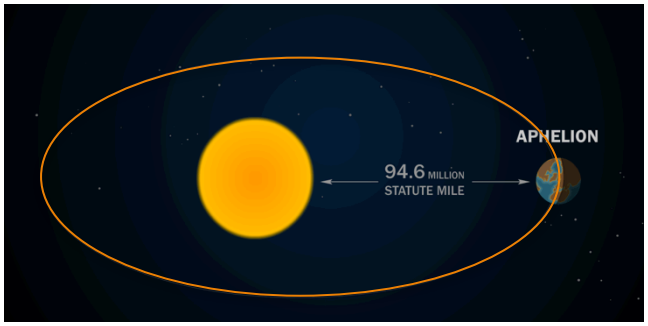
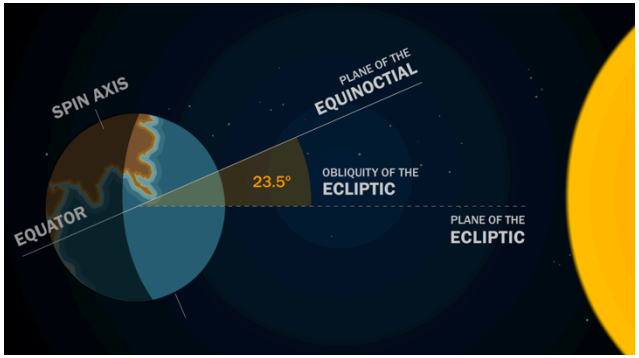
NAVIGATION 1 – FOUNDATION CBT

SOLAR SYSTEM

- Consists of 8 planets, the sun, asteroids and comets.
- Earth spins **anticlockwise** when viewed from NP.
- Earth rotates around the sun in an **elliptical orbit** with the distance from the sun varying between **91 and 95 statue miles.**

- **Aphelion –** Earth furthest away from sun (July)
- **Perihelion –** Earth closest to the sun (Jan)



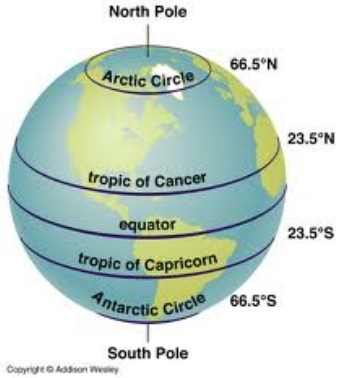


- **Ecliptic –** Apparent path of the Sun around the earth.
- **Plane of Ecliptic –** Imaginary plane containing the Earth's orbit around the sun.
- **Plane of Equinoctial –** Plane of equator extended into space.
- **Obliquity of the Ecliptic –** An angle of 23.5 ^{0}C between plane of ecliptic and plane of equinoctial.

EQUINOXES & SOLSTICE

- Sun crosses plane of equinoctial in March **(Spring Eqxinox)** and September **(Autumn Equinox)**.
- Hours of daylight and night are equal.

- **Summer Solstice -** Sun reaches it's most northerly at 23.5 N in June. Tropic of cancer.
- **Winter Solstice** – Sun reaches it's most southerly at 23.5 S in December. Tropic of Capricorn.



SHAPE OF THE EARTH

- The actual shape of the earth is an **oblate spheroid.**
- It is flattened at the poles. This is called the **compressibility** of the earth.
- Equatorial Radius = 3444 nm
- Polar Radius = 3433 nm
- The polar diameter is **1/300** (0.3%) less than the equatorial diameter.
  - 23 nm / 27 sm / 43 km

SHAPE OF THE EARTH

$$Compressibility = \frac{(Semi - Major\ Axis) - (Semi - Minor\ Axis)}{(Semi - Major\ Axis)}$$

- **1 minute is less than 60 nm at equator and increasing towards the poles.**

NAVIGATION 1 – FOUNDATION CBT

GREAT CIRCLE

- A circle of the surface of the Earth, whose **centre and radius are those of the earth itself.**
- Shortest distance between two points.

SMALL CIRCLE

- A circle on the surface of the Earth, whose centre and radius are **not** those of the Earth itself.
- I.E/ Any circle that isn't a great circle.

MERIDIANS

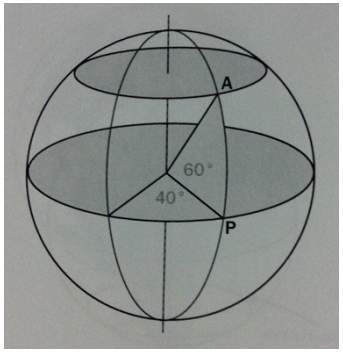
- Lines joining the poles.
- Every meridian has its own **anti-meridian.**
- They form **lines of longitude**
- Greenwich / Prime Meridian = 000^0 E / W
- Max angle = 180^0 E / W
- Going up meridian = Face north
- Going down a meridian = Face south

PARALLEL OF LATITUDE

- Lie in an east / west direction.
- Parallel of latitude = equator = 00^0 N
- Max angle = 90^0 N / S

LATITUDE AND LONGITUDE

- Point depicted is 60^0 N, 040^0 E
- Latitude fist then longitude
- Degrees ^{0} / Minutes ' / Seconds ''
- 60' in 1^0
- 21,600' in a circle (360 x 60)

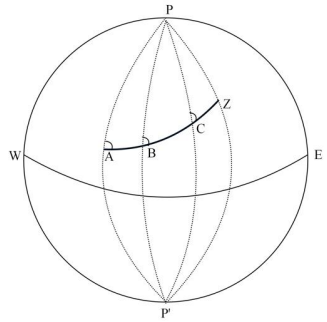


DIRECTION DEFINITIONS

- **Bearing –** Direction of a point / object measured to / from another point / object.
- **Heading** – Direction in which the nose of an aircraft is pointing.
- **Relative Bearing** – Bearings reference to the nose of an aircraft.

RHUMB LINE

- A line that cuts all meridians **at the same angle.**
- Has constant direction.
- Will be longer than the great circle.
- A rhumb line that cuts meridians at 90 degrees will coincide with a parallel of latitude.



VECTOR ANNOTATIONS

- -----> Heading
- ---->> Track
- --->>> Wind

NAVIGATION 2 – DIRECTION

TRUE NORTH

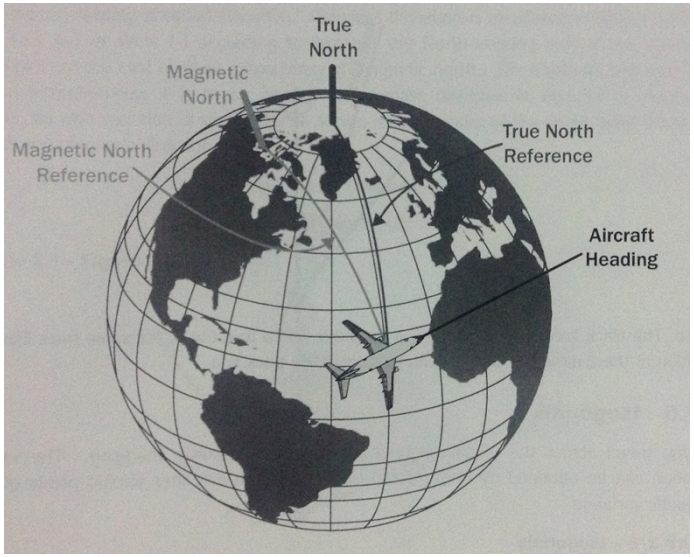
- **The meridian through any place defines True North and True South at that place.**
- Hence true direction can be measured with reference to the local true meridian.

MAGNETIC NORTH

- The needle in a magnetic compass will align itself with the **horizontal component** of the Earth's magnetic field – **directive force.**
- **Maximum strength** (of horizontal component) is max near magnetic equator and **reduces to zero** at the poles.
- The Earth's magnetic poles are **not antipodal.**
- The **vertical component (dip)** increases towards the poles.

MAGNETIC VARIATION

- **The angular difference between the direction of True North and Magnetic North.**
- **West is best, east is least.**
  - With variation west, magnetic is bigger than true.
- **Max Variation** is 180^0
  - When directly between magnetic and true north.



ISOGONALS

- **Lines joining points of equal magnetic variation.**
- A zero variation line is **agonic**

COMPASS DEVIATION

- **Angular difference between magnetic north and compass north.**
- Compass needle is subject to additional magnetic fields created by **electrical circuits** and **pieces of metal** within the aircraft.
- Easterly deviation expressed as +ve
- Westerly deviation expressed as –ve

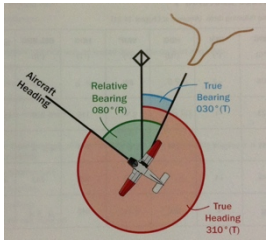
TRUE, MAG AND COMPASS

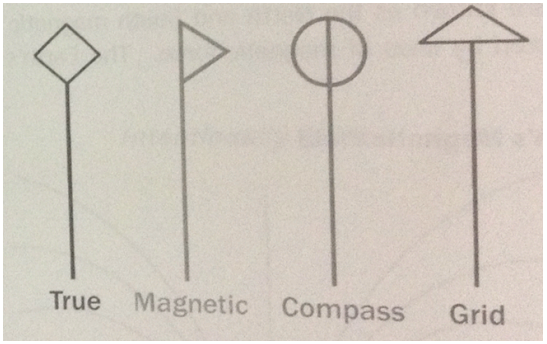
- **True ± Variation = Magnetic ± Deviation = Compass**
- True virgins make dull company.
- Add for west variation / deviation.
- Subtract for east variation / deviation.

- HDG(C) 345^0 | Deviation -7^0 | HDG(M) 338 | Variation $+27^0$ | HDG(T) 005^0

RELATIVE BEARING

- Measured from nose of an aircraft, clockwise to the object.
- **Bearing (M/T) = Relative Bearing + Heading (M/T)**

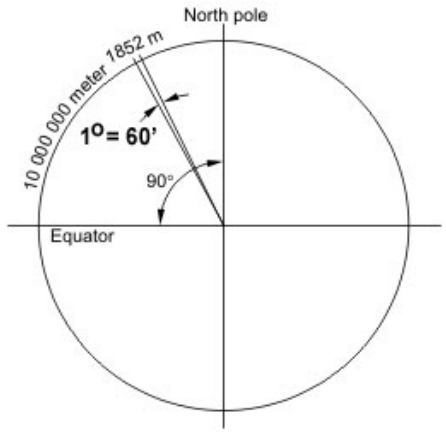




NAVIGATION 4 – DISTANCE

NAUTICAL MILE

- ICAO 1 nm = 1.852 km
- **The length of a great circle arc on the surface of the earth, subtending an angle of one minute at the centre of the earth.**
- 1' = 1nm
- There are 60' in 1^0 so the circumference of earth is 360 x 60 = **21,600 nm**



KILOMETER

- **1/10 000 of the distance from the equator to the poles.**
- Therefore, circumference of earth is **40,000 km**

CONVERSIONS

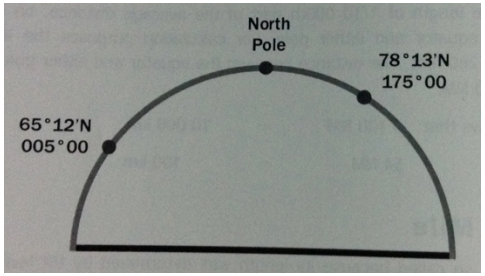
- **1 km = 3280 ft**
- **1 sm = 5280 ft**
- **1 nm = 6080 ft**

DISTANCE FROM CHANGE IN LATITUDE (SAME MERIDIAN)

- Distance between 40^0 12' N 05^0 00' W and 51^0 37' N 05^0 00' W
- 51^0 37' N - 40^0 12' N = 11^0 25'
- (11 x 60) + 25 = 685 nm

DISTANCE FROM CHANGE IN LATITUDE (MERIDIAN + ANTI-MERIDIAN)

- If the longitudes **add up to 180^0** we can also solve a change in latitude.
- Distance between 65^0 12' N 05^0 00' W and 78^0 13' N 175^0 00' E
- 65^0 12' N to NP = 24^0 48'
- 78^0 13' N to NP = 11^0 47'
- Total change = 36^0 35' = 2195 nm



DISTANCE FROM CHANGE IN LONGITUDE

- The distance along a parallel of latitude is called **departure.**
- **Departure = d.long x cos lat**
- Since all parallels are a rhumb line (cut meridians at 90^0), the departure is also referred to as a **rhumb line distance.**
- Distance between 37^0 N 03^0 07' E and 37^0N 27^0 05' E
- ch.long = 03^0 07' + 27^0 05' = 30^0 12'
- d.long = (30 x 60) + 12 = 1812'
- Departure = 1812 x cos(37) = 1447 nm

GREAT CIRCLE PATHS

- A great circle path will always **bend towards the nearer pole.**
- A distance calculated along a meridian / anti-meridian will always be a great circle distance.

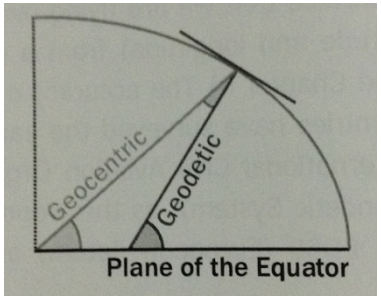
NAVIGATION 3 – FORM OF THE EARTH

ICAO DATUM

- **USA WGS 84** (World Geodetic System) datum is regognised by ICAO.

GEOCENTRIC VS GEODETIC

- **Geocentric** latitude is measured with datum at the centre of the earth.
- **Geodetic / geographic** latitude is measured by taking the local horizontal and dropping a plumb line to the plane of the equator.
  - Method used in aviation by ICAO
- Difference between measurements **varies with latitude.**
  - Equal at poles and equator
  - Greatest at 45 N / S with 11.6'



ANTIPODAL

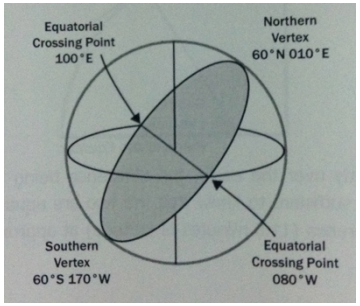
- **Antipodal:** Opposite ends of the earth diameter.
- Antipodal latitude will be the same but with opposite sign.
- Antipodal longitude is the reciprocal (± 180) with opposite sign.

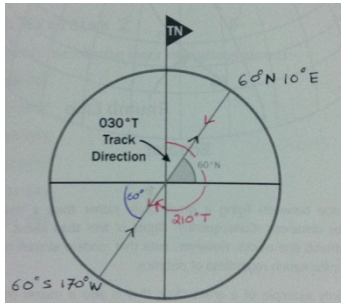
GREAT CIRCLE VERTEX

- The latitude and longitude of a great circles most northerly and southerly points and **vertices.**
- The vertices are **antipodal.**
- At these points, you are either going east or west.

EQUATORIAL CROSSING POINTS

- GC will cross equator at two antipodal points.
- **90⁰ ± vertex longitude**





EQUATORIAL TRACK DIRECTION

- A GC crosses the equator at an angle equal to the latitude of its vertices.
- Track direction is measured from true north and can be calculated by adding / subtracting the angles.

NAVIGATION 5 – CRP CONVERSIONS

PA + SAT + CAS --> TAS

1. Set pressure altitude and SAT in airspeed window.
2. Find CAS on inner scale
3. Read TAS from outer scale
4. If TAS > 300 apply CC (compressibility correction)
5. Find CAS on inner scale again and read off corrected TAS

MN + SAT ---> TAS / LSS

1. Set SAT against mach no index in the airspeed window.
2. Find mach number on the inner scale
3. Read TAS from outer scale
4. LSS can be found by finding 10 on the inner scale and reading the LSS from the outer.

SAT vs TAT

- **Static Air Temperature (SAT)** is the actual temperature of free air, unaffected by the aircrafts movement.
- **Total Air Temperature (TAT)** is the temperature as sensed by the aircraft. It is the SAT plus any warming that results from friction as the aircraft travels through air.

- **TAT** (IOAT) = **SAT** (OAT / COAT) +Heat

- IOAT (Indicated Outside Air Temperature).
- COAT (Corrected outside air temperature)

TAT + TAS ---> SAT

1. Find temp rise from the blue scale
2. Subtract this from TAT to give SAT

PA + TAT + IAS ---> TAS

* SAT is required to do this question *

1. Set PA and TAT in airspeed window
2. Find IAS on inner scale
3. Read approx. TAS from outer scale
4. Convert TAT to SAT

5. Set PA and SAT in airspeed window.
6. Set IAS on inner scale
7. Read TAS from outer scale
8. Apply CC if required

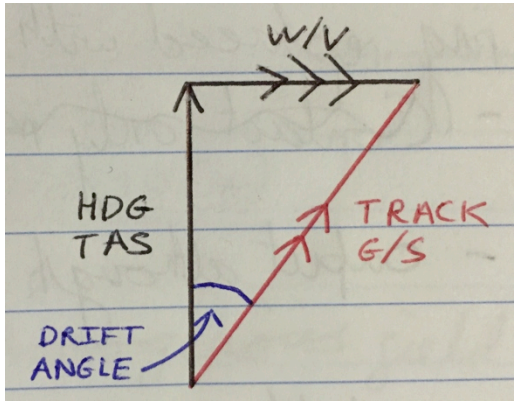
SPECIFIC GRAVITY

- **SG = Mass Fuel / Mass Water**
- **Weight (kg) = SG x Volume (litres)**
- **Weight (lbs) = 10 SG x Volume (Imp Gal)**

PA + SAT (Pressure Alt)---> True Alt

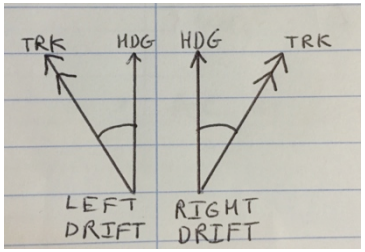
1. Set PA + SAT in altitude window.
2. Find PA on inner scale and read true altitude from outer scale.

NAVIGATION 6 – TRIANGLE OF VELOCITIES



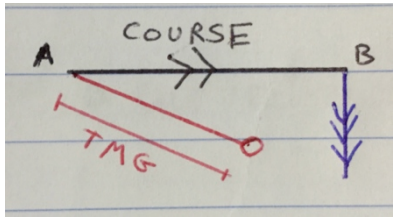
DRIFT ANGLE

- **Angle between heading and track.**



COURSE VS TMG

- Course = **Planned** track over the ground.
- TMG = **Actual** track over the ground.



TMG FROM HDG, TAS + W/V

- Set TAS on grommet
- Set wind direction on bezel
- Mark wind speed **down** from grommet
- Set bezel to HDG
- Read drift right / left and G/S

W/V FROM HDG, TAS, DRIFT + G/S

- Set TAS on grommet
- Set HDG on bezel
- Mark drift + G/S
- Rotate mark **down** onto 0 drift line
- Read off wind direction and speed

DOUBLE DRIFT

- Set grommet on TAS
- Mark first HDG and drift (as a line)
- Mark seconds HDG and drift (as a line)
- Rotate until intersection is **below** grommet
- Read off W/V

HDG & G/S FROM TAS, TRK AND W/V

- Set grommet on TAS
- Mark W/V (speed via wind down)
- Set TRK on bezel
- Calculate initial drift
- Set TRK underneath the drift on the outer scale (rotating towards direction of drift)
- Calculate next drift
- Set TRK underneath the new drift value on the outer scale
- Repeat until drift remains constant
- Read HDG from bezel
- G/S is located under the gromett

NAVIGATION 6 – TRIANGLE OF VELOCITIES

HEADWIND & CROSSWIND COMPONENT

- QDM = QFU = Runway Heading
- VOLMET is given in True. ATC + ATIS in Mag

- Put grommet up upper part of grid scale
- Set wind direction on bezel and set speed via wind down method.
- Rotate bezel to QDM
- Headwind component given by vertical distance to dot
- Crosswind component given by horizontal distance to dot
- Must specify whether x-wind component is R-L / L – R

- If tailwind present (dot is above grid scale after setting QDM), move slide until dot is on the first horizontal line.
- Drift read as normal but tailwind component is under the grommet.

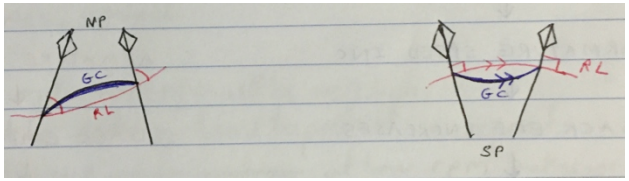
MIN AND MAX WIND SPEEDS

- Grommet on top of grid section
- Set wind direction on bezel
- Draw a line down the 0 drift line
- Set RWY QDM on bezel
- Draw a horizontal line below grommet to mark the headwind required
- Draw a vertical line at the max crosswind component
- Set wind direction on bezel again
- Read off min and max below grommet.

NAVIGATION 7 – EARTH CONVERGENCY

GC VS RUMB LINE PATHS

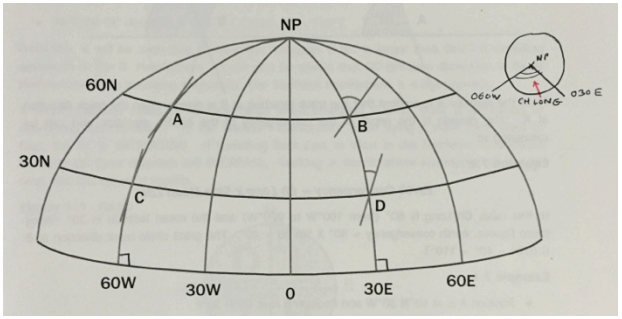
- **GC paths are concave to the equator.**
- **RL paths are concave to the poles.**



EARTH CONVERGENCY

- **Angle of inclination between two meridians.**
- 0^0 at the equator
- Max at poles where it's equal to Ch Long

(E) C_V = Ch Long x sin (mean lat)

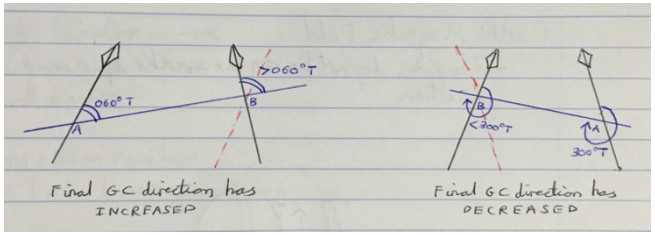


- Between C and B, the earth convergency is:

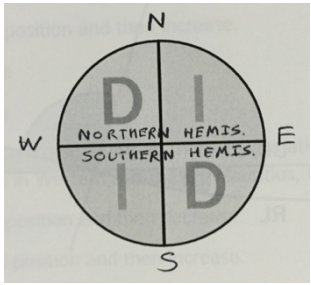
90 x sin (45) = 64^0

CHANGE IN DIRECTION OF GC

- **Earth convergency determines the change in direction of the great circle with a change in longitude.**



- Changes can be summarised with DIID:

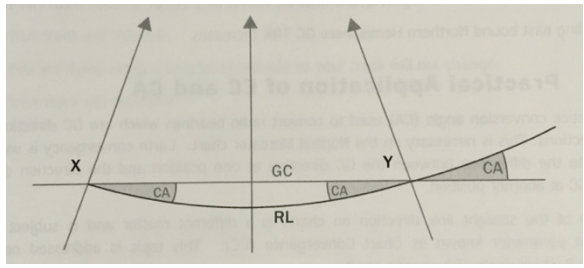


CONVERSION ANGLE

- **Angular difference in direction between a GC and RL.**

CA = ½ (E) C_V

- The direction of the GC at the mean meridian between two points is the same as the rhumb line track joining them.



FINDING RHUMB LINE TRACK

RL = GC ± CA

NAVIGATION 8 – CHARTS

ORTHOMORPHISM

- An **essential requirement** for any navigation chart is that it is orthomorphic.
- **Orthomorphic means the chart is conformal and bearings are correct.**
- This is achieved when:
  - Meridians / parallels are perpendicular
  - Scale at any point is the same in all directions

REDUCED EARTH

$$RE\ Scale = \frac{Distance\ on\ RE}{Distance\ on\ Earth}$$

REDUCED EARTH TO CHART

$$Chart\ Scale = \frac{Chart\ Distance\ (CD)}{Earth\ Distance\ (ED)}$$

FORMS OF REPRESENTING SCALE

- Representative Fraction
- Plain Statement
- Graduated Scale

SCALE FACTOR

$$Scale\ Factor\ (SF) = \frac{Chart\ Scale}{RE\ Scale}$$

- **Correct** if scale factor = 1
- **Constant** if 0.99 ≤ SF < 1.01

- If the scale is not constant, the local latitude can be used to measure distances.

MERCATOR CHART

CONSTRUCTION

- Based on a **cylindrical projection**
- It is mathematically calculated so is a **non-perspective projection.**
- Meridians are drawn as **straight and parallel lines.**
- It is not possible to project the poles.

STRAIGHT LINE = RHUMB LINE

- A straight line drawn on a Mercator is a rhumb line.
- GC bends towards the nearer pole (concave to the equator)

CHART CONVERGENCY

- The chart has a **constant convergency of zero.**
- **(C) C_V = (E) C_V at the equator only.**

EXPANDING SCALE

- The scale expands as you move away from the equator.

$$S_\lambda = S_{EQ} \times secant\ \lambda$$

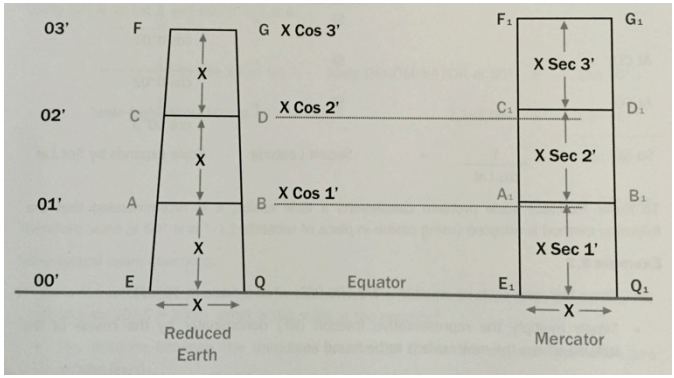
$$\frac{1}{D_\lambda} = \frac{1}{D_{EQ}} \times \frac{1}{\cos\lambda}$$

$$D_\lambda = D_{EQ} \times \cos\lambda$$

Where D is the denominator of the scale and lamda the latitude.

- An expanding scale means the denominator is getting smaller.

$$S = \frac{1}{D}$$



NAVIGATION 8 – CHARTS

CHART USE

- Used for **nautical charts** and for **met charts.**
- Can also be used as **aviation charts in the tropics between 8N – 8S**

- At 8N / 8S if you assume the scale is 1/100 at the EQ, it will be 1/99.
- Since the change in scale is ≥ 0.99 it can be considered constant over these latitudes.
- A straight line can be considered **as both a RL and GC** between these latitudes for practical purposes.

DISTORTION

- Due to the expanding scale, places of equal physical area on Earth will appear bigger towards the poles.

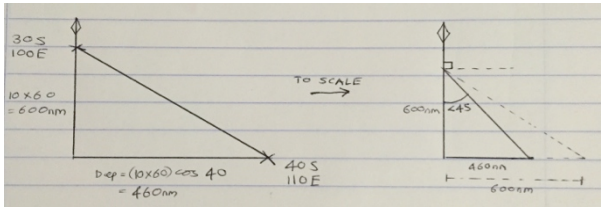
AB BA

- Given the scale at one latitude, the scale at another can also be found.

$$D_A \cos B = D_B \cos A$$

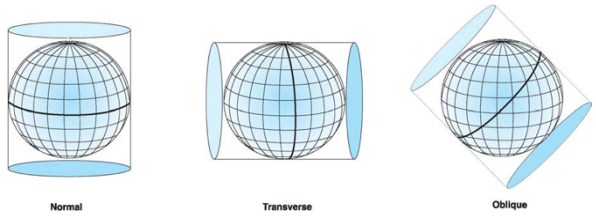
RL TRACK APPECIATION

- A rhumb line track is drawn between 30 S 100 E and 40 S 110 E. What is the track direction?
- Answer: More than 135°T



MERCATOR TYPES

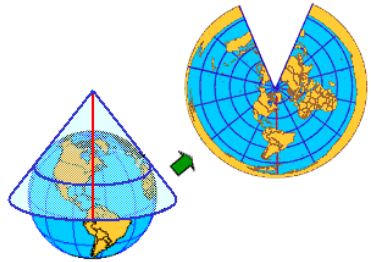
- **Normal / Direct**
- **Transverse**
  - Scale expands in E/W direction instead.
  - Useful for mapping areas of a large N-S extent but limited E/W (UK & Chile)
- **Oblique**
  - Projects an area either side of a great circle which is neither the equator / meridian / anti-meridian.



LAMBERT CHART

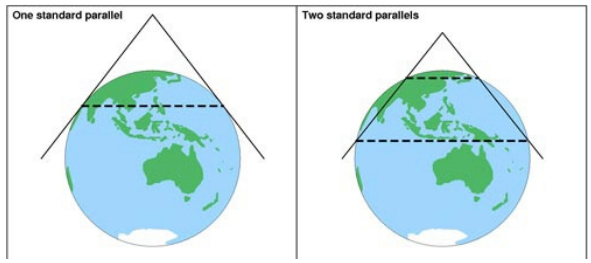
SIMPLE CONIC

- Scale of the cone is **only correct along the parallel of origin.**
- Elsewhere, the scale expands to an extent that makes it of little practical use in navigation.



LAMBERTS MODIFICATION

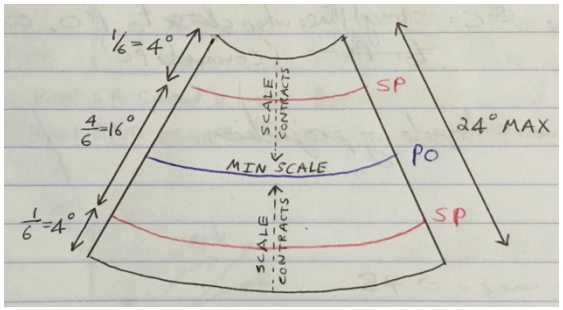
- By either increasing the size of the relative earth OR reducing the apex angle, **two standard parallels (SP) are produced.**
- The parallel or origin (PO) is midway between the two SPs.



NAVIGATION 8 – CHARTS

RULE OF SIXTHS

- The scale is now **constant at both SPs.**
- The **scale contracts towards the PO** and is a minimum at the PO.
- By following the **rule of sixths**, there is a **constant scale within a latitude spread of 24⁰**



CONSTANT OF THE CONE (n)

- **AKA Convergence Factor OR "n"**

n = sin (PO)

- n of ¾ means that when the when the projection cone is expanded and laid flat, 75% of it maps the reduced earth (developed sector). 25 % is missing.

- The formula is normally used to find the PO given n
  - With n of 0.75 the PO is at 48⁰35'

CHART CONVERGENCE (CC)

(C) C_V = Ch Long x sin (PO)

- Since PO is constant, it can be seen that **chart convergency does not vary.**
- It is **equal to earth convergency at the PO.**

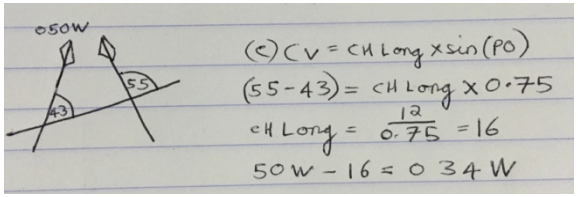
STRAIGHT LINE = GREAT CIRCLE

- Great circles are **slightly concave to the PO**
- For practical purposes they can be considered as straight lines.
- The only time the GC is an exact straight line is a meridian.

- A **RL is concave to the pole of projection.**

LONGITUDE CALCULATION

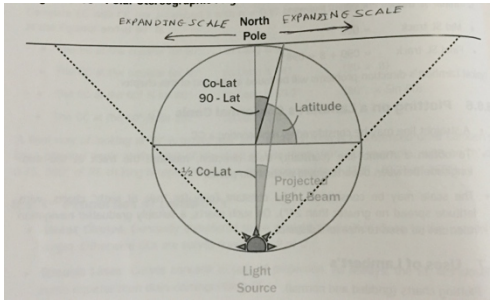
- Constant of the cone = 0.75
- Straight line is drawn from A (40 N 050 W) to B.
- The initial track is 043 T and at B it is 055 T
- Find the longitude of B



POLAR STEREOGRAPHIC

METHOD OF PROJECTION

- Flat sheet of paper placed tangential to the pole
- Light source placed at the opposite pole



SCALE

- Expands at the secant² of ½ co-lat
- At 80N/S = 1%
- At 70 N/S = 3%

USES

- Used to map the areas from about 70 N/S to 90 N/S

NAVIGATION 8 – CHARTS

THE GRATICULE

- Parallels of latitude appear as concentric circles, concave to the nearest pole.

- Rhumb lines (parallel of latitude) are therefore concave to the nearest pole.
- **Above 78^0, great circles are represented as straight lines.**

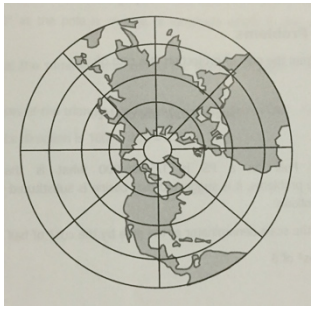


CHART CONVERGENCE

(C) C_V = Ch Long

- Meridians are straight lines therefore chart convergence is constant.
- Equal to EC at the pole of projection.

DIRECTION PROBLEMS

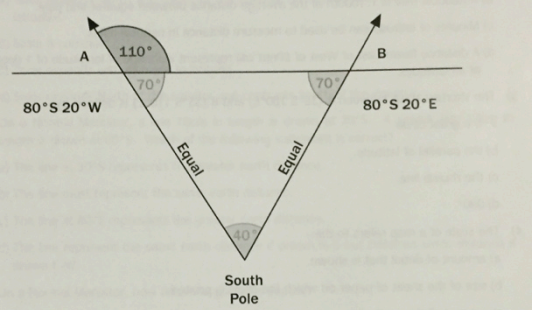
8.7.9 Direction Problems on the PS

As the GC may be considered a straight line, direction problems on the PS are approached using simple properties of triangles. When using a diagram for PS direction calculations, it is convention on such diagrams to keep North at the top of the diagram and draw the meridians converging at the top or bottom of the diagram. The diagram in the following example shows the southern hemisphere.

Example 8.9

Positions A (80° S 20° W) and B (80° S 20° E) are plotted on a polar stereographic chart and are joined by a straight line (great circle). What is the initial direction of this straight line track?

Figure 8-17



Consider the diagram above.

- The angle 40° at the pole is change of longitude which is also convergency on this chart
- A and B are at the same latitude and so the sides of triangle A to Pole and B to Pole are equal.
- The base angles of the triangle are equal and found from (180° - 40°) ÷ 2 or 70°
- The initial track direction is 180° - 70° = 110°

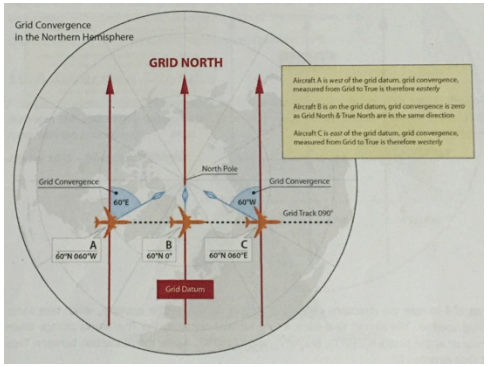
NAVIGATION 10 - GRID

WHY GRID?

- Close the True Pole / Magnetic Pole, track varies too frequently to be used for navigation.
- By referencing Grid North, a constant track can be followed.

CONVERGENCE

- **Convergence is the difference between grid north and true north.**

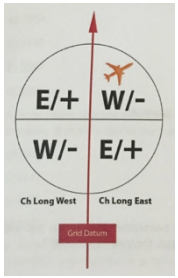


GRID DATUM

- The grid datum is where **grid north and true north are equal.**
- Convergency is zero at the grid datum.

CONVERGENCE CALCULATIONS

Grid Track = True Track ± CH Long From Datum



GRIVATION

- Difference between grid north and magnetic north.
- **Isogrivs** connect place of equal grivation.

Grivation = Grid Convergence + Variation

NAVIGATION 10 – PILOT NAVIGATION TECHNQIUES

1 IN 60 RULE

$$Track\ Error = \frac{Distance\ Off}{Distance\ Gone} \times 60$$

RATE OF DESCENT

$$ROD = Glideslope\ Angle \times Range \times 100$$

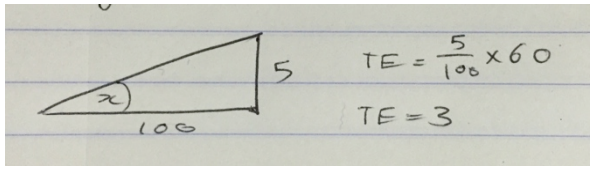
$$ROD\ (3^0\ Glideslope) = 5 \times Ground\ Speed$$

HEIGHT ON GLIDESLOPE

$$Height = Glideslope\ Angle \times Range \times 100$$

GRADIENT → GLIDESLOPE ANGLE

- 5% Gradient = 3^0 Glideslope

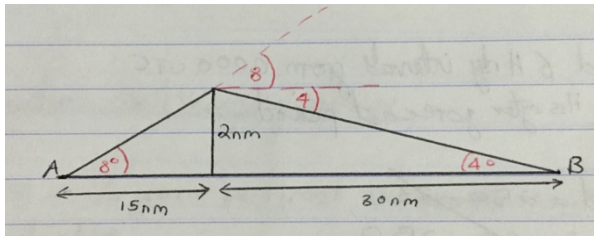


TRACK CORRECTION

- Off course by 2 nm after 15 nm. What is the required alteration to regain track at B?

Track Error = (2/15) * 60 = 8^0
Correction Angle = (2/30) * 60 = 4^0

Alteration = 8 = 4 = 12^0 Right



DOUBLE TRACK ERROR

- To regain course in the same distance taken to get off course, simply double to track error.

NAM VS NGM

- NAM = Nautical Air Mile
- NGM = Nautical Ground Mile
- Distance / Speed is time which will be the same in each case. Therefore, they can be equated as follows:

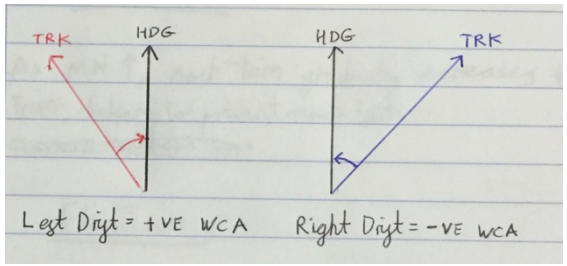
$$\frac{NAM}{TAS} = \frac{NGM}{G/S}$$

SPEED FACTOR

$$\frac{TAS}{60}$$

WCA

- Wind Correction Angle
- The correction that needs to be applied to the track to obtain the required heading (to fly the intended track)



MAX DRIFT & WCA

$$Max\ Drift = \frac{Windspeed}{Speed\ Factor}$$

- By applying the clock code to the max drift, the WCA can be obtained.