When setting the scales, consideration must be given as to whether to use red or black scale and micrometer readings. The micrometer drums often develop considerable back lash, that is the tangent screws can sometimes be rotated through several minutes of arc without affecting collimation.

(3) Is a precision instrument and subject to derangement if mishandled.

(4) Is difficult to operate in flight.

(5) Is heavier and bulkier than tables.

(6) No written record of the solutions remains for a later check.

(7) Is more expensive than tables.

51. Line of position computer, type A–4 (Fairchild-Maxson) (fig. 30).—*a. Description.*—(1) The A–4 computer is a mechanical computer for solving the astronomical triangle. The formulas upon which the mechanical solution is based are old ones; it is in the ingenious method by which these formulas are solved by a system of cams, grooves, and gears that the device is unique. The computer does not solve the triangle for azimuth and the known azimuth of a body cannot be set into the instrument. The line of position is orientated by finding where the position circle cuts two parallels of latitude or two meridians in the vicinity of the DR position. In this respect, the general procedure is similar to that which has been described for computing an LOP by Hagner using H_o and two assumed latitudes *or* longitudes as entering arguments.

(2) As is true of other methods, it will compute problems in great circle flying and may be used for star identification.

(3) The Air Almanac data for the sun are fed into the computing mechanism from a cam on which are cut the data for a 3-month period. The cam with its cam followers and accessory gearing is mounted in a subunit, four of which are supplied with each instrument, one being mounted on the computer proper and the other three supplied in individual containers each marked with the quarter and year to which it applies. This subunit is called the *quarterly almanac;* it is not to be confused with the Air Almanac. Provision is made in the carrying case for storing the computer with current unit and one extra unit.

(4) Figure 30 shows the face of the instrument with the operating controls numbered for reference.

(5) The computer can solve for lines of position for all latitudes north or south, for all longitudes east and west, using bodies of any declination north and south, and with right ascensions from zero to 24 hours.

(6) For problems involving fixed stars, planets, and the moon, the declination and right ascension of the observed body are set on the

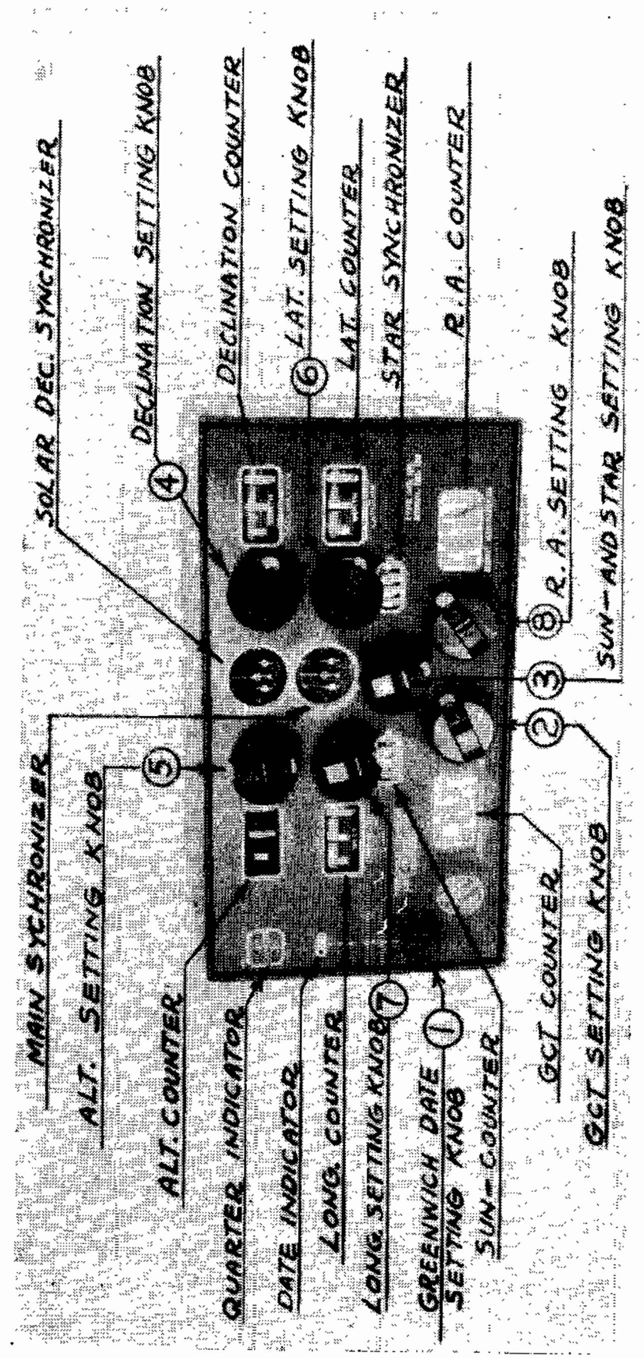

FIGURE 30.—Line of position computer, A-4 (Fairchild-Maxson).

appropriate counters. For sun observations the equivalent data are fed into the machine automatically.

(7) (*a*) No reference books, tabular solutions, or Air Almanac are necessary for making solutions involving the sun.

(*b*) In making solutions involving either a star, a planet, or the moon, the value of the RA and declination of the body at the instant of observation must be obtained. In the case of a star this is procured readily from the Air Almanac. At the present time the RA's of the moon and planets are not included in the Air Almanac and conversion of the tabulated GHA's of these bodies to obtain the RA's is so bothersome as to nullify the other advantages of the computer solution. The RA's of the moon and planets are contained in the Nautical Almanac; if that is not available the RA may be calculated from the Air Almanac data using the formula

RA ☾ — GHA ♈ — GHA ☾ or
RA planet — GHA ♈ — GHA planet.

The value of RA derived from the GHA ♈ − GHA body computation will be in degrees and must be converted to time units. 360° may be added to the tabulated GHA ♈, if necessary, to make the subtraction.

(8) Referring to figure 30, knob 1 is used to set in the Greenwich date of observation. This control is always turned through a complete revolution and must be left in the position indicated by the detent. Knob 2 is used to set in the Greenwich civil time of observation. Knob 3 operates the sun — and star counters, the direction of rotation for setting being indicated on the respective counters by arrows on the left hand drums. Knob 4 operates the declination counter and the solar declination synchronism indicator. Synchronism of an indicator is accomplished when all the pointers are in alinement. Both slow and fast pointers move in the same direction and the direction of cranking should be such as to aline in the shortest direction. In general, the second speed (lower right) pointer will indicate the direction. See instructions below for the direction of the final movement of the main synchronizer. North or south declinations are indicated on the counter shield, the shield automatically changing position as the declination counter passes through 0°. The altitude is set in by the operation of control knob 5. Latitude and longitude are set in by knobs 6 and 7, respectively. Each of these counters is provided with shields automatically showing north and south latitude and east and west longitude. Right ascension is entered by the operation of knob 8.

b. Operation. (1) *Precautions.*—Construction of the type A-4 computer requires that several precautions be observed in operation to avoid damaging the instrument.

(*a*) The Air Almanac units supplied with the computer provide for 3-month or quarterly periods beginning January 1, April 1, July 1, and October 1. An overlap of 2 or 3 days is provided on each end of the Almanac cams. It is essential that operation of the date-setting knob be confined to dates within the cam limits. If before the beginning or after the end of any quarter the date-setting knob does not move freely, DO NOT FORCE. Do not attempt to use the installed Almanac unit more than a day or two beyond the end or beginning of the quarter. The quarter to which the installed unit is applicable is marked plainly on the upper left hand corner of the machine.

(*b*) Do not attempt to force any of the computers through the stops provided on same. On the latitude, longitude, and declination counters there is no stop at the 0 position, thus permitting continuous operation through 0° to values of the opposite name. The limit stops on the various counters are—

1. *GCT*, 0 and 24 hours.
2. *RA*, 0 and 24 hours.
3. Altitude, 0 and 90°.
4. Latitude, 90° N and 90° S.
5. Longitude, 180° E and 180° W.
6. Declination, 90° N and 90° S.

(*c*) As occasionally happens while the machine is new, if a control appears to jam at values between the stops rock the control back and forth and the machine will clear itself.

(*d*) In each of the procedures given in (2) to (7) below, the final step is the alinement of the main synchronizer. In order to minimize effect of backlash, *always make final movement so that long pointer comes to index line in a clockwise direction.* This precaution need not be observed when synchronizing the declination pointers.

(2) *To find altitude of sun as it appears from an assumed position at any instant.*—The following procedure is used principally for precomputing only the altitude of the sun.

(*a*) Enter Greenwich date (knob 1).

(*b*) Enter preselected Greenwich civil time (knob 2) for the instant at which altitude is desired.

(*c*) Synchronize sun counter by cranking knob 3, that is, turn until the counter reads sun—(dash), not sun.

(*d*) Synchronize solar declination synchronizer (knob 4). It will be noted that when the pointers are alined, the sun's declination is automatically recorded on the declination counter.

(*e*) Enter latitude and longitude of selected (assumed) position (knobs 6 and 7).

(*f*) Crank the altitude control (knob 5) until the main synchronizer is in alinement. As previously cautioned, when making final adjustment bring long pointer to index in a clockwise direction.

(*g*) Reading of the altitude counter is required altitude.

(3) *Solution for precomputed sun line of position.*—This procedure is used when it is desired to determine not only the altitude at which the sun will appear from a selected (assumed) position at some instant but to orientate the position circle through the selected position.

(*a*) Solve for altitude as in (2) above and then proceed as follows:

(*b*) Estimate whether the sun will be bearing generally north or south from the selected (assumed) position at the given instant of GCT: if so, change longitude knob 1°. If instead the sun will be bearing generally east or west at the given instant of GCT, alter the latitude knob 1°.

(*c*) If the longitude setting has been changed 1°, synchronize main synchronizer by cranking latitude knob. If latitude setting has been changed 1°, synchronize main synchronizer by cranking longitude knob. Do not change altitude setting during entire procedure.

(*d*) Read and record new latitude and longitude.

(*e*) On the chart plot the selected (assumed) position and the point obtained in (*d*). Through plotted points draw required precomputed line of position.

(4) *Solution for sun line of position using observed altitude (H_o).* This procedure is very similar to that described above except that H_o is substituted for precomputed altitude. In other words, the procedure below is used to locate the *observer's line of position* and not a precomputed line through an assumed or otherwise selected position.

(*a*) Enter Greenwich date of observation.

(*b*) Enter GCT of observation.

(*c*) Synchronize sun counter; that is, turn knob 3 until counter reads sun – (dash), not sun +.

(*d*) Synchronize solar declination indicator.

(*e*) Enter corrected observed altitude H_o.

(*f*) By visual reference to the sun, decide whether the ultimate position line will run generally east and west, or north and south.

1. If it will run east and west, assume two whole degrees of longitude near the DR position and then setting each longitude in turn on the counter solve for corresponding latitude by synchronizing main synchronizer with latitude knob. The setting of the altitude counter remains unchanged during this procedure. Record the assumed longitude and the corresponding latitude after each synchronization. On the chart plot the two points thus recorded and through them draw a straight line which will be the observer's line of position.

2. If upon visual reference to the sun it appears that the ultimate position line will run generally north and south, assume two whole degrees of latitude near the DR position and then setting each latitude in turn on the counter solve for corresponding longitude by synchronizing main synchronizer with longitude knob. The setting of the altitude counter remains unchanged during this procedure. Record the assumed latitude and the corresponding longitude after each synchronization. On the chart plot the two points thus recorded and through them draw a straight line which will be observer's line of position.

(5) *To find altitude of star as it appears from an assumed position at any instant.*—The following procedure is used principally for precomputing only the altitude of a star.

(*a*) Enter Greenwich date (knob 1).

(*b*) Enter preselected Greenwich civil time (knob 2) for the instant at which the altitude is desired.

(*c*) Enter RA of star (knob 8).

(*d*) Synchronize star counter by cranking knob 3; that is, make the letters STAR appear.

(*e*) Enter declination of star on declination counter with knob 4 (disregard solar declination synchronizer).

(*f*) Enter latitude and longitude of selected (assumed) position (knobs 6 and 7).

(*g*) Crank the altitude control (knob 5) until the main synchronizer is in alinement.

(*h*) The reading of the altitude counter is the required altitude.

(6) *Solution for precomputed star line of position.*—This procedure is used when it is desired to determine not only the altitude at which a star will appear from a selected (assumed) position at some instant but to orientate the position circle through the selected position.

(*a*) Solve for altitude as in (5) above and proceed as follows:

(*b*) Estimate whether the star will be bearing generally north or south from selected (assumed) position at the given instant of GCT; if so, change longitude knob 1°. If instead star will be bearing generally east or west at the given instant of GCT, alter latitude knob 1°.

(*c*) If the longitude setting has been changed 1°, synchronize main synchronizer by cranking the latitude knob. If the latitude setting has been changed 1°, synchronize main synchronizer by cranking longitude knob. Do not change altitude setting during the entire procedure.

(d) Read and record new latitude and longitude.

(e) On the chart plot selected (assumed) position and the point obtained in (d). Through the plotted points draw the required precomputed line of position.

(7) *Solution for star line of position using observed altitude (H_o).* This procedure is very similar to that described in (6) above except that H_o is substituted for the precomputed altitude. In other words, the procedure below is used to locate the *observer's line of position* and not a precomputed line through an assumed or otherwise selected position.

(a) Enter the Greenwich date of observation.

(b) Enter the GCT of observation.

(c) Enter the RA of observed star (knob 8).

(d) Synchronize star counter (knob 3).

(e) Enter declination of star; (disregard solar declination synchronizer).

(f) Enter observed altitude H_o.

(g) By visual reference to star decide whether star line of position will run generally east and west or north and south, and assume either two whole degrees of longitude *or* latitude just as was done for a sun line of position in (4) above. For each assumed longitude or latitude and with altitude counter remaining set to read H_o find the other coordinate on the position line by synchronizing main synchronizer in the same way as was done for the sun. Record the latitude and longitude of the two points and plot them on chart. The straight line through the two points is the observer's position line.

(8) *Line of position solution for the moon and planets.*—Once the RA of these bodies has been obtained the solutions are identical to those for a star.

c. *Azimuth.*—Having plotted a line of position obtained from the computer, it is obvious that the azimuth of the body may be obtained by measuring the bearing of a line at right angles to the plotted line of position. Care must be taken that the azimuth rather than its reciprocal is measured. An azimuth obtained in this manner should never be used when a highly accurate azimuth measurement is desired.

d. *Altitude intercept.*—If an assumed latitude and longitude are entered into the computer and the main synchronizer is synchronized using the altitude control, the reading of the altitude counter after synchronization is obviously H_c. If, at the same instant of GCT, the observer has measured the altitude of a body and obtained H_o, the difference between H_c and H_o is the altitude intercept; if the line

of position for the assumed position has been solved by the computer and plotted on the chart, the observer's line of position can be plotted by drawing a line parallel to the assumed position line and at a perpendicular distance therefrom equal to the intercept. This method of plotting the observer's line of position is seldom used because it involves more steps than that described in b(4) and (7) above.

e. *Two solutions possible.*—When solving for a line of position using H_o there are two possible solutions for each set-up of the computer due to the fact that every parallel passing through the position circle is a chord of the circle and will intersect the circle at two different longitudes; likewise, every meridian is a chord and will intersect the position circle at two different latitudes. As these intersections are usually separated by at least several hundred miles, a knowledge of the DR position will indicate the proper value of the coordinate.

f. *Adjustments.*—(1) DO NOT ATTEMPT to disassemble the machine or make unauthorized adjustments.

(2) *Installing new Almanacs.*—(a) On the first day of the new quarter of the year a new Almanac unit must be installed. Up to the present time changing of the almanacs has been a constant source of trouble and has probably been responsible for more derangements than any one thing. The technical order pertaining to the computer outlines in detail procedure to be followed in changing the unit and the navigator is referred to that publication for the procedure because it contains the necessary illustrations to clarify the written explanation. Extreme care must be exercised during the entire process.

(b) After a change has been made the old Almanacs are returned to the Air Corps depots and are reset for the same quarter of the following year.

(3) Once each year the entire computer must be returned to the depot for adjustment.

g. *Checking computer.*—There are several ways of checking the machine for proper all round adjustment. The simplest way is to solve a meridian problem but at the same time avoiding zero settings. (A little manipulation of the computer will show that it is very difficult to set any of the counters exactly on 0.) The procedure is as follows:

(1) Set any date.

(2) Set 30° W longitude.

(3) Set GCT at $14^h 00^m 00^s$ with the equation of time on the date selected for 14^h GCT applied with reverse sign, that is, if the equation of time is $-6^m 14^s$ set the GCT at $14^h 06^m 14^s$. This is the

same thing as finding the GCT corresponding to 14h GAT for the given civil date.

(4) Synchronize Sun counter. The machine is now set for local apparent noon at 30° W longitude.

(5) Synchronize declination synchronizer. The declination counter should read the value of the sun's declination for 14h GCT on the date chosen.

(6) Now set declination counter to 36° 00′ N. and the latitude counter to 72° 00′ N.

(7) Synchronize main synchronizer by cranking altitude control.

(8) Altitude counter should read 54° 00′.

(9) Crank GCT to 14h 00m 00s even. This upsets the Sun counter.

(10) Synchronize Star counter by operating the RA knob.

(11) When counter reads S-T-A-R, the RA counter should read 12h 02m 18s plus the sidereal time corresponding to 0h GCT for the date chosen. If the sum thus calculated exceeds 24 hours, subtract 24 hours.

b. Advantages.—(1) Solution is equally applicable to all bodies regardless of their positions in the heavens or position of observer on the earth.

(2) Solution for a sun line of position is the fastest of all the methods (1 or 2 minutes to solve and plot).

(3) Solution for star, moon, and planet lines of position are not quite so rapid but are faster than any other method with the possible exception of the star altitude curves which are limited to 3 stars.

(4) No tables or reference books are needed except the Air Almanac. This book is needed when using the stars, moon, and planets.

(5) May be used as a star identifier and to solve problems in great circle flying.

(6) LOP's may be found without using altitude intercept.

(7) Is specially useful when constructing altitude curves.

c. Limitations.—(1) In its present stage of refinement, the accuracy of the computer may vary up to ±6′ even though extreme care is used in setting up the elements.

(2) Is subject to mechanical failure. To recognize derangement, especially when the error is small, requires a thorough knowledge of celestial navigation.

(3) Is heavy (20 pounds) and bulky.

(4) Is expensive.

(5) Will not yield azimuth directly.

SECTION VII

POSITION LINES

52. General.—*a. History.* The method of navigation involving the use of position lines was discovered by Captain Thomas H. Sumner, an American shipmaster, in 1837. In honor of its discoverer the position line is often called the "Sumner line."

b. Use.—(1) As first used the position line was a chord drawn through two points on the position circle that were determined by computation. Two separate computations were thus required (one for each point) before the position line could be plotted. This same principle is involved in the A-3 and A-4 computer solutions when they are used to find where the observer's circle of position cuts two parallels or two meridians. Such a method is cumbersome and lengthy when computations are made by hand but it was practical in the sailing ship era due to the slow speeds of the craft.

(2) In present tabular methods such as Ageton the position line is a tangent to the position circle and only one computation is necessary to lay down the line. The tangent method was conceived by Marcq St. Hilaire, a French navigator.

53. Comparison with older marine methods.—*a.* The practice of navigation using position lines was slow to be adopted, and to this day is not universally employed. A surprising number of present day merchant marine navigators employ the time-sight method to determine longitude and the Φ′Φ″ and meridian altitude methods for determining latitude.

(1) When using the time-sight method, the latitude of the vessel is assumed, declination of body is found from the Air Almanac, and the altitude of body is measured; these knowns enable the navigator to solve for longitude. It is most accurate when the observed body occupies a position on or near the prime vertical.

(2) When using the Φ′Φ″ method, the longitude of the vessel is assumed, declination of body and its altitude are known, and knowledge of these three quantities enables the observer to determine latitude.

(3) When using the meridian altitude method the body is observed as it is transiting the observer's meridian and latitude is obtained by combining altitude and declination.

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CELESTIAL AIR NAVIGATION

Prepared under the direction of the
Chief of the Air Corps

SECTION I

GENERAL

1. Purpose and scope.—*a.* The purpose of this manual is to provide in convenient form an elementary text on celestial air navigation.