REPORT ON RANA EQUIPMENT OF THE FRENCH NAVY HYDROGRAPHIC OFFICE

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Translation of an article written in November 1959

1. Design of equipment

At the end of the war, the Hydrographic Office critically examined the use of radionavigational methods for the accurate fixing of positions out of sight of land. These methods, which had resulted in the design of numerous types of equipment, were not applicable to hydrography, however, owing to the differences in specifications for hydrographic and navigational equipment.

A primary requisite is a higher accuracy value, and especially desirable is precise information as to the actual figure obtained. In compensation, a lesser amount of automatism can be tolerated during operations : the rough indications need only be adequate for carrying out the work, provided that while the results are analysed and the smooth sheet is plotted all the required corrections are made in order to produce the highest accuracy obtainable by the method.

The problem of ascertaining the accuracy can be solved easily only within sight of land — that is, precisely within the area where the equipment is least valuable — by comparing the results supplied by the electronic method and by conventional geodetic methods. Accuracy out of sight of land can only be known if ample data are available, such as a minimum of three position lines to obtain a fix. The dimensions of the small triangle formed by the position lines enable the correct evaluation of the accuracy, provided, of course, the systematic errors are eliminated by the operation method.

A hydrographic set of equipment must also meet certain conditions of application :

— the selection of the land sites should be subject to a minimum number of imperatives, in order that the equipment can be used off any type of shore, regardless of its geometric configuration or physical nature (soil, vegetation, buildings);

— the shore-based installations should be light enough to be easily transportable, and be set up by routine labor methods, within a few days;

— operation of the shore-based installations, if not entirely automatic, should be ensured by a small staff with ordinary qualifications;

— finally, it is desirable that the required computation of the position line prior to operation be possible with the sole assistance of a table of logarithms or an electric computing machine, and within the period of station installation. The precise coordinates of the antennas are occasionally obtained fairly late, and it may be necessary to move the stations during operations. If the position lines take too long to plot or require computation methods not ordinarily available to a survey party, the progress of the work may be delayed as a result.

With these considerations in mind and following the study of various then existing equipment, the Hydrographic Office concluded that one possible solution consisted in using the phase method. In 1953 the designing of the equipment was entrusted to Messrs. *Honoré* and *Torcheux,* the inventors of the Rana systems. The equipment was constructed by the Compagnie des Compteurs de Montrouge.

The Rana system underwent receiving trials during the early part of 1954, and has since been used for bathymetric surveying off the Atlantic shores of Morocco in 1954, 1955, 1957, 1958 and 1959. A substantial amount of data is now available to the Hydrographic Office, therefore, for an evaluation of the system's assets.

2. Principle of equipment

The theory of the equipment's operation has already been discussed in a number of publications, including SP 39 : Radio Aids to Maritime Navigation and Hydrography, issued by the International Hydrographic Bureau.

3. Description of equipment

We shall refrain from giving a detailed account of the instrument's design, since a thorough description already appears in the manufacturer's literature. Originally the instrument was merely an improved prototype, and its construction has since undergone a series of minor alterations which experience indicated as being necessary. The manufacturer is at present building similar equipment with a different exterior aspect.

We need only indicate that a Rana system consists of three chains, each supplying a position line (i.e. a geodetic hyperbola) of position. A shipborne receiver and a monitor receiver set up in a fixed position complete the equipment.

Each chain includes :

(*a*) a free transmitter (Master) consisting of a case containing the pilot oscillators and power amplifiers. This unit is connected by a 12-m coaxial cable to an adaptor box located at the foot of a guyed antenna mast, which is provided with a base plate and counterweight consisting of 25-m wires radiating around the base plate;

(*b*) a slave transmitter consisting of a receiver unit, and of five units stacked on a ventilating rack. These five units contain the pilot oscillators and power amplifiers, as well as the circuits needed to lock the transmitted frequencies to those of the free transmitter. The circuits are connected by a 12-m coaxial cable to an adaptor box and to an antenna similar to the free transmitter antenna.

The receiver unit contains the receiver circuits supplying the locking circuits with the beats required for operation of the latter. This unit is connected by a 500-m coaxial cable to a high-frequency head involving an initial frequency change and located at the foot of a 6-m guyed antenna mast with a base plate.

The shipborne equipment consists of three independent units connected by a flexible cable and with a preamplifier, antenna adaptor box and phasemeter case. This unit was later replaced by three recording phasemeters. The antenna consisted of a vertical wire hung from a yardarm above the room containing the receiver and phasemeters.

The monitor receiver consists of a unit containing all the circuits. It is connected by cable to a preamplifier switched to a receiving antenna.

4. Conditions of use in Morocco

Two important facts are to be noted affecting use of the equipment in Morocco :

(*a*) the poor quality of the soil, which usually consists of poorly conductive sand and arenite;

(*b*) a certain stability in meteorological conditions during the period of our operations (July, August, September), and particularly the total absence of rain or storms. Propagation conditions were accordingly stable, as the frequent haze and morning dew occasionally observed resulted in only a slight amount of dampness which rapidly evaporated.

The transmitters were hence sited under unfavorable propagation conditions. Yet in selecting the sites we were not unduly inconvenienced by obstacles such as buildings, trees, telephone or power lines that might have caused wave reflections or propagation changes, even though the choice of sites was confined to the shore area. It may be added that the method of use which was developed allowed for irregularities of propagation, provided these were constant in time, and subject of course to their not reaching such proportions as to completely eliminate the hyperbolic pattern.

The distance between the free transmitter and the slave transmitter of each chain was finally selected as about 10 km, with usually a direct view from one antenna to the other. It was thus possible to decrease this distance without interfering with accuracy, as the hyperbolic pattern is extremely fine : on the baseline the zero-phase hyperbolas are less than 50 m apart (*). The overall installations of a single chain are therefore relatively close together, which facilitates servicing.

The choice of this 10-km distance between the free transmitter and slave transmitter, combined with the fact that the chains were only used beyond 20-km range offshore, resulted in the proximity of the hyperbolas to their asymptotes throughout the operational area. This in turn gave rise to two favorable consequences :

(*) This distance is equivalent to one quarter of the mean or characteristic wavelength.

(*a*) In *preparing* selection of the sites, the angle at which the hyperbolas intersected could be estimated with sufficient accuracy by replacing them with their asymptotes.

(*b*) The *computation* and *plotting* of the patterns were facilitated, first because the hyperbolas, owing to their slight curvature, could be accurately plotted by computing a small number of points, and secondly because simpler computing methods could be used.

We have already mentioned that the slave antenna was connected with the slave transmitter by a 500-m coaxial line. This arrangement proved to be unsatisfactory in practice, as the levels of reception of signals from the slave transmitter and free transmitter were very different, and the modulation rate sometimes only attained 1 %. A decrease to about 10 km in the distance between the free and slave transmitters could not be expected to improve matters greatly, and the true remedy consisted in increasing the power of the transmitter farthest from the servo-receiver antenna, i.e. of the free transmitter. This was easily accomplished at the factory by altering the existing equipment, and proved to be a perfectly satisfactory solution.

Among improvements to the equipment should also be reported the development of recording phasemeters. The simultaneous reading of the three phasemeters as originally designed had invariably been difficult : the small oscillations to which the phasemeter needles are frequently subject make it hard to obtain an average reading and in practice three operators are required to read the phasemeters correctly at the same time. A recording device is a definite advantage in that it increases both reading convenience and its accuracy. It is easy to plot a mean curve eliminating fluctuations in the phase measurement and the larger, short-period variations due to random causes. The records were obtained on Tedeltos paper and the time pips of each station were simultaneously inscribed on each of the phasemeter recording charts, as well as on the echo-sounder chart when the ship was using Rana for depth surveying.

5. Testing and method of using equipment

Comprehensive tests preceded use of the equipment. Research and tests in the manufacturer's laboratories were followed by trials in the Paris area with prototype equipment. The results obtained led to the equipment as presently designed, and the receiving trials at sea were carried out in 1954 in the Seine estuary. It was possible here to devise application methods along general lines; later the Morocco project corroborated the empirical and theoretical process resulting in method selection, and permitted its closer definition and improvement.

We need not touch on our investigations of operational conditions, which resulted in the alterations described above, and enabled rules to be laid down for the personnel responsible for siting, operations and dismantling. Although of major importance, this type of work has no specific character since it must invariably be carried out whenever new equipment is broken in.

The primary feature to which the Hydrographic Office directed its attention was the study of accuracy. From the point of view of the geodesist and hydrographer, any radio positioning apparatus is a measuring instrument : hence its sensitivity, repeatability and precision must successively be examined. As in all the observational sciences, these qualities hinge on two types of processes : those occurring within the instrument — which to a certain extent can be studied in the laboratory —, and those developing extraneously — which accordingly must be investigated in the actual physical surroundings. It is obvious, however, that global results are always obtained during the latter operations in which both types of processes are active. Hence it is essential that the laboratory tests be carefully conducted, with the understanding that the instrumental accuracy thus derived in no way permits knowledge to be had of the overall accuracy, since this is additionally dependent on external processes.

(a) *Sensitivity*

Among the system's characteristics, sensitivity was the easiest to ascertain once the trials were begun in the Paris area : it was evaluated simply by installing a receiver on a small motor truck. It became evident that sensitivity was far in excess of one hundredth of a revolution, and this result was confirmed during an April 1954 sea trial. The *Amiral Mouchez,* equipped with a receiver, was moored to a buoy for compass adjustment, and during swinging operations successively placed itself on all headings. During the swinging the phasemeter indications were plotted against the headings on a graph. These formed smooth sine curves which clearly translated the successive movements of the ship, whose antenna described a circle of 60-m radius.

This excellent sensitivity was confirmed by all the subsequent trials, which would have been devoid of significance if sensitivity had been mediocre.

(b) *Repeatability*

If repeatability is present, the phasemeter indications should be identical whenever the vessel returns to a given point, regardless of conditions.

Repeatability appeared to be extremely satisfactory during tests in the Paris area. The test consisted in stopping the motor truck bearing the receiver opposite a milestone on a highway — with, for instance, the front wheel level with the stone — and reading off the phasemeter indications. The truck was thereupon driven off, and again brought back to the milestone by guiding the driver and instructing him to stop *on the basis of the phasemeter indication* : it was then noted that the truck occupied the same position in reference to the stone. This trial was very spectacular, as accuracy to within one decimetre was attained, corresponding to one-hundredth lane. It was an incomplete test, however, since all the factors affecting repeatability do not then operate. In actual fact, practically the only evidence obtained was repeatability of the equipment proper.

Other factors to be considered are :

(*a*) pattern stability
(*b*) influence of the ship.

Pattern stability can be checked by means of the monitor receiver, which is set up at a fixed position and should hence supply constant values against time of the phase measurements. It was ascertained — by investigations over several thousand hours — that phasemeter readings vary little (one to two hundredths of a revolution) over a period of several hours. The total range of variation reaches 5/100 revolution, the extreme values corresponding to about 2 % of the total number.

Two causes, instability of transmitters and variations in propagation, affect pattern instability. Transmitter instability is slight, except in case of poor synchronization due to inadequate modulation ratio. Variation then becomes rapid and cannot pass unnoticed : the corresponding chain must be considered as having broken down. This type of incident, caused by poor propagation met with in Morocco, is a rare occurrence since the power of the free transmitter in each chain was increased in order to raise the synchronization ratio.

Propagation variations are likewise slight under such conditions as we were working under, owing to the stability of weather conditions, as previously stated. In some cases two stability rates became evident, showing a difference of several hundredths of a revolution, during the daytime and at night. The hypothesis of night effect due to the interference of direct and reflected radiation cannot be rejected entirely, despite the short distance between transmitters and receiver. This phenomenon occurred but seldom.

Among the factors causing instability should also be included interference from neighboring transmitted signals, which worsens as propagation improves. The frequencies selected were of course remote from the ones used by the various Morocco transmitting stations, and in any event the narrowness of the bandpasses reduced the risk of such interference. Under normal operating conditions interference merely caused a momentary instability and constituted practically no obstacle.

Night effect, as well as interference, did not make themselves felt until the range tests. These were conducted up to a distance where it was no longer possible to read the phasemeters, owing to the amplitude and sluggishness of the needle's oscillations (from 10 to 20 hundredths of a revolution). This motion, produced by interference from the reflected waves, was occasionally accompanied by jumps caused by parasites. At night, when the reflected wave is more powerful and parasitic signals are received with greater intensity owing to better propagation, the range is shorter than in the daytime. Extreme ranges were as follows :

— by night : 88 n.m., or 164 km;
— by day : 166 n.m., or 214 km.

It should be noted that these ranges were obtained with a radiated power of 1 watt for each frequency (*), whereas the ranges indicated in the contract specifications were only 100 km by day and 70 km by night (**).

Results both during the trials and actual service showed excellent stability, although varying stability rates may occur. The purpose of the monitor receiver is precisely to define these rates and supply correction data. The indications of this receiver not only depend on the instability of the transmitters but chiefly on propagation variations, and hence the siting of the receiver requires particular care. For if we are able to assume that

(*) The power of the free transmitter was increased after this test. Incidentally only a slight increase in range can be expected from a power increase.

(**) These tests were carried out without recording phasemeters, which might have enabled valid indications to be obtained at an even greater distance from the transmitters.

propagation over the sea is highly regular, it follows that propagation over land causes the instability. Propagation over land, which is fairly generally the rule between the free transmitter and the slave antenna, has identical effects on both the ship at sea and the monitor station. This does not of course hold true for the paths between the transmitters and monitor station if these are shore based, when the monitor station may record variations not felt by the ship. In Morocco, where propagation is stable, this did not occur, but elsewhere the selection is indicated whenever possible of a monitor receiver site such that all the paths between the transmitters and the receiver travel over water. If the shape of the coastline prevents such a choice, the monitor-receiver indications should be used with considerable caution during the periods they are subject to variation.

The transmitters should of course be sited as close as possible to the shore, so that the paths from the transmitters to the shipborne receiver include no land portion varying in accordance with the position of the receiver.

Once stability is established — or at any rate the method for correcting instability — repeatability aboard ship does not necessarily follow. This ship effect has been the subject of special research, and may be produced by two causes :

(*a*) radio transmissions from the ship;
(*b*) superstructure effects on the receiving antenna.

The transmission of signals over antennas adjacent to the receiving antenna may influence reception or jam it entirely. Each ship requires a separate test. On the *Amiral Mouchez,* transmission in no way affects the phasemeter readings, apart from a signal on 12 875 kc causing total interference with reception. The frequencies used by Rana range between 1 620 kcps and 1 785 kcps, hence are 7 or 8 times smaller than the interfering frequency, and no really satisfactory explanation of the phenomenon has ever been found. The solution was of course to avoid transmitting on this frequency during the entire period the Rana equipment was used.

A greater hazard was the effect of heading, due to the influence of superstructure on the receiving antenna. The phase of an incoming wave changes in varying ways according to the direction of the transmitter in relation to the ship's axis. In order to ascertain this effect, it suffices to pass through an identical position on different headings, taking care to select this position in such a way that both transmitters lie on distinctly different bearings. This effect is of course peculiar to the ship and its receiving antenna arrangement. On the *Amiral Mouchez* tests were made by anchoring a buoy with a short line in shallow water, and by steering the ship close to the buoy on various headings. The reduction of the measurements for each heading was carefully determined in order to bring them in line with the buoy position. No heading effect was detected at the degree of accuracy applied. It may be noted that since the transmitters were 10 km apart and the equipment was used over 20 km offshore, both transmitters as seen from the ship lay on fairly close-lying bearings, and hence any heading effect, if one had existed, would have been inconsiderable.

To sum up, it may safely be stated that repeatability is good, amounting to one or two hundredths of a lane in at least 90 % of cases. This repeatability was later confirmed by precision tests.

(c) *Precision*

If both sensitivity and repeatability are present, the equipment may be used for geodetic measurements, but just as any measuring instrument, it must be calibrated beforehand. This means that its indications must be compared with those supplied by more precise equipment in order that the corrections required for the readings may be determined.

If behavior corresponded exactly to the theory of the instrument's performance, the locus corresponding to a phase measument would be a geodetic hyperbola with foci at the antenna sites, and with a parameter $2a$ (the difference in distances to the foci) equivalent to :

$$2a = \frac{\lambda\psi}{4\pi} + \frac{\lambda}{\lambda'}(d_A - d_B)$$

in which :

ψ = measured phase difference;
λ = wavelength for paths between transmitters and ship;
λ' = wavelength for path between free transmitter and slave antenna;
d_A = distance between slave antenna and free transmitter;
d_B = distance between slave antenna and slave transmitter;

In this formula d_A and d_B are known with extreme accuracy (0.1 m), since all the antenna positions are fixed by conventional geodetic methods and are connected with the general triangulation of the country. The two less well known parameters are the wavelengths λ and λ', owing to the considerable difficulty of predetermining the velocities of propagation and to the occurrence, in the vicinity of the transmitting antennas, of phenomena which may be best described briefly as follows : the phase velocity — the only velocity that need actively be considered — is not equivalent to the velocity of propagation.

Calibration consists, after preselection of values that must remain unchanged for λ *and* λ', *in determining the correction to the phase value as indicated by the phasemeter, in order to permit the legitimate application of the preceding formula.* This correction is of course dependent on ψ, and provided it is not caused by other uncertainties than those affecting the values of λ and λ', will be of the form :

$$\varepsilon = \alpha n + \beta$$

in which n is the (fractional) number of the hyperbola reckoned in a direction away from the zero-phase hyperbola passing through the slave antenna, and α and β are two constants, the first solely dependent on the choice of λ, and the second on that of λ'. As these values chiefly depend on the velocities of propagation adopted, one positive advantage is due to the fact that the velocity over water can be predetermined with a fair amount of accuracy. If the transmitters are sited on shore, i.e. if the paths between the transmitters and the ship travel over water only, the value of λ will be determined correctly and the coefficient α will be zero. The correction will be constant and be equal to β.

Theoretical considerations led to our selecting a value of 299 680 km per second for velocity of propagation over water. In computing λ', which may involve propagation over various types of ground and over the sea, the most likely values of propagation velocity were adopted in each case, so that the calibration corrections would be slight.

For determination of the calibration correction, the exact position of the ship's antenna must be known in order to enable computation of the difference in the distances to the transmitters. The value ψ of the phase can be derived immediately — since the wavelength λ is fixed — and the correction is :

$$\varepsilon = \psi' - \psi$$

ψ being the phasemeter reading.

The precise determination of the position of the ship's antenna can only be carried out in sight of land by geodetic methods. Originally it was believed that the conventional hydrographic method, consisting in the measurement aboard ship of horizontal angles by surveying sextant between landmarks of known geodetic position, would suffice. During the Seine estuary trials in 1954, however, this procedure proved inadequate, since the accuracy obtained with Rana was higher, and calibration by this method would not supply the amount of accuracy actually obtainable with Rana. From 1955 on the position of the ship's antenna was accordingly fixed by three simultaneous theodolite sights from three points of known geodetic position. This easily supplied the antenna position with an accuracy to within a few decimetres, and the theoretical value ψ' of the phase was known to within at least one hundredth of a revolution.

The calibration curves obtained during the five cruises off the Moroccan coast call for the following remarks :

(*a*) Scatter of the values for ε is slight, amounting to a few hundredths of a revolution. This is proof after the fact of all assumptions as to sensitivity and repeatability, as all the measurements obtained from a single chain were carried out under widely varying conditions. It should be pointed out in this connection that no appreciable differences were noted between daytime and night observations. In the few cases where it was believed evidence was acquired of differences amounting to one or two hundredths of a revolution, these broke down under analysis. As a result, a single calibration curve was plotted for each chain, which deviated from the most widely scattered points by no more than four or five hundredths of a revolution (*).

(*b*) When the paths between the ship and the transmitters were only located over the sea, implying that the transmitters were sited near the shore, the calibration curve was horizontal, i.e. α was zero : the propagation velocity adopted over water was therefore correct.

(*c*) When the paths between the ship and the transmitters included a small portion over land varying in accordance with the position of the ship, the calibration curve was no longer horizontal. This invariably occurs, regardless of the sites chosen for the transmitters, along a coast so little indented as the Morocco shoreline, as one approaches the baseline : part of the paths then become tangent to the shore and even cross over land. This shows that crossing the baselines, when this is possible, can supply no valid indication for the calibration of a chain.

At any rate these calibration curves represent within sight of land the corrections required for the phase measurements before the basic formula which supplies the parameter 2a can be applied. Included are all the

(*) The total number of points enabling the calibration curve to be plotted was between 50 and 100.

phenomena that are likely to alter the theoretical operation of the chain. The actual manner in which they are obtained results in identity of the Rana fix with the position determined by theodolite sights, i.e. by proven standard geodetic methods.

Use of these curves out of sight of land, where Rana can be of maximum value, requires that the following assumption be made, subject to verification *a posteriori* :

The value of the hyperbola correction determined in sight of land is applicable at any distance.

This assumption is plausible *a priori.* The only difference between phase measurements taken within sight of land during calibration and those obtained offshore is the evident difference in the paths between the receiver and transmitters. The portions over water of these paths are not subject to a different correction for each, since the velocity of propagation over the sea is admittedly constant. The portions over land, which are invariably short owing to transmitter siting near the shore, remain the same : as the transmitters are 10 km apart, the bearing of the ship over the horizon from each transmitter shows little variation when a hyperbola is radiated over 20 km from shore.

In any case the correctness of the assumption was verified, since Rana supplies three independent loci of the ship's position. It was ascertained that at a scale of 1/100 000 (0.1 mm equal to 10 m) the three loci converge at plotting accuracy, apart from a few scattered, manifestly aberrant stations where the position triangle is appreciable. This verification applies to several tens of thousands of positions ranging between 20 and 130 km from the coast. During each trip a number of these positions selected at random was calculated by an estimated position method with a 1/5 000 plot in order to ascertain the accuracy obtained : the selection of the point within the triangle shows an ambiguity of a few metres rarely attaining the 10-metre mark. Moreover the triangles have no systematic character. If we compute the correction that is arbitrarily applied to the phase reading on one of the chains to eliminate the triangle, we obtain values of 1 or 2 hundredths of a revolution.

These remarkable results bear out the assumption regarding the validity of corrections and verify *a posteriori* the entire experimentation, as well as all conclusions as to operational use.

6. Conclusions

The accuracy of Rana equipment fits it for all hydrographic and oceanographic work up to about 150 km offshore. This accuracy is obtained due to the quality of the equipment and the development of a method of application which owes its principal originality to the fact that the chains are calibrated at each siting.

Its qualities were tested during five expeditions involving the bathymetric survey of Morocco's Atlantic seaboard. The area surveyed (*) which extends along 530 km of coast and 130 km seaward, covers nearly 70 000 square kilometres.

(*) 130 km of coast had been surveyed during a prior cruise with a Decca chain. The total bathymetric operations therefore extend along 660 km of coast, from Mehdia in the north to south of Agadir at 30° north latitude. Total area : 85 000 km^2.

The present equipment is only an improved prototype, and when developed numerous refinements can be introduced. These have not been mentioned in this report since they do not affect the principle of the equipment, but involve increased convenience of operation, maintenance, assembly, and dismantling.

An increase in range should also be considered. This cannot be obtained merely by increasing the power of the transmitters : a longer wavelength should be used (*), and as a result night effect will only be operative at longer distances. It is clear that efforts should be made in this direction to provide oceanographers with a radio position-fixing system which will enable the precise morphology of the sea bottom to be surveyed up to several hundred kilometres away from the coast.

(*) The wavelengths in the present equipment are slightly under 200 m.