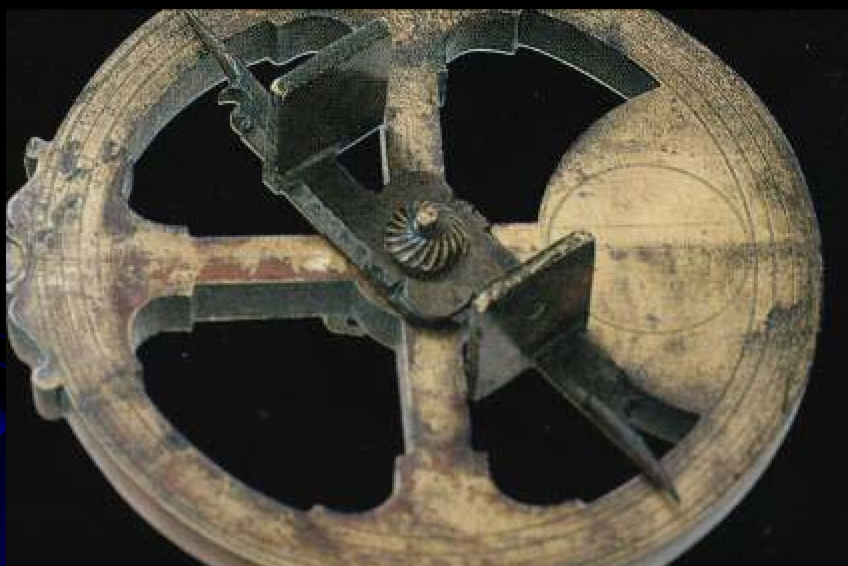
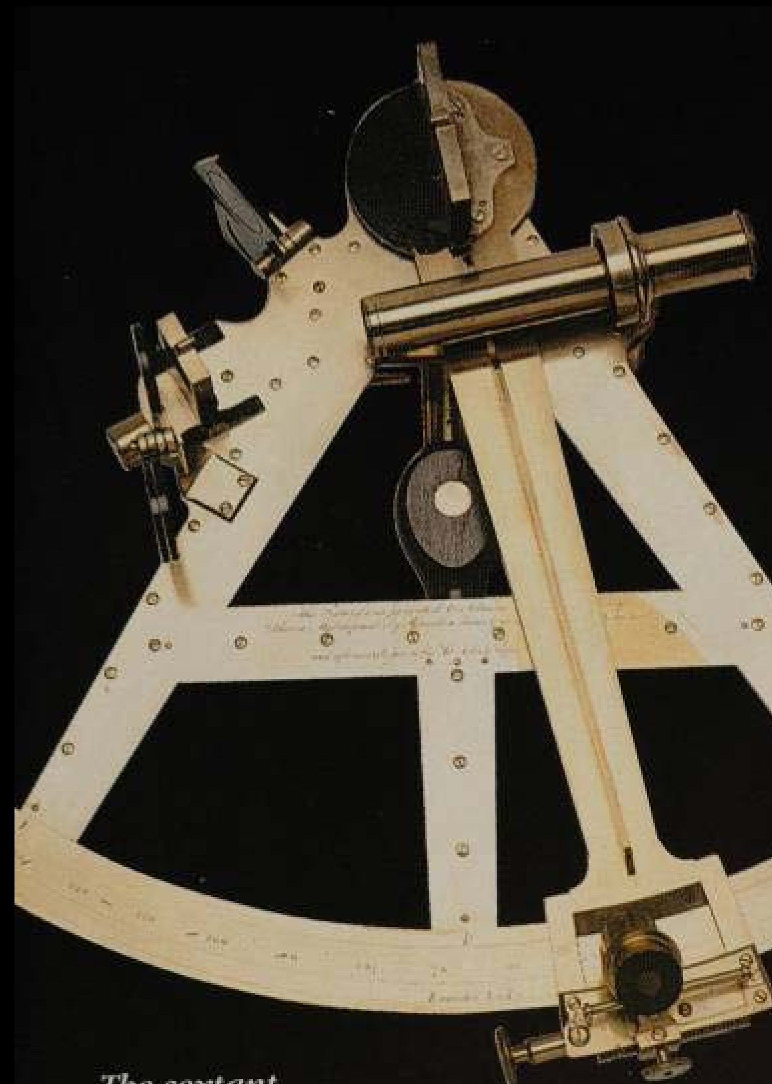
Celestial Navigation III

Presented by Ralph Naranjo

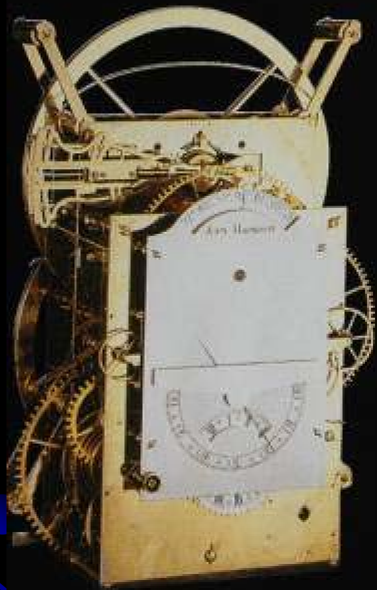
An evolving technology





Time and a Ptolemaic Universe

John Harrison: The Man who Found Longitude



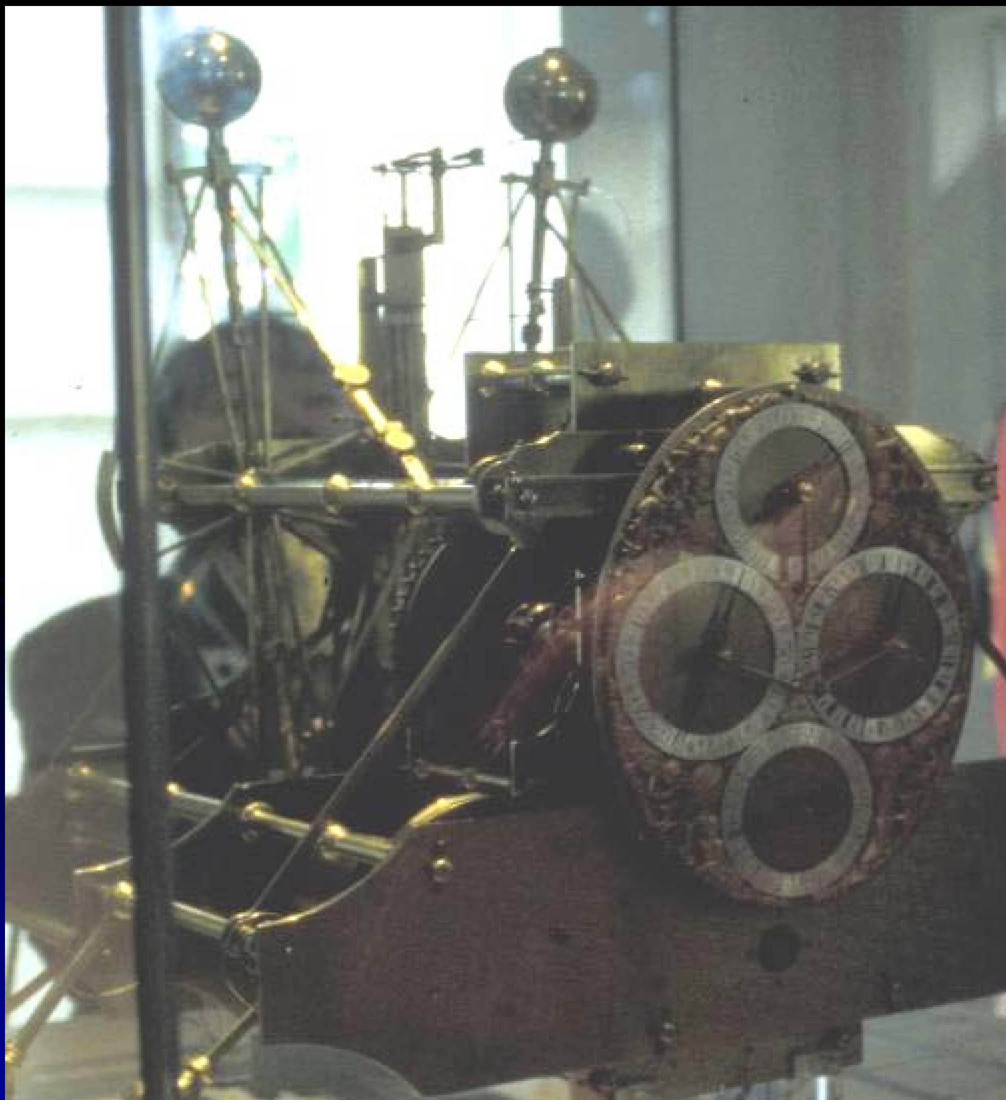
m Harrison's third

John Harrison was born in 1693, the son of a village carpenter. By the age of 20, he had taught himself the theory and practical skills of clockmaking and, when the Longitude Prize was announced, Harrison was sure that one of his clocks would win it.

In 1730, following four years of careful thought and study, he had formulated a plan for his first sea-going clock. Taking his plans with him, he set off from his home in Lincolnshire for Greenwich to seek advice from Edmond Halley, who was Astronomer Royal at the time. Halley received Harrison kindly and provided an introduction to the greatest clockmaker of the day, George Graham. Graham was entranced by Harrison's plans and even offered

Wooden ships and wooden clocks

Coping with time



Harrison's Clocks

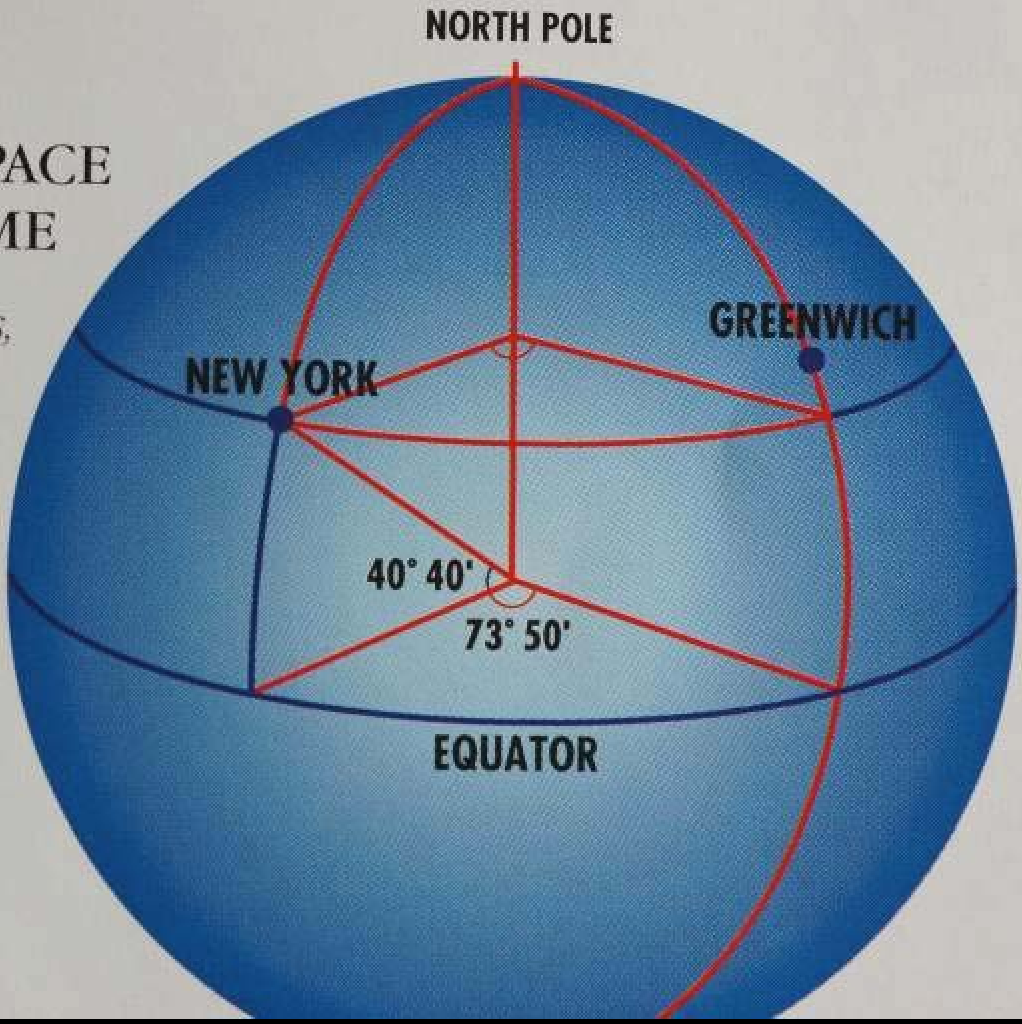
The answer to measuring longitude at sea

A 230 year technology

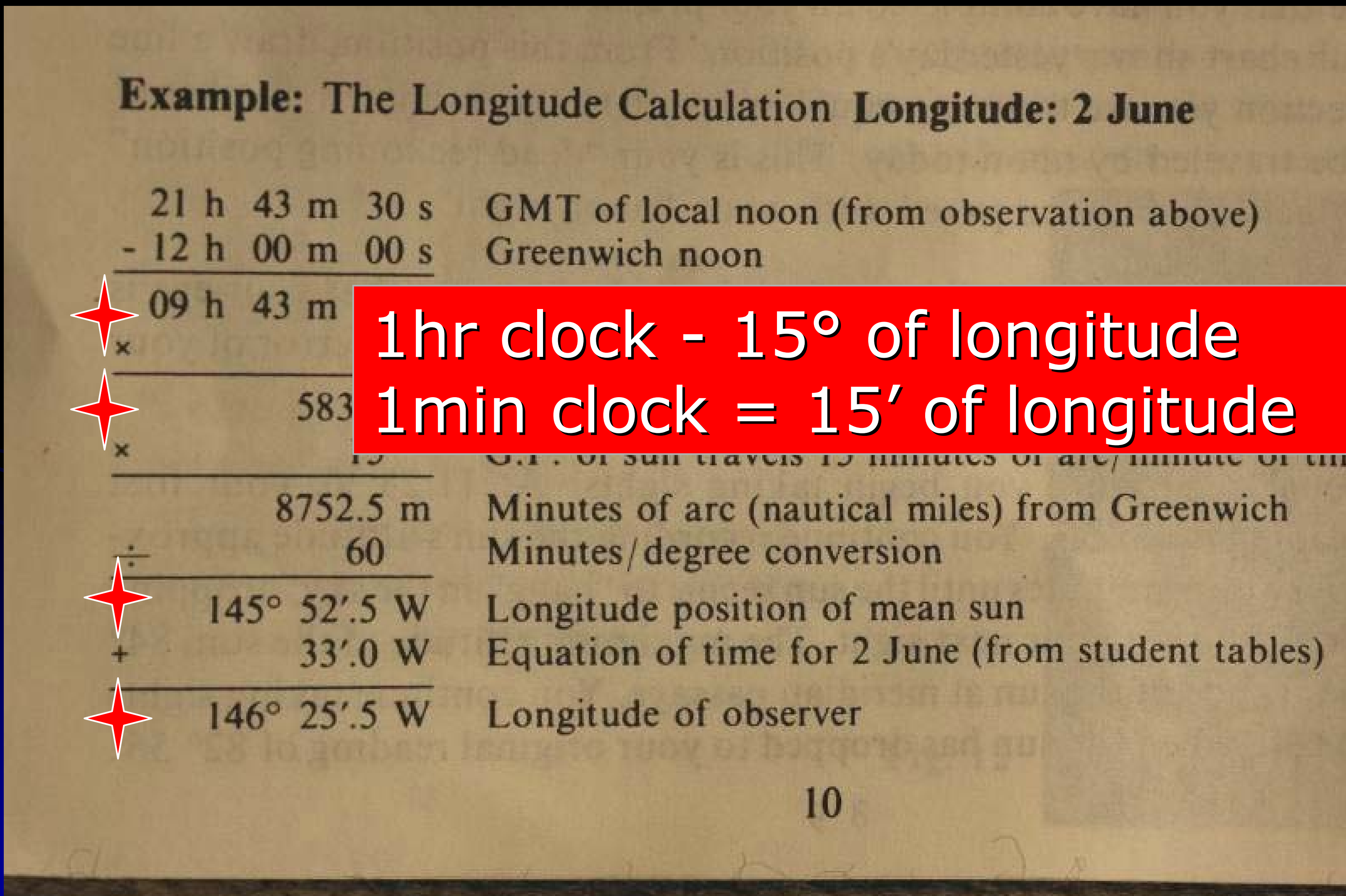
1965 - the electronic time piece finally upstages the mechanical clock.

WHY AND HOW SPACE EQUALS TIME

As this illustration shows, longitude is a co-efficient of time. New York is 73° 50' west of Greenwich. This means that local noon occurs in New York nearly five hours after it occurs in Greenwich.



Time and longitude


Example: The Longitude Calculation **Longitude: 2 June**

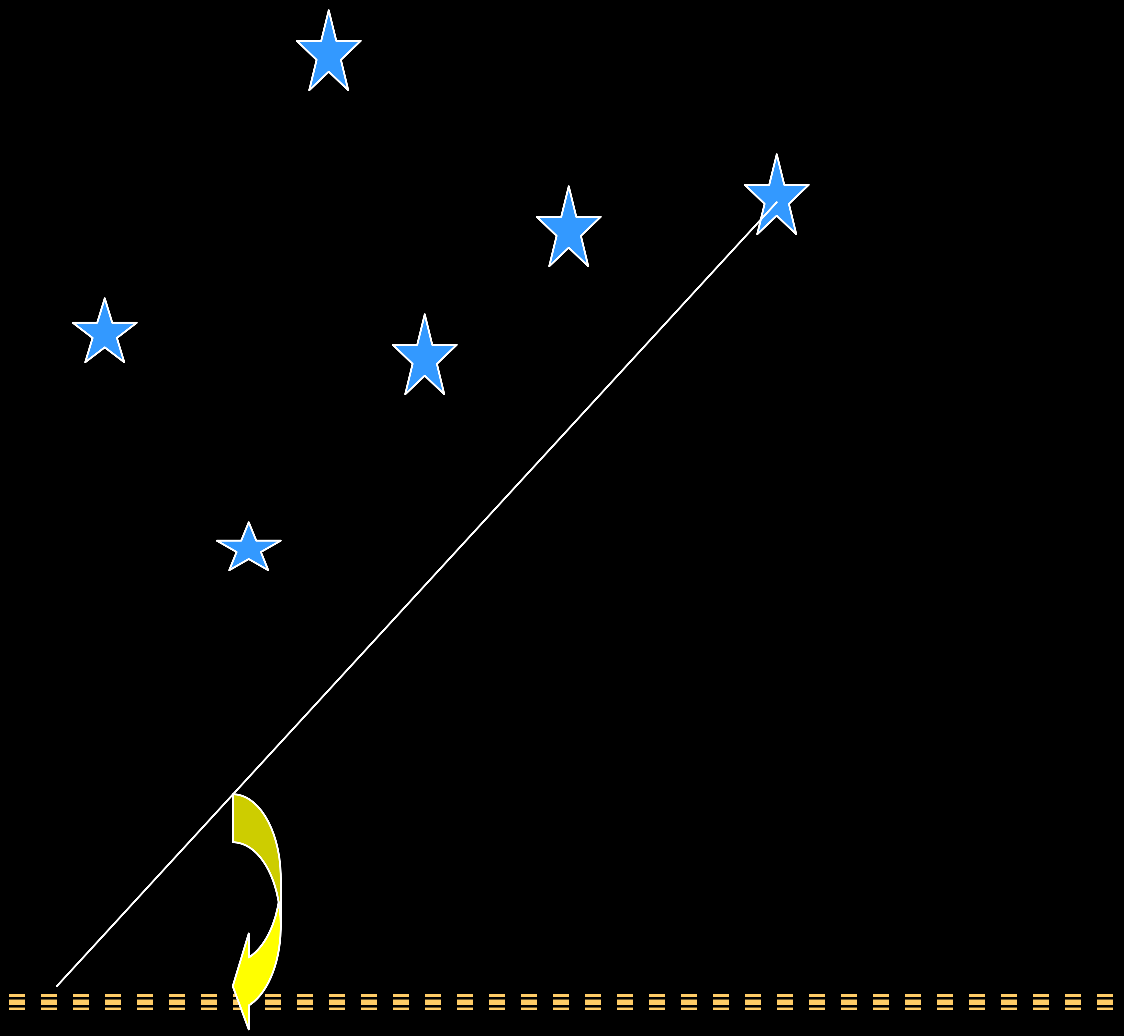
21 h 43 m 30 s	GMT of local noon (from observation above)
- 12 h 00 m 00 s	Greenwich noon
09 h 43 m	
×	
583	
× 15	
8752.5 m	Minutes of arc (nautical miles) from Greenwich
÷ 60	Minutes/degree conversion
145° 52′.5 W	Longitude position of mean sun
+ 33′.0 W	Equation of time for 2 June (from student tables)
146° 25′.5 W	Longitude of observer

10

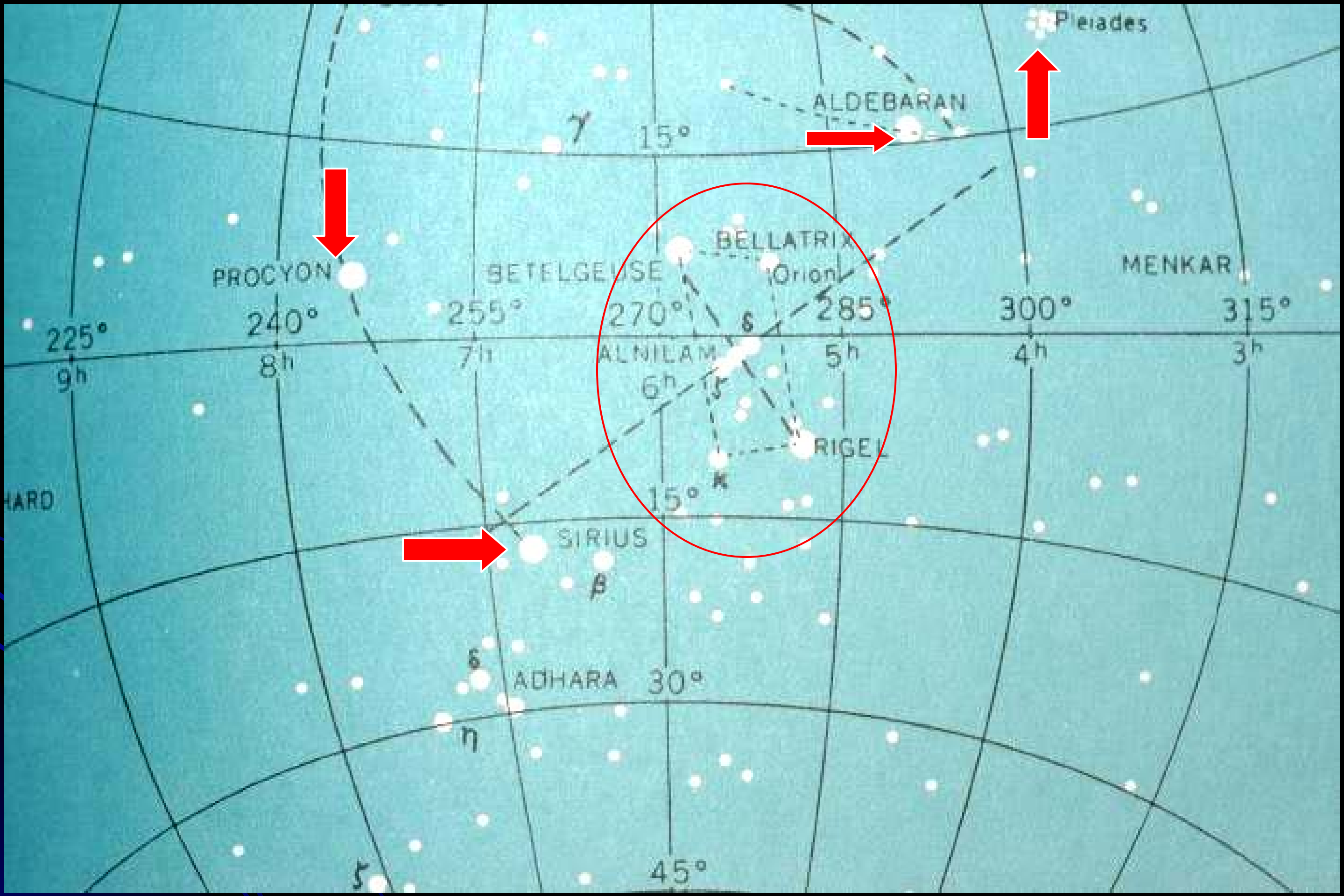
1hr clock - 15° of longitude
1min clock = 15′ of longitude

From theory to application

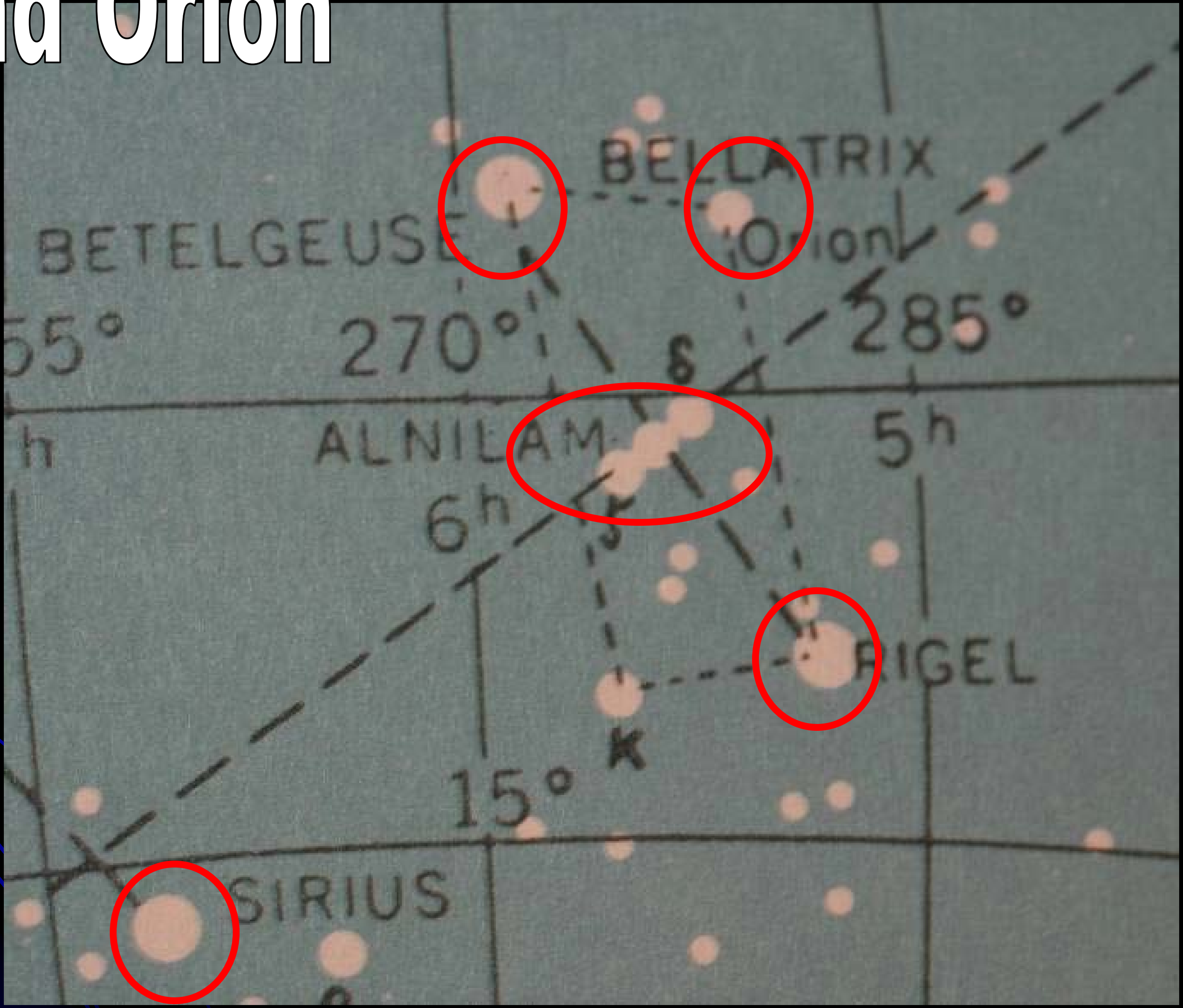
Star sights

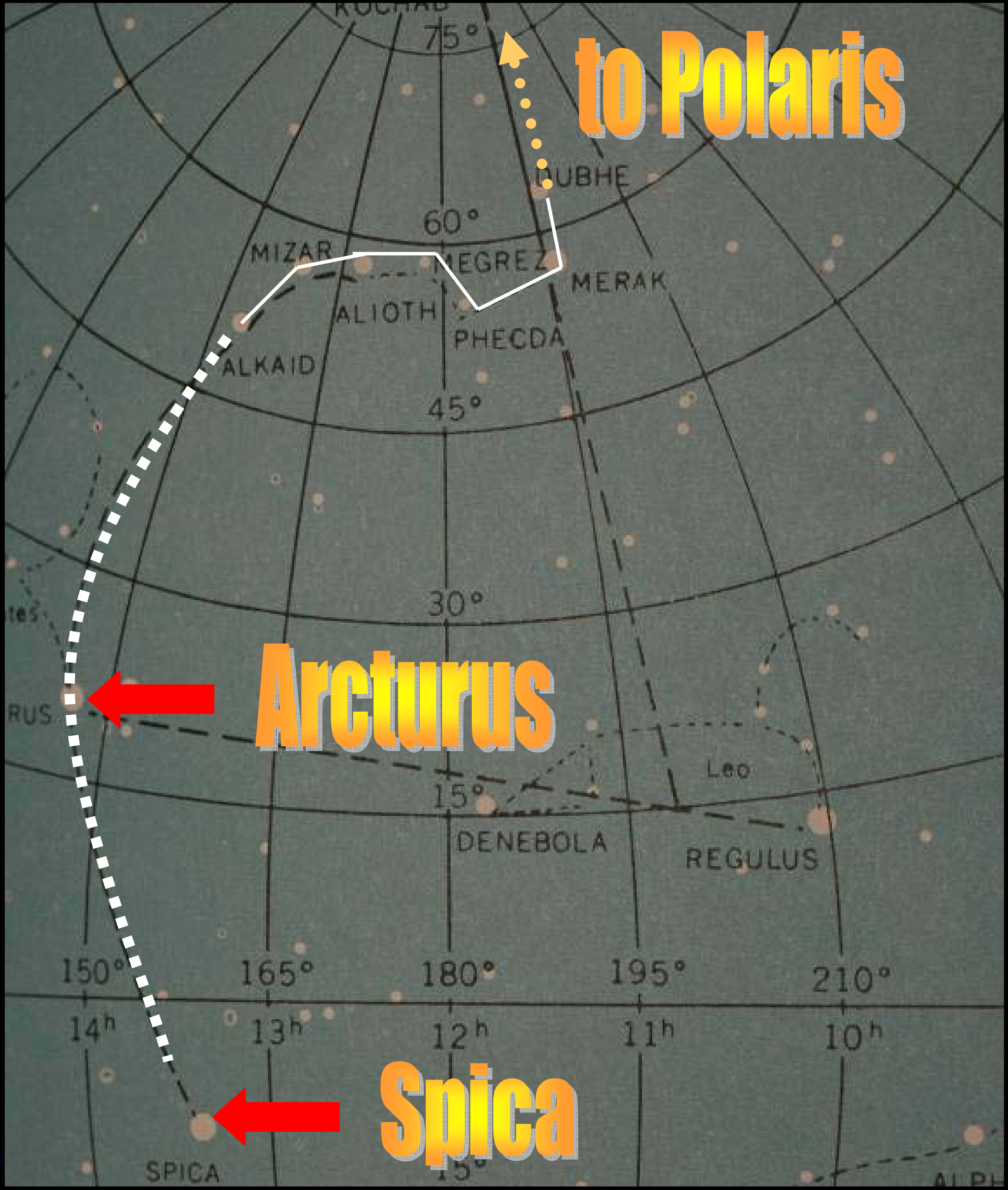


Building familiarity



Around Orion





to Polaris
75°
DUBHE
60°
MIZAR
MEGREZ
MERAK
ALIOTH
PHECDA
ALKAID
45°
30°
Arcturus
RUS
Leo
15°
DENEBOLA
REGULUS
150°
165°
180°
195°
210°
14h
13h
12h
11h
10h
Spica
SPICA

timepiece

sextant

Almanac

HO249

Body	CANOPUS
IC	+.3
Dip (Ht 44 ')	-7
R_o	-1
Sum	-8
hs	50-46
Ho (Obs Alt)	50-38
Date (GMT)	15 DEC 70
GMT (Obs Time)	17-12-09
DR Lat	34-19.0 S
DR Long	163-05.7 E
Tab GHA ♈	341-26.5
GHA ♈ incr'mt	0-32.0
GHA ♈	341-58.5
a λ (-W, +E)	163-01.5 E
LHA ♈	145
a Lat (N or S)	34 S
Hc (Comp Alt)	50-39
Ho (Obs Alt)	50-38
a (Intercept)	1 A
Zn (°T)	226°T
P and N Corr'n	N/A

Sp. 25

Body	MOON (UL)	VENUS
IC	+.3	+.3
Dip (Ht 44 ')	-7	-7
Ro	-2	-3
S.D.	[redacted]	
Sum	-24	-10
hs	28-10	16-47
P in A (Moon)	[redacted]	
Ho (Obs Alt)	28-35	16-37
Date (GMT)	15 DEC 70	15 DEC 70
GMT (Obs Time)	16-58-57	17-04-12
DR Lat	34-15.5 S	34-17.0 S
DR Long	163-11.7 E	163-09.1 E
Tab GHA	217-15	116-49
GHA incr'mt	2-10	1-03
SHA (Star)		
GHA	219-25	117-52
±360 if needed		
a λ (-W, +E)	163-35 E	163-08 E
LHA	383 = 23	281
Tab Dec	N 23-14	S 13-16
a Lat (N or S)	34 S Same (Cont)	34 S (Same) Cont
Dec Inc (±)d	14 | -56	16 | +32
Hc (Tab Alt)	28-57	16-15
Dec Corr'n	-13	+9
Hc (Comp Alt)	28-44	16-24
Ho (Obs Alt)	28-35	16-37
a (Intercept)	9 (A)	13 (T)
Z	S 156 W	S 84.7 E
Zn (°T)	336°T	095.3°T

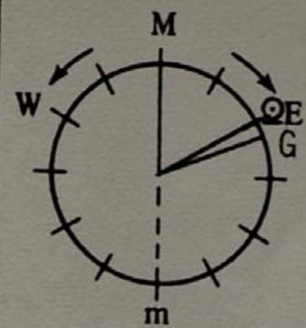
Body	CANOPUS
IC	+.3
Dip (Ht 44 ')	-7
Ro	-1
Sum	-8
hs	50-46
Ho (Obs Alt)	50-38
Date (GMT)	15 DEC 70
GMT (Obs Time)	17-12-09
DR Lat	34-19.0 S
DR Long	163-05.7 E
Tab GHA ♈	[redacted]
GHA ♈ incr'mt	[redacted]
GHA ♈	[redacted]
a λ (-W, +E)	163-01.5 E
LHA ♈	145
a Lat (N or S)	34 S
Hc (Comp Alt)	50-39
Ho (Obs Alt)	50-38
a (Intercept)	1 (A)
Zn (°T)	226°T
P and N Corr'n	N/A

Comparing HO 229 and 249

Sight Reduction
using H.O. 229

Cus:

Spd:



Body	SUN (LL)
IC	+ -.3
Dip (Ht 44 ')	-6.4
Sum	-6.7
hs	10-12.4
ha	10-05.7
Alt. Corr	+11.1
Add'l.	
H.P. ( )	
Corr. to ha	+11.1
Ho (Obs Alt)	10-16.8

Sight Reduction
using H.O. 249 Vols. II and III

Cs: 230

Sp. 25

Body	MOON(UL)
IC	+.3
Dip (Ht 44 ')	-7
Ro	-2
S.D.	-15
Sum	-24
hs	28-10
P in A (Moon)	+49
Ho (Obs Alt)	28-35

229 v. 249

Date		16 DEC 70	
DR Lat		31-08.1 N	
DR Long		64-48.0 W	
Obs. Time		08-12-06	
WE (S+, F-)		0	
ZT		08-12-06	
ZD (W+, E-)		+4	
GMT		12-12-06	
Date (GMT)		16 DEC 70	
Tab GHA	v	1-07.0	
GHA incr'mt.		3-01.5	
SHA or v Corr.			
GHA		4-08.5	
±360 if needed		364-08.5	
aλ (-W, +E)		65-08.5 W	
LHA		299	
Tab Dec	d	S 23-18.9	0.1
d Corr (+ or -)		0.0	
True Dec		S 23-18.9	
a Lat (N or S)		31 N Same (Cont.)	

Date (GMT)	15 DEC 70
GMT (Obs Time)	16-58-57
DR Lat	34-15.5 S
DR Long	163-11.7 E
Tab GHA	217-15
GHA incr'mt	2-10
SHA (Star)	
GHA	219-25
±360 if needed	
a λ (-W, +E)	163-35 E
LHA	383 = 23
Tab Dec	N 23-14
a Lat (N or S)	34 S Same (Cont)

LHA		299	
Tab Dec	d	S 23-18.9	0.1
d Corr (+ or −)		0.0	
True Dec		S 23-18.9	
a Lat (N or S)		31 N Same Cont.	
Dec Inc	(±)d	18.9	-38.9
Hc (Tab. Alt.)		10-26.7	
tens	DS Diff.	-9.5	
units	DS Corr.	-2.7	+
Tot. Corr. (+ or −)		-12.2	
Hc (Comp. Alt.)		10-14.5	
Ho (Obs. Alt.)		10-16.8	
a (Intercept)		2.3	A
Z		N 125.2 E	
Zn (°T)		125.2°T	

LHA		383 = 23	
Tab Dec		N 23-14	
a Lat (N or S)		34 S Same Cont	
Dec Inc	(±)d	14	-56
H_c (Tab Alt)		28-57	
Dec Corr'n		-13	
Hc (Comp Alt)		28-44	
Ho (Obs Alt)		28-35	
a (Intercept)		9	A
Z		S 156 W	
Zn (°T)		336°T	

HO229

29°, 331° L.H.A.   LATITUDE SAME NAME AS DECLI

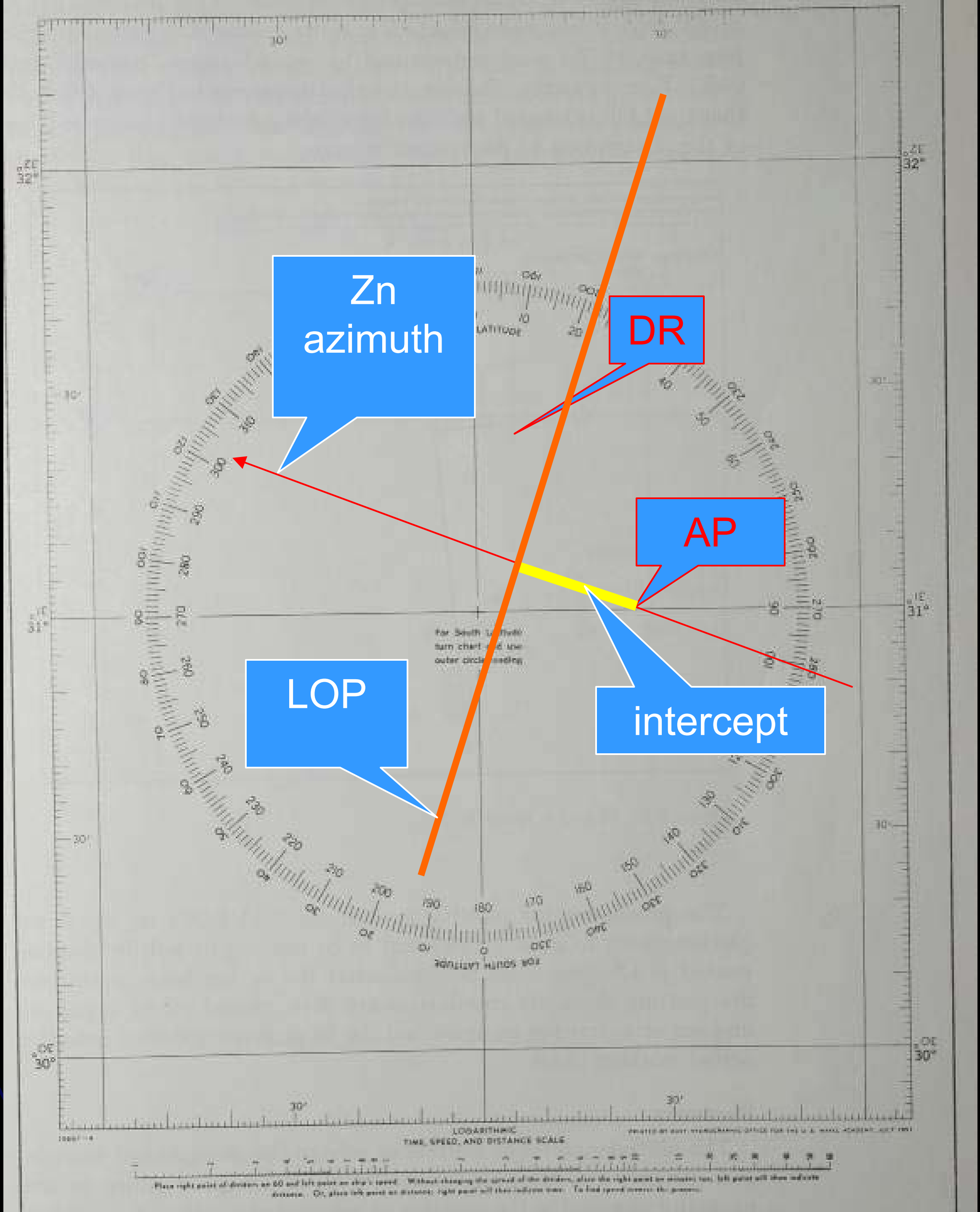
Dec.	75°			76°			77°			78°			79°		
	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z	Hc	d	Z
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°
0	13 05.0	+59.5	150.2	12 12.9	+59.6	150.3	11 20.8	+59.6	150.4	10 28.6	+59.7	150.5	9 36.4	+59.7	150.5
1	14 04.5	59.5	150.0	13 12.5	59.6	150.1	12 20.4	59.7	150.3	11 28.3	59.7	150.4	10 36.1	59.8	150.5
65	76 11.4	+50.4	120.9	75 39.1	+52.4	124.2	75 04.0	+54.0	127.3	74 26.4	+55.4	130.2	73 46.7	+56.4	132.8
66	77 01.8	49.0	118.5	76 31.5	51.2	122.2	75 58.0	53.1	125.6	75 21.8	54.6	128.7	74 43.1	55.9	131.6
67	77 50.8	47.3	115.9	77 22.7	49.9	119.9	76 51.1	52.1	123.6	76 16.4	53.9	127.0	75 39.0	55.4	130.2
68	78 38.1	45.1	112.8	78 12.6	48.3	117.3	77 43.2	50.9	121.4	77 10.3	53.0	125.1	76 34.4	54.6	128.5
69	79 23.2	42.5	109.4	79 00.9	46.2	114.3	78 34.1	49.2	118.8	78 03.3	51.8	122.9	77 29.0	53.8	126.7
70	80 05.7	+39.4	105.4	79 47.1	+43.6	110.8	79 23.3	+47.3	115.8	78 55.1	+50.3	120.4	78 22.8	+52.7	124.6
71	80 45.1	35.4	100.9	80 30.7	40.5	106.8	80 10.6	44.8	112.3	79 45.4	48.4	117.4	79 15.5	51.4	122.1
72	81 20.5	30.6	95.7	81 11.2	36.4	102.1	80 55.4	41.7	108.3	80 33.8	46.0	114.0	80 06.9	49.6	119.2
73	81 51.1	24.8	89.8	81 47.6	31.6	96.7	81 37.1	37.6	103.5	81 19.8	42.9	109.9	80 56.5	47.3	115.8
74	82 15.9	18.2	83.2	82 19.2	25.6	90.6	82 14.7	32.6	98.0	82 02.7	39.0	105.1	81 43.8	44.3	111.7
89	75 52.0	52.0	2.0	76 52.0	52.0	2.1	77 51.9	51.9	2.3	78 51.9	51.9	2.5	79 51.8	51.8	2.8
90	75 00.0	−52.9	0.0	76 00.0	−52.9	0.0	77 00.0	−53.0	0.0	78 00.0	−53.0	0.0	79 00.0	−53.1	0.0
	75°			76°			77°			78°			79°		

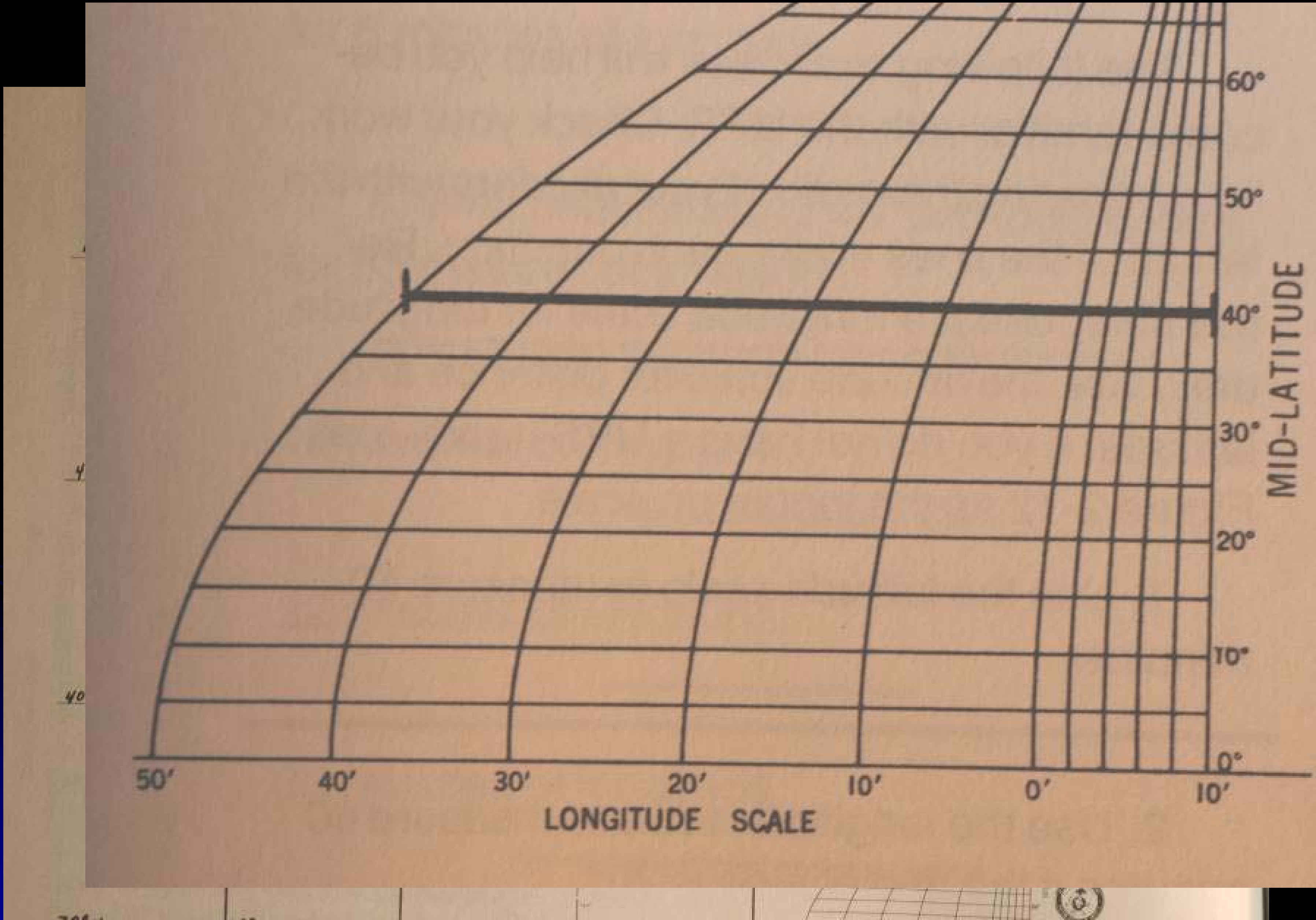
29°, 331° L.H.A.   LATITUDE SAME NAME AS DECLI

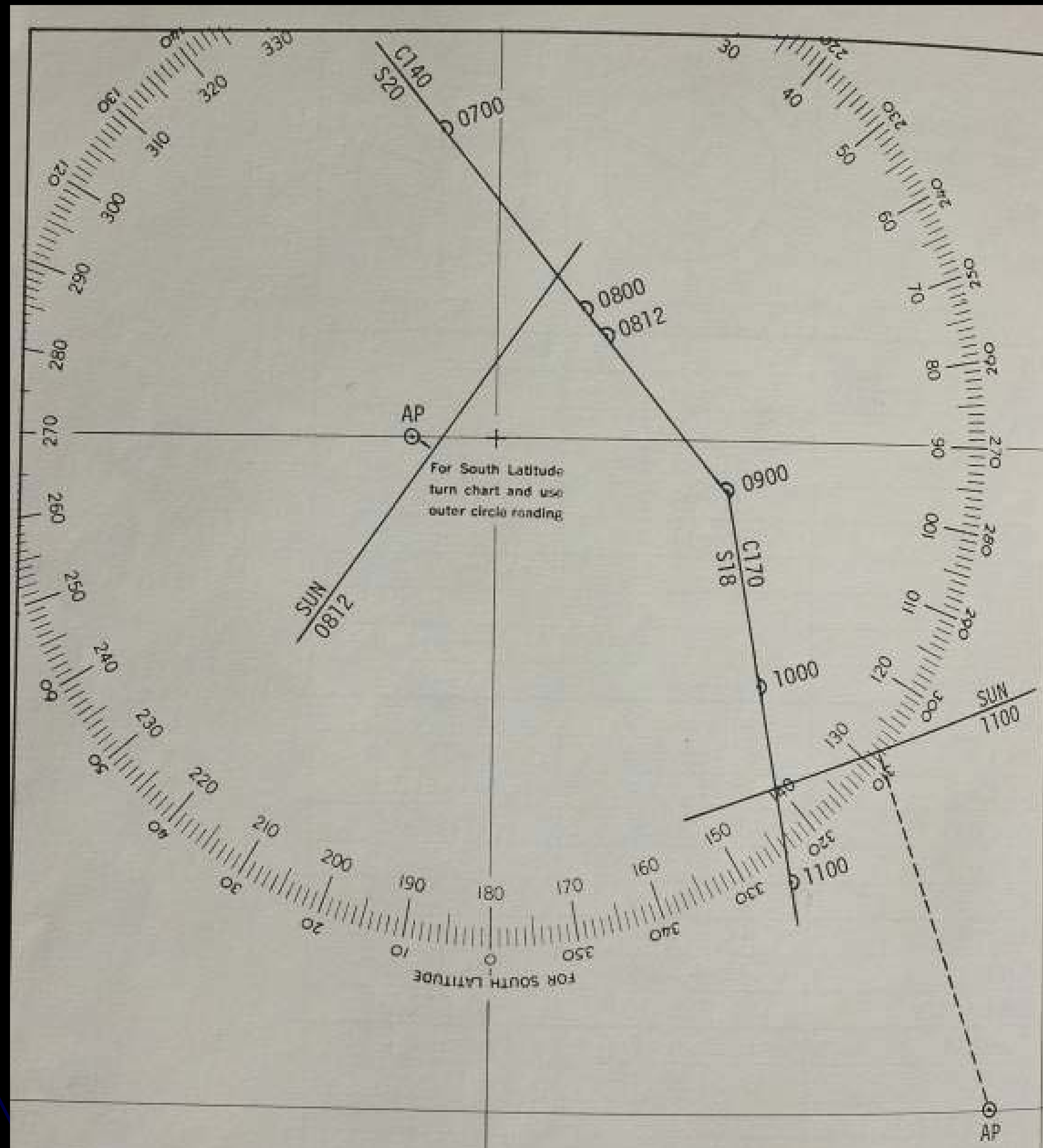
INTERPOLATION

Dec. Inc.	Altitude difference (d)																Double Second Diff. and Corr.		Dec. Inc.
	Tens					Decimals	Units												
	10′	20′	30′	40′	50′	↓	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′			
′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
28.0	4.6	9.3	14.0	18.6	23.3	.0	0.0	0.5	0.9	1.4	1.9	2.4	2.8	3.3	3.8	4.3	0.8	0.1	**36.0**
28.1	4.7	9.3	14.0	18.7	23.4	.1	0.0	0.5	1.0	1.5	1.9	2.4	2.9	3.4	3.8	4.3	2.4	0.2	**36.1**
28.2	4.7	9.4	14.1	18.8	23.5	.2	0.1	0.6	1.0	1.5	2.0	2.5	2.9	3.4	3.9	4.4	4.0	0.3	**36.2**
28.3	4.7	9.4	14.1	18.9	23.6	.3	0.1	0.6	1.1	1.6	2.0	2.5	3.0	3.5	3.9	4.4	5.6	0.4	**36.3**
28.4	4.7	9.5	14.2	18.9	23.7	.4	0.2	0.7	1.1	1.6	2.1	2.6	3.0	3.5	4.0	4.5	7.2	0.5	**36.4**
																	8.8	0.6	
28.5	4.8	9.5	14.3	19.0	23.8	.5	0.2	0.7	1.2	1.7	2.1	2.6	3.1	3.6	4.0	4.5	10.4	0.7	**36.5**
28.6	4.8	9.5	14.3	19.1	23.8	.6	0.3	0.8	1.2	1.7	2.2	2.7	3.1	3.6	4.1	4.6	12.0	0.8	**36.6**
28.7	4.8	9.6	14.4	19.2	23.9	.7	0.3	0.8	1.3	1.8	2.2	2.7	3.2	3.7	4.1	4.6	13.6	0.9	**36.7**
28.8	4.8	9.6	14.4	19.2	24.0	.8	0.4	0.9	1.3	1.8	2.3	2.8	3.2	3.7	4.2	4.7	15.2	1.0	**36.8**
28.9	4.9	9.7	14.5	19.3	24.1	.9	0.4	0.9	1.4	1.9	2.3	2.8	3.3	3.8	4.2	4.7	16.8		**36.9**
34.0	5.6	11.3	17.0	22.6	28.3	.0	0.0	0.6	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.2	0.8	0.1	**42.0**
34.1	5.7	11.3	17.0	22.7	28.4	.1	0.1	0.6	1.2	1.8	2.4	2.9	3.5	4.1	4.7	5.2	2.5	0.2	**42.1**
34.2	5.7	11.4	17.1	22.8	28.5	.2	0.1	0.7	1.3	1.8	2.4	3.0	3.6	4.1	4.7	5.3	4.1	0.3	**42.2**
34.3	5.7	11.4	17.1	22.9	28.6	.3	0.2	0.7	1.3	1.9	2.5	3.0	3.6	4.2	4.8	5.3	5.8	0.4	**42.3**
34.4	5.7	11.5	17.2	22.9	28.7	.4	0.2	0.8	1.4	2.0	2.5	3.1	3.7	4.3	4.8	5.4	7.4	0.5	**42.4**
																	9.1	0.6	
34.5	5.8	11.5	17.3	23.0	28.8	.5	0.3	0.9	1.4	2.0	2.6	3.2	3.7	4.3	4.9	5.5	10.7		**42.5**
34.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

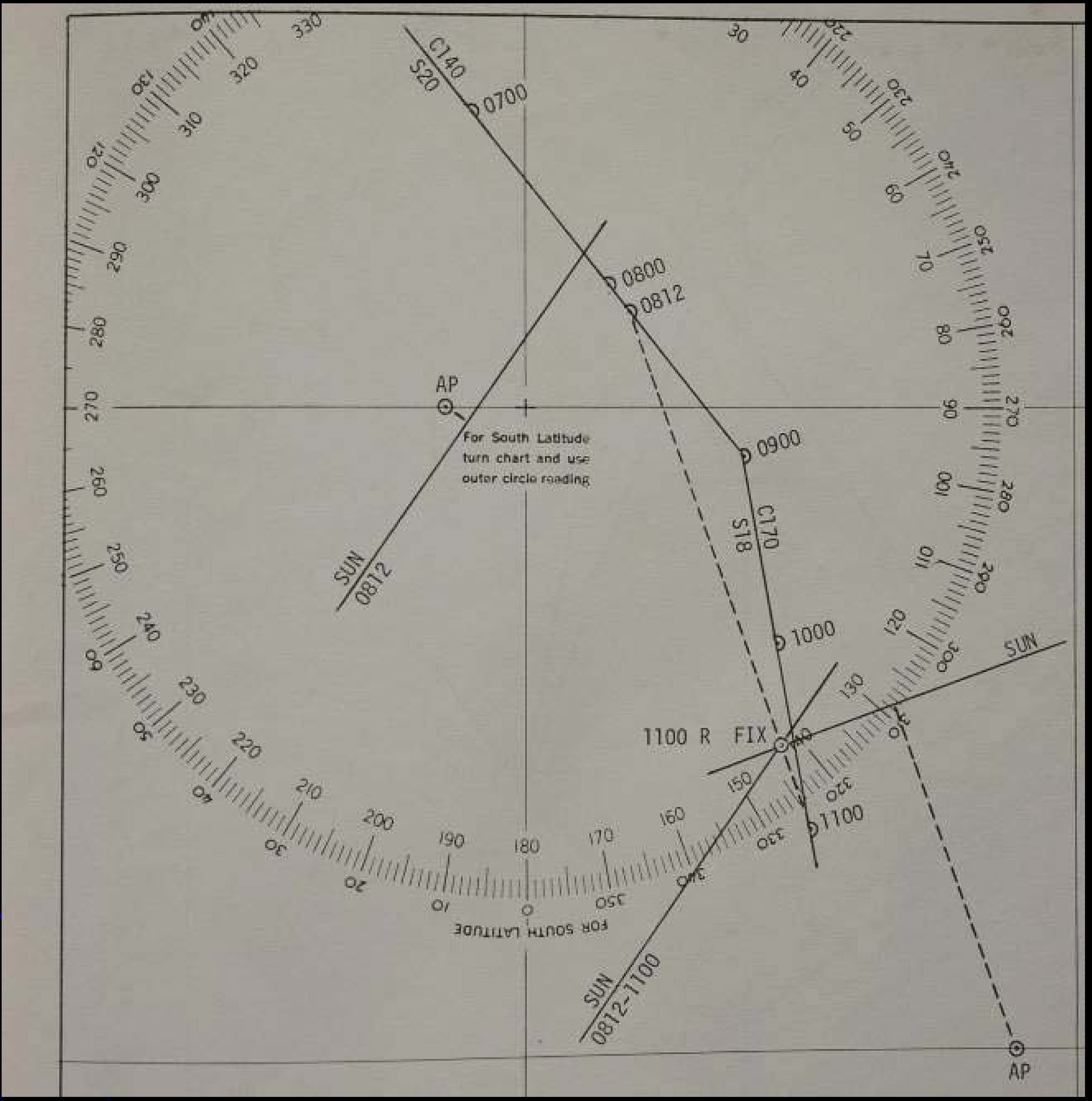
Plotting an LOP




60°
50°
40°
30°
20°
10°
0°
MID-LATITUDE
50′
40′
30′
20′
10′
0′
10′
LONGITUDE SCALE



C140
S20
0700
0800
0812
AP
For South Latitude turn chart and use outer circle reading
0900
C170
S18
SUN
0812
1000
SUN
1100
1100
AP
FOR SOUTH LATITUDE


C140
S20
0700
0800
0812
AP
For South Latitude
turn chart and use
outer circle reading
0900
C170
S18
SUN
0812
1000
SUN
1100 R FIX
1100
SUN
0812-1100
AP
FOR SOUTH LATITUDE

Calculator navigation

Entering arguments

PROMPT	REPLY
Compute Cel LOP	Enter
New fix?	Yes
Old fix erased	
Review Data	Yes
Day	1
Month	1
Year	2005
Assumed latitude	29.452
Assumed longitude	-142.18

PROMPT	REPLY
Eye ht. (ft.)	7
IC	-2.5
Speed (knots)	7.5
True course	225
Fix time	21.10
Review data	yes

Shot time	20.4616
Hs	43.35
body	40
Hc 43.234	Enter
Away -4.5	Enter
ZN 9.9	Enter
accept	Yes/no
Next LOP	

Push “Fix” button

Lat-lon fix	Enter
LOPs comp	Y/N
Use good cuts	Enter
Cancel LOP	Y/N
Fix Lat 29.408	Enter
Fix Longitude -142.186	Enter
Fix time 21.00	Enter

Scientific calculators

- Sub routine to convert to degrees and decimals 123°45.6’ = 123.7600°
- Work sheet to “cook book” calculations
- Solving PZX triangle with spherical trig
- Advantage of a celestial algorithm “chip”
- Laptop software

Critical path

- Exact time and accurate sextant
- Familiar sight taking routine
- Consistent approach to sight reduction
- Double check – "too good to be true rule"
- Hard copy back up and non electronic contingency plan

the end