research on air density and the figure of the Earth to predict the position of the orbit within a mile for a few days in advance. Beyond this time the variations in air friction, which are at present not understood, would reduce the accuracy. The position of the satellite in its orbit is less easily determined in advance, since variations in air friction have a greater effect: it might be necessary to distribute information about the time of crossing the equator no more than one day in advance to obtain a comparable accuracy. Over a whole week errors of up to ten miles might accumulate, although we may expect present experiments to show this to be a very pessimistic estimate.

Irregularities in propagation through the ionosphere and atmosphere have been demonstrated in the 40 Mc/s signals from Sputniks I and III. For this reason and from consideration of power consumption it would appear that a frequency in the region of 200 to 300 Mc/s would be a better choice, and here the irregularities would give negligible errors. The ionospheric disturbances which disrupt communications at lower frequencies would have no effect at all. The signal would, however, still fade periodically during a transit, owing to the Faraday rotation of polarization in the ionosphere.

Accuracy of measurement depends on the signal-to-noise ratio at the receiver. To allow for the fading of the signal several observations of the falling apparent frequency will be necessary, using a series of narrow frequency filters on the receiver. Several pairs of frequencies will then be available, and the centre time should be obtainable to about 0·2 sec., corresponding to 1 mile in position. Slant range should be obtainable to about ¼ per cent; the error in position here depends on the apparent elevation of the satellite at transit. If the satellite is at 45° elevation the accuracy will be about 1½ miles; if it is directly overhead the position is unknown to about 30 miles, and a good position must wait for observations of the next transit 1½ hours later.

7. Conclusion. It appears that a simple system of navigation could be set up giving world-wide coverage with an accuracy of about one mile. If the system were widely used, the cost of the satellites and of a central computing service would be relatively low; the receivers are little more than crystal controlled communications receivers. The presentation is simple, and can be done by graphical methods.

The main disadvantage of the system is the limitation in its usefulness to the times at which a satellite may be observed over the horizon. Even with ten satellites the gap between observations may be 1½ hours, and it would be hard to reduce this interval. At first sight it would seem that the system could be most useful for shipping, where errors in dead reckoning over such an interval are small. It is possible, however, that long-distance aircraft could use it with advantage.

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Navigation in Channel Swimming

from Commander Gerald Forsberg, O.B.E., R.N.

On 26 August 1875, Captain Matthew Webb landed in France after swimming for 21 hours, 45 minutes. This master mariner (and former *Conway* boy) was

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proclaimed 'swimmer of the age and performer of a feat never to be seen again'. Part one of that proclamation was entirely true; part two was not. But even if successes are nowadays classified 'of the year' rather than 'of the age', the feat remains a much esteemed and sought-after distinction. Indeed, last year there were fifty aspirants from four different continents. In addition, much emphasis has shifted from plain achievement to record-breaking achievement. Because of fierce competition, therefore, good navigation has become a matter of paramount, overriding, importance. For record-breakers, anyway, the era of setting off hopefully in the right general direction has gone.

The navigational approach to sea-swim problems is precisely the same for North Channel, Catalina Channel, Juan de Fuca Strait, Palk Strait, Cook Strait or elsewhere. It is to balance the tidal stream in one direction with that in the opposite direction (or better still to find a slight overbalance in a favourable direction). It is also to avoid banks, shoals and overfalls so far as is possible. The English Channel illustration is chosen because it is better known to more people, and because I have practical as well as theoretical experience there. In this article most attention will be concentrated on the France-to-England aspect. At present I hold the British amateur record in the reverse direction and handing information to rivals 'on a plate' is beyond human nature. But using my methods and their own calculations the answers may be readily obtained.

The first essential is to take a broad general view. And then to remember the basic habits of tidal streams. Other things being equal, streams run parallel with the coast. Offshore, the line of shoals is good indication of the line of the main stream. Close inshore, eddies and counter-streams may well exist. Streams turn in different places at different times. There will be seaward deflections off prominent headlands. A through current may be superimposed on the tidal stream. These thoughts are second nature to navigators but unfamiliar to others. A correspondent recently asked if I utilized the tide 'going out' on one shore and 'coming in' on the other!

From basic principles, it is seen that water travelling up-Channel must hit the French coast between the Somme and Gris Nez and be deflected north. As this deflected stream clears the land it will gradually re-curve north-east on meeting the main weight of water from down-Channel; it will pass through the Strait roughly parallel with the mean of the two coastlines amended by bottom-contour effect. As all other streams are roughly at right angles to the swimmer's course, it is obviously advantageous to ride this sole favourable stream to maximum advantage. I guessed that this meant being about $1\frac{1}{2}$ miles north-west of Gris Nez when the northerly stream started to run; a position closer inshore puts one in danger of missing the northerly deflection and being swept along the coast towards Calais. This first opinion was reached merely by general study and application of known principles. It is thus obvious that almost the next action was to test it with dividers and parallel rulers on a large scale chart.

Before beginning chartwork, knowledge of the swimmer's speed is an essential. This is particularly difficult to ascertain. A swimmer's stock reply is 'about two miles an hour'. But in navigating a 'small ship' across tidal velocities twice that of the ship's speed, it is evident that there can be no room for approximation. In my own case, knowing the importance of these data, I timed myself in measured pools over increasing distances as the season progressed. After timing accurately, in successive weeks, a 2-mile swim, a 3-mile swim and a 4-mile swim, it was possible to forecast on graph paper a probable 21-mile speed. This was sufficiently accurate for preliminary navigational planning. Thereafter as training swims lengthened, fresh speed-data became available, was plotted, and used to amend the 21-mile estimate.

When establishing data for another person, however, it is wise not to accept second-hand assurances. One acquaintance of the 'approx 2 m.p.h.' school was subsequently found to be doing no more than 1·5 m.p.h.; it can be imagined that such a large error is sufficient to wreck careful cross-tide computations. My solution is to set the swimmer going over measured distances, and to take snap-sample times at various stages. The observer must be hidden: it is a matter of pride to swim faster when watched, and nothing urges a flagging swimmer to a false and temporary acceleration more than the sight of a timekeeper with watch in hand.

Having ascertained accurate 'pool times', it is necessary to convert these into open-water times. Several factors tend to diminish speed, and two increase it. Plus-corrections should be given for (*a*) increased buoyancy in salt water (*b*) the fact that one has specially prepared and rested for the big occasion. Minus corrections are given for (*a*) loss of assistance from end-of-bath push-offs, (*b*) natural decline of speed when swimming without 'milestones', (*c*) insertion of stops for food, (*d*) rough water effect, (*e*) inevitable navigational inefficiency in small accompanying boats, (*f*) worry about weather, the big day, &c., (*g*) 'dirty-bottom' effect if grease is applied in quantity.

Because speed is the most important single factor in planning a sea-swim the above allowances require brief extra mention. Some are computed more by intelligent guesswork than by slide rule; only practical trial can confirm their correctness. Here are three random examples. In calm weather and minimum tidal conditions I swam Torquay–Brixham–Torquay in $4^h\ 8\frac{1}{2}^m$; my forecast, $4^h\ 13^m$. In fine weather, non-tidal, conditions $10\frac{1}{2}$ miles in Windermere took $5^h\ 19^m$; forecast, $5^h\ 16\frac{1}{2}^m$. In force 7 quarterly wind, $10\frac{1}{2}$ miles in Windermere took $5^h\ 50^m$, forecast, $5^h\ 37\frac{1}{2}^m$.

With accurate speed-data and an 'approximate best time to start', the next step is to plot routes commencing at that time, at intervals of one hour on either side. This reveals the *accurate* best time to start. Results at my speed and entering the water at Gris Nez, were as shown in Table I and Fig. 1.

TABLE I

Start before high water	Swim duration	
hr.	hr.	min.
$2\frac{1}{2}$	12	20
$3\frac{1}{2}$	11	20
$4\frac{1}{2}$	12	10

Obviously the second alternative was very much the best. It is convenient to say at this stage that plotting was done in hourly steps and utmost care taken to obtain accurate resultants of two or three nearest tidal diamonds. For convenience, a mean rate between springs and neaps was used.

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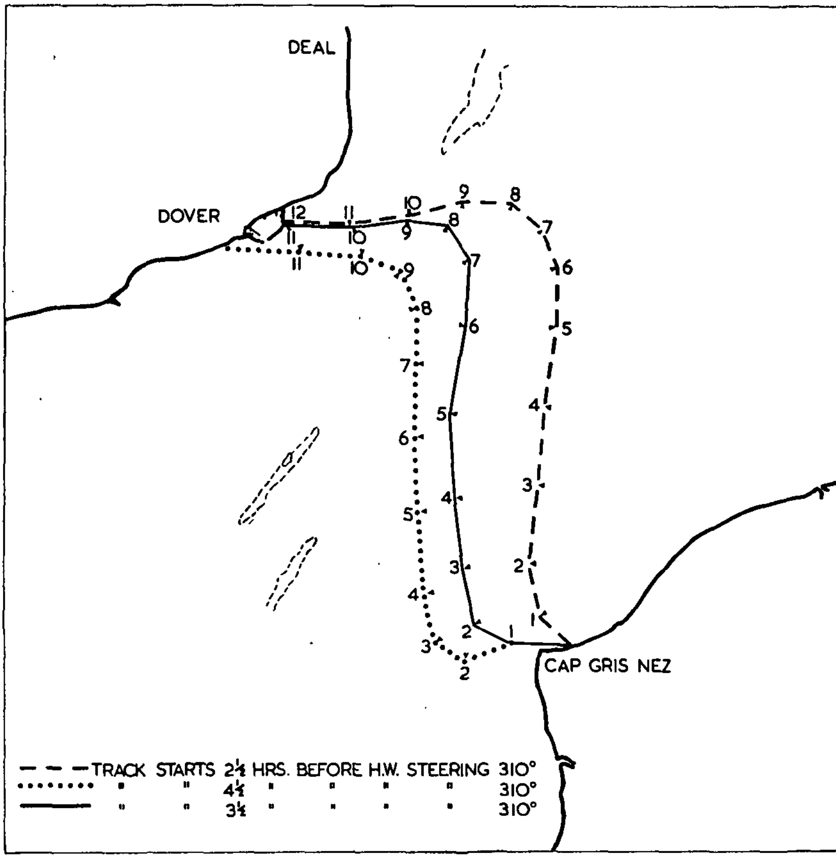

Fig. 1

It is next important to find the best course to steer. This is done by plotting routes either side of an approximate best course. Results, again using my speed, and going from Gris Nez at 'best starting time', were as shown in Table II and Fig. 2.

TABLE II

Steering	Swim duration	
°	hr.	min.
326	13	05
320	12	05
310	11	20

The very marked superiority of 310° is evident.

Is it better to swim at springs or neaps? If there is a slight tidal advantage must it not be accentuated by spring tides? The hidden incorrectness of this assumption cannot be seen until accurate spring and neap plots are put on the chart

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(using of course best starting time and best course). It is thrilling to see the seven league boots provided by the spring tides for 8 hours. Tremendous progress is made. But at 8½ one is faced with the physical barrier of the Goodwins—looking very dry and high near low-water springs. To avoid this predicament it is necessary to keep altering slightly to port from the fifth hour onwards. And altering course brings the tide 80° or so on the port bow instead of abeam.

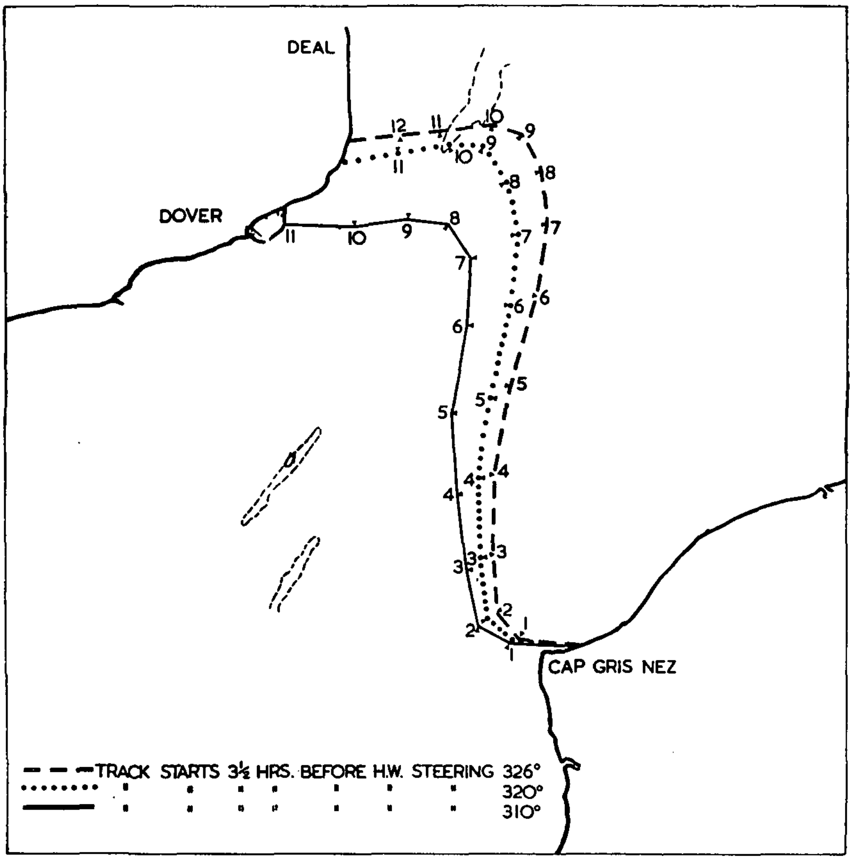

Fig. 2

At springs this adverse tidal component is sufficient to nullify the early benefits (Fig. 3).

Plotting shows that the position after 11 hours of neap swimming and that after 11 hours of springs is almost identical. From that joint 11-hour position the swimmer lands at exactly the same time, be it springs or neaps. The stream runs parallel to the coastline and the distance through the water is equal in either case. Spring tides are not therefore to be avoided at all costs. Neither are they the magic answer to a record-breaker's plea. Greater turbulence troubles the swimmer at springs but that is hardly a navigational matter.

How does theory compare with practice? In my swim from England to France I anticipated completion in $12^h\ 45^m$ but took $13^h\ 33^m$. Six per cent error is not unsatisfactory for navigating an ultra-slow craft for over half a day. But, in any case, it was not the published tidal information at fault but myself. Subsequent swimming in non-tidal Windermere showed my speed to have been 0·03 m.p.h. overestimated; this equals about 15^{m} in $13\frac{1}{2}^{h}$. Further, my Deal boatman admitted a deep-rooted and suspicious respect for the Goodwins; he therefore steered 'nothing to port' for the first two hours. The resultant unplanned westing later stood me in bad stead off Gris Nez when the north-easterly stream started

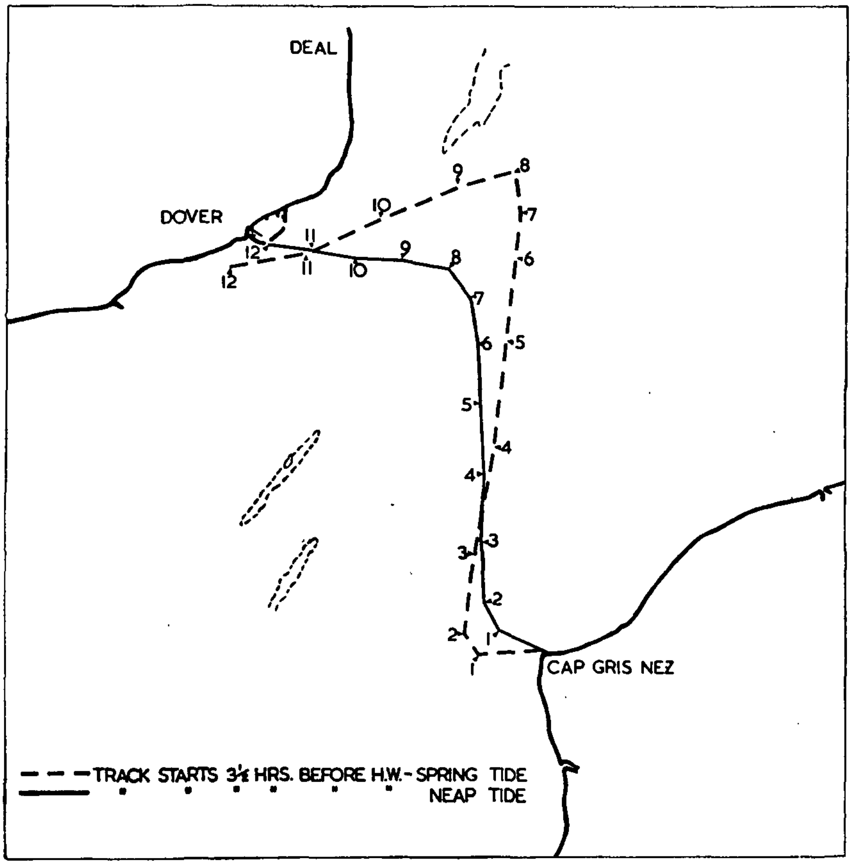

Fig. 3

running. Lastly, the final $2\frac{1}{2}$ hours were much darker and rougher than expected; in difficult conditions—with no fixing possible—my morale and speed faded a little.

In this short note no elaboration is possible. But it is of interest to know that the England–France swim is roughly 15 per cent more difficult than the reverse. (That is for an average swimmer; a slow swimmer increases his difficulties and a speedster decreases them.) A two-way swim is a navigational possibility, although, of course, one has to take pot-luck with the return tides; even half an hour's delay on the outward journey could ruin the homeward bound computations. At my speed I calculate a two-way swim would take 29 hours. This, however, is one piece of theory not to be put to practical test.

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This note shows three things. (*a*) The tidal information available to mariners is impeccable; (*b*) even with most primitive instruments, dead reckoning can be staggeringly accurate if pains are taken; (*c*) sea-swim problems can only be generalized to a certain extent; ultimately each swim becomes a special case. Even a difference of 0·1 m.p.h. can arrive a swimmer in a place where a very different train of tidal circumstances would have ensued 30 minutes earlier (or later.)

A precisely known speed is the only key to sea-swim navigation.

'NAVIGATION'

Navigation, the quarterly Journal of the American Institute of Navigation, is available to members of this Institute at a reduced subscription of £1 a year. The Summer 1959 number contains the following papers: