Further Investigations upon the Water Movements in the English Channel.

Drift-Bottle Experiments in the Summers of 1927, 1928 and 1929, with Critical Notes on Drift-Bottle Experiments in General.

By

J. N. Carruthers, D.Sc.,
Fisheries Laboratory, Lowestoft.

With 4 Charts and 2 Figures in the Text.

As long ago as 1897 the Marine Biological Association carried out experiments with surface-floating drift bottles in the English Channel. In the course of those experiments which were described by Garstang in this Journal (**1**), 430 bottles were sent adrift in 53 batches during the year 1897. The bottles were put out chiefly in the vicinity of the Eddystone, and when Garstang reported on the results of the experiments, rather less than one-third of the bottles had been recovered. Garstang worked out a relationship between the movements of his bottles and the strength of the winds, which convinced him that "the relation between wind action and surface currents is capable of quantitative study," and declared himself encouraged to proceed further with the idea of testing the reliability of his empirical relationship between bottle travel in miles and wind *pressure*. The study of wind influence by paying attention to *pressure* constituted a step of interest, and one would like to be able to turn up the continuation of Garstang's work promised at the conclusion of his paper already quoted. We here pay more than passing attention to the attempt made by Garstang to establish a quantitative relationship which should enable one to infer surface current speed from wind, because it is our intention to examine this matter further at a later stage in this paper. For the present, one may remark that any investigator who may seek to connect wind and surface drift by means of a quantitative relationship wherein the wind factor employed is wind velocity squared, is, to all intents and purposes, expressing wind influence in terms of pressure like Garstang.* We shall refer to this worker's results again later.

In 1925 a very brief paper on the movements of surface-drift bottles put out from the Sandettie Lightship during a whole year (1920–21) was

* See page 40 of *The Observer's Handbook*—M.O. 191.

published in this Journal by the present writer (**2**). This small paper was written to throw what light could at the time be thrown upon the question of water interchange between English Channel and North Sea. Actually at the present time this is a subject upon which we have ample information from sources other than drift-bottle experiments.

In 1927 a further paper dealing with drift-bottle experiments in the English Channel appeared in this Journal (**3**), and to certain results therein set down some later reference will be made.

In view of the fact that these three papers have been published in this Journal, it is convenient that the present paper should find a place here.

It is our intention to present below the results obtained from the setting adrift of numbers of bottles (not all of the same kind) from the International Station E2, situated at 49° 27′ North—4° 42′ West. The bottles were put out from the Ministry's research vessel *George Bligh* by the writer's colleague Mr. C. F. Hickling, in early August 1927, in August 1928, and in July 1929.

The experiments of July 1924 had involved the liberation of 500 bottles—of which half were common surface-floating bottles and half bottom-trailing bottles of Bidder type; in that case liberations of 50 of each kind were made at International Station E2, at International Station E3 (48° 34′ North—5° 13′ West), and along three chosen short stretches on the steamer route between Southampton and Saint Malo. From these earlier experiments (1924) 52 per cent of the surface bottles were recovered, and much information of interest resulted.

In the case of the experiments with which we are to be concerned below, no bottom-trailing bottles call for our attention; the liberations were made only at E2, and that on one occasion only in each of the three years in question. However, the experiments were made for very definite reasons which will become apparent later. There was, of course, the obvious general wish to find out more about the surface-water movements of the English Channel in order to amplify what had already been discovered, but, since we had in 1924 been particularly fortunate in choosing what proved to be an unusually interesting time for our experiments, we now wished to repeat these to see what journeys might *again* be accomplished by ordinary surface bottles. Subsequent to the 1924 liberations, there had been an onset of S.W. wind of almost uninterrupted predominance for some $5\frac{1}{2}$ months; some of the common surface bottles had travelled about 500 miles at an overall speed approaching 8 miles a day, a speed which we naturally surmised might be unusually great. This, amongst other reasons, led us to repeat the experiment. Another reason was the wish to see whether we could not obtain useful and representative data to enable us to work out on better foundations than had yet been possible, a reliable quantitative relationship between surface water movement and wind strength. On this point we have elsewhere indicated what we hold to be representative data (**3**, p. 717). The third, and chief reason, arose from our desire to try out other types of bottle, and to stage a race as it were between these latter and ordinary surface-floating bottles. Added to the foregoing reasons was the very natural wish to observe at what speed bottles travel up Channel, at a time during the whole of which we have records of the speed of water flow through Dover Straits. When the earlier drift-bottle experiments were made in the Channel we had no continuous current observations in train from the Varne Light vessel, such as are now available.

The English Channel is, of course, an ideal place for carrying out experiments with different types of floating drift bottles. Bottles may travel 1000 miles and more with very good chances of recovery when they strand ; no matter where they may go ashore short of this distance, the prospects of receiving the postcards from them are quite good.

General Remarks on Drift Bottles and their Use.

By our expression " other types of bottle " we mean various kinds of floating-bottle systems provided with sub-surface drags. The short-comings of simple surface-floating bottles have been apparent to earlier workers, of course, and bottles fitted with suspended objects of various kinds have been used.* The writer has devised various types of fittings to enable drag bottles to be made up satisfactorily and quickly ; one of these has been described and figured already (**4**), whilst others are pictured in this present paper. Now one point concerning the employment of drag-fitted bottles is of supreme importance, but strangely enough there seems to be little indication that all earlier workers have paid proper attention to it. It is all very well to put out drag-fitted bottles, but unless one can have very definite information that the postcard bottle had actually stranded *complete with fittings exactly as when set adrift* at the place wherefrom the postcard was sent back, one surely has no option but to discard the postcard as almost worthless. This is certainly the considered opinion of the writer who has carried out various experiments to evolve a really successful drag-fitted bottle. In the course of drift-bottle experiments in the Adriatic, Italian workers did take steps to learn whether the entire floating system stranded at the place from which the postcard was returned.

A few general considerations will repay attention at this point. If ordinary surface-drift bottles move (as they have been known to do) up the English Channel into the North Sea at an average speed exceeding 6 miles a day (**3**), we may not assume that there has been any commensurate translocation of water unless we have special evidence of this.

* References are given later.

Such evidence might be available from the study of changing salinity distribution. As Harvey (**5**, p. 103) so rightly remarks, "it appears probable that the wind-blown surface particles, after travelling a short distance, sink, to be replaced by particles from below, and in this way translocation of water masses with particular characteristics, containing characteristic organisms, does not take place at anything approaching the speed of a floating object."

It is surely high time that the implications of these considerations should be fully weighed. All the passively conveyed organisms whose movements in the sea interest us fishery researchers, are so nearly of the same specific gravity as the water itself, that we cannot refuse to entertain the possibility that they may undergo passive vertical movements in the upper water layers of equal magnitude with their passive horizontal movements. An object like a simple floating bottle (even when perfectly properly ballasted to float correctly) escapes the vertical movements referred to, and will move along at a rate approaching the onward movement of individual water particles as impelled by the wind during their brief sojourn at the surface. Now without going too fully into the matter, it is at any rate clear that a system comprising a buoyant bottle from which a drag is suspended, will move forwards at a rate much more nearly approximating to that of planktonic organisms in the same milieu; *in cases where the water movements can be regarded as wind-impelled*—an important reservation. Just how badly out (if errant at all) are the results obtained with simple surface bottles in an area like the southern North Sea, where wind plays a potent rôle in influencing waters constantly moved to and fro in immense masses by the swing of the tides, the writer is not prepared even to attempt to indicate here. Of course, the remarks just quoted from Harvey demand fuller attention in some cases than in others. Imagine a large still lake having no outlets and no noticeable currents. Let us put out in such a lake a number of simple surface-drift bottles and await the onset of strong persistent winds. We shall evince no surprise if the bottles (though properly adjusted to float only just awash) move away down wind at a speed very much greater than does, say, the centre of mass of a population of plankton which we may earlier have discovered to be distributed throughout the upper layers where we put out the bottles. This is a simple case. In a sea affected by strong tidal streams the question is very much less simple. It may be that on days without wind the sub-surface tidal streams are, at places, faster than are the surface streams. In the case of the English Channel at times of strong southwesterly winds, rapid North Sea-going travel of simple surface bottles may be attributable to the wind hindering the bottles moving back again on the southwest-going streams. Thus all sorts of complications arise; a certain strength of wind in one direction may be much more potent than the same strength of wind in the opposite direction in influencing the travel of surface bottles, due to unequal speed of the streams opposed. To what degree the ideas so clearly applicable to waters free of tidal streams apply, is a matter for experimental elucidation.

Granted that it is desirable to employ drag-fitted bottles, how best may we construct such bottles ? It is obviously desirable that the drag unit should hang as vertically as possible below the buoyant floating unit. This implies that as much weight as possible should reside in the drag to prevent it from riding up, for, in a sea where the water movements are wind impelled, we desire by the very nature of things that the drag should always hang as deep as possible. This desideratum requires that the upper floating bottle shall be as buoyant as possible so that it shall be able to support a drag of maximum weight. In turn this demands that the suspending line or wire shall be good and strong, and that its attachments to the two constituent units shall be above suspicion. All these features go to make a satisfactory system, but, as an offset, they impose a need for great caution in making safe deductions from the use of floats embodying them. It is clear that such a bottle system as meets all the requirements outlined above might float in good style from E2, say, as far as the Straits of Dover, whereupon it may elect to strand. It will become moored in a fathom of water perhaps, and the constant moving about and battering it may be subjected to there can very easily be expected to cause a breakage adrift as between bottle and drag. What happens now ? The buoyant bottle receives a new lease of life as it were, and may easily move offshore again for any one of a variety of reasons. It is now almost completely useless as an indicator of surface-water movements, for it will be blown about by the wind from place to place, being entirely unballasted. It may ultimately strand and be found, say, in Jutland, in which case its travel might be taken without comment as in no way amiss. It might on the other hand strand on the Yorkshire coast, when one would be presented with the choice between inferring an interesting because unusual drift, and the possibility of something being very much amiss. A period of southeasterly winds could (and has been known to) cause the upper unit of a drag-bottle system to travel to the Yorkshire coast after having come from E2 to the North Sea with nothing wrong with the system. All these considerations imply that we must have a gcol drag-bottle system so designed that we shall know whether *all* was present when the questionnaire bottle stranded. We shall feel inclined to appraise earlier work involving the use of drag-fitted bottles in the light of the foregoing considerations.

Relevant Comments on the Views held by, and the Apparatus employed by Earlier Workers with different kinds of Drift Bottles.

The literature concerning drift-bottle experiments is already very considerable, and it can be no aim of a paper such as this to attempt to give an adequate account of the actual apparatus employed by different workers except in such cases as have a particularly close bearing on matters here dealt with. The first point of interest, of course, is the importance attached by earlier workers to the necessity of using bottles very carefully ballasted to escape windage effect. Let us see what degree of reliance investigators have found it possible to place on the travels of simple surface bottles regarded as true indicators of surface currents. Thereafter will come the wish to learn what views have been held by earlier workers regarding the desirability of employing bottles fitted with sub-surface drags.

It is definitely a fact that there exists a cleavage of opinion. Krümmel (**8**) discusses the earliest-known drift-bottle experiments and weighs the opinions as to their usefulness held by various authorities. He declares his own opinion (**8**, p. 437) thus : " Wir wissen jetzt, dass die Flaschen auch ohne einen besonderen kleinen Ballast von Sand tief genug eintauchen (sie werden meist mit der Zeit immer schwerer durch Bewachsung), um überwiegend dem Strom, nicht einfach dem Winde zu folgen : ganz abgesehen davon, dass in der offenen See die Richtung der herrschenden Luft-und Meeresströmungen nicht eben sehr verschieden zu sein pflegt."

That drift bottles may move against the prevailing wind even when the current is weak and whether they are ballasted or not has been proved by Schott especially (**9**). Ryder (**10**) was content to use ordinary champaign [*sic*] bottles without ballast ; these we are told floated horizontally in the water but with only a very small part of their side above water, " so that they were practically inexposed to the action of the wind." Nielsen (**11**) attached great importance to using bottles carefully adjusted to approach very nearly the specific gravity of the water. Schmidt (**9**) apparently used ordinary champagne bottles, some ballasted to float with only a very little surface exposed, and some unballasted. He intended, however, to ascertain whether the two types performed journeys significantly different, and promised a discussion in the second report on the drift-bottle experiments, but in this report written by Giovanni Platania (**12**) no such discussion appears. Gilson (**13**) in his very fine and detailed report discusses in detail the advantages of using bottles other than simple surface floaters. Incidentally we learn (**14**) that his report only presents a quarter of the material at his disposal for publication. The surface-drift bottles used by the English Ministry of Fisheries (**7**) were all of a type carefully shingle ballasted to float vertically with the tips of their necks only just awash (**15**). In these experiments the bottles certainly did not experience a direct wind pressure, but their travels were conspicuously in accord with the direction of the prevailing winds, a fact which makes one wish very strongly that contemporaneous liberations of drag-fitted bottles had been possible, for it is fair to suppose that such a large-scale bottle experiment will never be repeated—indeed, two of the lightvessels from which the bottles were then set adrift are no longer in existence.

The foregoing remarks serve to show that various opinions have been held as to the necessity of carefully weighting simple surface bottles, but it is surely a very elementary precaution to take, and the present writer (who gives experimental findings bearing on this matter below) certainly holds the view that it is a necessary step to take, being convinced that the strictures made by Sir John Ross so long ago (see **8**, p. 437), when he spoke of the "bottle fallacy," could be levelled with good reason against results obtained from the use of bottles not weighted to ride with practically all their surface submerged.

There can be little doubt that it is much better to use bottles fitted with suspended sub-surface objects; though they are less easy to make up and use in large numbers, their superior usefulness can hardly be challenged. That many workers have held this view is quite clear, and it certainly represents the majority opinion of most marine researchers with whom the writer has spoken. A well-ballasted simple surface floater may certainly be taken along by the current in spite of the prevalence of a strong opposing wind, but it is a matter of experience that if one chooses an occasion when a pronounced surface stream is opposed by a strong wind to put out bottles of both kinds, one will soon see that the bottles separate considerably. This is a fact not to be neglected, and it can with reason be urged that the travels of a bottle system fitted with a drag of adequate surface hung, say, a fathom deep, are likely to give to the marine fishery researcher indications of superior value to the travels of simple surface-floating bottles.

Admittedly a most obvious advantage of the simple surface floater resides in the fact that with it, we are free from the risk that a large proportion of our returned postcards may be useless as a result of ignorance as to whether the bottles when they stranded were exactly as when set adrift. Drag-fitted bottles have been used by various earlier investigators, though reference can here be made only to such experiments as are of special interest to us. Garstang realised the desirability of experiments to determine the depth of the currents induced by wind action (**1**, p. 225) and envisaged a comparison of results obtained by bottles floating at the surface, and by other objects designed to come under the influence of lower strata of water. He appears, however, to have reported upon no experiments to the end outlined. Cunningham in a paper rarely quoted (**6**), in the third year of his drift-bottle experiments in the Irish Sea, continued his liberations of simple surface-floating bottles, " but side by side with it other schemes were tried with a view to ascertain the movements of the deep water. ' Vehicles ' of various form were designed, bamboo and wood being used in their construction ; some were weighted with lead to make them sink, and others left without any ballast to float lightly on the water."* It is not possible to learn all one would like from Cunningham's paper, and he gives no wind data.

References to work with drag-fitted bottles are given by the writer elsewhere (**7**, p. 7). In Gilson's well-known experiments (**13**, p. 7) coupled bottles were used. He deals fully with the reasons for using coupled bottles, describes his apparatus in detail, and gives an account of instances when he has noticed a marked difference in rate of travel in the southern North Sea as between simple surface-floating bottles and his drag-bottle systems, consisting of pairs of bottles linked together by cords 3 metres long. When wind and current are in the same sense the simple floater quickly races the other ; where opposed the reverse is the case. Gilson was aware when his postcards came back whether his coupled bottles had been found still fastened together, and realised that the upper buoyant members of his systems, in cases where the suspending cords had broken, were " beaucoup plus aptes à être emportés par le vent." He cites cases where simple bottles had travelled at 13½ miles a day, whereas their fellow coupled bottles had, under the same favourable wind conditions, travelled at only 6 miles a day. Again, he gives instances where simple floating bottles and coupled bottles put out at the same time have performed significantly different journeys in point of direction. We read of cases where simple bottles at times of strong on-shore winds have been cast on the beach, whereas their fellow coupled bottles escaped such a fate. Still, Gilson gives no account of just how his simple surface bottles floated, and there is a special point of interest which occurs to the present writer in connection with his experiments.

If the floating buoyant upper members of his coupled systems were found stranded *minus* their drag members, it can hardly have been possible for Gilson to know whether these bottles had finished their journeys whilst still properly linked. This is a point which has greatly exercised the writer in his experiments, because it is so clearly possible to receive many records which may or may not be above suspicion. Many drag bottles may become moored close inshore whilst complete, and though the severance of the links may take place at some distance from

* In this present paper experiments with bottles entirely unballasted are described—see below, page 267.

the beach, yet the upper bottles containing the postcards may go ashore in the immediate vicinity and be perfectly reliable witnesses to acceptable travels. An attempt to get over this difficulty has been made, as will be seen later. No doubt many of Gilson's coupled systems, from the upper bottles of which he received postcards indicating that the bottle systems had become "decoupled" before discovery of the questionnaire units, were found at places to which the complete system *had* travelled, but the element of doubt cannot but have existed.

In the case of the very fine Italian experiments (**16**), the postcards definitely asked whether when the postcard bottle was found it was alone or fastened to another. Of great interest in connection with these experiments are the entries in the tabulations of returns showing that many coupled systems were recovered still coupled long before stranding, and of particular interest is it to note that some such systems were retrieved complete at distances from the beach, which can mean only that they were moored there by reason of the suspended bottles having grounded. In our rougher northern waters we are much less likely to be so favoured, but it nevertheless remains our chief aim to have drag bottles retrieved whilst still complete—before their suspension cords or wires have become broken. An additional point of interest in these Italian researches lies in the fact that they evidently employed an upper questionnaire bottle almost identical with that since devised and thought novel by the present writer (see **4**, Fig. 2). This bottle was made in quantity for the writer by a commercial firm of bottle manufacturers* to permit drag bottles to be made up easily, but the Italian experimenters have the credit of having had this idea first carried into practical effect. The bottle in question has a pierced bulge at its base to permit the easy attachment of a cord or a wire.

Before passing on to consider the experiments which are the major concern of this paper one may note (**8**, p. 438) that coupled bottles were used a considerable time ago by Hautreux in the Bay of Biscay.

THE DRIFT-BOTTLE EXPERIMENTS OF AUGUST 1927, AUGUST 1928, AND JULY 1929 IN THE ENGLISH CHANNEL.

We may recall the fact that we desired to ascertain whether there would be any significant differences in the journeys performed by bottles of different types put out at such an ideal place for the purpose as E2. A very important secondary consideration was our desire to become possessed of ample good material upon which to base attempts to work out quantitative relationships between wind and bottle travel. The

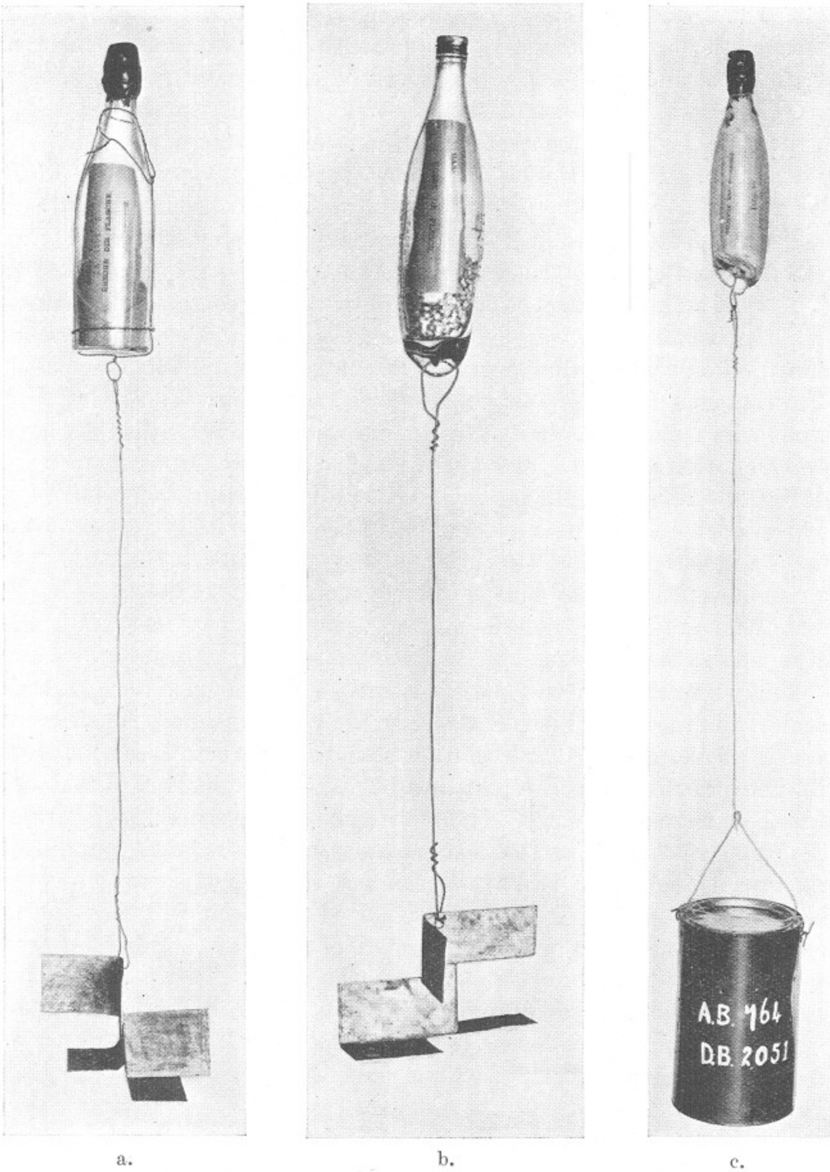
* By Messrs. Redfearn Bros. of Barnsley.

bottles were of three kinds, (1) ordinary simple surface floaters properly ballasted to float just awash, (2) bottles entirely unballasted so that wind could be expected to play its maximal rôle in influencing their movements, and (3) bottles fitted with sub-surface drags and expected to perform journeys as little affected by direct wind influence as possible.

The Bottles.

The simple surface floaters used in all three years need no comment; they are figured in (**7**). The completely unballasted bottles used in 1928 were what are known in the trade as "oval twelves," and they contained nothing save the questionnaire card and papers. The other bottles are figured opposite.

The drag bottles put out in August 1927 were of the type shown in Fig. 1 (a). The wire suspension was half a fathom long and the drag was that previously described (**7**, p. 7). The wire used had to be thinner than desirable in order that it might be manipulated satisfactorily in making the attachment. Actually, these floats closely resemble those which were used by the American investigators in their researches in the Bay of Fundy. Our bottles were of 20-oz. capacity. No means save correspondence with the finders was available to enable us to learn whether the drag was still attached when a bottle was found. These bottles were far from satisfactory, and unless we have known that the drags were still attached when found, the records have been regarded as unreliable. The drag-fitted bottles set adrift at E2 in August 1928 were of two kinds, as pictured in Fig. 1 (types b and c). Those with the metal drag were made up by using bottles of the special type already mentioned and whose unusual features can be seen in the illustration. In this case stronger wire was used, the bottles were sealed by means of screw-on copper caps, the suspension wire was 3 ft. long, and, in general, the systems were much better than those used in the previous year. The questionnaire postcards in this case definitely asked whether the drags were attached when the bottles were found. It may be seen that these bottles are easy to make up, since, when the drags are attached to the empty bottles, several dozen can be floated in a tank and sand poured in from a jug until ballasted satisfactorily. The second type used were designed to serve as drag systems, having specially large drags, the idea being to learn whether these would travel significantly differently from the bottles carrying the smaller metal drags. A number of large cylindrical brightly coloured toffee tins were obtained new (the one figured was painted for photography purposes) from the makers. These tins were nine inches high and of six inches diameter. It was thought inadvisable to ballast the tins and rely upon their proving watertight; holes were



a. b. c.

Fig. 1.—Illustrating various types of drag-fitted drift bottles.

punched in them and an unweighted bottle containing a postcard was suitably "imprisoned" in each of them before hanging the tins from the upper bottles. The underlying idea here was, of course, the thought that we might in some cases receive both postcards back from the same stranding place, which would be a very welcome experience indeed. Again, the lower buoyant bottle contained in the tin made it possible to have a larger drag than would otherwise have been practicable. The suspension wires were of good quality and were 3 feet long.

The drag bottles used in 1929 (not figured here) were better altogether, and consisted of two equal bottles linked together by means of a length (3 feet) of stout sashcord. Only the upper bottles contained postcards, and the bottom ones were so ballasted that the whole systems when afloat left only the smallest portion of the upper buoyant bottles exposed. The attachment of the cords was effected by means of loops of very stout wire fastened to the bottles by means of a device which we have found exceedingly useful, and whose nature can be seen from the pictures of Fig. 2. A monel metal cap pressed specially by the makers to bell out at the open end is screwed home on to the bottle neck to bear down upon a monel metal disc previously placed in position. The "disc" is an annulus; the central hole is just big enough to take the bottle neck, and there are holes punched in it to accommodate wires. Thus the attachments are easily made.

Being unwilling to rest satisfied until sufficient success had been achieved in these experiments as measured by the attainment of the aims stated above, one further liberation of bottles has since been made at E2 just prior to the time of writing. This time we have used material which we have good reason to hope will prove quite successful. Besides the customary simple surface floaters we have put out bottle systems of the type figured below (Fig. 2). In this case the bottle systems are much less likely to "come adrift," and it is hoped that some will be retrieved entire. It is hoped to present the results of this latest experiment next year in the form of a brief supplement to this paper. Then we shall have surface drift-bottle records from experiments in five separate years, and will find ourselves, it is hoped, in a position to speak with confidence as to the correspondence between wind and surface current in the English Channel.

The coupled bottle systems put out in July 1930, and which are much superior in strength and promise to others used earlier, are shown in Figure 2.

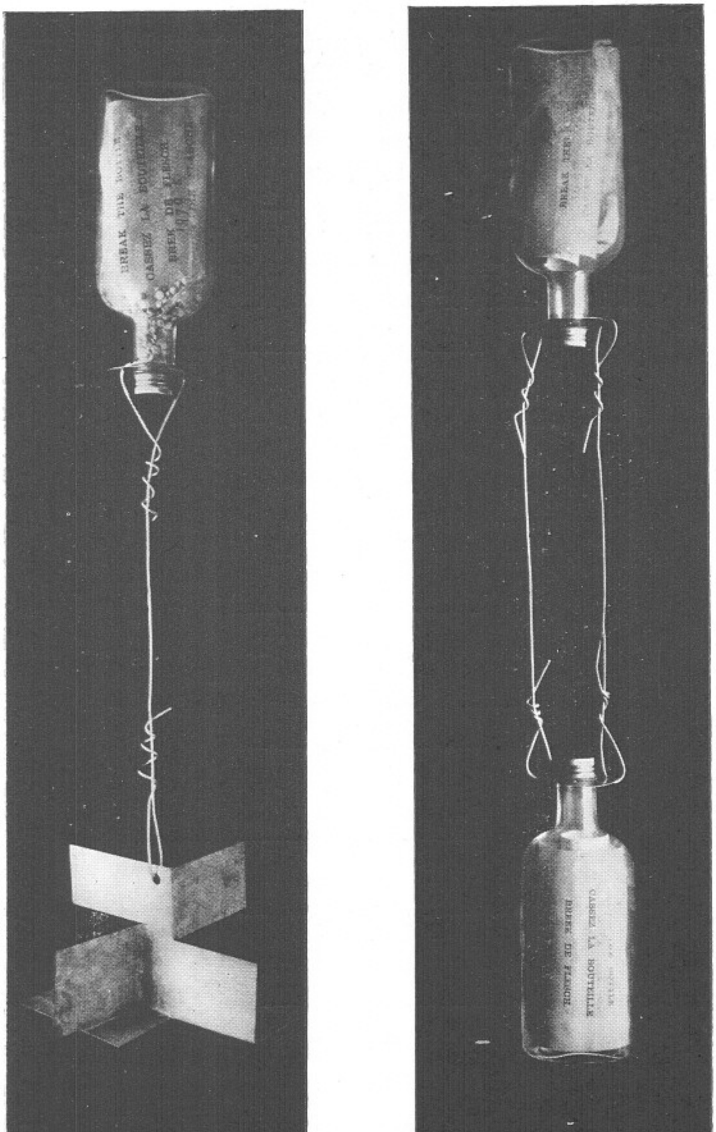


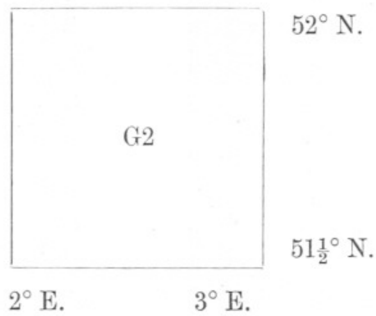
FIG. 2.—Illustrating improved types of drag-fitted drift bottles.

The Recoveries from the Experiments under Review.

The following procedure has again been adopted in reporting :—

A chart of sufficient geographical range was prepared embracing the whole of the English Channel, the North Sea as far north as the Shetlands, and the Cattegat—with the Belts. On this chart were superscribed the ordinary statistical rectangles, each rectangle being delimited by one degree of longitude and one-half a degree of latitude. The positions of recovery of the bottles were (as the records were received) referred to and tabulated in terms of these statistical rectangles. For greater precision in the statement of results, the rectangles were visually divided up into sub-rectangles after the manner of Army cartography practice, thus :—

the rectangle



can be considered to be subdivided thus :—

a	b	c
d	e	f
g	h	j

so that the position of recovery of a bottle might be tabulated as :—

G2 g,

and the latter can be much more quickly referred to a chart than could the usual co-ordinates of latitude and longitude. Chart 1 shows the position at which bottles were put out ; it is also divided up in the manner described to serve reference requirements for the recovery positions of the bottles. Remembering that all the bottles here dealt with were put out at E2, we may proceed to tabulate the details of recovery.

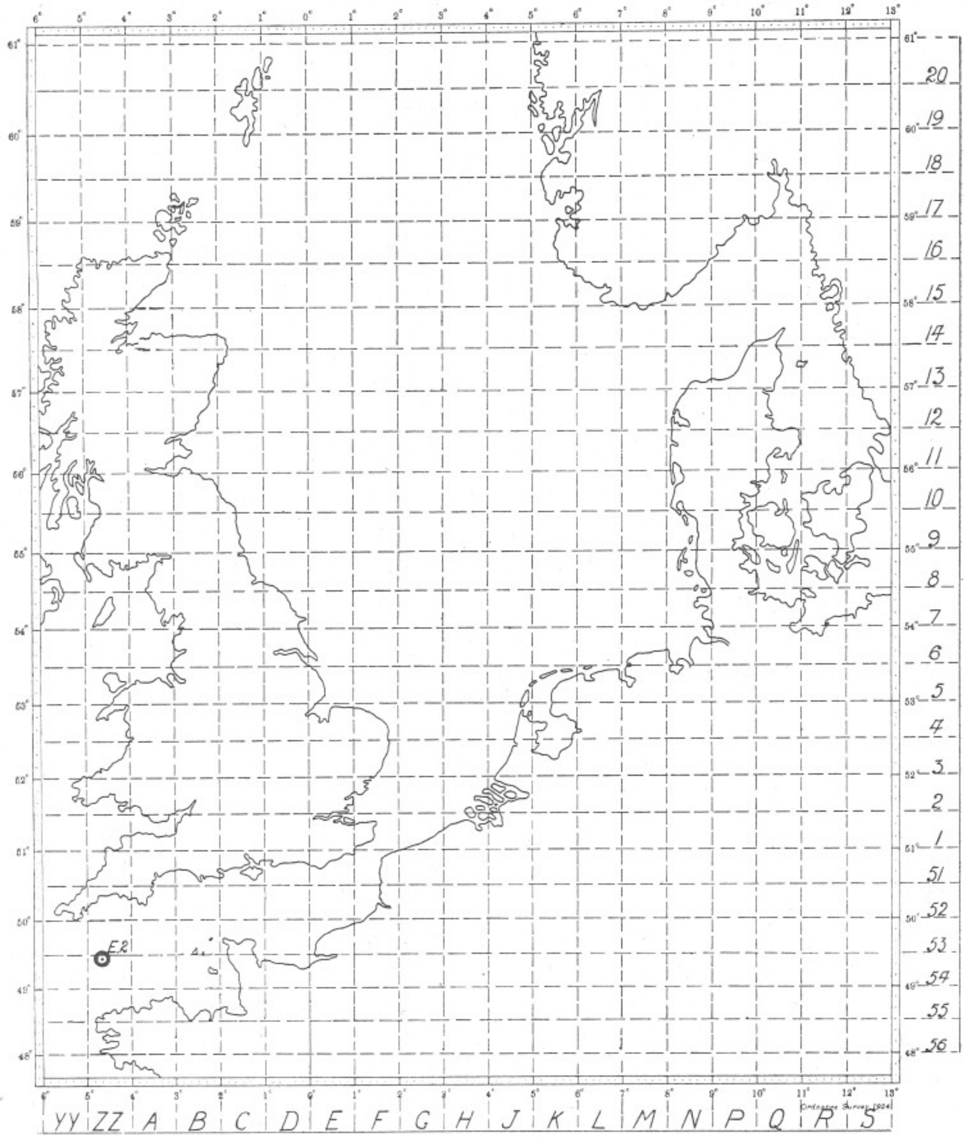


CHART 1.

Key Chart to which tabulated recovery positions of bottles may be referred.

TABLE I.

Experiment of 1927. (1) **Drag Bottles** (Fig. 1, a).

Liberation date : 2.8.27.

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days " out."	Distance travelled in miles.*
12	H 2 h	79	328
14	J 5 f	97	440
14	J 4 b	97	410
14	J 4 c	97	410
21	C 9 b	146	552
22	D 6 f	148	456
22	C 8 j	149	515
27	K 16 e	189	730

Number put out	30
Number recovered	8
Percentage	26·7

TABLE II.

(2) **Simple Surface Bottles.**

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days " out."	Distance travelled in miles.	Corresponding speed in miles per day.
10	J 3 g	65	378	5·8
10	,,	66	372	5·6
13	J 4 c	86	420	4·9
13	,,	86	410	4·8
13	J 5 j	86	418	4·9
13	J 4 c	86	410	4·8
13	J 5 j	89	420	4·7
13	,,	86	420	4·9
13	J 4 c	86	410	4·8
[illegible]	K 5 a	96	450	4·7
1[illegible]	N 8 a	97	585	6·0
31	K 16 e	201	730	3·6
37	N 26 g	257	1290	5·0
51	S 31 j	353	1250	3·5

Number put out	25
Number recovered	14
Percentage	56·0

* Lengths of the shortest tracks which can be drawn on the chart without crossing land. These distances are in many cases certainly much too small—particularly where bottles recovered beyond the Skaggerak are concerned.

TABLE III.

Experiment of 1928. (1) Completely Unballasted Bottles.

Liberation date : 10.8.28.

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
4	D 51 d	27	167	6·2
4	C 51 h	28	147	5·3
4	C 51 j	28	153	5·5
4	,,	28	153	5·5
4	,,	28	155	5·5
4	,,	28	155	5·5
4	,,	28	153	5·5
4	,,	28	153	5·5
4	C 51 e	28	146	5·2
5	C 51 f	29	158	5·5
5	,,	31	162	5·2
5	,,	34	159	4·7
5	,,	34	161	4·7
5	C 51 j	34	155	4·6
7	C 53 f	45	134	3·0
7	C 54 c	48	155	3·2
7	C 53 j	48	145	3·0
11	E 51 c	71	230	3·2
12	E 51 d	78	202	2·6

Number put out	25
Number recovered	19
Percentage	76·0

TABLE IV.

(2) Simple Surface Bottles.

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
11	D 51 d	71	167	2·4
11	C 51 g	72	130	1·8
11	C 51 h	72	147	2·0
11	,,	73	146	2·0
11	,,	74	147	2·0
11	D 51 c	75	192	2·6
11	C 51 j	75	153	2·0
11	D 51 c	77	192	2·5

TABLE IV—*continued.*

Weeks from liberation.	Position of recovery (refer to Chart I).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
11	D 51 d	77	173	2·3
11	,,	77	172	2·2
12	C 51 b	78	155	2·0
12	E 51 b	78	220	2·8
12	D 51 e	78	177	2·3
12	,,	78	177	2·3
12	,,	78	187	2·4

Number put out	75
Number recovered	15
Percentage	20·0

TABLE V.

(3) **Drag Bottles.** (Fig 1 b.)

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
12	D 51 c	78	192	2·5
12	E 51 d	78	198	2·5
15	,,	102	200	2·0
16	C 54 a	108	116	1·1
16	H 2 h	111	338	3·0
16	L 6 j	111	505	4·5
23	H 1 d	161	310	1·9
37	J 5 j	259	420	1·6
38	J 4 c	260	418	1·6
46	L 6 j	322	510	1·6
47	N 10 a	325	625	1·9
47	M 6 d	325	540	1·7
48	N 6 b	333	577	1·7
48	N 7 j	333	586	1·8
48	,,	334	586	1·8
48	N 7 e	336	582	1·7
49	P 6 a	342	600	1·8
51	N 7 j	351	685	2·0
51	N 9 f	351	618	1·8
71	N 6 c	491	575	1·2

Number put out	50
Number recovered	20
Percentage	40

TABLE VI.

(4) "Toffee-Tin" Drag Bottles. (Fig. 1, c.)

(SYSTEMS BOTH OF WHOSE BOTTLES WERE RECOVERED).

Bottle concerned.	Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
Upper	11	ZZ 2 e	71	170	2·4*
Lower	11	D 51 c	76	192	2·5
Upper	11	B 51 h	74	110	1·5*
Lower	11	C 51 e	71	143	2·0
Upper	11	D 51 d	76	168	2·2*
Lower	11	D 51 e	74	180	2·4
Upper	11	D 51 c	77	186	2·4
Lower	16	F 51 e	107	256	2·4

NOTE.—The "lower" bottles, i.e. those initially fastened in the tins, could only themselves perform journeys on escaping from their tins; in this eventuality the upper bottles would sink so long as wire and tin remained hanging from them.

(SINGLE RECOVERIES).

Member.	Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
Lower	11	D 51 e	76	180	2·4
Upper	11	D 51 c	76	196	2·6*
Upper	11	C 51 h	72	147	2·0
Upper	11	D 51 e	74	182	2·5*
Lower	11	D 51 c	74	186	2·5
Upper	15	E 51 d	105	200	1·9
Lower	11	E 51 b	75	220	2·9
Upper	11	B5 1 j	71	102	1·4*
Lower	10	C 51 g	64	130	2·0
Upper	11	D 51 c	75	190	2·5*

Number of pairs put out—25.

Number of pairs recovered intact—Nil.

Number of pairs both of whose bottles were recovered—4.

Number of single bottles recovered—10.

Number of bottles recovered in all—18.

* Denotes stated absence of attachment when found.

TABLE VII.

Experiment of 1929. (1) Sashcord Linked Coupled Bottles.

Liberation date : 30.7.29.

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
11	C 54 a	72	115	1·6
37	F 52 a	253	228	0·9

Number put out	47
Number recovered	2

NOTE.—In this case there was only one postcard, which was in the lower non-buoyant suspended bottle. Thus any recovery is witness of a journey performed with the system intact. The fewness of the returns may be due to breakage of the suspension cords ; if so (1) we are well rid of the useless postcards which we should have recovered had we put cards also in the upper bottles, and (2) we may perhaps later receive some postcards from bottles retrieved by trawl.

TABLE VIII.

(2) Simple Surface Bottles.

Weeks from liberation.	Position of recovery (refer to Chart 1).	No. of days "out."	Distance travelled in miles.	Corresponding speed in miles per day.
6	B 55 g	38	102	2·7
6	B 55 d	40	82	2·1
7	B 55 h	46	102	2·2
7	B 55 j	48	114	2·4
8	B 55 j	50	108	2·2
8	B 55 d	50	88	1·8
9	,,	60	82	1·4
10	E 51 c	70	220	3·1
11	C 54 a	71	114	1·6
11	,,	71	114	1·6
11	F 51 e	73	252	3·5
11	C 54 a	74	115	1·6
11	C 54 h	77	126	1·6
12	C 54 d	82	118	1·4
13	C 54 a	91	114	1·3
14	F 51 c	93	259	2·8
20	N 10 g	138	620	4·5
20	P 14 j	139	740	5·3
22	N 10 a	148	625	4·2
24	Q 17 e	166	850	5·1

Number put out	39
Number recovered	20
Percentage	51·3

GENERAL COMMENTS.

The extent to which the records from the various types of drag bottles used in the three experiments are to be regarded as reliable will be indicated in the discussion which follows. It is clear that we must set down some account of the relevant wind conditions, and it would be a great convenience if some of the more interesting bottle journeys were represented pictorially, as was done by means of charts in the earlier paper in this Journal (**3**). However, it is not possible here to present charts except for the more interesting records.

To present for each year detailed wind data from various suitable observing stations would occupy too much space. Such data as do demand inclusion must yield the following: (1) Information as to wind at some place not too far from E2, at least for a period just after the bottle liberation in that year which saw the putting out of the completely unballasted bottles, and (2) the most acceptable information for each year concerning what may be regarded as the average wind conditions applicable to the entire journeys of those simple surface bottles which moved right up-Channel into the North Sea. In this latter connection it might readily be agreed that suitable continuous wind records made at some place well up-Channel from E2 would best serve; in the considered opinion of the writer the most useful data for the purposes in view are the autographic wind data from the Eastbourne Observing Authority. We mean that these data are considered likely to reflect the mean wind conditions over the track of the far-travelled bottles as well as any we could turn to, and they have the merit of being very convenient.

It is deemed very desirable to seek some quantitative relationship between surface current and wind, a problem which can only be viewed as a series of steps. The fullest and most reliable bottle-travel data at present available are the travels of the simple surface floaters, since with these one pays attention to the travels of the fastest long-distance individuals—a convenience not possible in the case of the drag bottles for obvious reasons. It seems perfectly reasonable, therefore, to attempt first to associate wind and *surface* bottle journeys, hoping later to deduce some amending factor from results obtained with drag-fitted bottles, and to apply this amending factor later to whatever inter-relationship we may have been able to establish between wind and surface-bottle travel. This would be a step nearer to satisfaction, considering that surface current is what we ultimately wish to deal with.

As regards wind in this connection, it seems clear that we can best concern ourselves with data setting forth the daily mileage run of the wind up-Channel (as deduced from Eastbourne autographic records) for periods of time covering the journeys of the long-distance bottles. This means that, if we regard the trend of the Channel as S.W. to N.E., we must learn what run of N.E. going wind has been associated with the bottle journeys. In obtaining our wind data we should in this case simply regard S.W. going wind as of negative sign, knowing that over several months it cannot predominate. One feels that the numerical association of long period means of up-Channel winds with long bottle travels, is the only possible procedure in attempting to work out any useful quantitative relationship between bottle travel and wind, when dealing with an area like the Channel whose waters are always in tidal motion. The phrasing here intentionally avoids the implication that bottle travel and surface current are one and the same thing. With the remark that the wind data applicable to the 1924 bottle experiments from E2 were very simply handled, since the wind was uninterruptedly "up-Channel," we may pass on to set down such data as suit our present study.

Table IX.

RELEVANT WIND DATA FROM EASTBOURNE AUTOGRAPHIC RECORDS.

[Extracted from the appropriate yearly Meteorological Reports of the Eastbourne County Borough and thrown into a form suited to the present study. By "Up-Channel winds" we mean SW.+W.+NW. and by "Down-Channel winds" NE.+E.+SE.]

Period.	Total miles run by wind.	Daily mean mileage run of wind.	Corresponding hourly mean.	Derived multiplying factor to obtain up-Channel wind.	Derived multiplying factor to obtain down-Channel wind.
Aug. 1927	6076·00	196·00	8·17	0·69	0·20
Sept. ,,	6420·60	214·02	8·92	0·77	0·10
Oct. ,,	5567·12	179·58	7·48	0·62	0·15
Above Period	18063·72	196·35	8·18	0·69	0·15
Aug. 1928	5811·04	187·45	7·81	0·69	0·15
Sept. ,,	4450·48	148·30	6·18	0·38	0·33
Above Period	10261·52	168·22	7·01	0·53	0·24
Aug. 1929	5178·40	167·05	6·96	0·72	0·17
Sept. ,,	4088·90	136·30	5·68	0·49	0·36
Oct. ,,	6845·40	220·82	9·20	0·77	0·06
Nov. ,,	6998·28	233·28	9·72	0·64	0·06
Above Period	23110·98	189·43	7·89	0·67	0·16

DAILY MILEAGE RUN OF "UP-CHANNEL" AND "DOWN-CHANNEL" WIND AS DERIVED FROM THE FOREGOING TABLE.

Period.	up-Channel.	down-Channel.	Balance up-Channel.
Aug. 1927	135·24	39·20	96·04
Sept. ,,	164·80	21·40	143·40
Oct. ,,	111·34	26·94	84·40
Foregoing Three Months	135·48	29·45	106·03
Aug. 1928	129·34	28·12	101·22
Sept. ,,	56·35	48·94	7·41
Foregoing Two Months	89·16	40·37	48·79
Aug. 1929	120·28	28·40	91·88
Sept. ,,	66·79	49·07	17·72
Oct. ,,	170·03	13·25	156·78
Nov. ,,	149·30	14·00	135·30
Foregoing Four Months	126·92	30·31	96·61

[On treating the corresponding wind data for the three months July, August, and September of 1924 by this procedure, we obtain the figure 131·06 as the residual "up Channel" daily run of the wind in miles.]

Additional information which may be set down as likely to be definitely illuminating, concerns the known flow of water through Dover Straits at times germane to our present study. Long-period averages only are what we want in this connection, and such Dover Straits records are in the writer's hands in the form necessary.*

As a glance at the charts (Charts 2, 3 and 4) or at the tabulations of bottle recoveries shows, there must have been considerable differences between the three experiments as regards the paths of the bottles in the earlier stages of their wanderings. It is readily surmised that this may have been due to differing wind conditions in the western Channel, and it is necessary to see if such differences did characterise the months concerned in each case. If one can establish such an explanation something of importance will have been accomplished, for we know far too little of the influence of wind on water movement in the area concerned. One experiment would be of little avail in this connection, but we have four experiments (counting that of 1924 already published) in four different summers, and since, as is clear, the bottles moved off differently

* We refer to the continuous current measurements in train at the Varne Lightvessel.

our data can be regarded as being of special promise. We can get the requisite information respecting appropriate wind conditions from the relevant annual "Meteorological Notes" of Falmouth Observatory. Suitable treatment of the published data yields the following information :—

Table X.

WIND DATA FROM FALMOUTH

Period.	Direction and duration of residual wind.			
Aug. 1927	360	hours from	S. 59° W.	true.
Sept. ,,	420	,,	N. 70° W.	,,
Aug. 1928	370	,,	S. 57° W.	,,
Sept. ,,	86	,,	due E.	,,
Aug. 1929	425	,,	S. 86° W.	,,
Sept. ,,	145	,,	N. 12° W.	,,

Before proceeding to discuss the bottle experiments we will present that remaining set of data which might be expected to bear upon our study—the available information as to the contemporaneous flow of water through Dover Straits.

Table XI.

THE FLOW OF WATER THROUGH DOVER STRAITS AT TIMES CONCERNED

Period.	Mean daily flow in miles per lunar day.			
Aug. 1927	3·21	towards	N. 25° E.	true.
Sept. ,,	3·47	,,	N. 32° E.	,,
Oct. ,,	3·34	,,	N. 40° E.	,,
Aug. 1928	3·20	,,	N. 36° E.	,,
Sept. ,,	1·30	,,	N. 7° E.	,,
Oct. ,,	5·80	,,	N. 17° E.	,,
Aug. 1929	3·80	,,	N. 22° E.	,,
Sept. ,,	1·80	,,	N. 12° W.	,,
Oct. ,,	4·10	,,	N. 25° E.	,,
Nov. ,,	7·10	,,	N. 46° E.	,,
Dec. ,,	11·40	,,	N. 49° E.	,,

DISCUSSION OF THE EXPERIMENTS.

It will be convenient first to comment upon the individual experiments in turn, and later to make comparisons and draw contrasts between them.

Experiment of 2nd August, 1927.

In Table I have been set down the histories of the drag bottles put out. These bottles (see Fig. 1, a) were, as experience has shown, far from good enough. The wire was, of necessity, much thinner than desirable, and it is a safe inference to make that many of the suspension wires must have broken. It is fruitless to discuss these drag bottles in any detail, and one is not prepared to place any real reliance upon the apparent speeds attained by those individuals which stranded on the continental coast after 12 to 14 weeks. There is ample reason for this reluctance. Although the bottles which did so strand exhibit no excessive speed as compared with their fellow simple surface floaters, yet a consideration does arise which makes them suspect. One bottle was found on the Yorkshire coast, another near the Tyne, and one further north. This is indeed surprising, and can only mean that these bottles lost their drags, became much under wind influence, and were literally blown across the North Sea by the strong S.E. winds of December 1927.* It may be that some of the bottles which stranded earlier on the continental coasts had also lost their drags but had gone ashore before the onset of the December easterly winds, which caught the others still afloat. However that may be, here we have strong evidence of the potent influence of winds in influencing the travel of partially submerged bottles, and in causing them to perform journeys which properly ballasted bottles were not constrained to do.

As regards the simple surface floaters (see Table II), none stranded short of the North Sea which, in view of the winds tabulated above, is not surprising. The tracks can be seen in Chart 2, and that journey of 585 miles in 97 days will be referred to again. We may assume a speed of travel up-Channel on the part of these bottles of quite 6 miles a day.

Experiment of 10th August, 1928.

In this case no simple surface floater (see Table IV) was recovered beyond Kent ; all the recoveries were made on the south coast of England along a stretch between St. Alban's Head and Pevensey. Probably the overall rate of travel of the fastest was about 3 miles a day (see Chart 3). The easterly winds of September 1928 are to be held accountable for these facts.

* The residual wind for Gorleston over the period of 5 weeks commencing 20th November, 1927, was : 4·6 m.p.h. from S. 70° E. true.

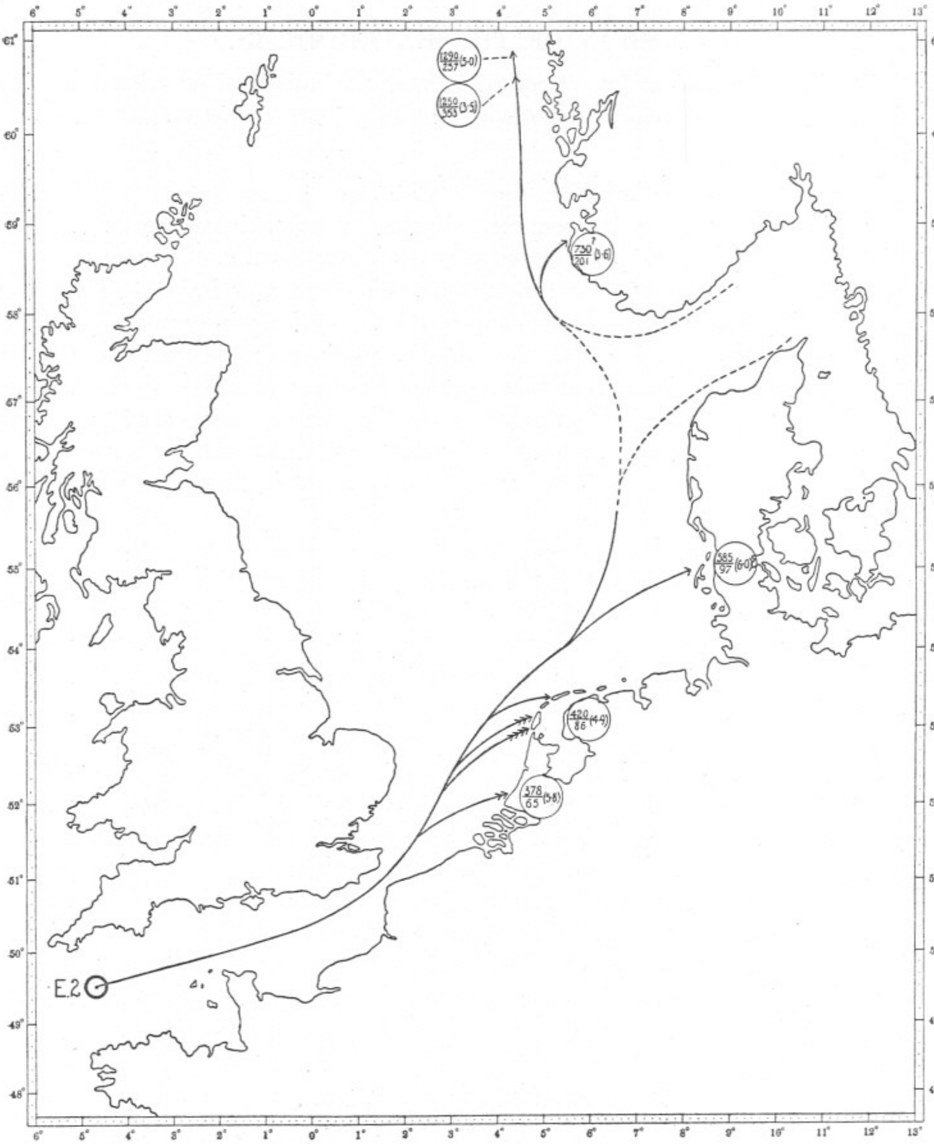


CHART 2.

Illustrating the journeys accomplished by simple surface floating bottles put out at International Station E2 on 2nd August, 1927. Where the arrows are multi-barbed, the number of barbs denotes the number of bottles recovered at the place indicated. The figures in the circles refer to the stranding places near by, and have the following signification :—

The numerator indicates chordal distance travelled in miles.
The denominator gives the time " out " (in days) of the fastest bottle.
The bracketed figures denote the corresponding speed in miles per day.

The completely unballasted bottles (see Table III) were most obviously at the mercy of the strong south-westerly winds which carried them on to the English coast around the Isle of Wight. They covered the short distance of some 150 miles at a speed of about 6 miles a day. Three individuals evidently came offshore again to strand later on the east coast of the Manche département—a fact which a study of the winds already presented can elucidate. It is of very great interest indeed to note that none of the properly ballasted surface floaters accompanied them to the

CHART 3.

Illustrating the journeys accomplished by simple surface floating bottles set adrift at International Station E2 on 10th August, 1928.

The figures in circles refer to the strandings near by, and have the same signification as on Chart 2—as also have the arrows.

Manche coast. Here then is an answer to those workers who have not thought it essential to ballast their drift bottles with great care.

The drag bottles put out (see Fig. 1, b) were of a type in which considerable reliance could be placed. A glance at Table V reveals much of interest. The journeys accomplished were very significantly different from those performed by both simple surface floaters and completely unballasted bottles. Recoveries were made all along the continental coasts from Belgium to north Jutland (several being recovered right in the German Bight), whereas no simple surface floater was recovered clear of the English

Channel. Why was this ? Only four of these drag bottle returns came from the English Channel, and it cannot be denied that these strandings may have been consequent upon loss of the drag. The balance of probability is that such was the case.

Here surely is indisputable evidence that the travels performed by drag-fitted bottles may be markedly different from those of simple surface floaters put out at the same time and place. We see clearly that the wind was unable to influence the movements of these drag-fitted bottles to nearly the same degree as those of their fellow simple floaters. We could not have wished wind conditions to have been other than what they were, seeing what striking results we have obtained, but at least they have deprived us of one piece of information which would have been very welcome. We had hoped from this experiment, to have learnt by what amount (if any) the speed of drag-fitted bottles falls in defect of that of simple surface floaters put out at the same time and place, for, as has been said earlier, we had wished to be able to apply an " amending factor " to the quantitative relationship to be presented connecting wind with travel of simple surface floaters. The idea here was, of course, to get information more acceptable as representing surface drift, than does perhaps the travel of simple surface bottles. Such information as was wished for, cannot be gleaned from the experiments in 1928, since the two types of bottle did not perform comparable journeys. One may note in passing, that the predominant speed of these drag bottles was round about $1\frac{1}{2}$ to 2 miles a day.

It remains to comment on our experiences with the bottles like that shown above (see Fig. 1, c). These " toffee-tin " bottles, as we may conveniently call them, cannot be considered to have proved much of a success. Not one system was recovered intact (see Table VI), but there emerge a few facts of interest. It is highly probable that the two bottles (both members of the same pair) which had stranded in the rectangle D51 did journey, there in concert, and we note that the speed was about 2·4 miles a day. Those bottles which were originally " imprisoned " in the tins, must, for some reason, have got free, perhaps owing to the tins perishing. Only by getting free could they avoid being carried to the bottom on the rupture of the suspending wires. One upper bottle on losing its large drag, journeyed to South Wales. It is to be noted that not one bottle (neither upper nor lower member) got free of the English Channel, the majority stranding on the south coast of England east of 3° W. longitude. This is very illuminating in view of what has gone before. Had they proceeded on and on as perfect drag bottles, we should (on the analogy of the results from the other drag bottles put out with them) have expected them to have got clear into the North Sea. Obviously they have proved to be " neither fish, fowl nor good red herring," though they have not been entirely without interest. It is probable that these " toffee tin " systems broke up just as the easterly winds which so affected the movements of the simple surface floaters, commenced.

Experiment of 30*th July*, 1929.

Much was hoped for from the coupled-bottle systems put out, but as yet (see Table VII) only two returns are to hand. This leaves us completely unable to assess speed satisfactorily ; for this purpose we require a number of returns to get rid of the difficulties arising out of the possibility that the bottles may have lain undiscovered for a considerable time. As regards direction of travel, the meagre records are quite good, for the postcard bottles can only have performed journeys at all so long as they hung from their buoyant partners. One suspects that many of these postcard bottles are lying at the bottom of the sea somewhere in very shallow waters just off-shore. The upper bottles were purposely devoid of postcards. Actually the further travelled bottle was recovered by trawl 29 miles north of Dieppe. The stranding place of the less travelled of the two bottles recovered is of interest in the light of the frequent northerly winds of September. As will be noted later, the simple surface-floating bottles were carried into the Bay of Saint Malo, and this drag bottle must also have been urged thither by the wind, for it failed to round Cap de la Hague. This fact speaks much for the influence of the wind on this occasion.

The journeys performed by the simple surface floaters put out on 30th July, 1929, are very striking (see Chart 4 and Table VIII). They were carried first into the Bay of Saint Malo and stranded round its shores after travelling at a speed low enough to make one surmise that they had been, as it were, hovering about in the open sea for some time under wind conditions not making for quick travel. With the onset of the frequent northerly winds of September they were evidently urged ashore. Such individuals as succeeded in rounding Cap de la Hague went on up-Channel, and some of them reached the Skagerrak.

Brief Review of the Main Results of the Three Experiments.

Common surface-floating bottles put out at the same place (E2) in the same part of the year in 1927, 1928 and 1929 have exhibited very marked differences in their travels ; these differences have been seen to reflect the wind conditions which characterised the three occasions.

In one of the experiments (liberation of 10.viii.1928) completely unballasted bottles, common surface-floating bottles properly ballasted, and drag-fitted bottles of two kinds were put out at the same time and

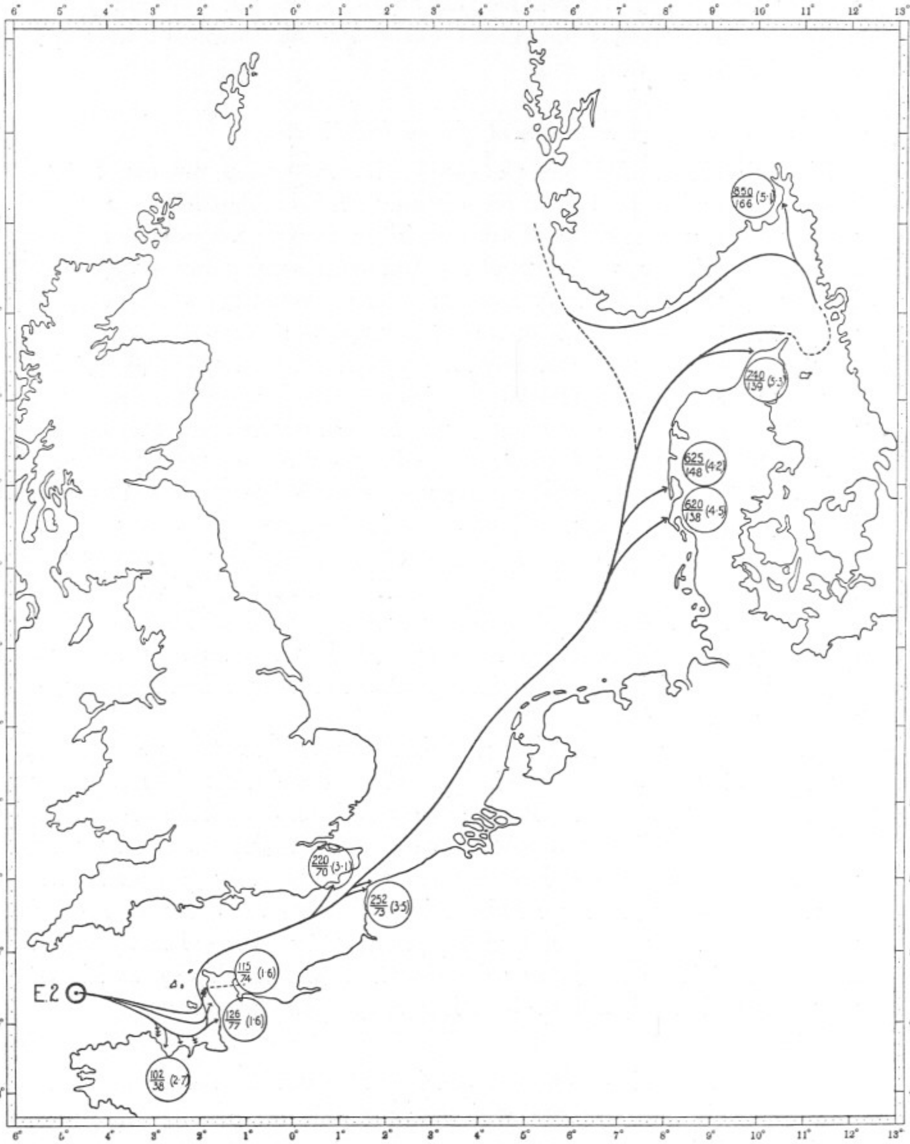


CHART 4.

Illustrating the journeys accomplished by simple surface floating bottles set adrift at International Station E2 on 30th July, 1929.

The figures in circles refer to the strandings near by, and have the same signification as on Chart 2—as also have the arrows.

place. The travels of the different types have been seen to have differed very significantly. The associated wind conditions were, of course, the same for all four kinds of bottle, but the influence which the wind-urged surface water had on the different types in determining their travels has proved strikingly variant.

In the case of the 1927 experiment, when the bottles were carried straight up-Channel without any stranding short of the Dutch islands, there was a continuous flow of water through the Straits of Dover of about $3\frac{1}{3}$ miles a day (see Table XI) during each of the three ensuing months.

Whilst August 1928 differed hardly at all from August 1927 in point of water flow through Dover Straits, yet September 1928 was a month characterised by strong reversals of the usual E.N.E. going flow from English Channel to North Sea. This fact throws much light on the travels of the 1928 simple surface-floating bottles. August 1928 must have been a month of good travel up-Channel, but in September 1928 the bottles were constrained to strand on the south coast of England. The extra brisk flow of water through the Straits in October 1928 was too late to give rise to subsequent strandings on the North Sea shores.

August 1929 was, so far as the Dover Straits current is concerned, little different from the same month in the two previous years, but September 1929 was quite remarkable. In this month the flow of water from English Channel to North Sea was completely held up ; the resulting condition in the Channel must have been that no pronounced drift of water existed. Thus local winds could play a specially strong rôle, and we have seen how the 1929 surface bottles, after drifting about the Bay of Saint Malo for some time, made progress up-Channel, and how three individuals stranded on the coasts bordering Dover Straits. The latter fact is of special interest in view of the contemporaneous hold-up of the water flow through the Straits.

Thereafter, in 1929, the Dover Straits flow of water waxed so very greatly in strength that bottles which had escaped stranding were able to accomplish such rapid journeys across the North Sea that their overall speed for their complete journey touches the high figure of at least 5 miles a day.

We have now one remaining task—to see if we can find any relationship of a numerical kind between the two quantities :—

(1) Speed of Surface-Bottle Travel, and
(2) Speed of Wind at the time.

It is necessary to emphasise here that one must just apply ordinary common sense to the problem. We are not dealing with quantities of a rigid character ; what we must use if we can get them are values for bottle travel and wind, which are acceptable as being the most comparable we could arrive at. The waters of the English Channel being continually in movement as a result of the tidal streams, we have no simple case of wind action on a placid body of water to tackle. It is necessary to proceed as follows :—

Suppose that bottles have moved up-Channel from E2 and have accomplished journeys of several hundred miles. We must, for our purpose, get ample wind data (preferably autographic) from some place situated, say, half-way along the bottle tracks, and work out the appropriate residual wind over the period of time occupied by the bottles' journeys.

It is difficult to see how one can allow sufficiently for the tidal streams if one seeks to establish the desired relationship any other way. Even if we do arrive at an acceptable result, we may not necessarily assume it to be applicable to other waters than those with which we are here concerned.

Over a period of time exceeding a few months, the balance of wind direction will always be up-Channel. We have earlier set down the requisite wind data for our present purpose (see Table IX), and they, together with the bottle-travel data with which we may associate them, will here be given. It is to be noted that the bottle data refer to the simple surface bottles for each year, and attention is drawn to the fact that we are not begging the question by tacitly assuming that bottle travel and surface current are the same thing. They may be so within a little, but we must wait until we have ample satisfactory contemporaneous data from drag bottles and simple surface bottles to work out what we have earlier called an "amending factor." In a previous paper (**3**) the writer was merely able to *fit* a constant to a type of wind-bottle equation. We are now able to go much further and to establish an equation for our area. We have re-cast the relevant data from our 1924 experiments for inclusion here, and in all have data from four different experiments at our disposal. Here are the quantities which call for our attention :—

Experiment.	Mean daily travel of fastest long-distance bottle* (miles per day).	Mileage run of "up-Channel" wind per day during relevant period.
July, 1924	8	130
August, 1927	6	105
August, 1928	2·8	50
July, 1929	5·3	95

* Having regard only to bottles which did not go beyond the Skagerrak ; beyond this the distances actually covered can only be very roughly assessed.

It would indeed be foolish, considering the kind of data with which we are dealing, to seek to deduce any equation other than a simple one. The inter-relationship between the quantities just set down can be expressed by the following simple equation as satisfactorily as by any other :—

$$S=\tfrac{1}{18}\ W.$$

where S is bottle travel in miles per day and W the wind speed in the same units—both being worked out over considerable periods as herein done.

ADDENDUM.

Since this paper was written, it has been felt that fuller wind data from the western English Channel could, with advantage, have been included. Accordingly, additional suitable records have since been worked up into the form of residual winds—this being a conveniently brief way of presenting much information in a small space. It was thought that by far the best thing to do would be to extract from the relevant daily weather reports, the records published for Scilly and Guernsey (four observations daily in each case) and to add these together so as to obtain results particularly representative of the average wind conditions over the western Channel. The following table presents the resulting information :—

Residual Wind Data relating to Scilly and Guernsey considered as one Observing Station.

1927	August	9·3 m.p.h. from	S.67° W. true.
	September	9·1 ,, ,,	N.88° W. ,,
1928	August	7·0 m.p.h. from	S.63° W. true.
	September	3·7 ,, ,,	N.75° E. ,,
1929	August	7·1 m.p.h. from	due W. true.
	September	2·0 ,, ,,	N.19° E. ,,

The fact that the simple surface bottles of 1927 travelled rapidly up-Channel and into the North Sea, is not surprising in view of the wind data just set down. In that year, the winds were overwhelmingly more favourable to the accomplishment of up-Channel travel than they proved to be in 1928, and much more favourable than those which prevailed in 1929.

All the bottles put out in 1928 must have set off up-Channel at a good speed aided by the favouring winds of August. The unballasted bottles reached the longitude of the Isle of Wight very quickly, being blown ashore near there within the month. The ordinary surface bottles escaped being blown ashore with their unballasted fellows, and went on up-Channel, until, before they reached the North Sea, easterly winds held up the Dover Straits current and caused them to strand on our south coast. It is to be noted that these surface bottles were not constrained to strand down wind at the time, as were the few unballasted bottles then afloat.

The extra "west in the wind" in August 1929 as compared with August 1928, made itself strongly felt. The surface bottles were carried into the Bay of Saint Malo, from which area the subsequent N.N.E.'ly winds prevented them easily escaping to travel on up-Channel.

Acknowledgment.

I am indebted to my colleague Mr. H. Stokes for preparing the fair copies of the charts from my rough drafts. The paper has been checked by the Statistical Branch of the Fisheries Department.

Many of the views elaborated in this paper have been previously dealt with in considerable detail by Professor Gilson in the course of his reviews of earlier papers by the present writer (see *Journal du Conseil*, February 1926, March 1927, and September 1928).

SUMMARY.

In July–August of three different years common surface-floating bottles were set adrift at International Station E2 (49° 27′ N.—4° 42′ W.). With them, various types of drag-fitted bottles were also put out. The journeys accomplished are discussed, and the striking differences as between year and year in the case of the common surface floaters, and as between the different types in the same year, are commented upon in the light of the prevailing winds. An inter-relationship of great simplicity is deduced between wind speed and the rate of travel of simple surface floating bottles up-Channel and across the North Sea from the results of experiments carried out in four different summers.

REFERENCES.

1. Garstang, W. Report on the Surface Drift of the English Channel and Neighbouring Seas during 1897. Journ. Mar. Biol. Assoc., N.S., Vol. V, No. 2, 1898.

2. Carruthers, J. N. The Water Movements in the Neighbourhood of the English Channel—North Sea Junction. Drift Bottle Experiments. Journ. Mar. Biol. Assoc., N.S., Vol. XIII, No. 3, 1925.

3. Carruthers, J. N. Investigations upon the Water Movements in the English Channel. Summer, 1924. Journ. Mar. Biol. Assoc., N.S., Vol. XIV, No. 3, 1927.

4. Carruthers, J. N. New Drift Bottles for the Investigation of Currents in Connection with Fishery Research. Cons. Internat. Journal, Vol. III, No. 2, 1928.

5. Harvey, H. W. Biological Chemistry and Physics of Sea Water. Camb. Univ. Press, 1928.

6. Cunningham, C. M. Report on the Drift of the Irish Sea. Fisheries, Ireland, Sci. Invest., 1907, VII (1909).

7. Carruthers, J. N. The Water Movements in the Southern North Sea. Part I. The Surface Drift. Ministry of Agric. and Fisheries, Fish. Invest. Ser. II, Vol. VIII, No. 2, 1925.

8. Krümmel, O. Handbuch der Ozeanographie. Stuttgart, 1911.

9. Schmidt, Johs. Experiments with Drift-Bottles. (First Report.) Rept. Dan. Oceanographical Expeditions 1908–10 to the Mediterranean and Adjacent Seas. Vol. III, 1, 1913.

10. Ryder, C. Some Investigations relating to the Ocean Currents in the Sea between Norway, Scotland and Greenland. Nautic. Met. Ann. of the Danish Meteorological Institute, Copenhagen, 1901 and 1904.

11. Nielsen, J. N. Contribution to the Understanding of the Currents in the Northern Part of the Atlantic Ocean. Medd. fra Komm. f Havunders. Ser. Hydrogr., Bd. 1, Nr. 11, Copenhagen, 1908.

12. Platania, Gio. Experiments with Drift Bottles. (Second Report.) Rept. Dan. Oceanographical Expeditions, 1908–10, to the Mediterranean and Adjacent Seas, Vol. III, 5, 1923.

13. Gilson, G. Recherches sur la Dérive dans la Mer du Nord. Expériences II à XIII. Mémoires du Musée Royal d'Histoire Naturelle de Belgique. No. 35, 1924.

14. Gilson, G. L'Exploration de la Mer au point de vue des pêcheries. Ostende, 1925.

15. Nelson, E. W. On the Manufacture of Drift Bottles. Journ. Mar. Biol. Assoc., N.S., Vol. XII, No. 4, 1922.

16. Marini, L. Lanci di galleggianti per lo studio delle correnti superficiali del Mar Ligustico eseguiti nel 1913. R. Comitato Talassografico Italiano, Bollettino Bimestrale, Num. 29–30, Venezia, 1914.