# Spherographical Navigation

by

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*Aerial navigators can solve celestial navigation problems to an accuracy of four nautical miles with new method using a precision-ground sphere.*

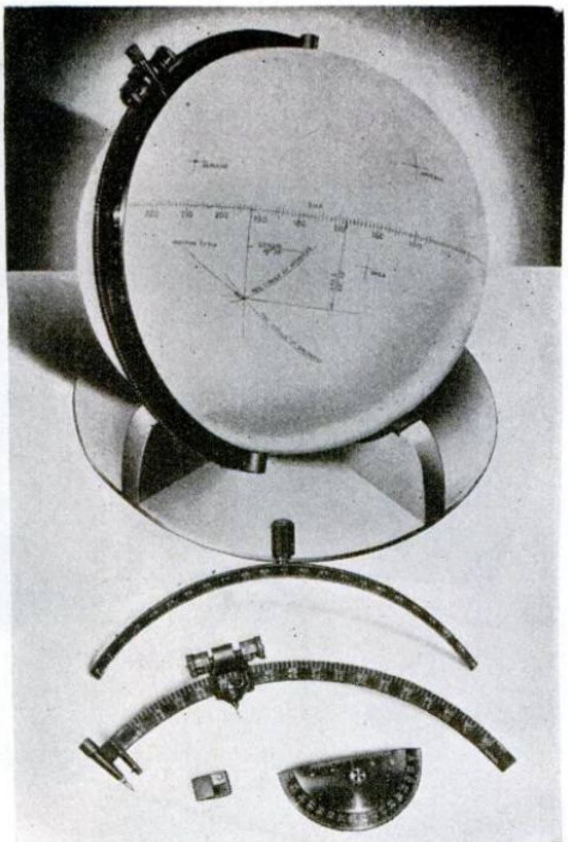

Fig. 1. Spherographical instruments are, top to bottom, sphere with meridian hoop, great circle ruler, spherical compass, spherical protractor.

CELESTIAL navigation problems may be solved to an accuracy of four nautical miles or better with the newly developed Spherographical system of navigation which utilizes a precision-ground sphere and three plotting instruments. Operation of the instrument can be so rapid that a typical two-star fix is established approximately one minute after observation. The whole unit weighs less than 15 pounds.

Besides the 14⅜-inch precision-ground *sphere* which is used for the plotting surface and has a *meridian hoop* attached to the poles, the instruments used are a *spherical compass*, a *great circle ruler* and a *spherical protractor*.

Among the many types of problems which the Spherograph can solve are (1) the determination of true course, (2) great circle distances, (3) great circle track, (4) true course segments for a great circle course, (5) drift check over a period of time, (6) course correction, and (7) advanced line of position.

Advantages over mathematical solutions claimed for spherographical navigation are:

1. Reduction of time.
2. Elimination of simple mathematical errors which would not be evident in mathematical systems until the navigator had completed his entire problem. The Spherograph actually represents celestial and terrestrial geometry correctly in three dimensions and any careless error is evident immediately, and can be easily corrected.
3. Elimination of errors in the reading of star altitude curves, or tables requiring the transformation of data into a factor before calculation, and then transformation of calculated factors into the required information. With the Spherograph, data is applied directly and required information is read directly, except for the addition and subtraction required to compensate for GHA♈ (Greenwich Hour Angle of Aries) in some types of problems.

The Spherographical system of navigation is not expected to revolutionize navigation in general nor to make maps, charts, or other navigation instruments or systems obsolete. It is, however, a navigational system which provides a means of determining a fix rapidly and accurately once the necessary information—such as star altitude, time, etc.—are known.

The basic instrument of the Spherograph is a hollow steel sphere precision ground to a close tolerance. It is then coated with a special synthetic plastic-base enamel which has the property of producing a black line when drawn upon with the metallic pencils with which the Spherograph instruments are equipped. The plastic coating will not crack or chip due to impact or scraping. The surface is finished down to final size so that 60 nautical miles on the equator are equal to exactly .1250 inches.

Tolerance on the diameter and roundness of the sphere is held to less than the diameter of a human hair. The equator of the sphere is graduated in intervals of 1° of arc to an accuracy of plus or minus 5″ of arc. The graduations on the equator are numbered every 10° for SHA (sidereal hour angle).

Attached to the poles of the sphere is a meridian hoop which may be swung on the polar axis to any position along the equator. The meridian hoop is graduated in 1° increments from 0° at the equator to 85° north and numbered every 5° with white figures and lines for work in the northern hemisphere. A second scale for work in the southern hemisphere is divided and numbered from 0° at the equator to 85° south, but with orange figures and lines.

The outside edge of the meridian hoop (Figure 2) has notches along its periphery. These are index notches which allow the micrometer slide to be positioned at any degree interval, latitude or declination, north or south. Contained within the micrometer slide is an index pawl which may be engaged in any desired notch. The micrometer slide, once engaged in the desired degree notch, may be further adjusted to the proper minute setting by rotation of either the white or orange thimble depending upon whether one is working in the northern (white) or southern (orange) hemisphere. The thimbles have 60 divisions and are num-

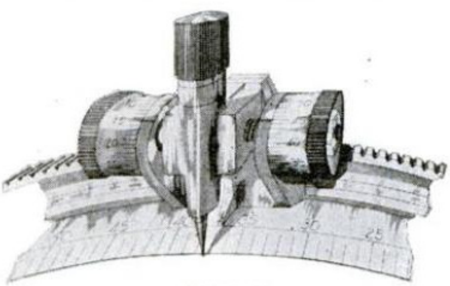

Figure 2.

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peller designed for land braking. The blades of the propeller were turned in ferrules which formed part of the hub, with the operating mechanism housed in the hub and the ferrules. A published report of those tests pointed out that "it was necessary to reduce the speed of the propeller while it was passing through the neutral pitch position (toward the negative blade setting) in order to prevent the engine from 'racing.'" Engine "racing," caused by propeller windmilling, was a problem for several years in the field of reverse research. It was finally overcome by providing almost instantaneous reversing.

Tests of a controllable, reversible variable pitch propeller for landing run braking were completed by the Airplane Appliance Company of Los Angeles in 1929. The airplane used was a Fokker *Super-Universal* and test flights were made by Lieut. Grission Haynes, Ray Howard and Cliff Schwartz of the Fokker company and Col. Arthur Goebel. Colonel Goebel on one occasion landed on a field at 100 m.p.h. and stopped the plane at the end of a 40-foot run with the propeller blades reversed. With the plane coming in at a steep gliding angle, the propeller was put in reverse with just enough engine speed to kill the tail group.

Much of the early experimentation with reversible propellers was directed toward their use as diving brakes. The NACA, the Bureau of Aeronautics, the Navy Department and the Army Air Corps in 1930 calculated the terminal velocity of a diving airplane with propeller in the reverse position. While the terminal velocity decreased with the blade angle setting, it was decided that a further decrease in pitch would lower the limiting velocity still further. The airplane used was a Navy F6C-4 equipped with a Pratt & Whitney R-1340-CD engine and a Hamilton Standard propeller of the controllable pitch type. The propeller was allowed to windmill against engine friction. The pitch-changing mechanism consisted of a hydraulic piston and centrifugal weights, which actuated the blades through a system of push-pull rods.

A European viewpoint of the significance of reverse thrust is contained in an article in the August, 1944, issue of Aircraft Engineering, a British magazine, discussing the Escher Wyss automatic variable pitch propeller:

"The landing brake operation of aircrews provides, at first, the possibility of shortening the landing run of a given aeroplane. Since the take-off distance becomes the most important factor in determining dimensions of the aerodrome necessary for an aeroplane provided with the possibility of airscrew braking, the aeroplane can be constructed in accordance with this new possibility so that it will land in approximately the same distance at a considerably greater speed. Consequently, it becomes possible so to increase the wing loading that, with the means now available, the maximum speed may be increased to a figure never before reached." END

## Spherographical Navigation

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bered every 5′ of arc. Each division represents 1′ of arc, as determined by the pitch of a precision ground lead screw. The latitude or declination setting as shown in Figure 2 is 37° 15′ S. The accuracy of these settings is plus or minus 5′ of arc or better. To draw a latitude of declination circle upon the sphere, the navigator need only rotate the pencil thimble until the spring-acuated pencil drops upon the surface of the sphere, then swing the meridian hoop. The pencil is metallic so that a fine line will be produced without excessive flattening of the point by wear or abrasion. A pencil sharpener is provided to recondition the point of the pencil.

The edge of the meridian hoop is ground so that when it is desired to construct a meridian circle or vertical circle, the navigator employs this edge of the meridian hoop as a guide for his pencil as he draws upon the surface of the sphere.

The spherical compass consists of a circular segment bar. Its center of radius is at the theoretical center of the sphere. The periphery of the bar is precision notched in 1° intervals the same as the meridian hoop (see Figure 3). On the bar is mounted a micrometer slide whose construction and manipulations are the same as that of the micrometer on the meridian hoop. Mounted on the micrometer slide is the index pin which is the pivot point of the compass when drawing a circle of position. Fixed at one end of the bar are two legs which, in

conjunction with the index pin just mentioned, serve to keep the bar at the proper distance from the surface of the sphere and maintain the pencil in a perpendicular position. Combined with the legs is the pencil housing containing the slideable metal pencil as on the meridian hoop. To draw a line the pencil thimble is rotated slightly and the pencil drops down upon the surface of the globe. Spring actuation assures uniform pencil pressure.

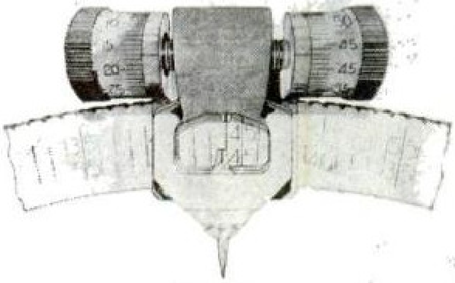
Figure 3.

It will be noted that there are two scales on the bar. The orange scale marked "Altitude" is the scale which the observed, corrected altitude is set upon when drawing a circle of position or line of position. Actually the arc subtended is the co-altitude. Figure 3 shows the compass set to draw a circle of position of a star whose observed corrected altitude is 46° 17′. The second or white scale is the actual angle which is subtended as measured along the equator. When employing this scale, the white minute thimble should be used. Figure 4 shows the compass set to mark off 65° 31′ on a great circle.

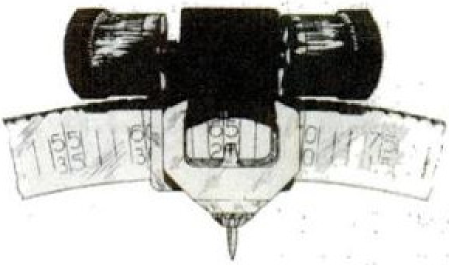
Figure 4.

To draw a great circle course and measure great circle distances in nautical miles, the great circle ruler is used. It is designed so that it will rest upon the surface of the sphere and its divided edge will represent any great circle. A great circle may be drawn by using this edge as a guide for the pencil.

Great circle distances may be measured by setting the edge of the great circle ruler through the two points which the distance separates and setting the "0" mark at one of the points. Each division represents 20 nautical miles and the figures represent hundreds of nautical miles. The great circle ruler is shown in figure 5 in position to measure 1,540 nautical miles. As an average, with a slight amount of practice, these distances can be measured to within three nautical miles.

The spherical protractor is similar to an ordinary plane protractor, except that it is spherical in contour so that its inside edge fits the surface of the sphere. Around its periphery is a scale divided in 1° intervals and numbered every 10° of arc. When measuring azimuth, the straight edge is set along a meridian circle, with the long orange line of the straight edge at the origin of the axis. Figure 6 shows a true course heading of 57°. When the straight edge is to the west, read the white scale which is marked from 0° to 180°. When the straight edge is to the east use the orange scale which is marked from 180° to 360°.

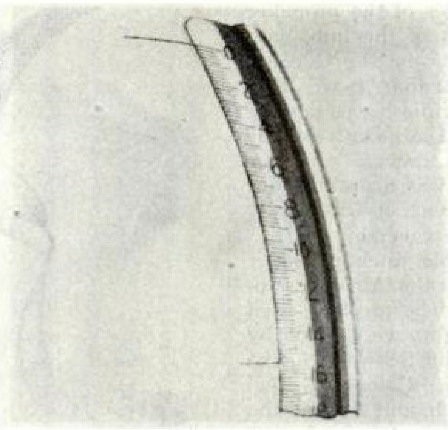
Figure 5.

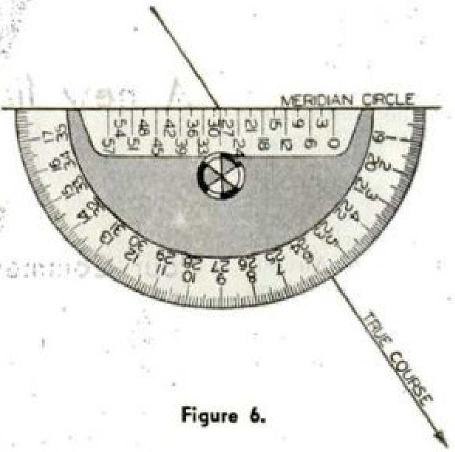

Figure 6.

The scale along the straight edge of the spherical protractor is a vernier scale for the equator of the sphere. This allows an equatorial angle to be directly read to 3′ of arc and readily estimated to 1′ of arc. Place the zero mark of the protractor, with the straight edge of the protractor along the equator, on the meridian circle in question and read the vernier division which registers with the equator division, giving minutes of arc. Figure 7 shows a vertical circle which has a sidereal hour angle (SHA) of 177° 39′.

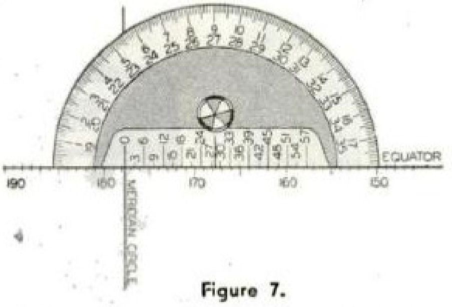

Figure 7.

On the surface of the sphere, .002 inches is approximately equal to one nautical mile. At once, the practicability of such a small scale is questioned. As the accuracy of the instrument theoretically allows the solution of problems accurate to within 500 feet, the main error may be attributed to the human element. These may be items such as altitude reading, which, if accurate to 3 of arc, is considered excellent, and variations of plotting by the navigator. These are errors which cannot be eliminated but do, however, tend to average.

With practice and a good scale, any person can scale a distance to an accuracy of less than .005 in. Toolmakers, machinists, and draftsmen do this daily. Others may doubt that the naked eye will detect .002 in. or smaller. Human hair ranges from .002 to .004 in. in diameter. If one lays one hair across another on a white background, both may be seen with ease. Spider webs are composed of threads of .0001 to .0005 in. in diameter. Yet they may be readily seen if the proper background is provided. Reasonable care in laying out, measuring, and drawing upon the sphere must be exercised. To produce a good job, the metallic pencils must be kept sharp, much the same as a carpenter or machinist must keep his tools sharp to produce a good job—or the same as a navigator keeps the lenses and filters of his sextant or octant clean and checks on the accuracy of his sextant or octant and watch.

An example of the use of the Spherographical System in navigation is the problem of obtaining a two-star fix.

We shall let $H_0$ represent star altitude after the corrections for index error, refraction, parallax, etc., have been applied. In a problem of this type it is not necessary to assume one's position before starting. Following are the data required to determine a fix from two stars (refer to Figure 8):

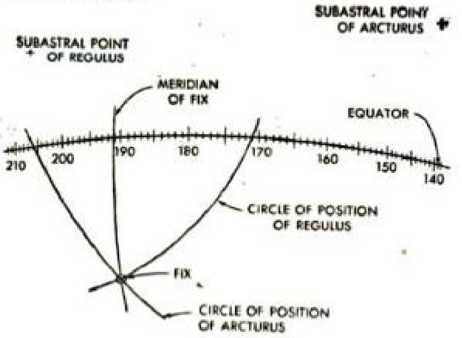

Figure 8.

Date: 4/13/43
Time: 0100 GCT
1st star: Arcturus
$\left.\begin{array}{ll}\text{SHA} & 146^\circ\ 44'\\ \text{Dec. N} & 19^\circ\ 29'\end{array}\right\}$ From Air Almanac
$H_0$ 28° 51′
2nd star: Regulus
$\left.\begin{array}{ll}\text{SHA} & 208^\circ\ 40'\\ \text{Dec. N} & 12^\circ\ 15\end{array}\right\}$ From Air Almanac
$H_0$ 50° 21′
GHA♈ = 215° 21′—From Air Almanac

As the 22 major navigational stars are permanently plotted upon the surface of the sphere, the SHA and declination of the stars in this problem are given for reference only. From year to year the correlations between these stars does not vary enough to affect the accuracy of navigation problems materially. Their positions, as spotted on the sphere, are good for several years.

To plot the above problem, we orient the globe to a convenient working position so that the sub-astral points of Arcturus and Regulus are on top. Set the spherical compass on the altitude or orange scale to read 28° 51′ which is the $H_o$ of Arcturus. Insert the index pin into the sub-astral point of Arcturus on the sphere and draw a segment of the circle of position of Arcturus which passes well across the approximate azimuth line of the star observation. Next, set the spherical compass to 50° 21 on the orange or altitude scale which is the $H_o$ of Regulus. Insert the index pin of the compass into the sub-astral point of Regulus and draw a segment of the circle of position of Regulus which passes well across the approximate azimuth line of the star observation and through the circle of position of Arcturus. The intersection of these two circles of position is our fix. Actually, the two circles of position will intersect at two points several hundred miles apart. The intersection which is our fix can be determined simply from noting the approximate azimuth of the star observations. To determine our latitude we set the micrometer slide of the meridian hoop *to the degree division closest to our fix and between the fix and the equator,* which in this case is 23° S. Next drop the pencil down and rotate the orange thimble, because we are in the southern hemisphere, until the point of the pencil is on the fix. The micrometer should now read 33′. The latitude is then 23° 33′ S.

The longitude of our fix is determined by the addition of SHA of our fix and GHA♈. We must, therefore, construct a meridian circle with the meridian hoop through our fix and extend it to the equator in order to determine accurately the SHA of our fix. By means of the equatorial scale on the sphere in conjunction with the vernier scale on the straight edge of the protractor, we find the SHA of our fix to be 191° 18′. We next add the SHA of the fix to GHA♈ for the time of observation, which we read from the Air Almanac

SHA fix = 191° 18′
GHA♈ = 215° 21′ From Air Almanac
406° 39′

As this sum is greater than 360° we must deduct 360°. This gives 46° 39′ which is our longitude. However, to determine safely whether east or west, the navigator should construct the usual time-longitude diagram. This calculation clearly indicates that our longitude is 46° 39′ W.

The Spherograph can likewise be used to work out a three-star fix; to solve an advanced line of position problem; to determine a radio fix; to work out a preplotted flight, and for numerous other navigational purposes. It is best mounted on special rubber shock mountings. The sphere may be inserted in the navigator's desk or on bulkheads. The accessory instruments are held in recessed pockets to avoid damage.

The manufacturers believe that long-range air transport calls for instruments free of delicate mechanisms needing constant checking, and they claim that the rugged design of the Spherograph will hardly permit it to become maladjusted in any normal flying conditions. END

## Arctic Air Watch

(Continued from page 23)

demic of "cabin fever." That's the reason why the man-and-wife-team idea was attempted.

At first, CAA drafted men with families. But children, they found, created other problems. One parent had to be with the children and that meant that husband and wife worked on different shifts. It wasn't long before both were short on sleep. In isolated regions schooling had to be done through correspondence courses.

Changed draft rules, plus the discovery that childless couples apparently had a better chance for success at their jobs, caused a third shift in CAA's personnel policy. This time they wanted 4F's with wives and no children. Recruiting them, however, proved difficult. It was a United Press news story that turned the trick. It promised "An extended honeymoon . . . just like the Alps for winter sports . . . a paradise for camera enthusiasts . . . hunting, fishing—50-inch rainbow trout . . . caribou, bears, grouse, ducks . . . gardens that yield bigger and better vegetables." The story provoked as many inquiries as a fizz tablet does bubbles. More than 16,000 letters poured into the Washington and Seattle offices. Enlistments were made, aptitude tests given and six-month training courses got under way.

Within seven months the first of the new recruits—artists, musicians, office workers—were Alaska-bound. For a few the Alaskan assignment meant boredom and loneliness. But the majority—couples like Tex and Anne Noey—will tell you that theirs is a full, good life.

The Noeys couldn't have dreamed a few years back of an isolated outpost at Kotzebue, Alaska, as a setting for marital contentment. Tex was a construction worker and Anne a nurse in an Anchorage hospital when they met. Now the Noey's are CAA aircraft communicators. They typify this little army of man-and-wife teams recruited by CAA to gather and disseminate weather information to pilots on Alaskan Airways. Their station forms a link in the chain of ground facilities built for safe aircraft operation along air routes in Alaska and on north of the Arctic circle.

Overtime pay, plus an extra allowance for Alaska's high living expenses, brings their base pay of $2,000 each to a joint total of $5,960. They pay $25 a month for the furnished five-room cottage which the CAA provides for each of the families on its staff. Because of difficulties in transportation, it sometimes costs the CAA $25,000 to place one of these houses at remote stations like Kotzebue. They are especially designed for Arctic weather, and are actually among the best houses in Alaska. They are oil-heated, have streamlined kitchens with fluorescent lighting, and are comfortably furnished. Four or five cottages like the Noey's and two-score private dwellings of an earlier vintage comprise Kotzebue.

Tex and Anne Noey keep a six months' supply of canned goods on hand and when they need fresh meat, they go out and

## UNUSUAL FIGHTER

ONE of the most unconventional fighters to be tested by the Army Air Forces in recent years was this experimental monoplane, the Consolidated Vultee XP-54. This design is understood to have been discarded in favor of fighters now in, or going into, production.

The XP-54 was powered with an experimental Lycoming engine, driving a four-bladed pusher propeller. The pilot had unusual visibility, sitting well forward of the inverted gull wing. The fuselage had an extremely long nose, which housed what appears to have been four cannon. Other structural features were twin tail booms, pressurized cockpit, and a device for ejecting the pilot in an emergency.