MODERN LUNARS (NavList)

A WORD ABOUT "LUNARS"

INITIAL WORD: This Document was initially triggered by a request e-mailed from Dave Walden (08 Aug 2016) to study a 1855 Lunar. The **"Classical" Lunar Methods** – some of them with a number of refinements – require a Sextant Distance to be taken between a Celestial Body and the Moon Limb. This Sextant Distance is transformed into its well-known Geocentric Center-to-Center "Cleared Distance" image. Such geocentric "Cleared Distance" is then compared to Geocentric Center-to-Center Distances predicted by a Planetary Theory. The requested UT1 time is reckoned backwards from such predicted geocentric distances to match the "Cleared Distance" derived from the Sextant Distance.

In **Classical** Lunar Methods the **benchmarks** are the [**Geocentric] "Cleared Distances"**.

Various Classical Lunar Methods were implemented and in use for about one century (1770 A.D. – 1870 A.D.) with satisfactory results through the use of tables. They required regular training from Observers and stayed within normal reach of standard – nonetheless extremely careful and meticulous - Navigators at sea. Whatever their refinements, there are still cases which cannot be [sufficiently] accurately solved by any such single Classical Method. In other words, some bits of accuracy are lost here and there (including due to round-off errors) in the course of the classical "Lunar clearing" hand computation process. **The very best classical hand computation methods have a built-in accuracy just reaching the 0.15'/ 0.2' level under most cases. Modern computers can implement Classical Methods to [much] better than 0.1' accuracy level. However, and even when ran with the Best Planetary Theories on modern computers the Classical Methods fail to immediately represent the "Longitude change / Sextant Distance change" ratio. In other words, they remain short of immediately providing Navigators with meaningful *"Warnings" on ill conditioned Lunars*.**

Although Lunars practical utility has totally vanished, modern computation power can tackle them with much greater efficiency: e.g. **computing the Sextant "synthetic" Distances (i.e. the Distances which should be observed in a Sextant) and fine tuning successive UT1 values until the computed Sextant "synthetic" Distance matches the Sextant Observed Distance [e.g. to +/- 0.5"] enables solving any Lunar.** Bodies' Limb(s) constantly change shapes and refraction is also specific to each point of them. Classical Computations *partially* account for refraction through adding a limited number of corrections to the Bodies SD's, but cannot match modern computation results and reliability. The latter - ALONE - can accurately compute the minimum distance between the ever-changing distorted Limbs under ANY configuration through considering the *Sextant synthetic distance as the angular distance between the distorted Limbs measured alongside the unique Great Circle perpendicular to both of them.* Modern methods can also use super accurate Planetary Theories (e.g. JPL **DE405/LE405** or "Bureau des Longitudes" **INPOP13C**) and reach built-in accuracies [well] below the arc second level. Their sole limitations remain the unavoidable refraction uncertainties at low altitudes (up to 10°), as well as the irregularities of the Moon Limbs reaching the 1" level. Compared to the straightforward "one shot" Classical Methods, Modern successive approximations computations are huge and cannot be performed by hand at all.

Hence, in **Modern Lunar Software**, there is a **significant change in paradigm** since the **benchmarks** have become the **Sextant Observed Distances**. It is no longer required to focus onto the "Cleared Distances" which have then become only [optional] computation by-products. **Modern Lunar Algorithms are excellent at accurately deriving "Longitude change / Sextant Distance change" ratios. IN PRINCIPLE: rather than "Cleared Distances", the best benchmarks are "Sextant Distances" since the latter are THE quantities directly measured. *HINT* !** Their [topocentric] rates of change may vary greatly according to local environment and may also considerably differ from their geocentric counterparts. **Hence it is important to accurately know how the Sextant Distances vary with both UT1 and observers' geographic positions.**

IMPORTANT NOTE: Because of Refraction uncertainties at low altitudes, it is preferable not to observe Bodies with heights less than 5° or even 10° above the horizon. However "Modern" Lunar Methods should nonetheless be considered as [much] more efficient and reliable at tackling low altitude Lunars than their "Classical" counterpart[s].

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4 different Lunar examples illustrate here-after the "Longitude change / Sextant Distance change ratio" concept and its practical importance.

Lunar (1): From: **THE AMERICAN EPHEMERIS AND NAUTICAL ALMANACh 1855** p 512 and as discussed by William E. Chauvenet:
From position N35°30' W030°00, on Sep 07th, 1855, a Moon to Sun Limbs closest distance is observed at 43°52'10". The Ship Chronometer says: UT1 = 08h08m56,0s (which is the same instant as 20h08m56,0 under their own hours reckoning). Height of Eye = 20ft, T = 75°F, P = 29.1" Hg.

I have solved it as follows, with ΔT = +7,7 s :

For UT1 = 08h08m56.0s, I find the Sextant "synthetic" Distance to be at 43°52'30.0" (with a "Cleared" Distance at 45°04'28.5").
For Sextant Distance = 43°52'10.0", I find UT1 = 08h11m45.6s (with a "Cleared" Distance at 45°03'11.7").

Geocentric Center to Center Distance -27.204"/min of UT1. Sextant Distance rate of change: -7.823"/min of UT1
Change on UT1: -46.0s/+0.1' Sextant Distance change
Change on Longitude: 11.5' towards the East/+0.1' Sextant Distance change.

THIS LUNAR ENVIRONMENT IS NOT OPTIMUM BECAUSE LOW ALTITUDE REFRACTION GREATLY "*SLOWS DOWN*" THE APPARENT BODIES CLOSURE RATE.

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Lunars (2), (3) and (4):

I have then investigated **3 simultaneous synthetic Lunars** occurring **in different places at the same time (UT1=08h04m52.32s / TT=08h05m00.00s)**

From: **Miriade.ephemcc.results** (http://vo.imcce.fr/webservices/miriade/?forms#)
Theory: **INPOP13C**, Coordinates: Equatorial coordinates (RA, DEC), Apparent coordinates (true equator; equinox of the date), Geocentric.

Target, Date, RA ("h:m:s"), DEC ("d:m:s"), Distance (au, with 1 au = 149 597 870 km)
Sun, 1855-09-07T08:05:00.00, 11 01 26.99883, +06 15 31.9350, 1.007251421 Geocentric SD = 0.264 647 774 2°(15.87886645') with SD = 695,997 km
For the Sun Semi-Diameter, no correction for irradiation has been made, as this is an observer dependent effect.

Moon, 1855-09-07T08:05:00.00, 08 10 10.16146, +25 17 31.0209, 0.002701090 Geocentric SD = 0.246 438 905°(14.78633432') with SD = 1,738 km
ARIES GHA = 107.057 931 8 ° (107°03'28"555). Here I have used ΔT = +7.68 s. HP = 0.904 419 770°(54.26518619') (23454.79095)
For the Moon, corrections of **Δλ = +0.50"** and **Δβ = -0.25"** have been added to the Mean Ecliptic of Date Coordinates to approximately account for correction from Center of Mass (from **INPOP13C**) to Center of Figure. Such corrections translate here into: **Δα = +0.478"** and **Δδ = -0.351"**.

Temperature is on-site Temperature, Pressure is also on-site Pressure, i.e. QFE and not QNH, (i.e. no QNH Pressure correction required).
"**Height of Eye**" is used for **Refraction and Dip**, while "**Altitude**" [above WGS84 Ellipsoid] is used for **Parallax and augmented SD** space 3D computations. In all the following examples: for ALT = 0 m (WGS84), Height of Eye = 0ft with 75°F (22.8°C) and QFE = 29.1" Hg. And:
for ALT = + 400 m (WGS84), Height of Eye = 0ft with 68°F (20°C) and QFE = 27.6" Hg.
dZ represents the parallax in Azimuth computed from the WGS84 Ellipsoid Surface.

It can be seen here-under that the "Longitude change / Sextant Distance change" ratios vary very greatly with their local environment.

07 SEP. 1855 , ΔT = + 7.68 s UT1 = 08h04m52.32s (TT=08h05m00.00s)	**Lunar (2)** Position: N30°06'39" W030°00'00"		**Lunar (3)** Position: N29°27'12" W005°00'00"		**Lunar (4)** Position: N30°00'00" E055°00'00"	
The RATE OF CHANGE of the Geocentric Center to Center Distance is:	Sun Z = 85.42227°, dZ = - 0.02538" Moon Z = 85.42280°, dZ = -14.59022"		Sun Z = 97.99004°, dZ = - 0.02765" Moon Z = 97.98965°, dZ = -28.94652"		Sun Z = 171.88345°, dZ= - 0.00864" Moon Z = 271.11891°, dZ= +16.39620"	
-27.206"/min of UT1, to be compared with values below.	75°F, 29.1"Hg ALT = 0m (WGS84)	ALT=+400m (WGS84) 68°F, 27.6"Hg	75°F, 29.1"Hg ALT = 0m (WGS84)	ALT= +400m (WGS84) 68°F, 27.6"Hg	75°F, 29.1"Hg ALT = 0m (WGS84)	ALT=+400m (WGS84) 68°F, 27.6"Hg
Moon LL with refraction	48.873 °	48.872 °	70.828 °	70.828 °	54.086 °	54.085 °
Sun UL with refraction	5.010 °	5.005 °	26.553 °	26.552 °	66.326 °	66.325 °
Synthetic Sextant Distances	43°51'45.9"	43°52'04.8"	44°16'31.0"	44°28'02.2"	45°00'59.1"	45°01'01.0"
Variations per minute of UT1	*+0.377"*	*+0.297"*	-15.107"	-15.128"	-19.494"	-19.492"
Δ UT1(s) / Δ Sextant Distance (0.1')	*+954.2*	*+1213.6*	-23.83	-23.80	-18.47	-18.47s
Δ Long.(') / Δ Sext. Distance (0.1')	*238.5 (→ West)*	*303.4 (→ West)*	*6.0 (→ East)*	*5.9 (→ East)*	*4.6 (→ East)*	*4.6 (→ East)*

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