THE DECCA NAVIGATOR AS AN AID TO HYDROGRAPHIC SURVEY.

Note of the I. H. B.

Since the publication in the *International Hydrographic Review*, Vol. XXIV No. 1, May, 1949, pages 13 to 25, of an article on the above subject communicated by C. POWELL of the Decca Navigator Company, the I. H. B. has received a new issue of the Company's Technical Handbook "The Decca Navigator as an Aid to Survey" issued in May, 1950, in which the Section on Error Theory has been re-written and new data have been included on equipment and on operating techniques.

Extracts from this new information appear hereunder and should be substituted for or added to that given in the May, 1949, *I. H. Review.*

ERROR THEORY.

The Root Mean Square Error.

Random errors give rise to a variable displacement of the position lines about their computed positions, of amplitude dependent on the Standard Deviation of the frequency distribution of such errors, and if the form of this distribution is known the expectation of an error of any given magnitude can be predicted. The "Gaussian" or Normal distribution gives the best general fit under the relatively short-range daylight-operating conditions, obtaining in survey work ; the Standard Deviation, though sensibly constant in daylight over the whole survey area, depends to some extent on terrain and other factors already discussed.

A combination of the effects of random movements in the two position lines results in a spread of Decca plots about the true geographical position of the receiver. To describe the likely degree of uncertainty of a single Decca fix taken at this or any position in the coverage, the Root Mean Square error criterion is used. The r.m.s. error is given by

$$d_{rms} = \operatorname{cosec} \beta \sqrt{\sigma_1^2 + \sigma_2^2 + 2\, r\, \sigma_1\, \sigma_2}$$

where β is the angle of cut between the position lines

r is the correlation coefficient between the deviation of the Red and Green co-ordinates from their mean values

σ_1 is the Standard Deviation of the Red co-ordinate in units of distance, derived as follows :

$$\sigma_1 = \sigma_R\, W_R \operatorname{cosec} \frac{\gamma_R}{2}$$

where σ_R is the Standard Deviation of the Red co-ordinate in Lanes,

W_R is the lane width on the Red baseline,

γ_R is the angle subtended by the Red baseline at the point of observation. (Hence $\operatorname{cosec} \frac{\gamma_R}{2}$ by which W_R is multiplied to give the width of the Lane at the observation point, is termed the "Lane Expansion Factor").

σ_2, σ_G, W_G, γ_G similarly for the Green co-ordinate.

The r.m.s. error can be described as the radius of a circle, which symmetrically drawn on the fix distribution, includes approximately 65 % of the plots ; in other words the odds against a single Decca plot falling outside this circle would be two to one. This probability level is the one generally used in estimating Decca errors for survey purposes but it is worth noting that a circle of twice this radius includes some 95 % of the plots.

Estimates of the Standard Deviation and correlation coefficient have been made on the basis of the results observed on operational chains. Over an area in which a Decca chain is likely to be used for surveying, the correlation coefficient by daylight is in general a small positive quantity and can be taken as zero with negligible effect on the value of the r.m.s. error. The Mean Lane is defined as having a width of 500 metres measured along the baseline, which is roughly the mean of the Red and Green lanewidths.

Taking .01 Mean Lanes as a representative value for the Standard Deviation, the factors in the formula reduce to

$$\sigma_R W_R = \sigma_G W_G = 5 \text{ metres}$$

$$r = o \qquad d_{rms} = 5 \operatorname{cosec} \beta \sqrt{\operatorname{cosec}^2 \frac{\gamma_R}{2} \quad \operatorname{cosec}^2 \frac{\gamma_G}{2}} \text{ metres}$$

and the r.m.s. error is a function only of the Standard Deviation and the angles subtended by the baselines at the point of observation. This formula is used in computing the accuracy contours after appropriate conversion from metres to feet. Fig. 1 shows contours for baselines at 120°.

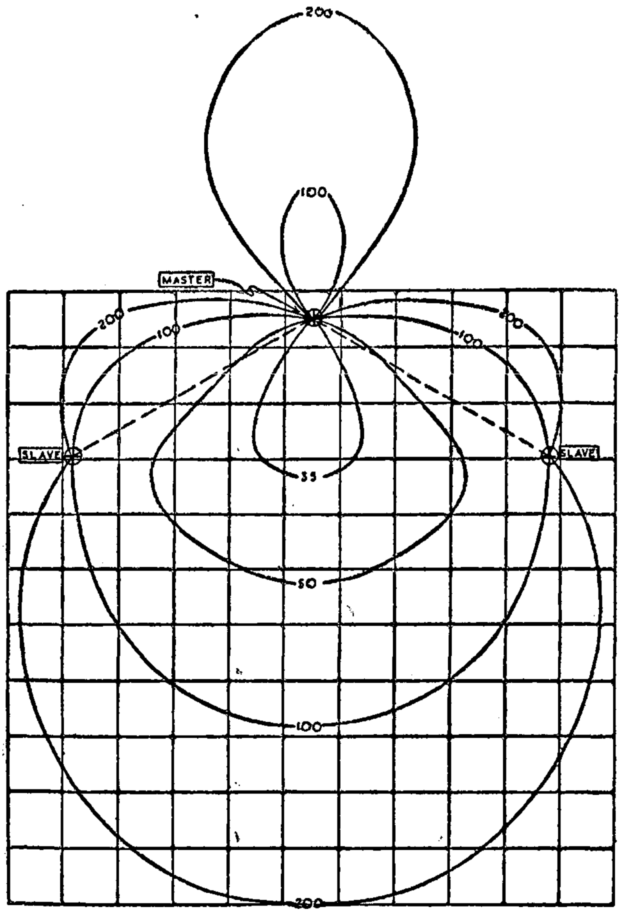


FIG. 1.
Accuracy contours in feet for Baselines at 120°.

The r.m.s. error as defined above is a "conservative" criterion in the sense that it is expressly designed to take no account of the direction in which the error displaces the Decca fix from the true position. The error distribution is of elliptical form, the ratio of major to minor axis increasing with range from the chain. At a given observation point, therefore, the error may be considerably less in a certain direction than the r.m.s. value assigned to that point. This assumes particular importance in air-survey tracking by the

Track Graph method described hereunder. In the Homing method of tracking, in which the ship or aircraft is steered along a Decca position line, prediction of tracking accuracy is given simply by σ_1, σ_2.

The figure below shows the computed Red and Green position lines passing through the observation point P and the "erroneous" position lines displaced plus and minus σ_1, σ_2 from the computed lines. Assuming the Standard Deviation to correspond to a probability level of 68.26 %, the parallelogram formed by the displaced position lines would contain 68.26 × 68.26 equals 46.60 % of a large number of fixes taken at P. As already stated, the circle drawn about P of radius equal to the r.m.s. error would contain approximately 65 % of the plots, the exact percentage being dependent on the ratio of major to minor axis of the ellipse (termed the σ-ellipse) enclosed by the parallelogram.

It can also be shown that the distance corresponding to the r.m.s. error is equal to the hypotenuse of the triangle formed by the half-axes *a*, *b* of the σ-ellipse.

$$d_{rms} = \sqrt{a^2 + b^2}$$

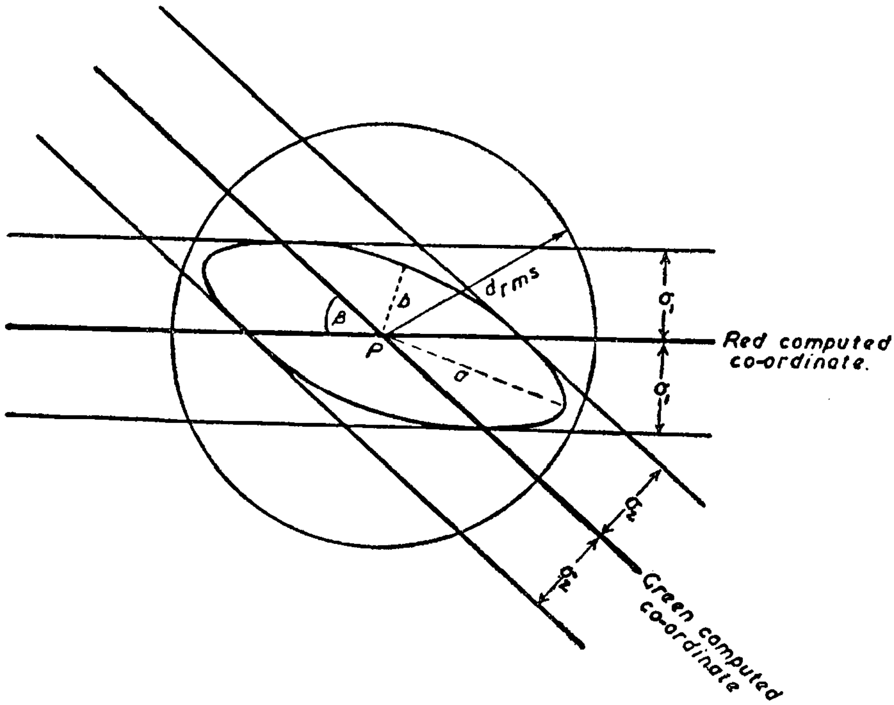


FIG. 2

Systematic Errors.

If the mean observed Decca co-ordinate at a given point differs from the computed value for that point, and the difference remains unaltered with the time, a systematic error in the pattern is said to exist at that point. No satisfactory theory so far has been given to account fully for errors of this type, which result almost entirely from effects taking place along the paths between the transmitters and the receivers.

An overall systematic error would result from an incorrect assumption of the mean velocity of wave propagation in computing the basic hyperbolic pattern.

From trials carried out with experimental transmitters and subsequent theoretical studies, three emerging points should be borne in mind :

(*a*) From a broad knowledge of the characteristics of the terrain to be covered by a proposed chain, velocity values can be chosen for different areas in the coverage with a resulting reduction of the likelihood and the values of systematic errors.

(*b*) It is possible to reduce the likelihood of systematic errors over much of the coverage by making empirical determinations of the effective velocity of propagation along each baseline.

(*c*) One visual check-fix may serve to reduce systematic errors to a negligible level over an area of hundreds of square miles around the point at which the observation is made. It is, of course, assumed as a general principle that some degree of visual control will be exercised in any radio-assisted survey, even though this often amounts in practice only to a single observation at the start of each day's working.

It should be noted that the definition of errors as systematic in time is fully valid. There is, in fact, no set of conditions variable with time that can affect ground conductivity to a sufficient depth other than a large-scale inundation of several feet. No change in fixed errors in the English chain has been detected under any weather conditions. This point assumes particular importance in geophysical surveying, in which it may be necessary to return on successive occasions to a spot whose Decca co-ordinates have been previously observed and recorded.

THE SURVEY EQUIPMENT.

Two alternative types of transmitting station are available for surveying, designated *Transportable* and *Lightweight*. Receivers are the same for each type.

The *Transportable Survey Chain* (Fig. 3) is constituted by : three *Transmitting Stations* (each one being similar in construction), comprising the following units :

Transmitter:
- Crystal Oscillator (Master only).
- Phase Control Unit (Slaves only).
- Drive units.
- Power amplifiers.
- Tank unit.

In addition to the basic items listed above, a comprehensive set of test equipment is supplied with each station and is normally housed in the transmitter hut.

Aerial Loading Coil.

Transmitting Aerial with an *Alternative Aerial System.*

Generator (2 generating sets of 3 kilowatts).

Each station can be run by two men per watch.

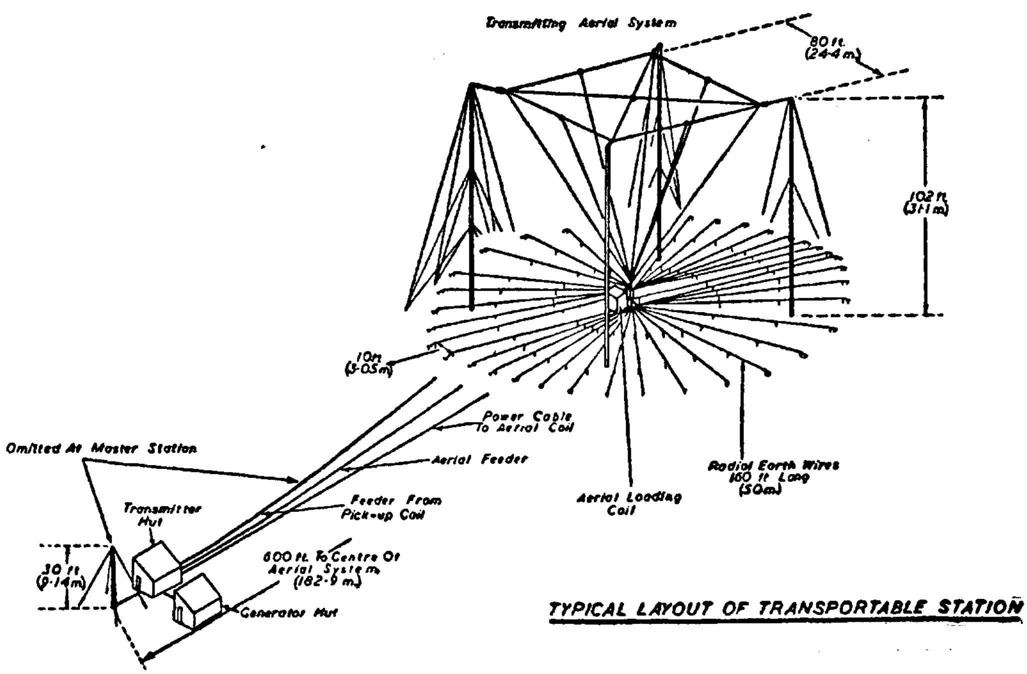


FIG. 3

The transmitting stations break down into a number of items of small size and weight, none of them being more than 450 lbs (200 kg). Each station comprises about 90 items. The radio equipment for a station weighs some 1.7 tons. The remainder consisting of aerials, etc. weighs some 10 tons.

This Transportable Survey Chain is designed to give long working ranges and to maintain continuity of service under exceptionally severe weather and operating conditions. Range ensured is at least 150 miles in areas of the highest regional "atmospheric" noise level.

The Lightweight Survey Chain.

Its basic units are the same as those of the Transportable type, with the exception that the aerial system is very much smaller and lighter and the transmitter is of lower power. A complete lightweight station can be operated in one vehicle placed alongside the aerial/earth system, the latter breaking down into small components that can be easily accommodated in or on the vehicle for transport.

The approximate weights and dimensions of the main items of radio equipment are as follows :

	Weight		*Dimensions*
Master Crystal Oscillator	18	lbs	10 1/2" × 14" × 13 ½.
	8.2	K	27 × 36 × 34 cm.
Slave Phase Control Unit	107	lbs	14 1/2" × 30" × 18".
	48	K	37 × 77 × 46 cm.
Transmitter Unit	220	lbs	56" × 14 1/2" × 22".
	100	K	143 × 37 × 56 cm.
Aerial Loading Coil	165	lbs	41" × 32" × 24 1/2".
	75	K	105 × 82 × 62 cm.
Aerial/Earth System	600	lbs	70 feet high, 70 feet radius.
	272	K	21.4 metres, 21.4 metres.

The figure of one ton (1000 k) may be taken as representative for the overall weight of each station. The station can be brought into action within a few hours of arrival on site.

Receivers.

The Survey receiver is available in versions suitable for marine and airborne operations. For geophysical and other types of terrestrial reconnaissance, a special battery-portable receiver has been introduced.

Two pairs of Decometers can be driven by the receiver if required and each pair can be installed at any convenient point in the ship or aircraft.

The controls are divided between the receiver unit itself and the Decometers. The power consumption of the receiver is approximately 100 watts. The hydrographic survey set operates at 230 volts 50 cycles and is adapted to D C supplies of various voltages by a suitable rotary converter. For aircraft operations the valve heaters are wired in series parallel and the H T voltage is produced by a light-weight rotary converter with associated voltage stabilizer and filtering ; in this form the receiver is suitable for operations in small boats and vehicles as well as in aircraft.

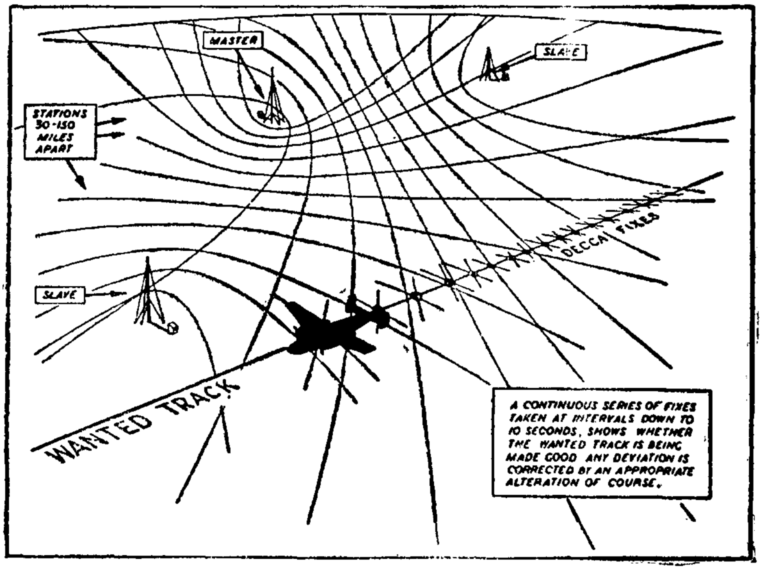
OPERATING TECHNIQUES.

I. - Aerial Survey.

One of the principal functions of Decca aid to survey is that of *tracking*, or controlling straight and parallel flightlines. Two methods of Decca tracking are used under a wide range of working conditions. (Fig. 4).

Straight-Line tracking by the Track Graph Method.

The procedure is one of compass course flying with continuous Decca "monitoring" of the track made good. A simplified latticed chart is employed called "Route Graph" or "Track Graph". It is based on the re-plotting of part of the Decca grid as a rectilinear grid. Part of a typical Track Graph for survey flying is shown in Fig. 5.



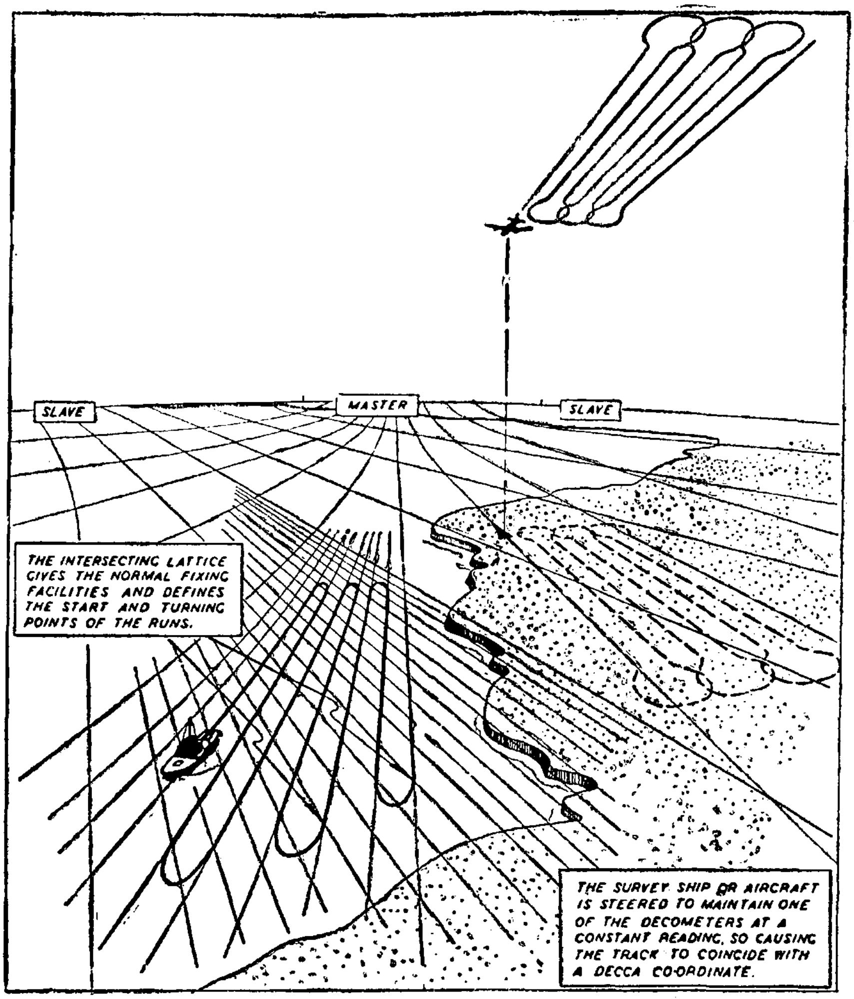


FIG. 4
The two complementary methods of Decca tracking.

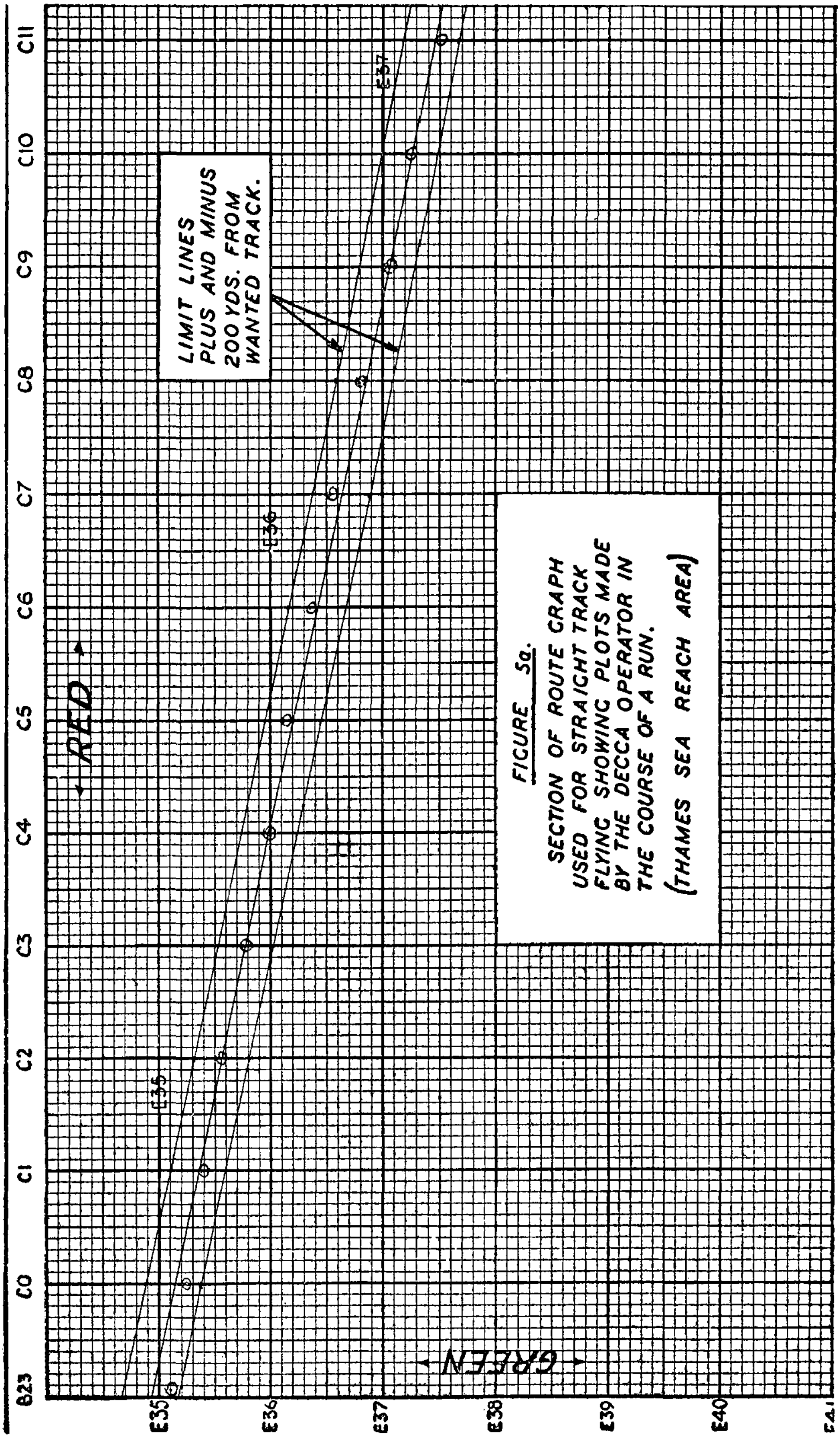


FIG. 5

Part of a typical Track Graph for Survey Flying.

The Homing method of tracking.

If the track of an aircraft coincides with a hyperbolic position line, the associated Decometer fraction pointer will remain stationary, and may be used by the pilot as a left-right indicator. It is thus possible to home the aircraft along any selected whole-number or fractional hyperbola.

This method is more accurate than the Track Graph at a given range, since it involves only one co-ordinate, and it can be used at considerably greater ranges from the chain for a given tolerance off-track. Results have been particularly valuable at the photographic scale of 1/2 500 which calls for a flight-line separation of 220 yards with a tolerance off track of only plus/minus 20 yards.

The Decca co-ordinates of the aircraft's position at the instant of each exposure of the survey camera can readily be recorded photographically. A typical recording unit, complete with 16 mm camera, Decometers, control box and synchronizing relays, weighs 58 lbs (26 k.)

II. - Ground Working.

In certain branches of reconnaissance surveying and exploration, the position fixing requirements can be satisfied by the Decca system in its present form and its substitution for visual methods can bring about very great saving in time and man power.

The four examples given below illustrate the scope of the Decca System as an aid to reconnaissance and show that it makes possible a virtually new type of operation in this category.

1° Sketch mapping by vehicle.

A standard 24v Decca Navigator was employed, installed in a car with Decometers fitted to the dashboard. The driver selected the observation points, took a series of successive Decca fixes and plotted these on a hyperbolic grid. All fixes were corrected for systematic errors, and the corrected fixes were plotted on a lattice grid at a scale of 1/10 560. Superimposing the grid on a topographical map of the same scale it appeared that 10 of the 51 fixes were lying outside the drawn boundary of the road. Of these ten the maximum distance from the boundary is less than 150 feet.

2° Vehicle reconnaissance at longer range.

The above procedure was repeated at double range from the Master station, using the same technique.

3° Boundary reconnaissance by air.

The use of an aircraft in place of a vehicle does not affect the accuracy obtainable from the point of view of Decca equipment, although errors arise in attempting to position the aircraft over the desired line unless a very slow and manœuvrable machine is employed.

The run took the form of a sketch-map of the Isle of Wight coastline. The approximate distance of the stations from the centre of the Island are 65, 105, and 100 miles.

The aircraft was flown along the coastline at an altitude averaging about 400 feet terrain clearance. An observer in the aircraft recorded the values of the two Decca co-ordinates continuously throughout the flight. After the flight the fixes were plotted on a hyperbolic grid covering the area, together with the tracks of the aircraft approaching the coastline and receding from it. The average displacement of the plots from the true coastline is in the order of 400 yards with a maximum of about twice this distance at some points.

4° Reconnaissance in heavily wooded country.

The object was to determine the accuracy of fixing in wooded areas, using the tree-error-correction technique and taking the fixes at points chosen for heavy density of trees and foliage. The observations were made in Epping Forest.

The tree-error-correction technique is a technique in which the error introduced by a tree through capacity and other effects can be measured and displayed to the observer directly in hundredths of a Lane.

A 12-volt Air type receiver was used, modified as a manpack portable equipment. Observations were made alongside points marked by wooden pegs, previously surveyed. The Decca fixes were plotted on a hyperbolic grid overprinted on a 1/10 560 Ordnance Survey map of the area. The known points were plotted on the same map. The mean error of the Decca fixes is less than 120 feet, and the maximum error approximately 200 feet. The Master Red and Green transmitting stations are about 15, 85 and 50 miles from the area respectively.