**Lunar clearance with calculator, Fuller 2(cos) replica, Mini Fuller2(cos) and Bygrave replica cylindrical slide rules. (John Karl Method page 93.)**

The latest version of the Fuller 2 full sized replica has cosine scale in place of upper log scale.

The miniFuller 2 has cosines in red/green added to the single sine scale going the other way. Both remove the previous requirement to convert all cosines to sines before starting operations.

**Process**

* Apparent Alts. Ha (sun alt) and ha (moon alt) corrected for IC and dip
* Hsd and hsd, ha corrected for +/- SD from almanac daily pages
* LDa corrected for ic but not dip.
* LDsd +/- SD both moon and sun. Usually + both for closest limbs.
* Fully corrected Ho, ho,
	+ Use Ha (not Hsd) almanac alt correction (ref+SD+para) to give Ho
	+ ha main correction + use HP from daily pages, to get 2nd correction, gives ho

**Formulae for calculator and Fullers**

1. **Find RBA. (Dif. Az) (relative bearing angle=difference in azimuth sun and moon.)**

***Cos RBA=(cosLDsd-sinHsdsinhsd)/cosHsd.coshsd***

1. **Find LDo**

***CosLDo=(sinHo.sinho )+(cosHo.cosho.cos RBA)***

**From Karl page 93**

LDsd=52˚23’

Hsd=38˚40’

Hsd=30˚36’

**Calculator**

1. **Find RBA. (Dif. Az)**

***Cos RBA=(cosLDsd-sinHsdsinhsd)/cosHsd.coshsd***

=(cos 52023.’)-(sin 38˚ 40’xsin30036.3’)/cos 38039.8’xcos30036.3’

=0.61037- ( 0.62474x0.50911=0.31806)/(0.70808x0.8607=0.6720)

0.61037-0.31806=0.29231.

0.29231/0.6720=0.43499=Cos RBA

**RBA (Δ Az) =64012.9’**

1. **Find LDo**

**Ho=38˚38.7’**

**ho=31˚21.4’**

***CosLDo=(sinHo.sinho )+(cosHo.cosho.cos RBA)***

= ( sin 38038.7’xsin 31021.4’) + (cos38038.7’xcos 31021.4’)

 =(0.62449 x0.5204) +(0.7810 x 0.85349 x0.43491)

 = 0.3249 + 0.2899 =0.6148

**0.6148 cos-1  =5203.7’**

**Time and accuracy. Total less than 5 minutes. Could be quicker using pre-programmed memories as per Karl. Waterproofed in sealed food bag. Use as final check at sea.**

 **Replica Fuller 2(cos) clearance of Lunars, John Karl page 93 . MiniFuller 2(cos) in red.**

**Find RBA ( Fuller2(cos) has cosine scale in place of old log scale. MiniFuller2 cos has cosine numbers in red/green added to single sine scale, going in opposite direction.**

**1)Find cos LDsd**

i)Index C(cos index in place of log L index top of main scale) to 52˚23’ on upper cos scale. **Read 0.61037** at F. **Record**

Mini. S>1. Cos 52˚23’>L, L>red dot (originally located by lining up sine 30˚ with 0.5 on main scale. Red dot placed where index L lands on sine scale.)**Read 0.61037** at lower index S **.Record**

**2) SinHsd x sinhsd =38˚40’x30˚36’/1x1**

ii) S>38˚40’ (0.6247) S>1, 38˚40’>L, L>red dot (0.6247 at s)

iii) A>1

iii) S> 30˚36’ (0.5090 at F) 30˚36’>L, L>red dot, read 0.31806 at S**. Record**

iv) 0.5090 >B. **Read 0.31806** at F. **Record (no need for this move on mini.)**

**3) v) 0.61037-0.31806=0.29224. Record**

**4) CosHsdxCoshsd**

vi) Index C to cos 38˚40’ (0.78079) S>1, Cos 38˚40’>L, L>red dot.(0.78079 at S). Cos 30˚36’>L,L>red dot, **read 0.6721 at S. Record**

viii)A>1

C>30˚36’ (0.8607)

ix) ).8607 >B, **read 0.6721 at F. Record**

1. 0.2994/0.6721 0.29224>S, 0.6721>L, , L>1, read 0.4348 at S.

 Red dot >L, S>1, **read 25˚46.5’ at S**

x) 0.2994>F

xi)B> 0.6721

xiii)!>A, read 0.4348 at F=25˚46’ at index S

**89˚60’-25˚46’=64˚14’=ΔAz 89˚60’-25˚46.5’=64˚13.5’ =correct ΔAz**

**Comments.**

Both took about 7 minutes. The big Fuller 2 replica uses slightly more moves but is easier to see and locate scale numbers. The mini Fuller has small condensed scales and needs magnifiers for accurate readings. This adds time. **Both are equally accurate despite the shorter scale length of the mini Fuller. The mini has no vulnerable brass cursers, is smaller and handier at sea. But the Big Fuller replica is more authentic and fun. And my granddad would have approved!**

1. **Find LDo**

 **Ho=38˚38.7’ (see above for corrections from almanac.)**

 **ho=31˚21.4’**

**Cos LDo = SinHox Sinho + CosHo x Cosho  x Cos RBA.**

**Fuller 2(cos) operations. MiniFuller(cos) in red.**

**SinHox Sinho**

1. S > 38038.7’ (0.62449) S>1, 38˚38.7’ >L, L> red dot, (0.62449 at s)
2. A>1 31˚21.4’ >L ,L>red dot. **Read 0.3249 at s record**
3. S>31˚21.4’ (0.5204 at F)
4. 0>5204>B
5. **Read 0.3249 at F.Record**

1. **Cos Ho x Cosho x Cos RBA. (0.28993)**

vi) Cos index to cos 38˚38.7’ (0.7810 at F) S>1, cos 38˚38.7’>L, L>res dot, (0.7810 at S)

 cos 31˚21.4’ >L, L>red (0.66701)

 cos 64˚13.5’>L,L>red **(0.290) Record**

vii)A>1

 C index to cos 31˚21.4’ (0.85394 a F)

Viii ) 0.85394 >B ,read 0.66701 at F (this move not necessary on mini)

ix)A>1

x) C index to cos 64˚14’ (0.4347 at S)

0.4347>B, read 0.28993 at F

xi)0.3249+0.28993**= 0.6148 0.3249+0.290= 0.6149 at S. Red dot >L, S>1, read 52˚3.3’ at L (cos scale)=LDo**

**0.6148>F, read 52˚3.8’ at C cos scale=LDo**

**Comments**

**Both took about 5 minutes and equally accurate. Big Fuller easier to read large scales.**

**Find LDo using Bygrave and correct, calculated ΔAz. (derived from calculator or Fullers)**

This was just a “fun” intellectual exercise, to see if it is possible to do more with the Bygrave.

H = RBA (Δ Az) =64˚13.2’ ( does not work if H>90˚, have to use Fuller (.Unless someone can show me otherwise? )

Dec = ho= 31˚21.4’

Lat = Ho= 38˚38.7’

Co-lat =90 – lat = 51˚21.8’

Uses Bygrave to calculate “great circle distance =90˚-hc. Formulae from Riet 2008. On Bygrave, y is used (same as W in Gary Lapook’s excellent instruction forms which I use.)

Tan y(W)=tan dec/cosh= 1/cot ho=cosΔaz/coty(W)

Tan Az =TanH.xcosy/CosY= cosy(W)/cotΔAz=cosy/cotAz

Tan hc = cos AzxtanY= cosAz/cotY=1/cothc

**Bygrave Operations**

1)Set S (cos) to 0, set L(cotan) to Dec (31˚21.4’), set S to RBA (64˚13.2’**), read y (or W) at L= 54˚32’** Record

2) X =co-lat +y = 105˚53’18”, W>90, **so Y**=180-**X =74˚6’42” Record**

3) Set S to y **= 54˚32’** , set RBA (dif Az) =64˚13.2’ to L, set S to Y **74˚6’42” ,read Az 77˚9’ at L record**

4) S to **Az 77˚9’,** set Y **74˚6’42”** to L, set S to 0, read **a = 37˚58’ at L.**

**5)LDo = 90- 37˚58’= 52˚2’ (correct figure from Karl is 52˚2.9’)**

**Comments.**

**I find this quicker and easier than the Fullers, but I have more experience with the Bygrave. The large scales are very easy to read accurately.**

**Possible method using Azimuth measurements of sun and moon using compass.(works in theory, but not yet tried in practice) Limited to ΔAz (H or RBA) <90˚.**

I could not figure a way of obtaining ΔAz sun/moon, by “reverse calculating using the Bygrave. However, the ΔAz can be obtained direct using an accurate azimuth compass.

* “Simultaneous” Az of moon and sun using adapted hand bearing “Azimuth” compass. (? Only accurate to about 2˚-5˚ ? My homemade azimuth hand bearing compass so far accurate in calm conditions (from garden couch!) +/-2˚ . So far, it works for ΔAz +/-10˚ from the correct, calculated value.
* Use Difference in Az (ΔAzcompass)
* Do Bygrave ops to calculate LDsd(c) (compass)
* Compare with actual LDsd from sextant reading
* Ratio LDsd actual/LDsdc= correction factor. (may need Fuller for the ratios?)
* Obtain fully corrected LDo.
* Multiply by the correction factor= cleared LDo . ( I do not understand why it works but it does.)
* Likely to be less accurate and just as time consuming as the full method using Fuller 2.

**Example based on theoretical ΔAz of 66˚ using compass.**

1. **Find LDsd(compass)**

Dec =hsd= 30˚36.3’

Lat= Hsd= 38˚40’

Co-lat= 89˚60’-38˚40’=51˚20’

“H” (compass)= 66˚ =ΔAz sun/moon

Using same Bygrave moves as above:

Y(W) =55˚32’. X=co-lat +y= 51˚20’+55˚32’=106˚52’

Y=179˚60’-106˚52’=73˚8’

Gives Az 77˚7’, which give Hc 36˚19’

89˚60’-36˚22’=**53˚38’ (LDsdcompass))**

**Actual LDsd measured by sextant=52˚23’**

**Correction factor for LDo  =52˚23’/53˚41’**

1. **Find LDo**

**Dec=ho= 31˚24’**

**Lat=Ho= 38˚7’**

**Co-lat=89˚60’-38˚7’=51˚53’**

**H=66˚**

**Moves**

Using same as above, y(W) = 56˚20’, X = 108˚13’, Y= 71˚47’, Az=75˚54’ which gives a **hc 36˚34’**

89˚60’-36˚34’= **53˚26’**

**Now multiply by correction factor.**

= **53˚26’/1 x52˚23’/53˚41’=52˚6’**

Moves By mini Fullerc. Have not figured how to do this with the big Fuller of the Bygrave.

S>,1, 53˚26’>L, L>53˚41’.

52˚23’>L, S>1 **read 52˚6’ at L**

**Comments. Not so accurate, but interesting early results!**

The Fuller mini 2 can do ratios direct on sine scale.

Eg.

(52˚/58˚)x59˚=52˚ 53’

S>0, 52˚>L, L>58˚, 59˚>L, L>0, read 52˚ 53’ at L

L