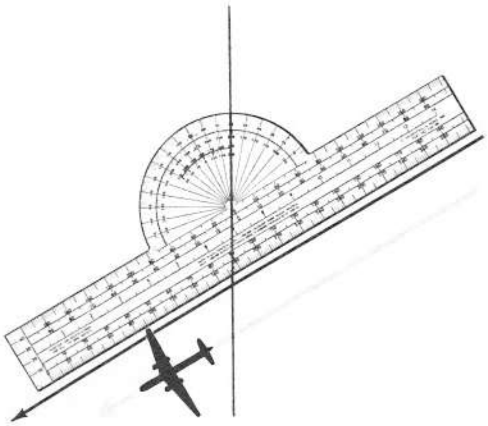
MOST PROBABLE POSITION

A HISTORY OF AERIAL NAVIGATION TO 1941



by
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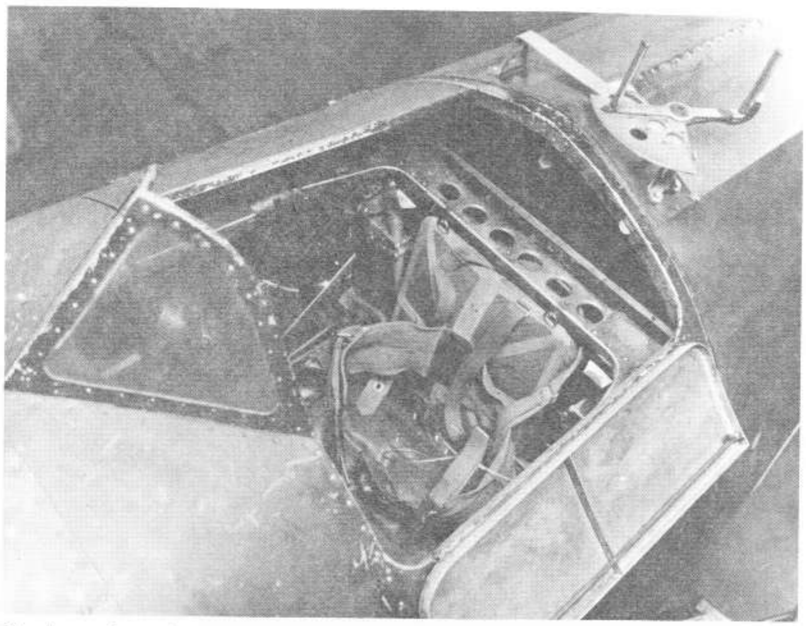
special reference to the air, and each claiming to be the quickest and most accurate: Ogura, 1920; Newton and Pinto, 1924; Smart and Shearme, 1922; Goodwin, 1926; Weems, 1927; Dreisonstok, Ageton and Gingrich, 1928–31; and Aquino, 1933." The Naval Institute published Weems's tables after he agreed to 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 most 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]

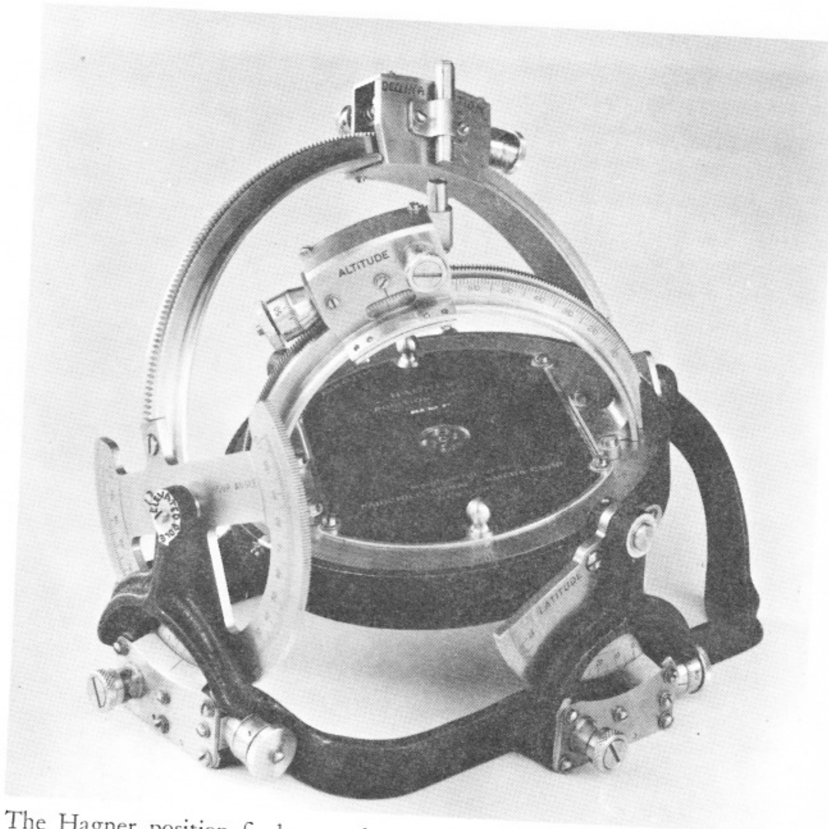
The best-known graphical reduction method to appear between the wars was Weems's star curves. Sets of precomputed curves had been used by balloonists before World War I, but Weems got the idea from Wimperis's *Air Navigation* of 1920 and a National Advisory Committee for Aeronautics report published 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



Navigator's cockpit of the Breguet *Question Mark*, showing pelorus, September 1930.
USAF photo.

could carry out the whole operation with only part of his attention. Only the last claim could be seriously questioned. While Francis Chichester several times used a hand-held sextant while flying solo, Lindbergh specifically denied being able to do so.[61] Gatty, by then associated with the Weems System of Navigation, used the second edition of the star curves on his world flight with Post and praised them. This testimonial was not the best, not only because of the economic interest, but because after landing in what they thought was Ireland, they found they were at Chester. Gatty's work over Siberia was more impressive. Two major criticisms were leveled at the curves. First, only two stars were provided. Later editions increased this to three, but still clouds over part of the sky might prevent use of the selected stars. Further, when the curves first appeared, navigators were shooting from open cockpits. As their view of the heavens was later more restricted, it was less likely that they could see the particular stars. Second, if celestial navigation had to be used during the day, a different method of reduction was required. A student could learn a single, universal method more easily than two.[62]

A French variation of the same principle, popularized by Bellonte's



The Hagner position finder, marketed by Fairchild Aerial Camera Corp.
Weems & Plath photo.

successful use of it in 1930, printed the altitude lines on the navigational chart. The chart was long and narrow, not the easiest to handle in an airplane, and only those celestial bodies whose positions could be plotted could be used.[63]

Much more elaborate than sets of curves were a series of mechanical reduction devices. One type replaced the sextant as well as the tables. The bubble level and the sextant optics were attached to a set of three interconnected circles that represented the variables of the celestial triangle. Using the instrument, the navigator solved for two possible positions and connected them on his chart to form the line of position. Capable of high precision and speed, the instrument was bulky, very expensive, and used fine scales that were difficult to read in an airplane.[64] Weems dabbled with the possibilities of an instrument that would track a celestial body continually and give the plane's

l Camera Corp.

position on an indicator on the instrument panel, but the attempt was 15 years before its time. The electronic computer would be needed to make such an instrument work. A complicated analog computer for converting height observations to geographical positions was marketed commercially by Fairchild Aerial Camera in 1938. The instrument was again heavy and expensive; worse, its excess of "counters, gear differentials, pin cams and the like" made the instrument almost impossible to keep calibrated.[65] Squadron Leader John F. Griffiths, one of Weems's RAF confidants, wrote after seeing specifications of the Fairchild instrument: "Looks like a wireless set, and costs about as much as a Dusenberg. Someone suggested that they fit a loud speaker to it . . . . which would tell the pilot which way to go . . . . A very useful aid to homing after a Guest Night in the mess." Less elaborate mechanical devices appeared in France during the 1930s. One was a development of the Favé and Brill instruments of pre-World War I (above, pp. 34–35); another was similar to the Baker plotting machine used by Alcock and Brown in 1919 (above, p. 109).[66] The only mechanical reduction device to achieve wide acceptance was the astrograph.

In October 1938, when Squadron Leader Griffiths had some leisure after the Munich crisis, he wrote Weems enthusiastically about an idea: the use of a transparent navigation chart over an opaque sheet carrying sets of altitude circles. In other words, he had rediscovered Favé's arrangement of 1906. Weems replied with less enthusiasm: he had considered such a device and abandoned it in favor of the star curves. Griffiths did not drop the idea, however, and ultimately interested his superiors in the instrument, called the astrograph. By that time the design had become more complicated. The curves, on transparent film, were run through a projector above the navigator's work table, so that the lines were projected onto the regular navigation chart. Once aligned properly, the navigator simply traced the proper line of position on the chart and turned off the projector. The difficulty was in the alignment. Because the film and the paper had different coefficients of expansion, a correctly aligned astrograph would be thrown out of adjustment by changing temperatures. Further, only a few stars could be accommodated on the film, so that the same objection leveled at Weems's star curves also applied to the astrograph: the navigator might not be able to see the selected stars that were plotted.[67]

Pan American investigated the various new methods but continued to rely on the basic tables, such as Dreisonstok. Pan American, however, could afford to pick its navigators carefully and train them leisurely. With the expansion of the RAF and the U.S. Army Air Corps before and during the war, training programs were accelerated at the very time that entrance standards were lowered. Griffiths, struggling to get his night bombing squadron combat ready in 1938, complained to Weems that "all these systems were too complicated and lengthy to be taught to the average pilot. . . . whose mathematical education appeared to have ceased when [he] could count up to 10." For such reasons the RAF adopted the star curves and the astrograph, while the U.S. Army Air Corps and Navy both adopted the curves, in spite of the limitations inherent in both devices.[68] Neither nation was satisfied with those expedients, however; in June 1941 Thurlow was busily comparing the latest British air navigation tables with the latest Hydrographic Office publication, recommending a new publication to incorporate the "best features" of each.[69]

The development of the various instruments used for aerial navigation between the World Wars has now been recounted: radio; airspeed meters; compasses from magnetic through directional gyro to magnetic-gyro combinations; driftmeters; pressure and absolute altimeters; sextants.[70] The increasing use of the weather map for planning long-range flights and the various methods of reducing celestial observations have been described. In practice the transocean navigators used all these instruments and techniques.

Dead reckoning continued to be basic. The transoceanic navigator read the compass, altimeter, airspeed meter, and driftmeter periodically, being careful to notice any changes from previous values, and used this data to keep a running account of his craft's position. Where the marine navigator computed the coordinates of a DR position mathematically and then plotted it on the chart (above, pp. 10–11), the aerial navigator had simplified the procedure. He combined the forces affecting the aircraft vectorially, found the course and distance traveled from the previous position, and plotted the DR position on the chart directly, using draftsman's dividers and protractor. The dead reckoning was updated regularly—hourly or less, depending on company policy—by whatever fixing methods were available. The navigator did not use only the most convenient navigational aid; he used all of them. Because any one method might fail, it was prudent to use them all, to have a procedure already established before it became necessary. Because one could not know what was ahead on the route, navigational data from all sources should be gathered and stored in the log for possible later use. Because no method was perfect, the radio bearing should be compared with the celestial line of position, and both with the dead-reckoning data. And the peak of navigational perfection was not the ability to carry on several different navigational techniques simultaneously, but the ability to integrate their results. Sometimes the navigator had to judge between conflicting data, ac-