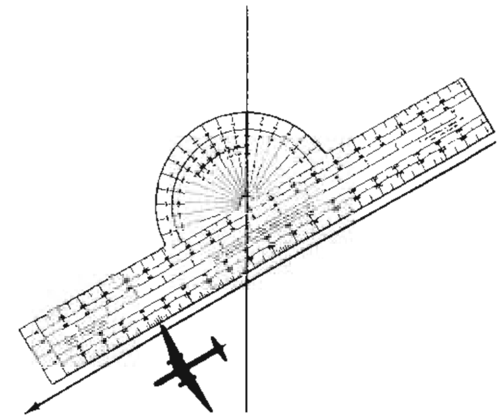
MOST PROBABLE POSITION

A HISTORY OF AERIAL NAVIGATION TO 1941



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and lengthy computations in the air, but he chose to work the dead reckoning wirh marine traverse tables (see above, p. 10). Using the sextant in the open cockpit was not easy. He had to twist himself into various positions to align the sextant with the celesrial body and brace himself as well as possible to hold the instrument steady in the airstream. At night he also had to manipulate a flashlight.[18]

The navigational task facing the American NC flying-boat crews seemed much simpler, because of the vast organization devoted to the effort. Three aircraft attempted the flight, following a route chosen to reduce the length of each stage: Long Island, Newfoundland, the Azores, Lisbon, England. Destroyers were spaced every 50 miles along tbe 3,800 mile route, to provide navigational assistance and to rescue downed airmen. By using some ships more than once, a total of 68 sufficed. During the day the destroyers made smoke; at night they lit up searchlights and fired star shells. Further, tbe flying hoats were large enough to carry every available navigational aid.[19] In the view of an Englishman who did not consider the weather, "the Americans had nothing to do but navigate by sight. . . . the navigational problem was reduced to the last terms of ease"; and an American participant agreed that it should have been "as easy as 'walking down Broadway' "—except for the rain and fog encountered during the night of the Newfoundland–Azores leg.[20] Direction-finding radio was the only navigation aid that could possihly operate inside clouds in 1919, and it failed all three aircraft during the night. Thunderstorms along the route produced severe static and the magnetos of the engines also produced radio noise. From magneto interference alone, one flying boat could take no radio bearings from sources more than 10 miles away. The crews of all three boats were uncertain of their positions approaching the Azores. Landing in high seas, one boat sank and another was damaged. Only the third, which landed in the shelter of one of the islands, could continue the flight. But directional radio, performing acceptably in clear weather, helped keep the last boat from going astray on the next leg to Lisbon. The steering compass was jarred loose on takeoff, and the pilot took up a course 8° too far right. As the destroyers appeared farther and farther to the left, the navigator used the radio to home on the fourth ship, and later discovered the compass error. The NC navigators used the bubble sextants only occasionally.[21]

Two more flights of the early 1920s demonstrated the possibilities of aerial navigation. The RAF conducted an exhaustive test of its navigation instruments, excepting radio, in August 1920. A well-qualified crew, including some R.A.E. instrument designers, flew a Handley Page 0/400 around Britain, over 1,000 miles in 11 stages.

The compasses and driftmeters gave excellent results in dead reckoning: at the end of legs varying from 25 to 200 miles, the DR error varied from 0 to 9 miles, an average of 3.3 miles. The celestial results, using an early model of the R.A.E. bubble sextant, were less impressive. The error in 16 sunlines ranged from 2 to 43 miles, averaging 14 miles. The sights were reduced with another new instrument: a slide rule devised by Captain L. C. Bygrave of the Air Ministry Laboratory. The difficulty with all previous mechanical and graphical reduction devices had been that, to secure acceptable accuracy, the instrument had to be so large that its use in a cockpit was difficult or impossible. By using a series of equations involving only cosines and tangents and wrapping the two required scales in a spiral around telescoping cylinders, he packed 56 feet of scale onto an instrument only 14 inches long, 3 inches in diameter, and weighing less than 2 pounds. He provided instructions on the instrument, arranged in a series of steps, so that a person who knew little of the theory but who had mastered the drill could work out an observation in about four minutes of time, to an accuracy of 1 or 2 miles.[22] As would be true for many years, the weakest link in celestial navigation for aircraft remained the sextant. A Portuguese naval officer, Gago Coutinho, carried the instrument one step further toward perfection.

Since 1919 Coutinho had considered flying from Portugal to Brazil on the centennial of the political separation of those countries. The route did not follow a shipping lane, and there were no powerful radio stations on shore, so he did not plan on using radio. The Portuguese could provide only a small, single-engine seaplane, incapable of making the journey nonstop; refueling would be necessary at four islands. The most difficult leg would be the thousand miles from the Cape Verdes to St. Paul's Rocks, a speck on the equator 600 miles northeast of Natal. The volcanic rocks covered an area of 650 square yards, with a maximum elevation of 30 feet; they would not be easy to find.

Coutinho painted drift marks on the tail of the seaplane, but he placed his greatest reliance in celestial navigation. He designed a bubble sextant and tested it on flights in 1921. It differed from those previously described in that, instead of a single, spherical bubble-chamber, it had two tubular chambers, perpendicular to each other, mnch like a carpenter's level. The pilot was expected to steer toward the celestial body during the observation, and the longitudinal level was therefore of primary importance. Because the radius of curvature of the spirit chambers was larger than in the spherical chambers used in the sextants described previously, the bubbles in tbe Coutinho instrument reacted more quickly to changes in the vertical—and to used it in his survey flights for Pan American in 1933 and found it especially helpful, but the surface sailors who controlled the Navy were not convinced that the duplication of effort was worth the cost. "Most unfortunately, the Air Almanac was discontinued in 1934, though some of its features in emasculated form [were] included in the 1934 Nautical Almanac." France next took up the project of an air almanac, adding a valuable contribution: all data for one day was printed on the two sides of a single perforated page so that, while the annual publication required 730 pages, the navigator could tear out those pertaining to his flight and leave the rest on the ground. The French continued the use of GHA, tabulating position information for the navigational bodies every 20 minutes of time.[52]

In 1936 Weems, in England in conjunction with the publication of a British edition of his navigation textbook, discussed the need for an air almanac wirh officials of Hughes & Son, the Admiralty, and the Air Ministry. Both military and civil members of the Air Ministry supported the publication of a British air almanac, and it first appeared in September 1937. Generally it combined the features of the 1933 American almanae with those of the French almanac.[53]

Weems was soon publishing the British almanac under license for sale in the United States, and the Army Air Corps became one of his best customers. The Navy was forced to reconsider the question in 1939.[54] In spite of personality conflicts and worse than usual organizational in-fighting within the bureaucracy, the American air almanac duly appeared.[55] Thurlow, on hearing that the Naval Observatory intended to publish an air almanac, wrote Weems in late May 1940: "Naturally we're happy to have a domestic source (looks like the British won't be putting theirs out in a few weeks; nor needing them either)." Fortunately the British continued to need an air almanac, and the irrationality of duplicate computations on both sides of the Atlantic led after the war to joint publication.[56] Today's *Air Almanac* appears three times yearly, bearing a joint imprint:

Washington:	London:
United States Naval Observatory	Her Majesty's Stationery Office

The almanac provided the location of the celestial body; the sextant measured the height. These items defined the celestial triangle, which still had to be solved. The preferred methods in the early post-World War I years included various marine tables and the Bygrave slide rule (above, p. 111). Two of Britain's most famous aerial navigators, Francis Chichester and Donald C. T. Bennett, relied on the Bygrave rule.[57] But "a large number of tables were published with special reference to the air, and each claiming to be the quickest and most accurate: Ogura, 1920; Newton and Pinto, 1924; Smart and Shearme, 1922; Goodwin, 1926; Weems, 1927; Dreisonstok, Ageton and Gingrich, 1928–31; and Aquino, 1933." The Naval Institute published Weems's tables after he agreed to reimburse them for any loss. He drew heavily on the method of the Japanese astronomer-mathematician Ogura; Ogura in turn had merely applied a formula suggested in 1850 by the first professor of navigation and mathematics at the U.S. Naval Academy. The Dreisonstok and Gingrich tables appeared hard on the heels of Weems's. Weems interpreted the appearance of Hydrographic Office publication number 208 (Dreisonstok) as a backhanded compliment. Gingrich's, published privately, differed primarily in that Weems provided azimuth by a diagram, Gingrich by tabulation. In the midst of this activity, E. B. Collins of the Hydrographic Office began another set of tables but abandoned the effort, observing that "it is difficult at this late date to juggle the astronomical triangle to a new form." Nevertheless, the tables that would be mosr widely used by American aviators in World War II, H. O. 214, did not start to appear until 1936. Arranged in bands of 10° of latitude per volume, so that a navigator need carry less than the complete set of nine volumes, the first eight volumes, covering 79° South to 79° North, were available by Pearl Harbor.[58]

Generally, any tabular solution of a celestial observation required extracting information from three or four different pages and writing down, adding, or subtracting figures 20 to 25 times, depending on how one counts the "steps" of the solution. Every table had its ardent supporters; it is difficult now not to conclude that the first method a navigator learned tended to be his favorite, and that evaluating one against the other is rather sterile. To the uninitiated, all tables look forbidding. More important, toward the end of a long flight, mistakes are easily made in the simplest computations. On both counts, tabular solutions are undesirable. Again following the direction taken by the balloonists (above, pp. 32–36), a number of nontabular methods of reduction appeared between the wars. They can be classified as graphical and mechanical.[59]

The best-known graphical reduction method to appear between the wars was Weems's star curves. Sets of precomputed curves had been used by balloonists before World War I, but Weems got the idea from Wimperis's *Air Navigation* of 1920 and a National Advisory Committee for Aeronautics report published in 1924.[60] Weems's patent application stressed that, with the curves, less schooling was required of the aerial navigator, fewer items needed to be carried in the aircraft, no assumed position was needed for plotting, and a pilot