and bumps on the surface of the sphere, as shown in figure 2

Several significant observations were made in the tow-tank tests Figure 3 shows the variation of force with velocity for three spheres the dimpled sphere, the smooth sphere, and the 336-hole-pattern sphere All of the data points lie on or very near the theoretical lines for the appropriate drag coefficients C_D, showing that the force exerted on the sphere is a function of the velocity squared Differences in the drag coefficients of the three sphere configurations are quite significant Roughening sphere surfaces by dimples or bumps tends to reduce drag, as also noted by early golfers Smooth golf balls do not go as far and as straight as old balls that are battered or have a roughened surface On the other hand, placing holes in the surface of the sphere increases the drag coefficient in the 0 to ±6 ft/sec velocity range Larger holes or more holes of the same size increased the drag coefficients

Based on these experimental results, the 3 7-inch-diameter sphere with the 336-hole pattern was selected for use on this water current meter The drag coefficient of this sphere configuration was determined experimentally to be 0 69, with a standard deviation of 0 017 over the Reynolds Number range considered (35,000 to 211,000) All the surface alterations discussed increased the stability of the spheres, but the 336-hole pattern had the most stabilizing effect, as shown in current meter outputs in figure 4 ("component perpendicular to flow")

RELATION OF FORCE TO FLOW VELOCITY

Steady Flow

In steady flow conditions, the drag force exerted on a submerged object is related to the flow velocity by the following equation

$$F = C_D Q A \tag{1}$$

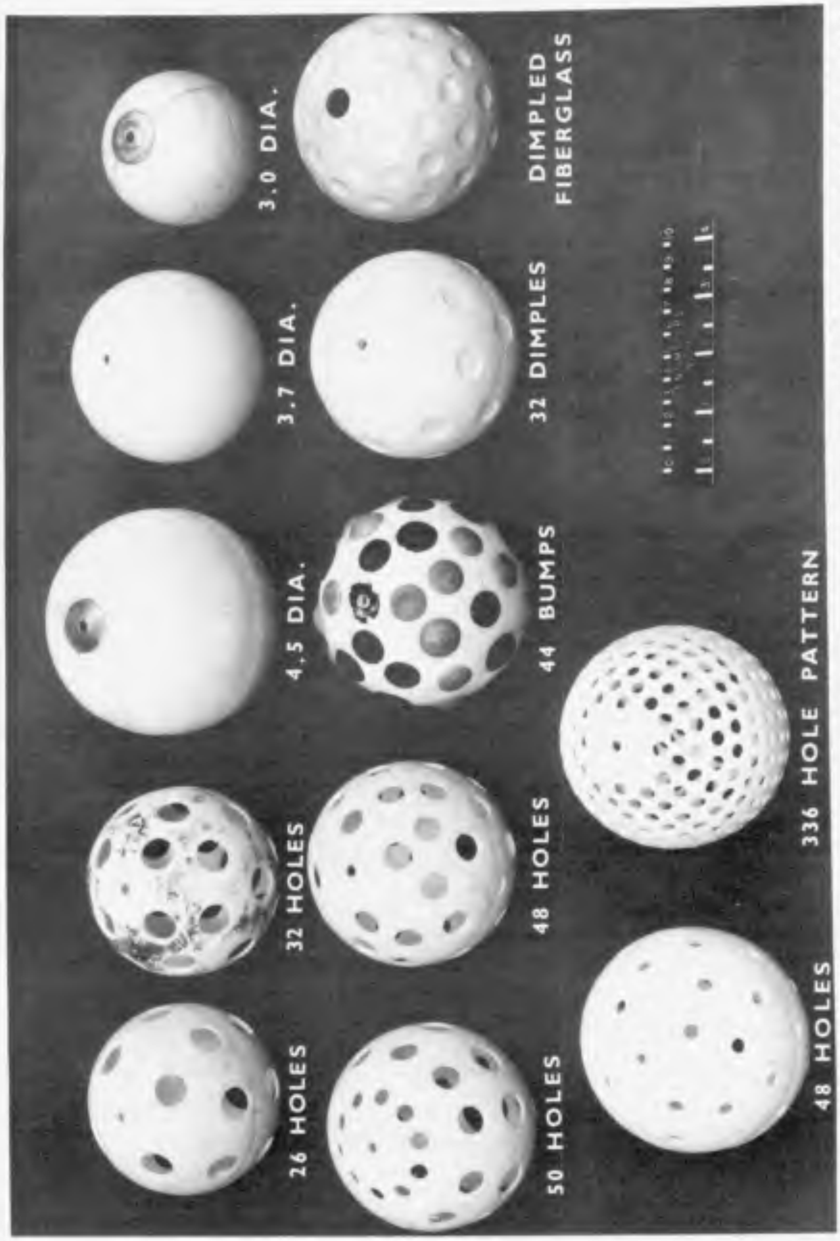


FIG. 2 DRAG SPHERE CONFIGURATIONS EVALUATED IN V.P.I. TOWING BASIN TESTS

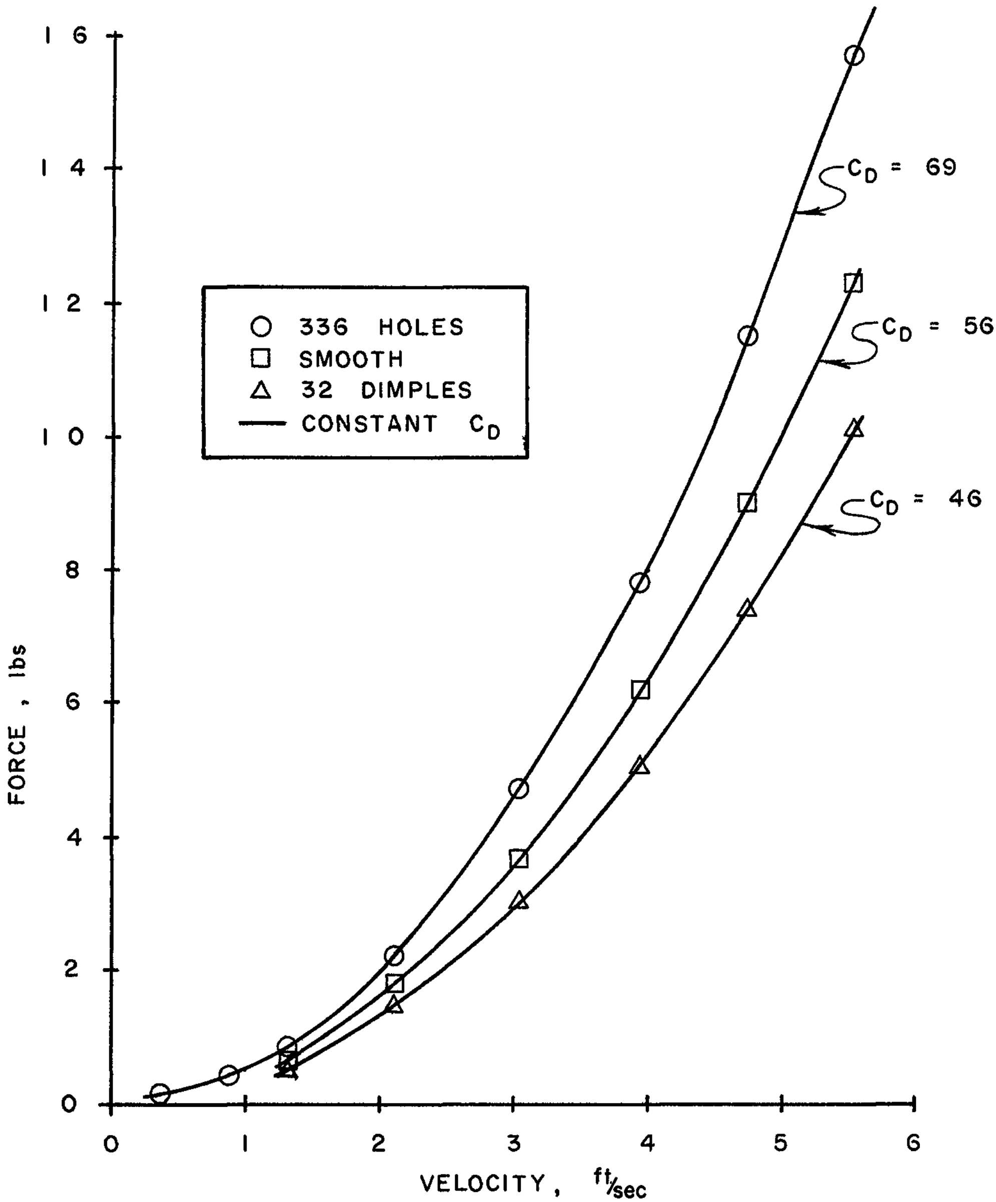
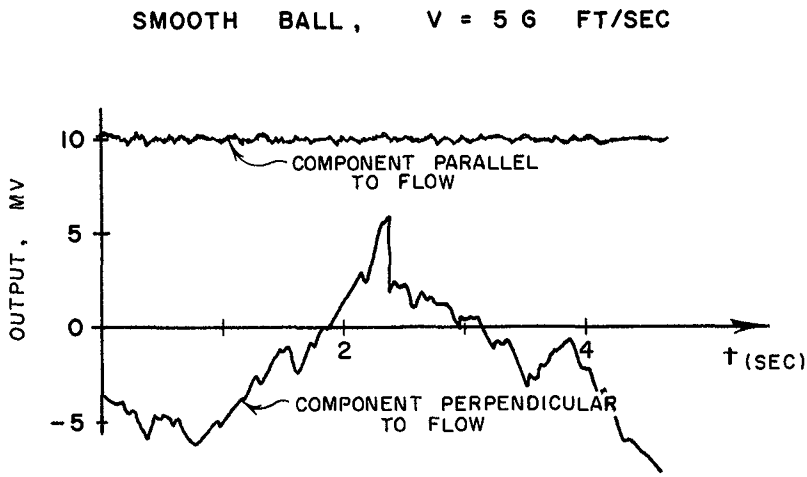


FIG 3

FORCE vs VELOCITY FOR THREE SPHERE-ROUGHNESS CONFIGURATIONS



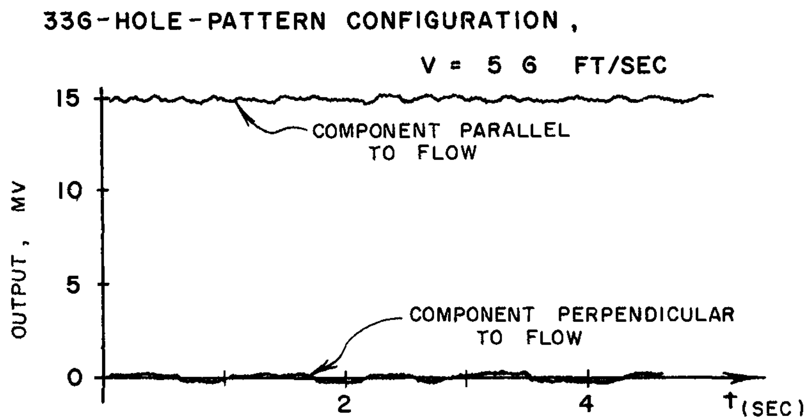


FIG 4 STABILIZING EFFECT OF 336 HOLE PATTERN COMPARED TO SMOOTH SPHERE'S OSCILLATION

Substituting $Q = \frac{1}{2}\rho U^2$, and solving for U yields

$$U = \left(\frac{2F}{\rho A C_D}\right)^{1/2} \quad (2)$$

where U = flow velocity, ft/sec
F = drag force, lb
C_D = drag coefficient
ρ = mass density, slugs/ft^3
A = frontal area of drag sphere, ft^2
The velocity vector has the same direction as the force vector

By having a well defined, constant C_D in the velocity range of interest, and knowing the density of the water as well as the projected area of the drag sphere, measuring the drag force vector enables the determination of the flow vector A significant point is that the total force vector must be used in calculating the velocity, i e , velocity components cannot be correctly computed from the individual force components using equation (2)

The velocity range of 0 to 6 0 ft/sec corresponds to drag forces on the order of 0 to 1 7 lb for the 336-hole-pattern drag sphere used

Accelerating flow

In unsteady or accelerating flow conditions, the forces exerted on the drag sphere are a function of both the flow velocity and the acceleration of the water [3, 8] The general expression for the force exerted on a submerged object in an accelerating flow is given as

$$\vec{F} = C_m\left(U, \frac{dU}{dt}\right)\rho V \frac{d\vec{U}}{dt} + \frac{1}{2} C_D \rho A |U| \vec{U} \quad (3)$$

where V = drag sphere volume, ft^3,

and $C_m = C_m\left(U, \frac{dU}{dt}\right)$ = coefficient of mass

Since C_m is a function of both the flow velocity and any fluid acceleration in the flow region near the drag sphere [9, 10], solving equation (3) for the velocity becomes very impractical, if not impossible Also, experimental results show that C_m is the same order of magnitude as C_D (3) Consequently, force-sensitive current meters must be used where the fluid acceleration is of very low magnitude and the $\frac{dU}{dt}$ term of equation (3) can be neglected

ERROR ANALYSIS

Error is velocity measurements can be obtained form a Taylor's expansion of equation [2], which yields

$$\frac{\Delta U}{U} = \frac{1}{2}\left(\frac{\Delta F}{F} + \frac{\Delta \rho}{\rho} + \frac{\Delta A}{A} + \frac{\Delta C_D}{C_D}\right) \tag{4}$$

The following maximum percent errors were determined

$$\frac{\Delta F}{F} = 0.5\%$$

$$\frac{\Delta \rho}{\rho} = 0.5\%$$

$$\frac{\Delta A}{A} = 1.0\%$$

$$\frac{\Delta C_D}{C_D} = 4.0\%$$

Substituting these values into equation [4] shows that the maximum overall error of the velocity magnitude is 3 percent of full scale A similar analysis of the vector direction shows that it is determined within 0 3° of the true value A significant point here is that only the $\frac{\Delta F}{F}$ term changes at lower range velocities, e g , at half scale, the inaccuracy of the current meter would be 3 25 percent of the reading, instead of 6 percent as would normally be expected

FIELD TESTS

Four drag-sphere current meters were deployed simultaneously in the York River estuary in an investigation of the tidal current regime near Gloucester Point, Virginia The meters were deployed by mounting them to rigid frames as shown in figure 5 Orientations of the current sensors were established by relating the location and position of the mounting frames to fixed landmarks The sensors were oriented to detect two horizontal drag force components, from which the flow vector in the horizontal plane was determined at each meter Because four meters were used simultaneously, the drag-force data were acquired by a portable digital data acquisition system and recorded on computer-compatible magnetic tape Initial zeroing and force calibrations of each meter in the X and Y directions were made just prior to placing the current meters in the water

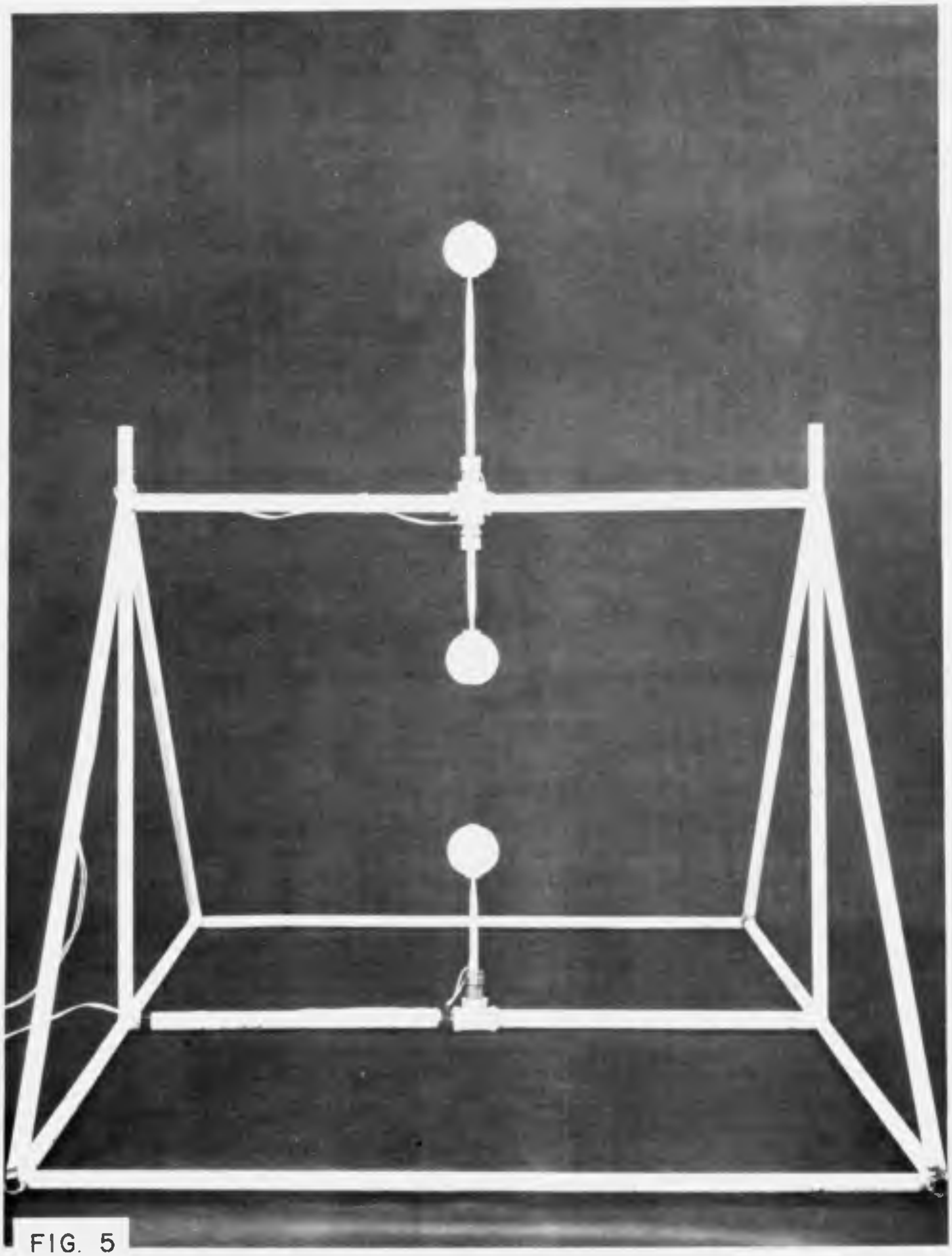


FIG. 5

RIGID FRAME FOR DEPLOYING DRAG-SPHERE CURRENT METERS

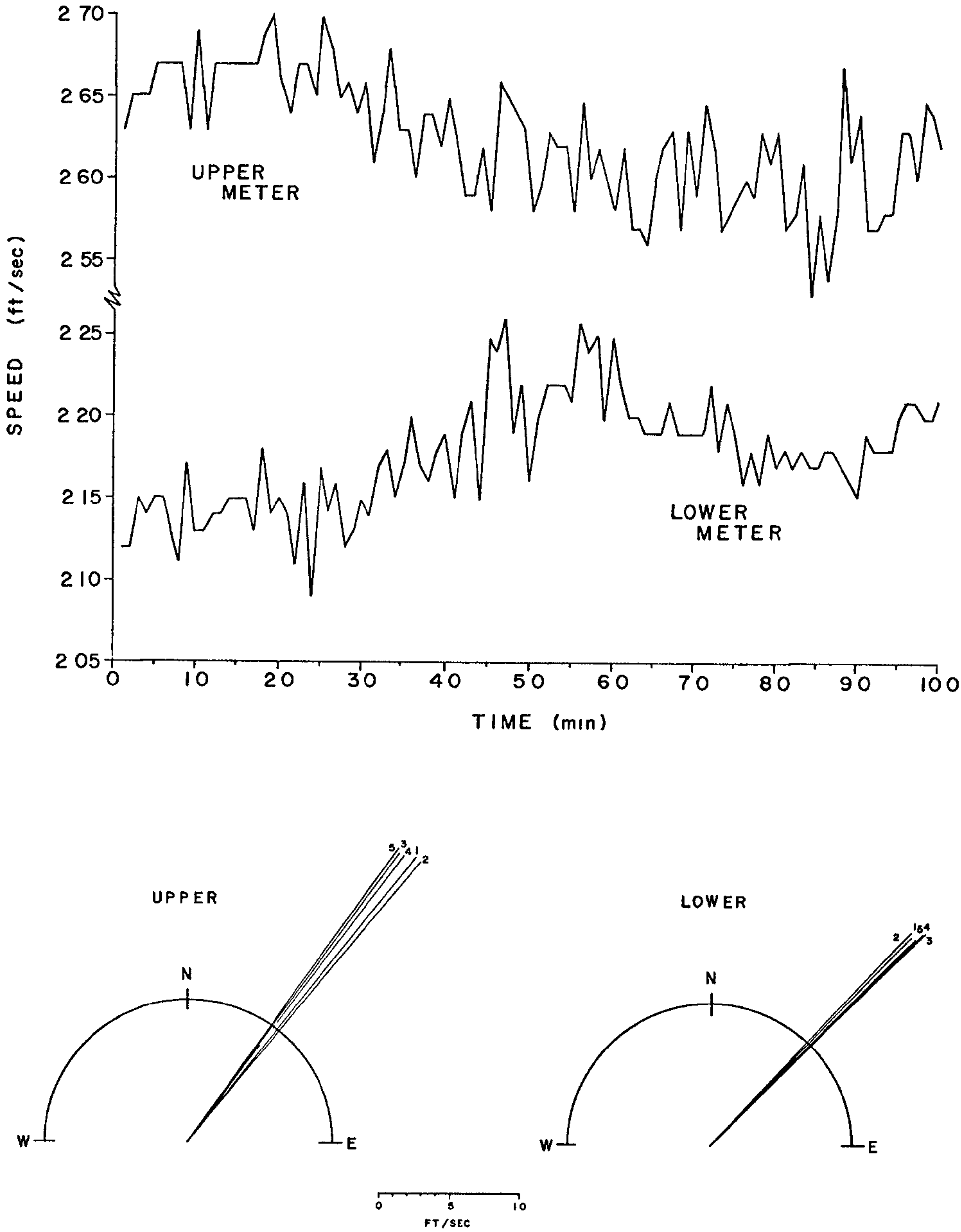


FIG 6 TYPICAL DATA FROM DRAG SPHERE CURRENT METERS VECTORS REPRESENT TWO-MINUTE AVERAGES OF SPEED AND DIRECTIONAL DATA EQUATOR OF UPPER DRAG SPHERE 46 IN ABOVE BOTTOM, LOWER SPHERE 16 IN ABOVE BOTTOM

At the end of one week, the meters were removed from the water, and the force calibrations were checked Only small descrepancies were noted for three of the meters The fourth meter had developed an electrical short-circuit within a few hours after deployment and was disconnected for the duration of the test This short-circuit appeared to result from a breakdown of the bond between the waterproofing compound and the force transducer

X and Y force-component date were then resolved to flow velocity vectors via a computer program Analyzed data (fig 6) revealed vertical differences in the flow consistent with expectable velocity profiles, and directions compatible with those of the known tidal-current field The net drift for various time intervals of interest was easily calculated

CONCLUDING REMARKS

These evaluations have shown that use of the drag-force water current meters in fluid-process and sediment-response studies is feasible in the 0 to 6 ft/sec range The net velocity vector at several points in a plane parallel to the sea floor may be obtained with these current meters over periods of a few minutes to several weeks

Rigid frames are convenient for deploying the current meters, or they can be mounted to a pile or permanent structure

The meter can be oriented to sense either the horizontal or the vertical flow vector

If the meters are deployed unattended for extended periods during seasons of significant marine fouling, it will be necessary to impregnate the polyethylene drag spheres with an antifouling compound

Since drag-force type current meters sense both acceleration-dependent forces and velocity-dependent forces, application of this meter is restricted to basically steady flows

The drag-sphere velocity meters are simple, relatively inexpensive, and when combined with an appropriate data acquisition system, they are well suited to applications where a large number of simultaneous measurements are needed

ACKNOWLEDGMENTS

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