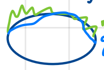
General Navigation

01 Basics of Navigation

The Earth

ecliptic: the plane in which the Earth orbits the Son
from Earth, the apparent movement of the Son

geoid: irregular shape of the Earth, based on the surface of the oceans influenced only by gravity and centrifugal forces

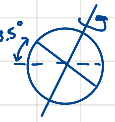


- Rate of change of daylight duration
  - → greatest at equinoxes
  - → directly proportional to Sun's declination

WGS 84 = international standard ellipsoid
→ equator is the only true great circle

Earth circumference:
- 21'600 NM
- 40'000 km

Diameter:
- 12'700 km



Units

1 NM = 1.852 km = 1.15 SM = 6080 ft

1 SM = 5280 ft

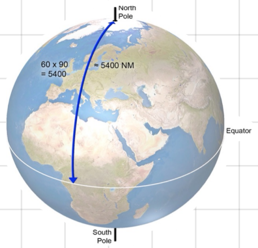
$1 \left[\frac{m}{s}\right] \cdot 3.6 = \left[\frac{km}{h}\right]$

1 inch = 2.54 cm

10 m/s = 20 kts

1 m = 3.28 ft

On a meridian: great circle
- 1° = 60' = 60 NM
- 1' = 1 NM (correct at 45° N/S)

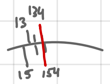


Converting units with E6-B

Ex: Convert 154 SM → NM

1) Align NM with SM

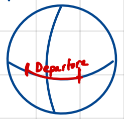
2) Read 154 SM = 134 NM

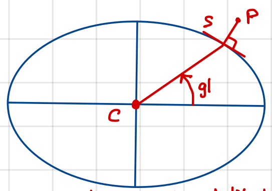


⚠ on E6-B you can only convert from ft to m (and not ft to km)

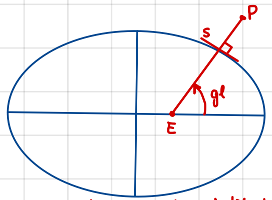
Position

Departure [NM] = Δlongitude [min] · cos(lat)



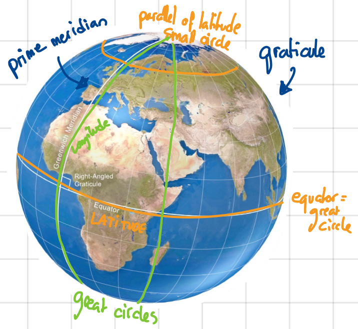


gl = geocentric latitude



gl = geographic latitude
geodetic

Distance between latitude increases



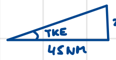
Direction

- **Isogonal**: equal magnetic variation. Converge at north and south geographic and magnetic pole
- **Isoclinal**: equal dip
- **Aclinic**: zero dip (magnetic equator)

(A = zero, Clinic = dip) — Agonic line: zero magnetic variation

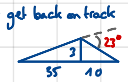
TKE = $\frac{\text{distance off-track}}{\text{distance along track}} \cdot 60$

Track Error Angle



$TKE = \frac{2 \cdot 60}{45}$

To get back on track



$TKE_1 = \frac{3 \cdot 60}{35} = 5°$

$TKE_2 = \frac{3 \cdot 60}{10} = 18°$

23°

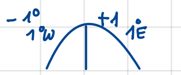
Drift = Difference between TH and TT (that you are actually flying)

Track error = Difference between TC and TT (not planned track)

Effective TAS = TAS · cos(WCA)

C	D	M	V	T
Compass heading	deviation	magnetic heading	variation	True heading

Deviation sign



WEST is best ← ⊕

East is least ← ⊖

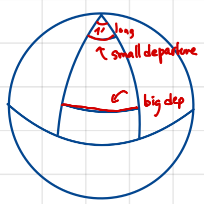
Magnetic track angle = direction of a line referenced to Magnetic North

(longitudinal axis refers to heading)

- Magnetic variation changes due to the changing position of magnetic material in the earth
- 1° in 5 years

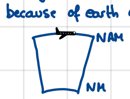
Distances

Departure [NM] = Δlong [min] · cos(lat)



$$\frac{TAS}{NAM} = \frac{GS}{NM}$$

At high altitude Air distance > Ground distance because of earth curvature



Calculate TAS

Ex: with Pressure Altitude = 7000 ft, OAT = +15°C, CAS = 125

⚠ if TAS < 300 kts don't apply compressibility factor

If QNH corrections are needed:
if QNH high you lower the pressure altitude (if you have more pressure it's like if you're at sea level)

Speed

average climb/descent

$$\text{Gradient degree } [°] = \frac{\text{vertical distance [ft]}}{100 \cdot \text{ground distance [NM]}}$$

$$\text{Gradient } [\%] = \frac{\text{vertical distance [ft]}}{60 \cdot \text{ground distance [NM]}}$$

$$\text{gradient } [\%] = \frac{\text{vertical distance [ft]}}{\text{horizontal distance [ft]}}$$

$$\text{Mach} = \frac{TAS}{38.95\sqrt{OAT + 273}}$$

$$CAS = \sqrt{\frac{1}{2}\rho} \cdot TAS$$

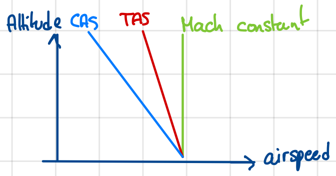
↑ air density

$$ROD/c \left[\frac{ft}{min}\right] = \text{gradient } [\%] \cdot GS \text{ [kts]}$$

ROD = GS · 5 for 3° slope

$ROD = \frac{GS \cdot 5}{3} \cdot \text{angle}$ for any slope

Chicken Tikka Massala



Speed [kts]	[NM/min]
60	1
120	2
180	3
240	4

ICE-T

Indicated → Calibrated → Equivalent → True

position, compressibility, density

$$TAS = CAS + CAS \cdot 2\% \cdot \frac{Alt [ft]}{1000}$$

Convert units with E6B

Imp Gal → US Gal

71 Imp = 85 USG

Triangle of velocities (TOV)

- Question using flight computer and wind
- ⚠ if WCA > 10° ⇒ calculate effective TAS = cos(WCA) · TAS

Dead reckoning (DR)

- Bearing is with respect to heading
- "forecasted wind"

Formula valid for 3° glide path:

ROD = GS · 5

ROD = Speed Factor (SF) · glide path angle · 100

Navigation in climb and descent

- Average TAS is calculated at the reference altitude
  - in climb: reference altitude = $\frac{2}{3}$ |Δ altitude| + initial alt
  - in descent: reference altitude = $\frac{1}{2}$ |Δ altitude| + final alt
- Average wind is also at the reference altitude

Rule of thumb

$$TAS = \frac{IAS}{CAS} + \frac{2\%}{1000} \cdot \frac{IAS}{CAS}$$

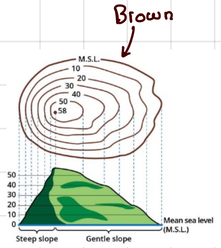
02 Visual Flight Rule (VFR) Navigation

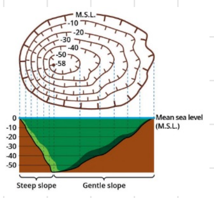
Ground Features

- "Power line"
- Night flight → problem in identifying colors

VFR Navigation techniques

- Contour lines close together indicate a steep slope
- Levels curve on hypsometric chart refer to altitude
- Visual checkpoint = visual position that coincides with position on chart

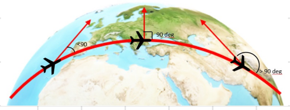




Great Circles and Rhumb lines

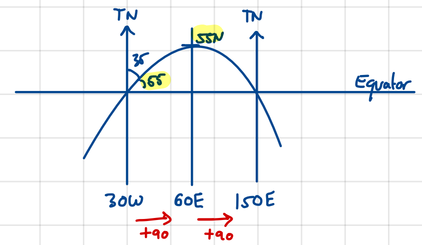
Great Circles

- Biggest circle you can draw on a sphere
- a circle on the surface of a sphere which lies in a plane passing through the sphere's center
- Represents the shortest distance between two points
- **Vertex** is the location on the surface of earth with the highest latitude N or S (two vertices)
  - → At a vertex, the track is either 090 (flying East) or 270 (flying west)



Convergence = Δlong [°] · sin(lat)

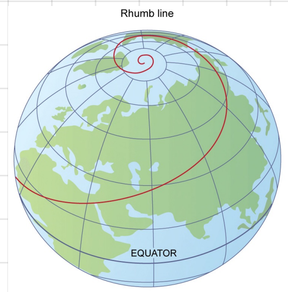
Conversion angle = ½ Δlong [°] · sin(lat)



Rhumb lines

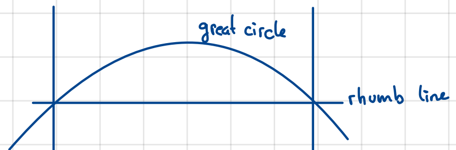
- line that crosses meridian at same angle
- line of constant direction on the surface of the earth

- equator = rhumb line
- parallel of latitude = rhumb line
- meridian = rhumb line



Relationship

Northern hemisphere



04 Charts

Chart requirement

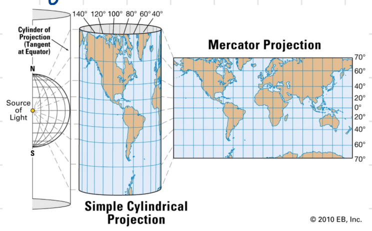
$$\frac{\text{Scale A}}{\cos(\text{lat A})} = \frac{\text{Scale B}}{\cos(\text{lat B})}$$

Chart convergency: 0° for mercator as meridian are parallel to each other

Great scale are number that are close (1/2), means we show small area with great detail
Small scale are number that are far apart (1/100'000), means everything is small compared to original
• conformal chart = straight line on chart approximates a great circle

Mercator

• Great circle curves are convex to the nearer pole
• Difference between Great circle and Rhumb line increases with increasing latitude
• Convergence factor = 0°
• Scale is correct at the equator but the higher the latitude, the more countries are deformed



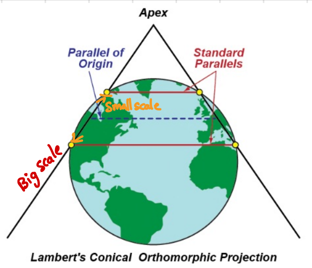
Lambert conformal conic chart

• $\boxed{\text{Constant of cone (n) (Convergence factor)} = \sin(\text{parallel of origin})}$ $\boxed{\text{Convergence} = \Delta\,\text{lat}[°] \cdot \sin(\text{poo})}$

→ Convergence factor is the opening of the cone / 360

• parallel of origin = $\frac{(\text{standard parallel A} + \text{standard parallel B})}{2}$
→ is the latitude on a chart when the earth convergence is correctly represented
→ is the parallel at which the scale reaches its minimum value

• Standard parallels
→ are the latitudes when scale is correctly represented



• Scale varies with different parallel (correct at standard parallels).
• Scales contracts between standard parallels and expands outside

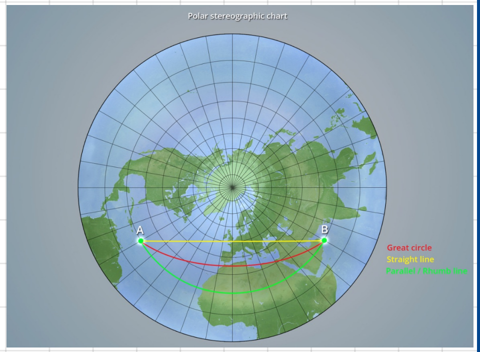
• Great circles in Lambert are concave to the parallel of origin

Polar stereographic chart

• Great circles are concave to the pole
• Rhumb line are concave to the pole
• Scale is minimum at north pole

$\boxed{\text{Convergency} = \Delta\,\text{long}[°]}$

• The higher the latitude, the more great circles they are straight lines



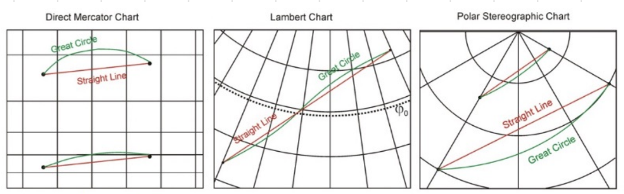


Fig. 75: Straight line versus great circle

Rhumb Line

- On the earth, the rhumb line has a spiral configuration (certain exceptions apply). In order to determine the course of a rhumb line on the map, it is best to orientate oneself according to the course of the parallels of latitude on the map, which, of course, represent a special type of rhumb lines.

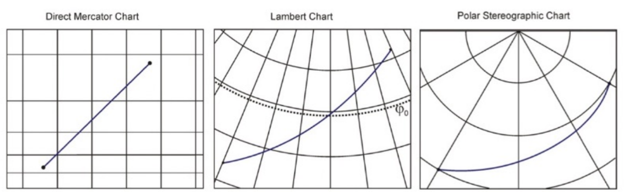
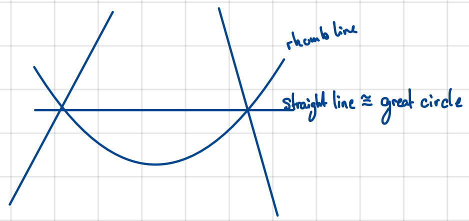


Fig. 76: Rhumb lines in chart projections

Projections

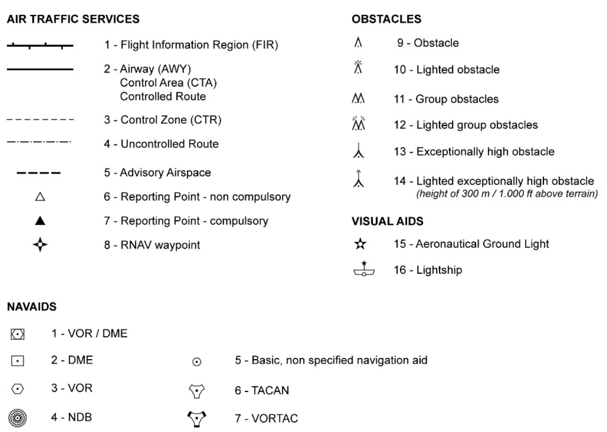
$$\text{Convergence factor} = \frac{270}{360}$$

Lambert



Practical use

• VOR use variation at the station
• NDB use variation at the airplane



05 Time

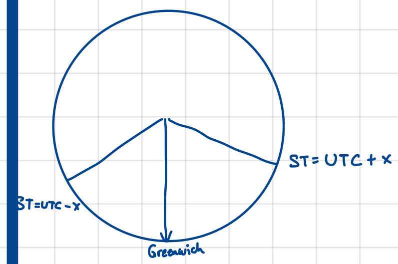
Local mean time LMT

• $\boxed{\text{Earth rotates at } \frac{15°}{1\text{ hour}} \text{ (UTC)}}$

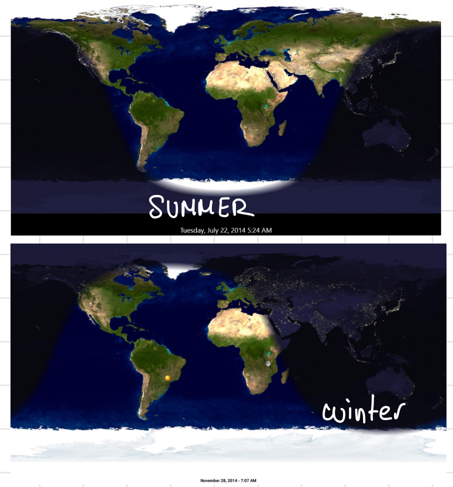
Mean Sun at anti-meridian at 00:00
Mean Sun at meridian at 12:00

Standard time

• Standard time difference are found in List 1,2,3 in the Air Almanac
• Time decided arbitrarly by countries (does not follow $\frac{15°}{1h}$ rule precisely)



Sunset and Sunrise



• Polar circles at 66.5° N/S
• Polar axis with a 66.5° inclination with the ecliptic plane
  • On 21st december, sun never rises above 66.5 N
  • On 21st june, sun never rises above 66.5 S and never sets above 66.5 N

• Cancer/Capricorn: 23.5 N/S
→ highest latitude sun reaches 90° above horizon, occurs once a year

• Morning civil twilight:
  • Centre of the sun 6° below the celestial horizon
  • Period from centre of sun 6° below horizon until upper limb of the sun appears at the horizon

• Solstice: Summer/winter, point when sun reaches its highest/lowest declination
• Equinoxe (equi-night): the influence of latitudes on duration of daylight is at it's smallest