TIME and NAVIGATION
The Untold Story of Getting From Here to There
Time and Navigation:
The Untold Story of Getting From Here to There.

An enduring connection between determining time and position.

“If you want to know where you are, you need a reliable clock.“
Dead Reckoning at Sea

A navigator can take measurements of the ship speed and direction and the effects of wind and current. He can estimate the ship's location fairly accurately - at least over short distances.

Celestial Navigation at Sea

Lunar Distance Method

Finding Local Noon with a Sextant
LONGITUDE

North Pole

Greenwich Observatory UK

Meridians

West Longitude

Prime Meridian

South Pole
**USING A MARINE CHRONOMETER**

Marine chronometers are precise, specialized clocks for finding longitude at sea. They serve as portable time standards.

Local time established by angle of the sun.

12 Noon, Local time

12 Noon, Ship's Chronometer

1 hour = 15° of Longitude
Replica of Galileo’s Giovilabio

Replica of Galileo Pendulum Clock Design from 1642
Navigation at Sea

John Harrison, five clocks 1735-1772.
(portrait 1766)

Chronometer, Thomas Mudge Jr. Number 14 (1802)
Navigation at Sea

Bond Chronometer (1812)

Chronometer Movement, John Roger Arnold (about 1825)
**Main Spring Arrangement**
Combines the spring with a fusee to equalize the force of the spring as it unwinds.
- Fusee
- Chain
- Spring
- Main Spring Barrel

**Spring Detent Escapement**
Transfers power from the spring to keep the balance swinging regularly, while interfering with it as little as possible.

**Balance Wheel**
Regulates the pace of the chronometer with a special combination of two metals that expand and contract at different rates to compensate for temperature changes.
- Balance Wheel
- hairspring

**Protective Box with Gimbal**
Holds the chronometer level with the horizon to prevent position changes that can alter its ability to keep precise time.
Navigation at Sea

Ramsden Dividing Engine (1775)

Sextant, Jesse Ramsden (after 1775)
Navigation at Sea

Thomas Sumner’s line of constant altitude (voyage 1838, published 1843)
Navigation at Sea

*United States Exploring Expedition*
(Pacific Ocean 1838-1842)

*Flying Cloud*
(New York – San Francisco 1854)
Synchronizing the World

Scales for time and location moved from local to global.

Railroad Time: Great Western Railway to Greenwich time (1840), US Railway Time (1883)

US Meridian in DC: Jefferson Pier Stone (1804), Old Naval Observatory (1850)

Geographical Congress (1881) - International Geodesic Conference, Rome (1883)
International Meridian Conference, Washington DC (1884)
Prime Meridian Contested: Selected Greenwich by vote of 22-1 (2 abstentions)

Time Zones proposed by Sandford Fleming in 1879 and again at 1884 Conference

Map shows current time zones. Each zone defined at national and local level.
Navigation in the Air

NC-4 by Ted Wilbur
(Atlantic crossing 1919)

Lockheed Vega *Winnie Mae*
(around the world in 1931, 1933)
Navigation in the Air

Fairchild-Maxson Line of Position Computer (1938)

Richie Compass from Winnie Mae (recovered 1935 after Post & Rogers crash)
Navigation in the Air

LONGINES...the world's most Honored Watch!

5. Honored by... Col. Charles A. Lindbergh, Inventor of the Lindbergh Hour Angle Watch!

6. Honored by... Lt. Comm. P. V. H. Weems (Instructor of Lindbergh) Who Gave Longines His Second-Setting Watch

In his six years as a navigation specialist, Commander Weems has taught thousands of pilots. He was formerly Research Officer in Air Navigation for the U. S. Navy Department—and was honored by the Medal of the Aero Club de France for his worldwide service in Aviation. He is an international authority on all facets of navigation by air or sea—and has to his credit a long list of firsts in the new science of "Avigation."

Lt. Comm. P. V. H. Weems, U.S.N., has just been appointed Chief of the Navigation and Avigation Division of Longines-Wittnauer Co., Inc.

Col. Lindbergh's flight by compass from New York to Paris convinced him of the necessity and importance of air navigation. While studying the subject in 1927 with Lt. Comm. P. V. H. Weems he invented the now famous Lindbergh Hour Angle Watch. He sought the cooperation of Longines in developing and patenting this watch and appointed Longines to manufacture it exclusively.

LONGINES IS GOVERNMENT STANDARD FOR AIR AND SEA NAVIGATION

Longines is the official timepiece of the National Aeronautical Association since 1926. Longines is the official timepiece of the International Federation of Aviation. It marked the end of Lindbergh's flight in Fokker Airplane, No. 304, at Le Bourget, Paris, France. It is under the rigid specifications specified for this purpose. A Longines second hand on the official watch which world-wide time varied with the official watch...is the Longines.
HYPERBOLIC SYSTEM

A-B Station Pair (2,000 microseconds line of position)

A-C Station Pair (1,700 microseconds line of position)

Position Line =
8,000
-6,000
2,000 microseconds
Synchronizing the World

Global Time Scales, but with expanding range of applications. How to define time scale for specific needs?

**Rotation of the Earth**
Local Solar Time
Universal Time - UT1 and UT2 (smoothed UT1)

**Movement of Celestial Bodies**
Ephemeris Time
1950 – revolution of Earth around Sun (IAU)
Relativistic Scales
1977 - Correction applied for clock altitudes
1979 - Terrestrial Dynamical Time (Earth center) and Barycentric Dynamical Time (Sun center)

**Atomic Time**
1955 – Greenwich Atomic (GA)
1956 – USNO A.1 scale related to ET, master clock updated to match UT2
1957 - NIST Boulder NBS-A followed A.1, NBS-UA offset to UT2 and broadcast on WWV

Who Needs Relativity?
Albert Einstein

The atomic clocks in the GPS system are so accurate that they take into account Albert Einstein’s understanding of time, space, and relativity. Because GPS satellites experience less gravity and move at high velocity, their clocks operate at a different rate than those on Earth. Since all the clocks in the system must be synchronized, a net correction of 38 millionths of a second per day must be added to the satellite clocks’ time signals.
Synchronizing the World

Who sets the time? Would it continue to follow Earth rotation? Differences between celestial time and atomic time are not new.

1959 – International Radio Consultative Committee (CCIR) studies time standard
1960 – Labs in US and UK coordinate time
1960 - International Time Bureau (BIH) mean atomic time (AM, A3) and \( \Delta UT2 \)
1960 – SI second defined by Ephemeris Time
1963 – UTC formalized and adopted by CCIR: included 100ms steps to match UT2
1966 – CCIR experiment: Stepped Atomic Time (SAT) – 0.1s of UT2 with 200ms steps
1967 – SI second defined by Cesium 133
1968 – Leap seconds proposed

1971 – International Atomic Time (TAI) – extension of BIH time (A3)
1972 – UTC altered: Approximates UT1 instead of UT2 - Leap seconds adopted

1987 – International Bureau of Weights and Measures (BIPM) maintains UTC, TAI
1987 - International Earth Rotation Service (now International Earth Reference Systems Service) forecasts DUT1 and announces leap seconds
Navigation in Space

Apollo Sextant (1968)

Space Shuttle star tracker (1981)
Navigation in Space

Pioneer 4 (1959)

Quartz Oscillator (1961)

Velocity precision improved from 10m/sec to 50mm/sec

1962 Atomic clocks: 5mm/sec

26 m antenna at Goldstone
Navigation in Space

70 m antenna at Goldstone

Mariner 10 (1973)
**Navigation in Space**

1. **Deep Space Network (DSN)** sends signals to a spacecraft, which returns these signals to the stations on Earth. The spacecraft may also track the position of its destination against a star field.

2. Using precise time information from these signals, navigators calculate the spacecraft's location and velocity with respect to the Earth, and ultimately with respect to its destination. They compare the spacecraft's current course with its desired target and calculate a course correction.

3. DSN stations transmit course correction commands, which the spacecraft executes.
Increasingly accurate clocks and improved navigation methods have allowed navigators to calculate spacecraft positions with greater accuracy. By 2012 missions could be tracked with 100,000 times the accuracy possible in the early 1960s.

MSL Landing Ellipse (2012)
Satellite Navigation

Second Transit satellite (1960)

Transit 5A satellite (1970s)
The Doppler shift of signals from a moving satellite is used to determine the satellite's orbit compared to the location of the tracking station. By then inverting the process, a vessel can locate itself compared to the satellite's known location.

1. Tracking stations measure the satellite's Doppler shift and relay it to a control center. The center determines the satellite's location and orbit and transmits it to the satellite, along with an accurate time.

2. When the satellite passes overhead, a vessel receives the time and orbital data from it and measures its Doppler Shift. The vessel uses this information to find its location.
Satellite Navigation

SINS from USS Alabama
Satellite Navigation

NTS-2 satellite (1977)
Satellite Navigation

Small Diameter Bomb

T-Hawk
Navigation for Everyone
GPS Time maintained at Schriever AFB to match USNO time.
Navigation for Everyone

Stanley (2005)
PNT (Positioning, Navigation, and Timing)

Positioning
Determining location...

Navigation
Finding your way from one place to another.

Timing
Supplying highly accurate time to synchronize complex systems.

All three are used together with map data and other information (weather or traffic data, for instance) in modern navigation systems.
Navigation for Everyone

John Sullivan  
Roy Bardole  
Eva González
Navigation for Everyone

Seiko Epson Digital Assistant (1997)

1. GPS receiver
2. Processor (computer)
3. Three-axis gyroscope
4. Magnetic compass
5. Radio receivers
6. Three-axis accelerometer

(Reverse)
Looking Ahead

How can navigation be more robust?
International systems, multiple sources: Ground-based backup, integrated precision time

Chip-Scale atomic clock
Looking Ahead
Future Time: Global Time, Local Implications

Multiple communities with diverse viewpoints rely on precise time services. UTC by itself is not a perfect solution for either celestial or radio navigation.

TAI – UTC now 35 seconds apart:
10 seconds in 1972, 25 leap seconds.

DUT1 = UT1 – UTC
Broadcast by WWV

Each GNSS has its own time scale.
Leap seconds in GPS message.
GLONASS impact in the past.
Future impact could increase.

Keep UTC as basis of civil time?
Rename UTC? Eliminate TAI?

Future of Leap Seconds?
2008 – ITU working party submits recommendation to stop leap seconds
2012 – ITU postpones decision to 2015 conference in Geneva
Time and Navigation open to the public at the National Air and Space Museum

Please visit web site:
timeandnavigation.si.edu

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Come visit the Einstein Planetarium!
Tuesday 10:00

Phoebe Waterman Haas Public Observatory (Wed.-Sun.)
Explore the Universe Gallery