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or retired to a common time if necessary, would define the position of the observer. The method would be limited to zenith distance within the range of the chart. A later version would produce greater accuracy, but with a little more trouble in making the measurements, by substituting the gnomonic projection (art. 317) for the oblique Mercator projection.

Dusinberre. In 1944 Lieutenant Commander H. W. Dunsinberre, USN, suggested a method using star diagrams. A diagram for each 1° of latitude and 1° of LHA ♈ would be provided. Each diagram would consist of a series of radial lines extending in the directions of the prominent stars favorable for observation. The 22 stars of H.O. Pub. No. 218 (art. 2113) were suggested. Until changed by precession of the equinoxes (art. 1419) the common origin of these lines would represent a definite altitude for each star. The altitude at the next higher whole degree or half degree, adjusted for refraction, would be indicated by a tick on the appropriate azimuth line. After observation, a transparent plotting board would be properly oriented over the appropriate star diagram, using LHA ♈ and adjusting for the run between observations. The line of position would then be drawn at the correct point, perpendicular to the azimuth line, using the tick as a guide. An LHA ♈ computer was proposed for determining LHA ♈ at the time of each observation from a single LHA ♈ for a time near the start of each set of observations. When all lines of position were plotted, the fix would be transferred to the chart or plotting sheet.

2124. Solution by sphere.—Solution of a spherical triangle directly on a spherical surface, or by means of arcs representing great circles on the surface of an imaginary sphere, must have occurred to man quite early. Pictures of ancient navigators surrounded by their instruments and accessories invariably show a sphere. Solution by sphere is still suggested from time to time. Although this method is relatively simple and easy, the problem of scale is even more acute than in the graphical solutions.

Spherical methods can be classified in three groups: (1) those which solve the navigational triangle for a single line of position, (2) those which solve two or more observations for a fix, and (3) those which combine observation and solution for a fix.

The first group constructs the navigational triangle with arcs of great circles. Essentially, such a device consists of three arcs. The one representing the celestial meridian is usually fixed and a part of the frame. The base to which it is attached usually carries the azimuth scale. Movable arcs are provided for the vertical circle and the hour circle. If the latitude, meridian angle, and declination are properly set, the three arcs form the navigational triangle, and altitude and azimuth angle can be read from their scales. If altitude is used for constructing the triangle, meridian angle can be read from the instrument for a longitude solution.

Willis. A large number of teaching aids has been based upon this design or one of the many possible variations of it. Several precision instruments have been proposed or actually constructed. In 1932 such an instrument designed by Edward J. Willis, an American engineer, was constructed in Scotland. The marine version, weighing about 27 pounds, is graduated to 1′; and the aeronautical version, weighing between seven and eight pounds, is graduated to 5′. The longest dimension of either version is 11 inches.

Japanese Navy. During World War II, the Japanese Navy used an instrument virtually in the form described above. Results were accurate to approximately 1′.

McMillen. Of the various methods of determining a fix by sphere, the most obvious is that of providing an actual sphere as a plotting surface, with provision for striking arcs equal to the zenith distances, using the geographical positions of the celestial bodies as centers. In 1943 such a method was proposed by D. A. McMillen, a

United States businessman in São Paulo, Brazil. His sphere, of a little more than 14 inches in diameter, had a scale of 8° (480 nautical miles) per inch along a great circle.

Hiltner. In 1945 Dr. W. F. Hiltner, a professor at Lehigh University, suggested a similar method using arcs of spheres and a billiard ball. This in effect, sets up two navigational triangles, locating the observer at the common zenith of both triangles. Simultaneous observations are needed.

U. S. Navy Training Device Center. About the same time, the Training Device Center of the U. S. Navy prepared a device called the "Sphereman Craft Positioner," combining the functions of the devices of both McMillen and Hiltner, and providing a plotting surface for dead reckoning. A line of position from a single observation can be drawn on the 17-inch aluminum globe, or the triangle of position from the observation of three stars can be mechanically set up. Provision is made for advancement or retirement of lines due to motion of the craft. The device was intended for training purposes.

Zerbee. In 1951 Louis J. Zerbee, of Bellfontaine, Ohio, proposed a device similar to that of Hiltner, but without the billiard ball. His instrument was called the "Zerbee Celestial Fix Finder." Like the Hiltner device, that of Zerbee makes no provision for nonsimultaneous observations (unless one of them is corrected to the value it would have if observed simultaneously with the other) or for a check by observation of additional bodies. Observations of bodies near the meridian or taken from high latitudes cannot be accommodated.

Combined sextant and computer. At least as early as 1895 an attempt was made to combine in a single instrument the functions of sextant and computer. Such instruments are fundamentally the same as those described above, except that they are set by alignment with one or more celestial bodies. If the instrument is level and accurately aligned with the meridian at the time of observation, the miniature sphere is oriented to the celestial sphere and the earth. If both the altitude and azimuth are used, a fix can be obtained by means of a single celestial body. If two bodies are observed simultaneously, accurate directional reference by compass is not needed.

The weakness of such methods is the need for a stable platform and either accurate directional reference or the need for observing two bodies simultaneously.

Beehler. In 1895 Lieutenant W. H. Beehler, USN, invented an instrument he called the "Solarometer," which was designed to furnish a position from observation of the sun. It requires a heavy cast iron base rigidly attached to the ship, with a bowl set in gimbals and filled with mercury. A float resting on the mercury carries the sighting instrument.

Hagner. In 1936 Fred Hagner, of San Antonio, Tex., invented a similar instrument he called the "Hagner Position Finder." This is a portable instrument operating on the same principle as the Solarometer, but obtaining the vertical by being hung from a suitable support, and therefore acting as a pendulum. This is reminiscent of the ancient astrolabe (art. 124).

Bedell. In 1953 A. L. Bedell, of St. Louis, Mo., proposed an instrument based upon simultaneous observation of two celestial bodies. The horizontal would be defined by spirit level.

2125. Azimuth.—Most of the methods described above provide for determination of both altitude and azimuth angle. Several provide only for altitude. The number of tables, diagrams, and devices providing solution for azimuth only is very great, approaching the number providing solution for both altitude and azimuth. The reason for this is that azimuth is needed for other purposes than sight reduction. One common use is for checking the compass. Since modern inspection tables have provided parallel