How Does Santa Navigate?

How to get from A to B whilst airborne.

The importance of precision…

So how does he do it?

Five methods of aerial navigation:

Pilot Navigation

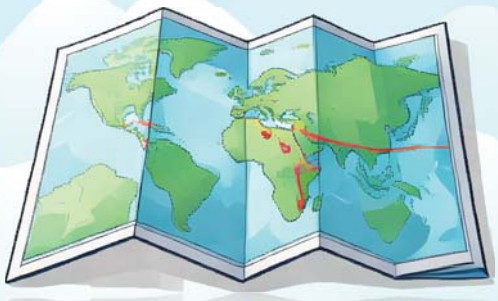
Astro Navigation

Radio Navigation

Inertial Navigation

Satellite Navigation

Pilot Navigation

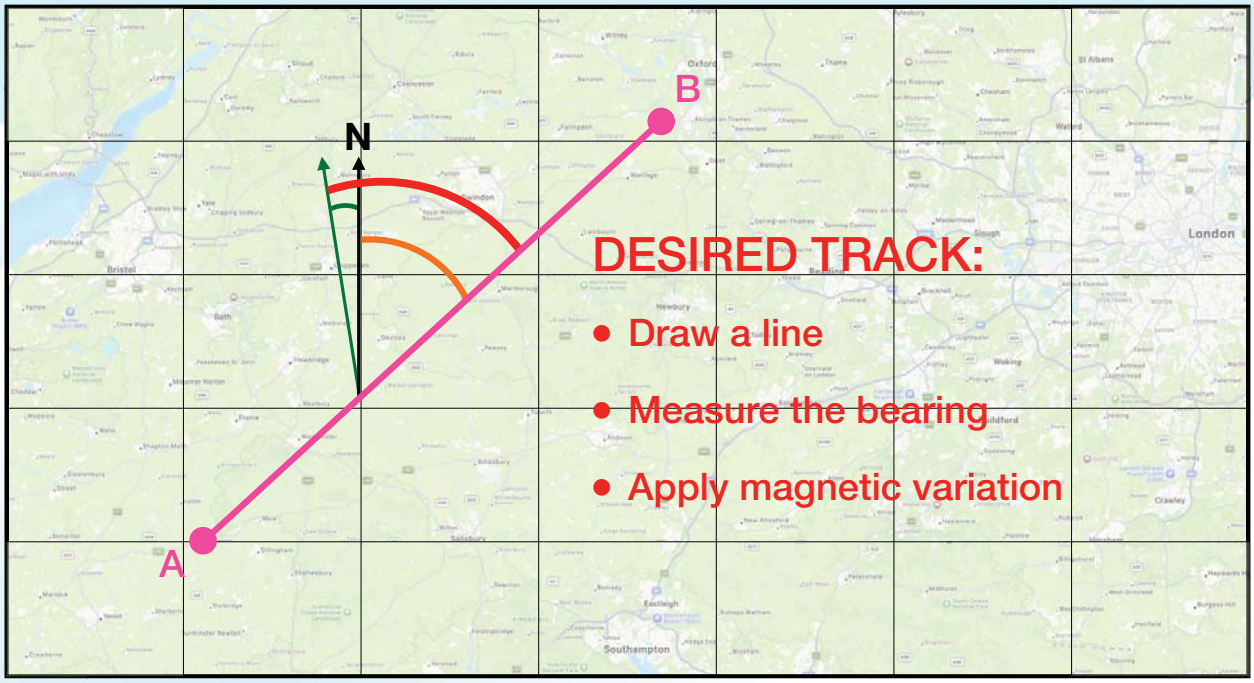


Map

Compass

Stopwatch

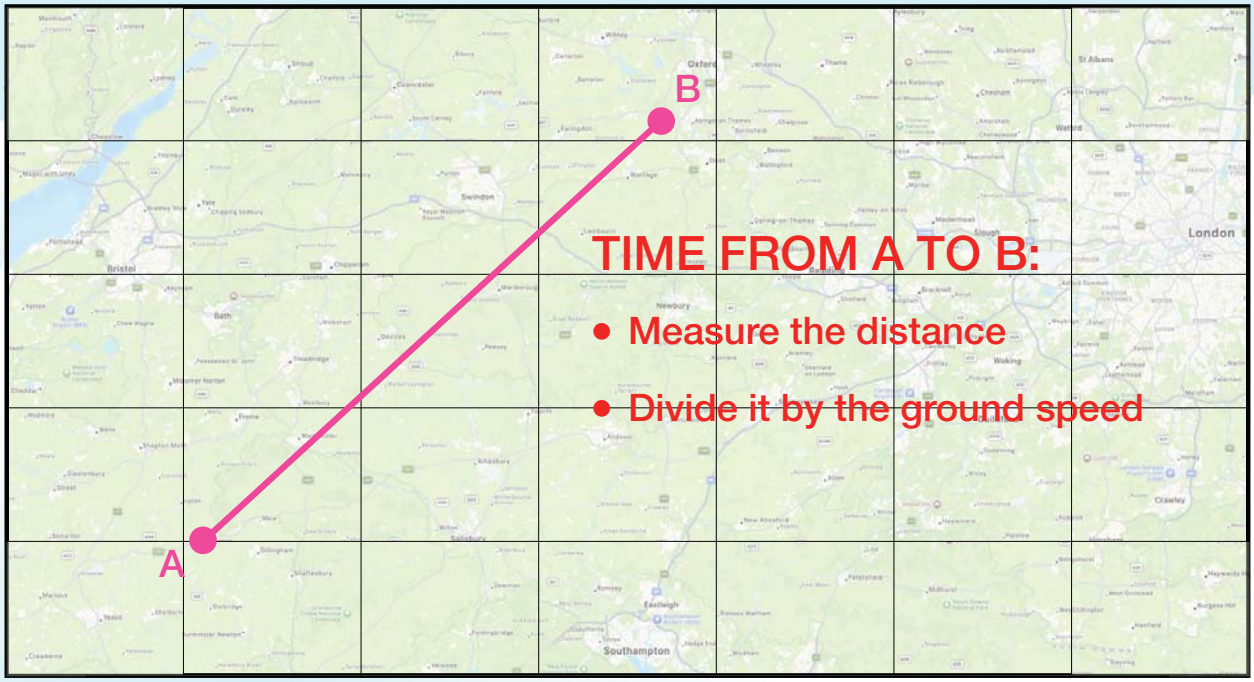
Pilot Navigation



DESIRED TRACK:

- Draw a line
- Measure the bearing
- Apply magnetic variation

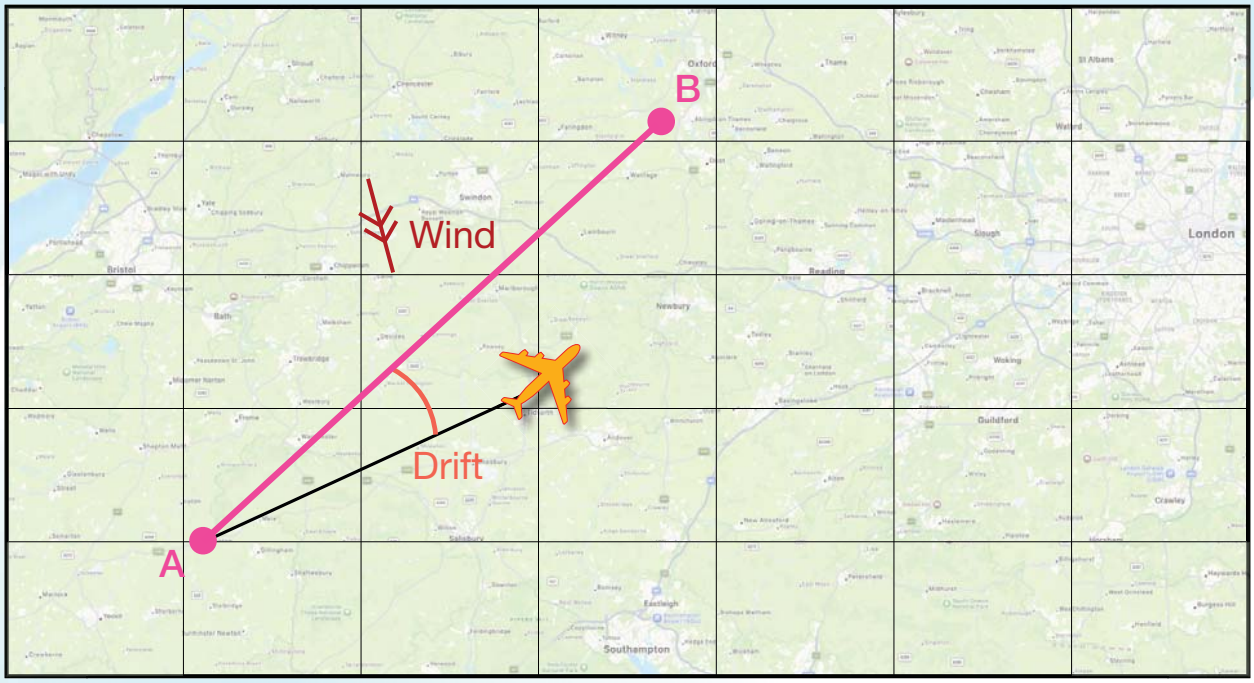
Pilot Navigation



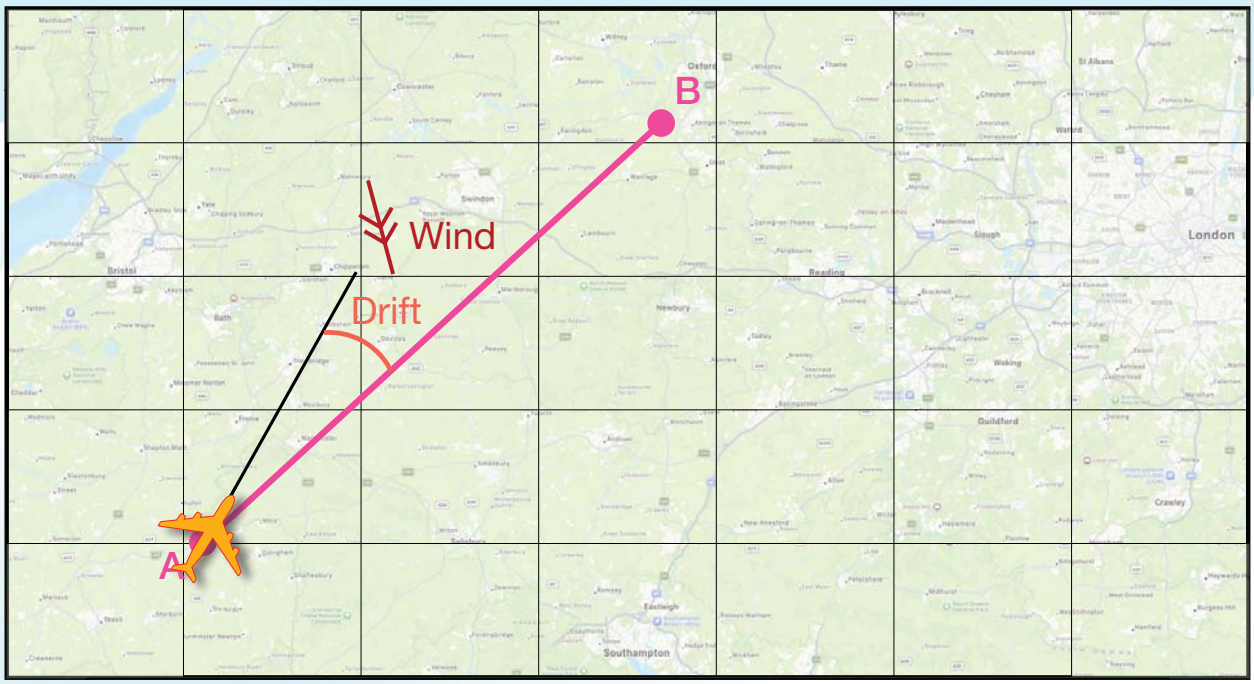
TIME FROM A TO B:

- Measure the distance
- Divide it by the ground speed

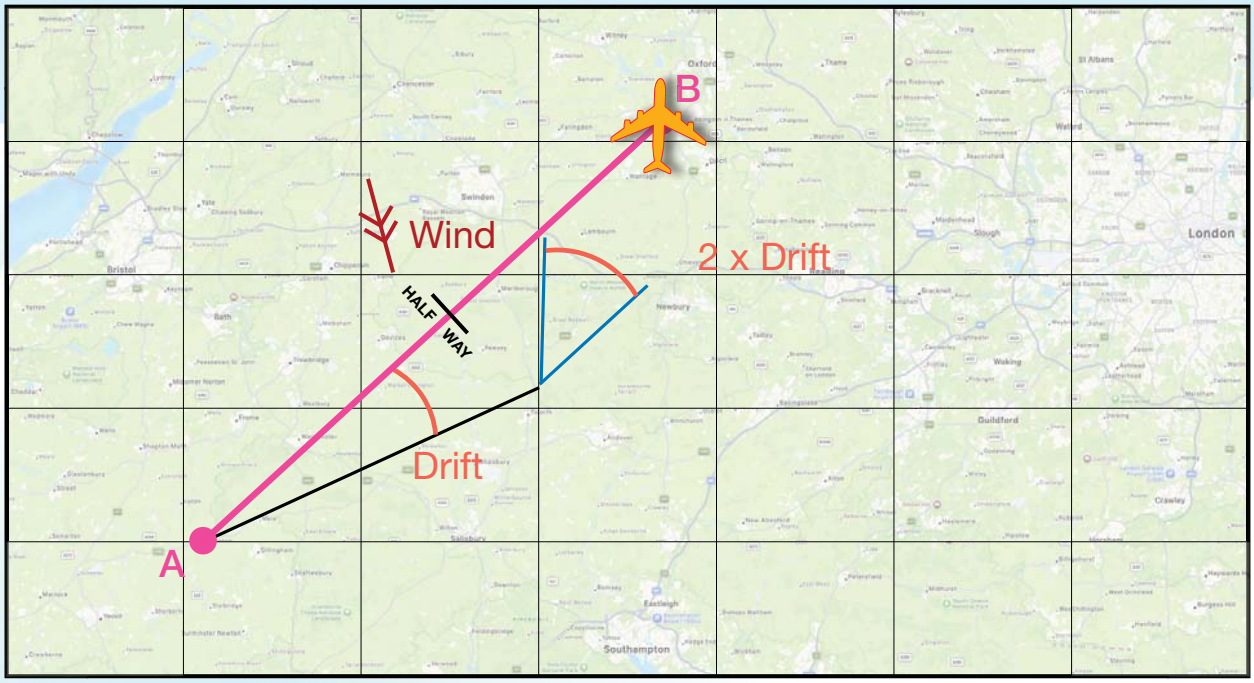
Pilot Navigation



Pilot Navigation



Pilot Navigation



Pilot Navigation

Suitable for Santa?

- Straightforward ✓
- Night-time issues ✗
- Number of maps needed ✗
- Lines on the map ✗

Five methods of aerial navigation:

~~Pilot Navigation~~

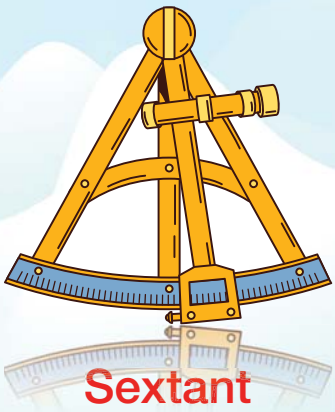
Astro Navigation

Radio Navigation

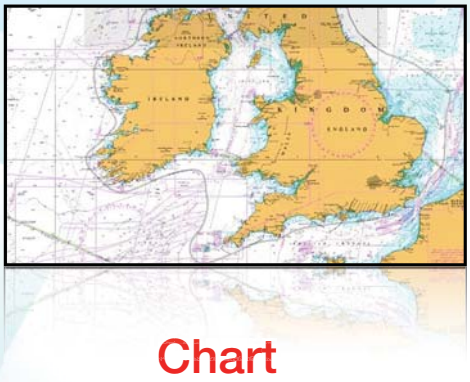
Inertial Navigation

Satellite Navigation

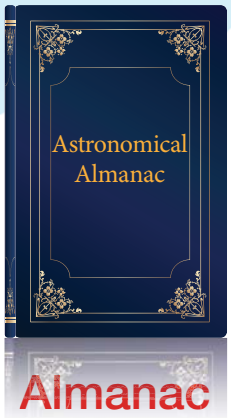
Astro Navigation



Sextant

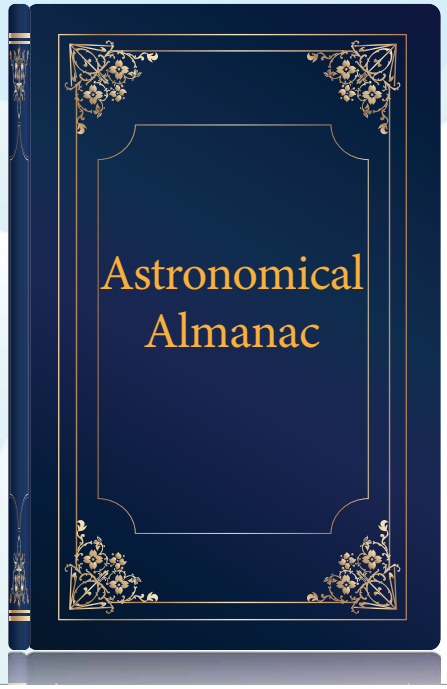


Chart

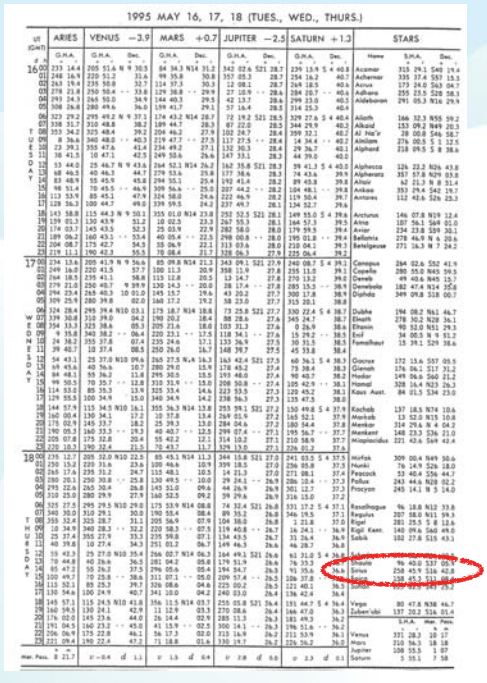


Almanac

Astro Navigation



Astro Navigation



1995 MAY 16, 17, 18 (TUES., WED., THURS.)

UT (GMT)	ARIES	VENUS −3.9	MARS +0.7	JUPITER −2.5	SATURN +1.3	STARS
	G.H.A.	G.H.A. Dec.	G.H.A. Dec.	G.H.A. Dec.	G.H.A. Dec.	Name S.H.A. Dec.
d h	° ′	° ′ ° ′	° ′ ° ′	° ′ ° ′	° ′ ° ′	
16 00	233 14.4	205 51.6 N 9 50.5	84 34.3 N14 31.2	342 02.6 S21 28.7	239 13.9 S 4 40.8	Acamar 315 29.1 S40 19.4
01	248 16.9	220 51.2 31.6	99 35.8 30.8	357 05.3 28.7	254 16.2 40.7	Achernar 335 37.4 S57 13.5
02	263 19.4	235 50.8 31.7	114 37.3 30.3	12 08.1 28.7	269 18.5 40.6	Acrux 173 24.0 S63 04.7
03	278 21.8	250 50.4 · · · 33.8	129 38.8 · · · 29.9	27 10.9 · · · 28.6	284 20.7 · · · 40.6	Adhara 255 23.5 S28 58.3
04	293 24.3	265 50.0 34.9	144 40.3 29.5	42 13.7 28.6	299 23.0 40.5	Aldebaran 291 05.3 N16 29.9
05	308 26.8	280 49.6 36.0	159 41.7 29.1	57 16.4 28.5	314 25.3 40.4	
06	323 29.2	295 49.2 N 9 37.1	174 43.2 N14 28.7	72 19.2 S21 28.5	329 27.6 S 4 40.4	Alioth 166 32.3 N55 59.2
07	338 31.7	310 48.8 38.2	189 44.7 28.3	87 22.0 28.5	344 29.9 40.3	Alkaid 153 09.2 N49 20.3
T 08	353 34.2	325 48.4 39.2	204 46.2 27.9	102 24.7 28.4	359 32.1 40.2	Al Na'ir 28 00.8 S46 58.7
U 09	8 36.6	340 48.0 · · · 40.3	219 47.7 · · · 27.5	117 27.5 · · · 28.4	14 34.4 · · · 40.2	Alnilam 276 00.5 S 1 12.5
E 10	23 39.1	355 47.6 41.4	234 49.2 27.1	132 30.3 28.4	29 36.7 40.1	Alphard 218 09.5 S 8 38.6
S 11	38 41.5	10 47.1 42.5	249 50.6 26.6	147 33.1 28.3	44 39.0 40.0	
D 12	53 44.0	25 46.7 N 9 43.6	264 52.1 N14 26.2	162 35.8 S21 28.3	59 41.3 S 4 40.0	Alphecca 126 22.2 N26 43.8
A 13	68 46.5	40 46.3 44.7	279 53.6 25.8	177 38.6 28.3	74 43.6 39.9	Alpheratz 357 57.8 N29 03.8
Y 14	83 48.9	55 45.9 45.8	294 55.1 25.4	192 41.4 28.2	89 45.8 39.8	Altair 62 21.3 N 8 51.4
15	98 51.4	70 45.5 · · · 46.9	309 56.6 · · · 25.0	207 44.2 · · · 28.2	104 48.1 · · · 39.8	Ankaa 353 29.4 S42 19.7
16	113 53.9	85 45.1 47.9	324 58.0 24.6	222 46.9 28.2	119 50.4 39.7	Antares 112 40.6 S26 25.3
17	128 56.3	100 44.7 49.0	339 59.5 24.2	237 49.7 28.1	134 52.7 39.6	
18	143 58.8	115 44.3 N 9 50.1	355 01.0 N14 23.8	252 52.5 S21 28.1	149 55.0 S 4 39.6	Arcturus 146 07.8 N19 12.4
19	159 01.3	130 43.9 51.2	10 02.5 23.3	267 55.3 28.1	164 57.3 39.5	Atria 107 56.1 S69 01.0
20	174 03.7	145 43.5 52.3	25 03.9 22.9	282 58.0 28.0	179 59.5 39.4	Avior 234 23.0 S59 30.1
21	189 06.2	160 43.1 · · · 53.4	40 05.4 · · · 22.5	298 00.8 · · · 28.0	195 01.8 · · · 39.4	Bellatrix 278 46.9 N 6 20.6
22	204 08.7	175 42.7 54.5	55 06.9 22.1	313 03.6 28.0	210 04.1 39.3	Betelgeuse 271 16.3 N 7 24.2
23	219 11.1	190 42.3 55.5	70 08.4 21.7	328 06.3 27.9	225 06.4 39.2	
17 00	234 13.6	205 41.9 N 9 56.6	85 09.8 N14 21.3	343 09.1 S21 27.9	240 08.7 S 4 39.1	Canopus 264 02.6 S52 41.9
01	249 16.0	220 41.5 57.7	100 11.3 20.9	358 11.9 27.8	255 11.0 39.1	Capella 280 55.0 N45 59.5
02	264 18.5	235 41.1 58.8	115 12.8 20.5	13 14.7 27.8	270 13.2 39.0	Deneb 49 43.6 N45 15.7
03	279 21.0	250 40.7 9 59.9	130 14.3 · · · 20.0	28 17.4 · · · 27.8	285 15.5 · · · 38.9	Denebola 182 47.4 N14 35.8
04	294 23.4	265 40.3 10 01.0	145 15.7 19.6	43 20.2 27.7	300 17.8 38.9	Diphda 349 09.8 S18 00.7
05	309 25.9	280 39.8 02.0	160 17.2 19.2	58 23.0 27.7	315 20.1 38.8	
06	324 28.4	295 39.4 N10 03.1	175 18.7 N14 18.8	73 25.8 S21 27.7	330 22.4 S 4 38.7	Dubhe 194 08.2 N61 46.7
W 07	339 30.8	310 39.0 04.2	190 20.2 18.4	88 28.6 27.6	345 24.7 38.7	Elnath 278 30.2 N28 36.1
E 08	354 33.3	325 38.6 05.3	205 21.6 18.0	103 31.3 27.6	0 26.9 38.6	Eltanin 90 52.0 N51 29.3
D 09	9 35.8	340 38.2 · · · 06.4	220 23.1 · · · 17.5	118 34.1 · · · 27.6	15 29.2 · · · 38.5	Enif 34 00.5 N 9 51.2
N 10	24 38.2	355 37.8 07.4	235 24.6 17.1	133 36.9 27.5	30 31.5 38.5	Fomalhaut 15 39.1 S29 38.6
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S 12	54 43.1	25 37.0 N10 09.6	265 27.5 N14 16.3	163 42.4 S21 27.5	60 36.1 S 4 38.3	Gacrux 172 13.6 S57 00.5
D 13	69 45.6	40 36.6 10.7	280 29.0 15.9	178 45.2 27.4	75 38.4 38.2	Gienah 176 06.2 S17 31.2
A 14	84 48.1	55 36.2 11.8	295 30.5 15.5	193 48.0 27.4	90 40.7 38.2	Hadar 149 06.6 S60 21.2
Y 15	99 50.5	70 35.7 · · · 12.8	310 31.9 · · · 15.0	208 50.8 · · · 27.4	105 42.9 · · · 38.1	Hamal 328 16.4 N23 26.3
16	114 53.0	85 35.3 13.9	325 33.4 14.6	223 53.5 27.3	120 45.2 38.1	Kaus Aust. 84 01.5 S34 23.0
17	129 55.5	100 34.9 15.0	340 34.9 14.2	238 56.3 27.3	135 47.5 38.0	
18	144 57.9	115 34.5 N10 16.1	355 36.3 N14 13.8	253 59.1 S21 27.2	150 49.8 S 4 37.9	Kochab 137 18.5 N74 10.6
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20	175 02.9	145 33.7 18.2	25 39.3 13.0	284 04.6 27.2	180 54.4 37.8	Menkar 314 29.6 N 4 04.2
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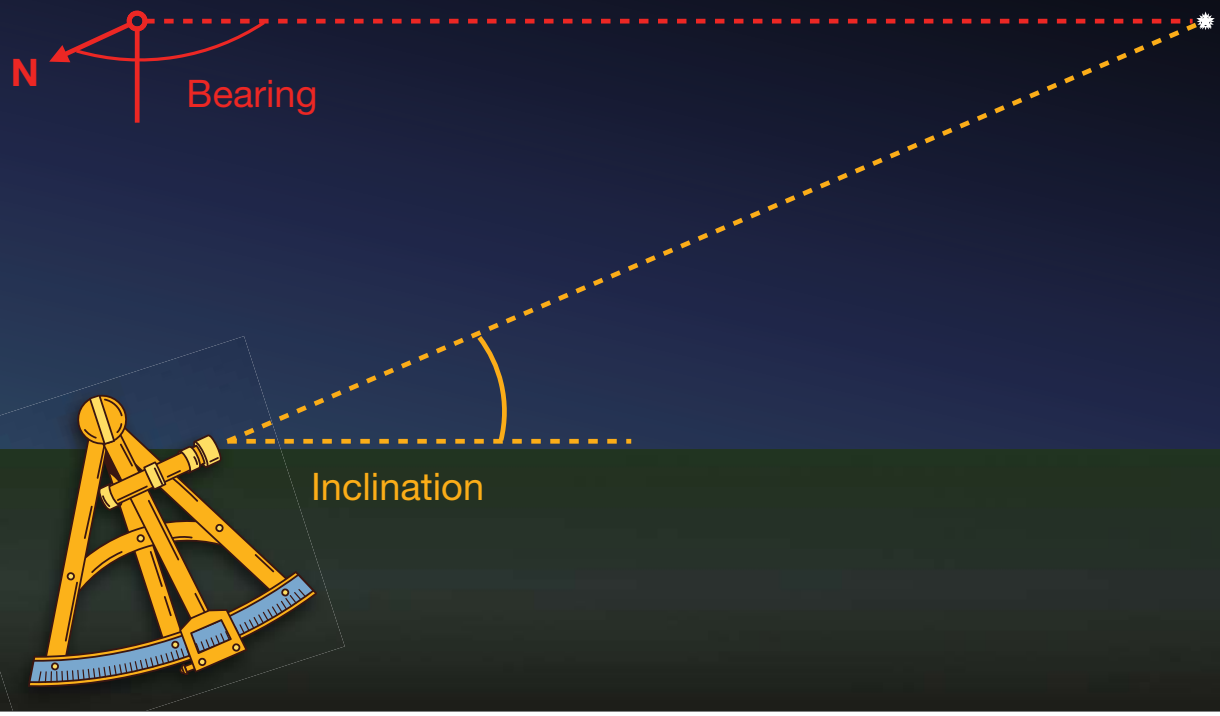
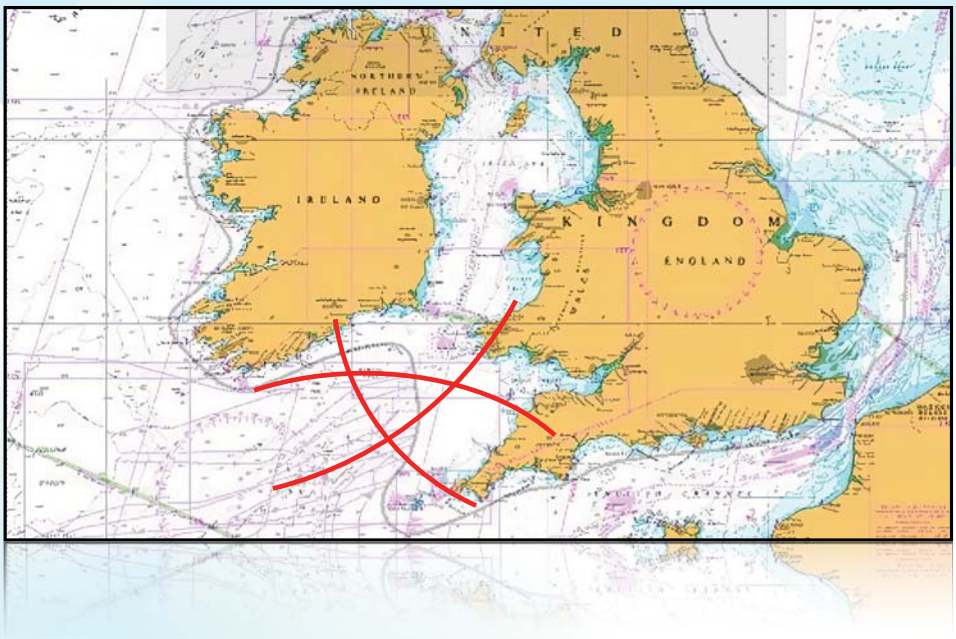
22	205 07.8	175 32.8 20.4	55 42.2 12.1	314 10.2 27.1	210 58.9 37.7	Miaplacidus 221 42.6 S69 42.4
23	220 10.3	190 32.4 21.5	70 43.7 11.7	329 13.0 27.1	226 01.2 37.6	
18 00	235 12.7	205 32.0 N10 22.5	85 45.1 N14 11.3	344 15.8 S21 27.0	241 03.5 S 4 37.5	Mirfak 309 00.4 N49 50.6
01	250 15.2	220 31.6 23.6	100 46.6 10.9	359 18.5 27.0	256 05.8 37.5	Nunki 76 14.9 S26 18.0
02	265 17.6	235 31.2 24.7	115 48.1 10.5	14 21.3 27.0	271 08.1 37.4	Peacock 53 40.4 S56 44.7
03	280 20.1	250 30.8 · · · 25.8	130 49.5 · · · 10.0	29 24.1 · · · 26.9	286 10.4 · · · 37.3	Pollux 243 44.6 N28 02.2
04	295 22.6	265 30.4 26.8	145 51.0 09.6	44 26.9 26.9	301 12.7 37.3	Procyon 245 14.1 N 5 14.0
05	310 25.0	280 29.9 27.9	160 52.5 09.2	59 29.6 26.9	316 15.0 37.2	
06	325 27.5	295 29.5 N10 29.0	175 53.9 N14 08.8	74 32.4 S21 26.8	331 17.2 S 4 37.1	Rasalhague 96 18.8 N12 33.8
07	340 30.0	310 29.1 30.0	190 55.4 08.4	89 35.2 26.8	346 19.5 37.1	Regulus 207 58.0 N11 59.3
T 08	355 32.4	325 28.7 31.1	205 56.9 07.9	104 38.0 26.8	1 21.8 37.0	Rigel 281 25.5 S 8 12.6
U 09	10 34.9	340 28.3 · · · 32.2	220 58.3 · · · 07.5	119 40.8 · · · 26.7	16 24.1 · · · 36.9	Rigil Kent. 140 09.6 S60 49.0
E 10	25 37.4	355 27.9 33.3	235 59.8 07.1	134 43.5 26.7	31 26.4 36.9	Sabik 102 27.6 S15 43.1
S 11	40 39.8	10 27.4 34.3	251 01.2 06.7	149 46.3 26.6	46 28.7 36.8	
D 12	55 42.3	25 27.0 N10 35.4	266 02.7 N14 06.3	164 49.1 S21 26.6	61 31.0 S 4 36.8	Schedar 349 45.2 N56 37.6
A 13	70 44.8	40 26.6 36.5	281 04.2 05.8	179 51.9 26.6	76 33.3 36.7	Shaula 96 40.0 S37 05.7
Y 14	85 47.2	55 26.2 37.5	296 05.6 05.4	194 54.7 26.5	91 35.6 36.6	Sirius 258 45.9 S16 42.8
15	100 49.7	70 25.8 · · · 38.6	311 07.1 · · · 05.0	209 57.4 · · · 26.5	106 37.8 · · · 36.6	Spica 158 45.3 S11 08.8
16	115 52.1	85 25.3 39.7	326 08.6 04.6	225 00.2 26.5	121 40.1 36.5	Suhail 223 03.2 S43 25.1
17	130 54.6	100 24.9 40.7	341 10.0 04.2	240 03.0 26.4	136 42.4 36.4	
18	145 57.1	115 24.5 N10 41.8	356 11.5 N14 03.7	255 05.8 S21 26.4	151 44.7 S 4 36.4	Vega 80 47.8 N38 46.7
19	160 59.5	130 24.1 42.9	11 12.9 03.3	270 08.6 26.4	166 47.0 36.3	Zuben'ubi 137 20.2 S16 01.4
20	176 02.0	145 23.6 44.0	26 14.4 02.9	285 11.3 26.3	181 49.3 36.2	
21	191 04.5	160 23.2 · · · 45.0	41 15.9 · · · 02.5	300 14.1 · · · 26.3	196 51.6 · · · 36.2	SHA Mer. Pass.
22	206 06.9	175 22.8 46.1	56 17.3 02.0	315 16.9 26.2	211 53.9 36.1	Venus 331 28.3 10 17
23	221 09.4	190 22.4 47.2	71 18.8 01.6	330 19.7 26.2	226 56.2 36.0	Mars 210 56.3 18 18
Mer. Pass. h 21.7	v −0.4 d 1.1	v 1.5 d 0.4	v 2.8 d 0.0	v 2.3 d 0.1	Jupiter 108 55.5 1 07	
						Saturn 5 55.1 7 58

Astro Navigation



Astro Navigation

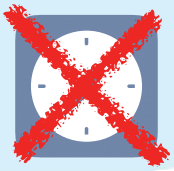


Astro Navigation

Suitable for Santa?

- Ground features not required ✓
- Cloudy skies ✗
- Time consuming and inaccurate ✗

Five methods of aerial navigation:



Pilot Navigation

Astro Navigation

Radio Navigation

Inertial Navigation

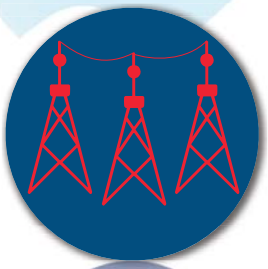
Satellite Navigation

Radio Navigation

Radio Beacons

Non-Directional Beacons (NDB)

Directional Beacons



Hyperbolic Systems

Radio Navigation

Radio Beacons

Non-Directional Beacons (NDB)

Radio Navigation

Transmits on 198KHz

Droitwich Transmitter

Radio Navigation

Transmits on 545KHz

·—·· ·· —·—·

L I C

Lichfield NDB

Radio Navigation

Droitwich Transmitter

Radio Navigation

Airborne Instruments (Avionics)

RBI

RMI

Radio Navigation

Radio Beacons

Directional

Radio Navigation

VHF Omni-Directional Radio (VOR)

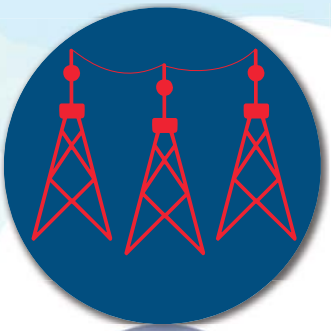
Radio Navigation

Airborne Instruments (Avionics)

VOR

Radio Navigation

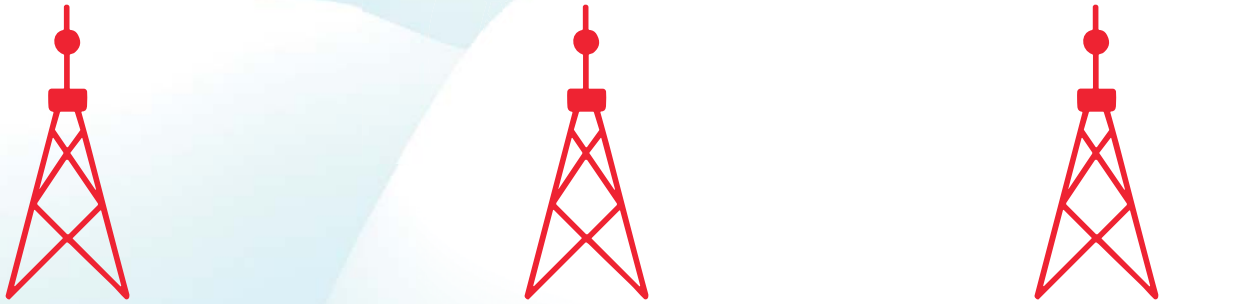
Radio Beacons



Hyperbolic

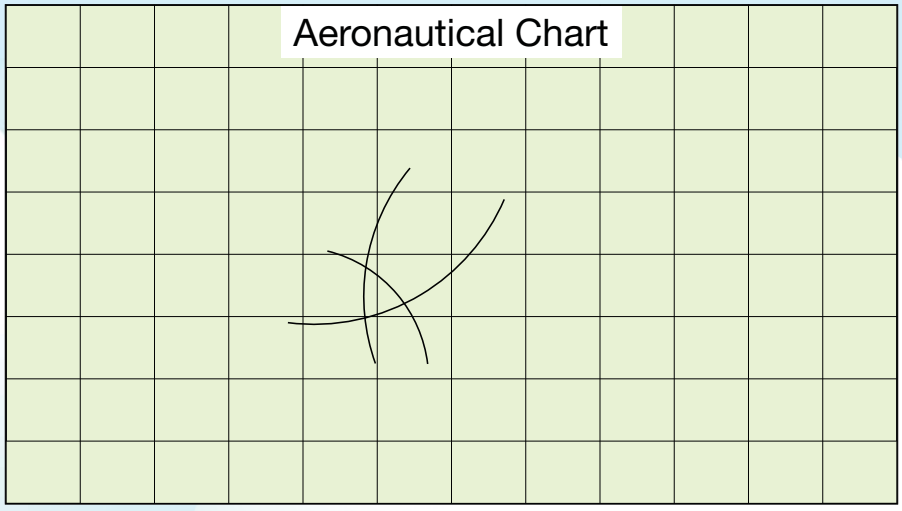
Radio Navigation

LORAN-C System



Slave Station | Master Station | Slave Station

Radio Navigation



Hyperbolic Position Lines

Radio Navigation

LORAN-C

Radio Navigation

Suitable for Santa?

- Ground features not required ✓
- Cloudy skies ✓
- Fairly accurate ✓
- Need a power supply ✗
- Need specific antennae ✗

Five methods of aerial navigation:

Pilot Navigation

Astro Navigation

Radio Navigation

Inertial Navigation

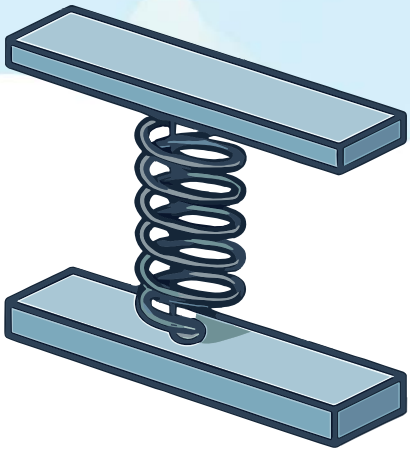
Satellite Navigation

Inertial Navigation

Gyroscope

Inertial Navigation

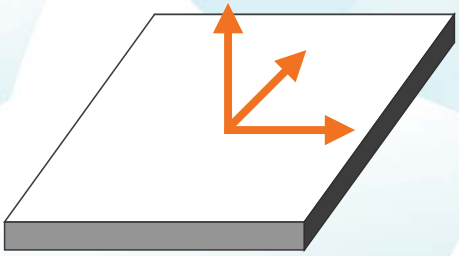
Gyroscope



Accelerometer

Inertial Navigation

Inertial Platform



- Gyro Stabilised
- Kept level with respect to the Earth's surface
- Measures acceleration in all three axes

Inertial Navigation

Operation

- Tell it where it is
- Allow it to align

INS will then calculate its position and speed by measuring each acceleration.

Inertial Navigation

- Enter coordinates of waypoints
- INS will calculate desired track
- No updates required

Inertial Navigation

Suitable for Santa?

- Self contained system ✓
- Operates anywhere ✓
- Limits to accuracy ✗
- Requires a power supply ✗

Five methods of aerial navigation:

Pilot Navigation

Astro Navigation

Radio Navigation

Inertial Navigation

Satellite Navigation

Satellite Navigation

Satellite Navigation

Each Satellite:

- Contains an atomic clock
- Transmits precise time data

Satellite Navigation

Satellite Navigation

Airborne GPS Receiver

Satellite Navigation

Suitable for Santa?

- Ground features not required ✓
- Cloudy skies do not matter ✓
- Extremely accurate ✓
- Easy to use ✓
- Real-time readout ✓
- Works off batteries ✓

Five methods of aerial navigation:

Pilot Navigation

Astro Navigation

Radio Navigation

Inertial Navigation

Satellite Navigation