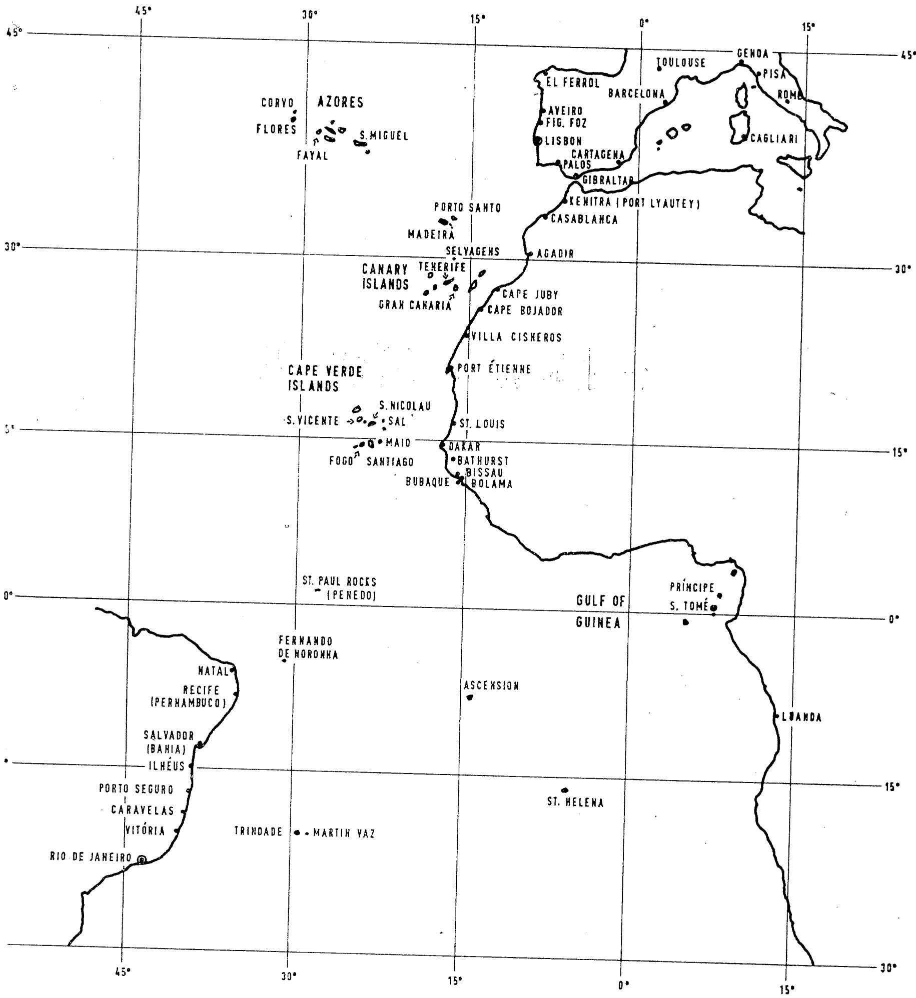

Atlantic Ocean Between Lisbon and Rio de Janeiro

ACADEMIA INTERNACIONAL DA CULTURA PORTUGUESA

PRECISION ASTROLABE

Portuguese Navigators and Transoceanic Aviation

by

Francis M. Rogers

Harvard University

LISBOA

1971

CHAPTER 6

The Search for a Suitable Bubble Sextant

Scholarship abounds with examples of discoveries or advances made because prepared minds were available and willing to make them. The phenomenon is rather the reverse of "serendipity", a word derived from a very old designation of Ceylon and from a tale, popular in the Renaissance, of the three young sons of the King of Serendippo.

Walpole defined serendipity as "accidental sagacity".[1] With respect to the bubble sextant, essential for the astronomical navigation of the early transoceanic planes, the necessary prepared minds were operating in abundance and virtually simultaneously in 1918 and 1919 in England, the United States, and Portugal. They did not improve the design of existing models by accident, however ,but by diligent application of their respective heritages along inevitable and predetermined lines.

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[1] Theodore G. Remer, ed., *Serendipity and the Three Princes: From the* Peregrinaggio *of 1557* (Norman, Oklahoma: University of Oklahoma Press, 1965), p. 6.

THE ROYAL AIRCRAFT ESTABLISHMENT (R. A. E.)

Of the three nations which pioneered in transoceanic air navigation immediatly upon the close of World War I, logic would indicate that England was the most advanced in techniques and equipment. She had participated in the entire war while yet being slightly removed from its ravages. She was in possession of considerable technical knowledge and skill as regards marine navigation. The venerable firm of Henry Hughes & Son of Fenchurch Street, London, stood ready to manufacture any needed new matériel developed by the military or by anyone else with a promising idea.

Prior to the war, the bubble sextant used aboard ships, including Mr. Wellman's airship, suffered from two defects. One derived from the fact that, as far as we know, the radius of curvature of the tubular spirit level was arbitrary, that is, not uniquely matched to the sextant. The device was affixed to the sextant in such a way that, in order for the sextant to be level, the bubble had to be maintained between what appeared in the eyepiece to be two horizontal guide lines. The observer then had to bring the sun down alongside the bubble, which was inevitably jumping around, and thus rivet his attention on two juxtapositions at the same time. Indeed, he had to keep a third factor in mind, the verticality of the sextant, possibly suggested by a pair of vertical guide lines. Figure 16 outlines the problem. [2]

[2] In the late thirties I acquired a learner's device called the "Boyce-Meier Sextant". It had a tubular spirit level of arbitrary radius attached to the side of the sighting tube, and the bubble had to be read by an assistant. With all its crudity, it did initiate me into the ways of the navigator, including the air navigator.

The other defect was due to the fact that a ship, and the motor balloon *America*, never followed a straight course at a constant speed. It yawed and pitched and rolled, often all at once, and concomitantly varied in the rate of its ongoing movement. The resulting accelerations threw the bubble off center and resulted in an appreciable error,

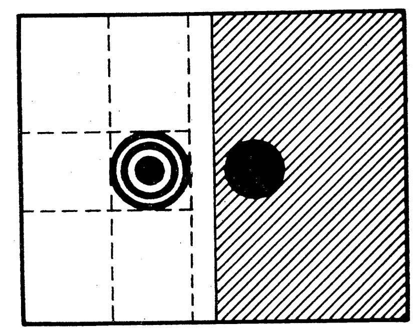

Figure 16

acceleration error, not to be overcome until World War II and the automatic averaging of sights; see Chapter 12.

It is probable that Whitten Brown's sextant (Plate III) included a tubular spirit level of arbitrary radius. Grieve was forced to use an ordinary marine sextant, and the *R 34*'s navigator also employed such an instrument. Both had recourse to the cloud horizon and so avoided the bubble problem altogether, although Major Cooke of the *R 34* also had a bubble sextant and on occasion took advantage of it. This bubble sextant was an early experimental model, however, and in fact proved unserviceable. [3]

[3] K. Hilding Beij, "Astronomical Methods in Aerial Navigation", N. A. C. A. Report No. 198, included as an appendix to the *Tenth*

In his interview with the *New York Times* in the middle of May 1919, Alexander Hughes expressed interest in the Byrd bubble device. He revealed that British experimenters had also developed a bubble sextant — not yet patented — and that one version had been delivered to yet another team in Newfoundland awaiting proper weather for a nonstop attempt across the Atlantic.

This team consisted of Captain Fred P. Raynham, pilot, and Commander C. W. F. Morgan, navigator. They started down their runway in their single-engined Martinsyde (not Short, as the *New York Times* story affirmed) biplane less than an hour after Hawker and Grieve took to the air. They never got off the ground, and Morgan was seriously injured. Raynham had the plane repaired. With a new navigator, he attempted to take off again in early July, while the *R 34* was over the Atlantic westbound. He crashed again. [4]

Mr. Hughes further stated that a second bubble sextant had been delivered to the British Air Ministry. It was probably this one which was supplied to the *R 34*. In other words, before the flight of the *NC-4* the British were paralleling the U. S. Navy experiments conducted by Byrd and Hinton in late 1918 and early 1919.

The designers in Britain were bold. They realized that an artificial horizon attached to a marine sextant made sense if there existed the possibility of the dual employment of the instrument: in a ship and in an aircraft, or in a ship

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Annual Report of the National Advisory Committee for Aeronautics 1924 (Washington: Government Printing Office, 1925), pp. 269-320, at p. 292.

[4] Thomases, pp. 19-20; Maitland, pp. 65 and 70; Alcock & Brown, p. 23.

with and without a natural horizon. For use exclusively in an aircraft under conditions which necessitated an artificial horizon, they felt that an entirely new type of sextant had to be fashioned.

In his *Primer of Air Navigation*, which must have been written in 1919 although published in 1920, Harry Egerton Wimperis, at the time head of the Air Navigation Research Section of the Air Ministry, described the "R. A. E. bubble sextant", which had been developed at the Royal Aircraft Establishment in Farnborough (Hampshire). This instrument, of a shape which startled old-time marine navigators, permitted the observer to sight directly at a celestial body (as from a crouching position in an open cockpit and out of the slip stream) or to look down into the instrument at the reflection of a body. The bubble was contained in a spherical level which could be illuminated for night use. Wimperis provided an important additional detail:

> As the lens is chosen to have a focal length equal to its optical distance from the bubble, and as the curvature of the upper surface of the latter is also equal to this distance, it follows that the bubble will always be in focus and will appear to move *with* the sun or star if the instrument should rock in the hand — this enormously facilitates observations. [5]

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[5] Wimperis, *Primer,* p. 85. Wimperis also described the basic R. A. E. design in his communication on "Navigational Equipment for Long-Distance Flights" presented to the 2nd International Congress of Aerial Navigation held in London in 1923. See *Report* of this congress (London, 1923), pp. 756-764, at pp. 761-763. In his paper read before the Royal Aeronautical Society on April 30, 1919, Wimperis provided very little information on sextant developments, pos-

In his paper on instruments for air navigation read before the Royal Geographical Society on May 10, 1920, and published in the November 1920 number of *The Geographical Journal*, G. M. B. Dobson of the R. A. E. described the "R. A. E. Bubble sextant, Mark II", obviously an improved version of the earlier model. He pointed out that the same principle was contained in the French Favé sextant. [6] He, like Wimperis, stressed the curvature of the bubble chamber:

> ... By suitably arranging the radius of curvature of the bubble lens and the focal length of the collimating lens, the image of the bubble and the sun can be made to remain coincident however the instrument is tilted (provided the bubble does not touch the side of its cell)...

The Mark II introduced the concept of a flexible diaphragm in connection with the bubble cell so that the size of the bubble could be adjusted by a screw. Neither the Mark I nor the Mark II provided for observation of the natural horizon; they would have been almost useless in a downed plane bobbing on the surface of the sea, like the *NC-4* off Cape Cod and the *NC-3* among the Azores.

The spherical level of uniquely matched radius as distinguished from the tubular one (toroidal form) of

sibly because security was involved: "Air Navigation: The Most Important of the Unsolved Problems Relating to Aviation", *Aeronautics: A Weekly Journal Devoted to the Technique of Aeronautics,* London, XVI (January-June 1919), 482-487.

[6] The Favé sextants were manufactured by the Établissements Lepetit, predecessors of the present Établissements Roger Poulin of Montrouge (Hauts-de-Seine). The present-day Poulin sextants are strictly for marine use and are not equipped with an artificial-horizon attachment.

arbitrary radius rendered the use of the bubble sextant relatively easy and is consequently a feature of all modern bubble sextants. The instructions which accompany my Pioneer Type 3014-2-A — essentially those contained in H. O. 216 — stress that the bubble and body can be juxtaposed anywhere in the field along the vertical center guide line (as in Figure 17, A, B, and C), or slightly to the left or right of the vertical line (D and E), but not far to the left or right (F). In the figure, the larger of the juxtaposed circles is the bubble.

In the technical literature, the R. A. E. sextant is also known as the "Booth sextant". [7] Undoubtedly, Lionel Barton Booth, for many years on the staff of the R. A. E., was one of the British experimenters referred to by Alexander Hughes who had developed the bubble chamber but had not patented the device. In any event, on October 27, 1919, he and the Superintendent of the R. A. E., William Sydney Smith, applied for a patent on the original sextant design. The design was given the provisional number 26,291/19 and eventually the definitive number 159,540. [8]

The R. A. E. sextant came to be marketed by Henry Hughes & Son. A series of models ensued. As already noted, Dobson referred to the Mark II in May 1920.

[7] Beij, p. 284; on p. 292 he discusses other British experiments with bubble sextants in the air over the years 1919-1920. See also P. V. H. Weems, *Air Navigation: First Edition* (New York & London, 1931), p. 389; Weems 1937, p. 291; and Hughes, *History,* p. 119.

[8] The history of the Plath firm, *C. Plath 1862-1962* (Hamburg, 1962), refers to the Booth patent as being dated October 27, 1919; see p. 119 of the German edition, p. 112 of the English. The patent specification states that the complete specification was left on July 27, 1920, and accepted on February 28, 1921.

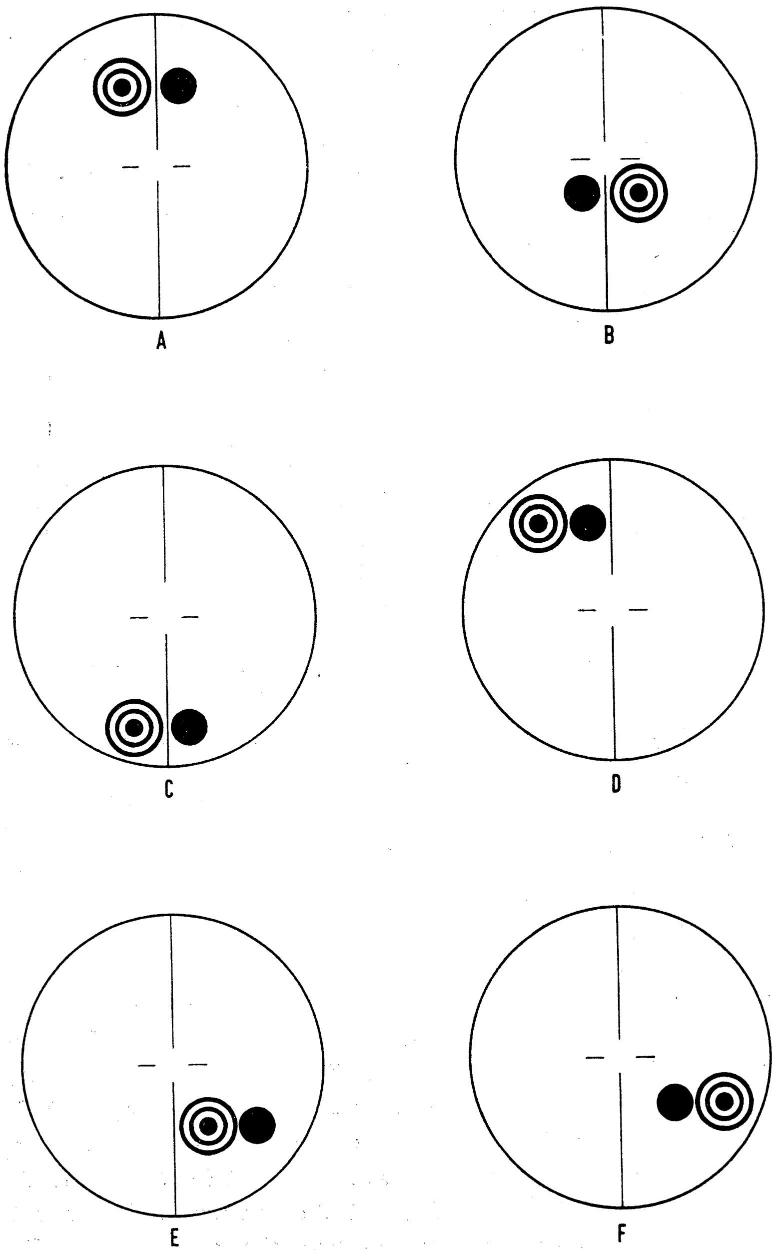

Figure 17

The Science Museum in South Kensington received the original Mark V in 1922, but as it bore the provisional and not the final patent number it clearly existed in 1921.[9] This model contained an adjusting screw to regulate the size of the bubble and also provision for observing the natural horizon. It was mentioned in the Hughes catalogue for 1925 as the Booth Sextant with Artificial Horizon, its price 32 pounds.

Booth described the Mark VI at the 1926 optical convention in London. This instrument represented an entirely new design, a reversion to the standard marine type of sextant. The adjustable bubble unit was identical with that of the Mark V but in the Mark VI could be rotated out of the way to permit use of the sextant with the natural horizon.[10]

Sacadura Cabral went to London in the fall of 1921 to be present during the construction of his transatlantic Fairey. While there, he was in constant correspondence with

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[9] Lionel Barton Booth, "The Aerial Sextants Designed by the Royal Aircraft Establishment", *Proceedings of the Optical Convention 1926*, Part II (London, 1926), pp. 720-728. See photograph of the Mark V facing p. 723. The Smithsonian Institution possesses an R. A. E. Mark V; the National Air Museum Catalog Card which describes it states that it was in service in 1921. The Science Museum, South Kensington, displays its Mark V with a card which states: "This is the first R. A. E. Mark V Sextant, produced in 1921. This type was used by many famous aviators from 1926 until about 1939".

[10] Brit. Pat. Spec. 193,638 (1923); application date February 2, 1922 (no. 2951/22). For the R. A. E. Marks V and VI as well as the Fleuriais, Baker, and Willson sextants, see C. J. Stewart, *Aircraft Instruments* (London, 1930), pp. 205-209.

Gago Coutinho, whom he often addressed affectionately as "Meu caro Ex-Chefe". On November 11, Cabral wrote that, the day before, he had seen an artificial-horizon sextant which was shaped like a doll (*boneco*), one, he implied, which could also be used with the sea horizon. On November 26, he sent his ex-chief — a reference to African surveying days — a description of the sextant and the price, 36 pounds, with three exclamation points. On December 11, he wrote that he still had not had time to bother with the sextant but that he probably would not buy it as it did not seem to be worth the money. Clearly, Cabral, an expert in optical instruments, had seen the R. A. E. Mark V sextant and had found it inferior to Coutinho's for the particular flight he envisaged.

Cabral was first and foremost a career line officer of the Portuguese Navy, thoroughly trained in marine navigation, and a specialist in hydrographic and terrestrial surveying. Planning his transatlantic flight, he foresaw that he would fly low, as on the flight to Madeira. He therefore wanted above all a reliable marine sextant of a type familiar to him, all the more as at this point there still existed the possibility that he himself would do the astronomical navigation while a relief pilot (Ortins Bettencourt) flew the plane. He did want a reliable artificial horizon available on the sextant for emergencies, but one that was rather an unobtrusive attachment than the core of the sextant's design. Therefore, the sextant which, at his suggestion, Coutinho had designed appealed to him far more than the doll-shaped instrument the R. A. E. had designed and the Hughes firm had manufactured. In his meeting with Arthur J. Hughes already referred to, he may well have outlined these specific requirements and conclusions.

It seems clear that the *Plus Ultra* left Spain in January 1926 with the Mark V, which Ruiz de Alda used, and also with a Mark I or Mark II which he kept in reserve.

Very precise information is available concerning Pinedo's sextant, the R. A. E. Mark V manufactured by Hughes, an instrument to which Pinedo referred as "il Booth inglese". Arthur J. Hughes visited Pinedo and Del Prete at Lake Maggiore in 1926 and watched them experiment with the sextant. He derived considerable satisfaction from the visit, for, as he later wrote, "in those days it was hard work to get anybody to use the bubble sextant".[11] In his own book, Pinedo, who numbered freehand drawing among his accomplishments, included an amusing sketch of Del Prete observing with the Mark V and another showing how they took their astronomical observations. Both are reproduced here as Figure 18.

For the flight of the Brazilian *Jahú*, Newton Braga settled on a Hughes "Booth" sextant which cost him 36 pounds. There is no doubt that this is the Mark V, for he published a picture of it in his book. And it would seem that Hughes was charging Portuguese and Brazilians a price slightly above that asked of his English customers.

THE AMERICANS

Even before the end of World War I the Americans were facing up to the new challenge of air navigation, and the National Advisory Committee for Aeronautics

[11] Hughes, *History*, pp. 48-51, with picture of the Mark V.

served as the official coordinating agency. In its fourth annual report, for 1918 and published in 1920, the N. A. C. A. noted concerning new instruments:

Constant efforts have been made to obtain information concerning the airplane instruments developed in foreign countries, and in

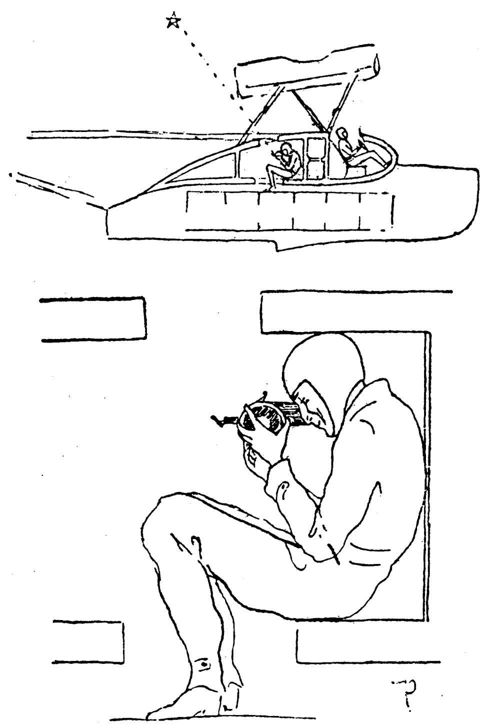

Figure 18

a number of cases actual instruments have been obtained. These have been tested, and the results, if favorable, have been transmitted to the proper military authorities.

Continuous correspondence has been carried on with French and British experts and investigators in order to keep in touch with

developments in Europe, especially with reference to long-distance operations.[12]

In its seventh report, for 1921 and published in the same year, the N. A. C. A. indicated that it was casting its net very far afield:

The Department of Commerce has, on request of the committee, instructed its commercial attachés and trade commissioners in England, France, Italy, Germany, and Holland to obtain reports and current information on developments in commercial aviation and forward same to this country for the use of the committee. Consular officers of the State Department, in all countries where any aeronautical activities exist, have been similarly instructed by the State Department. All the information that is received by the National Advisory Committee for Aeronautics is recorded in the committee's Office of Aeronautical Intelligence, and in this way becomes promptly available to the members of the committee and the governmental agencies concerned. If the information is not confidential, it is also made available to aircraft manufacturers.[13]

By 1928 the N. A. C. A. realized what a hornet's nest had been opened within the United States:

During the past year the attention of the committee has been invited to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, particularly in the fields of navigation instruments, aerial communications, and meteorological problems. It is the function of the Department of Commerce to provide aids to air navigation, but the coordination

[12] *Fourth Annual Report of the Nationl Advisory Committee for Aeronautics 1918* (Washington: Government Printing Office, 1920), p. 16.

[13] *Seventh Annual Report of the National Advisory Committee for Aeronautics 1921*, p. 27.

of fundamental scientific research on the problems of air navigation falls within the scope of the functions of the National Advisory Committee for Aeronautics as stated in the act establishing the committee... [14]

In August 1928 the N. A. C. A. organized a new standing committee on problems of air navigation, with Colonel Charles A. Lindbergh as a member. Three subcommittees were set up, on problems of communication, on instruments, and on meteorological problems. With standing committees and subcommittees, and with the fingers of many Government agencies in the pie, the fun years were clearly over, the Age of Pioneering Transoceanic Air Navigation. Back in 1918 they were just beginning.

The March 1918 number of the *Proceedings* of the United States Naval Institute, published in Annapolis, Maryland, contained an article by George W. Littlehales on the use of charts in air and marine navigation. [15] Littlehales proposed the use of a polyconic, and not a Mercator, chart for astronomical navigation in order that very long intercepts — up to hundreds of miles — might be plotted without distortion. He further proposed the use of precomputed altitudes and azimuths from a single assumed position for every four minutes of hour angle, that is, hour angle expressed in time and not in arc.

[14] *Fourteenth Annual Report of the National Advisory Committee for Aeronautics 1928* (Washington: Government Printing Office, 1929), p. 10.

[15] George W. Littlehales, "The Chart as a Means of Finding Geographical Position by Observations of Celestial Bodies in Aerial and Marine Navigation", *Proceedings,* United States Naval Institute, Annapolis, XLIV : 181 (March 1918), 567-584.

The navigator would take his sight, determine his sextant altitude, compare it with the precomputed altitude, draw his intercept line from the assumed position toward or away from the observed body along the precomputed azimuth, and draw his LOP perpendicular to the intercept line at the point corresponding to the amount of the intercept. Littlehales even included a chart of the entire United States with a single assumed position at 39° N, 97° W (a little west of Topeka, Kansas), a series of radii extending to all borders to serve as azimuth lines, and a series of circumferences spaced 60′ apart with ticks for every 10′ to facilitate plotting the intercept. Amazingly, Coutinho, who I doubt very much ever saw this article, proposed, and used in 1922, a method of sight reduction and plotting which was similar to Littlehales'.

And then in the August 1918 number of the same volume, Littlehales wrote on artificial-horizon instruments. [16] He began with the year 1733, when John Hadley reported having mounted a sensitive spirit level on a graduated quadrant to act as an artificial horizon. He also gave details of the "Speculum" or separate artificial horizon of the mid-eighteenth century, and of the Fleuriais gyrsocopic horizon sextant developed at the end of the nineteenth century and improved at the beginning of the twentieth.

[16] George W. Littlehales, "The Search for Instrumental Means to Enable Navigators to Observe the Altitude of a Celestial Body when the Horizon is not Visible", *ibid.,* XLIV : 186 (August 1918), 1801-1817.

ROBERT WHEELER WILLSON

The June 1919 number of the *Publications of the Astronomical Society of the Pacific*, a magazine which Coutinho could not possibly have known, carried a most important article by Professor Henry Norris Russell of Princeton University. On air navigation and dated Princeton University Observatory, April 22, 1919, it is a preliminary report of experiments conducted at Langley Field, Hampton, Virginia, between August 1918 and January 1919 for the Army Air Corps with the collaboration of the Naval Air Station at Norfolk.[17]

First, a separate artificial horizon mounted on gimbals and movable from one side of the plane to the other was used in conjunction with a marine sextant, and the ensuing "double altitudes" were halved. The method proved unsatisfactory.

Russell himself then tried a sextant with artificial-horizon attachment, one developed, *mirabile dictu*, by Robert Wheeler Willson, Professor of Astronomy at Harvard University.

Willson (1853-1922), born in West Roxbury, Massachusetts, was brought up in, and attended the public schools of, Salem, an old New England port city famed for its connections with Macao and Canton in the early nineteenth century. As his biographer suggests, "His constant association with the port of Salem during the impressionable years of his career doubtless early instilled that fondness for things nautical which he kept through

[17] Henry Norris Russell, "On the Navigation of Airplanes", *Publications of the Astronomical Society of the Pacific*, XXXI : 181 (June 1919), 129-149.

life, and which, later in his career, was to lead his attention to the application of Astronomy to Navigation and the development of improved instruments and methods in this cause". Willson received the A. B. degree from Harvard in 1873 and the Ph. D. from Würzburg in Germany in 1886. A few years later he began to teach astronomy at Harvard and in 1903 became a Professor, retiring in 1919.[18]

Willson's great interest lay in teaching — which he deemed equal in importance to research — and in developing apparatus to aid in teaching, and this orientation led to such a publication as the section on "Determining Position by Astronomical Observations" included in the Harvard Travellers Club's *Handbook of Travel.*[19] As early as 1894 he made a bubble sextant for marine use.[20] Beginning in 1910, his interest aroused by an aviation meet in the Greater Boston area, he turned his attention to air navigation. He also devoted the later years of his career to the Mayan calendar. After his death, Mrs. Willson established a fund the net income from which is "to

[18] Harlan T. Stetson, "Robert Wheeler Willson", *Popular Astronomy,* XXXI (1923), 308-313. See also Samuel Eliot Morison, *The Development of Harvard University Since the Inauguration of President Eliot 1869-1929* (Cambridge, Massachusetts, 1930), pp. 304-305, with photograph facing p. 306.

[19] Harvard Travellers Club, *Handbook of Travel* (Cambridge, Massachusetts, 1917), pp. 281-339. For the second revised and enlarged edition, edited by Dr. George Cheever Shattuck (1935), a new chapter by Weld Arnold entitled "Determination of Position" was included (pp. 269-279) with excerpts from Willson's chapter in the first edition.

[20] John Q. Stewart & Newton L. Pierce, *Marine and Air Navigation* (Boston, 1944), p. 395.

be used to support a professorship of applied astronomy including navigation, at the College itself as distinguished from the Astronomical Observatory". According to her conditions, the teaching of the Robert Wheeler Willson Professor of Applied Astronomy "shall be done for the most part by laboratory methods and not by lectures". His three surviving sisters established a Robert Wheeler Willson Scholarship Fund in Applied Astronomy, still very much alive. The most recent Harvard College financial aid booklet contains a complete outline of the conditions of award.

Russell writes of the bubble attachment which Willson designed for the marine sextant:

> ... it is an attachment to the telescope of an ordinary sextant, containing a level bubble moving freely on the under side of a spherical surface, and an unsilvered mirror inclined at 45° to the axis of the telescope, which reflects this bubble into the field of view. By an ingenious adaptation of the optical system, it results that a distant object which appears to be superposed on the center of the bubble will actually be on the true horizon, no matter at what point in the field of view both may appear to be.

Russell concludes: "On the whole, observation is decidedly easier with the bubble sextant than with the [separate] artificial horizon, and it is a great advantage to have but a single self-contained instrument to work with". He refers to Littlehales' article of March 1918 and points out that more than a thousand sights on sun, moon, and stars have been made during this investigation from airplanes and seaplanes of nine different types.

James Percy Ault of the Carnegie Institution of Washington's Department of Terrestrial Magnetism did the Langley Field work with the separate artificial horizon, under Russell's direction, between August and

December 1918. He also attempted observations using cloud and haze horizons. He himself apparently never used the Willson artificial-horizon sextant. For sight reduction he used the most satisfactory tables available to him, those by the Brazilian Radler de Aquino, included the year before by the U. S. Navy in H. O. 200.

Ault wrote up a supplementary and more detailed report published by the Carnegie Institution in January 1926. [21] At its end he mentioned Russell's experiments with Willson's bubble. His over-all conclusion, which he expressed as a reply to a question army officers asked him when he returned to Washington, was that the successful method of navigating aircraft in the future would be provided by radio. "Navigation of aircraft by astronomical methods, which these reports show is practicable and feasible", he declared, "is too slow and uncertain to be relied upon for future aerial development".

In his effort to emphasize speed, Ault quotes Russell on precomputation.

> ... Doctor Russell has outlined a method where the calculations are made previous to a flight, when the objective and time are known. Special tables are prepared and the altitudes and azimuths calculated

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[21] James Percy Ault, "Navigation of Aircraft by Astronomical Methods", in J. P. Ault *et al., Ocean Magnetic and Electric Observations, 1915-1921* (January 1926), which is Vol. V of *Researches of the Department of Terrestrial Magnetism,* which in turn is Publication No. 175 of the Carnegie Institution of Washington, pp. 315-337.

Bradley Jones included the following dedication in his *Avigation* published in 1931: "To J. P. Ault, Master of the *Carnegie,* whose work with the sextant at Langley Field in 1918 was the beginning of American astronomic avigation. A brave scholarly gentleman who perished with his vessel in 1929".

for different assumed positions and times. This method will give a position-line in 2 minutes of time, including the observation when a natural horizon is used and in 7 minutes when an artificial horizon is used.

To demonstrate to Portuguese readers, whose scholarly compatriots are fond of stressing *prioridades*, that some Americans are not above claiming firsts, Ault reported the following episode, also recounted in Russell's article:

> The first known instance of an airplane pilot being informed of his position by astronomical methods should be recorded here. During my flight to Washington from Langley Field September 23, 1918, the visibility was very poor. The pilot, Lieutenant Charles Cleary, wished to verify his position, so he slowed down and asked if the river below us was the Potomac. I had just completed drawing in position-line No. 5 (see my report of October 1, 1918), which intersected our track at the Potomac River, so I was able to inform him that my observations placed us at the Potomac River.

Russell also claimed a first. Referring to observations made on August 16, 1918, and January 10 and 11, 1919, he wrote:

> So far as is known, these are the first occasions on which astronomical observations sufficient to determine completely the position of an airplane have been made during flight. They were not actually worked out in the air, as the object at that time was mainly to test the instrumental possibilities, especially as regards accuracy.

From my association with British "Combined Operations" personnel just before and during the early years of U. S. participation in World War II, I am disposed to accept the notion that the British are courageous

innovators and bold experimenters. I find it difficult to believe that R. A. E. officers, who had developed the first model of their aircraft sextant before the flight of the *NC-4*, had not anticipated the Russell-Ault experiments in astronomical navigation. In any event, the Willson sextant, or octant, as it was called, was subsequently manufactured by Brandis & Sons, Inc., of Brooklyn, N. Y., and became widely known in world aeronautical circles.

Brandis soon became associated with the Pioneer Instrument Company, which began in 1919, and eventually Pioneer became the parent company of Brandis. In 1929 the expanding Pioneer became a subsidiary of Bendix Aviation Corporation, as did the firm known as the Eclipse Machine Company. In 1939 Pioneer joined forces with Eclipse and in 1943 they became known as the Eclipse-Pioneer Division of Bendix. Today this division is called the Navigation & Control Division of the Bendix Corporation and is located in Teterboro, New Jersey.

In the Smithsonian Institution I have examined four Brandis octants, each with its Willson telescope. The oldest, manufactured in 1921 if not earlier, is a conventional sextant with the Willson bubble attachment positioned vertically above the telescope. The bubble chamber itself is missing. The telescope may be identified in photographs by the location of the knob for forming and adjusting the size of the bubble, which is on the bottom side of the telescope. [22]

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[22] National Air Museum Catalog Card, Acc. No. NAM 924, Cat. No. 1957-637, received November 10, 1956, from Bureau of Standards of Department of Commerce. See also H. N. Eaton, "Aerial

The next two are both labeled Aeronautical Octant Mark 1 Model 3 and are dated by the Smithsonian Institution as "1924 Service".[23] The fourth is labeled Aeronautical Octant Mark 1 Model 4 and is dated by the Smithsonian Institution as "1931 Service".[24] These models are left-handed, a distinctive feature of the Plath production model of Coutinho's "precision astrolabe" as manu-

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Navigation and Navigating Instruments", N. A. C. A. Report No. 131, included as an appendix to the *Seventh Annual Report of the National Advisory Committee for Aeronautics 1921,* p. 29 and Figure 16B, and Beij, pp. 283-284 and Figure 8.

An early model of the Willson bubble sextant was well known to Wimperis, who refers to it in his *Primer*, p. 85. In his communication on navigational equipment presented to the London congress of 1923, p. 763, he specifically mentions the provision in the Willson sextant, as in the R. A. E. sextant, "to ensure that the image of the bubble and the heavenly body shall keep together in the field of view, once the sextant had been set to the correct angle, despite any oscillation or tilting of the instrument inseparable from its use in aircraft".

We have already seen how Pinedo considered the Willson sextant when planning his flight of 1927.

See also H. N. Eaton, "Aerial Navigation", *U. S. Air Service,* VIII : 9 (September 1923), 37-40, VIII : 10 (October 1923), 39-44, and VIII : 12 (December 1923), 45-47.

[23] National Air Museum Catalog Card, Acc. No. NAM 924, Cat. No. 1957-296, received November 10, 1956, from Bureau of Standards of Department of Commerce, manufacturer's no. 206B-40, U. S. N. Serial 20-29; National Air Museum Catalog Card, Acc. No. NAM 1351, Cat. No. 1963-73, transferred from U. S. Naval Observatory, manufacturer's no. 206B-39, U. S. N. Serial 19-29.

[24] National Air Museum Catalog Card, Acc. No. NAM 924, Cat. No. 1957-388, received November 10, 1956, from Bureau of Standards of Department of Commerce, manufacturer's no. 206C-109, U. S. N. Bureau of Aeronautics Serial 15-31.

factured beginning at the end of 1926 (see Chapter 10). Model 3 (manufacturer's no. 206B-50) is illustrated in the first edition of Weems's *Air Navigation* (1931) and in a 1930 Pioneer catologue entitled *Pioneer Marine Instruments of Aircraft Quality and Precision.* The original photograph is reproduced here as Plate IV.

The Pioneer publication provides a detailed description of the "Brandis Octant" with "Willson Bubble Telescope, a patented feature found only in Brandis instruments", and affirms the following:

> ... The Octant is designed to be held in the left hand so as to leave the right hand free to write down the time and the observed altitude. This feature, which might seem awkward to those who are already accustomed to the use of the orthodox right-hand instrument, is indeed very convenient. The habit of observing with a right-hand [*sic* for left-hand] instrument is no handicap whatever except perhaps, in the first two or three observations.
>
> It is indeed amazing that nobody ever thought before of making a sextant for the left hand so as to avoid the necessity of putting down the instrument or changing hands every time an observation had to be noted. The change of design from right to left was first proposed four years ago by the Bureau of Aeronautics of the United States Navy, and it has now met with general approval.

Clearly, the "four years ago" dates from earlier than the year of publication of this particular catalogue.

Both Model 3 and Model 4 read from — 5° to + 105°. Both are provided with a simple sighting tube without lens. The Model 3 has a fixed shade at an angle above the horizon glass; this feature was eliminated from Model 4. On both models a white celluloid writing card with columns headed "Time" and "Altitude" is affixed to the outside of the handle; it swings out to the left to permit inserting a battery in the handle to illuminate the scale and the bubble. On the Model 4 the three legs are cleverly placed on the telescope-arm-scale side to permit resting the instrument on a flat surface with the handle and consequently the writing card facing up. Model 3 has a suspension ring on the handle side, eliminated from Model 4.

The Willson telescope can be attached and pushed all the way to the left so that the observer sees only the silvered or left portion of the horizon glass, or it can be only partially inserted to permit seeing both the silvered half and the clear half of the horizon glass. Model 4 has a rubber cup over the eye end of the telescope to keep out extraneous light. Model 4 is provided with two sun filters of two different strengths for screwing over the far end to reduce the light and render the bubble more visible. On the Model 3, the only sun filters provided — other than the conventional sets of shades — screw over the near end of the sighting tube and the telescope. The telescope itself is inverting and focuses by pulling out on the eye end. [25]

The bubble attachment, above the eye end of the telescope, contains a screw on the right side for regulating the bubble. Immediately above the bubble chamber is an iris diaphragm similar to a camera's; moved by a knob protruding on the outside, it controls the amount of light which enters the chamber from above in daylight use. For night use, a lamp chamber is screwed into place above the iris and is connected by a wire to the battery in the handle.

[25] C. J. Stewart, p. 209, writes of the Willson sextant: "The use of this instrument is rather more difficult than that of the instruments previously described owing to the much reduced eye freedom in using a telescope, which, for air use, is generally considered unnecessary".

Other aircraft sextants were developed in the United States during the early and mid 1920's and are described in detail in the first edition of Weems. The Bureau of Standards-type sextant was originally developed between 1917 and 1921 by K. Hilding Beij at the Bureau of Standards for the U. S. Navy. Bausch and Lomb of Rochester, New York, produced Model A in 1924, Model B in 1929, and Model C in 1930. [26] The Darad sextant was devised by Lieutenant Commander Noel Davis and Lawrence Radford in 1927 and later manufactured by Keuffel and Esser of Hoboken, New Jersey.

BYRD

A question will at once occur to the reader: what was Byrd's connection with the Willson sextant, the Langley Field experiments, Russell, Ault, and the Brandis firm?

The available literature reveals a cleavage, a divorce. On the one hand — and including the books by Wimperis and Pinedo — we hear of the Willson sextant. In Byrd's autobiographical *Skyward*, on the other hand, and in the biographies of him, and in *New York Times* stories which could well have been inspired by U. S. Navy releases, we

[26] It is curious that Beij made no mention of this sextant in his report published in 1925. An example of the 1924 model is in the Smithsonian Institution's National Museum of History and Technology. According to a most informative letter from Mrs. Frances Hainer, the Museum's secretary, it comes from the Weems collection (accession group 242-229), is identified as Model No. 2, Serial No. 4, and was one of six made under patent and used by Lincoln Ellsworth, Byrd, and Lindbergh. In the same accession group is an early Willson sextant and a Byrd sextant, both made by Brandis.

never hear of the Willson sextant but only of the Byrd sextant.

That there were two different sextants there is no doubt. The Byrd sextant (Plate II) was widely described in both the popular and technical literature of the day. It contained a tubular spirit level mounted on a bracket below and beyond the horizon glass, as in both the home-made and production models of Coutinho's sextant and in later "Husun" and "KH" marine sextants equipped with artificial-horizon attachment, and unlike the Willson sextant and the latest production model of the Plath marine sextant with artificial-horizon attachment (in both of which instruments the bubble is above the telescope).

A 1924 description of the Byrd sextant explains:

> ... A plane mirror reflects an image of the bubble tube through the clear half of the horizon glass to the telescope, which is provided with an extra lens, semicircular in shape, to bring the bubble tube into focus. Adjusting screws are provided for setting both the bubble tube and the plane mirror. If it is desired to use a natural horizon, the plane mirror may be unclamped and swung downward out of the way. Illumination is provided for the bubble and the scale; the battery and switches are mounted in the handle. [27]

A 1921 description provides additional information:

> The bubble is contained in an ordinary spirit-filled tube set into the metal tube..., which is mounted rigidly to the frame. For day observations, the light entering through the bottom of the tube is sufficient to make the bubble visible to the observer...

[27] Beij, p. 283; his Figure 7 is of the Byrd sextant. See note 3-7 for the photograph in Byrd's *Skyward*. For a 1927 picture of Coutinho and a Byrd sextant, see Pinheiro Corrêa, *Gago Coutinho* 1969, facing p. 305.

> With this instrument, the images of the bubble and the celestial body move in the same direction when the sextant is inclined longitudinally. [28]

Curiously, neither of the official reports just quoted mentions Byrd's name in full nor does it credit him specifically with the design of the instrument beyond using the phrase "Byrd sextant". They both affirm that the sextant was "developed by the United States Navy".

Nor do these reports make clear that the bubble was apparently in a tubular spirit level of arbitrary radius and therefore necessitated the triple juxtaposition mentioned at the beginning of this chapter. Weems pointed out this defect in no uncertain terms in the first edition of his manual:

> This is one of the earliest types of bubble sextants. It was developed between 1916 [!] and 1918 by Rear Admiral R. E. Byrd, U. S. Navy, and consists of a spirit-level attachment mounted on an ordinary marine sextant. It necessitates bringing the observed body into coincidence with the bubble when the bubble is at the crossmark. Bringing three objects together simultaneously is naturally more difficult than bringing two into coincidence, and it is in this feature that most of the later-type sextants can justify a claim to superiority.

Lionel Barton Booth and Robert Wheeler Willson, working simultaneously yet independently, provided a solution to the problem, namely, the spherical level of uniquely matched radius. [29]

[28] Eaton, p. 28; his Figure 16A is of the Byrd sextant.

[29] I confess that I am uncertain as to whether the Byrd tubular level is of arbitrary radius or uniquely matched radius. The published literature is contradictory, and I have not yet been able to see a Byrd instrument. Jones in his *Avigation,* pp. 41-42, describes an artificial-

Except for a single fact revealed by *Skyward*, it would be easy to conclude that Russell, Willson, Ault, and company represented the army, that is, the Army Air Corps, and Byrd the navy, and that the two deliberately kept apart, as army and navy were to continue to do, unfortunately, into and through World War II. The disturbing element to the theory is Littlehales, a naval officer associated with the army development. Or, at least, Russell and Ault quoted Littlehales, who could not have been unaware of what they were doing and who shortly thereafter saw his horary tables published by the U. S. Navy Hydrographic Office (today the U. S. Naval Oceanographic Office). Telling of the furious activity of the Transatlantic Flight Section in preparation for the flight of the *NC*'s, Byrd relates how "Mr. G. W. Littlehales of the Hydrographic Office, a mathematical genius, evolved for us a short method of navigation". Later, telling of a method of plotting he used en route to the north pole, Byrd adds: "This method was taught me by G. W. Littlebales [*sic*] of the Navy Hydrographic Office and was first discovered by Arthur Hinks of the Royal Geographic Society".

Littlehales published his article on plotting in March 1918, before Byrd had earned his wings, so it does not seem likely that he evolved the method for "us", although he could have evolved it for transatlantic air delivery of U. S. Navy bombers and kept the purpose a deep, dark secret. In any event, working with Byrd in the late winter or early spring of 1919, he could not have failed to mention the Willson sextant, or so it seems to me.

horizon sextant. His drawing, which fits the text, appears to depict the Byrd sextant; it shows an auxiliary mirror behind the horizon glass and a curved spirit level.

The one hypothesis which fits the Weems and Jones and the Coutinho and Castilho evidence and also the information sent me from the Smithsonian Institution would hold that the tubular spirit level is curved in such a way as to bring the bubble to the crossmark when the sextant is horizontal (that is, of arbitrary radius) and not curved with the proper radius to enable juxtaposition of body and bubble regardless of the position of the sextant (that is, of uniquely matched radius). Admittedly, this hypothesis contradicts the statement made by Eaton. Or else more than one model of Byrd bubble tube circulated!

GAGO COUTINHO

The *NC-4*'s successful crossing of the Atlantic from Newfoundland to Lisbon via Horta and Ponta Delgada in May 1919 confirmed Cabral in his desire to fly from Lisbon to Rio de Janeiro. Aware that a formidable navigational problem confronted him, he at once asked his ex-chief of African geodetic days to design an artificial-horizon sextant and to ponder the most expeditious way to reduce the sights taken with it.

Coutinho carried out the first part of his mandate in exactly the way one would expect his years as marine navigator and terrestrial surveyor to have dictated. No amateur tinkering around in his home workshop, he possessed a solid background in mathematics and astronomy. He was thoroughly familiar with compasses, map projections, and the problems of magnetism, and of course with lenses, artificial horizons, and the principles of reflection. He produced the instrument diagrammed doubly in Figure 19 and promptly named it the "precision astrolabe" *(astrolábio de precisão)*. It is today in the Naval

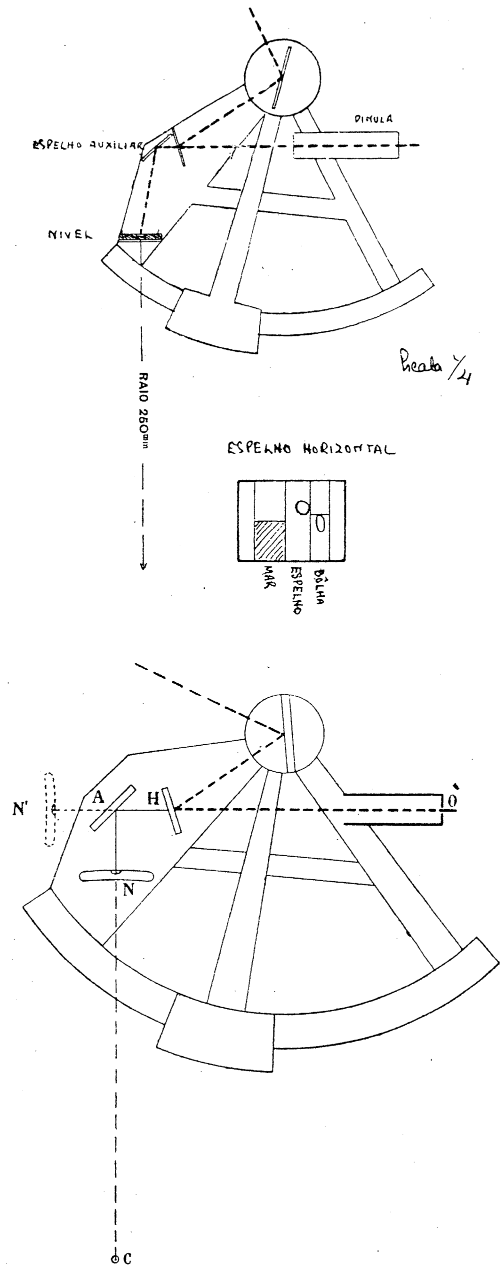

Figure 19

Museum, Belém, along with the Coutinho-Cabral course corrector and the hydroplane *Santa Cruz;* see Plate V. This is the very sextant which provided the LOP's by which Coutinho navigated the *F.3-4018* to Funchal in 1921 and the *Lusitânia* and two successors to Brazil in 1922.

Coutinho modified slightly the horizon glass *(espelho horizontal)* of a standard marine sextant, added an auxiliary mirror *(espelho auxiliar)* behind the horizon glass at such an angle as to throw into the observer's field of view the image of a bubble in a tubular spirit level *(nível)* placed beneath the auxiliary mirror, and substituted a simple sighting tube *(pínula)* for the telescope. Looking through the sighting tube, adequate for planets and first-magnitude stars as well as for sun and moon, he could see three items instead of the usual two: (1) the horizon of the sea *(mar)*, if visible, in normal fashion through the left or clear glass portion of the horizon glass; (2) the image of the celestial body in normal fashion in the silvered center portion *(espelho)* of the horizon glass; and (3) the image of the bubble *(bôlha)* in the auxiliary mirror as seen through the unusual clear portion at the right side of the horizon glass. At night the bubble could be perceived by the light of a tiny electric bulb.

An essential feature of the design was the proper curvature of the bubble tube, so that the sextant could be tilted longitudinally and the images of bubble and body remain in coincidence. And coincidence could be effected by bringing the image of the body either alongside or inside the image of the bubble. Coutinho was able to calculate the precise amount of the curvature that was required, a radius of 250 mm, equal to the distance from the peep hole at the eye end of the sighting tube to the image of the bubble in the auxiliary mirror. His admirers always felt that this fundamental principle, this *princípio genial*, was a manifestation of his genius and his great contribution to sextant design.

As noted in the preceding chapter, the Portuguese "precision astrolabe" was tested during July and August 1919. In its issue of September 22, 1919, *O Século* published a lengthy article on the instrument and included a version of the drawing reproduced here as the upper diagram of Figure 19. A portion of that article, including the drawing, was republished in a special supplement to the February 17, 1969, issue of *O Século* as a contribution by that newspaper to the celebrations occasioned by the centennial of the Portuguese naval officer's birth.

For the more specialized reader, Coutinho contributed to the August-September 1919 number of the *Anais do Clube Militar Naval* an article, dated September 16, 1919, describing his design in detail. The upper diagram of Figure 19 is reproduced from this article. [30]

By permitting publication of these two descriptions, the generous officer recognized that his invention would henceforth lie in the public domain. He never wanted to patent it, to "render it privileged", as a literal translation of the equivalent Portuguese expression would read.

[30] Gago Coutinho, "Novo sextante com horizonte artificial", *Anais do Clube Militar Naval,* L: 8 & 9 (August & September 1919), 364-374. This article was reprinted in Aero Clube de Portugal, *Viagens Aéreas,* pp. 31-34.

The article of September 16 stressed several important points:

(1) Its author had considered a spherical level (as in the R. A. E. and Willson sextants, neither of which he had seen). He had preferred his own design because of its simplicity and the sufficiency of its accuracy for the purposes envisaged.

(2) A reference line was included on the level, one which was absolutely unnecessary because of the uniquely matched radius of the tubular level.

(3) Because of inevitable changes in the length of the bubble due to fluctuations in ambient temperature, observations must be made in pairs against the two extremities of the bubble and then averaged. The upper diagram of Figure 19 illustrates the lower limb of the sun opposite the upper extremity of the bubble. An opposite sight — of the upper limb of the sun opposite the lower extremity of the bubble — would, when averaged with the first sight, eliminate the need for a correction for semidiameter.

(4) The introduction of a telescope instead of a sighting tube would needlessly complicate the instrument, for a collimating lens would have to be introduced into the system. Such a lens would be necessary in order for the navigator to focus simultaneously on the image of the bubble, some 250 mm away, and on the celestial body, hundreds of thousands if not millions of miles away.

Among Coutinho's papers examined after his death is a succinct autograph description of the sextant in French dated Lisbon, October 20, 1919. It is not known for whom its author intended this paper, which actually adds little new information.[31]

Coutinho also left unpublished a lengthy article in Portuguese on technical details of air navigation. Dated Lisbon, July 1920, it was destined for a journal outside of Portugal but did not appear because of a change in the publication's management.[32]

In this long study, Coutinho discusses acceleration error, and as solutions he repeats the suggestions contained in the article dated September 16, 1919: careful steering on the part of the pilot (who should alter course temporarily in the direction of the celestial body to be observed) and taking the average of a series of sights.

Because of this acceleration error, he continues, it is not practicable to rock the artificial-horizon sextant in order to assure oneself of the exact altitude of the body. Therefore, all sextants which require rocking, such as the Fleuriais gyroscopic sextant, the Pulfrich pendulum sextant, and sextants equipped with a single tubular spirit level ("sextantes de nivel recto unico") are not strong candidates for employment in air navigation. At this point, however, he does not present any alternative to rocking.

In this study of July 1920, in which he even refers to the primitive Hadley octant and its sighting vane, Coutinho next points out how no such degree of precision

[31] This "Notice sur un sextant avec horizon artificiel" was first published in Júlio Gonçalves, "Travessia Aérea Portuguesa do Atlântico 1921 [*sic*]: O sextante de Gago Coutinho", Sociedade de Geografia de Lisboa, *Boletim,* LXXVII (1959), 417-420.

[32] This article is included in Pinheiro Corrêa, *Gago Coutinho,* pp. 221-232 of both editions.

is required in the air as at sea. He suggests that the observer forget about the semidiameter of the sun and moon and bring the center of these bodies down to the natural or artificial horizon in the manner normally done with planets. Lastly, he specifies that the sextant must have its own lighting for night work.

After alluding to the use of chronometers in flight, the writer passes to plotting. With reference to LOP's, he points out that in air navigation it is normally impossible to advance one LOP to cross it with a second for a running fix because the course and distance between the times of the two observations are not known with sufficient accuracy.

In this masterful treatise, Coutinho lists two reasons why latitude by meridian altitude of the sun cannot normally be determined. One concerns the speed of the plane, and therefore of the sextant, on any but an east-west course, in relation to the sun: the altitude as observed in the sextant changes more rapidly due to the movement of the plane than to that of the body. The other concerns the general lack of precision of altitude observations from a plane: it is not possible calmly to await the body's maximum altitude as from the bridge of a ship.

Nevertheless, it is possible to determine noon latitude, as he himself has done experimentally in the air, namely, by taking a large number of ex-meridian altitudes *(alturas circunmeridianas)*.

As for chronometers, he feels that two or three good pocket-type chronometer watches are sufficient, on condition that their rate *(marcha)* does not exceed one second per day. One of the chronometer watches should furnish sidereal time.

and, behind the artificial horizon, three horizon shade glasses.

When viewed through an eyepiece, the horizon glass appears as shown in Figure 20. It is approximately 32 mm

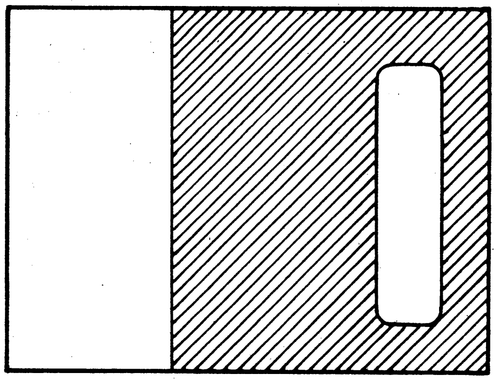

Figure 20

wide and 24 mm high. The silvering is today defective, so that the opening through which the longitudinal bubble is seen is not as clearly outlined as in the figure. I found no trace of the reference line *(traço de referência)* mentioned by Coutinho in his 1919 published description and in his unpublished account in French of the same year but not mentioned in the description which appeared in the *Anais* at the end of 1922. On the right side of the frame of the horizon glass, however, is a bracket with an arrow which, if it is properly placed, could conceivably serve as such a marker.

The longitudinal bubble tube lies below the triangular housing of the auxiliary mirror. The transverse bubble tube is located at the lower front end of the housing just behind the lower end of the horizon glass. I was unable to see the transverse bubble at the bottom of the vertical slit in the latter glass (which has no

horizontal slit across the width of the silvered portion), although I could see it distinctly through a round opening in the bottom of its tube. The transverse level, which acts in the capacity of an absolute level, is naturally much more sensitive than the longitudinal level, which must have a sensitivity specifically tailored to the sextant.

The longitudinal bubble tube contains a long, slit-like opening on its bottom in order for the bubble itself to be illuminated. Daylight is reflected into this opening by a movable reflector located beneath the bubble tube; the reflector swings up and down on an axis parallel with the tube.

For night observations, the handle is equipped to take batteries or else may be connected by means of two sockets at its bottom with an external power source. There is no switch labeled "Dark" and "Light" to control the intensity of the illumination. Two buttons on the back of the handle control this illumination. One serves the bulb on a small arm attached to the index arm; the bulb in the small arm swings over the length of the nonius. The other button serves the bulb placed just below the slit beneath the longitudinal bubble tube; the light of this bulb can be made to reflect from the movable reflector into the slit and thus illuminate the bubble from below.

The bracket for telescope *(luneta)* or sighting tube *(pínula)* has two sets of threads. The set to the right is designed to receive primarily the sighting tube, which, because of its inside position, permits the navigator to view the right part of the silvered portion of the horizon glass including the slit. The set to the left is designed primarily to receive the telescope, which, because of its outside position, permits the navigator to view the left part of the silvered portion and also the clear portion of the horizon glass. These two sets of threads correspond, in a very real sense, to the two peep holes in the fore sighting vane of the Hadley octant.

As already stated, I could not see the transverse bubble through the sighting tube. Through this tube in its inner or right position, on the other hand, I could easily see enough of the clear portion of the horizon glass to permit an observation by means of the natural or sea horizon.

The sighting tube can be screwed into either position. The telescope, which focuses by means of a push-pull tube at the eye end, can only fit into the left position (as depicted in Plate V), for its broad forward end strikes the sextant frame when an attempt is made to place it in the right position. It would be useless in the right position in any event, for no collimating lens is provided to enable the navigator to view the bubble and the distant celestial body simultaneously. The sighting tube cannot be placed in the right position when the telescope is in its seat to the left, for the latter interferes with the insertion of the former.

A screw-on eyepiece with a vertical slit containing a larger round opening at the top is available for the eye end of the sighting tube, possibly to diminish the amount of light hitting the eye. José María Aymat, on the other hand, states that its purpose is to render sights with the natural horizon more accurate by reducing the effects of parallax. [35]

[35] For Aymat's book, see note 10-12.

CHAPTER 7

Gago Coutinho and the Rapid Reduction of Normal Sextant Sights

In my view, members of the guild would have read Gago Coutinho's treatise on air navigation of July 1920 with avidity had it been published when written. The first portion of its text, outlined at the end of the preceding chapter, treats essentially of the artificial-horizon sextant required by the air navigator. The remaining portion is devoted to precomputation and to sight reduction. As Coutinho practiced during the 1922 transoceanic flight what he preached in mid-1920 — and subsequently came to refer to as his 1920-1922 doctrine — a summary of the 1920 theory will aid the reader in comprehending Chapter 9, which discusses the actual sights taken from the *Lusitânia.* First, however, a reminder to the navigator of the 1970's is in order.

Our jointly published British-American *Nautical Almanac* gives the sun's Greenwich hour angle and declination for every hour, and the table of increments and corrections permits us to obtain the GHA for each second and the "d" for each minute of time. The time of the sun's meridian passage is given to the nearest minute. The equation of time is given to the nearest second for every twelve hours of GMT and is little used in modern navigation.