A NEW GEE AIRBORNE EQUIPMENT FOR CIVIL AVIATION AND PROPOSALS FOR THE DEVELOPMENT OF THE PULSE SYSTEM OF HYPERBOLIC NAVIGATION.

It is now quite apparent that the future navigational methods employed by Civil Aviation will be based on Gee and the use of Pulse Hyperbolic Principles.

Design of the new miniaturised airborne Gee set for civil aviation is well advanced and production prototypes are being developed. Plans, which are discussed in this booklet, are laid for the future development of the system and, although these may be changed in detail as the result of experience gained as the programme proceeds, it is generally agreed that the ideas round which they are built are basically sound.

Cossor Radar Ltd., in conjunction with the Telecommunication Research Establishment will develop and produce the future Gee Airborne and Ground Equipment.

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GEE NAVIGATIONAL EQUIPMENT

The Gee System was developed as a result of an urgent requirement by the R.A.F. for an accurate navigational aid of the broadcast type which would allow unlimited numbers of aircraft to fly to any chosen parts of the coverage area. At the end of the European War practically every operational aircraft, other than single-seat fighters, was fitted with Gee, and perhaps the most outstanding success of the system lay in the D-Day operations, the whole navigational organisation of which was carried out by Gee.

The system, which served with such spectacular success in the War, can be expanded, modified and improved in every respect to meet the present and future needs of Civil Aviation and this brochure is intended to describe the proposed future development of systems based on Gee and using Pulse Hyperbolic Principles.

Civil Aircraft must fly with regularity, punctuality and safety, irrespective of weather conditions on routes involving:—

(1) Medium and Short Range Navigation in high traffic densities.
(2) Long Range Navigation on Trunk Routes (Ocean Flying).
(3) Short Range Navigation in Low Traffic Density Regions (e.g., near air bases in undeveloped tropical regions).

Equipment which is being designed to meet these requirements by using Pulse Hyperbolic Navigation technique is described in the following pages.

At no stage in the development programme will any equipment previously produced become obsolete, although naturally the full navigational facilities will not be available to the operator of the older types of airborne equipment.

Facilities which will be available to the user of the fully developed Hyperbolic System of Navigation are:—

(1) Ability to determine his position at any time and at any point within the coverage area of the system.
(2) Ability to fly on any required course between two points within the coverage area.
(3) Ability to orbit about any given point.
(4) Ability to "home" to bases even in undeveloped regions if a simple Track Guide Ground System exists.
(5) Ability to inform ground controllers of his aircraft's position continuously and automatically.

The programme of development of the equipment which will give all these facilities will take place stage by stage as follows:—

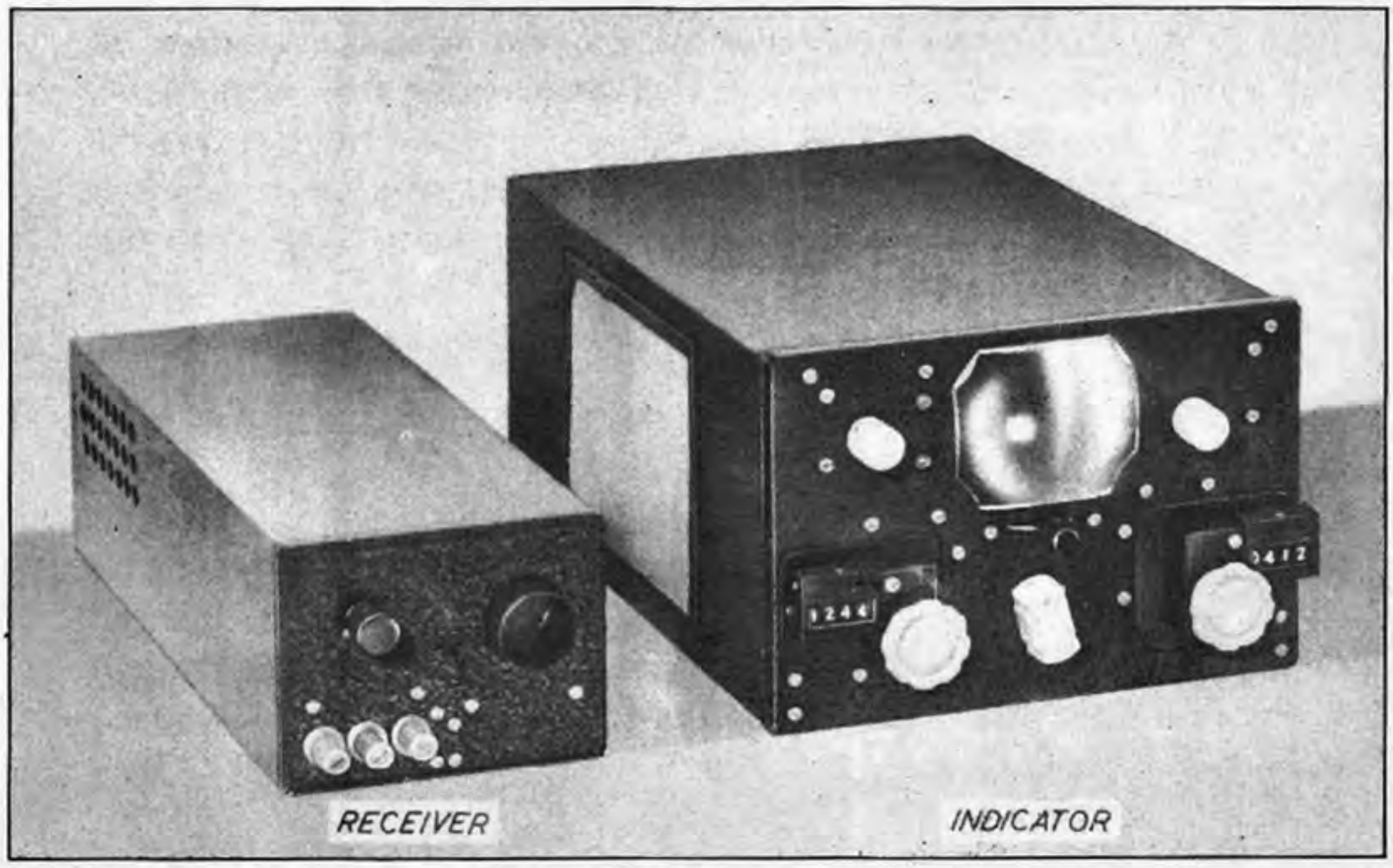
(1) Design of a miniature Gee airborne equipment suitable for operation by the co-pilot. Work is well advanced on this unit and production prototypes are under development.
(2) Design of new ground stations which will be entirely automatic and which will require the very minimum of supervision and maintenance.
(3) Design and production of combined Gee-Loran-Track Guide equipment for use in large aircraft flying Trunk and Ocean routes.
(4) Design and production of an extremely small and simple track guide equipment to enable small aircraft to fly along lattice lines laid down by any pulse hyperbolic system.
(5) Development of a Hyperbolic Computer to enable Gee and Loran co-ordinates to be converted into range and bearing co-ordinates from any desired point within the coverage area.
(6) Design and production of an entirely automatic Gee airborne equipment, not requiring manual alignment of pulses and complete with hyperbolic computer to give range and bearing of destination and automatic impulse signalling to provide, when required, continuous information of the aircraft's position to ground controllers.

THE NEW GEE AIRBORNE EQUIPMENT FOR CIVIL AVIATION AND ITS OPERATION

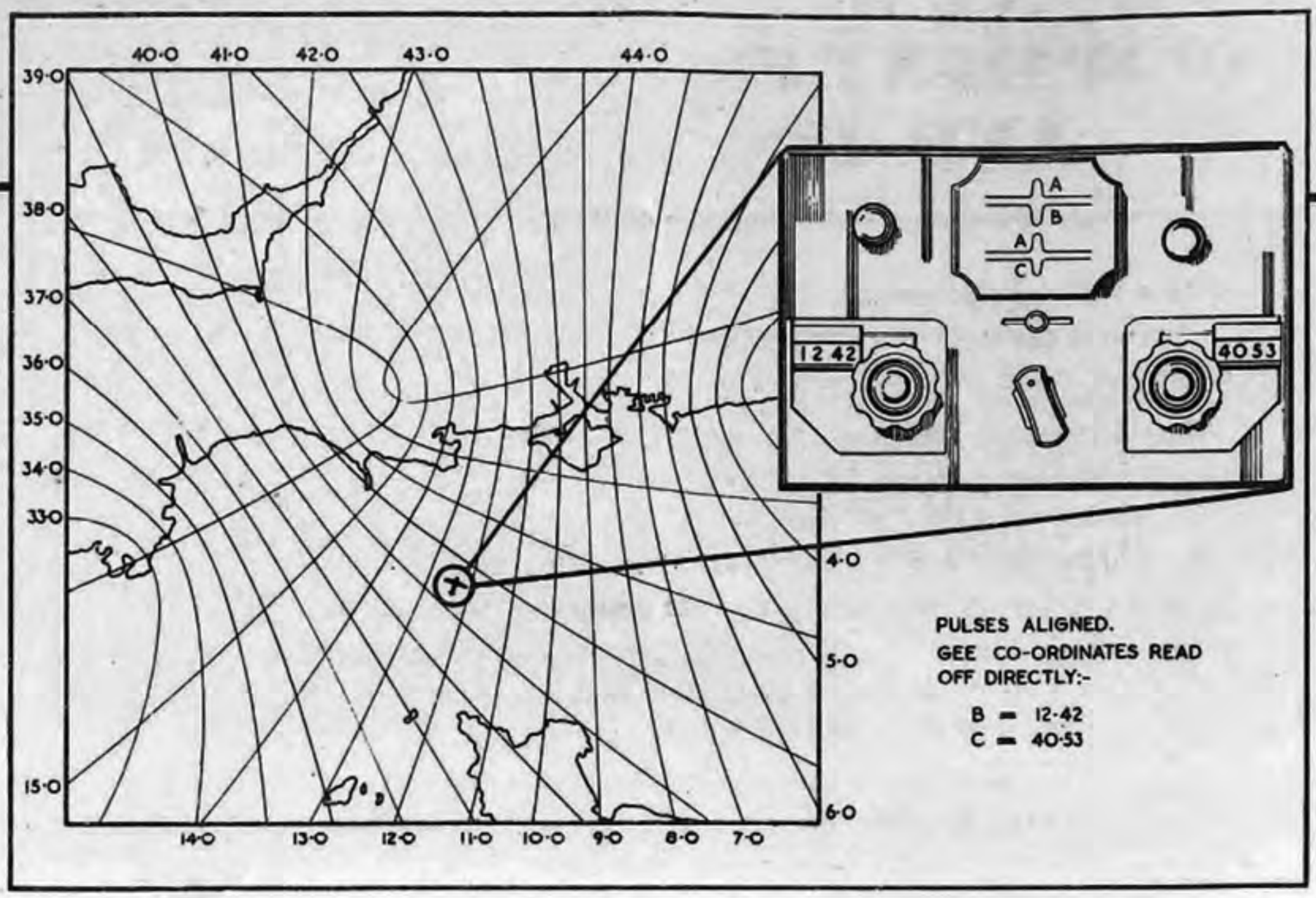
This new equipment for Civil Aviation is intended to replace the present Mk. II set : it contains many features which greatly simplify its operation and it is of miniaturised construction.

The indicator, designed for cock-pit installation, is fitted with a 1½in. daylight viewing cathode ray tube and a lens which magnifies the trace to approximately the size of that on the old Mk. II screen. The receiver and power supply unit will be remotely controlled and will be mounted in any convenient place in the aircraft. The miniaturised indicator as at present constructed measures only 5½in. x 8½in. x 12in., and the receiver only 4½in. x 3½in. x 12in. ; it is, however, proposed that many of the circuits at present mounted in the indicator should be transferred to the receiver unit so that the volume of space taken up in the cockpit can be reduced to a minimum. It is also proposed to allow for the addition of special circuits to the remotely stowed unit to give extra navigational facilities. These are described later.

The power consumption of the new set is less than half that required by the Mk. II set. The frequency coverage will be suitable for use with all existing and proposed chains of ground stations and R.F. tuning will be of the pre-set type with switched channel selection.



This is an early miniaturised equipment. It is probable that production models will be re-packaged in such a way that the indicator becomes the smaller of the two Units, all adjustments of the receiver being carried out by remote control from the indicator.



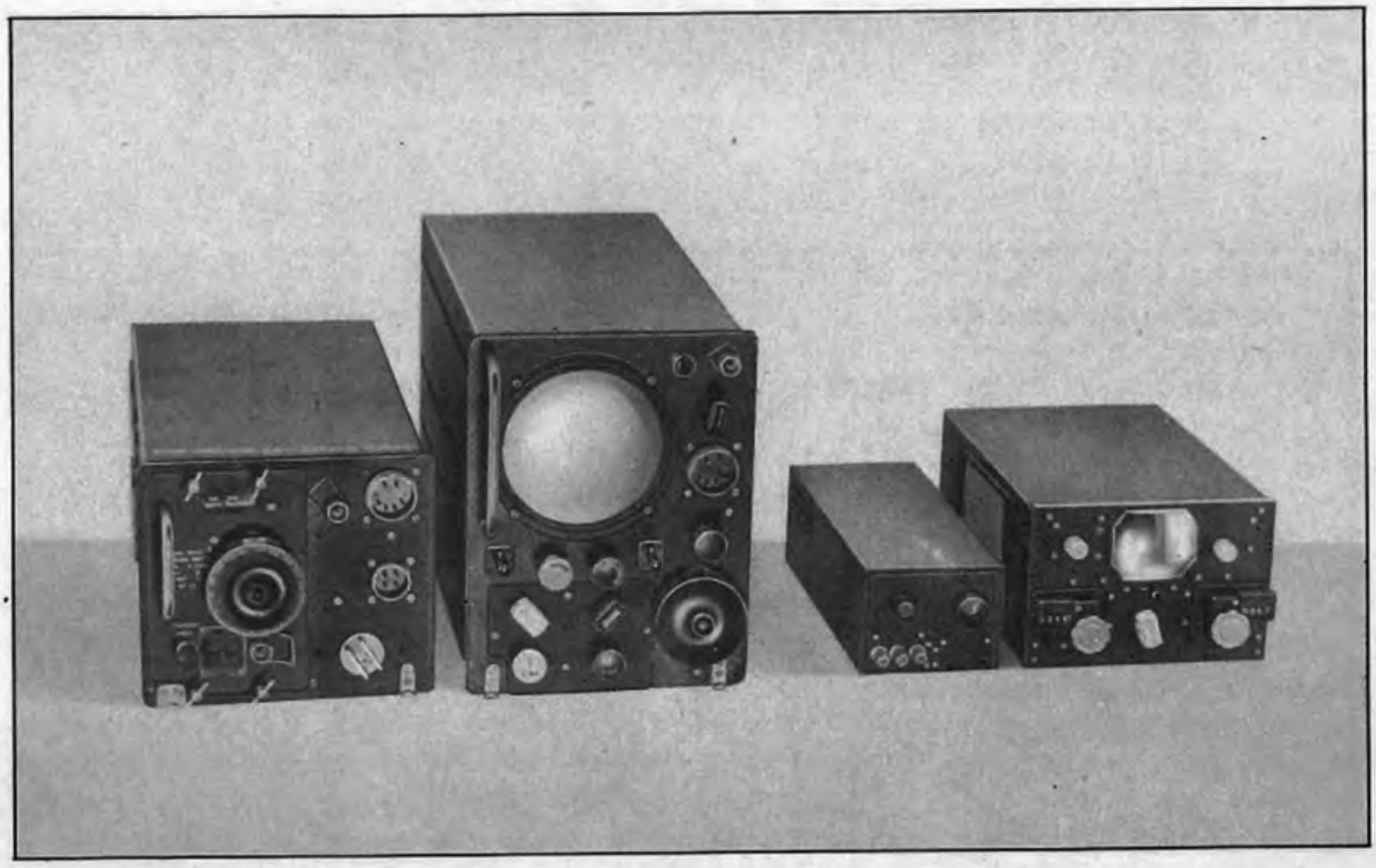
In operation the new Gee equipment is similar in many respects to the original Mk. II set, although the method of obtaining the Gee co-ordinates is very greatly simplified. It will be remembered that in the Mk. II set the drill for obtaining a position fix is first to strobe the pulses on the main time base, secondly to align the pulses accurately on the strobe time base and then finally to switch over to the calibration marker positions on both main and strobe time bases and count up the decimal and whole number readings.

In the case of the miniaturised equipment, the strobing of the pulses on the main time base and their alignment on the strobe time bases is carried out in exactly the same way, but the action of moving the strobes along the time base at the same time operates numerator dials which indicate Gee co-ordinates directly. Thus when the pulses have been aligned on the strobe time base it is merely necessary to read the two dials (one for the B pulse and one for the C) to obtain the Gee co-ordinates. These are read directly to the second decimal place.

Continuous adjustment of the crystal oscillator is no longer required to maintain the Master pulse on the A strobe time base. The new set automatically locks to the master pulse when this has been set up on the A strobe by means of a left-right switch on the front panel, and when locked, the set will remain set up indefinitely in spite of bad interference of all kinds.

It will be appreciated that the time required to take a fix is now only a fraction of that required with the old set. Once set up the Master Pulse remains locked on the A strobe and when set to any required position the B & C strobes can never drift, thus the operator is free to direct the aircraft on much more complicated tracks than was possible hitherto, e.g., an aircraft can easily execute an orbit bounded by four Gee lattice lines merely by switching the strobe knobs to pre-selected values at the appropriate times and using the well established homing technique.

At present a separate radio frequency channel is allocated to each Gee chain (except where chains are remote geographically) thus a comprehensive Gee coverage plan calls for a large number of R.F. channels. In future, Gee stations will be arranged in such a way that up to four neighbouring chains may operate on one R.F. channel, but each chain will have a slightly different pulse recurrence frequency from the others. Chain selection will thus be a matter of selecting the correct pulse recurrence frequency by means of a switch on the airborne equipment. The miniaturised airborne set will contain this feature and the older Mk. II equipment may be modified so that it too can use P.R.F. selection of chains.



Total weight 70 lbs.
Total volume 2 cubic feet.
Power consumption 270 watts.

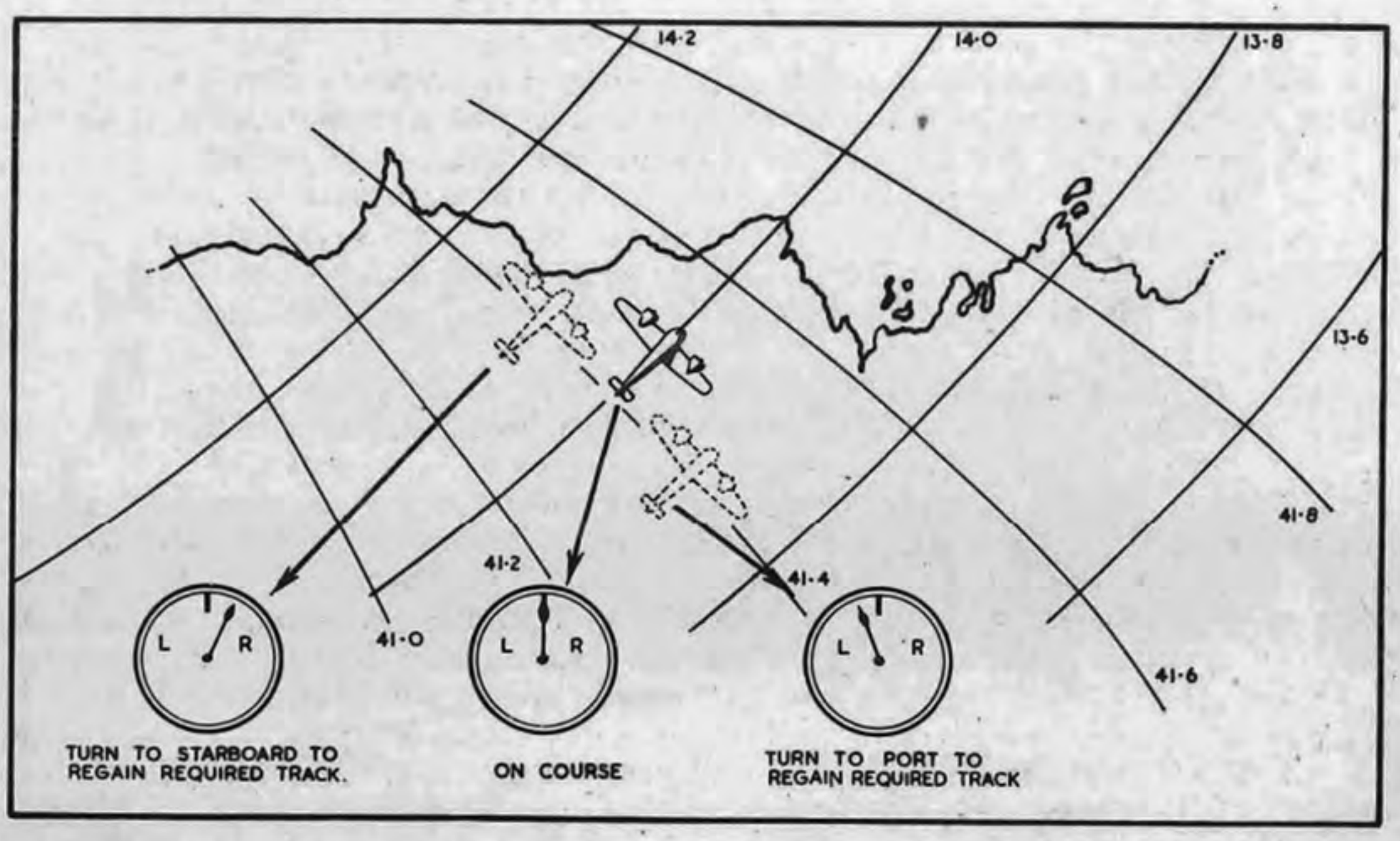
Total weight 18 lbs.
Total volume ½ cubic foot.
Power consumption 130 watts.

LATTICE LINE TRACKING BY MEANS OF MINIATURISED GEE. EQUIPMENT

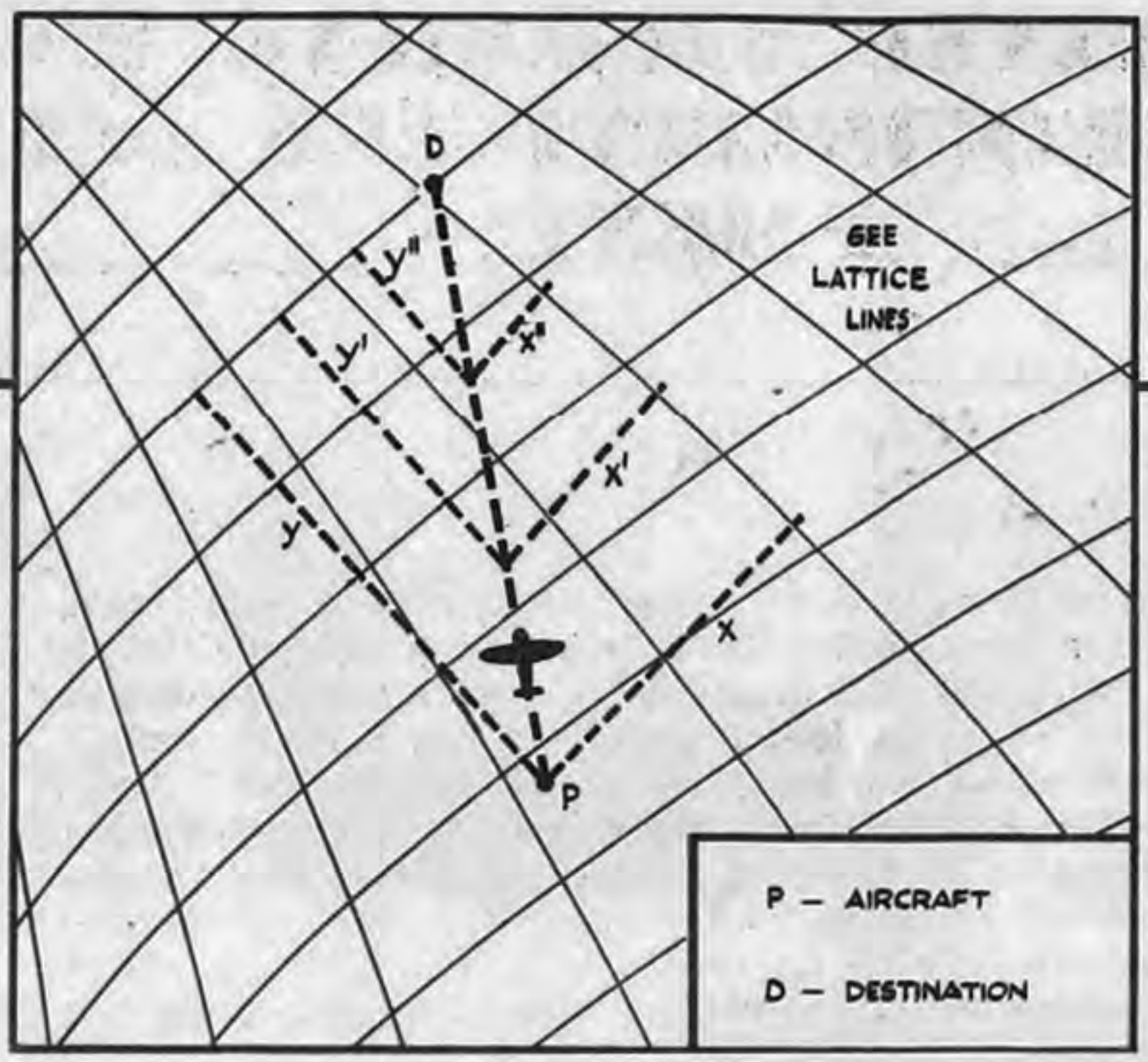
It is possible to provide a Left-Right meter in the pilot's compartment, connected to the Gee set in such a way that the pilot can steer the aircraft along any chosen Gee lattice line, a deflection of the meter needle to the left indicating that the aircraft is to the left of the chosen line and vice versa.

When the particular lattice line has been chosen and the aircraft flown to such a position that it is within a few miles of the line at any point along its length, the Gee operator sets a control on the indicator so that the Gee number of the line appears on the calibrated dial. The pilot then receives automatic left-right indications from his meter, or as an alternative scheme aural left-right information can be provided by means of interlocking dots and dashes as in the case of ordinary C.W. beam systems.

Additional circuits involving the use of about six extra valves are required to add this tracking facility to the standard miniaturised airborne equipment. The earliest production models may not be fitted with the tracking circuit but there will be provision for them to be added at a later date if they are required. The proposal is to mount as many of the circuits which do not require manual control, in the same unit as the receiver so that the volume of equipment actually mounted in the cock-pit of the aircraft is as small as possible.



CROSS LATTICE FLYING AND ORBITING WITH MINIATURE GEE



Whilst it is often convenient to fly along a Gee lattice line it very frequently becomes necessary to fly on a track which cuts across both sets of lattice lines of a Gee system. An additional unit may be designed so that almost straight line flying between any two places in the coverage area may be accomplished by means of a left-right meter in the pilot's compartment.

It will be seen by the diagram above that all points along the track joining P and D (two places in the coverage area of a Gee system) the ratio of the distances from the two lattice lines running through D has a constant value :—

$$\text{i.e.,} \quad \frac{x}{y} = \frac{x'}{y'} = \frac{x''}{y''} = \text{constant.}$$

In order to fly along the track P D it is therefore necessary to provide the pilot with an instrument which indicates the ratio x/y to him and he then merely has to ensure that the aircraft follows a course such that the reading remains constant.

One method proposed to provide this facility is to employ a circuit which produces currents proportional to the displacement of the aircraft from each of the lattice lines through the destination. The two currents would be fed to either a Desyn (which has a compass type pointer which takes up a position depending on the ratio of the applied currents) or to a system of sine cosine potentiometers with a meter indicator. In either case the instrument pointer would automatically indicate the bearing of the destination and a track from P to D could be flown by keeping the needle reading constant. If preferred, the body of the Desyn could be rotated to give a vertical needle position when the aircraft is on track, and then left-right movements of the needle would indicate deviations from the desired track.

In addition to cross lattice flying it may sometimes be necessary to orbit about some given point, e.g., whilst waiting to land, and this may be accomplished by using the circuits which are used for cross lattice flying, with some additions. In order to simplify the flying technique two output currents from sine cosine potentiometers would be fed to two dials, one of which would continuously indicate the bearing of the destination and the other the distance from the destination. If the distance reading were maintained at a constant value a circle would be flown, and this could be rendered even simpler by the use of a centre zero and left-right type of meter which would be set up to read zero for any required orbit radius. Any slight deviation from a circular track would be due to curvature of the lattice lines.

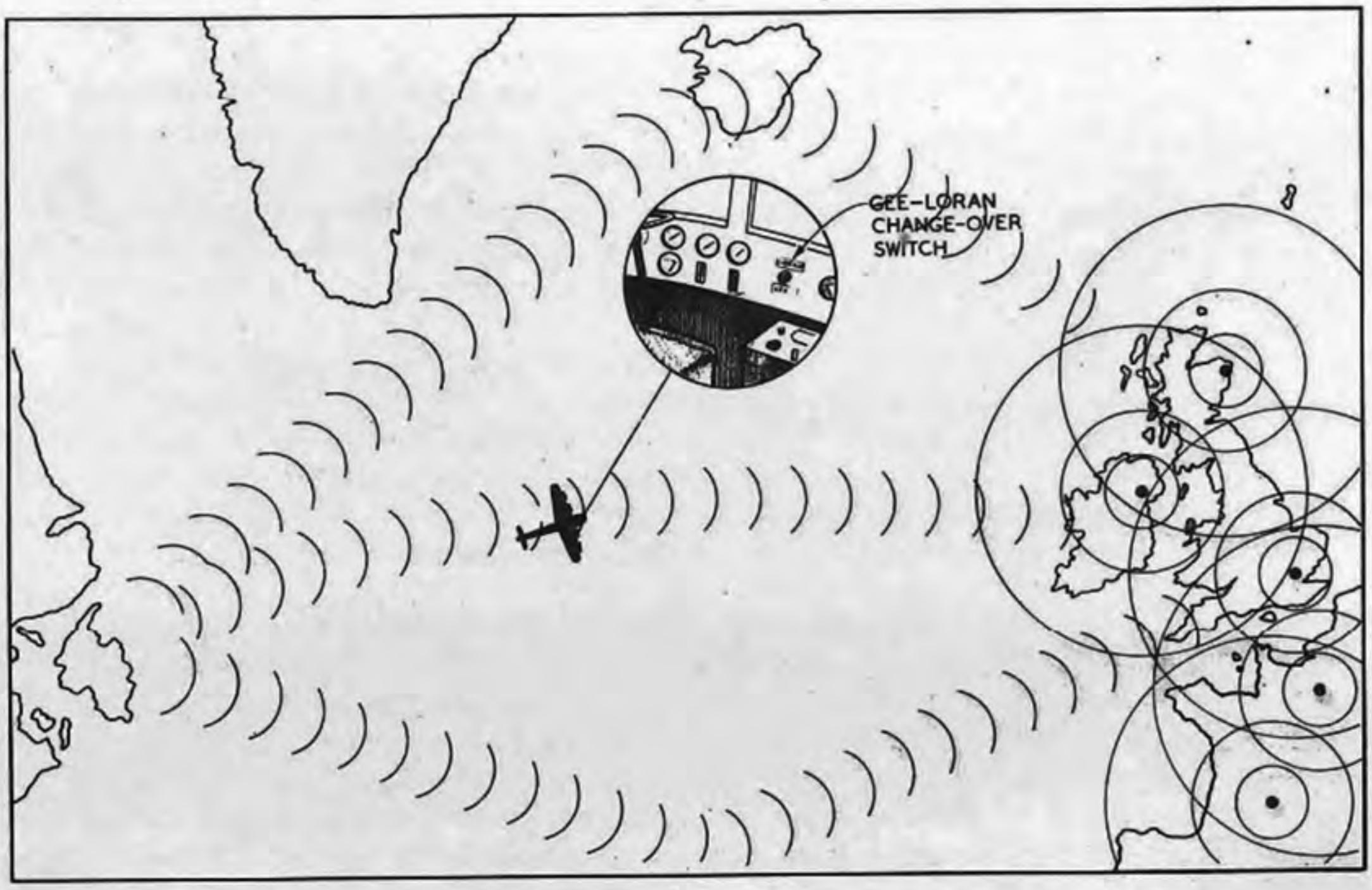
COMBINED GEE/LORAN EQUIPMENT

Large aircraft operating on trunk and ocean routes require a navigational aid which will allow them to plot their position with reasonable accuracy (say to five or ten miles) at any point along the route. Loran is such an aid.

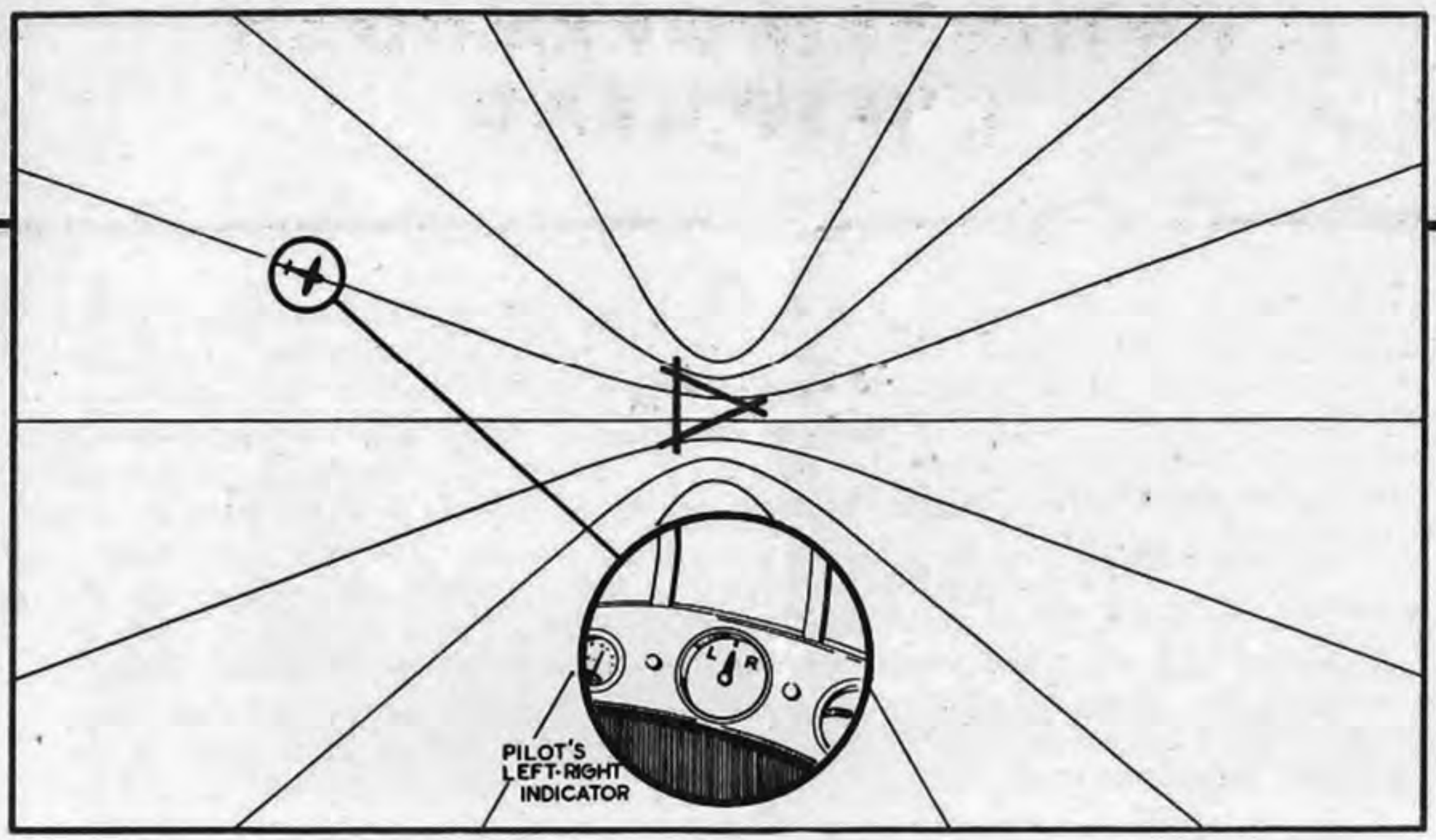
Loran is basically the same as Gee in that the pulse hyperbolic technique is employed ; the radio frequency used, however, is very much lower (about 2 Mc/s) so that the ranges covered can be considerably in excess of those obtainable in the case of Gee. Ranges up to 700 miles are available by day over sea and at night the range may sometimes be extended up to 1,500 miles by the use of sky waye propagation. The new Low Frequency Loran is capable of giving even greater ranges and it is especially suitable for use over large land masses where standard Loran has a very limited range.

It is possible to design a single airborne equipment to provide Gee, Loran and L.F. Loran facilities for use in large aircraft engaged in long range flying.

The single equipment will naturally be considerably smaller and lighter than a Gee equipment plus a separate Loran equipment, since a great deal of the circuit is common to both sets, but it will be somewhat larger and more complex than a normal Gee set alone.



LORAN covering Trunk and Ocean routes. GEE covering dense traffic routes.



GEE TRACK GUIDES

In undeveloped areas where traffic density is low, sufficient navigational facilities would be afforded by a simple system of track guides which would enable aircraft to home to an airfield and manœuvre themselves into the blind approach funnel. Any ground equipment associated with such a system must be either on the airfield itself or very close to it.

If two small Gee transmitters are sited one on either side of the airfield, say about three miles apart, the Gee hyperbolæ take the form shown in the above diagram.

It will be seen that at distances greater than two or three miles they are effectively radial straight lines. By using the lattice line tracking technique described earlier it is possible for an aircraft to home right into the airfield from a distance of at least 100 miles.

Any aircraft fitted with Gee, or Gee/Loran equipment, could make use of the Track Guide service when required.

In addition, it is planned to produce a very light and simple receiver designed purely for track guide purposes for use in light aircraft of all types, including privately-owned and charter aircraft.

This receiver will not only enable a pilot to make use of the special track guide ground systems described above, but he may also track along any Gee lattice line which may be available from one of the standard Gee chains.

When a pilot flies into an area covered by a Track Guide System he merely turns a control knob until his meter reads zero, thus indicating that his equipment is set up on one of the radial lines (the control knob may be calibrated to indicate to him which line he is on) and he then flies on a straight course, keeping the L—R meter on the zero mark. The practicability of such a system has already been demonstrated and a number of successful tracking flights have been made.

THE GEE HYPERBOLIC COMPUTER

The figures obtained from a Gee or Loran aircraft set give the aircraft's position relative to an arbitrary system of curves—the familiar Gee hyperbolæ.

An automatic computer can be constructed which converts the co-ordinates associated with hyperbolic navigation systems into range and bearing from any point in the coverage area, and also provides steering indications on a L—R meter so that the aircraft can be flown along an almost straight track to any desired destination.

When using the hyperbolic computer, four constants, determined by the chain in use, are set up from the flight plan, and these constants will not be altered during a flight unless it becomes necessary to change from the coverage area of one chain to that of another. The constants associated with each chain will be given in tabular form in a data book supplied to all users of the system, but it is possible that the constants of several chains can be pre-set into the equipment and called up as required in the air by means of a single selector switch.

Ideally the Gee co-ordinates would be fed into the computer automatically and continuously, but this represents an engineering problem of some magnitude which has not yet been fully solved, although there is every reason to suppose that it will be successfully carried out. In early models of the computer it would, however, be practicable to feed the Gee co-ordinate information in manually from the Gee indicator, and the computer would then automatically provide the pilot with information concerning the range and bearing of the destination from his present position. This information would be revised each time new Gee co-ordinates were fed into the computer. The bearing information could be presented in the form of a compass needle reading and/or as a left-right indication if he wished to fly on a direct path to the destination.

THE ULTIMATE AIRBORNE EQUIPMENT FOR PULSE HYPERBOLIC NAVIGATION

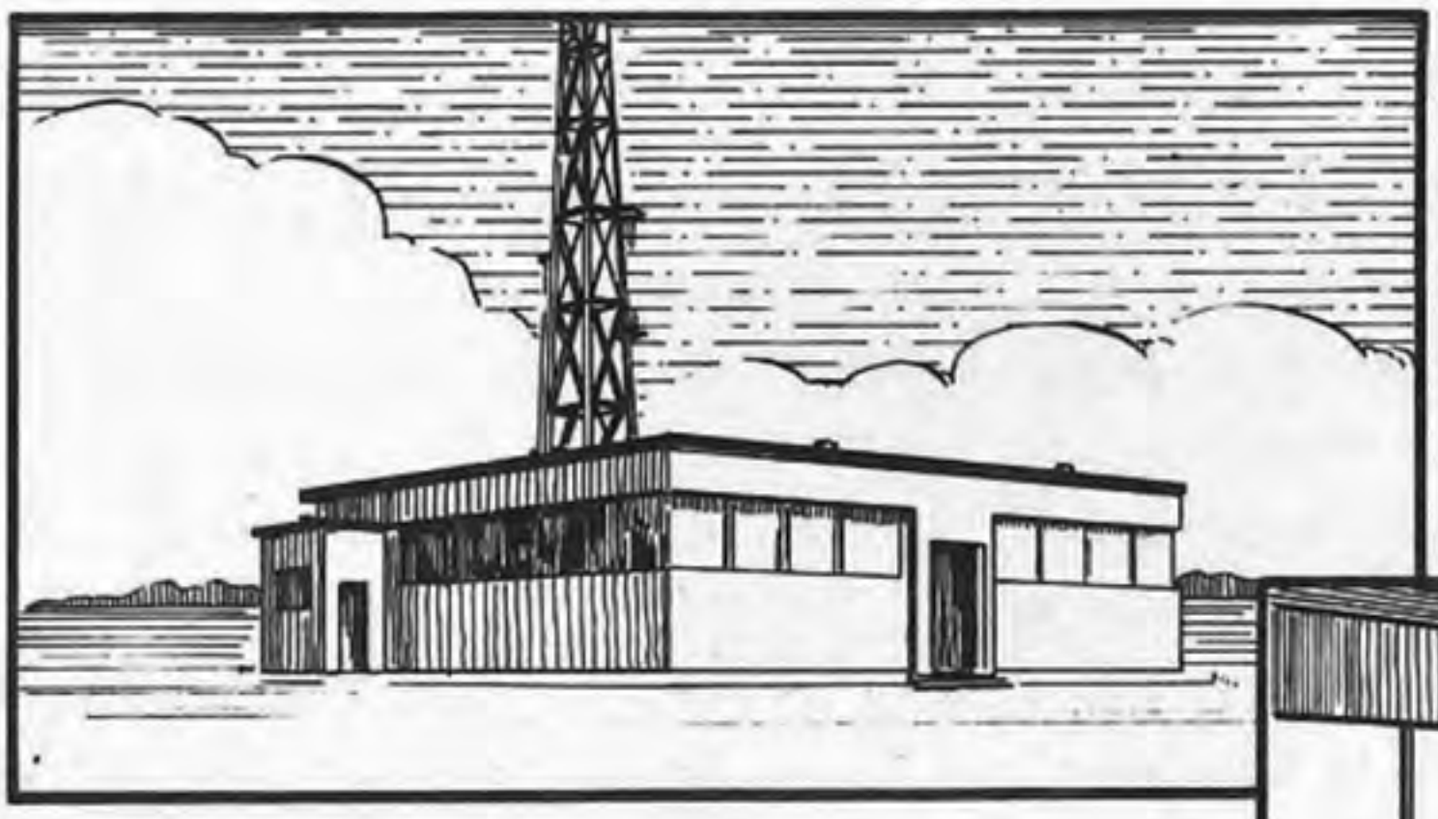
It is, of course, not possible to give precise details of the final form of the standard airborne Gee equipment of the future since new ideas and techniques will certainly be found during the comprehensive development programme which has been discussed briefly in the previous sections of this brochure. It is thought, however, that new ideas will mainly concern the details of the scheme and it is visualized that in its final form, the airborne apparatus will be fully automatic and will present information concerning distance and bearing from destination to the pilot continuously. It will also provide left-right tracking and orbiting indications if these are required.

At the same time, V.H.F. impulse signalling will enable full information on the aircraft's position to be sent automatically to the ground controllers at terminal airports and it will be possible for the bearing, distance and height of all aircraft, within a given radius of the airport, to be automatically and continuously recorded and presented to the ground controller on a chart.

GEE
GROUND STATIONS

Although the existing designs of ground station equipment have given extremely satisfactory service throughout the War years and, in fact, they continue to do so, they do not incorporate the most up-to-date electronic techniques. Whilst they are capable of providing Gee transmissions with an accuracy which is quite adequate for even the most stringent requirements, it is necessary to provide a staff of operators whose sole work is almost continuous monitoring of the slave station phasing. It is also standard practice to man a special monitor station (which may be situated on the master station site) and operators at this station keep a permanent watch on the phasing and stability of the whole chain. Continuous telephone communication between the various units of a chain is also maintained, and whilst this expenditure of labour could be justified during the War when the stations were always liable to enemy attack, peace-time Gee ground station systems must be run on more economical lines.

A brief examination of the economics of ground station operation as practised during the War years reveals that the annual cost of operation and maintenance is very high indeed, mainly due to the fact that a staff of operators and mechanics live on the station site and have to be supported by a complete domestic and administrative organisation. In order to reduce this heavy expense it is proposed that future Gee ground stations shall be entirely automatic, thus dispensing with "operators," and be maintained by a small staff of mechanics, only one or two of whom would be on duty at any one time. They would make their own living arrangements and thus remove the necessity for a staff of domestic personnel.



Typical modern layout for Gee Ground Station.

Interior view of Transmitting and Receiving Room.

In order to achieve this end it is proposed to design new ground station equipment using the most advanced electronic technique, and in order to standardise station layouts and maintenance procedure, as far as possible it is proposed to design a range of standard transmitters, timers, power supplies, etc., each of which can be used for Gee, Loran, L.F. Loran, or Track Guide Systems.

All the technical equipment will be fully automatic, and no personal monitoring will be required. Transmitters will be crystal controlled to ensure operation on the correct R.F. channel at all times and slave receivers will be either crystal controlled or automatically tuned to the same R.F. frequency as the Master transmitter.

Slave stations will automatically radiate their pulses at the correct phasing position after reception of the master pulse. Automatic monitoring circuits will correct phasing errors and will re-lock and re-phase the station after failure of lock resulting from such causes as momentary power failures or momentary interruption of master signals.

Automatic monitoring circuits will be in continuous operation at the master station, monitoring the phasing accuracy of the whole chain, any discrepancies which may develop will immediately give the alarm to the duty mechanics and the master station will be equipped to make over-riding adjustments of slave station phasing.

In the event of mains power supply failures the reserve generators will automatically start, and in the event of timer or transmitter faults the reserve sets will automatically come into operation after only a very brief period.

The new sets, which will be designed as self-contained cubicles, two or three of which will make up a station, will be constructed on pleasing lines with a minimum of external controls and they will naturally incorporate many new circuit features which are not present in the older sets, e.g., the chain selection by pulse recurrence frequency scheme will be available, transmitters will be completely redesigned to give minimum interference to services occupying neighbouring R.F. channels, and the equipment will be designed for ease of maintenance with a unit construction for ease of installation, transportation and overhaul.

COSSOR *Radar* **LTD.**
HIGHBURY — LONDON — N.5.