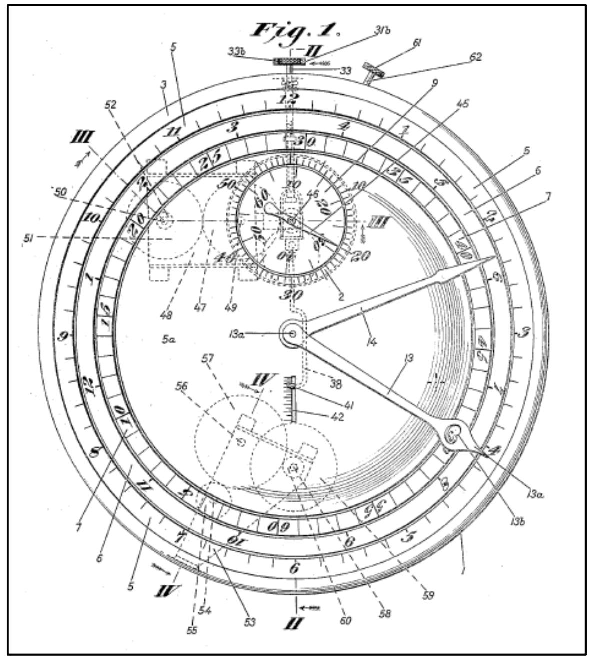
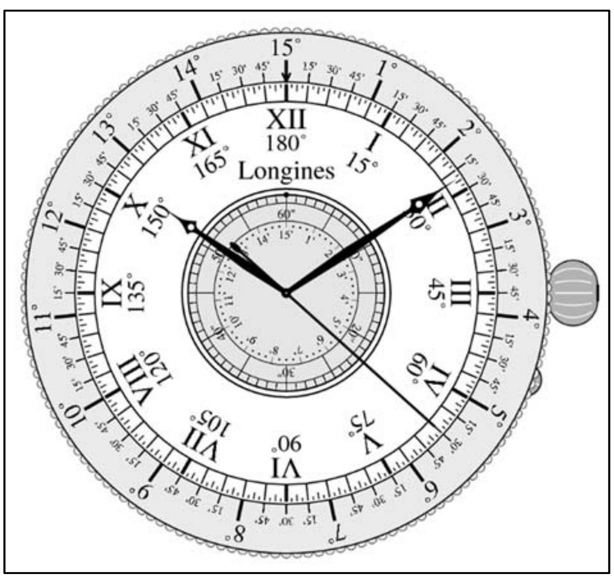
Lindbergh-Weems Second-Setting Watch

Notes on Design and Use

By Edward Popko





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Cover credits clockwise from upper left:

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

P.V.H. Weems second setting watch Detail of second-setting mechanism from P. Van H. Weems' 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 output by Edward Popko

Acknowledgements

I would like to recognize Brad Morris for his encouragement and comments while preparing this paper. His inputs greatly improved the paper's clarity and accuracy. Stan Klein 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 Lindbergh-Weems watch discussion (see the Bibliography for specific references). Their threads inspired me to look closer and write a PostScript 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 are always the possibility of errors. Any errors in this document are strictly mine.

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 dial face that would aid in calculating the sun's Greenwich Hour Angle (GHA). The sun's GHA may be translated to the sun's longitude by multiplying the watches hour, minutes and seconds by 15, the number of degrees or earth's rotation in an hour. The watch faces would do the multiplication; thus it acted like a mechanical circular calculator.

Navigators frequently need to determine their own longitude. It's a two-step process. First, they compute the sun's GHA from GMT, this is what the new watch would do. Second, they need to find the angle between themselves and the sun called their Local Hour Angle (LHA). GHA tells them where the sun is with respect to the Greenwich Meridian, LHA tells them where *they* are with respect to the sun. The navigator's longitude is the addition of the two.[1] The watch does not find LHA.

In 1929, Weems patented a way to precisely set a watch to GMT. [2] An innovative feature, called 'second-setting', used a small center time dial to synchronize the fast moving second hand with a precise time reference such as a radio tone or beep. In 1931, Lindbergh suggested additional improvements: a rotating bezel and angles displayed on the dials, that would make it easier to convert time to an angle. 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 shows an early production version and Lindbergh's design sketches.[3] It would be the first wrist watch specifically designed for

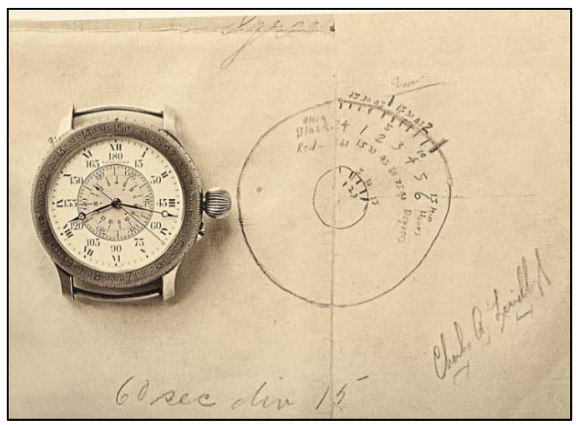

Figure 1 - Early Longines Lindbergh Watch circa 1940 and on of Lindbergh's Design Sketch

[1] Contrary to Longines' marketing material and many internet chronometer forums, the Lindbergh-Weems watch *does not* directly compute the navigator's longitude, the navigator's LHA is also needed.
[2] See
Patent 2,008,734 on page 28.
[3] Photo: www.hautetime.com/celebrating-the-lindbergh-hour-angle-watch-with-longines/83312/,
Also at: timetransformed.com/2017/05/31/longines-lindbergh-hour-angle-watch-90th-anniversary/

pilots doing celestial navigation. Several modernized versions are available today as part of Longines' Heritage Collection.[4]

Time Keeping and Navigation

Watches and clocks designed 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, high humidity, changes in barometric pressure and wide temperature ranges. Chronometers keep constant *mean time,* exactly 24 hours per day, based on the *average length* of the day over the entire year. And since the earth rotates 360 degrees per day there is a direct correspondence between hours of time and the degrees of earth's rotation, in one hour the earth rotates 15 degrees. The most common navigation time standard in the past was Greenwich Mean Time (GMT); it's always in step with earth's rotation.[5]

The sun is also a clock, a celestial one, that keeps its own time called *solar* or *apparent time*. The earth's yearly orbit around the sun is not a perfect circle. As a result, the sun doesn't cross the same meridian, or longitude, at the exact same watch time each day, it differs slightly day-to-day depending on the time of year. This continuous day-to-day change is gradual and subtle. It's caused by the earth's 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 or solar time)* is called the *Equation of Time*.[6] On some days of the year, the Equation of Time is quite large. In November, the sun arrives more than 16 minutes early when compared to watch time. We say it is running fast. And by February it's slow, running more than 14 minutes late. That's a half-hour difference between mean and apparent time! The navigator cannot ignore it when he uses his watch to find the sun's longitude. The Equation of Time tells him how many minutes and mean and apparent time are apart.

Celestial navigators make frequent use of the sun's longitude, mostly to determine their own longitude. First, the navigator converts Greenwich Mean Time, read from the watch, to the sun's apparent time by accounting for the Equation of Time. This converted time is called the Greenwich Apparent Time (GAT), the longitude of the sun expressed in time. Next, the navigator converts GAT hours, minutes and seconds to angular degrees, minutes and seconds by multiplying the time by 15. The result is the sun's Greenwich Hour Angle (GHA), its longitude. GHA is measured westward from the Greenwich Meridian to the meridian of the sun and ranges from 0 to 360 degrees.

This is what the Lindbergh and Weems watch does. It keeps accurate GMT, mechanically accounts for the Equation of Time to display GAT (the bezel feature) and calculates the sun's

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[4] www.longines.com/watches/heritage-collection/l2-713-8-11-0
[5] 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.
[6] The word *equation* is used in the medieval sense of "reconcile a difference"; there is no equation in the sense of mathematics. An observation of navigation historian Frank Reed.

GHA with the aid of annotations on the main and center dials. It greatly simplified going from GMT to GHA. Each of the watch's hands point to apparent times and their corresponding angular conversions. It's just a matter of adding up the angles to get total Greenwich Hour Angle. The watch design is simple, elegant and easy to use.

Additional Comments on the Equation of Time

"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]

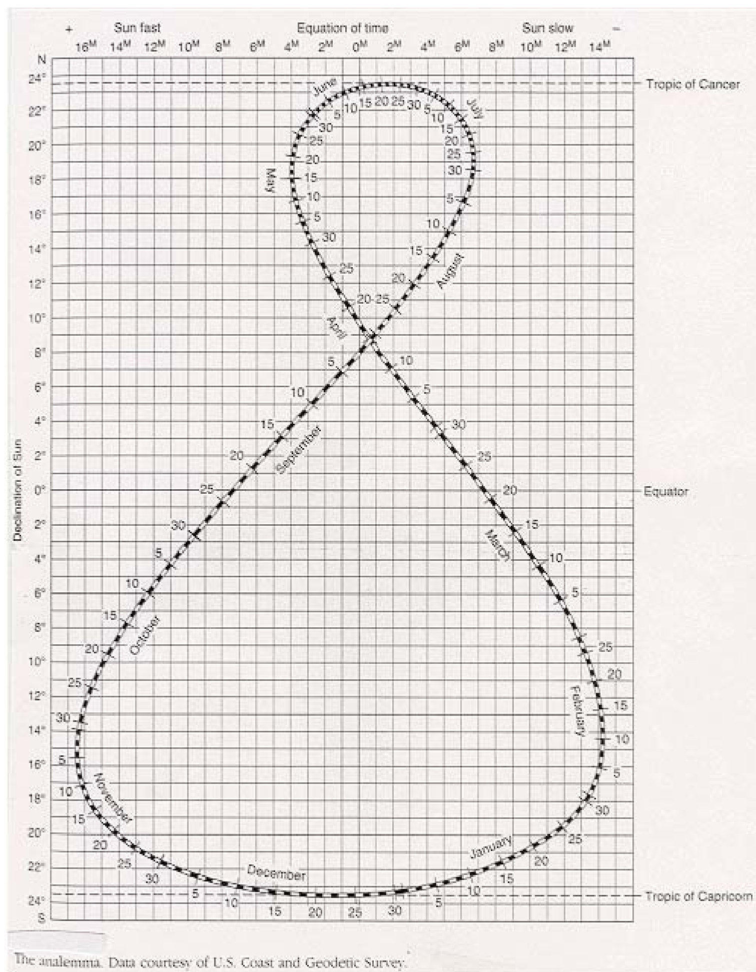

Figure 2 - Daily Change in Equation of Time during the Year

[7] en.wikipedia.org/wiki/Equation_of_time
[8] Analemma data courtesy of the Coast and Geodetic Survey.

Watch Simulator

There aren't many Lindbergh-Weems watches in circulation today; they are collectors' items and expensive to acquire. A PostScript simulator program has been written to generate facsimiles of the watch. It's a convenient way to learn how the watch works. Given Greenwich Mean Time, expressed in 12-hour notation, an AM or PM designation, and the Equation of Time in minutes and seconds, the simulator displays large, very accurate and highly detailed facsimiles of the watch. Images include bezel rotation, precise hour/minute/second hand positions, and second-setting center dial synchronization if this feature is used. A static display has another advantage, the hands are not in continual motion.[9] Figure 3 annotates the main areas of a typical display.

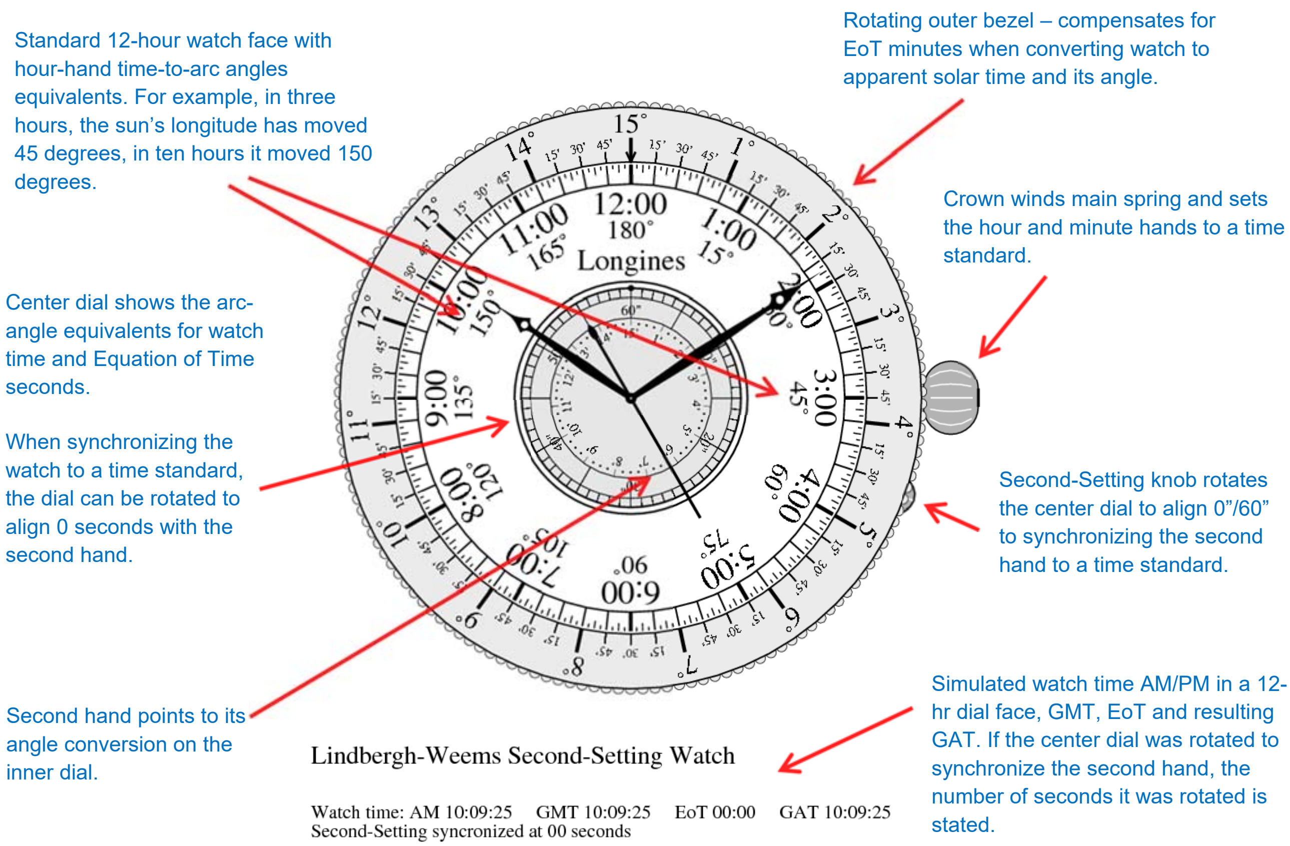

Figure 3 - Typical Simulator Display of Lindbergh-Weems Watch

There are a few important differences between simulator displays and the faces of Longines' various production watches. All time and angles have their appropriate unit symbols such as degree º, minute ' and second ". They are not part of the production watch. In addition, simulator displays are much larger than the actual watch face and include many more time and angle tick

[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 resume their time and 'catch up'.

marks, see Figure 4. The static display is easier to read and more precise than the actual watch, the hands are not in motion.

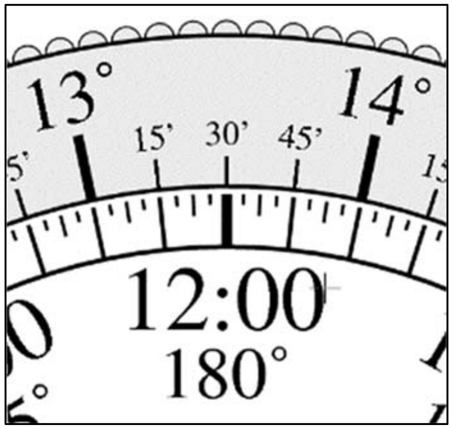

Figure 4 - Detail of Simulator Time and Angle Unit Marks

An additional symbol marks the Equation of Time *seconds* conversion to angular minutes and seconds (Equation minutes are accounted for by rotating the bezel). This small reference mark, a dot-line pointer on the center dial, is not part of the actual watch design. See Figure 5. When using the actual watch, the navigator must visually scan the center dial to match up the correct time-to-angle value, it's a potential source of error. In simulator displays, If the EoT includes seconds, this small graphic appears and ensures the correct value is read. In Figure 5, the EoT includes 30 seconds which is angle 7'30". Each dot equals and additional 15" of arc.

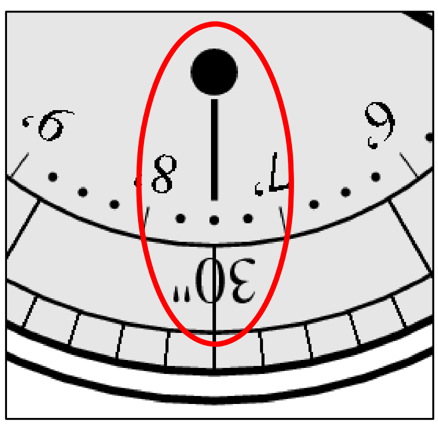

Figure 5 - Equation of Time Seconds to Angle Pointer

Synchronizing the Watch Angle

The first step in using the simulator is to set the watch to the GMT of interest. In the real watch, the crown does this like most analog watches. In the simulator, it's just data entry to the

PostScript program. In the real watch, the second-setting knob rotates the center dial to synchronize the second hand with the time standard's seconds. Again, it's data entry to the PostScript program. Figure 6 shows the simulated time is set to 04:37:12 GMT, bezel set for zero 00:00 EoT and the center dial was rotated a little to simulate synchronizing the second hand. Rotating the center dial does not affect how the various watch hands or angles are read.[10]

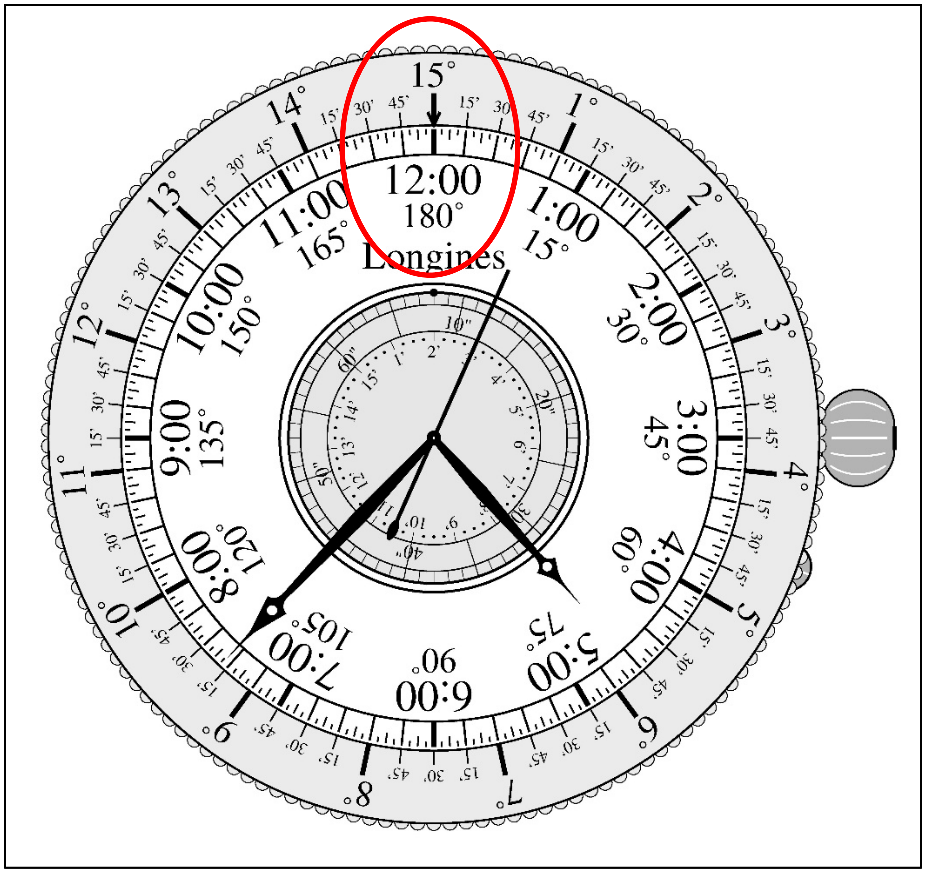

Figure 6 – Initial Synchronization of Watch to 04:37:12 GMT

[10] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 00-a.jpg

In our example, we simulate an EoT of 04:50 (sun is fast). In practice, you must know the EoT and its sign - positive (fast) or negative (slow) - when you calculate GHA. One source of the EoT is the Nautical Almanac. It lists the EoT for GMT 00:00 and GMT 12:00 for every day of the year.

To account for EoT minutes, we rotate the bezel's 15º mark clockwise when the EoT is negative or counter clockwise when positive, the number of EoT minutes. In this example, EoT is fast 4 minutes so the bezel mark is rotated *four minutes counter clockwise on the main dial*. See Figure 2 and the detail.[11] We do not have to pre-set the watch for EoT seconds. We convert it to an angle later by simply reading its angular conversion from the center dial. When there are EoT seconds, the simulator displays a small dot-line pointer indicating the seconds-to-angle conversion. In our example, 50 EoT seconds equal 12' 30", it's circled in the figure below. We will discuss in more detail in the next section.

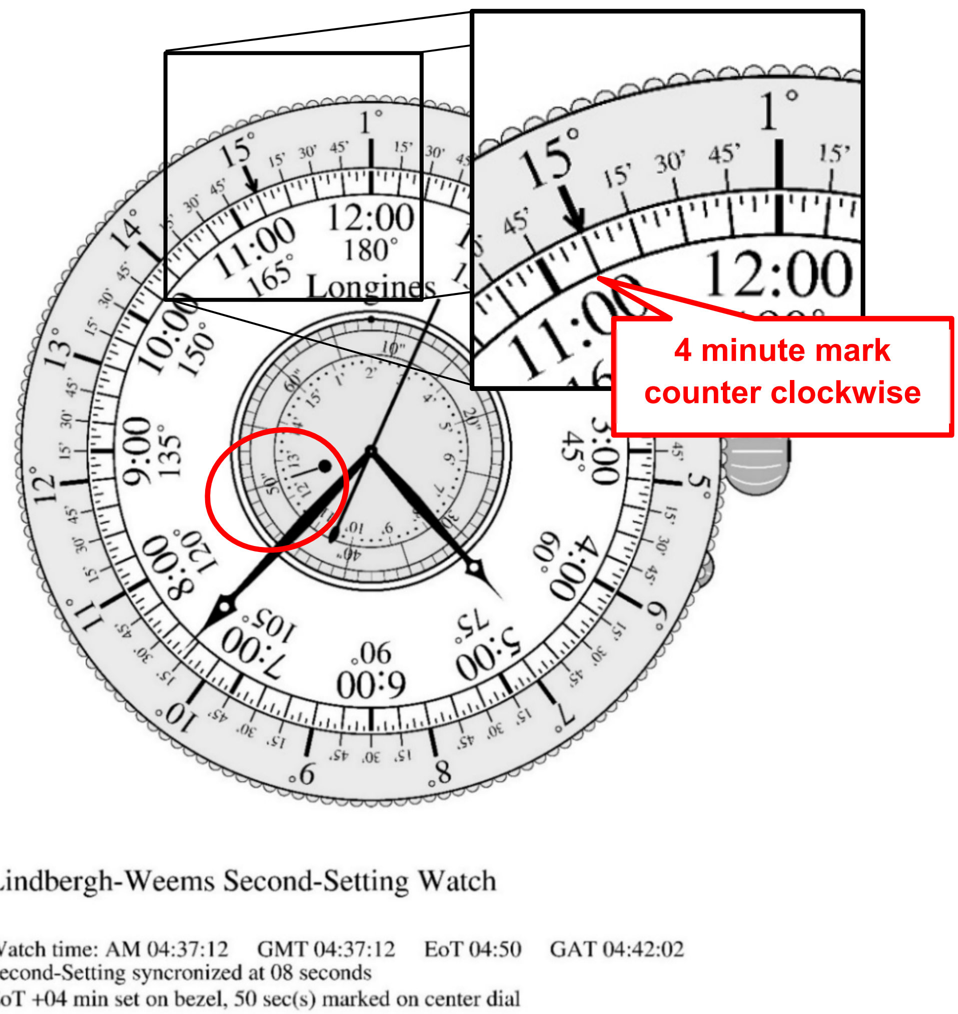

Figure 7 - Bezel Rotation Compensation for EoT Minutes

[11] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 00-b.jpg

Calculating the Sun's Greenwich Hour Angle

Assuming the watch is properly synchronized to GMT and the bezel rotated for any whole EoT minutes, do the following to find the GHA of the sun. Simply make a list of the various hour, minute, and second hand's time-to-arc angle conversions, and then add them up. The total is the GHA. Referring to the previous figure, the steps for making the list are as follows:

[1] Note if the time is AM or PM. Greenwich Mean Time is a 24-hour system; however, the Lindbergh-Weems watch displays 24-hour time on a 12-hour face. If GMT displayed is AM, start your GHA angle list with 180º, the sun is on the lower meridian at midnight and GHA is measured west from Greenwich Meridian. If the GMT is PM, the initial 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 degree conversion from the main dial. Ignore any partial hour readings. Then, check by inspection to see if the application of the EoT will advance the hour to the next hour or cause it to retreat to the previous hour. In most cases, it will be obvious by inspection, but the aviator may need to resort to pencil and paper to confirm the GHA hour when the EoT value and the minutes of time near the hour are very close. Section *Basic Hour-Angle Examples* provides more examples. Section *Subtler Hour-Angle Examples* shows examples where readings on the hour or near so are affected by the EoT. They are less common but the user needs to be aware of them and use the appropriate hour-to-angle multiplier. In this example it is 60º.

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

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

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

[6] GHA is the sum of the list.

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

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 center dial.

[1] 180º AM sun is on the lower meridian at midnight
[2] 60º hour hand main dial
[3] 10º 15' minute hand bezel dial
[4] 3' second hand center dial
[5] + +12' 30" center dial tick EoT 50 seconds compensation, sign is positive since fast
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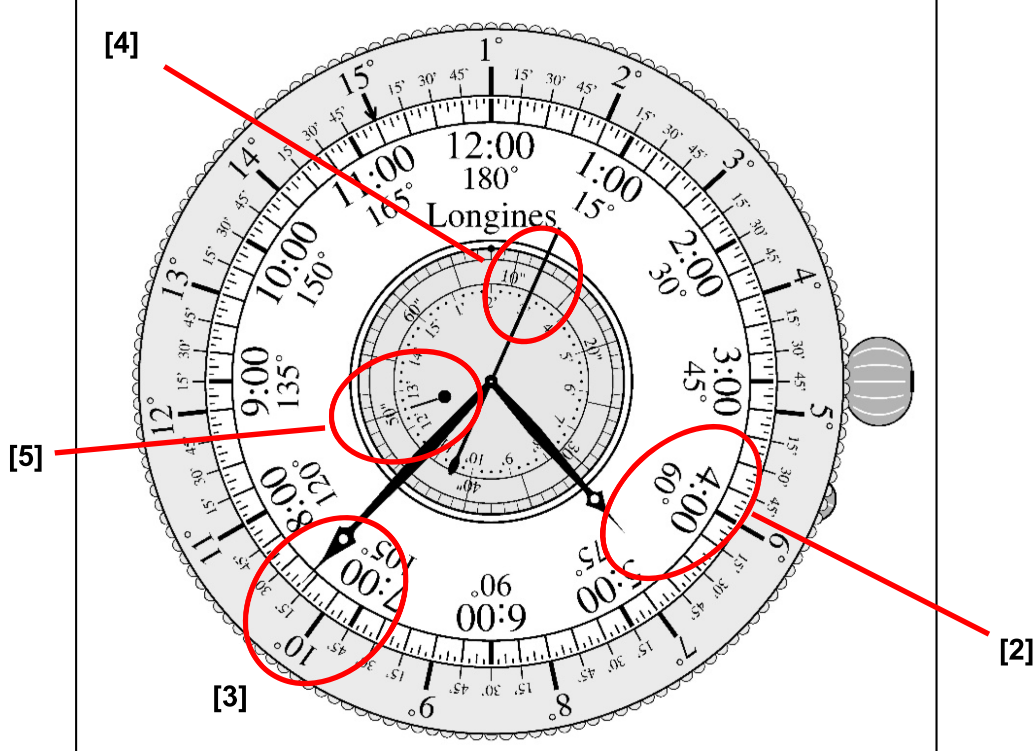
[6] 250º 30' 30" GHA



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

[12] Graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 10a.jpg

Examples

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

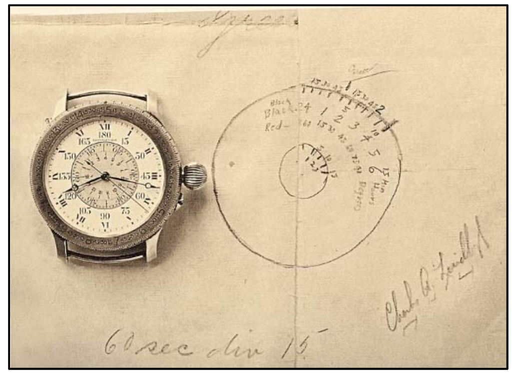
The first group, *Basic Hour-Angle Examples*, shows AM-PM and positive-negative Equation of Time combinations. These examples are easy to understand and provide some practice in bezel rotation for EoT minutes and reading each watch hand's angle conversion. The list of angles is summed up for the total Greenwich Hour Angle. 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 of examples, illustrate how the EoT can affect GMT time-to-apparent-time readings when GMT it is on the hour or near so. Depending on how close the hour hand is to the hour and the magnitude of EoT, the apparent time (a combination of GMT plus EoT) may actually be one hour before or after then what appears on the watch face. These cases are not common 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 read the watch and perform the GHA arithmetic correctly.

Basic Hour-Angle Examples

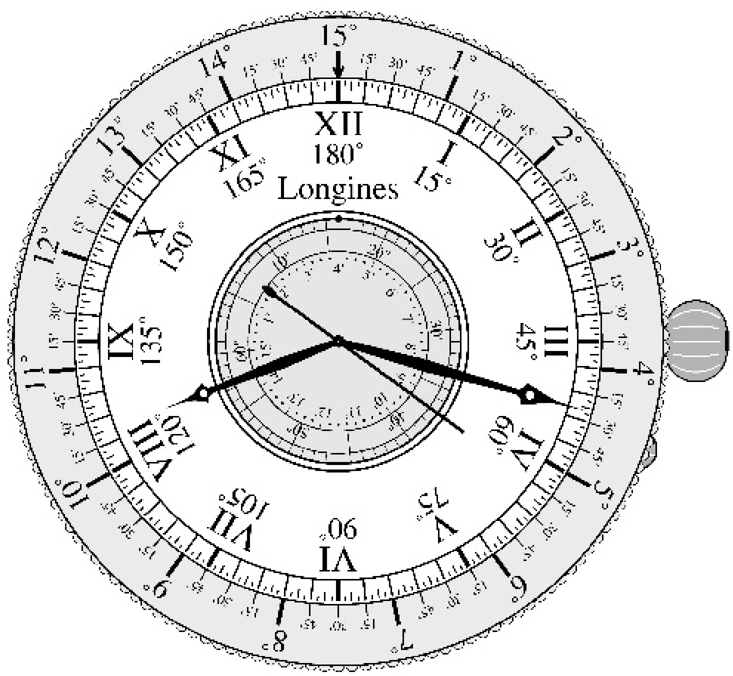
Concept Drawing for Longines' Watch   GMT 08:17:37 + EoT 00:00 = GAT 08:17:37 [13]

No bezel or center dial compensation, EoT is 00:00. Second-Setting center face rotated 16 seconds to synchronize the second hand at zero seconds.



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



Lindbergh-Weems Second-Setting Watch
GMT time 8:17:37   EoT 0:0   Second-Setting syncronized at 16 seconds
EoT is 00:00

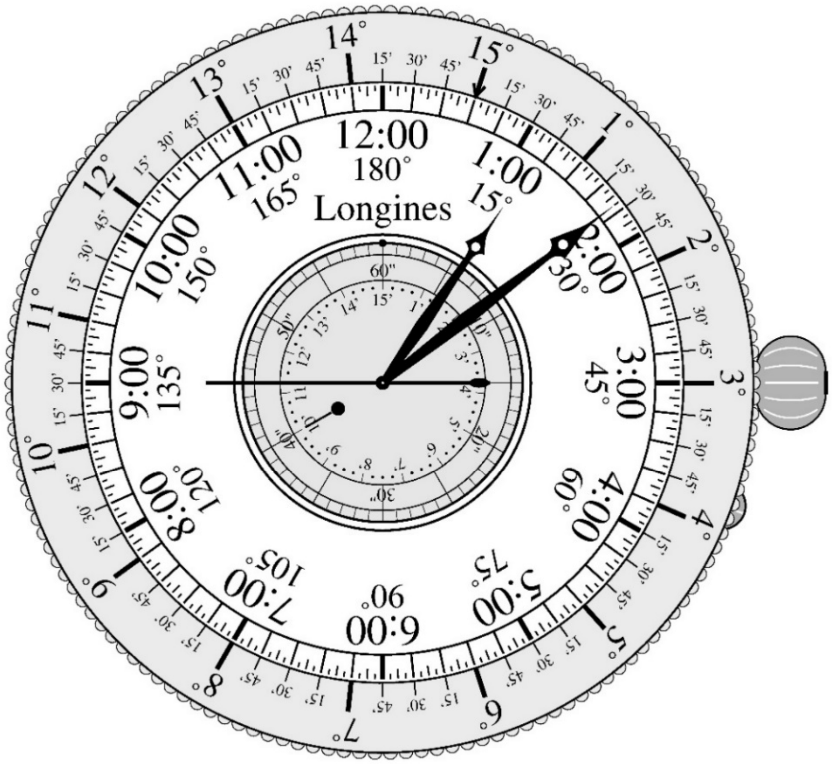
[13] Photo: www.hautetime.com/celebrating-the-lindbergh-hour-angle-watch-with-longines/83312/,
Also at: timetransformed.com/2017/05/31/longines-lindbergh-hour-angle-watch-90th-anniversary/
Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 36 Sketch.jpg

Example 1 - Watch AM 01:08:45   GMT 01:08:45 + EoT -03:40 = GAT 01:05:05 [14]

Bezel is rotated clockwise 3 minutes for negative EoT, EoT's 40 seconds angle conversion is marked on center dial. Second-Setting center dial not rotated to synchronize the second hand at zero seconds.

180º AM, sun is on the lower meridian at midnight
15º hour hand main dial
1º 15' minute hand bezel dial
11' 15" second hand center dial
\+ -10' center dial arc compensation for negative 40 seconds EoT

196º 16' 15" GHA



Lindbergh-Weems Second-Setting Watch

Watch time: AM 01:08:45 GMT 01:08:45 EoT -3:40 GAT 01:05:05
Second-Setting syncronized at 00 seconds
EoT -03 min set on bezel, 40 sec(s) marked on center dial

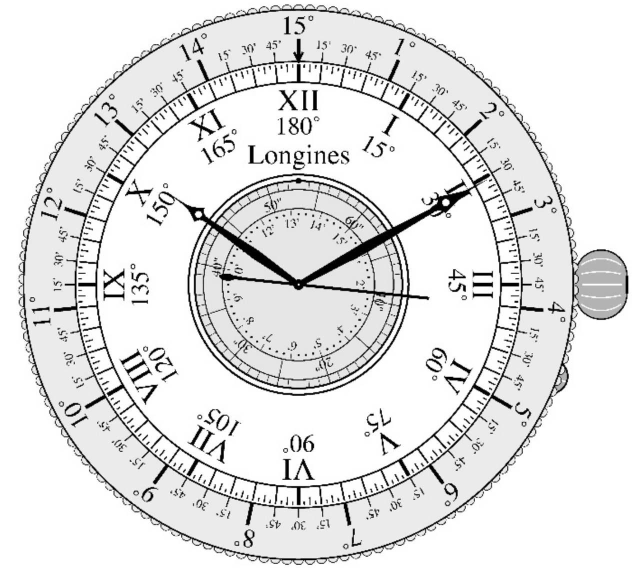
[14] Example originally posted on NavList by Gary LaPook. fer3.com/arc/m2.aspx/LHA-listing-minute-looking-for-LaPook-jan-2015-g29895
Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 12 LaPook.jpg

Example 2 - Watch AM 10:10:09   GMT 10:10:09 + EoT 00:00 = GAT 10:10:09 [15 16]

Bezel is not rotated, EoT is 00:00. Second-Setting center dial rotated 3 seconds to synchronize the second hand at zero seconds.

180º   AM, sun is on the lower meridian at midnight
150º   hour hand main dial multiplier
   2º 30’   minute hand bezel dial
 +   2’ 15” second hand center dial
         0’   no EoT seconds compensation

332º 32’ 15” GHA



Lindbergh-Weems Second-Setting Watch

Watch time: AM 10:10:09   GMT 10:10:09   EoT 00:00   GAT 10:10:09
Second-Setting syncronized at 53 seconds

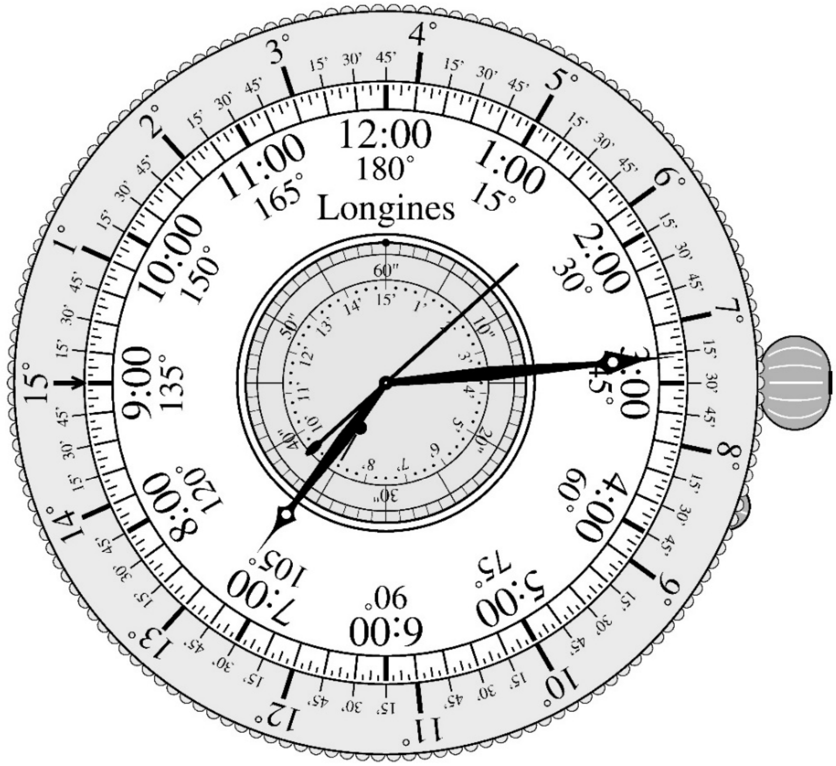
[15] Longines original production watch, www.longines.com/watches/heritage-collection/l2-678-4-11-0
[16] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 19 Actual.jpg

Example 3 – Watch PM 07:14:08   GMT 19:14:08 + EoT 15:35 = GAT 19:29:43 [17]

Bezel is rotated counter clockwise 15 minutes for positive EoT, EoT's 35 seconds angle conversion is marked on center dial. Second-Setting center dial not rotated for second hand synchronization.

	0º	PM
	105º	hour hand main dial multiplier
	7º 15'	minute hand bezel dial
	2'	second hand center dial
+	+8' 45"	center dial arc compensation for positive 35 seconds EoT

	112º 25' 45"	GHA



Lindbergh-Weems Second-Setting Watch

Watch time: PM 07:14:08   GMT 19:14:08   EoT 15:35   GAT 19:29:43
Second-Setting syncronized at 00 seconds
EoT +15 min set on bezel, 35 sec(s) marked on center dial

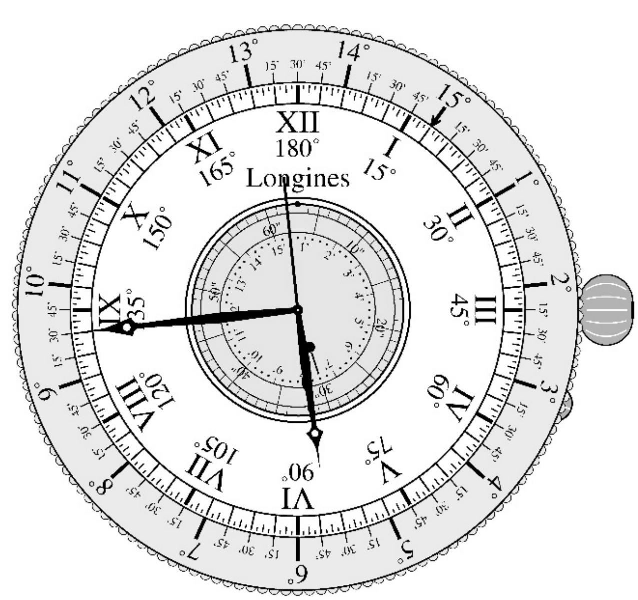
[17] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 20.jpg

Example 4 – Watch AM 05:44:02   GMT 05:44:02 + EoT -06:30 = GAT 05:37:30 [18] [19]

Bezel is rotated clockwise 6 minutes for negative EoT, EoT's 30 seconds angle conversion is marked on center dial. Second-Setting center dial rotated 3 seconds to synchronize the second hand at zero seconds.

180º	AM sun is on the lower meridian at midnight
75º	hour hand main dial multiplier
9º 30'	minute hand bezel dial
30"	second hand center dial
+ -7' 30"	center dial compensation for negative 30 seconds EoT

264º 23' 00"	GHA



Lindbergh-Weems Second-Setting Watch

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

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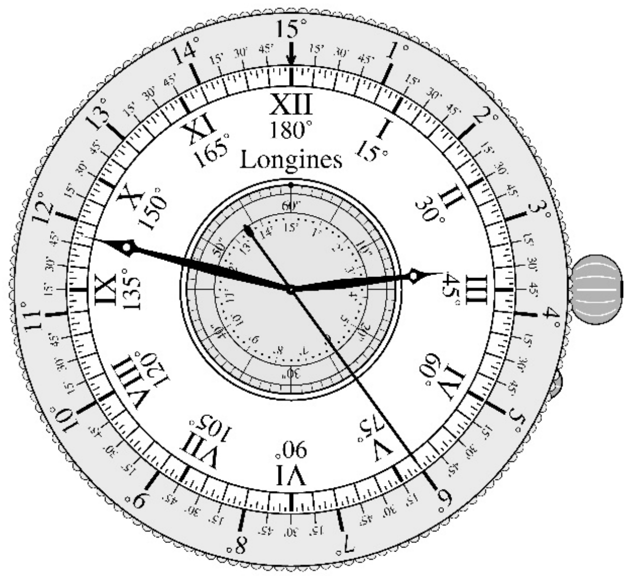
[18] www.modernmontra.com/Utmerket-Verdi-Svart-GullSt%C3%A5l-Longines-LINDBERH-HOUR-ANGLE-WATCH-Automatisk-Lindbergh-Hour-Angle-Herreklokker-xq7Afs11-p-2920.html
[19] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 29.jpg

Example 5 – Watch PM 02:47:24 GMT 14:47:24 + EoT 00:00 = GAT 14:47:24 [20] [21]

Bezel is not rotated, EoT is 00:00. Second-Setting center dial is not rotated for second had synchronization.

0º	PM
30º	hour hand main dial multiplier
11º 45’	minute hand bezel dial
+ +6’	second hand center dial
0’	no EoT seconds compensation

41º 51’ 00”	GHA



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

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[20] Photo: www.hodinkee.com/articles/the-history-and-science-behind-the-lindbergh-longines-hour-angle-watch
[21] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 32.jpg

Subtler Hour-Angle Examples

The following examples show subtler Greenwich Hour Angle cases that occur when the hour hand is on or very near so. Depending on the magnitude of the Equation of Time, it's positive or negative value may shift the hour-multiplier 15° less (Example 6) or more (Example 7) than what is directly read from the main dial.

The same situation may occur when GMT time on or near 12:00, and the of Equation of Time shifts AM to PM (Example 8) or noon to AM (Example 9).

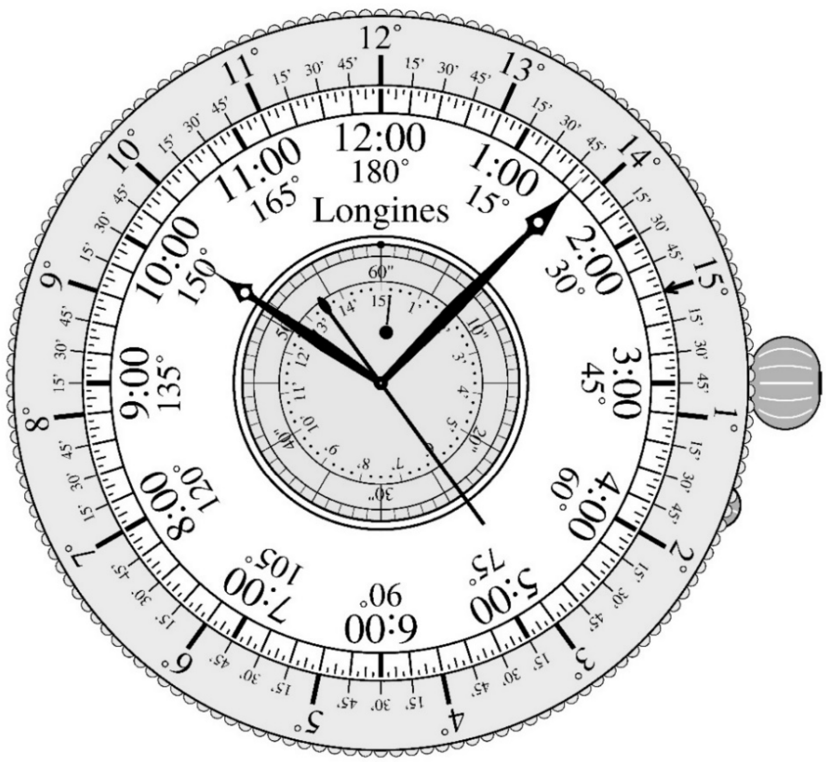
Example 6 – Watch AM 10:07:24 GMT 10:07:24 + EoT -12:01 = 09:55:23 [22]

Bezel is rotated clockwise 12 minutes for negative EoT, EoT’s 01 second angle conversion is marked on center dial. Second-Setting center dial is not rotated for synchronization.

The hour hand is near 10:00. When the EoT is applied to convert mean time to apparent time, the apparent hour becomes *one less* thus the hour multiplier 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 center dial
\+ -15” center dial arc compensation for negative 01 second EoT

328º 50’ 45” 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, 1 sec(s) marked on center dial

[22] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 13b.jpg

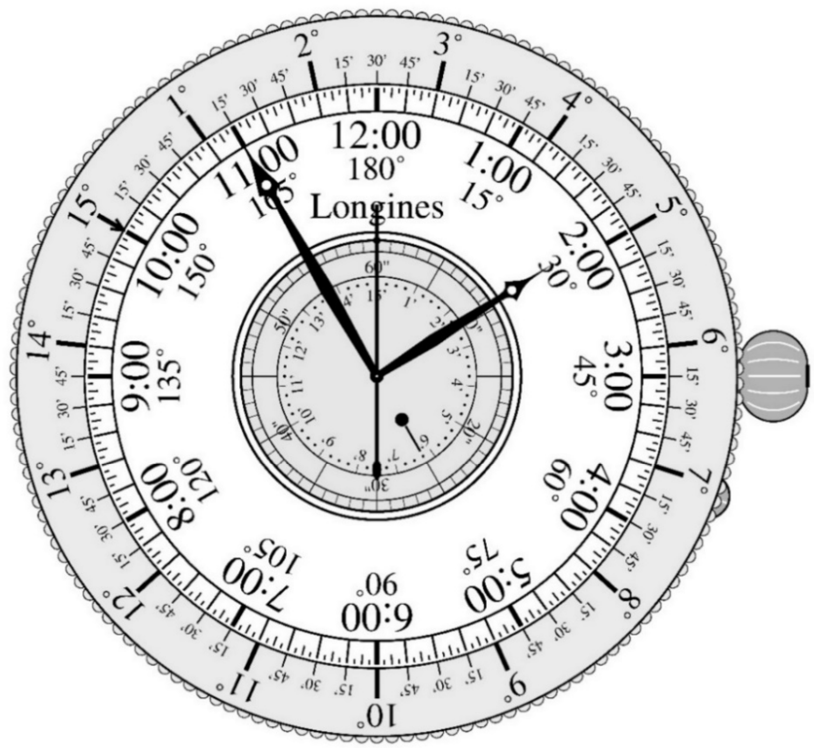
Example 7 – Watch AM 01:55:00 GMT 01:55:00 + EoT 10:25 = GAT 02:05:25 [23]

Bezel is rotated counter clockwise 10 minutes for positive EoT, EoT's 25 seconds angle conversion is marked on center dial. Second-Setting center dial not rotated for synchronization.

The hour hand is near 02:00. When the EoT is applied to convert to mean time 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 center dial
+ +6' 15"	center dial arc compensation for positive 25 seconds EoT

211º 21' 15"	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

[23] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 27.jpg

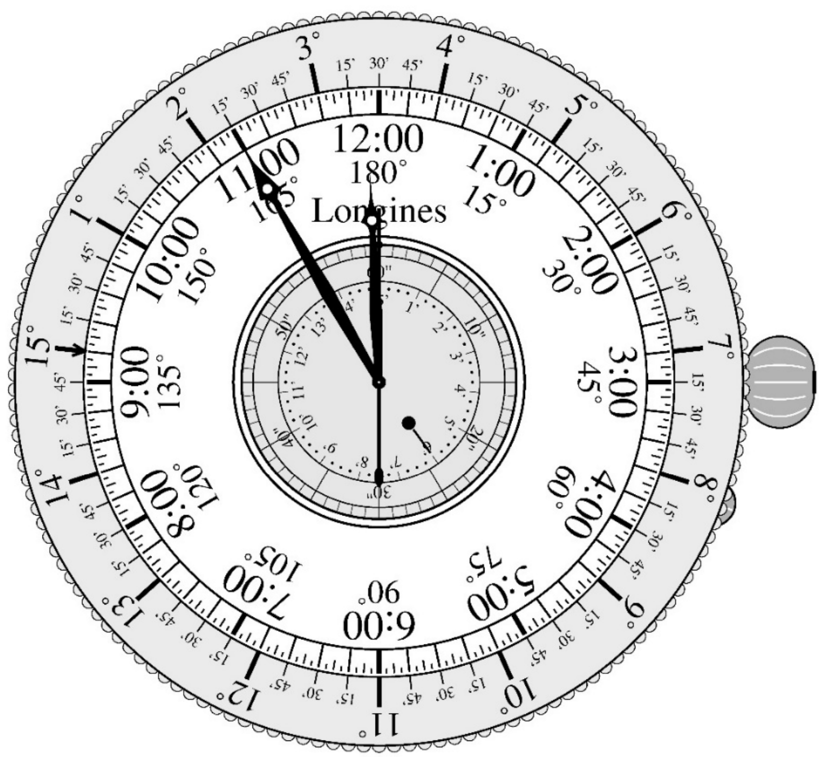
Example 8 – Watch AM 11:55:00   GMT 11:55:00 + EoT 14:24 = GAT 12:09:24 [24]

Bezel is rotated counter clockwise 14 minutes for positive EoT, EoT’s 24 seconds angle conversion is marked on center dial. Second-Setting center dial is no 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 center dial
+	+6’ 00”	center dial arc compensation for positive 24 seconds EoT

	2º 21’ 00”	GHA



Lindbergh-Weems Second-Setting Watch
EoT shifts time to PM
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

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[24] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 28.jpg

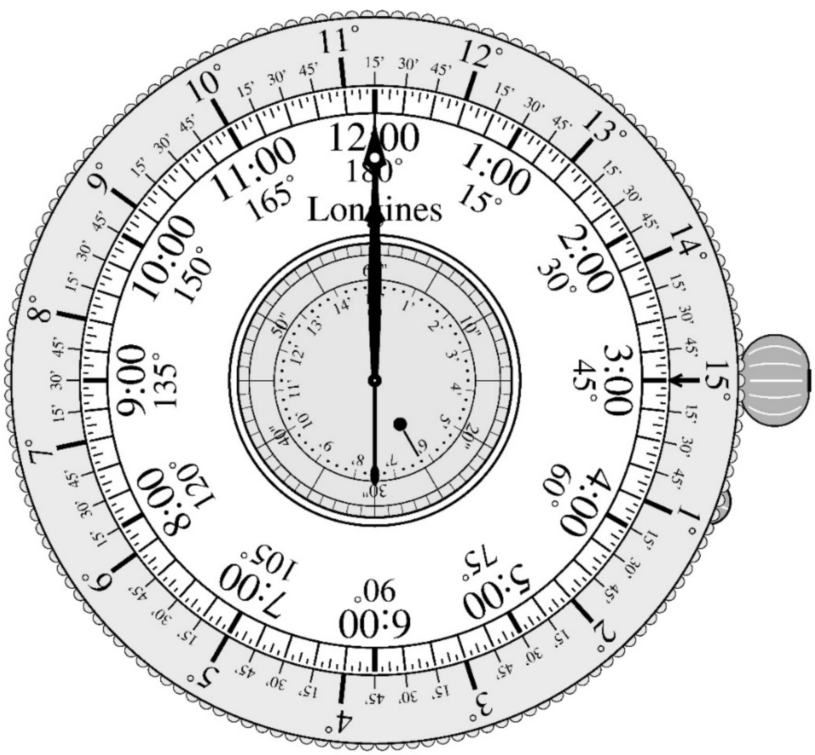
Example 9 – Watch 12:00:00 Noon GMT 12:00:00 + EoT -15:25 = GAT 11:44:35 [25]

Bezel is rotated clockwise 15 minutes for negative EoT, EoT's 25 seconds angle conversion is marked on center dial. Second-Setting center dial is not rotated for synchronization.

The hour hand is on 12:00 noon. When the EoT is applied to convert mean time to apparent time, the apparent hour becomes *one less;* 12:00 noon mean time becomes 11 AM apparent time.

180º sun is on the lower meridian at midnight
165º hour hand main dial multiplier, GAT is previous full hour, use 11:00
11º 15' minute hand bezel dial
0' second hand center dial
\+ -6' 15" center dial arc compensation for negative 25 seconds EoT

356º 08' 45" GHA



Lindbergh-Weems Second-Setting Watch

Watch time: AM 12:00:00 GMT 12:00:00 EoT -15:25 GAT 11:44:35
Second-Setting syncronized at 00 seconds
EoT -15 min set on bezel, 25 sec(s) marked on center dial

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[25] Simulator graphic: Lindbergh-Weems Second-Setting Watch v12 Ex 24a.jpg

Comments on Design and Use

The Lindbergh-Weems Second-Setting 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 second-setting feature
- Simple method for converting mean time to the sun's Greenwich Hour Angle. Sequential reading of each hand reduces time-angle conversion errors
- Innovative bezel rotation compensation for Equation of Time minutes, converts GMT to GAT mechanically
- 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
- Small format makes it difficult to read Bezel's 15'/30'/45' angle marks
- Potential for large GHA calculation error when the minutes hand is on the hour or near so and the EoT is non-zero. Application of a non-zero EoT may cause the apparent hour to be one more or less than the watch's displayed mean time. Thus, the hour multiplier may be correspondingly be 15º more or less. A similar condition can change mean AM to apparent PM or mean PM to apparent AM.
- General lack of unit symbols such as degrees º. minutes ', and seconds "
- Lack of center dial tick marks for 15"/30"/45" seconds or arc
- Potential GHA calculation error when adding sexagesimal angles. Adding and subtracting sexagesimal angles often lead to carrying errors
- Hands, dial faces and bezel not luminous
- Watch is not shock or water proof

Although the list of cons seems long, navigators will quickly overcome most of them with a little 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.[26]

[26] Promotional photo from www.swisswatchexpo.com/watches/Longines/Heritage-Lindberg-Hour-Angle-L2-678-4-11-0-8124#popup_product

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: [27]

> *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.*

Today, pilots have quite a selection of navigation watches to choose from. Modern pilot 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

[27] Credit: National Air and Space Museum, Smithsonian Institution, https://timeandnavigation.si.edu/multimedia-asset/longines-weems-second-setting-and-lindbergh-hour-angle-watch-advertisement.

longer a navigator’s task. Pilot watches now offer a bewildering array of new functions such as GPS position, altitude, barometric pressure, elapsed-timers, rattepante stopwatch, split timers, antimagnetic movements, rotary bezel slide rules, luminous dials, tachymeters to calculates 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 Watch.

Reference

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).[28]

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.

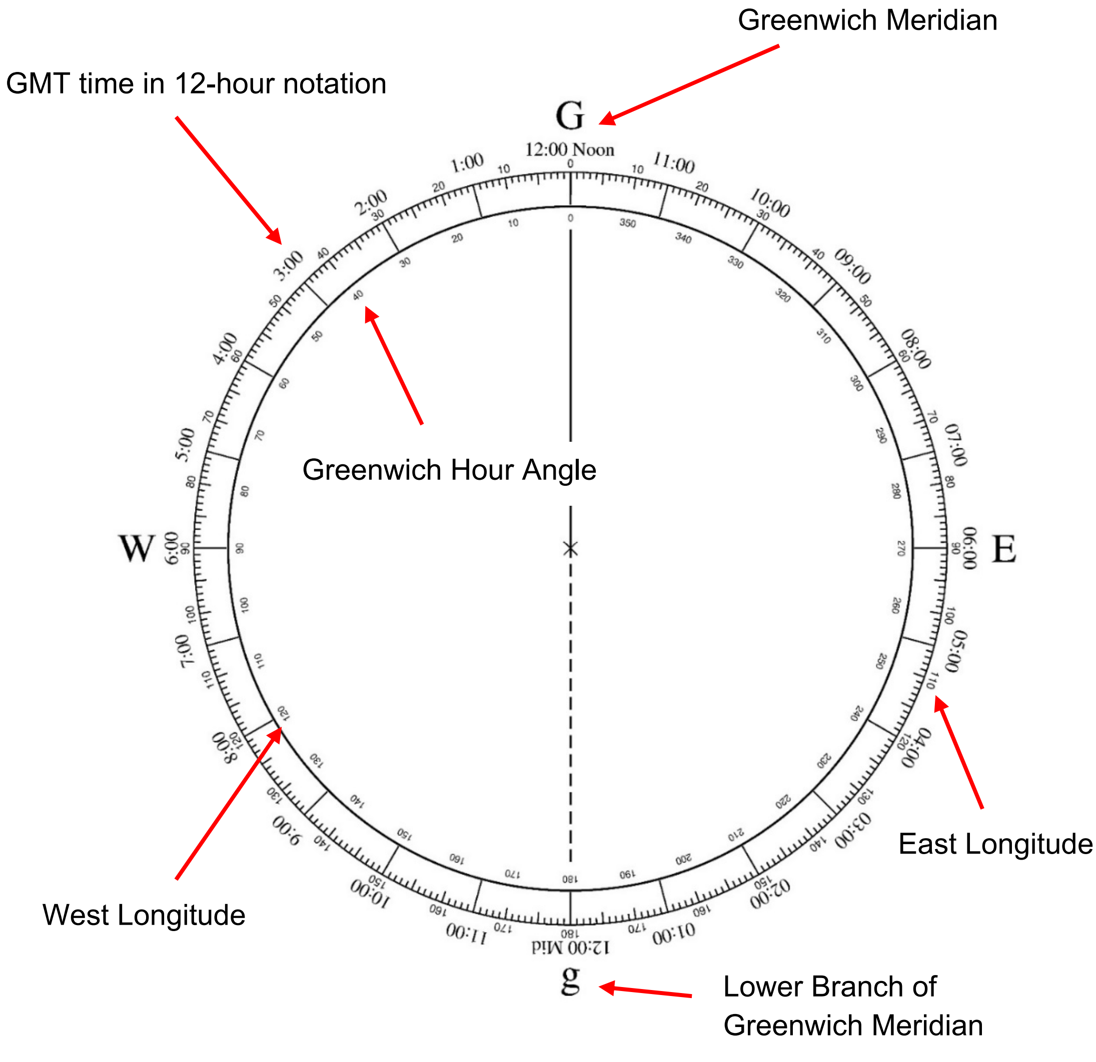
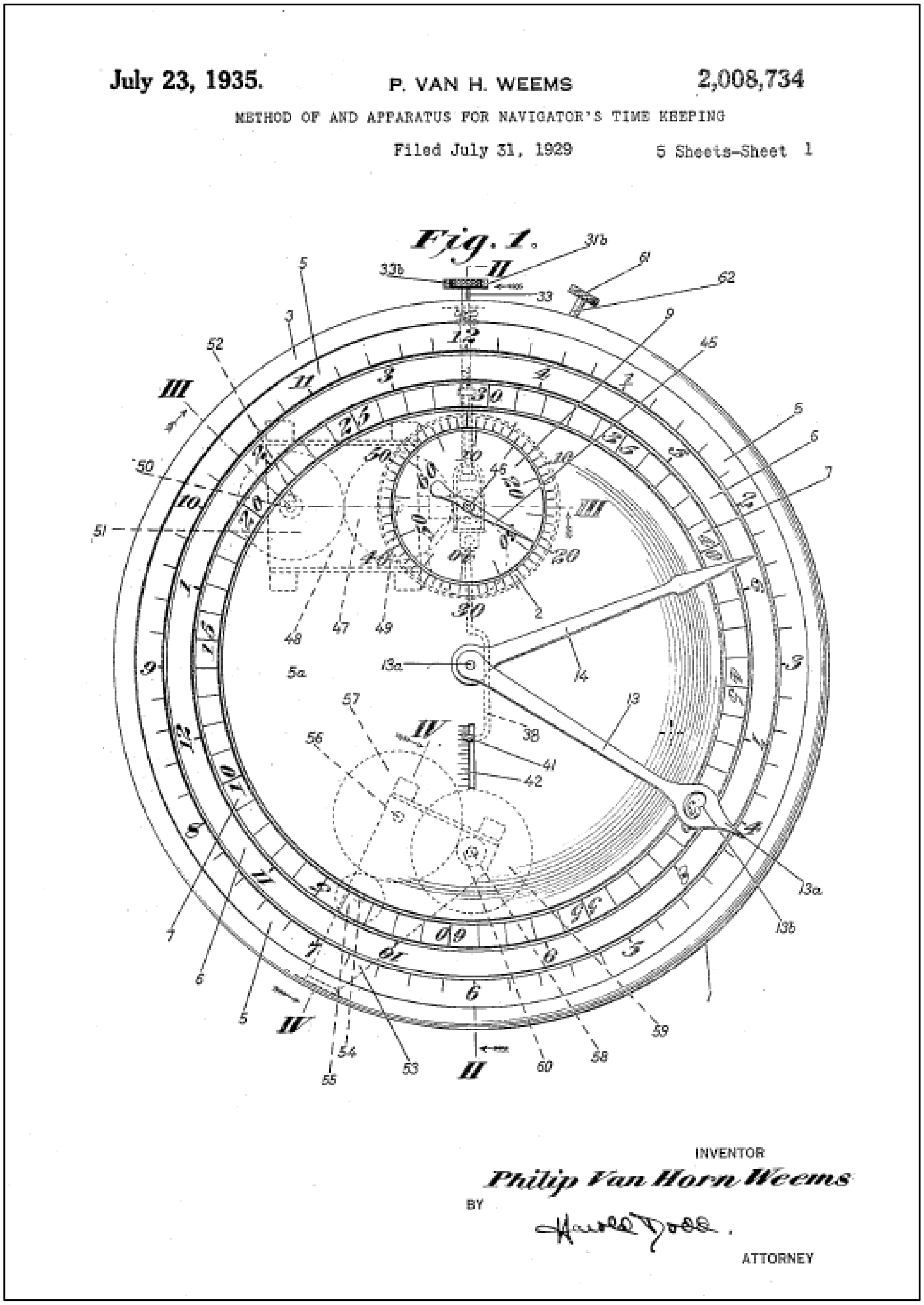


Figure 10 - Relationship of GMT, GHA and East/West Longitude

[28] GMT 12-hour GHA Latitude Diagram.eps

Patent 2,008,734



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

METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

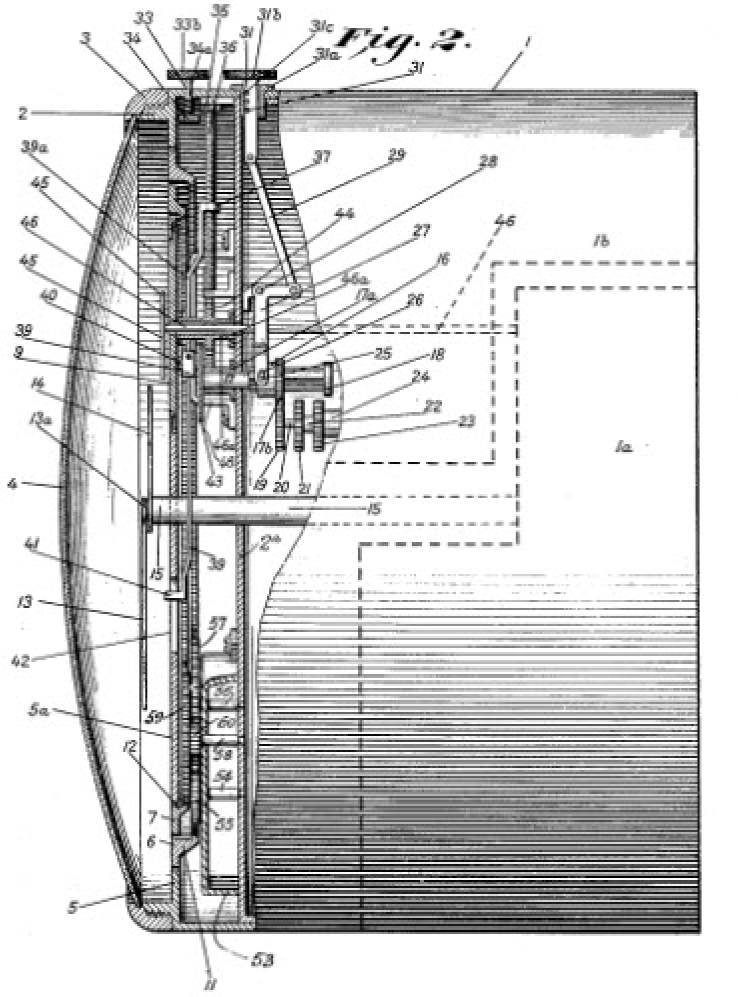
Filed July 31, 1929 5 Sheets-Sheet 1

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



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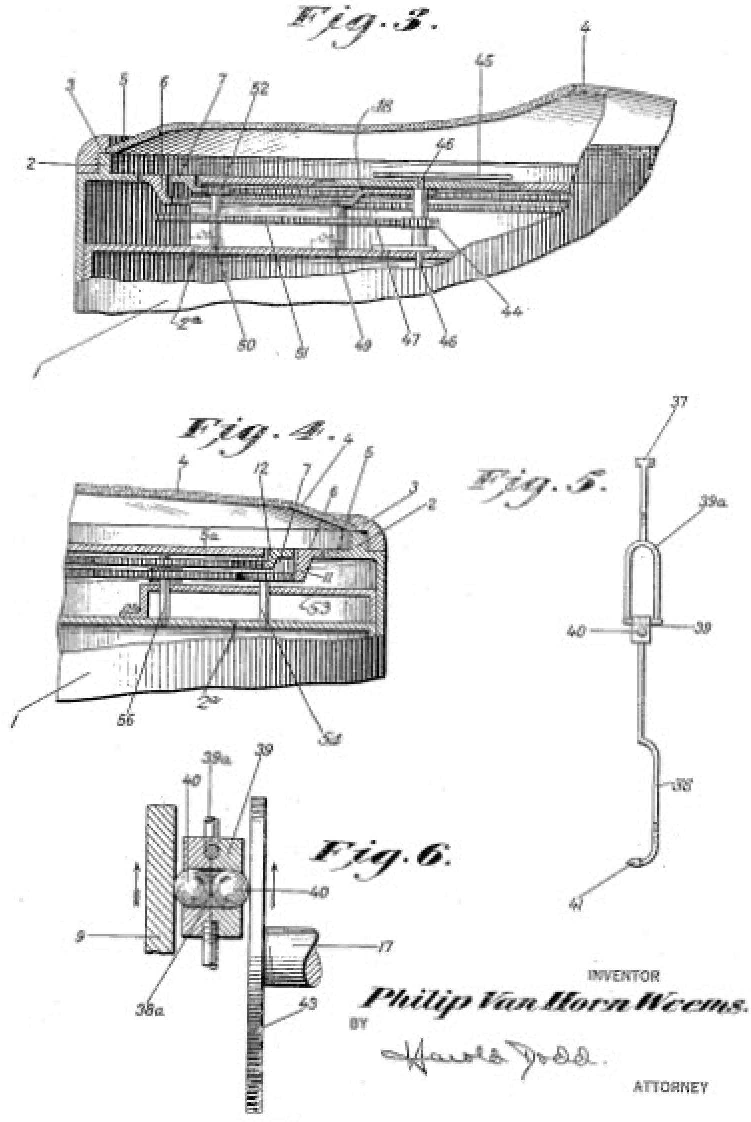
METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

Filed July 31, 1929 5 Sheets-Sheet 3



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METHOD OF AND APPARATUS FOR NAVIGATOR'S TIME KEEPING

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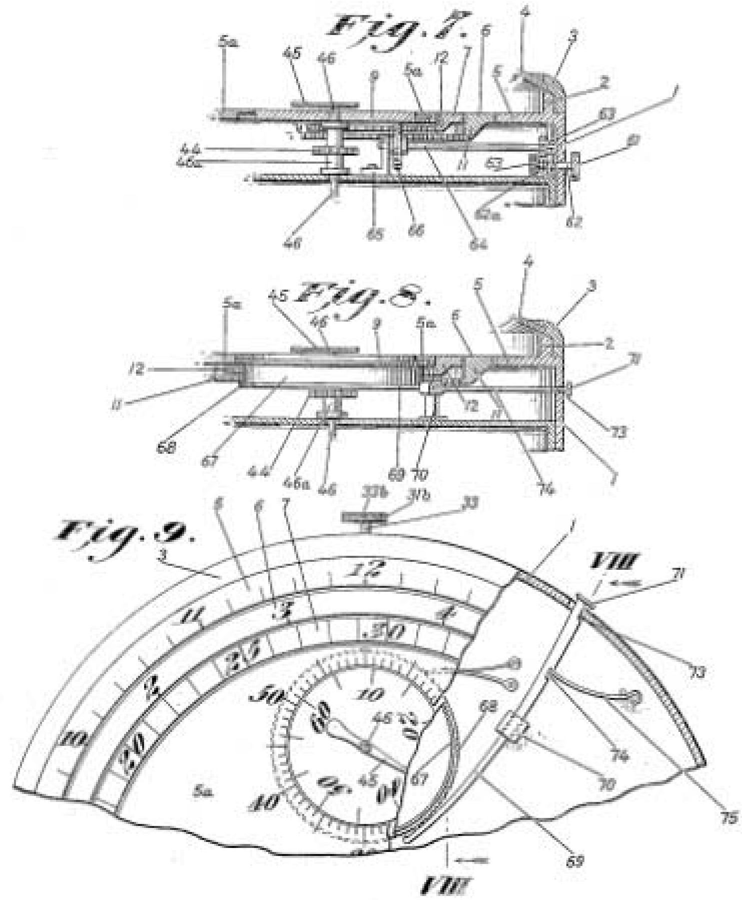

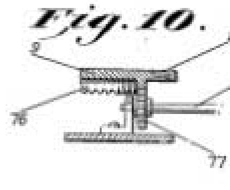

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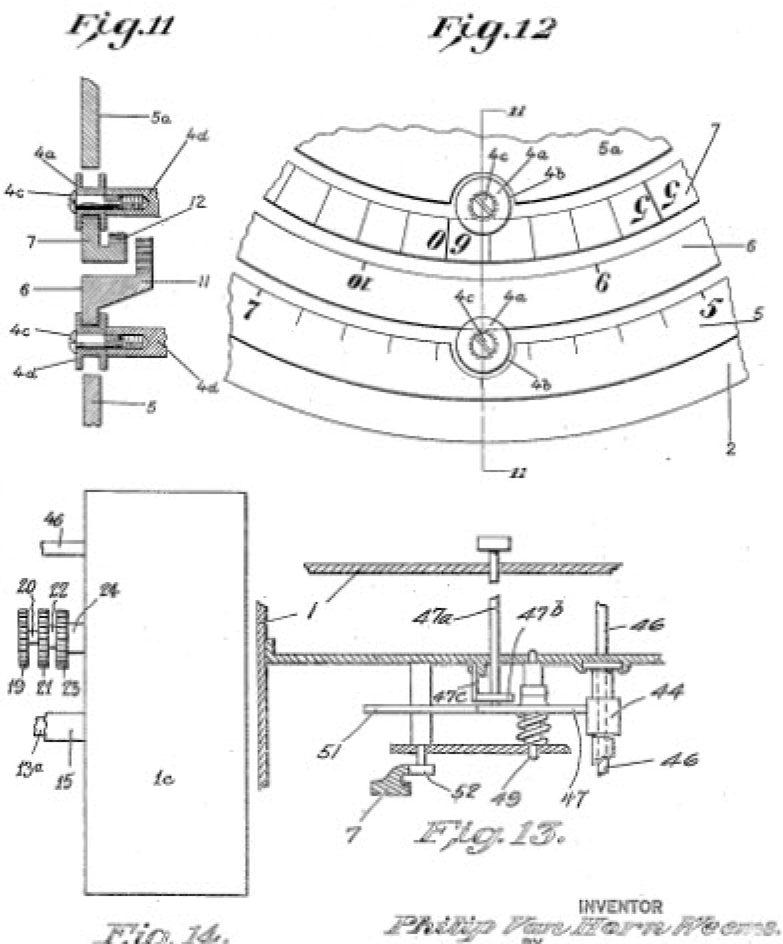
Filed July 31, 1929 5 Sheets-Sheet 5



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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 time-keeping 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 [29]

Figure 12 shows Longine'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 in the figure. There is only one moment in time each day when this statement is true and that's when the sun is exactly due south or north of the navigator when GMT is recorded and converted to GHA. Only at that exact moment, the Local Hour Angle, the angle between the navigator and sun, becomes zero and the Greenwich Hour Angle *is* the user's longitude. At any other time, the user must compute his LHA and added it to the 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

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

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