

# APPLICATION OF THE HI-FIX SYSTEM IN THE MEASUREMENT OF THE SPEED OF SHIPS AND THE ASSESSMENT OF THEIR STEERING QUALITIES

(Trials at sea of the liner *France* in November and December 1961)

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## I. — REVIEW OF GENERAL PRINCIPLE

The Hi-Fix system, type A or type B, has already been described in several documents. However, it seems necessary to recall the main features. It is a high-precision radio location system which is lightweight and portable, using the phase comparison of pure continuous wave signals transmitted by three distinct stations : a master station and two slave stations. The phase comparison of master and slave signals taken two by two creates either the classic hyperbolic network or a two-range pattern formed by concentric circles.

Whilst, for hydrography, geodetic or topographic surveys, one or the other of two solutions may be used, the two-range system with circular patterns is particularly adapted to measuring the speed of ships. It should be noted that in this version the laborious elaboration of charts overprinted with hyperbolae is replaced by the relatively simple tracing of distance circles.

In the hyperbolic solution for hydrography, the master station is the common centre of two baselines which end in the two slave stations, while, in the case of the two-range pattern, the master station is placed on board the vessel using the system and no saturation of the receiver, which is also carried by the ship, results therefrom (fig. 1).

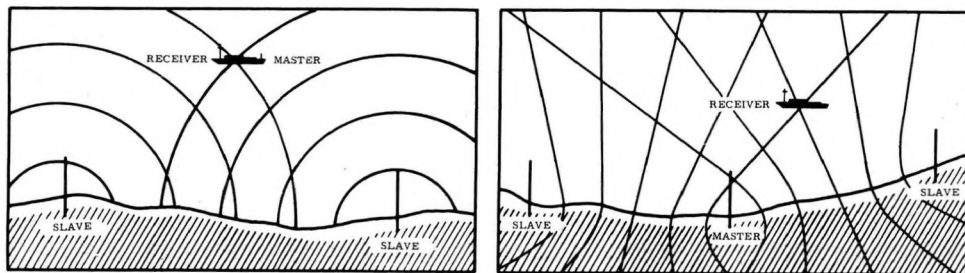


FIGURE 1

This possibility is, in fact, justified by a fundamental innovation which gives several advantages.

Contrary to similar radio location systems, Hi-Fix only uses one frequency in transmissions which are not simultaneous but time-shared in successive sequences. Phase comparison can thus be carried out without changing frequency; also, the interference and the distortion of long distance propagation are more likely to have a similar influence on the two signals compared.

This single frequency of the order of 2 Mc/s is high enough for the unit of measurement, which is the lane equal to the half-wavelength, to permit the evaluation on a separation of one metre.

Another innovation is the use of an automatic phase comparison process for the two transmissions through the action of inertia-free servogoniometers, capable of generating significant torques and of measuring, without error of linearity, a phase difference of about one degree.

The Hi-Fix thus shows definite advantages over hyperbolic systems which transmit several frequencies simultaneously or which need synchronized stations.

## II. — CHARACTERISTICS OF HI-FIX EQUIPMENT

Hi-Fix type A equipment operates by continuously integrating the information supplied by the signal pairs, starting from the information obtained at an approximately known original position. A special device for identification can be included in the transmitting stations and the system is then called Hi-Fix type B. The latter requires a total of two carrier frequencies, but these do not have to be harmonically related.

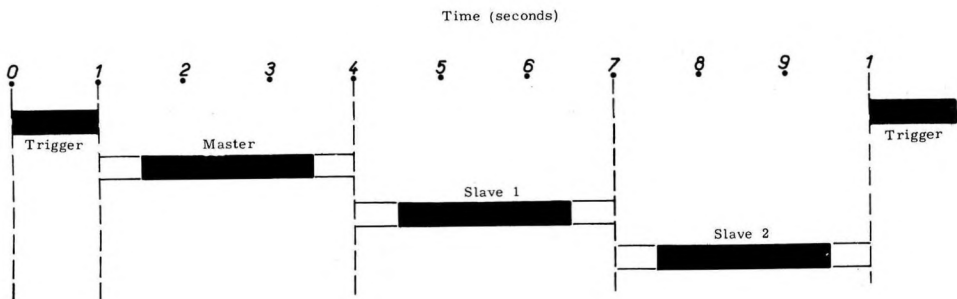


FIGURE 2

At the present time, the single carrier frequency may be chosen among five selected frequencies between 1 700 and 1 950 kc/s. The slave station signals are keyed successively by a trigger signal from the master station; the frequency of this signal is then suddenly reduced by 60 c/s with delays rigorously fixed at 0.3 and 0.6 seconds. The master transmission, lasting 0.3 seconds, is then followed by slave transmissions of the same duration, completing a constant cycle of one second during which the location and

monitoring receivers are switched on for the same periods. The time sharing device is a timer forming part of the master oscillator unit; it is a transistor relaxation oscillator operating as a ring counter (fig. 2).

The transmitting equipment is the same at the three stations. It comprises three basic units : the master oscillator, the transmitter and the receiver. At the slave stations a master oscillator and the receiver are used for phase monitoring in order to assure a constant reference and to adjust the observed phase difference of the signal received from the other slave station. The location and monitoring receivers are identical on the mobile and at the slave stations. Their bandwidth is approximately 100 c/s.

### III. — INSTALLATIONS

Each slave station consists of a master oscillator, a transmitter and a receiver, a transmitting aerial about 10 metres high with radial earth wires approximately 10 metres long, a receiving aerial about 3 metres high with an earth system, and finally a 24-volt power source. The master station comprises only the master oscillator and transmitter, a 24-volt power source and a transmitting aerial.

All the equipment : master oscillator, transmitter, receiver is contained in portable racks measuring  $50 \times 35 \times 25$  cm, and does not need any special protection. The transmitter may be placed at the base of the aerial, and the master oscillator and the receiver should be set up about 10 metres away from the transmitting aerial (fig. 3).

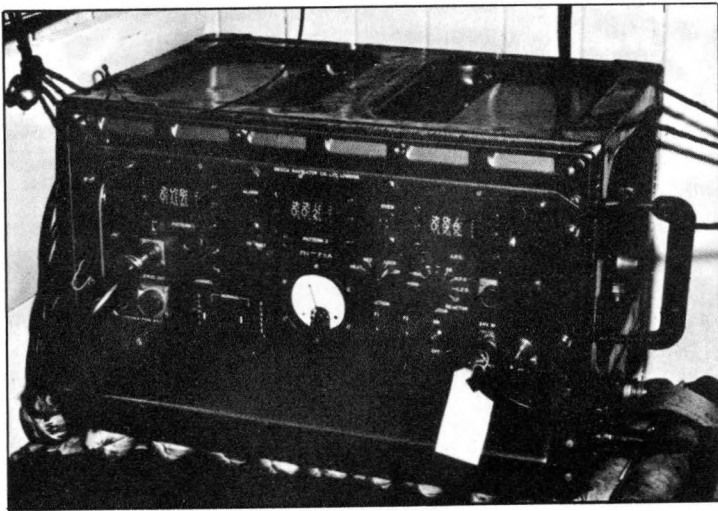


FIGURE 3

The area necessary for setting up a slave station is approximately a circle 10 metres in diameter. On board, the master station is placed at the foot of the aerials on the bridge.

#### IV. — OPERATION

##### 1. — *Monitoring*

The master station oscillator and the oscillator-control receiver set at the slave stations supply the pilot signal to the transmitters at an average voltage of 1 volt. After amplification in the transmitter circuit which contains the aerial tuning and the loading circuits, this voltage provides the aerial with a power of approximately 10 watts.

##### 2. — *Role of receiver*

The receiver may carry out its function of localisation on the mobile, and, at the slave stations, it may act as monitor by maintaining the phase difference between the master transmission and the signal from the other slave station at a predetermined value.

###### (a) *Receiver for position fixing*

For the duration of a normal operation, the master signal is phase compared, through a reactance discriminator, with a high stability master oscillator. This comparison is made on an intermediate frequency of 132 kc/s obtained directly at the output of the master oscillator and indirectly by suitably heterodyning the received master signal.

During slave transmissions, the master phase is thus represented by the output of the master oscillator which has just been locked to the master signal.

The slave signal and the signal coming from the master oscillator are phase compared in a discriminator. Any voltage supplied by the discriminator powers a servo mechanism which operates a goniometer, the rotation of which corresponds to the phase difference. The goniometer operates, for each pattern, a digital counter with 5 figures accommodating 999.99 lanes. The dials of these counters are fixed to the front panel of the receiver rack (fig. 4).

One possibility of reference is supplied at will by generating an internal signal formed by the beating between the heterodyne output and the intermediate frequency signal which comes from the oscillator and which maintains the same phase as the master. This reference supplied to the slave indicator circuits permits the turning of the goniometer stators in order to obtain the zero reading of the indicators.

###### (b) *Receiver for control*

The receiver of a slave station may be used to control the phase difference of the other slave station. The reference signal also allows the introduction of a predetermined phase difference between the reference of the master signal and the transmission of the slave station. This operation is carried out by turning manually the servo goniometer corresponding to the local slave pattern which results in the introduction of the required phase difference between the slave transmission and the master reference signal.

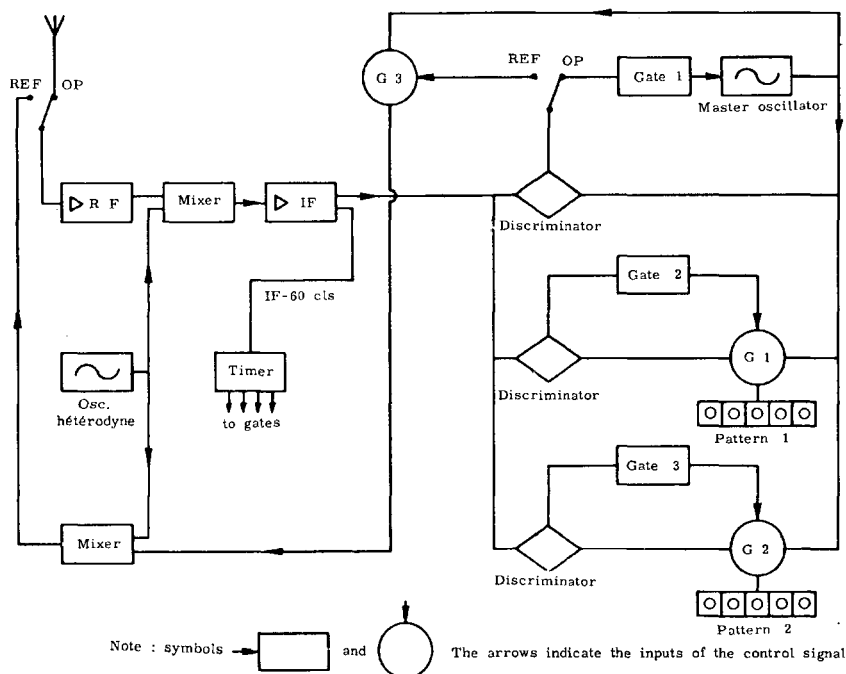


FIGURE 4

### 3. — Personnel

Apart from the technicians or navigators in charge of processing observations on board the ships, the personnel necessary to ensure the working of the chain is very small. A single technician is required for a chain and only the slave stations require a non-technical attendant.

### V. — RANGE

Generally, it is known that the range depends on the limit of distance possible for the phase-locking of the chain, and also on the distance between slave stations in the case of operation over double distance. In addition, it is known that in similar phase-difference systems, the range is also limited during sky-wave periods by the fact that various frequencies are propagated in different manners which cannot be anticipated. Concerning the distance of locking, during the trials of the *France* it was ascertained that the chain remained phase-locked up to more than 150 nautical miles from the slave stations.

It was also ascertained that with a radiated power of a few watts, the distance separating the slave stations may be much greater than 50 nautical miles. The best area is obviously that where the lines of position cut each other at right angles, but the constant accuracy depending on the separation of the distance circles is still ample for intersections of 70 to 80 degrees. If the effects of indirect waves occur rarely at distances

between 50 and 60 miles, they do not affect the measurement made using signals having the same frequency and which are propagated in the same manner.

## VI. — PRELIMINARY EXPERIMENT WITH TANKER *SIRIUS*

During the trials at sea of the 60 000-ton tanker *Sirius* of the *Compagnie Navale des Pétroles*, a first experiment was carried out as a demonstration, from 25 to 28 October 1961, under the direction of the *Chantiers de l'Atlantique*.

These shipbuilders were, in fact, anxious to break away from the inconveniences of using visual measured distances which were so far from the shipyards that it meant long journeys to reach them, and whose limited length over relatively shallow depths was little suited to the manœuvring and speed of large, fast vessels. The same desire was particularly well-founded for the next sea trials which were planned by the same shipyard for the liner *France*, whose size and speed presented still more difficult problems due to the narrowness of the area covered by visually-measured distances. Hi-Fix seemed capable of allowing accurate measurements in areas near the port of construction where there was complete freedom of choice for course, track or depth. The object of the experiment of the *Sirius* was to give, using the standard measured distance at Glénans over depths of 83 to 90 metres, a conclusive test by comparing visual measurements obtained by taking bearings from the shore with the Hi-Fix observations carried out on board ship. This measured distance, only 5 647 metres long, is situated about 7 nautical miles 170° from Pointe de Penmarch.

With this aim, two slave stations were set up, one at Sémaphore de Penmarch and the other at Pointe de Trévignon, forming a baseline about 21 nautical miles long. The master station being installed on board ship, the system was of the two-range type with circular lines of position centred on the two stations. The common frequency adopted was 1 710 kc/s, which fixed the constant value  $\frac{\lambda}{2}$  of each lane at about 87.63 metres and the hundredth of a lane, i.e. about 1 metre, was detectable on the counters. In spite of very unfavourable weather conditions (bad weather from the south-west, rough sea and continuous squalls) the ship (of 66 184 tons displacement and 11.6 metres draught) carried out with between 10 000 and 15 000 h.p. about ten runs, grouped three by three, along the alignment with its track alternately 80° and 260°.

In spite of the frequently unfavourable conditions and the small measured distance, the mean speeds calculated from the Hi-Fix observations over 3 runs differ by a maximum of 5 or 6 hundredths of a knot from the speeds calculated using the shore bearings. These comparisons may be summarized in the following table :

	Mean power	Visual speed	Hi-Fix speed
1st base . . . . .	12 500 h.p.	14.436 knots	14.500 knots
2nd base . . . . .	15 400 h.p.	15.586 knots	15.548 knots
3rd base . . . . .	10 600 h.p.	13.398 knots	13.440 knots

Following these measurements, turning trials were undertaken at 15.5 knots, the helm put 35° to port and starboard. The ship made two complete turns to starboard, the measured turning radius being 590 metres, and two turns to port with a radius of 610 metres. For the first time, these turning circles appeared directly traced, on a large scale (2 inches for one wave-length or 1 cm for 38 metres) on the track plotter type 350 and it was possible to measure distinctly a mean current of 0.2 knots setting towards the east-north-east (fig. 5).

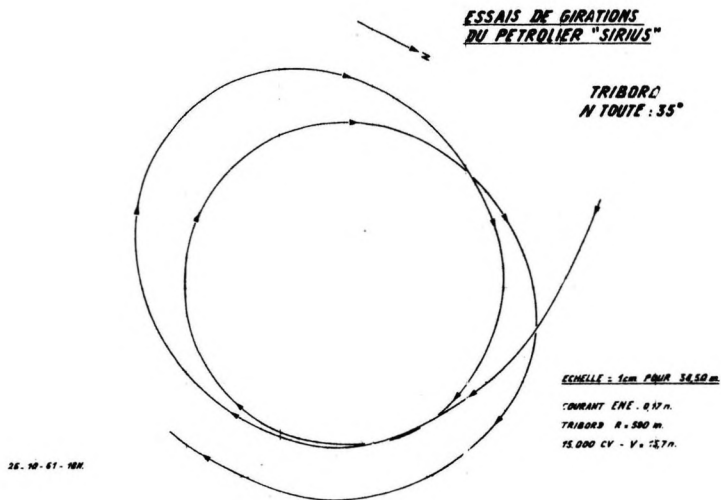


FIGURE 5  
Turning trials of tanker *Sirius*.  
Full speed — Port 35°.

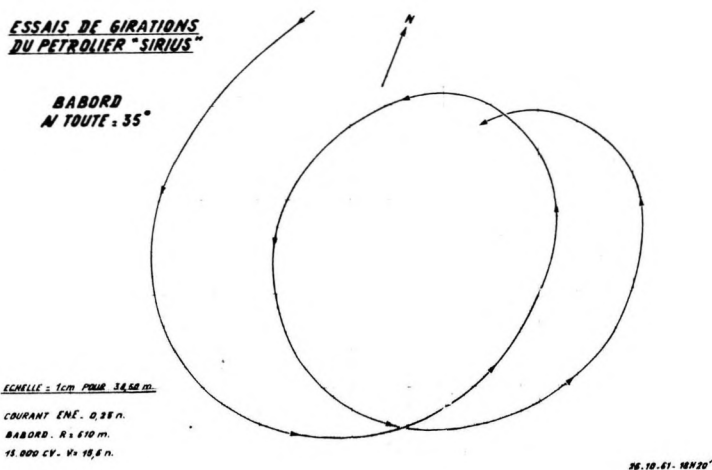


FIGURE 5<sup>bis</sup>  
Turning trials of tanker *Sirius*.  
Full speed — Starboard 35°.

It should be noted that even within the limit of the differences observed, the mean speeds supplied by the visual bearings cannot be considered as absolute references, owing to the difficulty in keeping a steady course because of rough sea or bad visibility. It may be seen, in practice, the length of the measured distance along the exact alignment between the visual end marks being 5 647 m at 80°, that the fact of navigating parallel to that alignment does not cause significant error in the speed measurement, but that navigating 2° off course causes an error of 5 hundredths of a knot on the speed at 15 knots.

### VII. — CONDITIONS OF THE TRIALS OF THE *FRANCE*

The test made on board the *Sirius* having been considered as conclusive, the plan was to navigate the *France* over distances of about 8 miles, with depths of more than 100 metres, out of sight of land, and in an area free from fishing vessels.

Sites for the slave stations were chosen at Lesconil for one and at Beg er Len Point at Quiberon for the other, with a baseline of 46 miles. The circular lines of position intersected at about 70° at a distance varying between 30 and 40 nautical miles from the stations (fig. 6).

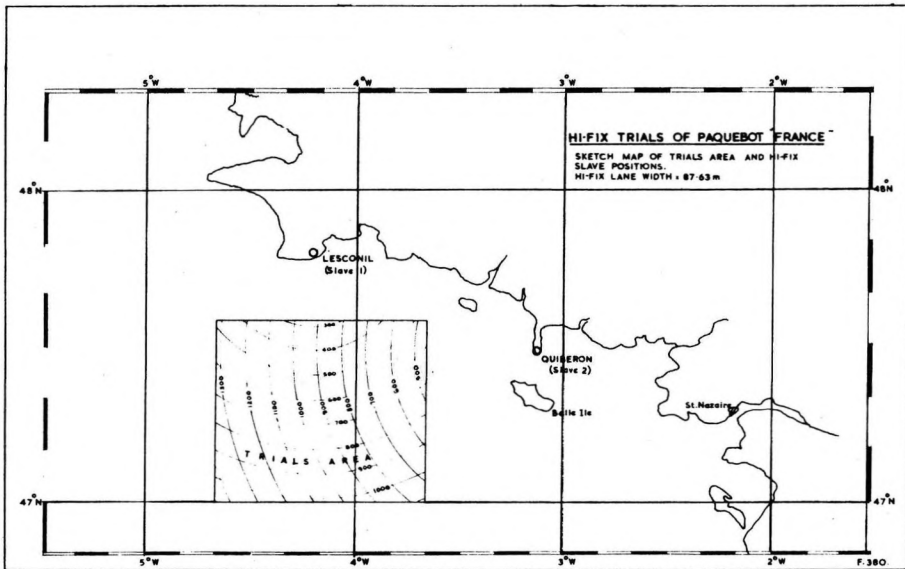


FIGURE 6

### VIII. — RUNS

In order immediately to have the best measurement of variation of distance, using one of the patterns, the outward and homeward courses



of the ship on each run were chosen according to the direction of one of the slave stations, i.e. following a course perpendicular to one of the circular patterns. Most of the runs, in the case of the *France*, were followed heading in the direction of Quiberon or in the opposite direction. However, this is not imperative since all recorded observations gave a fix defined by two patterns. Thus, in the case of unfavourable wind, any other direction may be chosen.

The principle always adopted was that of following alternate courses of  $80^\circ$  and  $260^\circ$  during a series of 3 runs constituting a speed trial to determine an average speed of  $\frac{V_1 + 2V_2 + V_3}{4}$ .

### IX. — OBSERVATIONS

On board, when the vessel has reached its speed in the direction chosen, the following observations are made :

- 1) A ciné-camera operated by a crystal clock records every ten seconds the five figures of each distance counter and the heading and the time to the nearest hundredth of a second.
- 2) An observer in charge of immediate and temporary measurements notes, every ten circles of a pattern, the time to a hundredth of a second as well as the circles of the other pattern and avoids every ambiguity by using the control given by the Decca network, if there is one in the area.
- 3) A third operator (who may be one of the ship's deck officers) carries out the continuous plotting of these positions on a chart at the scale of 1/50 000 including the two patterns. He thus reconstitutes the track made good and compares it to the heading adopted.

### X. — DATA PROCESSING

#### 1. — *Determination of approximate speed*

This speed, intended to provide immediate information to users, is given by visual readings which are averaged at the rate of 10 groups of 10 distance circles during the run which, in the case of the *France*, corresponded to a distance of 8 nautical miles, and was of about 15 minutes

duration. For an interval of about  $\frac{\lambda}{2} = 87$  metres between each circle, each group of 100 circles was crossed in about 550 seconds. In the case of a deviation from the course, the plotting enables this route to be projected on the direction perpendicular to the distance circles.

The speed thus provisionally determined is to the nearest five hundredths of a knot.

## 2. — *Calculation of final speeds*

This calculation is done using the films taken by the ciné-camera.

These films are projected on to a screen and the various indications of the counters, the clock and the compass are then recorded on punch cards, giving information every 10 seconds; that is, for each run about 90 readings.

The perforated cards are then fed into a digital computer and analyzed by ordinary statistical methods, thus giving a mean quadratic value of the speed, to a hundredth of a knot, and a standard deviation.

This process revealed the entirely new possibility of determining every ten seconds the instantaneous value of the speed and consequently the accelerations of the vessel, thus surpassing the present possibilities of measuring the number of revolutions of the engines moment by moment.

## 3. — *Turning and manœuvring graphs*

After processing the information, the successive positions of the ship, both on the turning circles and on the crash stop, are plotted on a graph at 1/5 000, emphasizing all the interesting parameters of curvature, drift and diameter. This graph may be obtained directly and continuously using the track plotter 350.

With the object of simplifying the provisional speed measuring operation and of reducing the number of operators, an improved indicator is being planned which will replace the classic distance counters of the position-fixing receivers by a direct reading of the mean speed through a mechanical device moved by those counters.

## XI. — RESULTS OBTAINED

The trials at sea of the liner *France* all took place in the same area off Belle Island, in two series : from 19 to 23 November 1961 and from 16 to 22 December 1961. The first consisted of 20 runs with 70 000 to 150 000 horse power and a displacement of approximately 52 000 tons; the second series consisted of 7 groups of 3 runs made at between 114 000 and 170 000 horse power with a 53 000-ton displacement and a draught of 12.5 metres over a depth of 110 to 120 metres. In spite of relatively slight but variable currents, the average speeds obtained provisionally and communicated to the shipyard at the time were remarkably consistent, ranging from 26 to 35.2 knots, approximately. After these measurements of speed, manœuvrability trials requested by the *Compagnie Générale Transatlantique* permitted the measurement of the turning radius at various speeds as well as of the crash stop distances and of the rate of acceleration. Later processing of camera recordings gave further confirmation of the provisional results to less than 4 hundredths of a knot, on an average, with a standard deviation of less than 1/100 knot. The turning circles permitted the measurement at 24 knots of the turning diameter with 30°

of helm and the results were : diameter 1 750 metres, and north-westerly current of 0.3 knots. Various graphs were drawn as a result of the different tests :

- 1) Graph of the speed with respect to the number of revolutions (fig. 7).
- 2) Graphs of the speed measured every 10 seconds (fig. 8).

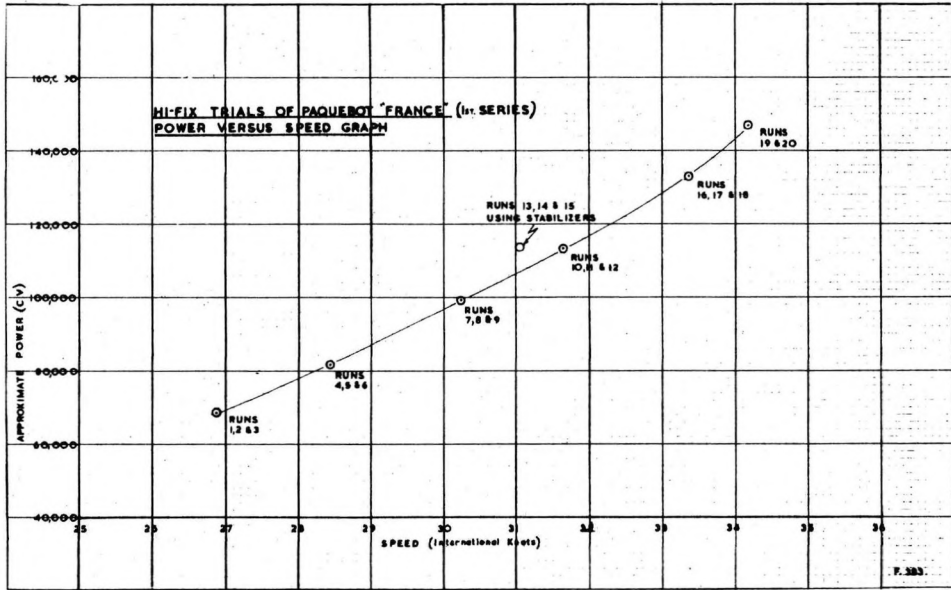


FIGURE 7

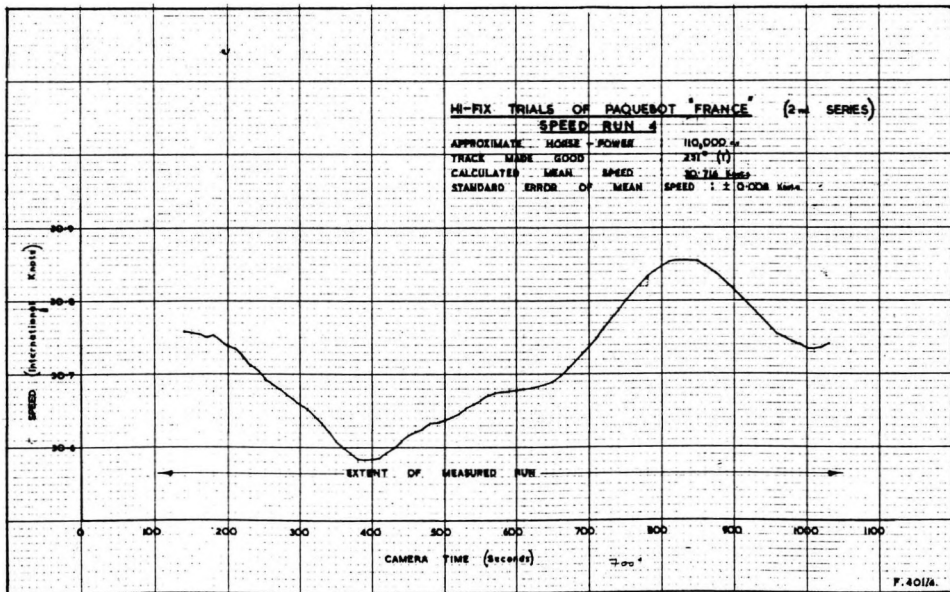


FIGURE 8

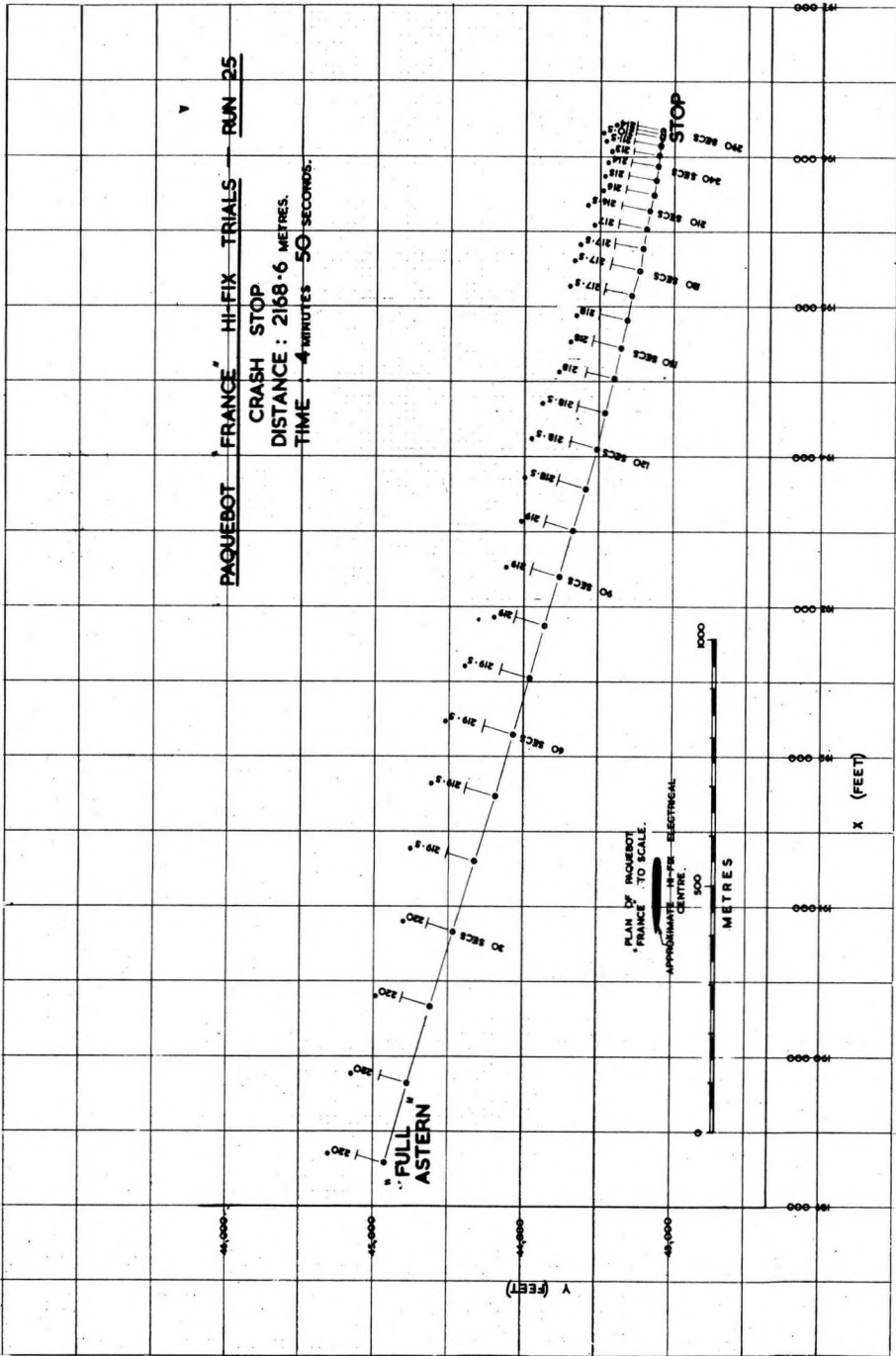


FIGURE 9

- 3) Distances and stopping times of vessel travelling at 30 knots, by putting four engines full astern (fig. 9) (length of stopping distance : 2 100 metres, stopping time : 4 minutes 50 seconds).
- 4) Graphs of turning circles, the helm being put hard to port then hard to starboard at 13 knots (diameter of turning circle : 1 200-1 300 metres).
- 5) Progressive resumption of speed after stopping.

## XII. — REMARKS

The different graphs of turning circles as well as the crash stop trials revealed remarkable steering qualities : the turning circles are regular in form, the ship moves in a straight line when she goes astern with the helm amidships and with slight wind.

We have already emphasized the interest of the graphs obtained by plotting, with respect to time, the Hi-Fix speeds obtained after processing the recorded data every ten seconds. These graphs lead to a hitherto unattainable method for showing short period accelerations of the vessel.

Although it is a question of speed and variations in speed made good, it would have been interesting to compare these instantaneous measurements to the corresponding number of revolutions of the engine. However, under present conditions of speed trials for ships, these numbers of revolutions are not directly obtainable, especially as it is a question of comparing independent revolutions of four distinct shafts in the case of the *France*. A mean number of revolutions is arrived at by an approximate totalization, between the beginning and the end of the run, and it is a figure which does not show the effects of mechanical acceleration.

Undoubtedly, the rotation speeds of the four shafts have, during a run of 15 to 16 minutes, variations which give rise to dissymmetrical propulsion components. But these effects would need to be analysed more accurately and we are faced with the measurement of a particular phenomenon with a much greater degree of accuracy than in the determination of its various causes.

The examination of the graphs of instantaneous speed seems, in several cases, to reveal an apparent pseudo-cycle which, on several runs, seems to be of the order of 14 to 15 minutes.

If it is possible to explain the amplitude of these periodic variations, which reach  $\pm 0.3$  knots at speeds of 30 knots, by an acceptable variation of 1/100 of the number of revolutions (i.e. about 1.5 revolutions for about 145 revolutions per minute), it seems, at first sight, that these variations in speed should be irregular. Such a long period cannot in any way be due to radio electric causes. The origin should be sought in phenomena of propulsion, drift or current, but the fact still remains that using Hi-Fix enabled this periodic variation to be noticed for the first time.