coincidence with a second star about 90° in angular distance away from it in the heavens. Move the sextant about so that the observed stars are seen through different parts of the telescope's field. There is no collimation error if the star and star-image remain in coincidence. This is an unlikely error and, even if present, is scarcely worth worrying about unless large altitudes are being observed. Adjustment is made by altering the setting of the telescope collar.

DEFECTIVE SHADES

A glare-screen may be bent by pressure from the metal frame gripping it. If the two faces are not parallel, rays passing through will be deviated from their true path. The weakest screen can be tested by first observing a planet without the screen, then with; the two readings should agree (if allowance is made for any change of altitude during the interval). No. 2 shade can be tested by observing first a weak sun with only No. 1 shade, then with No. 2 added to No. 1, and so on. The horizon screens can be tested in the same way by bringing a planet and its image into coincidence and observing whether they are still in coincidence when a horizon screen is interposed.

CHAPTER XXVII

Running Down a Position-Line

OBSERVATIONS RESTRICTED BY DAYLIGHT

For most of the time in daylight only the sun can be observed. Occasionally the sun and a planet are both visible and on a few days in the month the sun and the moon can be observed together during part of the day. Actually the moon is "up" during nearly half the month's daylight, but for several days on each side of "new moon," it is too close to the sun for its position-line to make a worthwhile cut with the sun's, and these few days account for the greater portion of its daylight appearance.

In short, for most of the time in daylight only one heavenly body is available for observation. What effect does this have on daylight astro-navigation?

WHEN ONLY THE SUN CAN BE OBSERVED

If only one body can be observed, only one position-line can be determined at each observation. This makes it impossible to fix the position by a single observation. If the air navigator stayed at the same spot while the sun's azimuth changed by, say, 45°, a second position-line from the sun would cut the first at an angle of 45° and would fix the position. This would mean remaining at the same place for several hours which, of course, is impossible in air navigation. Could a fix be obtained by transferring the first position-line in the direction and for the distance flown by the aircraft in the interval? This is how the marine navigator fixes his position in the daytime, but a ship only travels about 60 miles in three hours and an error of 2½ % in a distance of 60 miles only puts an error of 1½ miles into a position-line transferred that distance. Also, a ship's track-error due to drift, compass inaccuracy, steering inaccuracy, etc., will probably be less than 2½° which cannot put a position-line transferred 60 miles in error by more than 2½ miles.

TRANSFERRING POSITION-LINES FOR THREE HOURS' FLIGHT

An aircraft, however, is likely to travel 500 miles in 3 hours and a 10 % error in the estimated distance travelled must be allowed for; this can put an error of 50 miles into the run-up position-

line. Also, instead of 2½°, it may drift 10°, which, if not allowed for during a 500-mile flight, can put the transferred position-line 87 miles in error.

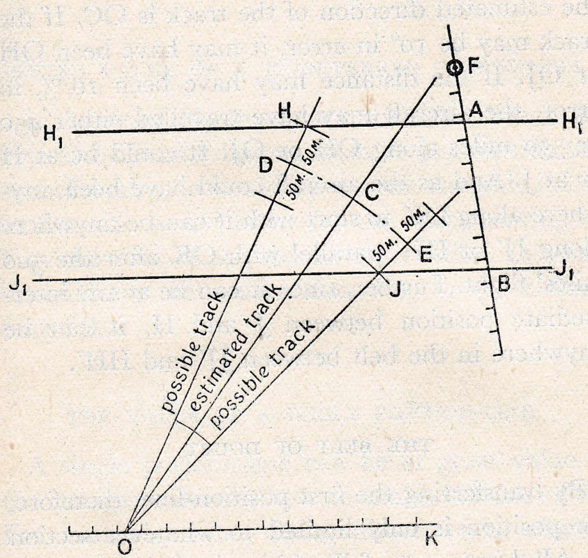

FIGURE 38

The final fix can be even more in error (see Chapter XXIV).

Fig. 38 shows the effect of transferring a position-line in such a case. First the aircraft's position is found by sun observation to be somewhere on the position-line OK. After 500 miles' flight (estimated) a second position-line AB is determined.

If OK is run up, what accuracy in the fix can be relied on?

Suppose the first position was at O and that the estimated direction of the track is OC. If the track may be 10° in error, it may have been OH or OJ. If the distance may have been 10 % in error, the aircraft may have travelled either 450 or 550 miles along OH or OJ. It could be at H or at J. And as the aircraft could have been anywhere along OK to start with it can be anywhere along JJ′ or HH′ parallel with OK after the 500 miles' flight. Further, since it can be at any intermediate position between J and H, it can be anywhere in the belt between JJ′ and HH′.

THE BELT OF DOUBT

By transferring the first position-line, therefore, the position is only limited to whatever section of AB happens to fall within the belt of doubt. This section of AB cannot be less than 100 miles long, which occurs if OC is at right angles to OK and AB is also at right angles to OK; it may be several hundred miles long if the cut between the two position-lines OK and AB is acute.

This shows that a navigator must be extremely cautious about transferring a position-line for a long flight interval. He must decide what errors

in the track and groundspeed are possible and must transfer a position-belt instead of a position-line.

LIMITED VALUE OF A TRANSFERRED POSITION-BELT

If, however, the navigator wished to reach an objective F, and F happened to lie just outside the belt of doubt, he would have some valuable information. He would know (*a*) the exact bearing of F at the time of the second observation, (*b*) that it could not be nearer than FA, or (*c*) further than FB.

THE VALUE OF A SINGLE POSITION-LINE

A single position-line can be of great value if the navigator knows how to make full use of it. For example, when flying above 10/10 cloud; suppose that a navigator determines by observation of the sun that he is somewhere on a position-line AB (Fig. 38).

If AB does not pass near any ground above 200 feet (allowing for possible error in the position-line) a navigator has found out that he can safely descend through the clouds to 200 feet if his altimeter reading is correct.

Here is another case: Even if a navigator does not know his whereabouts along AB to 100 miles so that AB is 200 miles long, he knows that if he flies in the direction BA he will come to F. This may be extremely valuable information if AB lies in a sea area and when produced, cuts the coast at F—the navigator has found out where he will

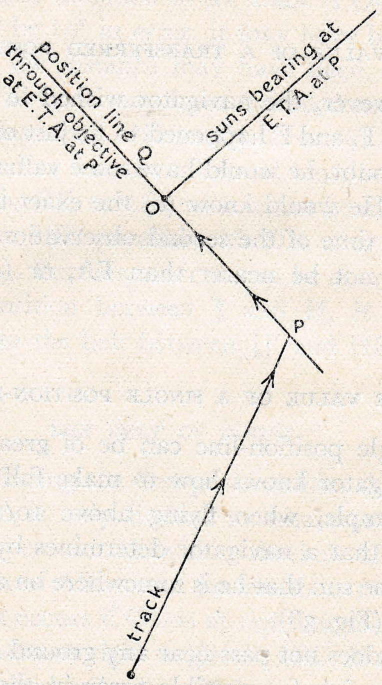

FIGURE 39

strike the coast. Flying along a position-line is called "running down a position-line."

With a little "twist" of the method, running down a position-line can be made still more valuable. Suppose that a navigator wishes to find a definite point O (Fig. 39). He can fly along until by observation he finds he is on a position-line OP which passes through O. If he then turns and flies along that position-line, he must come to O.

He must, however, make sure that after reaching PO he keeps close enough to it to strike O; taking into consideration the possible distance of P from O and the size or visibility of O. Also he must be certain that he is on the right side of O and not flying away from it. One way of ensuring this is to aim for a point on OP sufficiently far from O to be sure of arriving on the P side of O.

If, however, a navigator aims for a point quite near O, he will be able to tell whether he is flying away from O if he continues to observe the sun at intervals while he strictly maintains a track along the position-line. In Fig. 40, if the sun is bearing 045° from O when the navigator reaches OP and its altitude is 50°, it will bear 040° in, say, 20 minutes' time and its altitude observed from O will increase to, say, 52° in that 20 minutes. If a position-line is plotted through O at the later time, it will be seen that the altitude observed from the aircraft must be greater than 52° if the

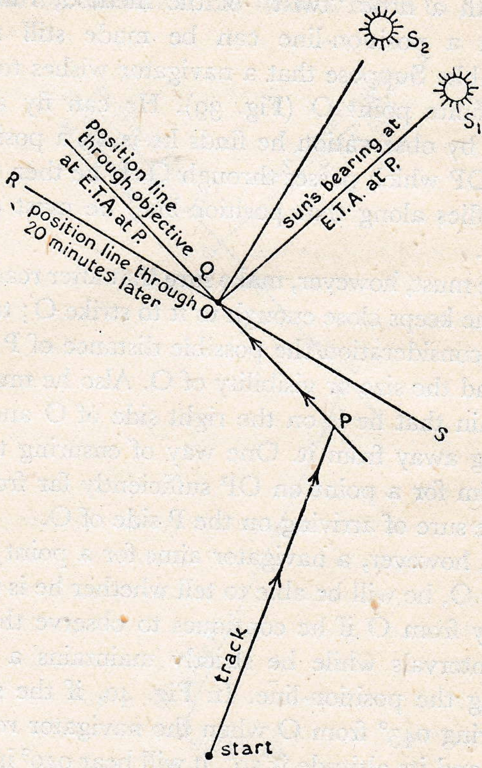

FIGURE 40

aircraft is flying away from O, less than 52° if flying towards O.

ACTUAL EXAMPLE OF RUNNING DOWN A POSITION-LINE

To illustrate the value of running down a position-line, perhaps the writer may be permitted to cite the use he himself made of it in 1931.

Required to fly from Norfolk Island to Lord Howe Island in the Pacific, a rhumbline distance direct of 478 nautical miles. This distance is only trivial for a modern bomber pilot, of course, but in this particular case extra difficulties made up for the short distance; the flight was made solo, and therefore the navigation had to be carried out while piloting the aircraft. It was in a Moth seaplane which had a cruising speed of about 75 knots and only an hour or two's petrol to spare; there was, therefore, no other land within range if the island was missed. Also the island-objective was small—about 3,200 acres—and there was reason to suspect a changed compass deviation.

Immediately after taking off, the sun's bearing at the objective at a time 6 hours later, i.e. 1¼ hours before the E.T.A. at O, was computed, and a position-line OP plotted on the chart (see Fig. 41). P was made an earlier objective and was selected so that the track to P was 10° N. of the track direct to the island.

The wind was estimated twice an hour by treble

ADVANTAGE OF HAVING THE SUN ON THE BEAM WHEN NEAR THE OBJECTIVE

In the above example the sun was in the worst position for making full use of the method of running down position-lines. If it had been on the beam of the track at the end of the flight (Fig. 42), an almost direct route to the island could have been taken while yet flying along position-lines and the track made good would have been known with considerable accuracy for several hundred miles before reaching the objective.

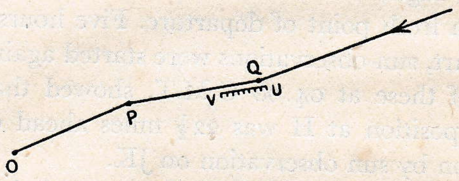

FIGURE 42

The procedure would have been:

(1) To determine the sun's azimuth an hour before the E.T.A. at the objective and plot a datum position-line OP through the objective O (see Fig. 42).

(2) Along this line mark P one hour's flight from O.

(3) Compute the sun's bearing at P two hours before the E.T.A. and plot a second datum position-line PQ through P.

(4) Mark Q an hour's flight from P.

(5) Set a course at the start of the flight for Q instead of for the objective O.

(6) Two hours before the E.T.A. observe the sun. The result will be to place the aircraft somewhere on a position-line UV to one side of PQ.

(7) Set a course to put the aircraft on the line PQ during the next hour's flight.

(8) One hour before the E.T.A. observe the sun again. This will place the aircraft somewhere on a line parallel to OP.

(9) A course should be set to put the aircraft on OP within the next few minutes. Flight along the bearing PO will then take the aircraft to O.

The procedure can be extended for several hours' flight. By this means a track along an invisible path four or five hundred miles long can be checked at intervals, and great accuracy in the track made good should result when near the objective.