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Trends in drogue design[1, 2]

ABSTRACT

Drogues in use today in the Lagrangian measurement of currents are in general inferior in behavior to those in use a century or more ago. This results from the historical tendency toward smaller drogues. For optimum measurements, one should select a drogue design that maximizes ease in handling and then scale it up to the largest size practicable.

In conducting a general review of devices used in the Lagrangian measurement of current, we considered in particular that category of drogue, drag, or sea anchor whose motion is determined by tracking a surface buoy from which the submerged device is suspended at a selected depth. The various types of drogue are illustrated in Fig. 1.[3] Each design is assigned to one of four classes based on geometrical considerations. Certain trends in drogue usage can be seen that limit the quality of the measurements obtained with the modern drogues.

BASIC DROGUE MECHANICS

A drogue-buoy pair undergoes only very slow changes in speed or direction of motion, i.e. very slight accelerations. It is thus appropriate to assume at any instant that a drogue-buoy system has no net external force acting on it. In the unique instance where the horizontal flows at the surface and at the depth of the drogue are the same, then the drogue-buoy system has no horizontal forces acting on it, and the drogue and the buoy, taken individually, have no horizontal external forces acting on them. (In this example, and in the one to follow, it is assumed that the force exerted by the wind on the exposed portions of the buoy can be neglected. This is a reasonable assumption if the buoy is almost awash and has only a thin radio antenna or a small radar transponder element protruding upward, but if the buoy has considerable freeboard, a flag, a radar reflector, or several such features, then for winds greater than a few meters per second, the wind force will be significant and must be included as an external force on the drogue-buoy system.)

In the situation typically encountered, where the surface current is greater than the current at the depth of the drogue, the drogue-buoy system has several external forces acting on it which sum to zero. In those cases where the wire by which the drogue is suspended from the buoy is not of excessive length, these horizontal external forces are two in number and equal in magnitude: the drag force resulting from the motion of the surface water relative to the buoy and the drag force due to the motion of the drogue relative to the current at its depth. The drag force on the buoy is essentially proportional to the square of

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[2] Publication No. 213 from the Department of Atmospheric and Oceanic Science, The University of Michigan.

[3] A copy of this figure, with a complete list of bibliographic citations, is available from the University of Michigan Sea Grant Program (Monahan and Monahan, in prep.).

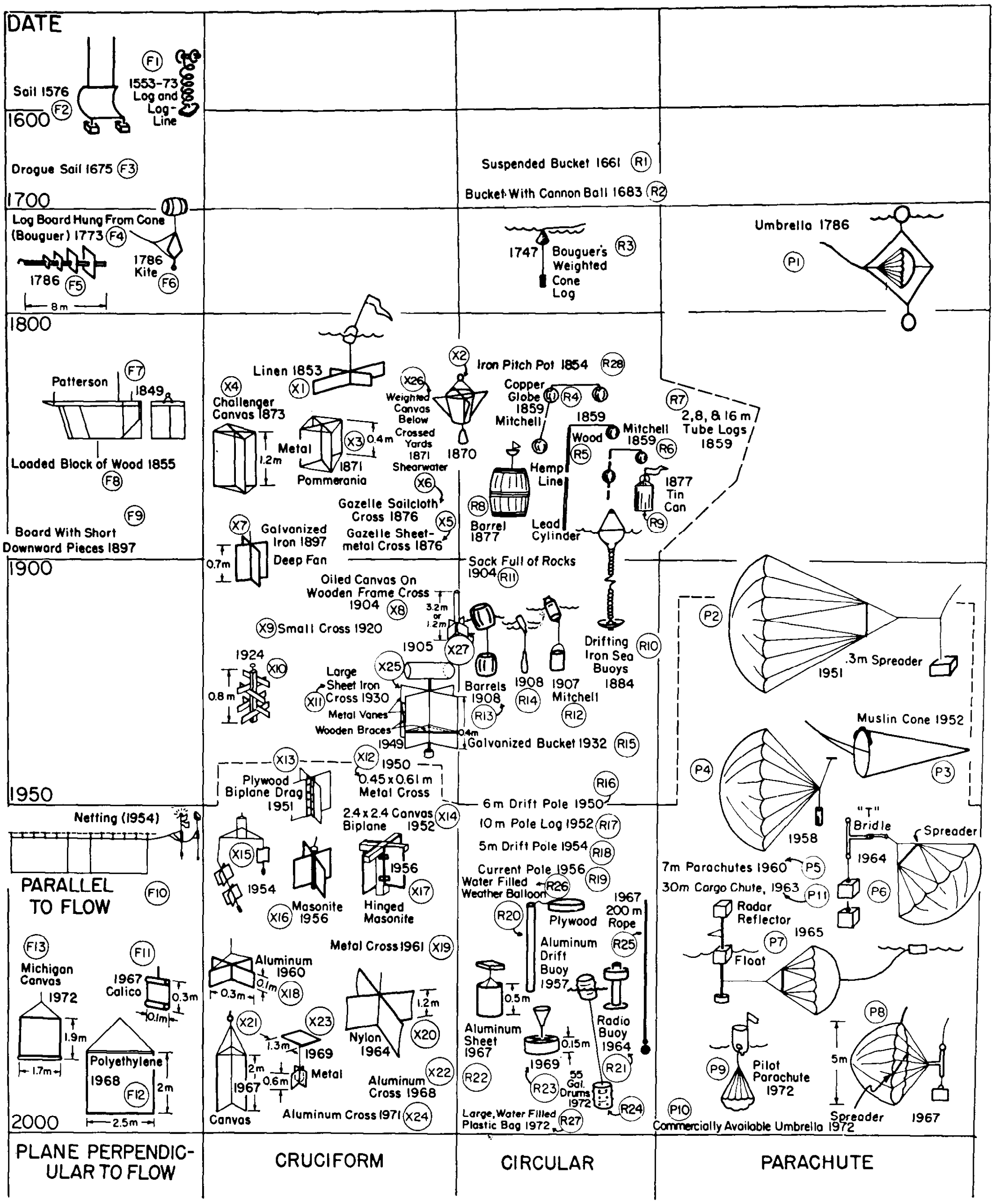

Fig. 1. Evolution of drogue designs. Dates given indicate first use of the design, when known, otherwise they represent the date of publication. Citation for the designs are given in text. A complete list of bibliographic citations for all designs represented in this figure can be found in Monahan and Monahan (in prep.).

the slip velocity between the buoy and the surface water and to the projected area of the buoy exposed to the surface current. Likewise, the drag force on the drogue is approximately proportional to the square of the slip velocity between the drogue and the water at its depth and to the cross-sectional area of the drogue at right angles to this slip velocity. Since the two drag forces will always be equal in magnitude, the only possible way to minimize the slip velocity between the drogue and the water at its depth is to maximize the ratio of the drogue area exposed to the current at its depth to the buoy area exposed to the surface current. Ways of calculating this drogue slip velocity from simple formulas, thus correcting the results obtained using drogue-buoy pairs for the effect of the surface currents on the buoys, are described by Terhune (1968). A more exact approach, using plots of drag force versus relative velocity obtained by towing drogues and buoys individually through a long tank with an instrumented carriage, has been set forth by Monahan et al. (1973).

Recently current measurements have been made in a bay of Lake Michigan using "vee" drogues of 33,200 cm^2 projected area (item X21 on Fig. 1) in conjunction with disk-shaped flag-buoys of 228 cm^2 submerged projected area (Monahan et al. 1973). Use of these drogue-buoy pairs, where the ratio of areas is 146:1, in a situation where the surface current is 15 cm sec^{-1} and the current at a drogue depth of 35 m is 5 cm sec^{-1}, results in a slip velocity of 0.65 cm sec^{-1}. Thus, if the assumption were made that the common motion of the drogue and buoy can be taken to be the motion of the water at drogue depth, a 13% error would be incurred. It is clear from this example that even with large ratios of projected areas, the correction for the drogue slip velocity should be applied when there is significant vertical shear in the current structure. If the additional information needed to determine the drogue slip velocity, i.e. the surface current velocity and the drogue and buoy drag coefficients (or their drag force calibration curves) are not obtained, then it is imperative that the largest possible ratio of projected areas be incorporated in the selection of a drogue-buoy pair. This admonition holds in particular for the many jury-rigged deep drogue devices where such basic information as the draft of the surface buoy usually goes unrecorded.

MINIATURIZATION

The demise of the use of sail led to a reduction in the size of ships' crews and to the disappearance of various pieces of tackle that had once been standard. The general purpose research vessel of today is often less suited for the launching and retrieval of large current drogues than a vessel of 100 years ago. Even those who have the use of specially designed research vessels often find themselves aboard the smallest ship feasible for their particular assignment, and hence are discouraged from using large, cumbersome drogues. Thus the tendency to use small, easily handled drogues is understandable.

The significance of this trend becomes apparent if one considers the design criteria for drogue-buoy pairs.

A well-designed drogue-buoy pair includes a buoy which is just large enough to support a flagpole, radar reflector mast, or radio antenna, and to provide sufficient excess buoyancy to offset the negative buoyancy of the drogue proper. The drogue itself should, in comparison to the buoy, present a very large cross-sectional area to the flow and have sufficient negative buoyancy to keep the buoy mast upright and to keep the connecting wire essentially vertical. This last consideration is important because it is assumed that the drogue is at a depth equivalent to the wire length and because certain drogue designs show a tendency for unstable oscillation when they are tilted from the intended vertical orientation.

It is impossible to take such a well-designed drogue-buoy pair and scale it down in size without sacrificing performance. If such a pair is scaled down by a factor R in linear dimension, the vertical component of the tension in the wire is reduced by a factor of R^3, since the vertical component of wire tension is simply equal to the negative buoyancy of the drogue which is proportional to the drogue's volume. This same scaling will result in a reduction in the horizontal component of wire tension by a factor of only R^2, since it is equal to the net drag force on the drogue proper or on the buoy (they are equal in magnitude), each of which is proportional to the respective projected area. Since the tangent of the wire angle is equal to the ratio of the drogue drag force to the drogue's negative buoyancy, the suggested reduction in size by a factor of R results in an increase by a factor of R in the tangent of the wire angle, and hence an increased wire angle. To overcome the increase in wire angle one can add ballast to the drogue, but this will cause the surface buoy to float lower in the water or, if it had negligible freeboard to begin with, it will necessitate the use of a new, larger buoy. In either case, it will result in a pernicious reduction in the ratio of the drogue's projected area to the buoy's projected area exposed to the current.

It is true that not all the early current measurements involved the use of well-designed drogue-buoy pairs, but it is clear that the trend toward smaller drogues has often led to intrinsically inferior current measurement procedures. The sail drogue in use 400 years ago (F2 on Fig. 1, Gilbert 1598) was thus conceptually preferable to the "window-shade" drogue in use today (F12, Terhune 1968; F13, Monahan et al. 1973). Likewise, few of the present day current-crosses are a match for the one used on the *Challenger* expedition (X4, Tizard et al. 1885).

Considering those drogues that are circular in horizontal cross section, the recently popular cylindrical drogues (R22, Scott and Landsberg 1969; R23, Gannon and Brubaker 1969) do not measure up to the U.S. Coast and Geodetic Survey's barrel drogue of 100 years ago (R8, Marindin 1877).

The use of small pilot parachutes (P9, Miller et al. 1972) in place of the much larger personnel parachutes (P2, Volkman et al. 1956) is a step backward, and a regular umbrella (P10, Palmer 1972) is a poorer drogue than Benjamin Franklin's "umbrella swimming anchor" (P1, Franklin 1785).

OTHER TRENDS

The use of a drogue-buoy pair where the drogue's effective cross-sectional area to the flow is of the same order of magnitude as the submerged cross-sectional area of the buoy as a device to measure surface currents has a long history (e.g. R12, Richard 1907). Such a device is essentially a flexible version of the pole log (R7, Mitchell 1859), somewhat inferior to the pole log in the manner in which it "averages" the currents at the several depths in the surface layer. Recent attempts to use such systems to measure deep currents (e.g. R23, Gannon and Brubaker 1969) represent doubtful extensions of the role of such devices.

Although most users of parachute drogues recognize the need to use spreaders (e.g. P2, Volkman et al. 1956; P8, Hamblin and Rodgers 1967) to keep the canopies open at the low relative velocities encountered by properly functioning drogues, some users do not. Those who use pilot parachutes invariably rely on the coil spring contained within the fabric to keep the canopy open (P9, Miller et al. 1972), yet when a pilot parachute is drawn through the water at a few centimeters per second, it hangs limply beneath its buoy.

When it comes to building drogues, there is a marked tendency to "reinvent the wheel." A recent news item (Amer. Geophys. Union 1972) describing how the personnel aboard the NOAA ship *Mt. Mitchell* devised a drogue out of two oil drums (R24) to tag a Gulf Stream eddy makes interesting reading when juxtaposed with a description of the much older drogue made of two wooden barrels (R13, Thoulet 1908).

CONCLUSIONS

Clearly to obtain the best current measurements in any given case, the largest drogues possible should be used.

From a consideration of the hydrodynamics of such low velocity flows as that of the water relative to a drogue, it is apparent that the particular geometry of the drogue is not very important. The drag force on a "window-shade" drogue is essentially the same as that on a "vee drogue" (X21, Hamblin and Rodgers 1967) or a current cross of the same projected area, for example.

One should therefore select a drogue design that maximizes ease in handling, and then scale it up to as large a drogue as practicable. A very large sail drogue, for instance, can be deployed and retrieved from a surprisingly small ship.

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