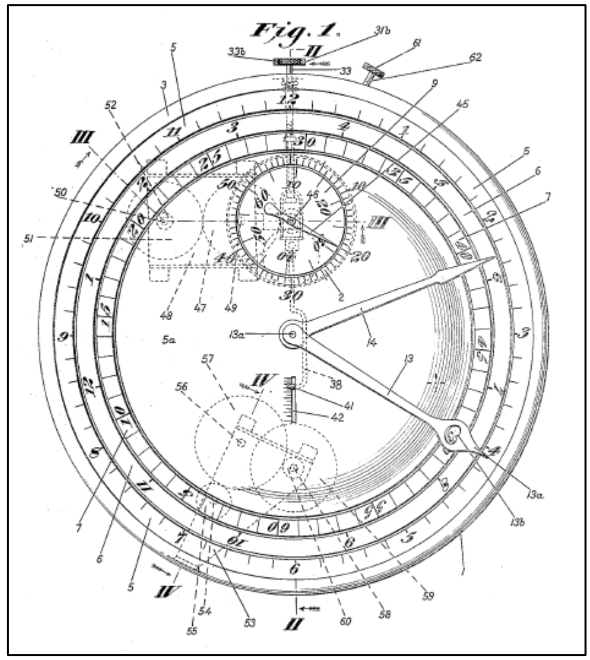
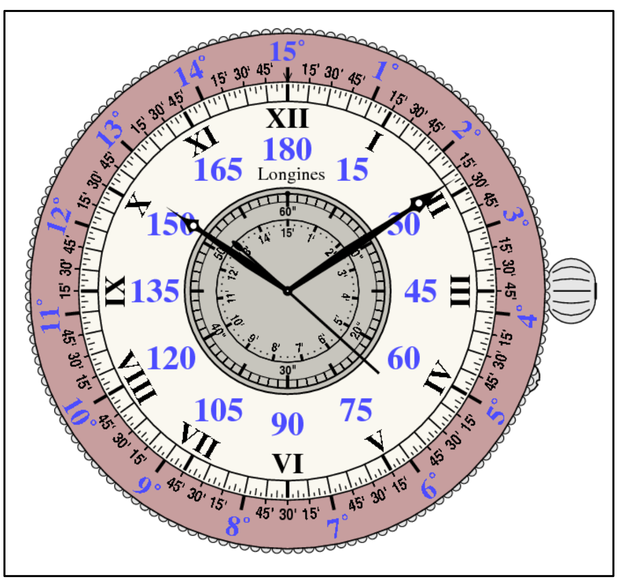
Lindbergh-Weems Second-Setting Pilot's Watch

Notes on Design and Use

By Edward Popko





Cover Credits ***(clockwise from upper left)***

Charles Lindbergh with Second-Setting watch - image composed by Strickland Vintage Watches at stricklandvintagewatches.com/products-page/

P. Van H. Weems' detail of second-setting mechanism from his 1929 patent 2,008,734 entitled 'Method of and Apparatus for Navigator's Time Keeping"

Longines Heritage Collection catalog photo

Lindbergh-Weems Second-Setting watch simulator by Edward Popko

Acknowledgements

I would like to recognize Brad Morris for his encouragement and comments while preparing this paper. His input greatly improved the paper’s clarity and accuracy. Stan Klein and Robin Stuart did a great job of proofing and cross checking the final text. Thanks to both of them.

NavList posts by Gary LaPook and Paul Dolkas started the NavList Lindbergh-Weems watch discussion (see the Bibliography for specific references). Their threads inspired me to look closer and write a simulator to study how the watch works. I want to thank them for the head start they gave me.

Like any technical write-up, there’s always the possibility of errors. Any errors in this document are strictly mine.

Table of Contents

Introduction

The Lindbergh-Weems watch was a product of the Golden Age of Aviation. In the late 1920s, Charles Lindbergh collaborated with his celestial navigation instructor, Philip Van Horn Weems, to design a navigation watch specifically for pilots. The design would be a precision *Greenwich Mean Time* (GMT) keeper that could be set to an exact time reference such as a radio signal. It would have an innovative rotating bezel and unique dials that would aid in converting GMT to the sun's *Greenwich Hour Angle* (GHA). GHA is a critical value when determining one's longitude. The watch would keep precise time and its dials would do the time-to-angle conversion. It did double-duty, it was both an accurate time keeper and a mechanical circular calculator for converting time to arc.

Navigators frequently need to determine their longitude. It's a two-step process. First, they compute the sun's GHA knowing GMT. This is what the watch does. Second, the navigator needs to find the angle between himself and the sun, it's called his *Local Hour Angle* (LHA). GHA tells them where the *sun is* with respect to the Greenwich Meridian. LHA tells him where the sun is with respect to where *he is*. The navigator's longitude is the difference of the two. While the watch finds GHA, it does not calculate the sun's LHA or ones longitude.

In 1929, Weems patented a very innovative way to synchronize a watch's fast moving second hand with a precise zero second time reference such as a radio tone or beep. The design was called the *Second-Setting Watch*.[1] This was an important feature. A watch error of 30 seconds could throw position calculation off as much as seven miles.

In 1931, Lindbergh suggested additional improvements: a rotating bezel and angle marks on the dials that would make it easier make time/angle conversions. Longines Wittnauer, the American partner of the Swiss Longines company, decided to combine these features and manufacture a new second-setting hour-angle watch. Longines thought that associating Lindbergh's name with the watch and the rapid growth of aviation would open a new market. The watch was sold as the *Lindberg Hour-Angle Watch* or *Lindbergh-Weems Second-Setting Watch*.

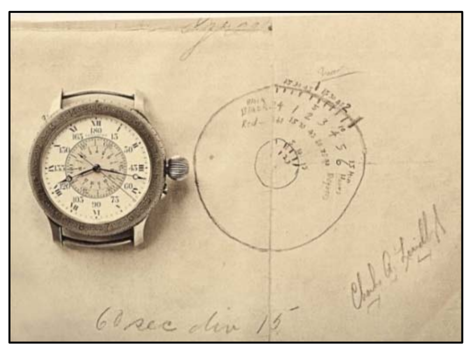


Figure 1 - Early Longines Lindbergh Watch circa 1940 and one of Lindbergh's Design

Figure 1 shows an early production version and Lindbergh's signed design sketch.[2] It would be the first wrist watch specifically designed for pilots doing celestial navigation. Several modernized versions are available today as part of Longines' Heritage Collection.

[1] See Figure 13 for Weem's complete patent drawings and claims.
[2] Photo credit: www.hautetime.com/celebrating-the-lindbergh-hour-angle-watch-with-longines/83312/

Time Keeping and Navigation

Watches and clocks intended for navigation are called *chronometers*. They are designed and manufactured to high standards to keep exact time at a constant rate in marine and aviation environments such as motion, changes in barometric pressure and wide temperature and humidity ranges.[3] Chronometers keep constant *mean time,* exactly 24 hours per day, based on the *average* (mean) *length* of the day over an entire year.[4] And since the earth rotates 360 degrees per 24 hour day there is a direct correspondence between time and degrees of earth's rotation. In four minutes, the earth rotates 1 degree; in one hour, 15 degrees,

Local and Greenwich Apparent Time

The sun is also a clock, a celestial one. It keeps its own time called *apparent time* – time as the real sun appears. This is the same time sundials show. Your personal 'noon' (apparent time) occurs when the sun is directly north or south of your meridian. Apparent time, local to the observer's local meridian, is called *Local Apparent Time* (LAT). To create a more general time reference for worldwide use, the 0º meridian of the Greenwich Observatory in England is used. LAT at Greenwich is called *Greenwich Apparent Time* (GAT). The longitude difference between two locations is the difference in their LATs converted to an angle. For example, if one location's LAT is 4:30 and at another, further west, is 1:20, their time difference is 3:10. They are 47º 50' of longitude apart (one hour time equals 15 degrees longitude). If the first location was at Greenwich, the second location is at 47º 50' W longitude.

Equation of Time

The earth's yearly orbit around the sun is not a perfect circle. As a result, the sun does not cross the same meridian at the same clock time every day of the year. Sometimes it arrives early and other times later when compared to watch time. This continuous day-to-day change is gradual and subtle. It's caused by the earth's elliptical yearly orbit around the sun and some other factors. The difference between the time kept by a watch (*mean time*) and time kept by the sun (*apparent time)* is called the *Equation of Time* (EoT).[5] It's the minutes and seconds difference between the two time systems. EoT tells him how many minutes and seconds his watch (mean time) and solar time (apparent time) are apart.

On some days of the year, EoT is quite large. For example, in November, the sun arrives more than 16 minutes early as compared to watch time. We say the sun is running fast. And by February it's slow, running more than 14 minutes late. That's a half-hour range and equivalent to 7.5º longitude over the course of a year. To put that longitude in perspective, it's a distance

[3] Few watches keep perfect time. Most gain or lose seconds each day or week or month. Navigators keep track of their gain or loss and figure it in when they use the watch.

[4] GMT is based on the sun and the average length of the day per year. Today, time references are based on atomic clocks rather than the sun. It's called *Coordinated Universal Time* and it is kept within 1 second of mean time. Greenwich Mean Time is often used as a synonym for Coordinated Universal Time.

[5] The word *equation* is used in the medieval sense to "reconcile a difference"; there is no equation in the sense of mathematics. An observation of navigation historian Frank Reed.

about halfway across a standard time zone. The navigator cannot ignore the Equation when he uses his watch to find the sun's GHA.

To find out what the day's EoT is, navigators consult the *Air* or *Nautical Almanac* which lists it at GMT 00:00 and 12:00 every day of the year[6]. Figure 2 shows a graph of the daily EoT over the year. This 'figure 8' graph is called the *analemma***.**

While there are slight variations year-to-year, the apparent sun is slowest (behind of mean time) near February 10th and fastest (ahead) on November 2nd. Four times a year, indicated by the red line, apparent time is momentarily in perfect sync with mean time: April 15th, June 12th, September 1st and December 25th.

"The equation of time represents the difference between apparent time of the sun and the mean time of our watches. A graphical representation is shown in Figure 2.

During a year the equation of time varies as shown on the graph to the right; its change from one year to the next is slight. Apparent time, and the sundial, can be ahead (fast) by as much as 16 min 33 s (around 3 November), or behind (slow) by as much as 14 min 6 s (around 12 February).

The equation of time has zeros near: 15 April, 13 June, 1 September and 25 December. Only at these four times is mean time equal to apparent time.

The values are positive from April 15 to June 15 and from Sept. 1 to Dec. 24. They are negative from June 15 to Aug. 31 and from Dec. 25 to April 14. The greatest (positive) value of the equation of time is on Nov. 3, when it is 16 minutes, 33 seconds, ahead of mean time. Feb 11 is largest (negative) value".[7] [8]

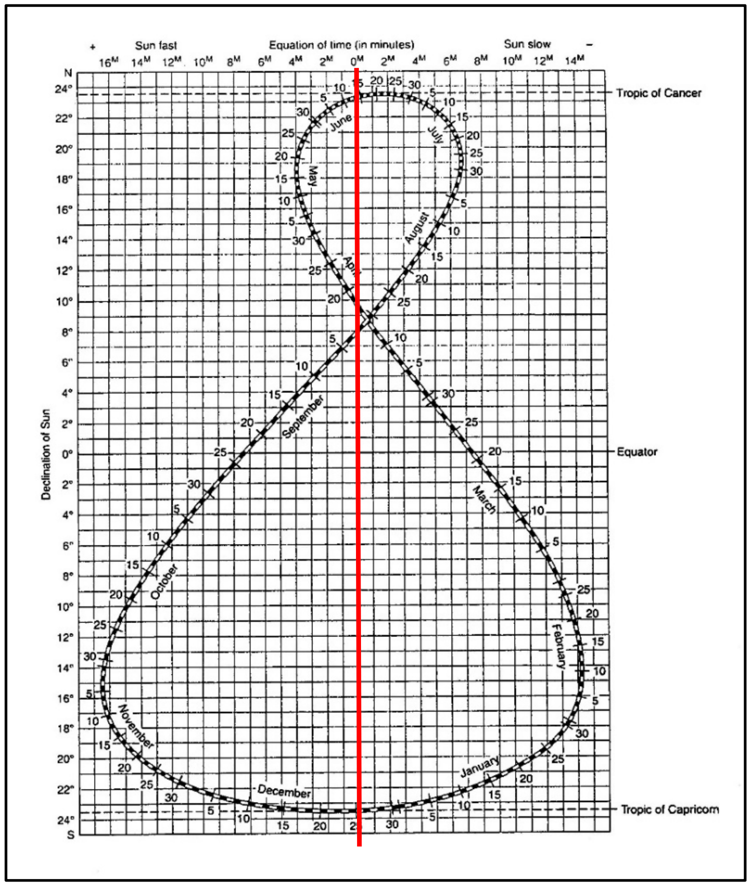


Figure 2 - Daily Change in Equation of Time during the Year

[6] Some almanacs list the daily Equation of Time but it's easily computed by looking at the sun's GHA at GMT 00:00 and comparing it to 180º or at GMT 12:00 and comparing it to 0º . The degrees difference, converted to time is the EoT.
[7] From: en.wikipedia.org/wiki/Equation of_time
[8] Analemma graph courtesy of the Coast and Geodetic Survey.

Greenwich Hour Angle

The *Greenwich Hour Angle* (GHA) is the sun's actual meridian position over the earth at an instant in time. The point directly below the sun at that instant is called the sun's *geographic position* and constantly moves west as a result of the rotating earth. The GHA is a critical angle for navigators and the main design-use of the Lindbergh-Weems watch. If the navigator knows the sun's GHA *and* his LHA, the combination is his longitude.

Unlike terrestrial longitude that's measured in degrees east or west of the Greenwich Meridian, GHA is measured only westward and it wraps around the earth through 360º. If the GHA is 0º, the sun is over Greenwich, if it's 180º, the sun is on the opposite side of the earth from Greenwich. It's easy to convert GHA to the sun's terrestrial longitude. When GHA is less than 180º, it is it's actual longitude west. If greater than 180º, its longitude east is 360º-GHA.

Greenwich Mean Time

In the 20th century, the most common navigation time standard was *Greenwich Mean Time* (GMT). GMT is the average solar or apparent time at longitude 0°, the location of the Royal Greenwich Observatory in England. The observatory's meridian is called the Prime Meridian or Greenwich Meridian.

There is a direct relationship between GMT and EoT times and the sun's GHA. First, the navigator converts GMT and EoT to their equivalent angles. The EoT angle is then added or subtracted from mean time angle depending if the sun is ahead or behind GMT. The *Air* or *Nautical Almanacs* provide the day's EoT. The Lindbergh-Weems watch provides GMT and its bezel and dials convert these GMT and EoT to degrees, minutes, seconds of arc. GHA is a simple matter of reading dials, noting the arc conversions and adding them up. The result is the sun's longitude, GHA.

Watch Simulator

Watch Overview

There aren't many Lindbergh-Weems watches in circulation today; they are collectors' items and expensive to acquire. A simulator program has been written to generate facsimiles of the watch face. It's a convenient way to learn how the watch works. Given GMT expressed in 12-hours, knowledge of AM or PM and the Equation of Time's minutes and seconds, the simulator displays detailed facsimiles of the watch's face. Images include bezel markings, rotation position, hour/minute/second hand positions, and seconds synchronization if the second-synchronization feature is used. A static display has another advantage, the hands are not in continual motion, this makes it easier to analyze the various scales.[9] Figure 3 annotates the main areas of a typical display.

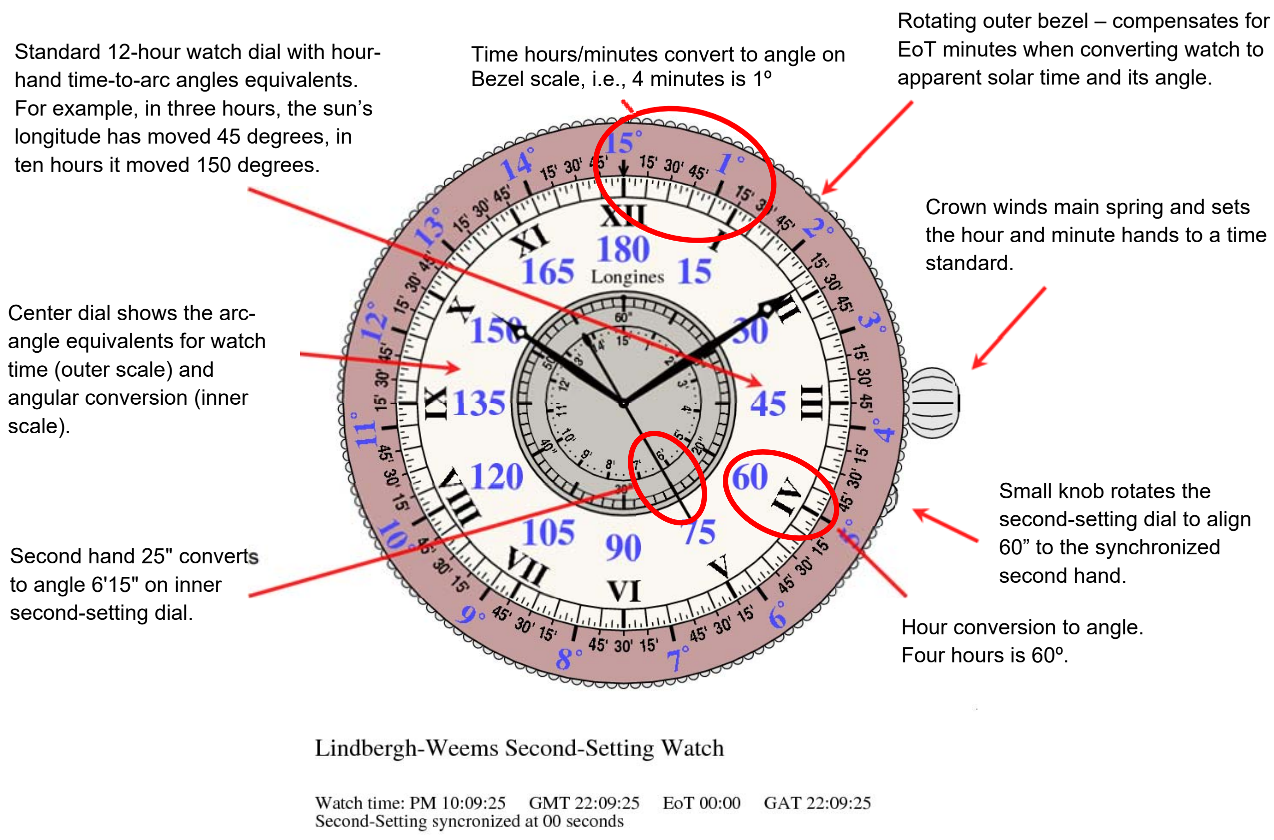


Figure 3 - Typical Simulator Display of Lindbergh-Weems Watch

[9] A highly useful, but rare, feature in navigation watches is the ability to instantly freeze the position of the watch hands or digital readout allowing a moment to read and record the time and then to resume the time movement as if it the watch had not been stopped. It's similar but not the same thing as a stop watch. Some high-end chronographs incorporate this feature, it's called *rattrapante*, a French word meaning *to catch up*. The paused hands, when released, resume their time by 'catching up'.

There are a few important differences between simulator displays and the various dials of Longines' production watches. All simulator time and angles have their appropriate unit symbols such as degree °, minute ' and second ". They are not part of the production watch. In addition, simulator displays are larger and include many more time and angle tick marks. Figure 4 shows example markings. And since the hands are not in motion, simulator displays are more precise and easier to read than the actual watch.

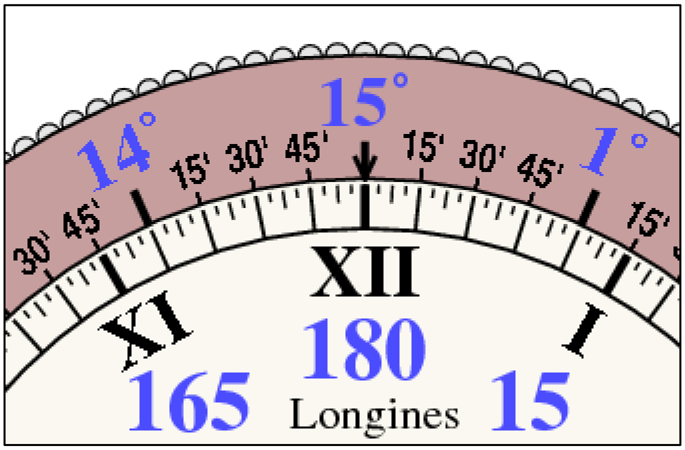


Figure 4 - Detail of Simulator Time and Angle Unit Marks

To facilitate EoT to arc conversions, a small pointer on the second-setting dial has been added. If EoT seconds are not zero, the pointer indicates its arc minutes and seconds conversion (Equation minutes are accounted for through bezel rotation). This pointer is not on the original watch. Figure 5 shows EoT 30 seconds converts to 7'30" arc. The dots between arc minutes indicate ascending 15"/30"/45" of arc.

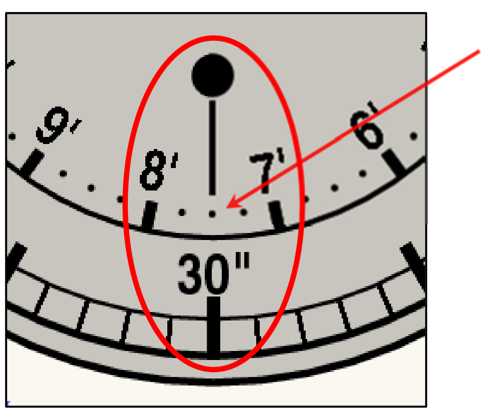


Figure 5 - Equation of Time Seconds to Angle Pointer

The Second-Setting Dial

The central second-setting dial is a very innovative watch feature and serves two purposes: synchronizing the second hand with a time standard and visually converting seconds of time (outer scale) to arc minutes and seconds (inner scale) and vice versa.

The first step in using the watch is to set the watch to GMT. The crown sets the hour and minutes. To set the second hand exactly to a time standard, such as a radio signal, the second-setting dial is rotated clockwise or counter clockwise with a small side knob next to the crown. At the instance of synchronization, the dial's outer scale 60" mark is positioned exactly under the second hand. In the example below, the second hand was eight seconds fast when synchronized.

The watch below displays 04:56:22 GMT. The bezel is set for zero 00 minutes EoT and the second-setting dial EoT 30 seconds converts to 7'30" arc. Note that rotating the second-setting dial for synchronization does not affect time (seconds) to angle (minutes and seconds) relationships.

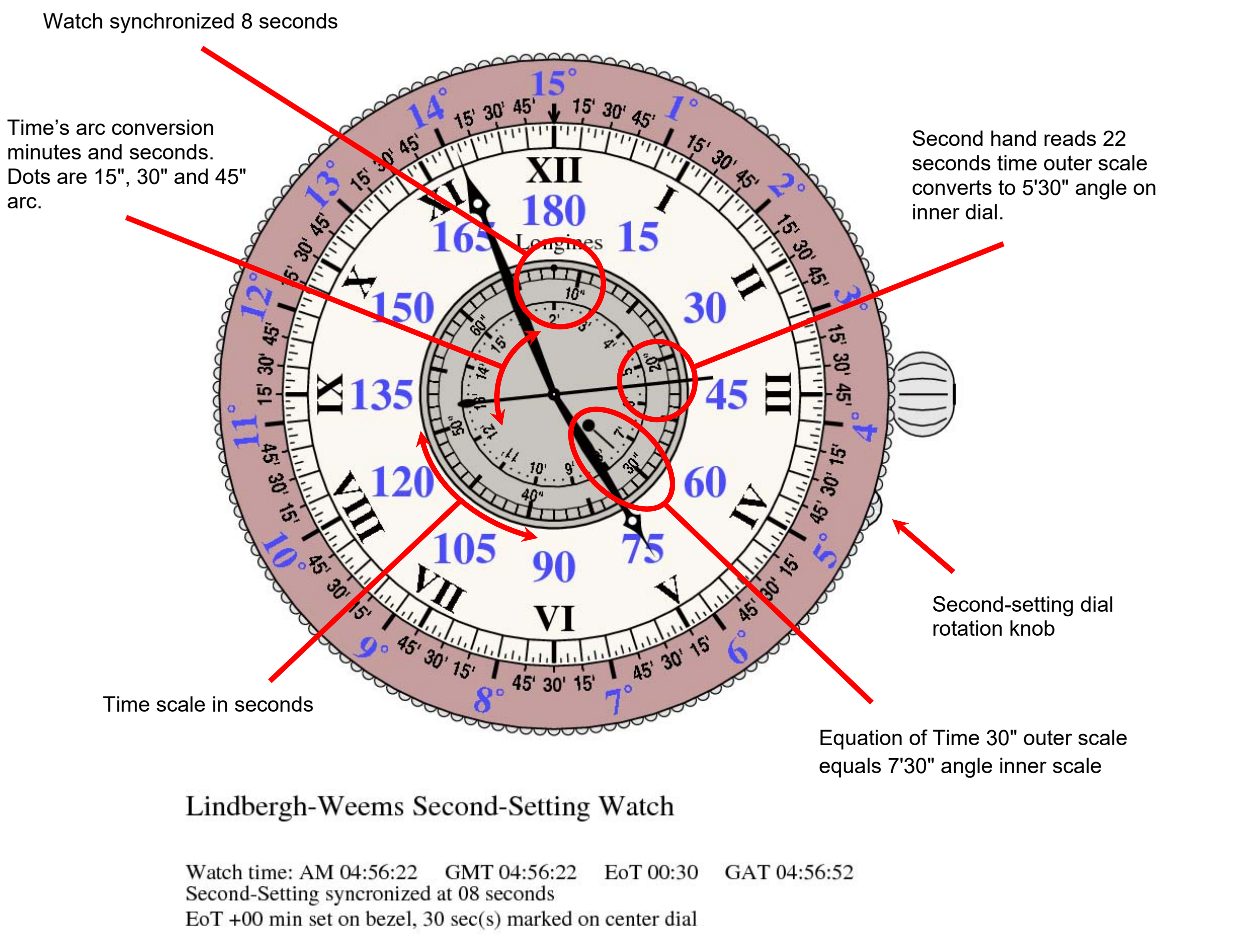


Figure 6 – Second-Setting Dial

To calculate GHA, you must know *both* the GMT and EoT. The watch provides the first. Reliable sources, such as the *Air* or *Nautical Almanac*, list the EoT for GMT 00:00:00 and GMT 12:00:00 for every day of the year.

To account for any EoT minutes, we rotate the bezel's 15º mark (indicated by a small arrow) the number of minutes or time, clockwise when the EoT is negative and counter clockwise when positive. In this example, EoT is fast 4 minutes, thus the bezel 15º arrow mark is rotated *four minutes counter clockwise on the main dial*. See the detailed insert. We do not have to pre-set the watch for any EoT seconds. We convert them to an angle by simply reading their arc conversion from the inner scale on the second-setting dial. In this example, 50 EoT seconds equal 12' 30" arc, the conversion is circled in the figure.

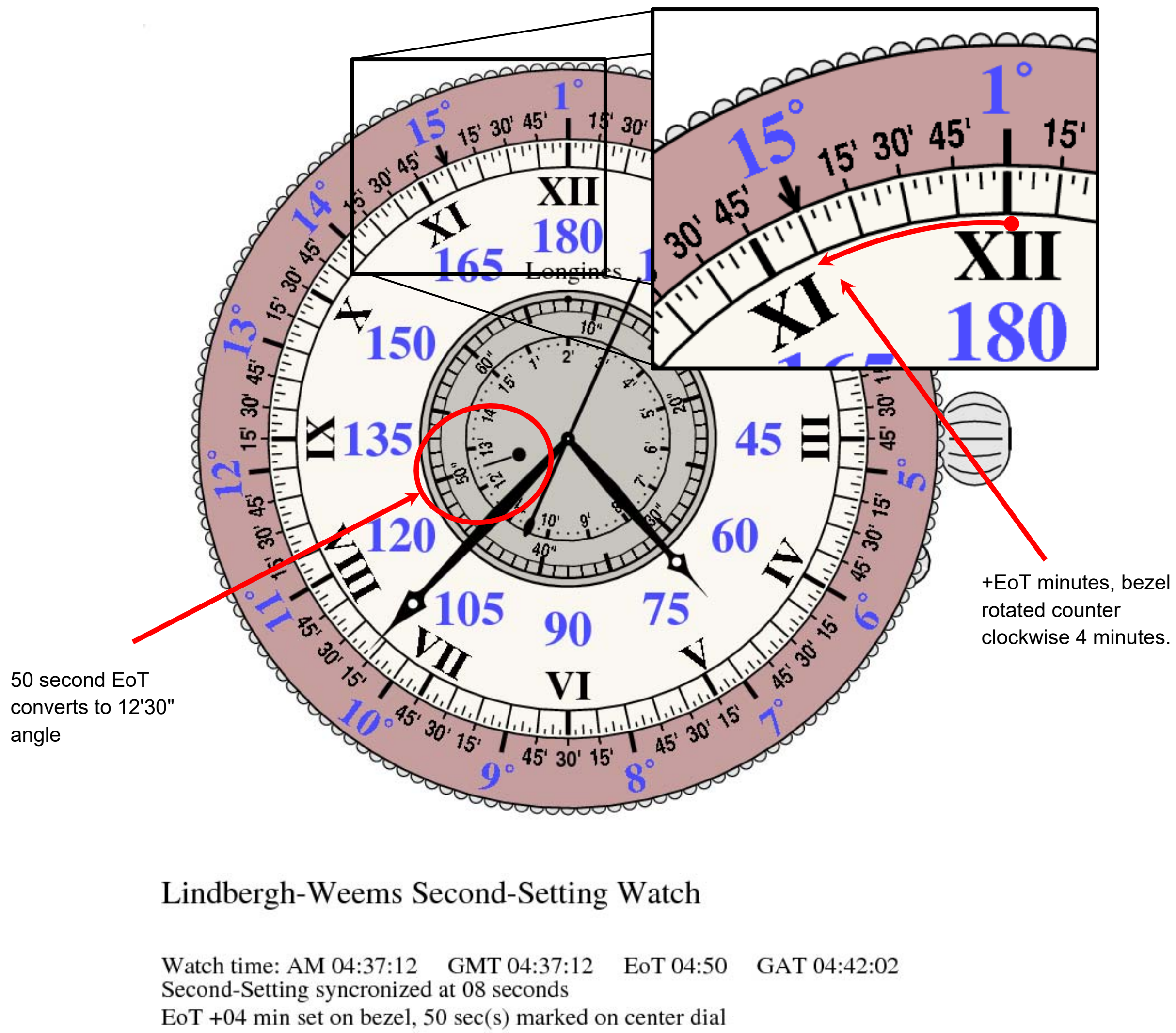


Figure 7 - Bezel Rotation Compensation for EoT Minutes

Calculating the Sun's Greenwich Hour Angle

Assuming the watch is properly synchronized to GMT and the bezel rotated to account for any whole EoT minutes, do the following to find the sun's GHA. Make a list of the various hour, minute, and second hand time-to-arc conversions, then add them up. The total is the GHA.

Referring to Figure 8, the steps are as follows:

[1] Keep in mind if the watch time is AM or PM, GMT is a 24-hour system, however, the Lindbergh-Weems watch has a 12-hour dial. The navigator must keep track of AM or PM. If time is AM, start the GHA angle list with 180º, the sun is on the Greenwich lower meridian at midnight because and GHA is measured westward from the Greenwich Meridian. If the watch's time is PM, the initial arc value is 0º. *Figure 10 - Relationship of GMT, GHA and East/West Longitude* shows the correspondence between 12-hour displays, 24-hour GMT, GHA angle and East/West Longitude and why AM calculations start with 180º.

[2] From the hour hand, read the *completed whole hour* GHA degrees conversion from the main dial. The hour hand has completed 60º, add it to the list.[10]

[3] Read the minute hand's *whole* arc-degree and any *completed* increment of 15'/30'/45' arc-minutes from the bezel. In this example, 10º15' arc have been completed. Add this angle to the list.

[4] Read the second hand's angle conversion on the second-setting dial. In this example, 12" time converts to an even 3' of arc. Add this arc and any 15"/30"/45" arc-seconds (dots between arc-minutes) to the list.

[5] Read the second-setting dial dot-line marker for the angle value of EoT seconds, here EoT's 50 seconds is 12'30" of arc. Note that arc conversions of EoT seconds will never exceed 15'. Its sign is always the same as that of EoT minutes. Add it to the list and include it's sign.

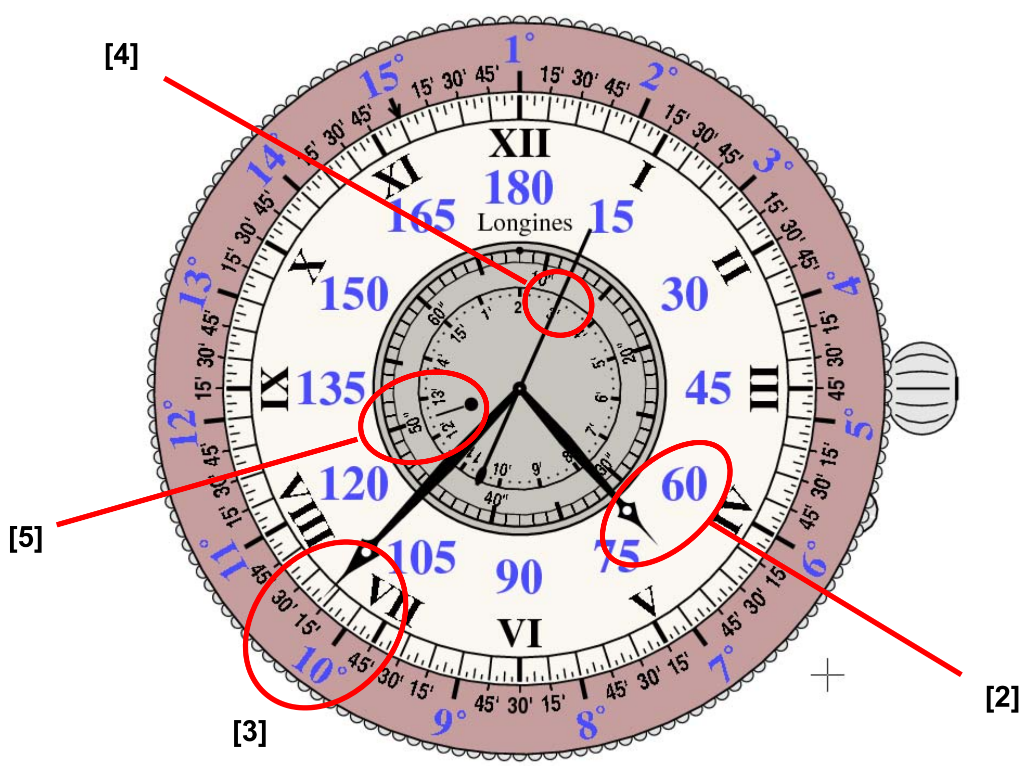
[6] GHA is the sum of the list arcs - 250º 30' 30".   To convert GHA to the sun's terrestrial longitude, when GHA<180º, it *is* the sun's longitude west. When GHA>180º, 360º-GHA is its longitude east.

[10] In rare cases, the EoT may advance the hour to the next hour or cause it to retreat to the previous hour if the hour hand is at or very near the hour. These exceptional cases are discussed in section *Subtle Hour-Angle Examples.*

Watch reads AM 04:37:12   GMT 04:37:12 + EoT 04:50 = GAT 04:42:02

Watch face annotations below illustrate each step in the above instructions. The bezel rotation was pre-set counter clockwise 4 minutes for positive EoT. EoT's 50 seconds angle conversion is marked on the second-setting dial. The watch was synchronized by rotating the second-setting dial 8 seconds.

[1] 180º AM sun is on the lower meridian at midnight
[2] 60º read the hour hand's completed angle, 60º, from the main dial
[3] 10º 15' read the minute hand's completed angle 10º and 15" increment from bezel dial
[4] 3' read second hand minutes/seconds angle from second-setting dial
[5] + +12' 30" read EoT minutes/seconds angle from the second-setting dial
--------------- a positive 12'30" angle.
[6] 250º 30' 30" GHA, sum of the above angles   Sun is longitude 109º 29' 30" E   (360º-GHA)



Lindbergh-Weems Second-Setting Watch

Watch time: AM 04:37:12   GMT 04:37:12   EoT 04:50   GAT 04:42:02
Second-Setting syncronized at 08 seconds
EoT +04 min set on bezel, 50 sec(s) marked on center dial

Figure 8 – Steps in Reading the Lindbergh-Weems various Time-to-Angle Conversions

Examples

The next two sections provide a number of watch reading and GHA calculation examples.

The first group, *Basic Hour-Angle Examples*, show AM-PM and positive-negative Equation of Time combinations. These examples are easy to understand and provide some practice in bezel rotation for EoT minutes and reading each watch hand's angle conversion. The list of angles is summed up for the sun's Greenwich Hour Angle and conversion to it's terrestrial longitude. In each example, the watch's GMT time, AM-PM designation and the Equation of Time is given. The simulator displays the resulting time, lists the Hour-Angle contribution each watch hand makes to the total. EoT seconds compensation are labeled plus or minus. EoT minutes are compensated by the bezel's rotation.

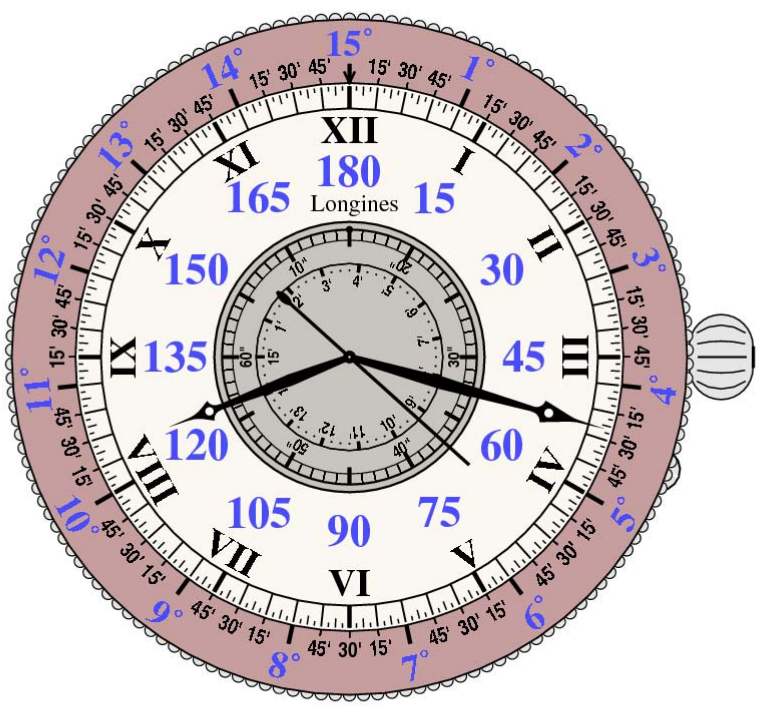
The second set, *Subtle Hour-Angle Examples*, illustrate how the EoT can affect the GMT's hour reading when the hour hand is at or very near a whole hour. Large EoT seconds, either positive or negative, can shift the required hour hand angle by one hour either before or after from what appears on the watch face. These cases are rare but the navigator needs to be aware of them. Once you see how the EoT interacts with on-or-near-the-hour times, it is easy to compensate and select the right hour angle from the main dial.

Basic Hour-Angle Examples

Example 1 – Watch AM 08:17:37 GMT 08:17:37 + EoT 00:00 = GAT 08:17:37 [11]

No bezel rotation is required, EoT is 00:00. The second-setting dial was rotated 15 seconds counter clockwise to synchronize the second hand at zero seconds (watch was running 15 seconds slow).

```
180º          AM sun is on the lower meridian at midnight
120º          hour hand
  4º 15'      minute hand
      9' 15"  second hand
 +    0'      no EoT seconds compensation
---------------
304º 24' 15"  GHA   Sun is longitude 55º 35' 45" E  (360º-GHA)
```



Lindbergh-Weems Second-Setting Watch

Watch time: AM 08:17:37 GMT 08:17:37 EoT 00:00 GAT 08:17:37
Second-Setting syncronized at 15 seconds

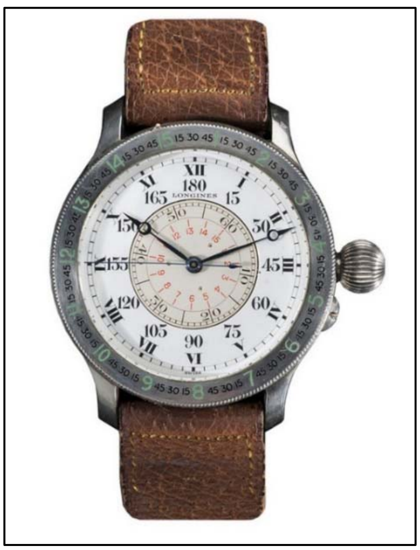
[11] Photo credit: www.hautetime.com/celebrating-the-lindbergh-hour-angle-watch-with-longines/83312/

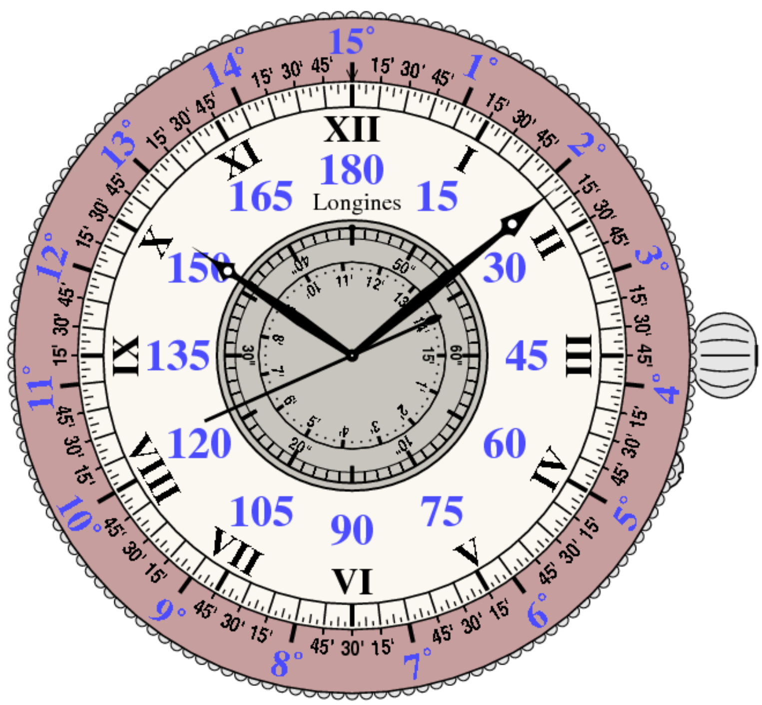
Example 2 – Watch AM 10:08:26 GMT 10:08:26 + EoT 00:00 = GAT 10:08:26

No bezel rotation is required, EoT is 00:00. The second-setting dial was rotated -15 seconds to synchronized it with the time standard.

180º		AM, sun is on the lower meridian at midnight
150º		hour hand main dial blue degrees
2º		minute hand bezel dial blue degrees
	6' 30"	second hand inner minutes and seconds second-setting dial angle scale
+	0'	no EoT seconds compensation

332º	6' 30" GHA	Sun is longitude 27º 53' 30" E (360º-GHA)





Lindbergh-Weems Second-Setting Watch

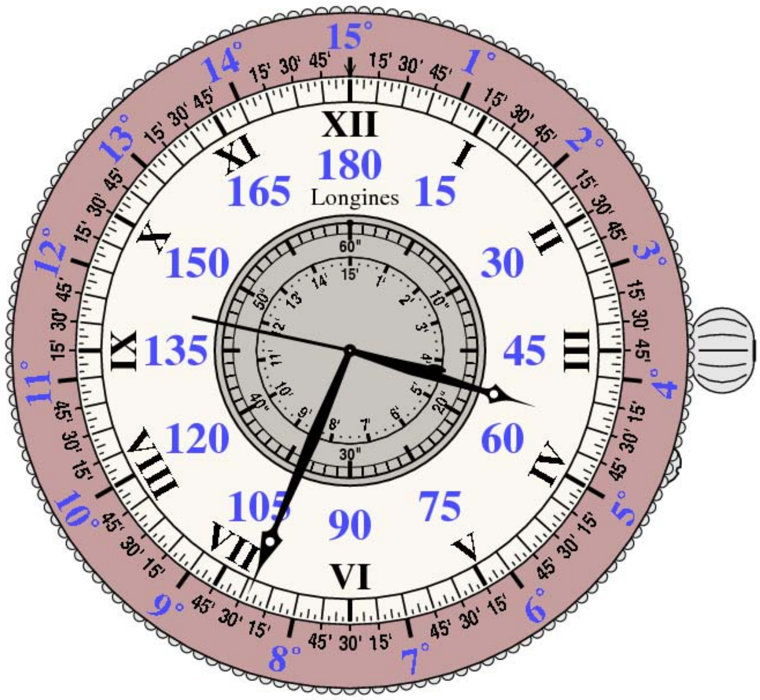
Watch time: AM 10:08:26 GMT 10:08:26 EoT 00:00 GAT 10:08:26
Second-Setting syncronized at -15 seconds

Example 3 – Watch AM 03:33:47   GMT 03:33:47 + EoT 00:00 = GAT 03:33:47 [12]

No bezel rotated is required , EoT is 00:00. The second-setting dial was not rotated for second hand synchronization.

180º AM, sun is on the lower meridian at midnight
45º hour hand main dial multiplier
8º 15' minute hand bezel dial
11' 45" second hand, second-setting dial
+ 0' no EoT seconds compensation

233º 26' 45" GHA Sun is longitude 126º 33' 15" E (360º-GHA)



Lindbergh-Weems Second-Setting Watch

Watch time: AM 03:33:47 GMT 03:33:47 EoT 00:00 GAT 03:33:47
Second-Setting syncronized at 00 seconds

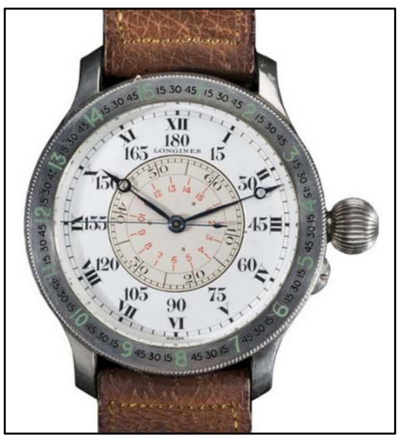
[12] Photo credit: www.hodinkee.com/articles/the-lindbergh-hour-angle-watch-possibly-the-most-toolish-tool-watch-ever-made

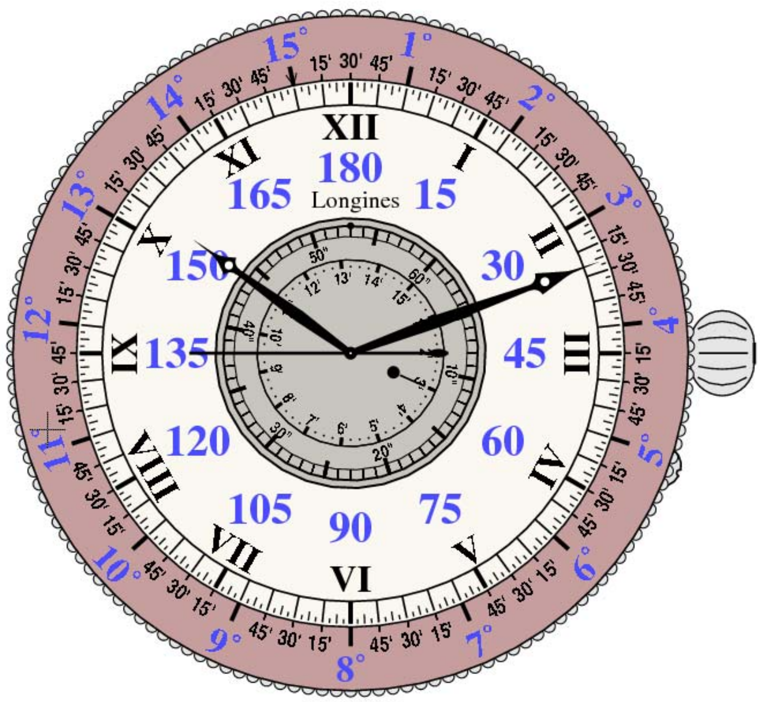
Example 4 – Watch PM 10:11:38   GMT 22:11:38 + EoT 02:12 = GAT 22:13:50 [13]

The bezel is rotated counter clockwise 2 minutes for positive EoT, EoT's 12 seconds angle conversion is marked on the second-setting dial. The second-setting dial was rotated 7 seconds, watch was fast.

	150º	hour hand main dial multiplier
	3º 15'	minute hand bezel dial
	9' 30"	second hand, second-setting dial
+	+3' 00"	second-setting dial's arc compensation for positive 12 seconds EoT

153º 27' 30" GHA   Sun is longitude 153º 27' 30" W





Lindbergh-Weems Second-Setting Watch

Watch time: PM 10:11:38   GMT 22:11:38   EoT 02:12   GAT 22:13:50
Second-Setting syncronized at -7 seconds
EoT +02 min set on bezel, 12 sec(s) marked on center dial

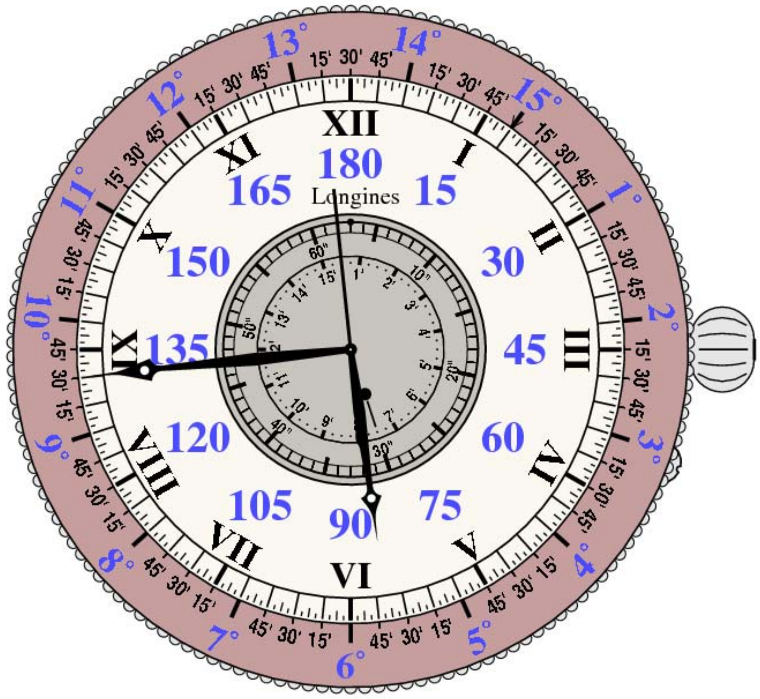
[13] Photo credit: https://www.yourwatchhub.com/longines/the-history-of-the-longines-lindbergh-hour-angle-watch/

Example 5 – Watch PM 05:44:02 GMT 17:44:02 + EoT -06:30 = GAT 17:37:32 [14]

The bezel is rotated clockwise 6 minutes for negative EoT, EoT's 30 seconds angle conversion is marked on the second-setting dial. The second-setting dial rotated 3 seconds counter clockwise to synchronize the second hand at zero seconds (watch was running 3 seconds slow when synchronized).

75º hour hand main dial multiplier
9º 30' minute hand bezel dial
30" second hand center dial
\+ -7' 30" second-setting dial's compensation for negative 30 seconds EoT

84º 23' 00" GHA Sun is longitude 84º 23' 00" W



Lindbergh-Weems Second-Setting Watch

Watch time: PM 05:44:02 GMT 17:44:02 EoT -6:30 GAT 17:37:32
Second-Setting syncronized at 03 seconds
EoT -06 min set on bezel, 30 sec(s) marked on center dial

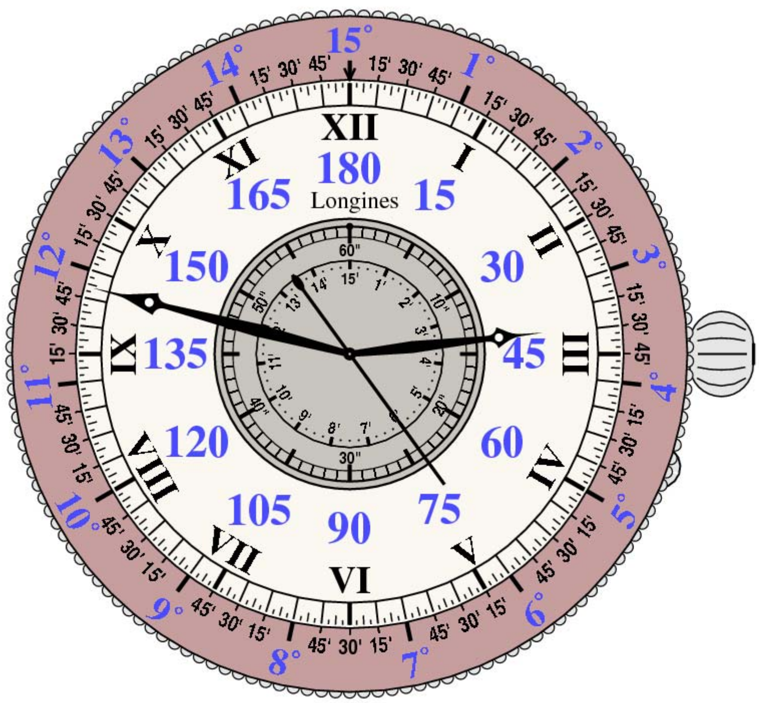
[14] Photo credit: www.modernmontra.com/Utmerket-Verdi-Svart-GullSt%C3%A5l-Longines-LINDBERH-HOUR-ANGLE-WATCH-Automatisk-Lindbergh-Hour-Angle-Herreklokker-xq7Afs11-p-2920.html

Example 6 – Watch PM 02:47:24 GMT 14:47:24 + EoT 00:00 = GAT 14:47:24 [15]

The bezel is not rotated, EoT is 00:00. The second-setting dial was not rotated for second hand synchronization.

0º	PM
30º	hour hand main dial multiplier
11º 45'	minute hand bezel dial
+ +6'	second hand, second-setting dial
0'	no EoT seconds compensation

41º 51' 00" GHA	Sun is longitude 41º 51' 00" W



Lindbergh-Weems Second-Setting Watch

Watch time: PM 02:47:24 GMT 14:47:24 EoT 00:00 GAT 14:47:24
Second-Setting syncronized at 00 seconds

[15] Photo credit: www.hodinkee.com/articles/the-history-and-science-behind-the-lindbergh-longines-hour-angle-watch

Subtle Hour-Angle Examples

The following examples show subtle Greenwich Hour Angle cases that occur when the hour hand is on the hour or very near so. Depending on the magnitude of the Equation of Time, it's positive or negative seconds value, if large enough, can shift the hour's multiplier 15° less (Example 7) or more (Example 8) than what is directly read from the main dial.

The same situation may occur when GMT time on or very near 12:00:00. The Equation of Time can shift AM to forward to PM (Example 9) or PM noon back to AM (Example 10).

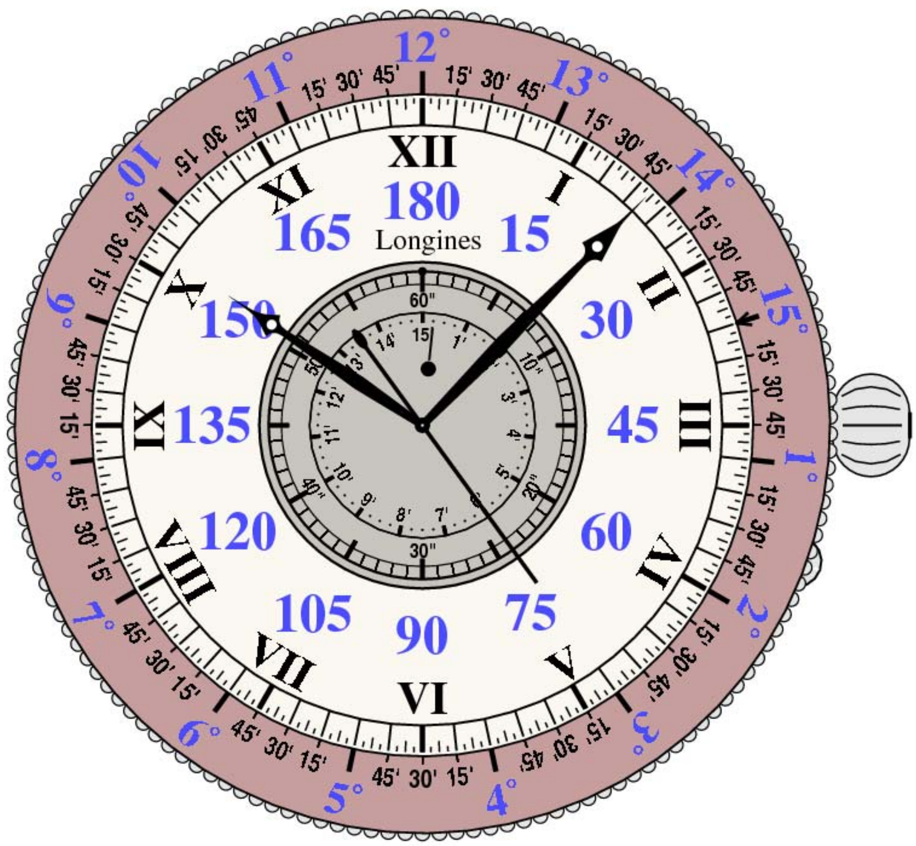
Example 7 – Watch AM 10:07:24   GMT 10:07:24 + EoT -12:01 = 09:55:23

The bezel is rotated clockwise 12 minutes for negative EoT, EoT's 01 second angle conversion is marked on the second-setting dial. The second-setting dial was not rotated for synchronization.

The hour hand is near 10:00:00. When the EoT is applied to convert mean time to apparent time, the apparent hour becomes *one less* thus the hour arc conversion is 135º and not 150º.

180º	AM, sun is on the lower meridian at midnight
135º	hour hand main dial multiplier, GAT is previous full hour, use 9:00
13º 45'	minute hand bezel dial
6'	second hand, second-setting dial
+ -15"	second-setting dial's arc compensation for negative 01 second EoT

328º 50' 45" GHA	Sun is longitude 31º 09' 15" E (360º-GHA)



Lindbergh-Weems Second-Setting Watch

Watch time: AM 10:07:24   GMT 10:07:24   EoT -12:01   GAT 09:55:23
Second-Setting syncronized at 00 seconds
EoT -12 min set on bezel, 01 sec(s) marked on center dial

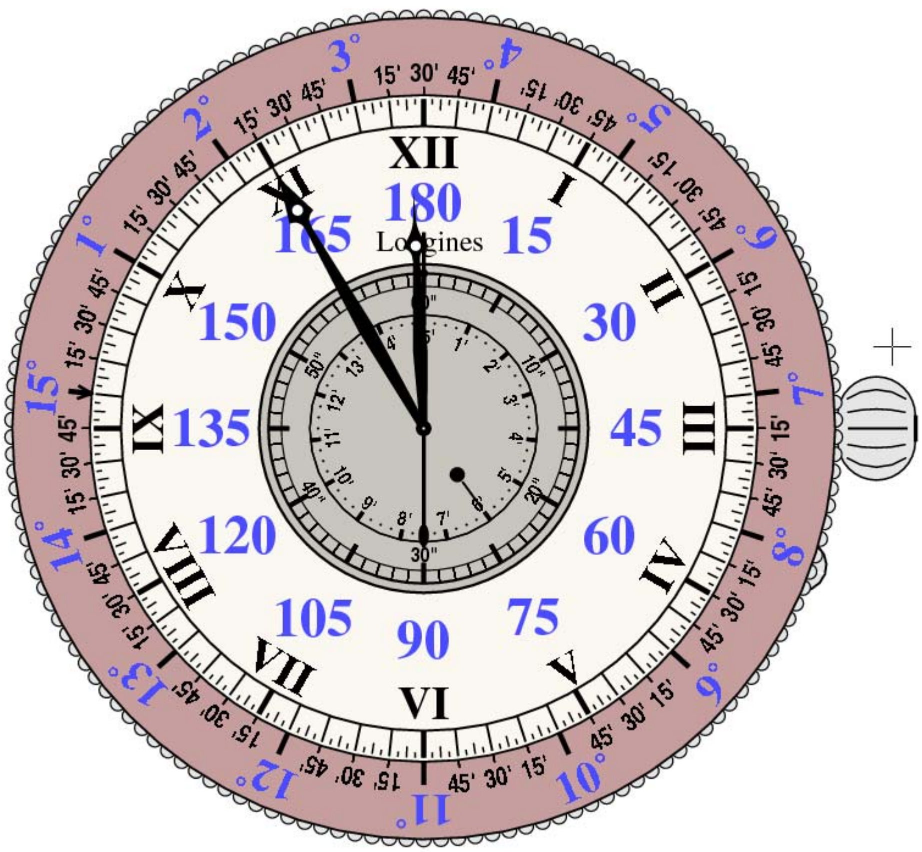
Example 9 – Watch AM 11:55:00   GMT 11:55:00 + EoT 14:24 = GAT 12:09:24

The bezel is rotated counter clockwise 14 minutes for positive EoT, EoT's 24 seconds angle conversion is marked on the second-setting dial. The second-setting dial was not rotated for synchronization.

The hour hand is AM, not quite 12:00 noon. When the EoT is applied to convert mean time to apparent time, the apparent time becomes *PM* and a full PM hour has not yet been completed.

	0º	PM
	0º	hour hand main dial multiplier, an hour has not yet been completed
	2º 15'	minute hand bezel dial
	0'	second hand, second-setting dial
+	+6' 00"	second-setting dial's arc compensation for positive 24 seconds EoT

	2º 21' 00"	GHA Sun is longitude 2º 31' 00" W



Lindbergh-Weems Second-Setting Watch

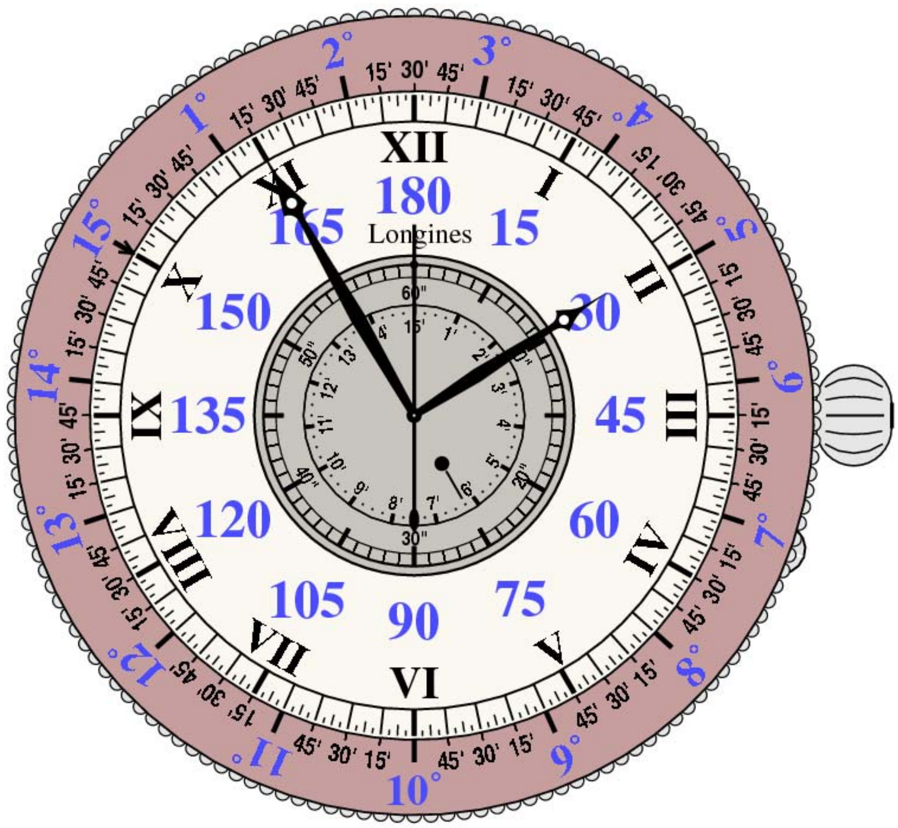
Watch time: AM 11:55:00   GMT 11:55:00   EoT 14:24   GAT 12:09:24
Second-Setting syncronized at 00 seconds
EoT +14 min set on bezel, 24 sec(s) marked on center dial

Example 8 – Watch AM 01:55:00   GMT 01:55:00 + EoT 10:25 = GAT 02:05:25

The bezel is rotated counter clockwise 10 minutes for positive EoT, EoT's 25 seconds angle conversion is marked on the second-setting dial. The second-setting dial was not rotated for synchronization. The hour hand is near 02:00. When the EoT is applied in the conversion to apparent time, the apparent hour becomes *one more* thus the hour multiplier is 30º and not 15º.

180º   AM, sun is on the lower meridian at midnight
30º   hour hand main dial multiplier, GAT is next full hour, use 2:00
1º 15'   minute hand bezel dial
0'   second hand, second-setting dial
+   +6' 15"   second-setting dial's arc compensation for positive 25 seconds EoT

211º 21' 15" GHA   Sun is longitude 148º 38' 45" E (360º-GHA)



Lindbergh-Weems Second-Setting Watch

Watch time: AM 01:55:00   GMT 01:55:00   EoT 10:25   GAT 02:05:25
Second-Setting syncronized at 00 seconds
EoT +10 min set on bezel, 25 sec(s) marked on center dial

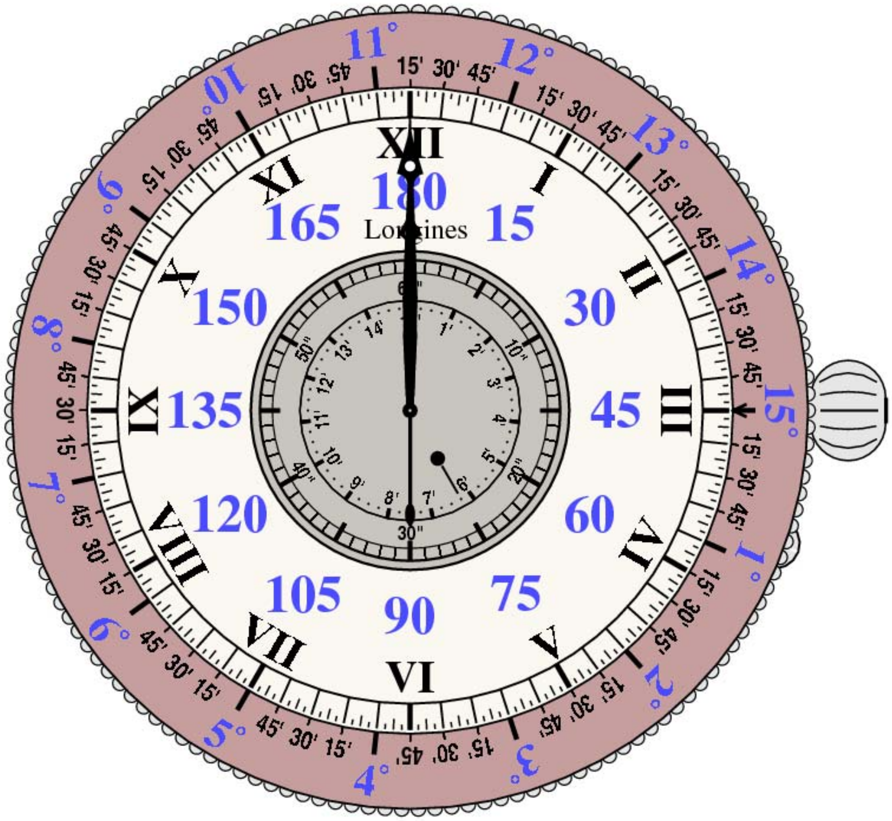
Example 10 – Watch 12:00:00 Midnight   GMT 00:00:00 + EoT -15:25 = GAT 11:44:35

This examples shows how the EoT can shift the hour reading from AM midnight to PM the day before. The bezel is rotated clockwise 15 minutes for negative EoT, EoT's 25 seconds angle conversion is marked on the second-setting dial. The second-setting dial was not rotated for synchronization.

The hour hand is 12 midnight (AM). When the EoT is applied to convert mean time to apparent time, the apparent hour becomes *one less;* 11:00:00 PM apparent time, and the day before.

165º hour hand main dial multiplier, GAT is previous full hour, use 11:00
11º 15' minute hand bezel dial
0' second hand, second-setting dial
+ -6' 15" second-setting dial's arc compensation for negative 25 seconds EoT

176º 08' 45" GHA Sun is longitude 176º 08' 45" W



Lindbergh-Weems Second-Setting Watch

Watch time: AM 12:00:00 GMT 00:00:00 EoT -15:25 GAT -1:44:35
Second-Setting syncronized at 00 seconds
EoT -15 min set on bezel, 25 sec(s) marked on center dial

Comments on Design and Use

The Lindbergh-Weems Second-Setting Pilot's watch was a milestone in celestial navigation watch design. It offered many benefits but it was not a perfect design.

Pro

- Accurate time piece with minimum gain/loss rate for a 1920s watch
- Convenient time synchronization with innovative its second-setting feature
- Easy to read time to angle conversions
- Simple sequential reading of each hand reduces time to angle conversion errors
- Innovative bezel rotation compensation for fast/slow Equation of Time minutes.
- Simple seconds, in time, conversion to arc minutes and seconds on second-setting dial
- Conversion from GMT to GAT is totally mechanical
- Only addition or subtraction are needed to calculate the Greenwich Hour Angle. No steps involve multiplication or division

Con

- The second-setting and bezel features greatly increased manufacturing costs and limited the acceptance of the watch
- No documented field tests exist
- Limited and misleading user documentation, particularly the claim the watch directly computes the user's longitude
- Watch dial is 12 hour face, not the 24 hours used by GMT. Navigator must remember if it's AM or PM. A potential source of error.
- Small format makes it difficult to read bezel's 15'/30'/45' angle marks
- Potential for GHA calculation error when the minute hand is on the hour or near so and the EoT is non-zero. Application of a non-zero EoT can cause the apparent hour to be one more or less than the watch's displayed mean time
- General lack of unit symbols such as degrees º. minutes ', and seconds "
- Lack of second-setting dial tick marks for 15"/30"/45" seconds or arc
- Hour and minute hands may obscure numerals on the second-setting dial
- Hands, dials and bezel not luminous
- Watch is not shock or water proof, frequent conditions in period aircraft

Although the cons list seems long, navigators will quickly overcome most of them with practice in reading the watch hands and performing the necessary time-to-angle conversions. All in all, the Lindbergh-Weems Second-Setting Watch for celestial navigators was revolutionary for its time. Longines still offers the watch as part of their Heritage Collection, one model is shown in Figure 9.[16]

[16] Promotional photo from www.longines.com/search/?q=lindbergh

Figure 9 - Longines Heritage Lindbergh Hour Angle Watch

Historic Importance

There is scant information on how many second-setting watches were sold or what they were actually used for. They were very expensive in their day, still are. It's likely that only a few saw any real navigation use. As such, we have no record of how well this design performed in real navigation practice. Perhaps the National Air and Space Museum Smithsonian Institution's assessment is correct:

> *Longines Wittnauer, the American partner to the Swiss Longines company, found that the combination of the public's fascination with aviation and Charles Lindbergh's celebrity an excellent combination for selling watches. The actual demand for navigation watches was relatively low in the mid-1930s, but their appeal as artifacts of the air age made them irresistible to some wealthy individuals who could afford them. These watches were often more popular for their use as fashion accessories than their practical application as navigational tools.*[17]

Today, pilots have quite a selection of navigation watches to choose from. Modern watches are extremely precise time keepers, some loosing or gaining only a second a month. Their functions, design and layout vary considerably as do their prices. Celestial navigation is no longer a navigator's task. Pilot watches now offer a bewildering array of new navigation functions such as GPS position, altitude, barometric pressure, elapsed-timers, rattrapante stopwatch, split timers, antimagnetic movements, rotary bezel slide rules, luminous dials, tachymeters to calculate speed based on travel time or distance based on speed and dual-time (time in several different time zones) to name a few. Still, the new generation of pilot watches owe a lot to the first real pilot watch - the Lindbergh-Weems Second-Setting Pilot's Watch.

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[17] National Air and Space Museum, "Time and Navigation - The Untold Story of Getting from Here to There" exhibit, Smithsonian Institution, Washington, D.C..

GMT in 12 hr System and Longitude

Figure 10 shows the relationships between GMT time in 12-hour notation (outer-scale), its equivalent Greenwich Hour Angle (inner-scale) and longitude East/West (mid-scale).

The sun's Greenwich Hour Angle is measured westward from Greenwich (**G**) in degrees. Note that the Lindbergh-Weems watch displays GMT time in 12-hour notation. When the display is AM, the navigator must add 180º to the calculation of the Greenwich Hour Angle when using the Lindbergh-Weems watch.

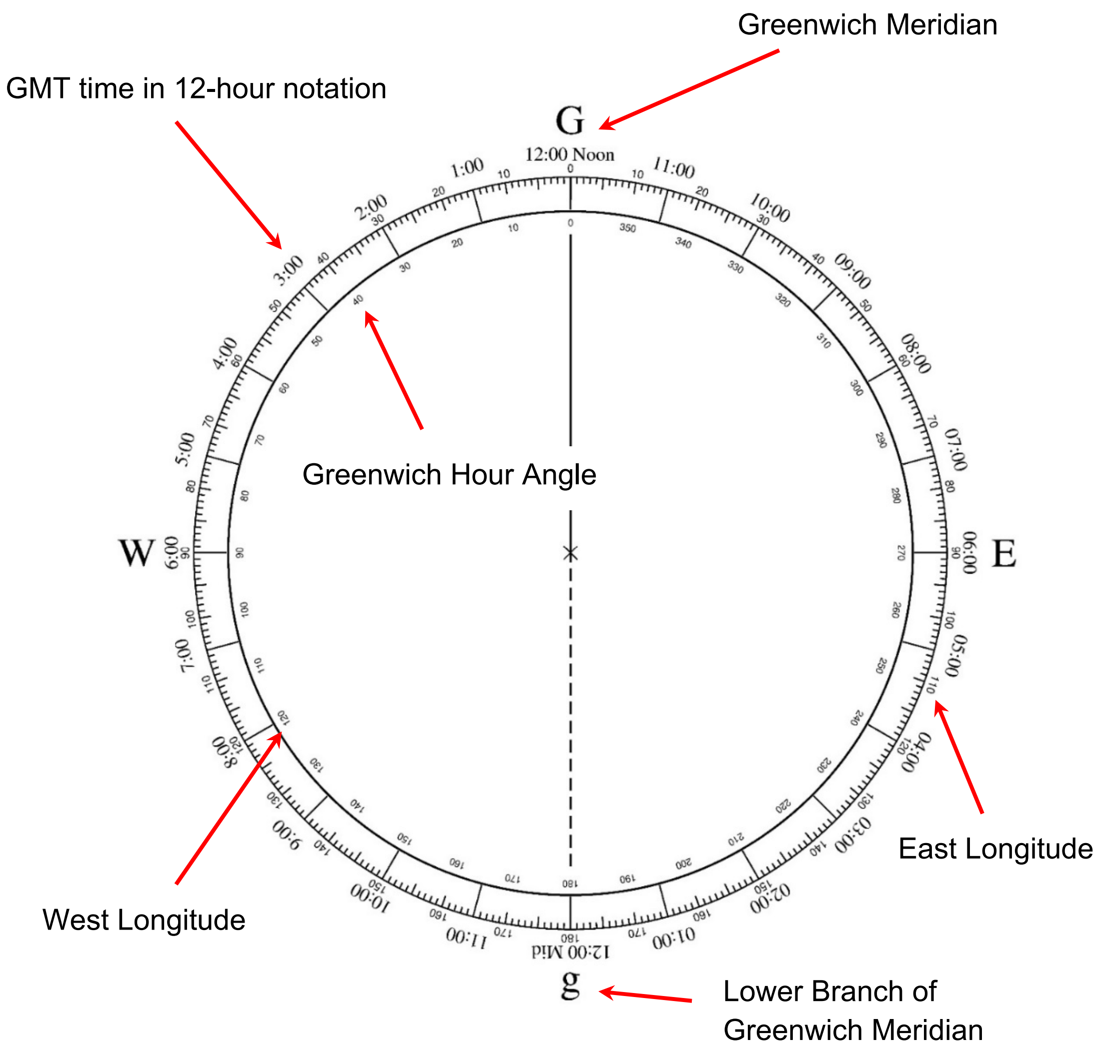


Figure 10 - Relationship of GMT, GHA and East/West Longitude

Time Angle Conversions

HMS	Arc
01:00:00	15°
00:04:00	1°
00:01:00	15'
00:00:04	1'
00:00:01	15"

Figure 11 – Time-Arc Conversions for Common Times and Angles

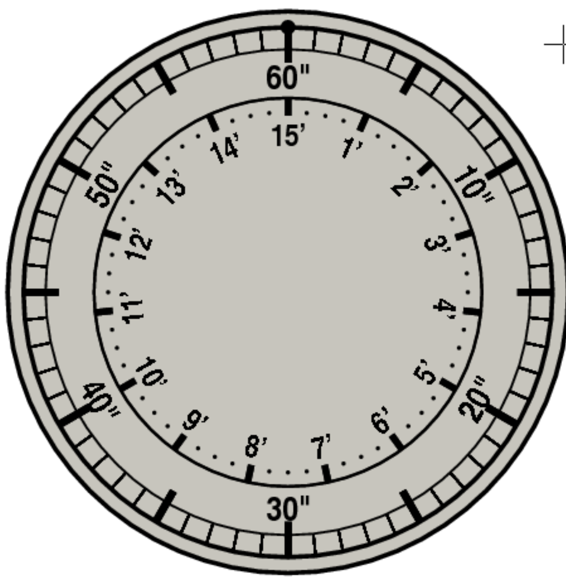


Figure 12 - Detail of the second-setting dial showing the outer rim time scale in seconds and direct conversion to angle minutes and seconds on the inner scale.

Patent - Method of and Apparatus for Navigator's Time Keeping

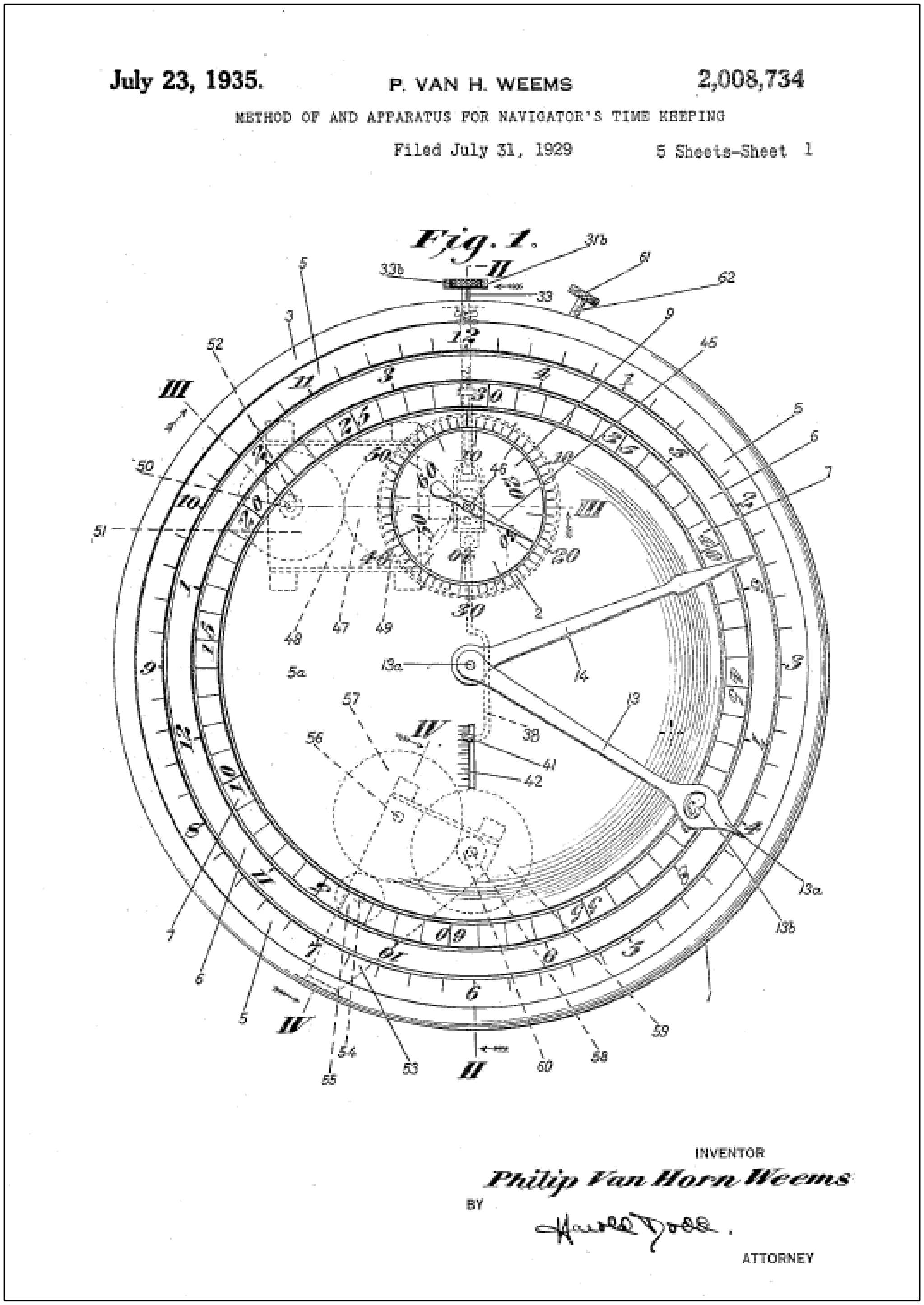


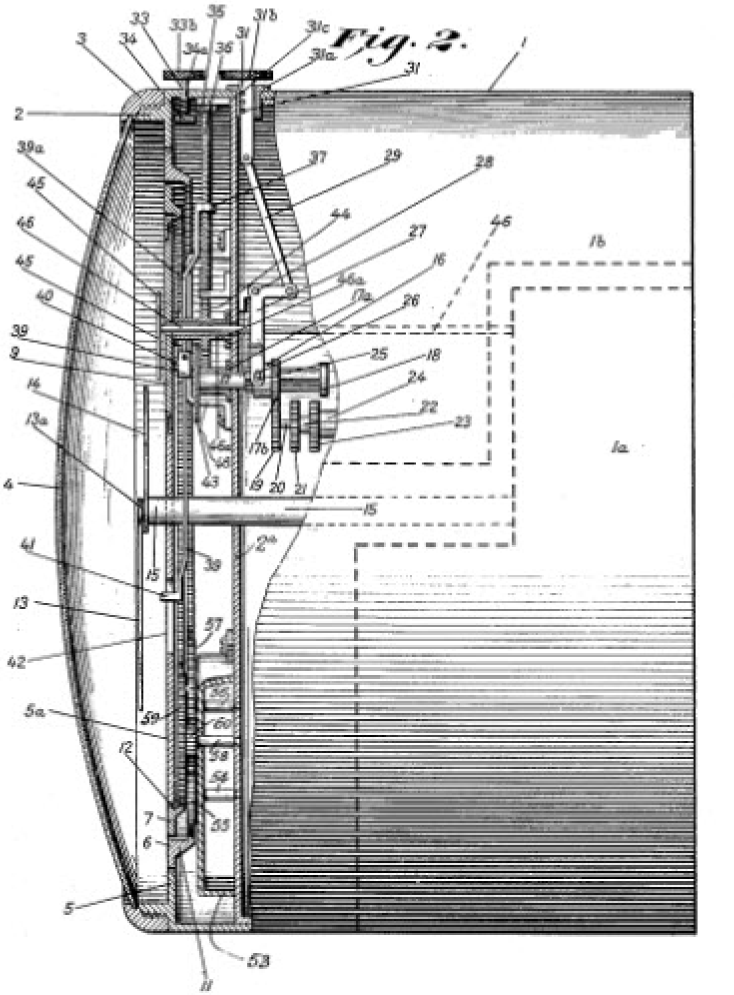
Figure 11 - Illustration from Philip Van Horn Weems' patent "Method of and Apparatus for Navigator's Time Keeping"

July 23, 1935. P. VAN H. WEEMS 2,008,734

METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

Filed July 31, 1929 5 Sheets-Sheet 2

Fig. 2.



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BY

Harold Dodd.

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July 23, 1935. P. VAN H. WEEMS 2,008,734

METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

Filed July 31, 1929 5 Sheets-Sheet 3

Fig. 3.

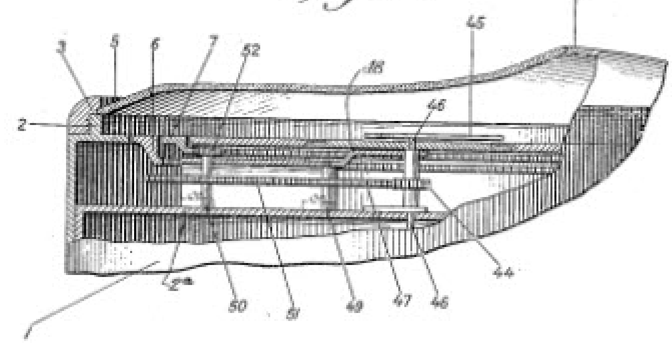


Fig. 4.

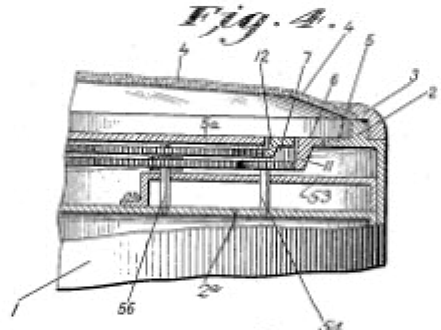


Fig. 5.

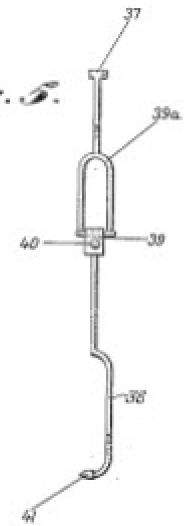
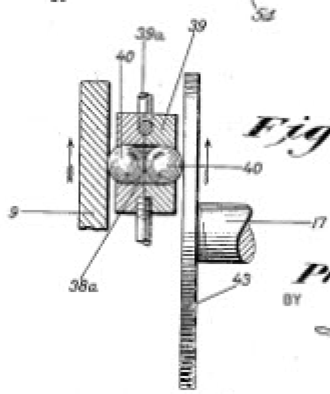


Fig. 6.



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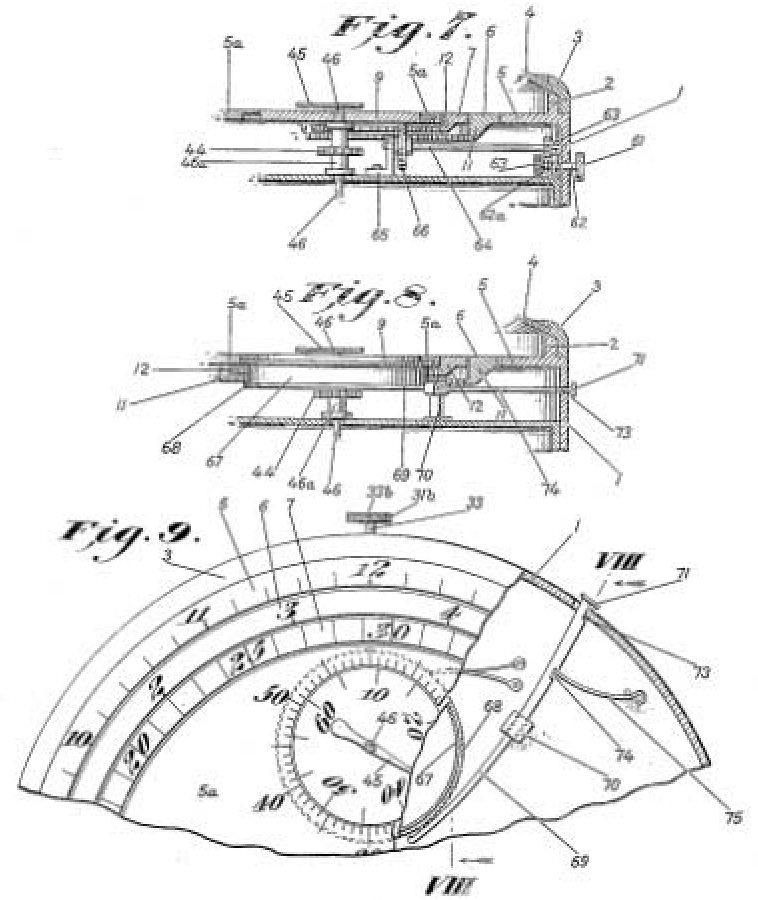
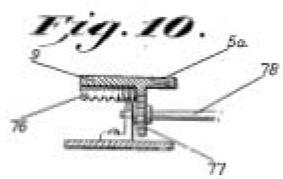
July 23, 1935. P. VAN H. WEEMS 2,008,734

METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

Filed July 31, 1929 5 Sheets-Sheet 4





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METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

Filed July 31, 1929 5 Sheets-Sheet 5

Fig.11 Fig.12

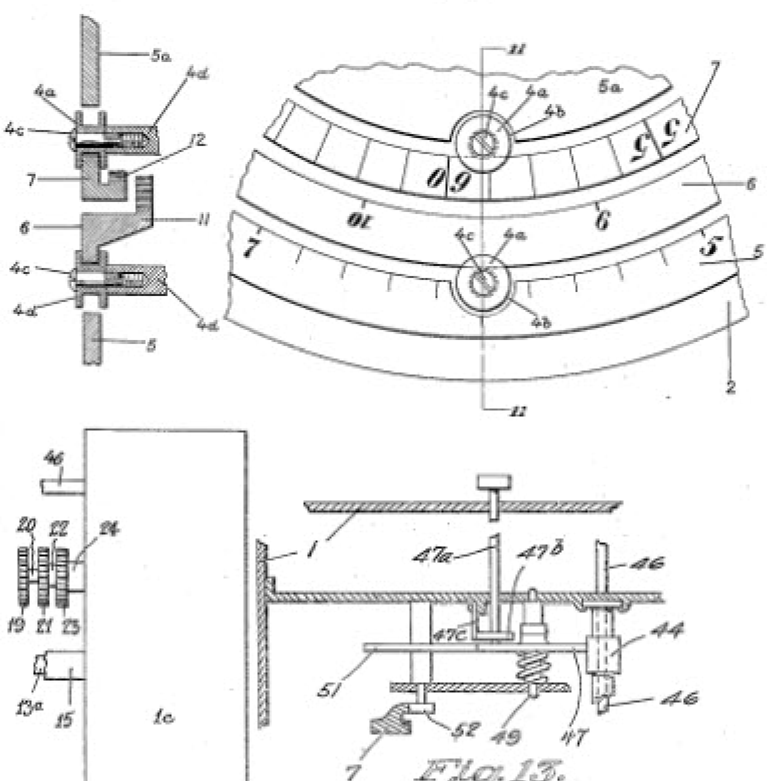

Fig.13.

Fig.14.

INVENTOR
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BY
ATTORNEY

Patented July 23, 1935 | 2,008,734

UNITED STATES PATENT OFFICE

2,008,734

METHOD OF AND APPARATUS FOR NAVIGATORS' TIME KEEPING

Philip Van Horn Weems, Coronado, Calif.

Application July 31, 1929, Serial No. 382,562

40 Claims. (Cl. 58—3)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

My said method and apparatus relates to timekeeping for all navigators as well as for employment in aerial navigation where the problems are more grave and difficult than any other navigation, due to the essentially higher speed of aircraft, the limited time in which a navigator must make his determinations, the limited equipment and space available in such craft therefor, the fact that at times only one person may be on an aircraft with his time usually so occupied in keeping the same safely in the air that he has little time to devote to matters concerning the various times necessary in navigation determining as well as to such determinations.

My invention provides the method and means whereby the keeping of the various times required in navigation and the ascertainment thereof may be afforded readily, even in aircraft and to the operator of a one-man craft without imperiling his management of said craft, as well as without appreciably encumbering such craft.

Heretofore navigators have been obliged to keep separate chronometers for the keeping of the several times which they are obliged to so accurately keep. Heretofore even a one percent error in a chronometer movement, having 3,600 seconds per hour, will result in an error of 36 seconds per hour, which will result in an error of approximately nine miles in determining the navigator's position. Such error is fraught with grave liability endangering life and property. Greater percentages of chronometer error have heretofore resulted in correspondingly larger errors in position determining. Heretofore, to obviate such grave errors and liabilities each of the regular chronometers have been obliged to be very delicately and expensively constructed and maintained in specially cushioned mountings.

With water navigation such several chronometers and their said mountings, and their required weight, space and attention were not such a serious problem as with aerial navigation.

Heretofore for complete chronometer equipment the following chronometers would be required:—One keeping Greenwich civil time; one keeping Greenwich sidereal time; one keeping time by the true sun; and one keeping time by the mean sun. Where a lesser number of chronometers are employed time is required to compute the other required times from those afforded.

While the advent and prevalency of radio and its facilities for the checking of the several times have somewhat ameliorated this condition by more frequent such time checkings, it has heretofore been somewhat unsatisfactory in water navigation and far more unsatisfactory in aerial navigation.

The great problem in all kinds of navigation, which is more acute in aerial navigation due to its greater required and possible speeds, is to minimize to the greatest practical degree the effects of chronometer errors, so that lighter, cheaper and substantially mountingless chronometers may be availed of with as much, or greater, accuracy as now available with the cumbersome, expensive mounted chronometers.

To illustrate, the maximum difference between the true sun and the mean sun varies from a maximum of about thirty seconds in twenty-four hours, so that such difference exists between time by the true sun, or apparent time, and time by the mean sun, mean time; while the difference between said apparent time at Greenwich and Greenwich sidereal time differs approximately ten seconds per hour. Other times have differences but the foregoing typical instances are sufficient for illustration.

The object of this invention is to provide a method and apparatus for keeping time, for instance navigator's time, or times, with greater accuracy and to dispense with, or lessen the necessity of, frequent recourse to more expensive chronometers comparatively inexpensively and by which the several times required, for instance, by a navigator, may readily be indicated with great, or greater than heretofore, accuracy by relatively light and inexpensive means.

To attain these and other objects, and in accordance with the general features of this unitary and related invention, my improved method takes advantage of the physical fact of the differences existing between the several times and utilizes said fact to attain greater accuracy, even with a cheaper mechanism than otherwise would be practical for purposes of navigation, especially aerial navigation.

Said method contemplates in one step thereof the keeping of any one of the desired times by any standard lever escapement time movement, or otherwise, and contemplates as a further step the provision of a separate like time movement, movable only at the rate of difference between the time provided in said first-named step and the other time required, and to associate said two times in substantially close proximity so that the same may, when desired, be read simultaneously. In said association said last named step contemplates that the indices for both said times shall be the same, in the sense that where time according to the first-named step is indicated by the relative movement of a dial

The Lindbergh Hour Angle Watch Instructions [18]

Figure 12 shows Longines's simple guide to using the Lindbergh Hour Angle Watch. It's quite short and somewhat misleading. Firstly, angles are not expressed in the sexagesimal form the watch bezel and dials display. Secondly, it does not explain that the direction of bezel rotation depends on the EoT being fast or slow (positive or negative). Thirdly, and more serious, is the claim the sun's ***Greenwich hour angle of the sun*** is ***(your longitude)***, it's circled in red on the guide. There is only one instance in time each day when this statement is true and that's when the sun is exactly due south or north of the navigator. At that instance, GMT when converted to GHA and adjusted for east or west longitude does the watch give the observer's longitude. At any other time, the user must compute his LHA and compare it to the sun's GHA.

L614, L699 – THE LINDBERGH HOUR ANGLE WATCH LONGINES

Consequently:

The hour hand indicates 15° per hour. One complete circle of the dial (12 hours) is equivalent to 180°.

The minute hand indicates 1° per 4', in other words 15° per hour. Each of the 15° is subdivided into four sectors of 15' of arc. All these indications are engraved on the rotating bezel.

One complete circle of the centre seconds is equivalent to 15' of arc. The rotating central dial is divided into 60" and 15' of arc.

How to use your Lindbergh Hour Angle Watch

Having synchronised your watch with a time signal. As an example when you check it your watch shows 4 hours, 37 minutes and 12 seconds. The equation of time for the day in question is minus 4 minutes and 50 seconds.

Therefore move the marker situated at "15" on the bezel 4 graduations to the left. These graduations represent the minutes engraved around the case.

Your data are as follows:

Seconds hand (centre dial)		**3'**
Minute hand (bezel)	**10°**	**15'**
Hour hand (main dial)	**60°**	

As you have only turned the bezel by 4 minutes, you still have to take into account the 50 seconds (the equation of time being 4 minutes and 50 seconds for the day in question).

On the central dial, the 50 is opposite 12½		./. **12½'**
Greenwich hour angle of the sun **(your longitude)**	**70°**	**5½'**

78 Self-winding watches

Figure 12- Longines' Lindbergh Hour Angle Watch Users Guide

[18] Longines' Lindbergh Hour Angle Watch Users Guide, www.longines.com/watches/heritage-collection/l2-678-4-11-0

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