

TIME BALLS AND TIME SIGNALS

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Navigation is a combination of three sciences — geometry, trigonometry, and astronomy — all of which were developed in varying degrees by the Phoenicians and Greeks, thousands of years ago. A concept of the first two led to the invention of a vertical-measuring device, the common quadrant, which was used to measure the altitude of a heavenly body; from their knowledge of astronomy, they could readily compute the latitude. Longitude, the second element for position fixing, defied ready solution until about the middle of the 18th century.

There is a fixed relationship between longitude and time and the terms are interchangeable, but the lengths of a unit of either are dependent upon latitude, decreasing as the meridians converge toward the poles very nearly as the cosine of the latitude. A minute of longitude, or four seconds of time, varies from about 6 000 feet at the equator to about half that in latitude 60°.

Since longitude is the difference between local time at a given place and the corresponding time at Greenwich, England — the zero meridian for reckoning longitude — the problem became one of determining two times simultaneously. Various methods were used, such as solar and lunar eclipses, star occultations, and lunar distances. Of these, only the method of lunar distances was widely used. But this required three simultaneous or nearly simultaneous observations of extreme accuracy and long and complex computations for reducing the observations to the center of the earth, all of which made the results of doubtful accuracy.

The historic breakthrough came in 1735 when John HARRISON built his marine chronometer No. 1, though it was not until after the Board of Longitudes tested his famous No. 4, in 1761, that he won an award of £ 20 000 from Parliament. The chronometer is a highly accurate time keeper which is set to a reference meridian such as Greenwich. This provides a simple method of comparing local time (from astronomic observations) with Greenwich time (from the chronometer) and thereby the difference in longitude.

Considering the tremendous impact the chronometer had upon navigation, it is of little wonder that it has been the subject of many articles, accounts, and stories. Very little, however, has been written about the important correlative of determining the error, and thereby the rate, of the chronometer when away from home port.

Chronometers came into general use aboard ship during the early 1800s, but it was not before the introduction of time balls and time signals that the mariner had an easy and accurate method of checking his time piece. Although there were some few ports where observatory clocks could be used, the principal method was to observe a morning or afternoon sight at a place of known longitude — a harbor, bay, or at a known distance off a charted landmark. This was done by the well-known time sight or, more accurately, by the method of equal altitudes — several hours before and after the meridian passage of the sun. With the use of a sextant, these methods presuppose a sea horizon, certainly a condition difficult to satisfy in the vast majority of ports or in a restricted anchorage. The 1846 edition of *The American Practical Navigator* (Bowditch) states that a transit instrument excels all other methods in brevity and accuracy ashore. This, however, is a doubtful statement, as the use of a sextant and artificial horizon would yield more accurate results unless the transit were fitted with a large and accurately-graduated vertical circle. But the vessel equipped with a transit, together with the mariner who would carry it ashore, must have been extremely rare, and an artificial horizon demands a very stable platform, not readily obtainable in the vicinity of a busy dockside. In general, the observation of a time sight must have been a troublesome task.

Before the advent of the electronic age there was little demand for accurate time; the factory whistle, the church or school bell served admirably for the occasional setting of the household clock. Even that paragon of accuracy in the minds of several generations of Americans — the railroad watch — needed to keep time only within 30 seconds a week to be officially certified. Much of the world had less need for accurate time. In one Latin-American country the only standard available was the flagship of the fleet which, when in port, momentarily lowered the flag at local mean noon.

The mariner required accurate time in order to rate his chronometer and his needs were admirably met with the introduction of time balls and time signals. The first of the former was installed at the Royal Greenwich Observatory in 1833 and consisted of a leather-covered sphere about 5 feet in diameter mounted on a 15-foot mast. It was dropped at 1:00 p.m. by trigger, but after 1852 it was released by an electrical signal from the Observatory. That same year signals were sent to London via telegraph lines to a ball in the Strand, the Southeastern Railroad, and in a circuit to chronometer makers in the City.

A few years later, in 1863, the 1:00 p.m. signal was used to fire guns at Newcastle and North Shields and within a few decades this form of time signal became fairly popular. In the event the flash could not be seen, corrections for distance and atmospheric conditions other than standard were available.

The 1881 edition of LECKY'S *Wrinkles in Navigation* stated that there were about 65 time signals available to the mariner and that equal altitudes were no longer necessary. It stated further that the limits of error on Greenwich mean time need be no more than 20 seconds for any sailing vessel and certainly not half that for a steamer. In mid-latitudes these amount to about four miles and two miles, respectively. By 1880 there

were at least 250 time signals, of which 20 were in the United States. Although the great majority were time balls, the list included guns, flags, semaphores, barrels, lights, a steam whistle in Honolulu, and a clock in Bombay with the seconds hand beating in unison with the observatory clock. LECKY'S tabulation included information on the type of signals, instant of drop at both Greenwich and local times, and many interesting remarks among which were the following : not to be relied upon, dropped once a week, dropped upon request at any hour, reported of no value for rating chronometers, and local time determined by sextant and artificial horizon.

In Great Britain, Canada, and the United States they were dropped on Greenwich mean time; in France, on Paris mean time and Paris mean time plus two minutes. In other ports, almost without exception, they marked local mean time.

Time balls and time signals did not necessarily mean accurate time. Transportation of chronometers was the only practical method of determining longitude before the day of the ocean cables and land telegraph lines. The longitudes of the great majority of ports were determined by comparison of merchant and naval chronometers with local time pieces or by astronomical observation. By the 1870s the longitude of most of the great ports and important capes had been determined with an accuracy sufficient for navigational purposes — few were in error as much as four minutes of arc, or sixteen seconds of time. Remote islands and capes, dependent upon but a few observations, could be grossly in error. For instance : Loyalty Island, in the Solomons, and Cape Hinchinbrook, a landfall for making Prince William Sound, in Alaska were in error about 45 and 13 miles, respectively.

Precise distances demand infinite attention to detail : a careful selection of chronometers and the elimination of temperature effects on their rates, the use of the same stars in obtaining reference and local time, the determination of the personal equations of the observers, and a study of all possible sources of error in the meridian instruments used to note local time. To obtain reliable mean values a number of chronometers were used on several expeditions. For example, the Greenwich — Valentia difference depended upon 30 chronometers transported to and from the two stations more than 20 times; and the Greenwich — Cambridge, Mass., difference was the result of 1 065 passages, of which nearly 800 were carried on five special expeditions on both eastward and westward voyages.

Telegraphic time signals in the United States were inaugurated at the end of the Civil War. Previously, the Navy's "standard" chronometer was carried from port to port to allow such comparison. The need for nationwide correct time was met by the U.S. Naval Observatory and distributed over the wires of the Western Union Telegraph Company, beginning about 1877. Eventually, there were more than 120 000 self-winding clocks in about 20 000 towns and cities in the circuits, all kept accurate by hourly corrections from a central master clock which in turn was synchronized with Observatory time at noon each day. It was these circuits that controlled the drop of time balls in this country.

During this era various governments determined meridian distances

by means of a cable and telegraph lines. Several U.S. Naval expeditions fixed longitude in many ports of Central and South America and in Asia. The Great Trigonometrical Survey of India connected Suez with Bombay; the Director of the Argentine National Observatory determined the longitude of the observatory at Cordoba from Buenos Aires and Vera Cruz, both of which had previously been fixed by the United States. The Vera Cruz connection was by way of Central America and the west coast of South America. In the northern hemisphere, the Russians extended a line from St. Petersburg to Vladivostok, by way of Siberia, which was later connected with a station in India. The accuracy of these ties, extending over thousands of miles, was proven by loop closures of about a 20th of a second at Cordoba and about 2/5th of a second at Vladivostok. On the ground these amounted to about 60 feet at Cordoba and 400 feet at Vladivostok. Many positions were determined between terminal points. Considering that local time had to be observed at all sites (lacking an observatory) by portable instruments and under a wide variety of weather conditions, the results were truly remarkable.

The telegraphic time-signal method was standard until well after 1904 when the first official transmission of time signals by radio began at the U.S. naval station at Navesink, New Jersey. These were low-powered and could only be heard for a distance of about 50 miles. Five years later the range had been doubled and as other nations began sending time signals, the navigator was soon able to check his chronometer around the world, thus ending the centuries-old quest for longitude. Today there are at least 40 radio stations transmitting time signals, with a number of them operating continuously. With a relatively simple receiver the mariner can obtain a time tick any minute of the day or night.

The need for time balls and time signals was over and they gradually disappeared; the last two in the United States — atop the Fairmount Hotel in San Francisco and on the topmost flagstaff of the Old Navy Building in Washington — were last dropped in 1937. The Japanese signals had all been discontinued by 1937, the last German one was destroyed during World War II, and the Liverpool gun — after 102 years of operation — was last fired in 1969.

Two time balls remain : the National Maritime Museum, now occupying the old Royal Greenwich Observatory buildings, continues to drop the ball daily, as does the Marine Historical Association at Mystic, Conn. These, it is believed, are the last survivors of a time service that was indispensable to the mariner for nearly a hundred years, and it is befitting that they are in the care of nautical museums so as to recall a bygone day.