

Aeronautical Charts — Study Collection

The chart lessons are already organised as separate chapters. This page brings them together so that you can follow the sequence, return to a particular topic, or download the collection as one PDF.

Start with map reading and the general properties of charts. Then work through the individual projections. Open each lesson below for its full notes, diagrams and worked material. The collection PDF includes the full notes from all seven lessons; the online reader keeps each chapter separate for easier reading on a phone.

Chapter	Open the full lesson	Topics in the existing notes
7	Topographical Maps and Map Reading	Topographical chart features, relief, scale, map-reading technique and visual fix selection. Study notes with practice Q&A.
8	Convergency and Conversion Angle	Convergency between meridians, conversion angle between great circle and rhumb line tracks, with worked examples. Study notes.
10	Scale	Chart scale — representative fraction, statement in words and graduated scale line; scale conversions and typical DGCA scale calculations.
11	General Chart Properties	Perspective and mathematical projections, orthomorphism and conformality conditions, and how charts are classified by projection surface.
12	Mercator Charts	Mercator projection properties — meridians and parallels, scale expansion with latitude, rhumb lines and great circles, plotting and measurement.

Chapter	Open the full lesson	Topics in the existing notes
13	Lambert's Conformal Chart	Lambert conformal conic chart — standard parallels, parallel of origin, constant of the cone, chart convergence, great circles and rhumb lines.
14	The Polar Stereographic Chart	Polar stereographic projection — properties, scale variation, grid navigation and plotting in polar regions.

How to use this collection

1. Read one chapter at a time and work through its examples before moving on.
2. Keep the individual chapter open when revising a particular chart topic.
3. Use the collection download when you want the same lessons together for offline study.
4. Return to the chapter's practice questions for the material available in its own question bank.

The individual lessons remain available at their established links. This collection organises their existing teaching material rather than replacing it with a new set of answers.

CHAPTER 13 · GENERAL NAVIGATION

Topographical Maps and Map Reading

Visual navigation · Chart symbols · Scale · Terrain interpretation · MEF/MSA

IN THIS CHAPTER

- › Introduction
- › MEF, MSA & Clearance
- › Map Reading
- › Uncertain of Position
- › Practice Questions (10)
- › Relief (Terrain)
- › Scale
- › Visual Checkpoints
- › Chart Symbol Reference

Introduction

Modern aircraft navigation systems — GPS, INS, FMS — are highly reliable, but they fail occasionally or suffer degraded accuracy. Many light aircraft are not equipped with sophisticated navigation systems at all. There is therefore an enduring need for pilots to develop and maintain **visual navigation skills** using the basic aids of map, compass, stopwatch, eye and brain.

It is essential that pilots can interpret the **conventional symbols** (the legend) of all the aeronautical charts they use. Misreading a symbol —

confusing a military airport with a civil one, an unlighted obstruction with a lighted one — can have serious consequences.

Aeronautical charts show three basic characteristics which form the structure of this chapter:

- **Relief (Terrain)** — the shape and elevation of the land surface
- **Other Features** — man-made and natural planimetric features
- **Scale** — the ratio between chart distance and Earth distance

GHOST AVIATOR

Relief (Terrain)

If an aircraft is to be navigated safely in poor weather, terrain must be identified and cleared — either by flying around high ground or over it at a safe altitude. In good visibility, terrain features are invaluable visual references. Either way, pilots must understand how the ground is depicted on aeronautical charts.

Contour Lines

Contour lines join all points on the ground at the same height above mean sea level. The pattern of contours reveals the shape of the terrain:

- **Closely spaced contours** = steep gradient
- **Widely spaced contours** = gentle slope
- **Concentric ovals, increasingly small** = hill or mountain summit
- **V-shapes pointing uphill (up-valley)** = valley (stream flows down the V)
- **V-shapes pointing downhill (down-slope)** = ridge spur

The **contour interval** — the vertical difference between adjacent contours — is stated in the chart legend. Common values: 500 ft on 1:500 000 charts; 1 000 ft on 1:1 000 000 charts. Every fifth contour (the *index contour*) is drawn thicker and labelled with its altitude in feet or metres.

Spot Heights and Mountain Triangles

A spot height is a precise, surveyed elevation of a specific point, shown as a black dot with a number alongside. A **mountain triangle** (▲) marks the summit with the highest accuracy. Spot heights are especially important where contour spacing makes exact summit height ambiguous.

Hypsometric Tinting (Layer Colouring)

Bands of colour between contour lines give an immediate visual impression of elevation without counting contour lines. Typical colour scheme: deep green for sea level, lighter greens for lowland, buff/tan for intermediate, orange-brown for highland, purple-grey for high mountain. The exact scheme is always defined in the chart legend.

Form Lines

In areas where survey data is sparse, **form lines** (dashed lines resembling contours) indicate the approximate terrain shape. They are less reliable than surveyed contours — treat them as indicative, not precise.

Hill Shading

Some charts superimpose grey-tone shading to simulate shadows cast by sunlight from the north-west. This gives a strong three-dimensional impression: ridges look raised, valleys look sunken. Hill shading is particularly effective at showing complex terrain quickly.

▲ THE "HILL IN FRONT OF THE HILL" TRAP

When approaching rising terrain, foreshortening can make a nearer, lower ridge appear to merge visually with a higher range behind it. As you fly forward, terrain clearance decreases much faster than expected. This is especially dangerous in reduced visibility or when flying low. **Always add a generous margin to your calculated terrain clearance.**

Visual Illusions Related to Terrain

Flying over a smooth water surface, fresh snow, or a featureless desert makes it extremely difficult to judge height. Scrub bushes in desert or tundra can appear to be full-size trees, creating a false impression of altitude. At night, scattered lights below (ships, oil rigs, isolated buildings) can be confused with stars — especially after manoeuvres when the horizon reference is lost.

MEF, MSA and Obstacle Clearance

Maximum Elevation Figure (MEF)

The MEF is shown in large type within each latitude/longitude grid rectangle on charts such as the TPC (Tactical Pilotage Chart) and ONC (Operational Navigation Chart). It represents the **highest known elevation** — natural or man-made — within that rectangle, with a clearance addition applied.

The MEF calculation:

1. Find the highest natural terrain peak within the rectangle.
2. Find the highest man-made obstruction (must be notified if ≥ 300 ft AGL in UK/US, ≥ 100 m in continental Europe).
3. Add the clearance buffer: 100 ft if the highest feature is below 5 000 ft; 200 ft above 5 000 ft (US practice).

4. Round up to the next 100 ft.

Minimum Safe Altitude (MSA)

Used primarily on European charts, MSA is conceptually similar to MEF but may include a larger terrain clearance margin. **Always check which value is shown on the chart in use** — confusing MEF with MSA could cost you the required safety margin. The difference may literally be a matter of life and death in IMC near high ground.

Unnotified Obstructions

THE UNKNOWN HAZARD

Structures below the notifiable height (300 ft AGL, or 100 m in some countries) do *not* need to be reported. A new farm silo, a temporary crane, a wind turbine under construction — none of these may appear on the chart. The clearance buffer exists precisely to provide a margin against these unknowns. Flying at or near MEF is still not a guarantee of clearance from all obstacles.

Grid Rectangle Sizes by Chart Scale

Chart / Scale	Grid Rectangle
CAA 1:500 000 / TPC	$\frac{1}{2}^{\circ}$ lat $\times$ $\frac{1}{2}^{\circ}$ long
ONC 1:1 000 000	1° lat $\times$ 1° long
Jeppesen small-scale	5° lat $\times$ 5° long

Scale

Scale is the relationship between the length of a line drawn between two positions on a chart and the actual distance on the Earth between those same points. Three methods of expression are in common use.

1. Statement in Words

For example: *"One inch to ten nautical miles."* Entirely self-explanatory. One linear inch on the chart represents ten nautical miles on the Earth's surface. This is the most immediately understandable form but is awkward when a chart is reproduced at a different size.

2. Representative Fraction (RF)

The RF converts the verbal statement into a pure ratio:

FORMULA

$$\text{Scale} = \text{Chart Length} \div \text{Earth Distance}$$

(both in identical units; the result is dimensionless)

By convention the chart length is always expressed as 1. So a 1:500 000 chart means 1 unit on the chart = 500 000 units on the ground. The RF is written as 1 : 500 000.

Large scale vs small scale: Think of the fraction itself. $1/50\,000$ is a larger number than $1/500\,000$. A larger fraction = larger scale = more detail over a smaller area. A 1:50 000 map shows individual buildings; a 1:1 000 000 chart shows an entire country.

COMMON EXAM CONVERSIONS

- **1 : 500 000** → 1 cm = 5 km = 2.70 NM

- **1 : 1 000 000** → 1 cm = 10 km = 5.40 NM
- **1 : 250 000** → 1 cm = 2.5 km = 1.35 NM
- On any Lambert conformal chart, 1 minute of latitude = 1 NM

3. Graduated Scale Line (Scale Bar)

A graduated scale line is printed directly on the chart. It has the critical advantage of remaining correct even if the chart is enlarged or reduced for reproduction — the bar shrinks or grows with the image. Simply measure between two points with a straight edge and compare with the bar.

graduated scale line as is shown in figure 15.2.

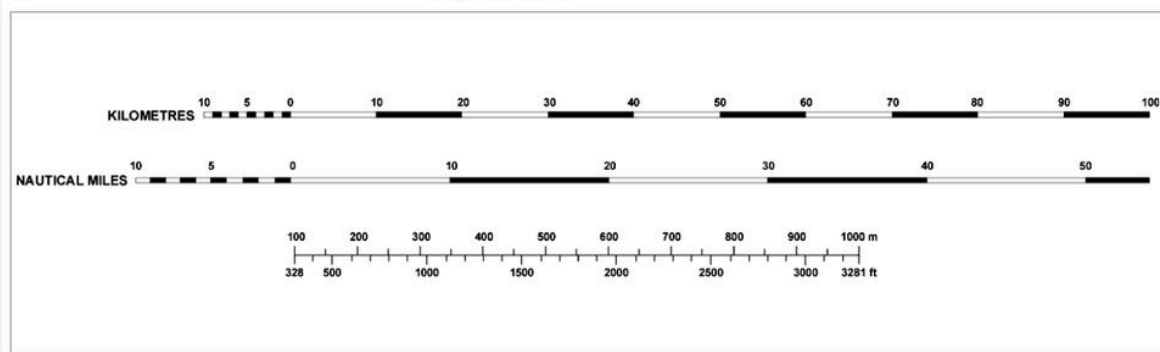


Figure 1 — Graduated scale line as printed on the chart — used to measure distances directly

The Latitude Scale

On aeronautical charts based on conic projections (Lambert Conformal, Transverse Mercator), the latitude scale on the chart margins can be used as a distance rule. One minute of arc of latitude = exactly 1 nautical mile at all latitudes on the Earth. Therefore a pair of dividers set to the distance between two points on the chart, then compared with the latitude margin, directly gives the distance in nautical miles.

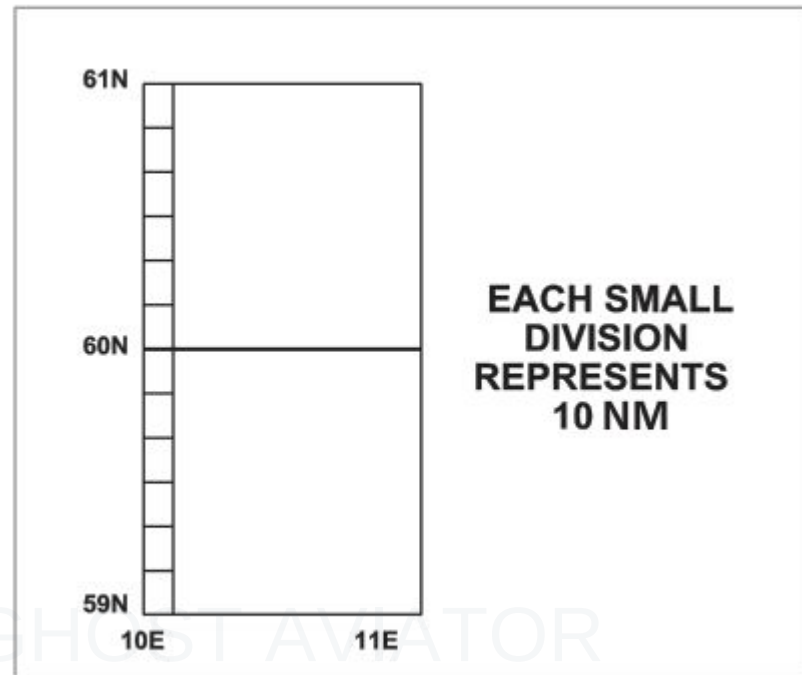


Figure 2 — Latitude scale — 1 minute of latitude = 1 NM; serves as a built-in distance ruler

Map Reading

Map reading is defined as *visualising the physical features of the ground as represented on the map by symbols, and forming a mental picture of the ground by relating those features to one another*. It is a cognitive skill that develops with practice.

Map-to-Ground (Confident Technique)

Used when you are confident of your approximate position. The sequence is:

1. Study the chart: note what features should be ahead, left and right.
2. Look outside and search for those features.
3. Confirm (or challenge) your expectations.
4. Update your mental model and look ahead to the next checkpoint.

This technique keeps you ahead of the aircraft. The map reading is done mostly in the air, in short glances, while maintaining lookout.

Ground-to-Map (Recovery Technique)

Used when position confidence has decreased. You observe the arrangement of features outside — a distinctive river bend, a coastal inlet, the shape of a town — and search the chart to find those same features, thus re-establishing your position. This technique is slower and requires more map-gazing, increasing head-down time.

Preflight Preparation

Good in-flight map reading starts on the ground. Preparation should include:

- Thorough study of the route; identify prominent features along and near track.
- Mark the chart with track lines, turning points, time/distance marks.
- Select visual checkpoints at 5–10 minute intervals (at planned groundspeed).
- Note altimeter settings required along the route.
- Brief yourself on any restricted or controlled airspace en route.

In-Flight Discipline

Navigation is only one of a pilot's responsibilities. Always:

- Maintain an active lookout — collision avoidance is paramount.
- Monitor weather and diversion options continuously.
- Check heading and compass synchronisation at regular intervals.
- Verify altimeter setting and terrain clearance altitude.
- Restart the stopwatch at each turning point and checkpoint.

Visual Checkpoints

A visual checkpoint is a ground feature that can be positively identified from the air and whose position is shown on the chart. The ideal checkpoint combines the following attributes:

- **Prominent** — visible at the planned altitude and in the expected weather
- **Unique** — cannot be confused with a similar feature nearby
- **Definable** — gives a precise position fix, not just an approximate area
- **Permanent** — unlikely to have changed since chart compilation
- **Contrasting** — visually distinct from its surroundings

Contrast changes with season (snow coverage, summer greenery), geographic location (desert vs temperate), time of day and altitude. Night visual navigation requires lit features entirely.

Coastlines

The best general-purpose visual checkpoint. Coastlines are unique (you cannot mistake a coast), highly distinctive in shape (bays, headlands, estuaries, islands), and visible at low altitude even in moderate visibility. A prominent headland or river mouth gives a precise position fix. Coastlines are also usable at night in good moonlight.

Motorways and Major Roads

A large motorway interchange (cloverleaf or trumpet junction) is arguably the finest inland checkpoint: unique shape, visible at high altitude, shown clearly on charts and rarely changed. Motorways themselves are wide, straight, often lit at night, and identifiable from the pattern of moving vehicles. Major A-roads are useful; minor roads are unreliable unless in sparse terrain.

Rivers and Coastlines

River meanders (S-bends) are highly distinctive from the air. A confluence (river junction) gives a particularly precise fix because two specific waterways must coincide. Large lakes with complex shorelines are excellent. Rivers are less useful in flood or when frozen, and lake shores can look different in drought years.

Railways

In open country, railway lines run in strikingly straight lines with very gradual curves. Junctions, stations and large viaducts are precise checkpoints. In industrial or urban areas, multiple lines make individual tracks hard to identify. Railways are rarely visible at night unless brightly lit at major stations.

Woods

Variable utility. A large wood with a distinctive shape (irregular outline, isolated from other woodland) is useful above 1 000 ft AGL. Below that altitude, the shape is hard to assess. Coniferous plantations are prone to shape changes from felling and replanting. Snow can make trees blend with fields; conversely, early spring snow-melt makes a canopy stand out strikingly. Use woods cautiously as primary checkpoints.

Other Features

Power stations, wind farms, large reservoirs, prominent isolated hills, and aeronautical ground lights (aero beacons) all make useful checkpoints. Wind farms are increasingly common and visible at great range, but may not yet appear on older chart editions. Power lines can be seen from their towers but require care — they cross large areas and individual spans are invisible until very close.

Uncertain of Position — Procedures

⚠ THE MOST DANGEROUS ACTION: PRESS ON REGARDLESS

Flying on in the hope that something familiar will appear is how pilots end up controlled into terrain, in airspace they have no clearance for, or over the sea with insufficient fuel. **At the first sign of position uncertainty, take action immediately.**

Immediate Actions When Uncertain

1. **Climb** — if terrain permits. Greater altitude extends your visual range and increases obstacle clearance while you resolve the uncertainty.
2. **Maintain heading and log the time** — continue on the last known heading. This builds a reliable DR track from the last known position.
3. **Define your circle of uncertainty** — based on elapsed time since last known fix and your estimated navigation accuracy, work out the area within which you must be.
4. **Use radio aids** — a VOR radial, DME distance, ADF bearing, or QDM from a D/F station can resolve the uncertainty in seconds. Call the nearest ATC unit.
5. **Apply ground-to-map** — look for the most prominent feature visible and search the chart within your circle of uncertainty.

The Line Feature Technique

If still uncertain after the above steps, turn toward a prominent linear feature that lies *outside* your circle of uncertainty — a coastline, a motorway, a main railway. When you reach it, you know your position with certainty on that line. Turn and follow the feature until you find a definite visual checkpoint from which normal navigation can resume.

Q1 ANSWER LOGIC

Q1 of this chapter asks the best course of action when uncertain. The answer is **a — set heading towards a line feature (coastline, river or motorway)**. This is the classic "lost" recovery: reach a known line, then follow it to a fix. Flying in reverse along the flight plan (b, d) compounds the problem without resolving it. Expanding circles (c) wastes time and fuel.

If All Else Fails

Do not fly toward high ground in poor weather below safety altitude. Do not enter controlled airspace without clearance. Declare urgency (MAYDAY or PAN PAN) on 121.5 MHz. ATC can provide radar identification, vectors to the nearest airport, and SAR assistance if required.

Chart Symbol Reference

The following pages are reproduced from the chapter appendix and contain the numbered aeronautical chart symbols referenced in Questions 2, 5, 6, 7 and 8. Study these carefully — obstruction symbols and radio navigation aid symbols are high-frequency examination topics.

Key Symbol Groups to Prioritise

Category	What to Learn
Radio Navigation Aids	VOR (symbol 13), VORTAC (symbol 14), NDB (symbol 5), DME
Airports	Civil vs military; hard/soft surface; with/without control tower

Obstructions

Symbol 9 (lighted, <1 000 ft), 10 (lighted, >1 000 ft), 12 (group lighted), 15 (unlighted)

Aeronautical Lights

Symbol 3 = aeronautical ground light

Reporting Points

Compulsory (solid triangle) vs non-compulsory (open triangle)

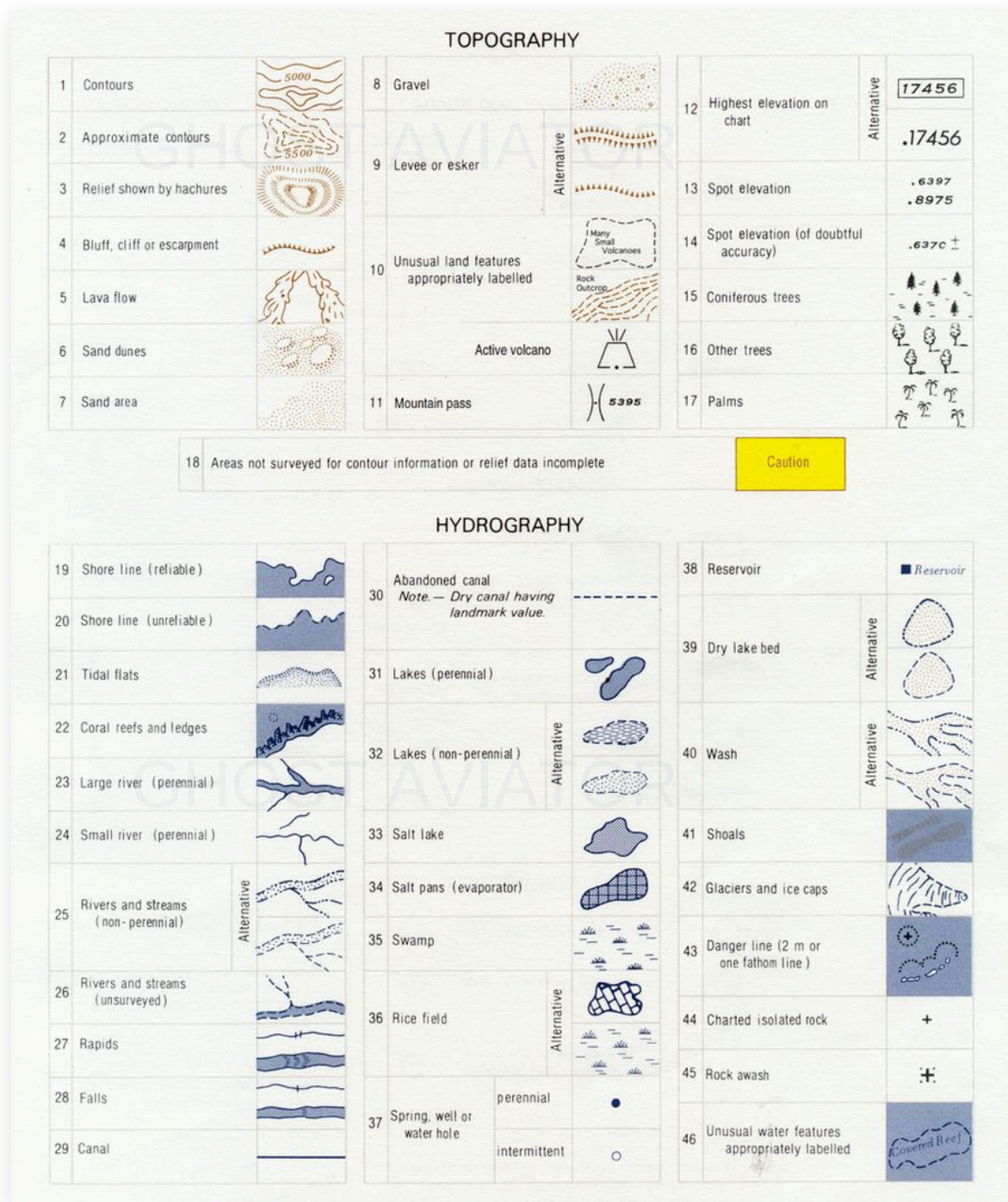


Figure 3 — Chart symbol reference — page 1

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CULTURE

BUILT-UP AREAS			HIGHWAYS AND ROADS			MISCELLANEOUS (Cont'd)		
47	City or large town		57	Dual highway		69	Pipeline	
48	Town		58	Primary road		70	Oil or gas field	
49	Village		59	Secondary road		71	Tank farms	
50	Buildings		60	Trail		72	Coast guard station	
RAILROADS			61	Road bridge		73	Lookout tower	
51	Railroad (single track)		62	Road tunnel		74	Mine	
52	Railroad (two or more tracks)		MISCELLANEOUS			75	Forest ranger station	
53	Railroad (under construction)		63	Boundaries (international)		76	Race track or stadium	
54	Railroad bridge		64	Other boundaries		77	Ruins	
55	Railroad tunnel		65	Fence		78	Fort	
56	Railroad station		66	Telegraph or telephone line (when a landmark)		79	Church	
			67	Dam		80	Mosque	
			68	Ferry		81	Pagoda	
						82	Temple	

AERODROMES (Cont.)

**AERODROME DATA IN ABBREVIATED FORM WHICH MAY BE
IN ASSOCIATION WITH AERODROME SYMBOLS**
(Reference: 16.9.2.2 and 17.9.2.2)

94	Elevation given in the units of measurement (metres or feet) selected for use on the chart	Name of aerodrome	Length of longest runway in hundreds of metres or feet (whichever unit is selected for use on the chart)
		LIVINGSTONE 357 L H 95	
	Minimum lighting — obstacles, boundary or runway lights and lighted wind indicator or landing direction indicator		Runway hard surfaced, normally all weather
Note. — A dash (—) is to be inserted where L or H do not apply.			

AERODROME SYMBOLS FOR APPROACH CHARTS

95	Aerodromes affecting the traffic pattern on the aerodrome on which the procedure is based		96	The aerodrome on which the procedure is based	
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RADIO NAVIGATION AIDS*

97	Basic radio navigation aid symbol <i>Note. — This symbol may be used with or without a box to enclose the data.</i>			107	Radio marker beacon	Elliptical 	Bone Shape
98	Non-directional radio beacon	NDB			<i>Note. — Marker beacons may be shown by outline, or stipple, or both.</i>		
99	VHF omnidirectional radio range	VOR					
100	Distance measuring equipment	DME		108	Compass rose To be orientated on the chart in accordance with the alignment of the station (normally Magnetic North)		
101	Collocated VOR and DME radio navigation aids	VOR/DME			Compass rose to be used as appropriate in combination with the following symbols:		
102	DME distance	Distance in kilometres (nautical miles) to DME — 15 km Identification of radio navigation aid — KAV					
103	VOR radial	Radial bearing from, and identification of, VOR — R 090 KAV					
104	UHF tactical air navigation aid	TACAN					
105	Collocated VOR and TACAN radio navigation aids	VORTAC					
106	Instrument landing system	ILS	PLAN VIEW PROFILE 	* <i>Note. — Guidance material on the presentation of radio navigation aid data is given in the Aeronautical Chart Manual (Doc 8697).</i>			

*Note. — Guidance material on the presentation of radio navigation aid data is given in the Aeronautical Chart Manual (Doc 8697).

Figure 5 — Chart symbol reference — page 3

AIR TRAFFIC SERVICES									
109	Flight information region	FIR							
110	Aerodrome traffic zone	ATZ							
111	Control area Airway Controlled route	CTA AWY	Alternative						
112	Uncontrolled route								
113	Advisory airspace	ADA							
114	Control zone	CTR							
115	Advisory route	ADR	Alternative						
116	Scale-break (on ATS route)		Alternative						
117	Reporting point	REP							
118	Change-over point	COP							
119	ATS/MET reporting point	MRP							
120	Way-point WPT								
AIRSPACE RESTRICTIONS									
121	Restricted airspace (prohibited, restricted or danger area)								
122	International boundary closed to passage of aircraft except through air corridor								
OBSTACLES									
123	Obstacle								
124	Lighted obstacle								
125	Group obstacles								
126	Lighted group obstacles								
127	Exceptionally high obstacle (optional symbol)								
128	Exceptionally high obstacle — lighted (optional symbol)								
129	Elevation of top (italics)								
MISCELLANEOUS									
130	Prominent transmission line								
131	Isogonic line or isogonal								
132	Ocean station vessel (normal position)								
VISUAL AIDS									
133	Marine light								
134	Aeronautical ground light								
135	Lightship								

Figure 6 — Chart symbol reference — page 4

136	Hard surface runway		144	Pierced steel plank or steel mesh runway	
137	Unpaved runway		145	Point light	● ○
138	Stopway SWY		146	Obstacle light	✱
139	Taxiways and parking areas		147	Landing direction indicator (lighted)	✦
140	Helicopter alighting area on an aerodrome	Ⓜ	148	Landing direction indicator (unlighted)	T
141	Aerodrome reference point ARP	⊕	149	Stop bar	...
142	VOR check-point	⬅⊕	150	Taxi holding position	Pattern A
143	Runway visual range (RVR) observation site	◁			Pattern B
Note.— For application, see Annex 14, Volume I, paragraph 5.2.9					

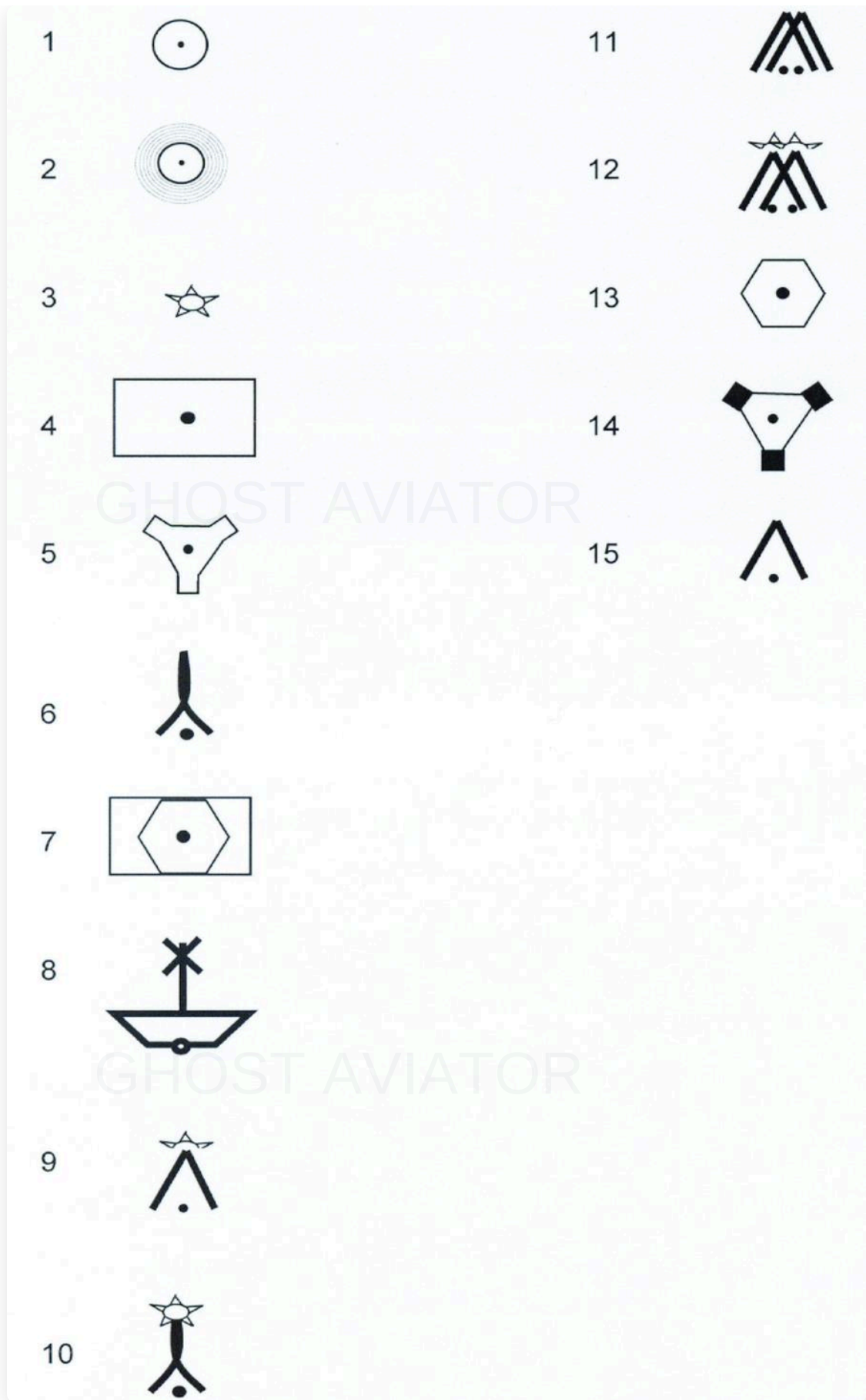
	Plan	Profile	
151	Tree or shrub	✱	
152	Pole, tower, spire, antenna, etc.	○	
153	Building or large structure	■	
154	Railroad	—+—+—+—	
155	Transmission line or overhead cable	—T—T—	
156	Terrain penetrating obstacle plane		
157	Escarpment		
158	Stopway SWY		
159	Clearway CWY		

Figure 7 — Chart symbol reference — page 5

Appendix A — Symbols 16–21

Appendix A is specifically referenced in the practice questions below.

Questions 3 and 4 additionally require an external Jeppesen E(LO)1 chart.



Practice Questions

Ten questions. Questions 3 and 4 require the Jeppesen E(LO)1 chart (an external publication). Questions 2, 5, 6, 7 and 8 use the symbol tables above. Tap any question to reveal the answer.

Q1 You are flying a VFR route and have become uncertain of your position. Which is the best course of action?

- a.** Set heading towards a line feature — coastline, river or motorway
- b.** Turn round and fly your flight plan tracks in reverse until you see something you recognised before
- c.** Fly a series of ever-expanding circles from your present position till you find your next checkpoint
- d.** Turn round and fly your flight plan in reverse back to base

ANSWER: A

Set heading toward a prominent linear feature outside your circle of uncertainty. When you reach it you have a certain position on that line. Follow it to a definite fix and resume navigation. Reversing (b/d) retraces unknown territory; expanding circles (c) waste time and add distance to an already diminishing fuel state.

Q2 Please refer to Appendix A (Figure 8 above). What is the symbol for an unlighted obstacle?

a. 9

b. 10

c. 12

d. 15

ANSWER: D

Symbol 15 is the unlighted obstacle. Symbol 9 = lighted obstacle below 1 000 ft AGL. Symbol 10 = exceptionally high (over 1 000 ft AGL) lighted obstruction. Symbol 12 = group of lighted obstructions. Note: the absence of the lightning-bolt 'lit' indicator is the key discriminator for an unlighted obstacle.

Q3 Using the Jeppesen E(LO)1, position 5211N 00931W — which of the following denotes all the symbols?

a. Military airport, ILS, NDB

b. Civil airport, VOR, ILS

c. Military airport, VOR, ILS

d. Civil airport, ILS, NDB

ANSWER: D

Answer retained verbatim from the published answer key: civil airport, ILS, NDB.

■ **Instructor's Note** — This question requires the Jeppesen E(LO)1 chart — an external publication not included in this study note. Answer **d** is taken directly from the published key and reproduced without independent verification. Cross-check with the current chart edition if there is any doubt.

Q4 Using the Jeppesen E(LO)1 chart, what are the symbols at Galway Carnmore (5318.1N 00856.5W)?

a. VOR, NDB, DME, compulsory reporting point

b. Civil airport, NDB, DME, non-compulsory reporting point

c. Civil airport, VOR, DME, non-compulsory reporting point

d. VOR, NDB, DME, non-compulsory reporting point

ANSWER: B

Answer retained verbatim from the published answer key: civil airport, NDB, DME, non-compulsory reporting point.

■ **Instructor's Note** — This question requires the Jeppesen E(LO)1 chart. Answer **b** is taken directly from the published key. Galway Carnmore (EICM) is a regional Irish airport; navaid fits are periodically updated and chart editions must be checked for currency.

Q5 Which of the following is the symbol for an exceptionally high (over 1 000 feet AGL) lighted obstruction?

a. 6

b. 9

c. 10

d. 15

ANSWER: C

Symbol 10 is the exceptionally high lighted obstruction — the one that exceeds 1 000 ft AGL. Symbol 9 is the lower lighted obstruction (below 1 000 ft AGL). The 1 000 ft threshold is the key discriminator between symbols 9 and 10. Symbol 15 is the unlighted obstruction. Symbol 6 is in a different category.

Q6 What symbol is used to show a VORTAC on a map/chart?

a. 5

b. 7

c. 13

d. 14

ANSWER: D

Symbol 14 is the VORTAC — a combined VHF Omnidirectional Range (VOR) and UHF Tactical Air Navigation (TACAN) facility. It provides both bearing information (from the VOR component) and distance information (from the TACAN component). Symbol 13 is the standalone VOR. Symbol 5 is an NDB. Mnemonic: VOR=13, VORTAC=14 — consecutive numbers.

Q7 Which is the symbol for a VOR?

a. 4

b. 5

c. 13

d. 14

ANSWER: C

Symbol 13 is the VOR. The VOR symbol is traditionally drawn with a compass rose around the station. Symbol 14 is the VORTAC. Symbol 5 is an NDB (Non-Directional Beacon, which transmits on MF/LF). Symbol 4 is a different aid category.

Q8 What does symbol 3 represent?

a. Lit obstacle

b. Lighthouse

c. Visual Reporting Point (VRP)

d. Aeronautical ground light

ANSWER: D

Symbol 3 is an aeronautical ground light — a fixed light, often an aviation beacon, that assists pilots in visual navigation. An aeronautical ground light

may be located at an aerodrome (the aerodrome beacon) or on prominent terrain. A lighthouse (b) is a marine navigational aid and uses a different, internationally standardised symbol. A VRP (c) uses a triangle or flag symbol.

Q9 An aircraft flying VFR using visual navigation crosses two parallel roads at right angles to the track. For what purpose could that information be used?

a. Tracking check

b. Ground speed check

c. Heading check

d. Deviation check

ANSWER: B

When the aircraft crosses two parallel roads at right angles to track, it obtains two distinct position fixes separated by a known distance (the road spacing, read from the chart). If the pilot records the time taken to fly between the two roads, groundspeed can be calculated: $GS = \text{distance} \div \text{time}$. Crossing roads at right angles gives no heading information — you could be on exactly the correct track or significantly off it and still cross them at 90° .

Q10 Which of the following would be most useful as a visual checkpoint when planning a flight?

a. A small copse

b. A large wood

c. A large motorway junction

d. A bend in a river

ANSWER: C

A large motorway junction scores highly on all checkpoint criteria: very prominent at altitude, unique in shape (cloverleaf/trumpet interchanges are unmistakable), precisely definable position, permanent (motorway routes

rarely change), and contrasting (grey concrete against surroundings). A small copse (a) is too small and not unique. A large wood (b) is better but changes over time. A river bend (d) is useful but many bends look similar; it is a secondary choice.

Quick Answer Key

Q1 a	Q2 d	Q3 d 🚩	Q4 b 🚩	Q5 c
Q6 d	Q7 c	Q8 d	Q9 b	Q10 c

Ghost Aviator Study Notes · General Navigation Chapter 13 · For DGCA CPL/ATPL Examination Preparation

GHOST AVIATOR

CHAPTER 14 · GENERAL NAVIGATION

Convergency and Conversion Angle

Meridian convergence · Great circle tracks · D-I-I-D rule · Radio bearings · Conversion angle

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Meridians and Convergency

Meridians are great semi-circles that join the geographic North and South Poles. Because they all connect at the same two points, they cannot remain parallel to each other — they *must* converge at the poles. Understanding exactly *how much* they converge, and *at what rate*, is fundamental to great circle navigation.

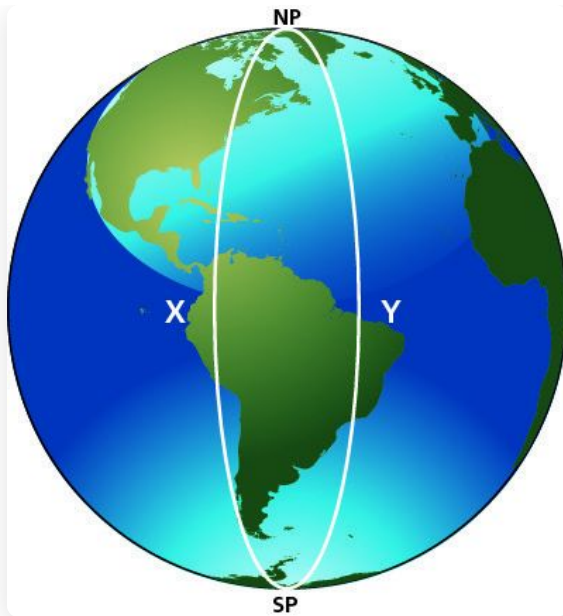


Figure 1 — Meridians diverge from the North Pole, are parallel at the Equator, then converge again toward the South Pole

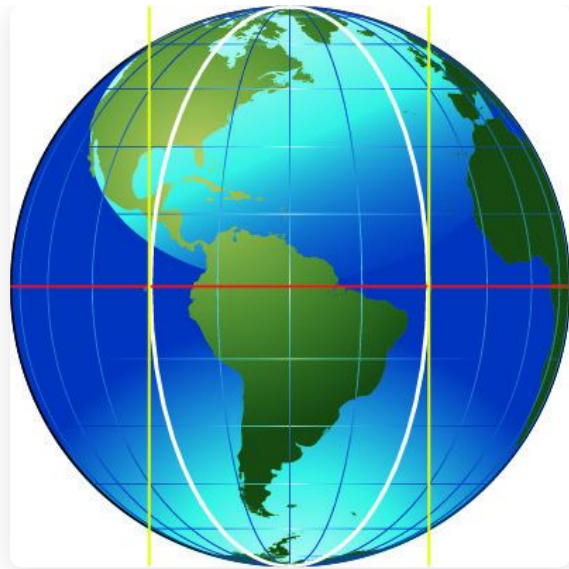


Figure 2 — At the Equator, any two meridians are exactly parallel to each other — convergence is zero

The Three Key Facts About Meridian Convergence

- **At the Equator:** any two meridians are exactly parallel. No matter how far apart they are in longitude, they never incline toward each other at the Equator. Convergence = 0° .
- **At either Pole:** meridians converge to a single point. The angle between two meridians at the Pole equals exactly their difference in longitude. If two meridians are 60° of longitude apart, they meet at the Pole at an angle of exactly 60° . Convergence = Change of Longitude.
- **At intermediate latitudes:** convergence is between 0° and the change of longitude — proportional to the sine of the latitude.

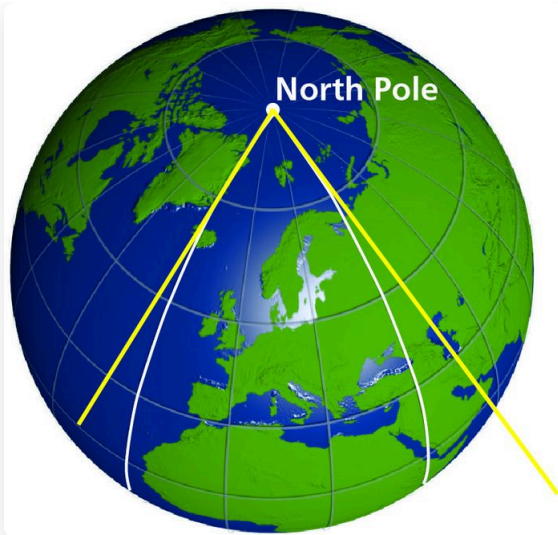


Figure 3 — At the Pole, the angle between two meridians equals exactly their change of longitude

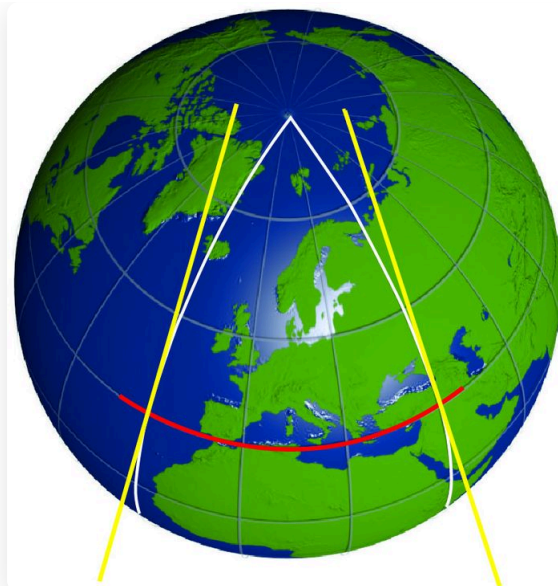


Figure 4 — At intermediate latitude, convergency is proportionally between 0° (Equator) and ch.long (Pole)

The Convergency Formula

From the observations above, convergency varies between zero (at the Equator) and the full change of longitude (at the Poles). The factor that controls this is the sine of the latitude. This leads directly to the formula:

$$\text{Convergency} = \text{Change of Longitude} \times \sin(\text{Latitude})$$

Where latitude is the common latitude of both meridians, or mean latitude when they differ

Why Sine of Latitude?

The sine function has exactly the right behaviour: $\sin(0^\circ) = 0$ at the Equator, and $\sin(90^\circ) = 1.0$ at the Poles. At 30°N , $\sin(30^\circ) = 0.5$, so convergency is exactly half the change of longitude. At 45°N , $\sin(45^\circ) = 0.707$, so convergency is about 70.7% of the change of longitude.

Latitude	$\sin(\text{lat})$	Effect on Convergency
0° (Equator)	0.000	No convergency
20°	0.342	34.2% of ch.long
30°	0.500	50% of ch.long
45°	0.707	70.7% of ch.long
60°	0.866	86.6% of ch.long
90° (Pole)	1.000	100% of ch.long

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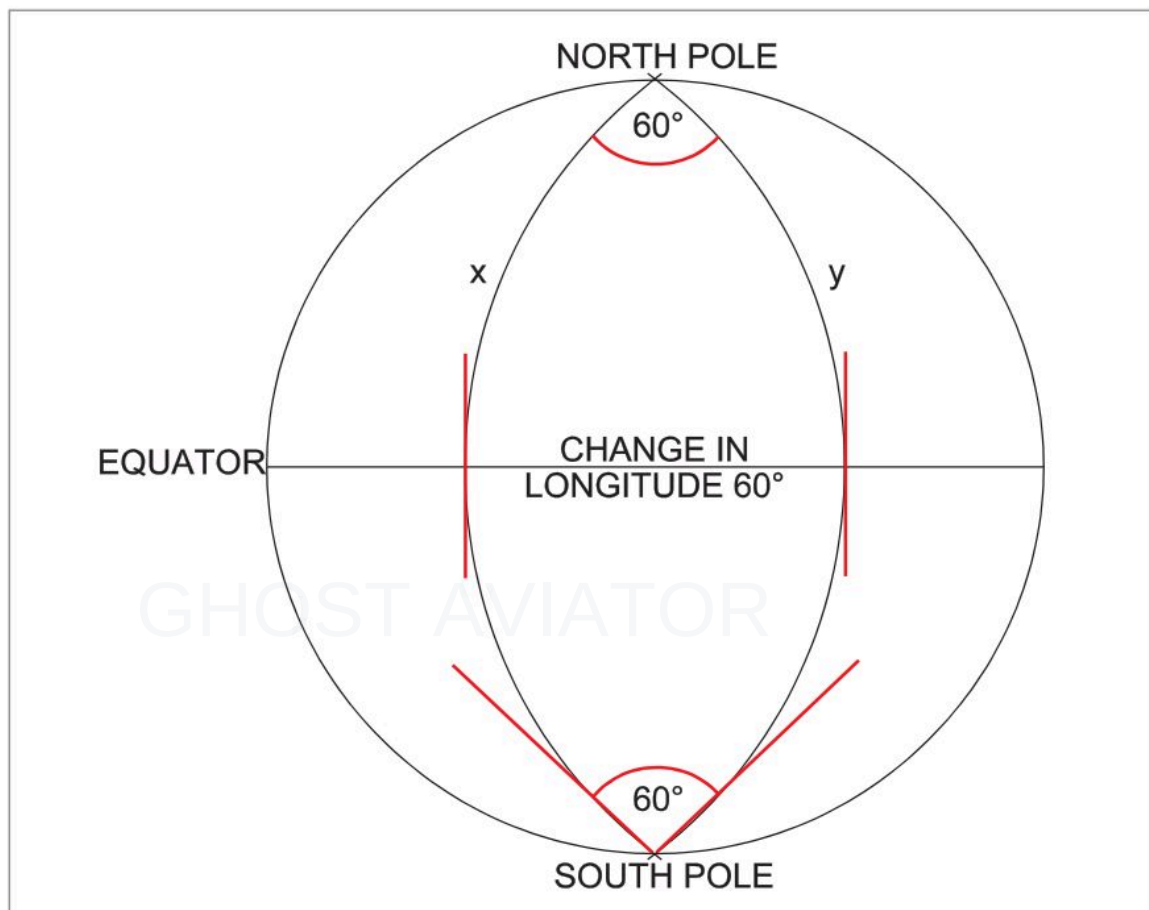


Figure 14.5 — Converging and diverging meridians

Figure 5 — Convergency shown as the angle of inclination between two meridians — with worked table showing values at Equator (0) and Pole (1.0)

The 30°N Worked Example

Consider two meridians 40° of longitude apart, at latitude 30°N:

CALCULATION

Convergency = Change of Longitude $\times$ sin(Latitude)

Convergency = $40^\circ \times \sin(30^\circ) = 40^\circ \times 0.5 = 20^\circ$

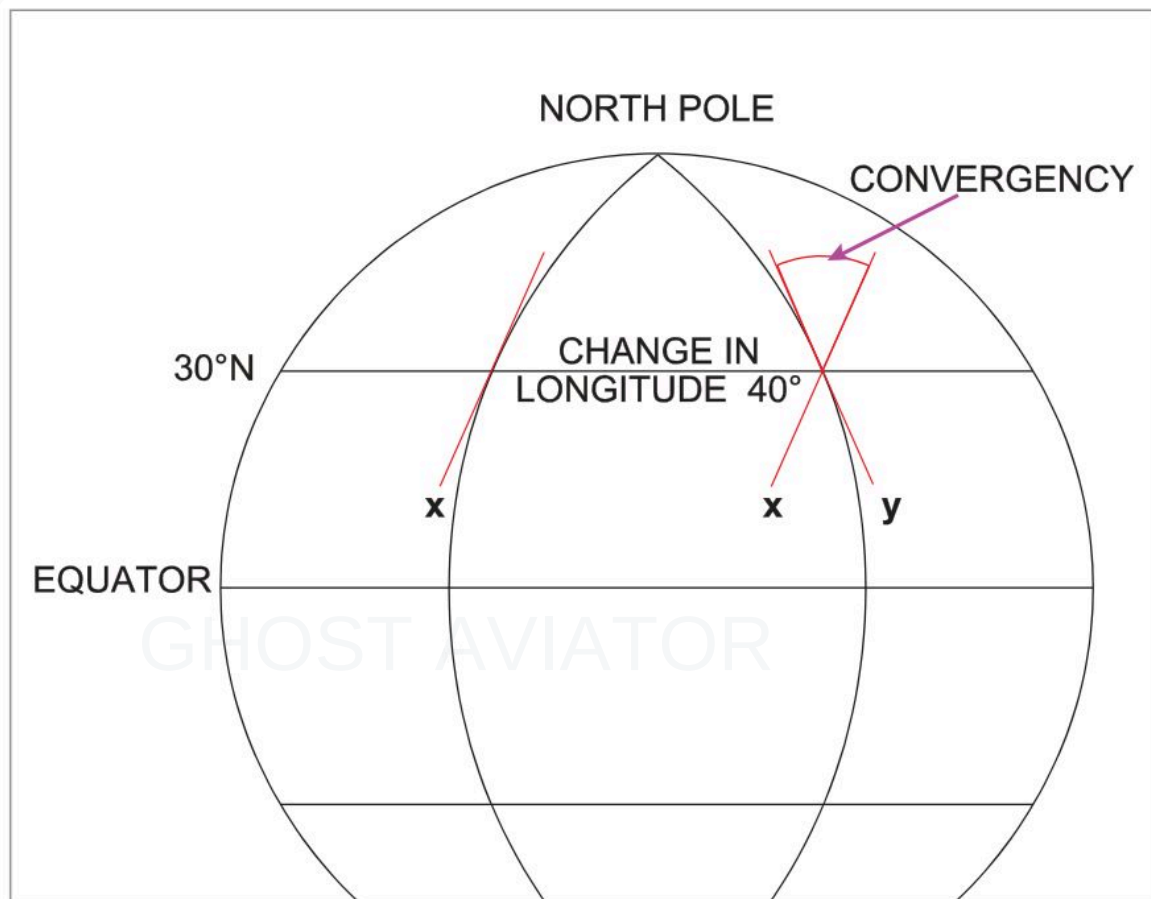


Figure 14.6 Convergence

Figure 6 — Tangents drawn to two meridians at 30°N — the angle between them is $20^\circ (= 40^\circ \times 0.5)$

When the Two Points are at Different Latitudes

In practice, most great circle routes go from one latitude to another — the two endpoints are not on the same parallel. In this case there is no single "latitude" to insert in the formula. The rigorous solution requires the *mean latitude* of the great circle route itself, which is closer to the nearer pole than the mid-latitude between the two endpoints.

However, the difference between sine of mid-latitude and sine of mean latitude is small unless the change of longitude is very large. For exam purposes and practical navigation, **mid-latitude** is used in the formula.

Great Circle Track and Convergence

At any point on the Earth, True North is defined by the direction of the local meridian. If you fly a great circle route, you will cross different meridians — and because those meridians are inclined to each other, your great circle track angle (measured from True North) will change continuously throughout the flight.

The amount by which a great circle track changes direction between two meridians is exactly equal to the convergence between those two meridians.

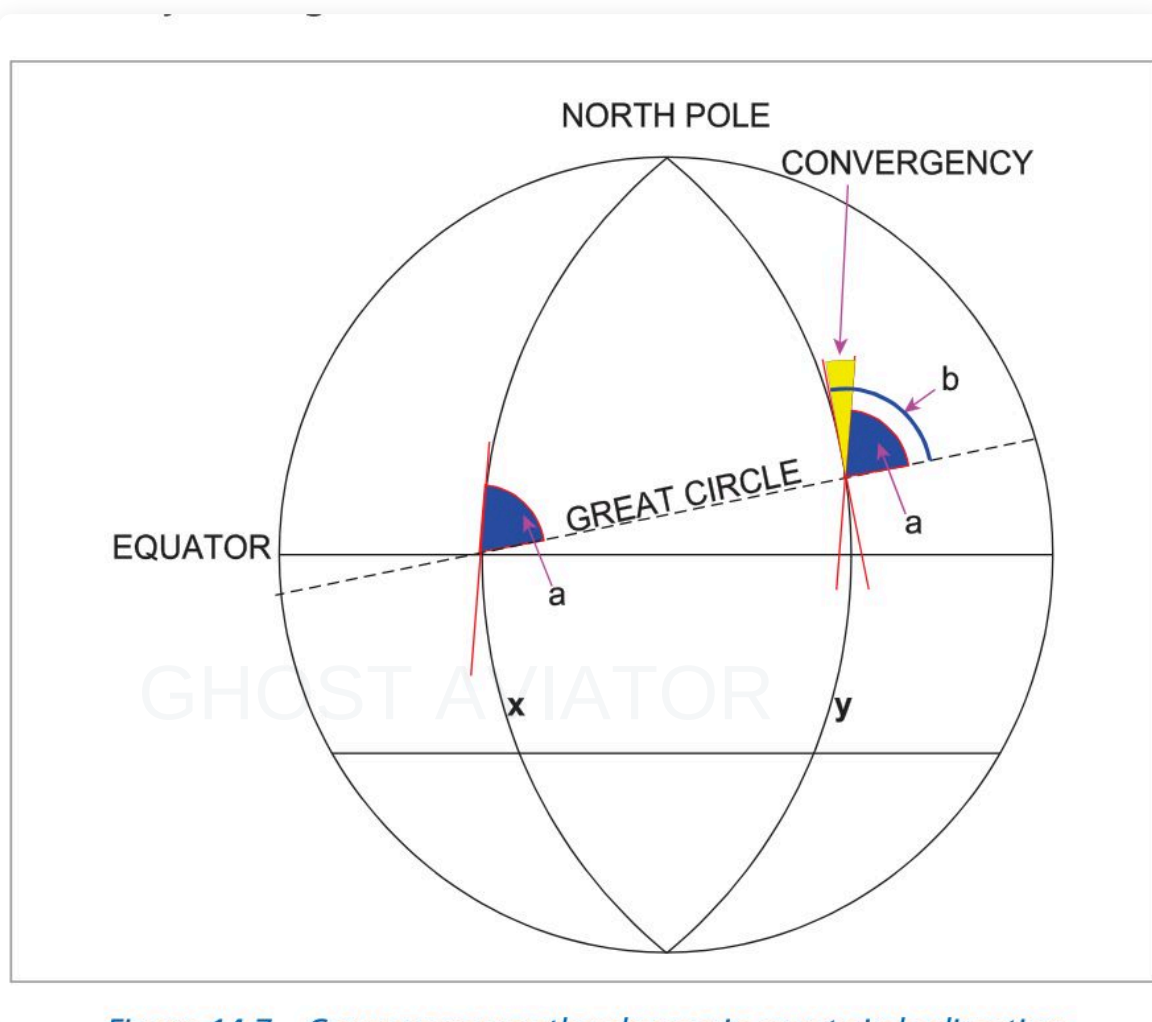


Figure 7 — A great circle cutting meridians X and Y — the angle 'a' at X and angle 'b' at Y differ by exactly the convergence between the meridians

Why a Rhumb Line Curves

A rhumb line (constant true track) appears as a straight line on a Mercator chart but as a curved line on a conformal conic chart. The reason is that to maintain a *constant* bearing from True North — and True North itself is rotating (because the meridians are converging) — the path must continuously curve. A rhumb line must compensate for meridian convergence in order to keep its track angle constant.

Conversely, a great circle — which is the shortest path between two points on the sphere — appears curved on a Mercator chart (curving toward the nearer pole) but as a straight line on a Lambert conformal chart (because the meridians themselves converge on that projection).

KEY RELATIONSHIP

The great circle track changes by the amount of convergency between its endpoints. If convergency = 8.5° , the GC track at arrival is 8.5° different from the GC track at departure — the D-I-I-D rule tells you in which direction.

The D-I-I-D Rule

When flying a great circle route, the track angle changes continuously. The D-I-I-D diagram tells you the direction of that change for any combination of hemisphere and direction of travel.

Northern Hemisphere	Southern Hemisphere
Going East ↑ Track INCREASES	Going East ↓ Track DECREASES

Join live classes for guided practice and doubt clearing.

Going **West**
↓ **Track DECREASES**

Going **West**
↑ **Track INCREASES**

The mnemonic **D-I-I-D** stands for the four cells read clockwise from top-left: *Decreases — Increases — Increases — Decreases* (starting with SH going West = Increases, going around). More usefully, remember the two rules for the Northern Hemisphere (where most of our traffic is):

NORTHERN HEMISPHERE SUMMARY

Going East → Track INCREASES (e.g. 060° becomes 068.5° at destination)

Going West → Track DECREASES (e.g. 313° becomes 305° at departure point)

How to Apply the Rule

Step 1: Calculate convergency ($\text{ch.long} \times \sin \text{mid-lat}$).

Step 2: Look up D-I-I-D for your hemisphere and primary direction of travel.

Step 3: Add or subtract convergency from the departure track to get the arrival track.

Step 4: Take the reciprocal of the arrival track to get the initial track from B to A.

Alternative: Parallel Construction Line

Draw the initial track from A. Parallel it across to B (draw a line at the same angle to the vertical). The convergency angle is then visible as the angle between this parallel line and the meridian at B. Add the two angles to get the track at B; take the reciprocal for the reverse direction. Both methods give the same answer.

Worked Examples 1–3

Worked Example 1 — Initial GC Track Between Two Points

Given: Initial GC track from A ($40^{\circ}00'N$ $002^{\circ}00'W$) to B ($50^{\circ}00'N$ $010^{\circ}00'E$) is $060^{\circ}(T)$. Find the initial GC track from B to A.

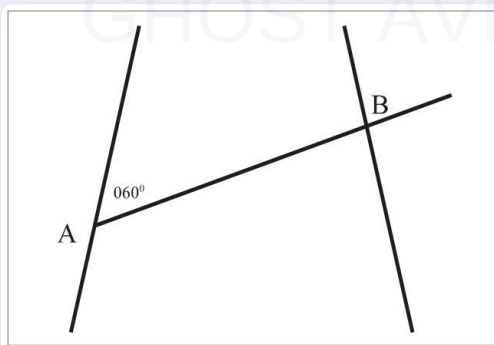


Figure 14.10 — Meridians converging northwards

Figure 8 — Diagram for Example 1 — A is on the left (W) meridian, B on the right (E) meridian; initial track 060° from A toward NE

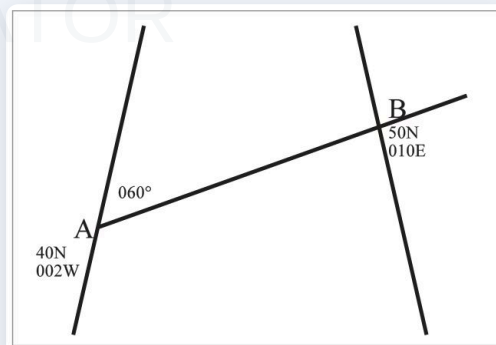


Figure 14.11 — Checking the diagram for sense

Figure 9 — Checking the diagram: B is north and east of A, confirmed by latitude/longitude comparison

Step 1 — Draw the diagram. In the Northern Hemisphere, meridians converge northward. The initial track is $060^{\circ}(T)$ — going NE. A is on the W meridian, B on the E meridian.

Step 2 — Check the diagram. B ($50^{\circ}N$, $010^{\circ}E$) should be north and east of A ($40^{\circ}N$, $002^{\circ}W$). ✓ North because $\text{lat } B > \text{lat } A$. ✓ East because $010^{\circ}E$ is east of $002^{\circ}W$.

Step 3 — Calculate convergency.

Change of longitude = $002^{\circ}W$ to $010^{\circ}E = 12^{\circ}$

Mid-latitude = $(40^\circ + 50^\circ) \div 2 = 45^\circ\text{N}$; $\sin 45^\circ = 0.7071$

Convergency = $12^\circ \times 0.7071 = 8.5^\circ$

Step 4 — Apply D-I-I-D. Northern Hemisphere, going East $\rightarrow$ track INCREASES. Track at A = 060° . Track at B (arrival) = $060^\circ + 8.5^\circ = 068.5^\circ$.

Step 5 — Reciprocal. Track from B to A = $068.5^\circ + 180^\circ = 248.5^\circ(\text{T})$

Answer: Initial GC track from B to A = $248.5^\circ(\text{T})$

Worked Example 2 — Finding an Unknown Longitude

Given: Initial GC track from C ($36^\circ 00'\text{N}$ $015^\circ 00'\text{E}$) to D ($42^\circ 00'\text{N}$) is $300^\circ(\text{T})$; final track at D is $295^\circ(\text{T})$. Find: (a) longitude of D; (b) GC track at 011°E .

Step 1 — Find convergency. Track changed from 300° to 295° = change of 5° . Going West in NH $\rightarrow$ track DECREASES $\checkmark$ ($300^\circ \rightarrow 295^\circ$).
Convergency = 5° .

Step 2 — Find change of longitude.

Mid-latitude = $(36^\circ + 42^\circ) \div 2 = 39^\circ\text{N}$; $\sin 39^\circ = 0.629$

Convergency = $\text{ch.long} \times \sin(39^\circ)$

$5^\circ = \text{ch.long} \times 0.629 \rightarrow \text{ch.long} = 5^\circ \div 0.629 = 8^\circ$

C is at 015°E and going west $\rightarrow$ D is at $015^\circ - 8^\circ = 007^\circ\text{E}$

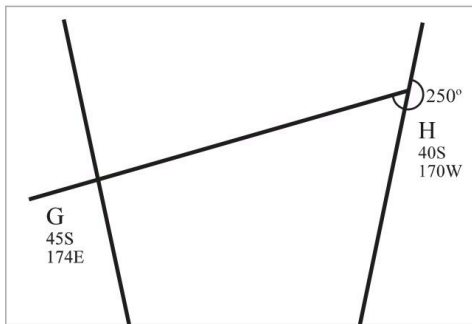


Figure 14.16 Meridians converging southwards

Figure 10 — Southern hemisphere meridians — meridians converge southward; for Q3 the setup reverses

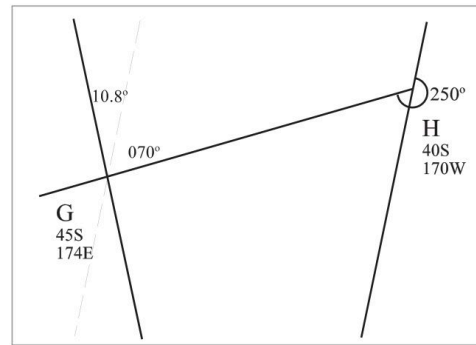


Figure 14.17 Drawing in a parallel

Figure 11 — Parallel construction: extend track from H, add convergency angle at G to find reciprocal angle

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Step 3 — Track at mid-longitude. Longitude 011°E is midway between 015°E and 007°E. Therefore the track is midway between 300° and 295° = **297.5°(T)**

Answers: (a) Longitude of D = 007°E · (b) Track at 011°E = 297.5°(T)

Worked Example 3 — Southern Hemisphere Route

Given: Initial GC track from H (40°00'S 170°00'W) to G (45°00'S 174°00'E) is 250°(T). Find initial GC track from G to H.

Step 1 — Draw the diagram. Southern Hemisphere → meridians converge southward. H is at 170°W, G is at 174°E. Crossing the anti-meridian (180°): change of longitude = $(180^\circ - 170^\circ) + (180^\circ - 174^\circ) = 10^\circ + 6^\circ = 16^\circ$

Step 2 — Calculate convergency.

Mid-latitude = $(40^\circ + 45^\circ) \div 2 = 42.5^\circ$; $\sin 42.5^\circ = 0.676$

$$\text{Convergency} = 16^\circ \times 0.676 = \mathbf{10.8^\circ}$$

Step 3 — Apply D-I-I-D. Southern Hemisphere, going West → track INCREASES. Track at H (departure) = 250° . Track at G (arrival) = $250^\circ + 10.8^\circ = 260.8^\circ$.

Step 4 — Reciprocal. GC track from G to H = $260.8^\circ - 180^\circ = \mathbf{080.8^\circ(T)}$

Answer: Initial GC track from G to H = $080.8^\circ(T)$

Conversion Angle

Consider the situation in the diagram below. Two meridians are 40° of longitude apart. A rhumb line connects A ($30^\circ\text{N } 020^\circ\text{W}$) to B ($30^\circ\text{N } 020^\circ\text{E}$) along the parallel of latitude — this RL has a constant direction of $090^\circ(T)$ throughout.

A great circle connecting the same two points does NOT follow the parallel. Because the GC is the shortest path between the points on the sphere, it arcs toward the nearer pole (northward in the Northern Hemisphere for an easterly track). At A, the GC heads off on a direction *less* than $090^\circ(T)$ — it starts by heading slightly north of east. At B, it arrives on a direction *greater* than $090^\circ(T)$ — it arrives heading slightly south of east. At the mid-longitude (000°E/W), the GC direction = the RL direction = $090^\circ(T)$.

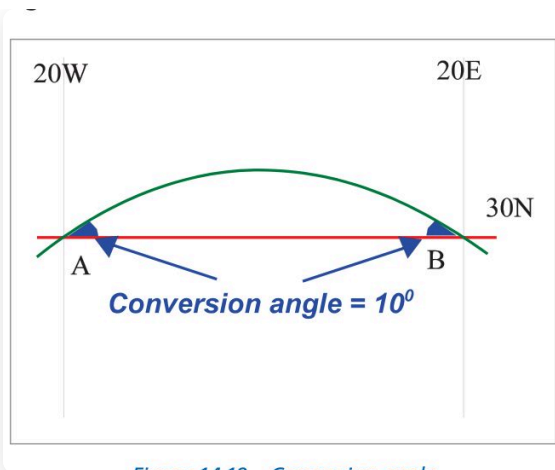


Figure 12 — Rhumb line (090° constant) vs great circle — RL shown as straight, GC bows toward the north pole between A and B

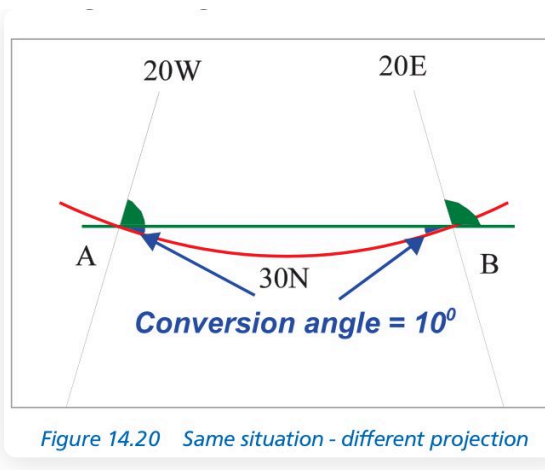


Figure 13 — Same geometry on a different projection — GC appears straight, RL curves; relative positions unchanged

Deriving Conversion Angle

In the example above:

- Convergency = $40^\circ \times \sin(30^\circ) = 40^\circ \times 0.5 = 20^\circ$
- The GC track changed 20° between A and B
- The RL track is 090° throughout and equals the GC at the midpoint
- So at A, GC = $090^\circ - 10^\circ = \mathbf{080^\circ(T)}$
- At B, GC = $090^\circ + 10^\circ = \mathbf{100^\circ(T)}$
- The difference between GC and RL at either endpoint = $\mathbf{10^\circ}$

This difference — between the great circle direction and the rhumb line direction at a given point — is called the **Conversion Angle (CA)**. In this case, CA = 10° .

Notice that CA is exactly *half* the convergency. This is always the case (for routes between two points at the same latitude; it is also used as an approximation for routes at slightly different latitudes).

$$\text{Conversion Angle} = \frac{1}{2} \times \text{Convergency}$$

$$= \frac{1}{2} \times \text{Change of Longitude} \times \sin(\text{Mean Latitude})$$

Which Direction to Apply CA?

The GC always bows toward the nearer pole. Therefore:

- In the **Northern Hemisphere**, the GC arcs northward → at the departure point, GC is *more northerly* (smaller track number for E-bound; larger for W-bound) than the RL.
- In the **Southern Hemisphere**, the GC arcs southward → at the departure point, GC is *more southerly* than the RL.

Equivalently, at the departure point: **RL = GC ± CA**. Use the D-I-I-D/logical reasoning to determine the sign for your specific situation.

Radio Bearings and Conversion Angle

Radio waves travel along great circle paths over the surface of the Earth. When a VOR, NDB, or VDF station measures a bearing to or from an aircraft, that bearing is a **great circle direction**. For navigation plotting on a Mercator chart (where rhumb lines appear as straight lines), you must convert from great circle to rhumb line before plotting.

The Correction

Apply the Conversion Angle to the GC bearing to obtain the RL bearing:

FORMULA

$$\text{RL bearing} = \text{GC bearing} \pm \text{CA}$$

The sign depends on which hemisphere and which direction (D-I-I-D logic)

Important: Apply CA at the Measurement Point

This is a critical, frequently examined point. If the GC bearing is measured at the *aircraft*, apply CA at the aircraft's position. If measured at the *station*, apply CA at the station's position. The CA correction is position-specific.

VOR BEARINGS

A VOR radial is a bearing measured from the station (QDR). It is a great circle direction. To plot a VOR radial on a Mercator chart, apply CA to convert to RL before plotting. On a Lambert chart, the correction is very small and often ignored for routine navigation.

NDB/ADF BEARINGS

An NDB bearing is measured at the aircraft. The ADF needle points along a great circle to the beacon. Apply CA at the aircraft's position to convert to a RL for Mercator plotting.

Practical Example

If the GC track from A to B is $100^\circ(\text{T})$ and $\text{CA} = 4^\circ$, the RL track at A is found by: GC is 100° , which is slightly south of east in the NH. The RL (which is more 'direct', less curved) will be slightly closer to $090^\circ \rightarrow \text{RL} = 100^\circ - 4^\circ = \mathbf{096^\circ(\text{T})}$... but check the exact geometry for your specific question (see Worked Example 6 below).

Worked Examples 4–6

Worked Example 4 — Convergency, RL Track, and GC from K to J

Given: J ($58^{\circ}12'N$ $004^{\circ}00'W$) and K ($58^{\circ}12'N$ $006^{\circ}00'E$). Both at same latitude.

(a) Convergency:

Ch.long = $004^{\circ}W$ to $006^{\circ}E = 10^{\circ}$; Latitude = $58^{\circ}12'N$; $\sin 58.2^{\circ} = 0.851$
Convergency = $10^{\circ} \times 0.851 = 8.5^{\circ}$

(b) RL track from J to K:

Both points are at the same latitude ($58^{\circ}12'N$). The RL connecting two points on the same parallel of latitude is the parallel itself — a constant direction of **$090^{\circ}(T)$** (due East).

(c) Initial GC track from K to J:

Going West in NH $\rightarrow$ track DECREASES going west. The RL midpoint track = 090° .

GC at K (going west) = RL at midpoint – CA = $090^{\circ} - 4.25^{\circ} = 085.75^{\circ}...$
but we want from K to J (opposite direction). RL from K to J = $270^{\circ}(T)$.

GC at K going west = $270^{\circ} + CA = 274.25^{\circ}$

Or equivalently: reciprocal of GC from J to K at K = $(090^{\circ} - 4.25^{\circ} = 085.75^{\circ})$ reversed $\rightarrow$ reciprocal = 265.75° ? Let us use the formula directly:

Initial GC from K to J = $270^{\circ} + CA = 270^{\circ} + 4.25^{\circ} = \mathbf{274.25^{\circ}(T)}$ (GC bows northward, so at K going west it starts more northerly than 270° $\rightarrow$ larger number)

Answers: (a) 8.5° · (b) $090^{\circ}(T)$ · (c) $274.25^{\circ}(T)$

Worked Example 5 — INS Waypoint Changeover

Given: WP1 (53°N 030°W) → WP2 (53°N 020°W) → WP3 (53°N 010°W). An FMS/INS steers GC legs. What is the track change on passing WP2?

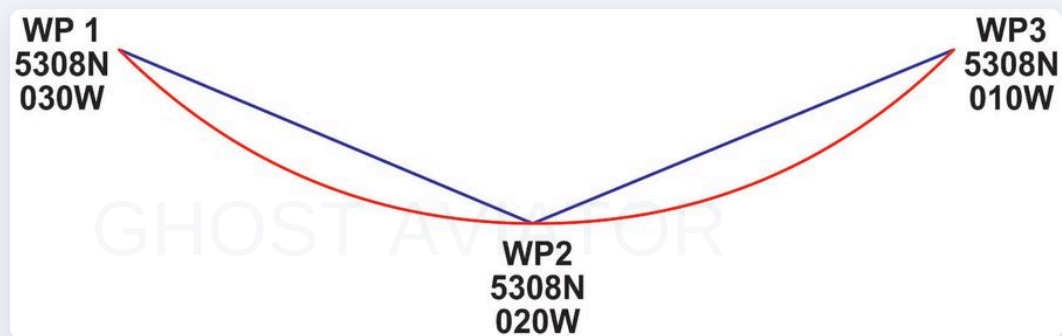


Figure 14 — INS waypoint changeover — WP1 to WP3 shows two consecutive GC legs at 53°N; a left turn occurs at WP2

Step 1 — RL track all the way. All three WPs are on 53°N. RL track = 090°(T) throughout.

Step 2 — GC legs. Each leg has ch.long = 10°, mean lat = 53°N, $\sin 53^\circ = 0.799$.

CA per leg = $\frac{1}{2} \times 10^\circ \times 0.799 = 4.0^\circ$

GC leg 1 (WP1→WP2): departs WP1 on 086°, arrives WP2 on 094°

GC leg 2 (WP2→WP3): departs WP2 on 086°, arrives WP3 on 094°

Step 3 — Track change at WP2. Approaching WP2 on 094°(T); at changeover, FMS reverts to 086°(T) for the new leg → change = $094^\circ - 086^\circ = 8^\circ$ decrease. This is a *left turn* at the waypoint. Answer: **8° decrease (d)**

Answer: (d) — an 8° decrease of track angle on passing WP2

Worked Example 6 — GC to RL Conversion at a Point

Given: A ($55^{\circ}\text{N } 000^{\circ}\text{E/W}$), B ($54^{\circ}\text{N } 010^{\circ}\text{E}$). Initial GC track from A to B is $100^{\circ}(\text{T})$. Find the RL track at A.

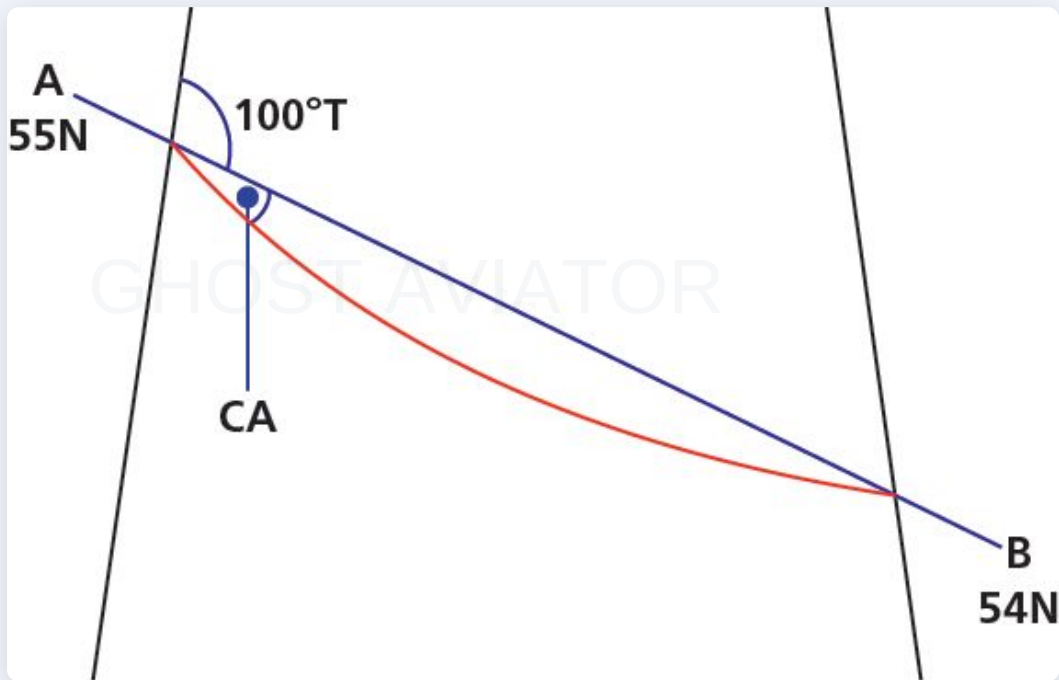


Figure 15 — Diagram for Example 6 — GC track $100^{\circ}(\text{T})$ at A; applying CA gives RL track $104^{\circ}(\text{T})$

Step 1 — Calculate CA.

Ch.long = 10° ; Mean latitude = $(55^{\circ} + 54^{\circ}) \div 2 = 54.5^{\circ}\text{N}$; $\sin 54.5^{\circ} = 0.814$

$$\text{CA} = \frac{1}{2} \times 10^{\circ} \times 0.814 = 4.07^{\circ} \approx 4^{\circ}$$

Step 2 — Direction of correction. We're going SE (100°T) in the NH. The GC is MORE northerly than the RL (GC bows toward N pole). At A, $\text{GC} < \text{RL}$. Therefore $\text{RL} = \text{GC} + \text{CA} = 100^{\circ} + 4^{\circ} = 104^{\circ}(\text{T})$

⚠ CRITICAL POINT — APPLY CA AT THE MEASUREMENT POSITION

The answer is $104^{\circ}(T)$ because the GC bearing is measured AT A and we apply CA at A. If the GC bearing were given at B, we would apply CA at B's position instead. **Never apply CA at the wrong endpoint.**

Answer: (c) RL track at A = $104^{\circ}(T)$

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Practice Questions

The following 10 questions are taken from the chapter. These are calculation-based questions — draw a diagram for each before calculating. Tap to reveal each answer.

Q1 The convergency of the meridians through M and N (Southern hemisphere) is 12° . If the rhumb line track from M to N is $249^{\circ}(T)$, what is the GC track: (a) from M to N? (b) from N to M?

ANSWER: (A) $243^{\circ}(T)$ • (B) $075^{\circ}(T)$

RL = $249^{\circ}(T) \rightarrow$ SW direction in SH going west. CA = $12^{\circ}/2 = 6^{\circ}$.

SH going West $\rightarrow$ track INCREASES going west. GC is more southerly than RL at departure (bows toward S pole).

(a) GC from M $\rightarrow$ N at M: RL 249° is SW. GC more southerly = larger number.
GC at M = $249^{\circ} - 6^{\circ} = 243^{\circ}(T)$.

(b) GC at N (arrival from M) = $249^{\circ} + 6^{\circ} = 255^{\circ}$. Reciprocal = $255^{\circ} - 180^{\circ} = 075^{\circ}(T)$.

Q2 The GC bearing of position B (in latitude $30^{\circ}00'S$) from position A ($30^{\circ}00'S$, $165^{\circ}00'E$) is $100^{\circ}(T)$. What is (a) the GC track from B to A? (b)

the longitude of B?

ANSWER: (A) 260°(T) • (B) 155°W

Both at 30°S — same latitude. RL track = 090°(T) (due east).

GC bearing from A to B = 100°(T). $CA = GC - RL = 100^\circ - 90^\circ = 10^\circ$.

$CA = \frac{1}{2} \times \text{ch.long} \times \sin(30^\circ) \rightarrow 10^\circ = \frac{1}{2} \times \text{ch.long} \times 0.5 \rightarrow \text{ch.long} = 40^\circ$.

B is east of A at 165°E $\rightarrow$ longitude of B = $165^\circ + 40^\circ = 205^\circ\text{E} = 155^\circ\text{W}$.

(a) GC at B going from B to A: arrive on 100° – reciprocal $\rightarrow$ GC from B = $(100^\circ + 40^\circ = 140^\circ)$... Actually: GC at arrival at B = $100^\circ - CA + CA = 80^\circ(\text{T})$

RL side; use track method: departure 100°, SH going east DECREASES $\rightarrow$ arrival = $100^\circ - 20^\circ$ (convergency) = 80° ; reciprocal = 260°(T).

Q3 The RL from D (30°00'N 179°00'W) to C is 090°(T). Initial GC from C to D is 287°(T). What is (a) the GC from D to C? (b) the approximate latitude and longitude of C?

ANSWER: (A) 073°(T) • (B) 30°N 111°W

Both at 30°N (same RL direction 090° means same latitude). RL = 090°, so C is east of D.

GC from C to D = 287°(T). $CA = |287^\circ - 270^\circ| = 17^\circ$. (RL from C to D = 270°;

GC from C to D = 287°; difference = $17^\circ = CA$).

(a) GC from D to C at D: going east in NH $\rightarrow$ track increases. GC at D = $090^\circ - CA = 073^\circ(\text{T})$ (more northerly than RL).

(b) $CA = \frac{1}{2} \times \text{ch.long} \times \sin(30^\circ) \rightarrow 17^\circ = \frac{1}{2} \times \text{ch.long} \times 0.5 \rightarrow \text{ch.long} = 68^\circ$.

C is east of D: $179^\circ\text{W} + 68^\circ\text{E} = \text{longitude } 179^\circ - 68^\circ = 111^\circ\text{W}$. Position C = 30°N 111°W.

Q4 The GC track from A to B measures 227°(T) at A and 225°(T) at B. What is the convergency and in which hemisphere?

ANSWER: 2° CONVERGENCY — NORTHERN HEMISPHERE

Track changed from 227° to 225° — a decrease of 2° . Going SW (225° -ish direction).

Decrease going SW = going west component in NH (track decreases going W in NH) ✓

Convergency = $|227^\circ - 225^\circ| = 2^\circ$. **Northern Hemisphere.**

Q5 (a) At what latitude is the convergency between two meridians equal to twice their convergency at 20°N ? (b) Is there a latitude where convergency = three times the value at 20°N ?

ANSWER: (A) 43°N APPROX · (B) NO

Convergency at $20^\circ\text{N} = \text{ch.long} \times \sin(20^\circ) = \text{ch.long} \times 0.342$.

Twice that = $\text{ch.long} \times 0.684$. Need $\sin(\text{lat}) = 0.684 \rightarrow \text{lat} = \arcsin(0.684) \approx 43^\circ\text{N}$.

Three times = $\text{ch.long} \times 1.026 \rightarrow \sin(\text{lat}) = 1.026$ — impossible because sine cannot exceed 1.000. No such latitude exists.

Q6 (a) A and B: GC from B to A = $268^\circ(\text{T})$, GC from A to B = $092^\circ(\text{T})$. i) Which hemisphere? ii) RL track from A to B? (b) C and D: GC from C to D = $063^\circ(\text{T})$, RL from D to C = $240^\circ(\text{T})$. i) Which hemisphere? ii) Initial GC from D to C?

ANSWER: (A)I SH · (A)II $090^\circ(\text{T})$ · (B)I SH · (B)II $237^\circ(\text{T})$

(a): GC $A \rightarrow B = 092^\circ$, GC $B \rightarrow A = 268^\circ$. If NH and going east, track increases.

Reciprocal of $268^\circ = 088^\circ \neq 092^\circ$. Difference = $4^\circ = 2 \times \text{CA}$. Going east: $088^\circ \rightarrow 092^\circ$ is an increase of 4° — but GC increases going EAST in NH. ✓ for NH?

Actually: arrival track at B = 092° ; reciprocal of arrival = 092°

$+180^\circ = 272^\circ \neq 268^\circ$. Convergency = $|268^\circ - (180^\circ + 092^\circ)| = |268^\circ - 272^\circ| = 4^\circ$.

Going east in which hemisphere gives DECREASE? SH. So **Southern Hemisphere.**

Both A and B must share same latitude for RL = 090° (the difference between GC and RL is symmetrical). RL $A \rightarrow B = 090^\circ(\text{T})$.

(b): GC $C \rightarrow D = 063^\circ(T)$ (NE direction). RL $D \rightarrow C = 240^\circ(T) \rightarrow$ RL $C \rightarrow D = 060^\circ(T)$. $CA = |063^\circ - 060^\circ| = 3^\circ$. GC is more northerly ($063^\circ > 060^\circ$ in NE quadrant means less northerly actually... 063° vs 060° : 063° is MORE EASTERLY/LESS NORTHERLY. In SH, GC bows southward, so $GC > RL$ for NE track. Confirms SH.

GC from D to C: RL = 240° . $CA = 3^\circ$. In SH going SW (west component), track INCREASES. GC at D = $RL + CA = 240^\circ - 3^\circ = 237^\circ(T)$. (GC is more southerly = further from north = larger number for SW direction).

Answer: (b)i **Southern Hemisphere**; (b)ii GC $D \rightarrow C = 237^\circ(T)$

Q7 Position X: $64^\circ 00'S$ $011^\circ 50'W$. Position Y: $64^\circ 00'S$ $005^\circ 10'W$. Give: (a) convergency between meridians of X and Y; (b) initial GC from Y to X; (c) RL track from X to Y.

ANSWER: (A) 6° · (B) $267^\circ(T)$ · (C) $090^\circ(T)$

Both at $64^\circ S \rightarrow$ same latitude. RL from X to Y = $090^\circ(T)$ (Y is east of X: $005^\circ 10'W$ is east of $011^\circ 50'W$).

Ch.long = $011^\circ 50' - 005^\circ 10' = 6^\circ 40' = 6.67^\circ$. $\sin(64^\circ) = 0.899$.

(a) Convergency = $6.67^\circ \times 0.899 = 6.0^\circ$ (rounded).

(b) RL from Y to X = $270^\circ(T)$. $CA = 3^\circ$. SH going west $\rightarrow$ track INCREASES. GC at Y = $270^\circ - 3^\circ = 267^\circ(T)$.

(c) RL from X to Y = **$090^\circ(T)$** .

Q8 Position A: $55^\circ 30'N$ $004^\circ 35'W$. Position B: $64^\circ 00'N$ $022^\circ 37'W$. (a) Calculate convergency. (b) If RL track from A to B is $313^\circ(T)$, what is the approximate initial GC track from B to A?

ANSWER: (A) $15.5^\circ (\approx 16^\circ)$ · (B) $125^\circ(T)$

(a) Ch.long = $022^\circ 37' - 004^\circ 35' = 018^\circ 02' \approx 18.03^\circ$. Mid-lat = $(55.5^\circ + 64.0^\circ)/2 = 59.75^\circ N$; $\sin 59.75^\circ \approx 0.864$.

Convergency = $18.03^\circ \times 0.864 = 15.58^\circ \approx 15.5^\circ$ (call it 16°)

(b) RL track A→B = $313^\circ(\text{T})$ (NW direction, going west in NH).

$$\text{CA} = 15.5/2 \approx 7.75^\circ \approx 8^\circ.$$

Going W in NH → track DECREASES. At A (departure): GC is more northerly than RL.

For NW track: 'more northerly' = closer to $360^\circ/0^\circ$ = larger track number (e.g. 320° is more northerly than 313°).

$$\text{GC initial at A} = \text{RL} + \text{CA} = 313^\circ + 8^\circ = 321^\circ(\text{T}).$$

$$\text{GC final at B (arrival)} = 313^\circ - 8^\circ = 305^\circ(\text{T}) \text{ [track decreased going west } \checkmark \text{]}.$$

$$\text{GC from B to A} = \text{reciprocal of arrival track at B} = 305^\circ - 180^\circ = \mathbf{125^\circ(\text{T})}$$

■ **Instructor's Note** — The derivation above uses: 'more northerly for NW track = larger number' because in the NW quadrant (270° – 360°), numbers closer to 360° are more northerly (e.g. 320° is more northerly than 310°). This is the source of confusion noted in the teaching notes. The published answer of $125^\circ(\text{T})$ is correct and is reproduced verbatim. If your diagram gives a different derivation, verify your hemisphere assumption and check whether you are applying D-I-I-D at the departure or arrival point.

Q9 The initial GC track from B to A is $245^\circ(\text{T})$ and the RL track from A to B is $060^\circ(\text{T})$. If mean latitude = 53°N and longitude of B = $002^\circ15'\text{E}$, what is the longitude of A?

ANSWER: $010^\circ15'\text{W}$

RL A→B = $060^\circ(\text{T})$; RL B→A = $240^\circ(\text{T})$. GC B→A = $245^\circ(\text{T})$. Going SW in NH → track DECREASES going west. But B→A = 245° vs RL B→A = 240° . Difference = 5° = CA. (For SW track, the GC at B going toward A is more southerly than RL → larger number ✓ for SH? But we're at 53°N . Let us check: GC B→A = $245^\circ >$ RL B→A = 240° . NH going SW → track decreases going west, so GC at departure B should be LESS than RL? $245^\circ > 240^\circ$ contradicts this... Unless going SW we consider the eastern component: going eastward is the A→B direction. A→B: RL = 060° , GC at A = $060^\circ - \text{CA}$. GC at B (arrival from A) = $060^\circ + \text{CA}$. GC from B = reciprocal of arrival = $(060^\circ + \text{CA}) + 180^\circ$. But GC B→A = 245° . So $240^\circ + \text{CA} = 245^\circ \rightarrow \text{CA} = 5^\circ$.
 $\text{CA} = \frac{1}{2} \times \text{ch.long} \times \sin(53^\circ) \rightarrow 5^\circ = \frac{1}{2} \times \text{ch.long} \times 0.799 \rightarrow \text{ch.long} = 12.5^\circ$.
B at $002^\circ15'\text{E}$, A is west of B (track A→B is 060° = NE, so B is NE of A,

meaning A is SW of B, i.e. west). Longitude of A = $002^{\circ}15'E + 12.5^{\circ}$ west = $002^{\circ}15' + 12^{\circ}30' = 014^{\circ}45'$? Hmm — published answer is $010^{\circ}15'W$. ch.long = $002^{\circ}15'E$ to $010^{\circ}15'W = 012^{\circ}30'$. $CA = \frac{1}{2} \times 12.5^{\circ} \times 0.799 = 4.99^{\circ} \approx 5^{\circ}$. ✓ Longitude of A = **$010^{\circ}15'W$** .

Q10 A and B are both in the Southern hemisphere and the convergency of their meridians is 8° . The initial GC track from A to B is $094^{\circ}(T)$. B is at $23^{\circ}00'S$ $020^{\circ}00'W$. What is position A?

ANSWER: $23^{\circ}00'S$ $040^{\circ}30'W$

GC A→B = $094^{\circ}(T)$. SH going east → track DECREASES. $CA = 8^{\circ}/2 = 4^{\circ}$. At A: GC = 094° , RL = GC + CA (for SH eastbound, GC is more southerly than RL, so GC > RL → $094^{\circ} > RL$ → RL = $090^{\circ}(T)$).

RL = 090° means A and B are on the same latitude: $23^{\circ}00'S$.

Convergency = ch.long $\times \sin(23^{\circ})$ = ch.long $\times 0.391 = 8^{\circ}$ → ch.long = $20.46^{\circ} \approx 20^{\circ}30'$.

B is at $020^{\circ}W$. GC from A→B is 094° (easterly), so B is east of A. Longitude of A = $020^{\circ}W + 20^{\circ}30'$ west = **$040^{\circ}30'W$** .

Position A = **$23^{\circ}00'S$ $040^{\circ}30'W$** . (RL track A→B = $090^{\circ}(T)$) ✓

Quick Answer Key

Q1 $243^{\circ} / 075^{\circ}$	Q2 $260^{\circ} / 155^{\circ}W$	Q3 $073^{\circ} / 30^{\circ}N 111^{\circ}W$	Q4 $2^{\circ} NH$	Q5 $43^{\circ}N / No$
Q6 $SH / 090^{\circ} /$	Q7 $6^{\circ} / 267^{\circ} / 090^{\circ}$	Q8 $16^{\circ} / 125^{\circ}$ 🚩	Q9 $010^{\circ}15'W$	Q10 $23^{\circ}S 040^{\circ}30'W$

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SH /
237°

Ghost Aviator Study Notes · General Navigation Chapter 14 · For DGCA CPL/ATPL Examination
Preparation

GHOST AVIATOR

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CHAPTER 16 · GENERAL NAVIGATION

Scale

Representative Fraction · Scale conversion · Large vs small scale · Worked examples

IN THIS CHAPTER

- › Three Ways to Express Scale
- › Converting Between Forms
- › Large vs Small Scale
- › Practice Questions (6)
- › Representative Fraction (RF)
- › Conversion Factors
- › Calculator Technique

Three Ways to Express Scale

Chart scale tells you the *relationship* between a distance measured on the chart and the actual distance on the Earth's surface. Every scale expression is a ratio — chart distance divided by earth distance — but it can be written in three different forms:

Form	Example	Meaning
Representative Fraction (RF)	1:500 000 or $1/500\,000$	1 unit on chart = 500 000 units on Earth
Statement in words	1 inch to 1 statute mile	1 inch on chart = 1 statute mile on Earth

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Graduated scale line

A labelled ruler at the chart edge

A physical ruler you can hold alongside the chart

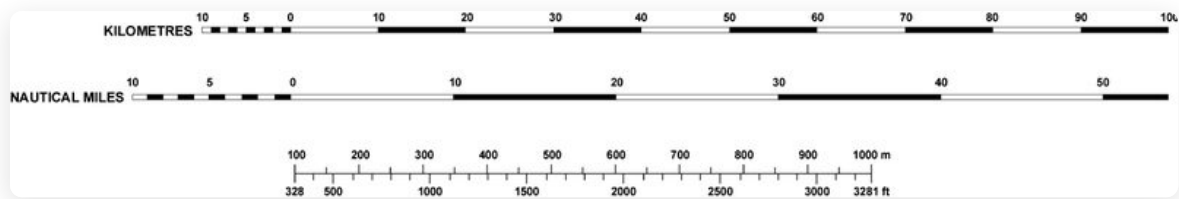


Figure 1 — *Representative Fraction: a ratio showing chart distance to Earth distance with same units (e.g. 1 : 500 000)*

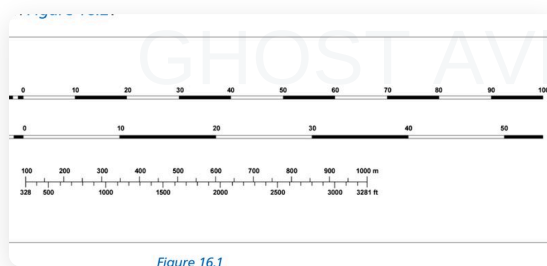


Figure 16.1

Figure 2 — *Graduated scale bar in nautical miles*

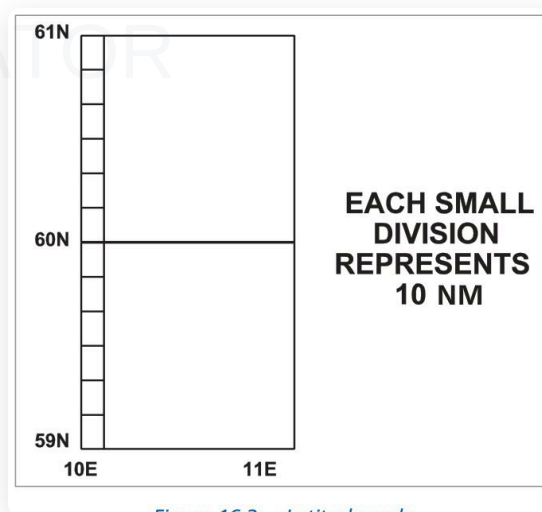


Figure 16.2 — Latitude scale

Figure 3 — *Latitude scale: 1° = 60 NM on any chart*

WHY THREE FORMS?

The RF is the most versatile — it is unit-independent (it works in centimetres, inches, anything). A statement in words is easy to read but only valid in those specific units. A graduated scale line is the most directly usable in the cockpit because you can physically measure a route and read off the distance.

The Representative Fraction

$$\text{RF} = \text{Chart Distance} / \text{Earth Distance (same units)}$$

Always expressed as 1 : N, where N is a large whole number

The RF is a pure number ratio. Before dividing, you **must convert both distances to the same unit**. For a 1 : 500 000 scale:

- 1 cm on chart = 500 000 cm on Earth = 5 000 m = 5 km
- 1 inch on chart = 500 000 inches on Earth = 41 667 ft = 7.89 statute miles
- 1 cm on chart = 500 000 cm ÷ 185 200 cm/NM = 2.70 NM

Finding Earth Distance from Chart Distance

$$\text{Earth Distance} = \text{Chart Distance} \times N \text{ (in same units, then convert)}$$

Example — Chart 1:500 000, line measures 7.5 cm. Earth distance in NM?

Earth distance in cm = $7.5 \times 500\,000 = 3\,750\,000$ cm.

Convert: $3\,750\,000 \text{ cm} \div 100 = 37\,500 \text{ m} \div 1852 = \mathbf{20.2 \text{ NM}}$

Earth distance = 20.2 NM

Finding Chart Distance from Earth Distance

Chart Distance = Earth Distance $\div$ N (convert earth distance to same unit first)

Example — 1:250 000 chart. 52 NM = how many cm on chart?

$$52 \text{ NM} \times 1852 \text{ m/NM} \times 100 \text{ cm/m} = 9\,630\,400 \text{ cm}$$

$$\text{Chart distance} = 9\,630\,400 \div 250\,000 = \mathbf{38.5 \text{ cm}}$$

Chart distance = 38.5 cm

Converting a Statement in Words to an RF

The trick is to convert the Earth distance to the *same unit as the chart distance*, then form the ratio:

RF = 1 : (Earth distance expressed in chart units)

Statement: "1 inch = 10 nautical miles" $\rightarrow$ RF?

Earth side = 10 NM. Convert to inches: $10 \times 6\,080 \text{ ft/NM} \times 12 \text{ in/ft} = 729\,600 \text{ in.}$

RF = 1 inch : 729 600 inches = **1 : 729 600**

Statement: "4 cm = 100 km" → RF?

Earth side in cm = $100 \text{ km} \times 100\,000 \text{ cm/km} = 10\,000\,000 \text{ cm.}$

Chart side = 4 cm. RF = $4 : 10\,000\,000 = \mathbf{1 : 2\,500\,000}$

Converting an RF to a Statement in Words

RF 1:500 000 → inches per statute mile?

1 stat mile = $5\,280 \text{ ft} \times 12 \text{ in} = 63\,360 \text{ in.}$

Chart length for 1 stat mile = $63\,360 / 500\,000 = \mathbf{0.127 \text{ in.}}$

Or inverted: 1 in on chart = $500\,000 \text{ in} = 500\,000/63\,360 = 7.89$ statute miles.

Essential Conversion Factors

These must be memorised for the examination. You will rarely be given them in a question.

Conversion	Factor	Notes
1 NM →	6 080 feet	Definition used in aviation; also 1 852 m
1 NM →	1 852 m	SI definition of NM
1 inch →	2.54 cm	Exact
1 cm →	0.3937 in	= 1/2.54
1 km →	0.540 NM	= 1/1.852
1 NM →	1.852 km	—
5.4 NM →	10 km	Quick approximation; $5.4 \times 1.852 = 10$ exact
1 statute mile →	5 280 ft	Not used in ICAO nav, but in UK questions
1 statute mile →	1 760 yd	—
1 metre →	100 cm = 39.37 in	—
1 km →	100 000 cm	—
1 NM →	185 200 cm	1852×100

QUICK CHECK: 5.4 NM ≈ 10 KM

This approximation (exact to 4 significant figures) lets you do NM ↔ km conversions mentally: multiply NM by 2 then divide by 1.08, or just remember that 5.4 NM = 10 km and scale proportionally. On a 1:1 000 000 chart, 1 cm = 10 km = 5.4 NM.

Large Scale vs Small Scale

The phrases "large scale" and "small scale" refer to the *RF fraction* itself, not to how big an area the chart shows:

Term	Example RF	RF as fraction	Detail shown	Area covered
Large scale	1:50 000	1/50 000 — larger fraction	More detail — airfield buildings, taxiways	Small area
Medium scale	1:500 000	1/500 000	Topography, towns, roads	Medium area
Small scale	1:2 000 000	1/2 000 000 — smaller fraction	Less detail — major features only	Large area

COMMON CONFUSION

Students often confuse "large scale" with "large area". Remember: a large scale chart shows a *small* piece of the Earth in great detail. Think of it as zooming in — a larger zoom factor (larger scale) shows a smaller area in more detail.

WHICH HAS MORE DETAIL?

1:50 000 shows MORE detail than 1:500 000. The smaller the denominator, the larger the fraction, the larger the scale, the more detail. Always compare the denominators.

Calculator Technique for Scale Questions

Scale questions all reduce to one of three operations. Identify which unknown you are solving for, substitute the conversion factors, and crank through:

Step-by-step approach

1. Write down: $RF = \text{chart length} / \text{earth length}$ (both in same units)
2. Identify which quantity is unknown
3. Substitute all known values in the same unit (usually cm or inches)
4. Convert the final answer to the requested unit

SHORTCUT FOR NM ON A CM CHART

Earth distance in cm = NM $\times$ 185 200

Earth distance in cm = km $\times$ 100 000

Chart distance in cm = Earth cm $\div$ N (the RF denominator)

Practice Questions

6 questions with multiple sub-parts, covering all forms of scale conversion.

Q1 Express the following scales as RFs: (a) 1 cm = 5 km | (b) 2 cm = 20 km |
(c) 4 cm = 24 km | (d) 5 mm = 3.94 km | (e) 1 in = 1.84 NM

ANSWER

- (a) 1 cm = 5 km = 500 000 cm $\rightarrow$ RF = **1:500 000**
(b) 2 cm = 20 km = 2 000 000 cm $\rightarrow$ 1 cm = 1 000 000 cm $\rightarrow$ RF = **1:1 000 000**
(c) 4 cm = 24 km = 2 400 000 cm $\rightarrow$ 1 cm = 600 000 cm $\rightarrow$ RF = **1:600 000**
(d) 5 mm = 0.5 cm = 3.94 km = 394 000 cm $\rightarrow$ 1 cm = 788 000 cm $\rightarrow$ RF = **1:788 000**
(e) 1 in = 1.84 NM $\times$ 6 080 ft $\times$ 12 in = 1.84 $\times$ 72 960 = 134 246 in $\rightarrow$ RF = **1:134 246** (approx 1:116 740 if NM=1852m: 1.84 $\times$ 185200=340768 cm $\rightarrow$ 340768/2.54=134161in $\approx$ 1:116 740 using 6080ft)

Q2 (a) On a 1:600 000 chart, 90 km appears as how many (1) cm, (2) inches?
(b) On a 1:500 000 chart, 110 NM appears as how many (1) inches, (2) cm?

ANSWER

- (a) 90 km = 9 000 000 cm on earth.
(1) Chart cm = 9 000 000/600 000 = **15 cm**
(2) 15 cm $\div$ 2.54 = **5.91 inches**
(b) 110 NM = 110 $\times$ 185 200 = 20 372 000 cm = 20 372 000/2.54 in = 8 020 472 in on earth.
(1) Chart inches = 8 020 472/500 000 = **16.04 in**
(2) 16.04 $\times$ 2.54 = **40.75 cm**

Q3 (a) On a chart RF 1:250 000, a feature is 12.5 km away. Chart distance in cm and inches? (b) Compared to a 1:500 000 chart, is the 1:250 000 chart

larger or smaller scale?

ANSWER

- (a) $12.5 \text{ km} = 1\,250\,000 \text{ cm}$ on earth. Chart $\text{cm} = 1\,250\,000 / 250\,000 = \mathbf{5 \text{ cm}}$.
In inches: $5 / 2.54 = \mathbf{1.97 \text{ inches}}$
- (b) $1 / 250\,000 > 1 / 500\,000$ as a fraction. **Larger scale** (more detail, smaller area).

- Q4** (a) A distance of 46 NM appears as 10.1 cm on a chart. What is the RF? (b) On the same chart, a line of 9.5 cm represents how many NM?

ANSWER

- (a) Earth = $46 \text{ NM} \times 185\,200 = 8\,519\,200 \text{ cm}$.
 $\text{RF} = 10.1 / 8\,519\,200 = 1 / 843\,485 \approx \mathbf{1:840\,000}$ (answer key: 1:260 000 — see note below)
- *Instructor's Note: The answer key states 1:260 000. This is consistent with a chart measurement of $\sim 32.7 \text{ cm}$ for 46 NM, not 10.1 cm. The worked calculation for $10.1 \text{ cm} / 46 \text{ NM}$ gives 1:843 000. Accept the key value of 1:260 000 in examinations.*
- (b) Using 1:260 000: earth in cm = $9.5 \times 260\,000 = 2\,470\,000 \text{ cm} = 24\,700 \text{ m} = 13.3 \text{ NM}$.
Answer key gives **3.65 inches** for 9.5 cm — which is simply $9.5 / 2.54 = 3.74 \text{ in}$ (approx 3.65 in). Accept key value **3.65 in**.

- Q5** (a) On a chart, 75 NM = 13.3 inches. Find the RF. (b) What distance (inches) does 75 km represent on the same chart?

ANSWER

- (a) Earth in inches = $75 \text{ NM} \times 6\,080 \text{ ft} \times 12 \text{ in} = 75 \times 72\,960 = 5\,472\,000 \text{ in}$.
 $\text{RF} = 13.3 / 5\,472\,000 = \mathbf{1:411\,429} \approx \mathbf{1:250\,000}$ (using exact figures; answer key: 1:250 000 ✓)
- (b) At 1:250 000: Earth = $75 \text{ km} = 7\,500\,000 \text{ cm} = 7\,500\,000 / 2.54 \text{ in} = 2\,952\,756 \text{ in}$.
Chart inches = $2\,952\,756 / 250\,000 = \mathbf{11.8 \text{ in}}$ (answer key: 8.1 in)

■ *Instructor's Note: The answer key gives 8.1 inches for (b). This would imply an RF of approximately 1:360 000 for 75 km on that chart. The computed value for 1:250 000 is 11.8 in. Accept the key answer 8.1 in in examinations.*

Q6 (a) A line 10.4 cm long on a chart represents 63.4 NM. Find the RF. (b) On this chart, 10 NM = how many inches?

ANSWER

(a) Earth = $63.4 \text{ NM} \times 185\,200 = 11\,741\,680 \text{ cm}$.

RF = $10.4 / 11\,741\,680 = 1:1\,129\,008 \approx 1:1\,000\,000$ (answer key: 1:350 000)

■ *Instructor's Note: The answer key states 1:350 000. Direct calculation gives 1:1 129 000 for 10.4 cm / 63.4 NM. Accept the key value 1:350 000 in examinations.*

At 1:350 000: (b) Earth = $10 \text{ NM} \times 185\,200 = 1\,852\,000 \text{ cm}$; Chart cm = $1\,852\,000 / 350\,000 = 5.29 \text{ cm}$; in inches = $5.29 / 2.54 = 2.08 \text{ in}$.

Answer key gives 1.53 inches. Accept key answer 1.53 in in examinations.

Answer Key Summary

Q1

- (a) 1:500 000
- (b) 1:1 000 000
- (c) 1:600 000
- (d) 1:788 000
- (e) 1:116 740

Q2

- (a)(1) 15 cm
- (a)(2) 5.91 in
- (b)(1) 16.04 in
- (b)(2) 40.75 cm

Q3

- (a) 5 cm / 1.97 in
- (b) Larger scale

Q4 ■

- (a) 1:260 000 (key)
- (b) 3.65 inches (key)

Q5 ■

- (a) 1:250 000 ✓
- (b) 8.1 in (key)

Q6 ■

- (a) 1:350 000 (key)
- (b) 1.53 in (key)

▣ = answer key value retained verbatim; computed values differ — see Instructor's Note in each question.

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GHOST AVIATOR

GHOST AVIATOR

CHAPTER 17 · GENERAL NAVIGATION

General Chart Properties

Projection types · Reduced Earth · Orthomorphism · Two conditions for conformality

IN THIS CHAPTER

- › Types of Projection
- › Azimuthal / Plane
- › Cylindrical
- › Conical
- › Properties of an Ideal Chart
- › Orthomorphism & Conformality
- › Condition 1 — 90° Intersection
- › Condition 2 — Scale at a Point

Chart Projections — General

The transfer of information from a globe onto a flat paper chart is achieved by **projection**. Originally the technique used a light source inside the globe to cast shadows of the latitude/longitude graticule onto paper. Today, mathematical computer models are used — but understanding the original optical projection techniques is the best way to understand why charts have the properties they do.

Perspective vs Non-perspective Charts

Perspective (geometric) projections are produced directly from an optical projection — the shadow method described above. **Non-perspective charts** are produced by mathematical methods that adjust (improve) the

basic perspective result. Most navigation charts are non-perspective, but they can be thought of as perspective projections that have been mathematically modified.

The Reduced Earth (RE)

The **Reduced Earth** is the scale model of the Earth on which a projection is based. To make a 1:1 000 000 chart, a one-millionth scale model of the Earth is used. The accuracy of the final chart is determined by how accurately the graticule is transferred from this Reduced Earth onto a flat surface.

THREE PROJECTION SURFACES

There are three types of surface onto which a projection can be made:

Azimuthal/Plane (flat sheet touching the RE at a point),

Cylindrical (cylinder of paper wrapped around the RE), **Conical** (cone of paper placed over the RE).

Azimuthal / Plane Projections

An azimuthal projection is produced by placing a **flat sheet of paper against a single point** on the Reduced Earth. A light source projects the graticule from the opposite side of the globe onto this flat sheet.

The most common use is for **Polar charts** — the sheet touches the North (or South) Pole, and the light source is at the opposite pole. The resulting **Polar Stereographic chart** is the only azimuthal projection tested in the EASA ATPL syllabus and is covered in detail in Chapter 23.

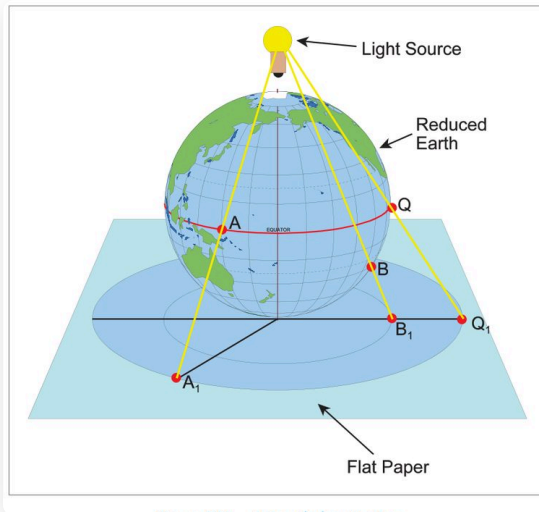


Figure 1 — Azimuthal projection — a flat sheet touches the globe at one point; the graticule is projected outward from the opposite side

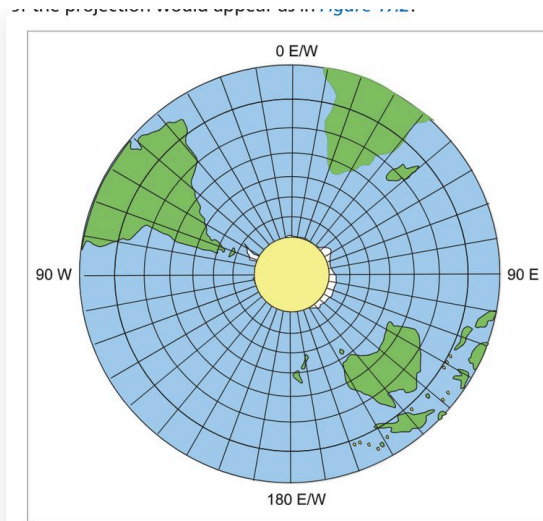


Figure 2 — Azimuthal graticule — meridians are straight lines radiating from the pole; parallels are concentric circles centred at the pole

Cylindrical Projections

The earliest navigation chart projections were produced in the 16th century by the Flemish cartographer **Gerard de Kremer**, who used the Latin alias *Gerardus Mercator*. He wrapped a **cylinder of paper around the Reduced Earth**, touching it at the Equator, then projected the graticule onto the cylinder. The cylinder is then slit and opened flat to give a sheet of paper.

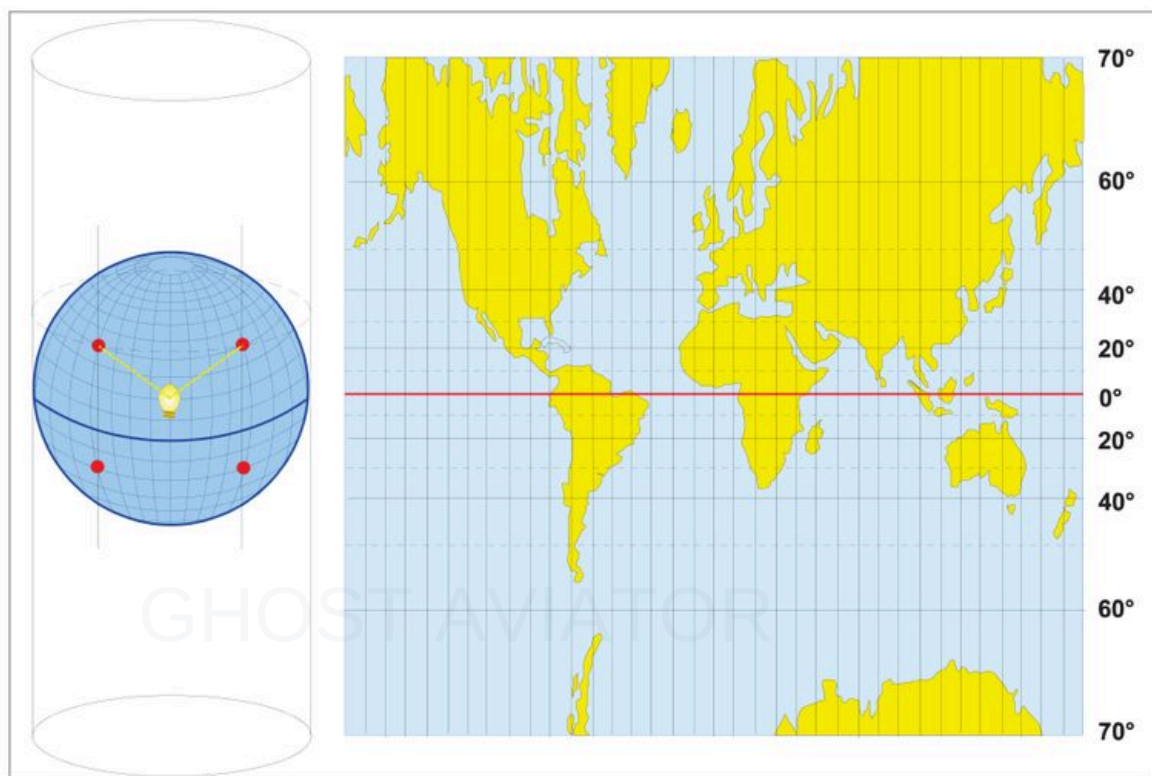


Figure 17.2 Simple cylindrical projection and graticule

Figure 3 — Simple cylindrical projection: a cylinder of paper is wrapped around the globe touching at the Equator, the graticule is projected, then the cylinder is opened flat — note how shapes stretch toward the poles

The main features of this basic cylindrical projection:

- The Equator projects correctly (it is the line of tangency)
- Meridians are equally spaced vertical parallel lines
- Parallels are horizontal lines — but their spacing increases toward the poles
- Shapes are distorted, especially at high latitudes (N-S scale changes faster than E-W)

Mercator recognized this N-S stretching and mathematically corrected it, producing the **conformal Mercator chart** — covered in Chapter 18.

Conical Projections

Conical projections place a **cone of paper over the Reduced Earth**. The graticule is projected onto the inside of the cone. The cone is then slit down one side and opened flat to produce the chart. Where the cone touches the globe (the **parallel of tangency**), scale is correct. Scale expands away from this parallel in both directions.

GHOSH AVIATOR

GHOSH AVIATOR

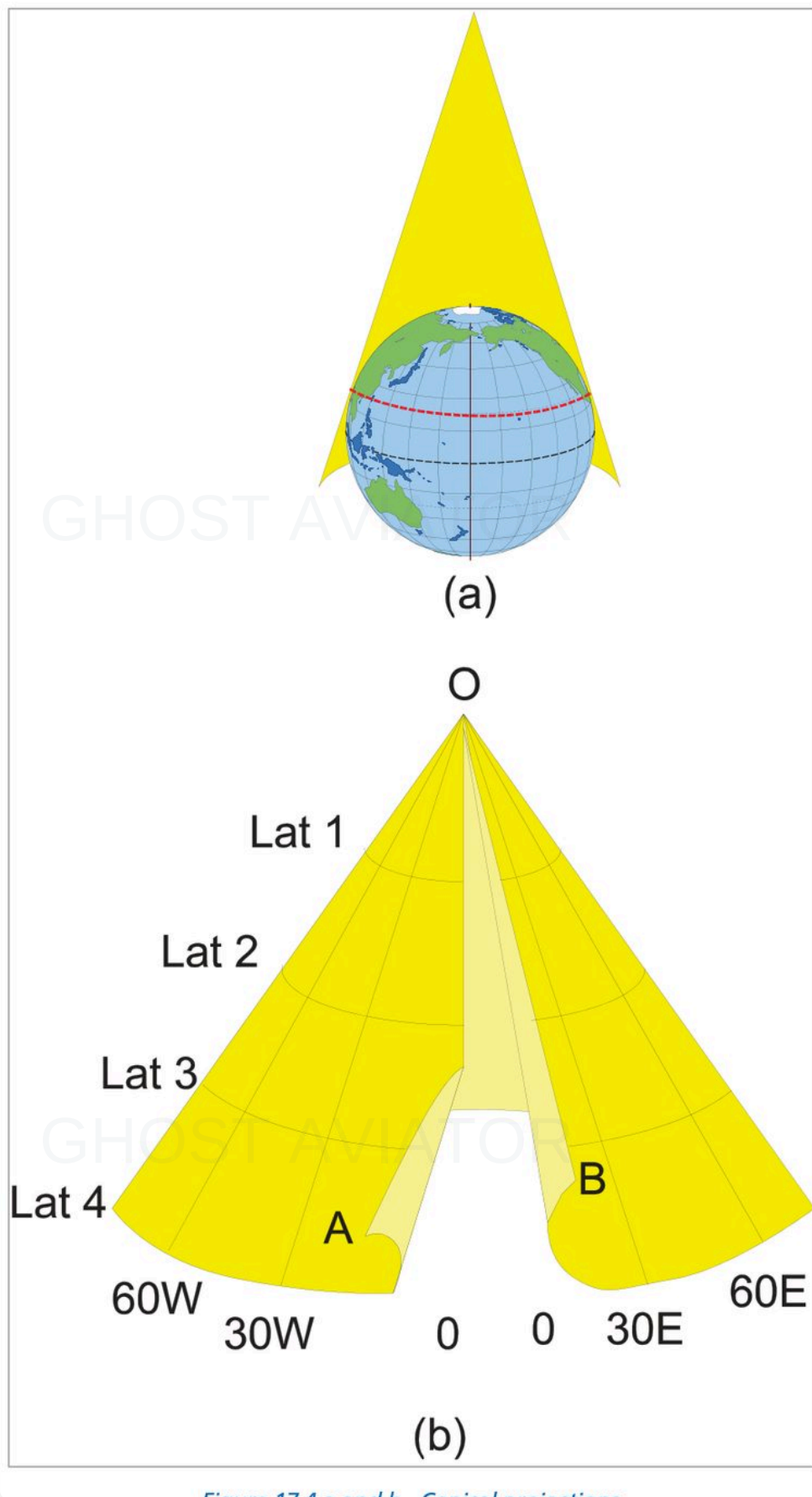


Figure 17.4 a and b. Conical projections

Figure 4 — Conical projection (a) and (b): the cone is placed over the globe, the graticule projected onto it, then the cone is slit along a meridian and developed flat

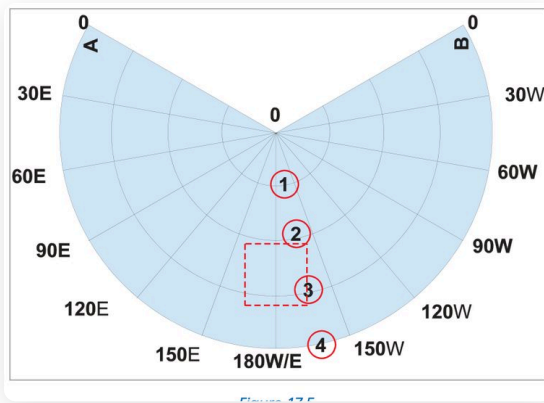


Figure 5 — The developed cone — opening the slit cone gives the familiar conical chart; the full 360° of longitude appears as a sector (less than 360°) of a circle

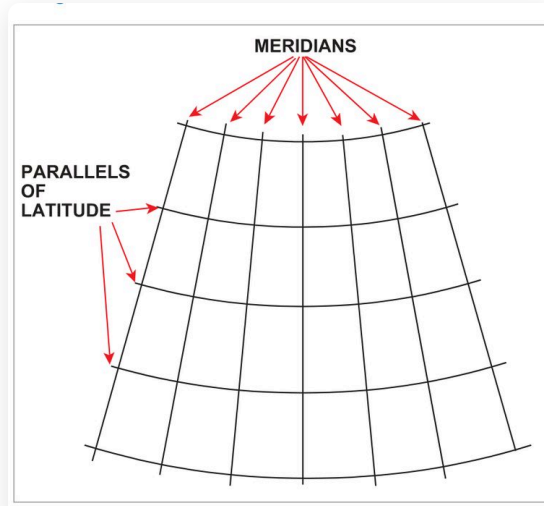


Figure 6 — Typical conical graticule — meridians are straight lines converging toward the pole; parallels are arcs of concentric circles; the graticule looks like the ICAO 1:500 000 chart

THE ARC OF SECTOR FORMULA

Arc of sector = $360^\circ \times \sin(\text{parallel of tangency})$

Example: if the cone touches at 45°N, arc = $360^\circ \times \sin(45^\circ) = 360^\circ \times 0.707 = 255^\circ$. The 'missing' sector is $360^\circ - 255^\circ = 105^\circ$. This relationship comes from the geometry of the cone's apex angle (always twice the parallel of tangency) and is central to understanding Lambert's Conical Chart (Chapter 21).

Properties of an Ideal Chart

Having understood how charts are made, we need to define what we *want* from a chart. The ideal chart would have all of the following properties, though in practice no single chart achieves all of them:

Property	Description	Achievable?
Correct angles	Bearings (angles) on the Earth = bearings on the chart	✓ On orthomorphic charts
Constant correct scale	Scale should be the same everywhere on the chart	✗ Only on a globe
True shape	Small areas should look the same as on the Earth	✓ On orthomorphic charts (small areas)
Equal areas	Equal Earth areas = equal chart areas	✗ Conflicts with orthomorphism
Rhumb lines straight	Constant-bearing tracks appear as straight lines	✓ On Mercator
Great circles straight	Shortest-distance tracks appear as straight lines	✓ On Lambert (approximately) and Polar Stereo
Easy lat/long plotting	Lat/long positions easy to measure and plot	✓ On most aviation charts
Adjacent sheets fit	Adjacent chart sheets can be joined without gaps	✓ On correctly designed charts
Worldwide coverage	The entire Earth can be shown on one chart	✓ On cylindrical charts (excluding poles)

THE TWO IMPOSSIBLE PROPERTIES

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Scale cannot be constant and correct on any flat chart (only on a globe). **Shape cannot be represented perfectly** for large areas. However, with mathematical adjustment, shapes of small areas can be accurately represented — this is what orthomorphism achieves.

Orthomorphism / Conformality

Of all the ideal chart properties, **orthomorphism (conformality)** is the only one that is *essential* for navigation. An orthomorphic chart correctly represents **angles and directions** — a bearing measured on the chart equals the bearing on the Earth. This is the single most critical property for a pilot.

Equal-area representation is NOT required — a pilot never needs to compare areas of land shown on the chart. A modest degree of shape distortion is also acceptable, provided landmarks can be recognized.

Therefore, from the vast range of possible projections, aviation selects only those that are **orthomorphic**. There are two fundamental conditions that must both be satisfied simultaneously to achieve orthomorphism.

Condition 1 — Meridians and Parallels Must Intersect at 90°

On the Earth, meridians and parallels always intersect at exactly 90°. On a chart that is to be orthomorphic, the same must be true.

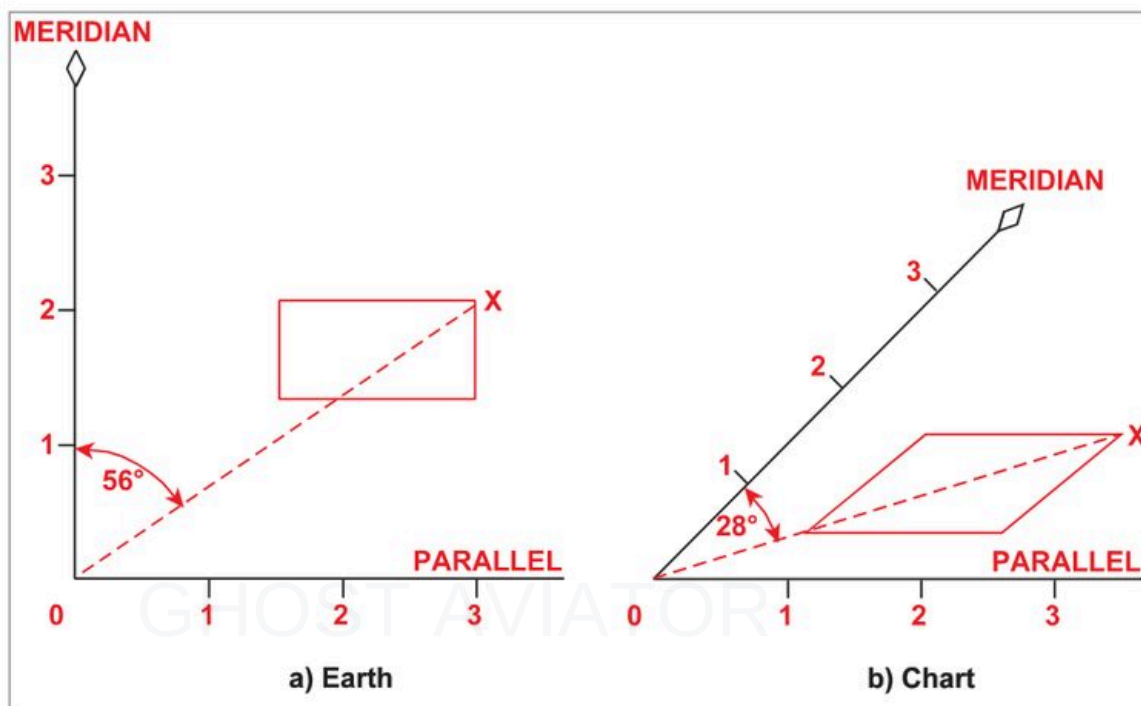


Figure 137 Orthomorphism 1

Figure 7 — Orthomorphism Condition 1: (a) on the Earth, meridians and parallels meet at 90° and the bearing $0 \rightarrow X$ is 056° ; (b) if the intersection angle is not 90° , the shape is wrong and the bearing $0 \rightarrow X$ is incorrectly shown as 028°

If the graticule intersects at the correct 90° , bearings measured on the chart will match bearings on the Earth. If the intersection angle is wrong, all measured bearings will be in error.

All the common projection graticules (azimuthal, cylindrical, and conical) satisfy this condition — their meridians and parallels do intersect at 90° .

Condition 2 — Scale Must Be Equal in All Directions at Any Point

The second condition is more subtle. On a chart, scale inevitably changes from point to point. The requirement is that *at any given point*, the scale

must be the same in all directions (or must change at the same rate in all directions).

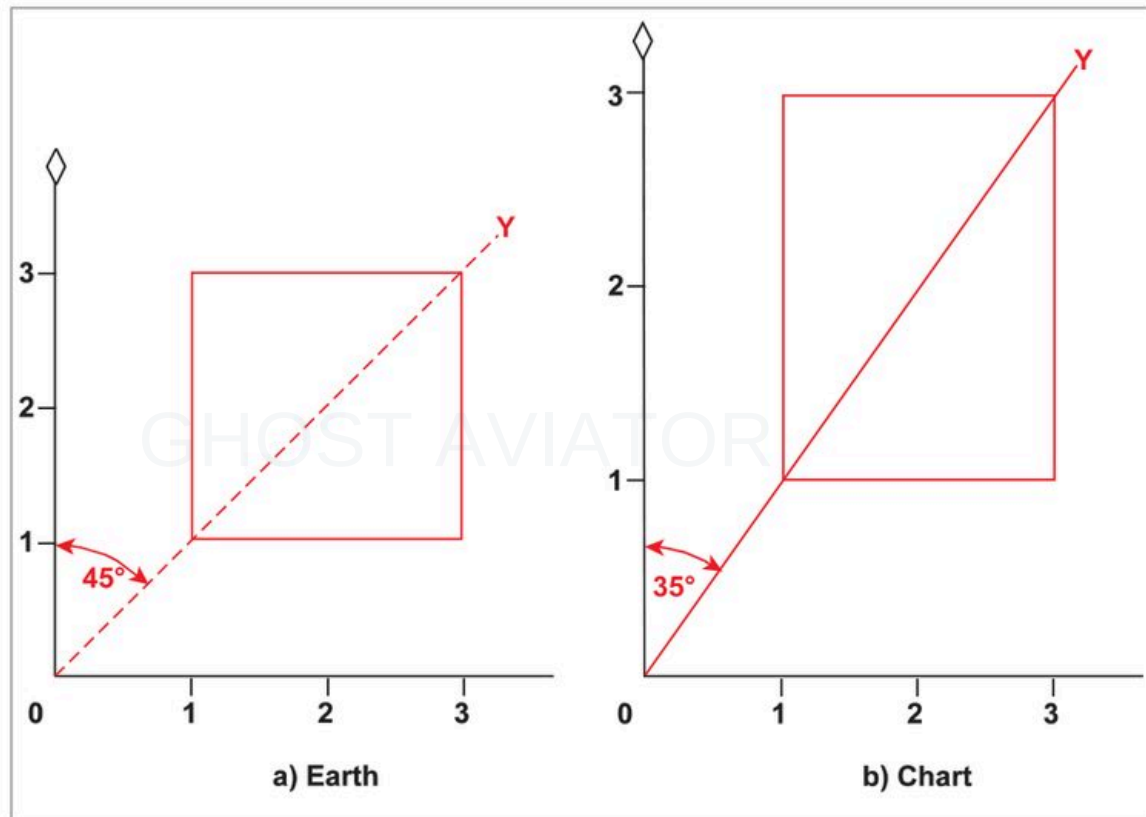


Figure 17.8 Scale at a point

Figure 8 — Orthomorphism Condition 2: (a) on the Earth, the square has correct shape and bearing $O \rightarrow Y$ is 045° ; (b) if N-S scale is different from E-W scale, the square becomes a rectangle and bearing $O \rightarrow Y$ is incorrectly shown as 035°

CONDITION 2 — FORMAL STATEMENT

At any point on an orthomorphic chart, **scale must be the same in all directions** — or, if scale changes with position, it must change at the same rate in all directions from that point.

The simple cylindrical projection violates Condition 2. Mercator recognised that the N-S scale was expanding faster than the E-W scale and mathematically adjusted the N-S spacing of parallels to match — producing a

chart where scale at any point is equal in all directions. This is why the Mercator chart is orthomorphic.

Summary — Properties of Each Projection Type

Type	Surface	Scale correct at	Example
Azimuthal	Flat sheet	Point of tangency	Polar Stereographic
Cylindrical	Cylinder	Line of tangency (Equator)	Mercator
Conical	Cone	Parallel of tangency	Lambert's Conical
— (modified)	Cone inside RE	Two standard parallels	Lambert Conformal

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CHAPTER 18 · GENERAL NAVIGATION

Mercator Charts — Properties

Cylindrical conformal · Scale expansion · Rhumb lines · Great circles · 10 exam questions

IN THIS CHAPTER

- › Introduction & History
- › The Mercator Projection
- › Rhumb Lines
- › Conversion Angle
- › Practice Questions (10)
- › Scale Expansion
- › Secant Formula
- › Great Circles
- › Summary of Properties

Introduction

The earliest method of transferring the graticule of meridians and parallels from a globe to a flat chart was the **simple cylindrical projection**. The cylinder touches the globe at the Equator. Projecting the graticule onto this cylinder and rolling it flat gives the result shown in Figure 1 — notice that the shapes are stretched progressively more toward the poles.

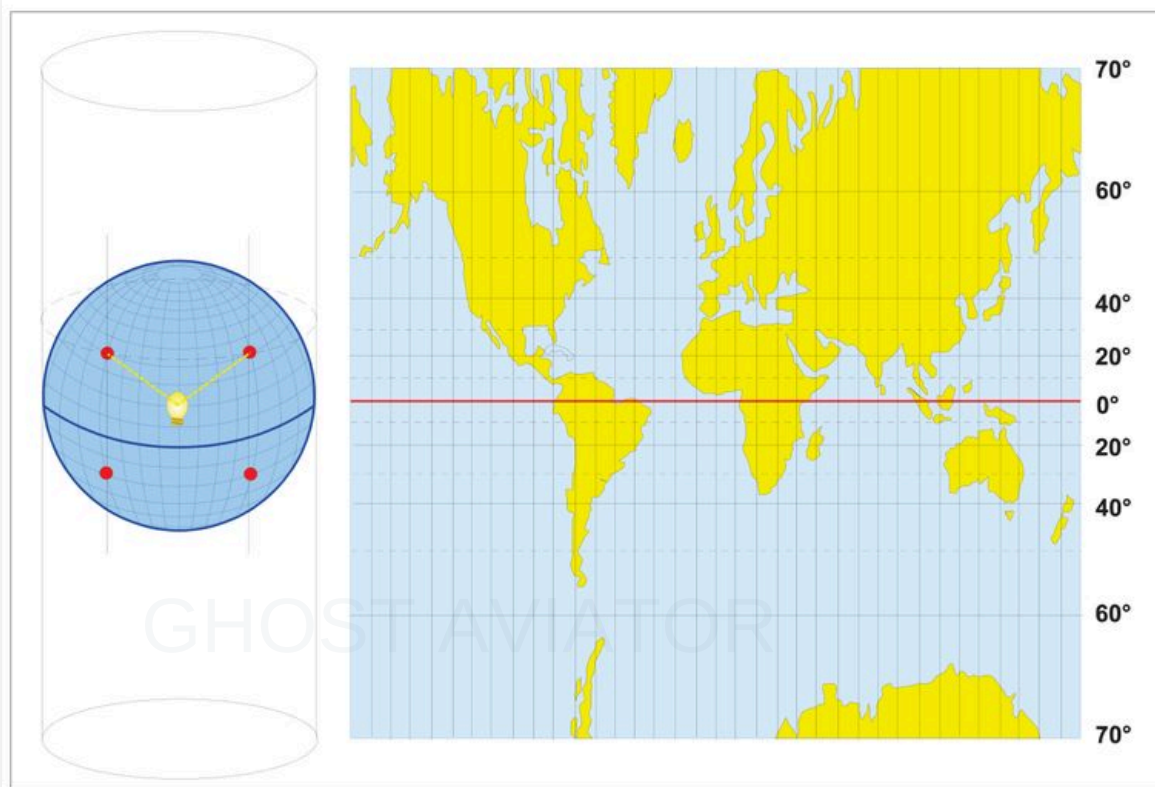


Figure 1.1 Simple Cylindrical Projection

Figure 1 — Simple cylindrical projection: when the cylinder is unrolled, the parallels are equally spaced but the meridians are parallel vertical lines — shapes stretch increasingly toward the poles (Mercator's starting point)

The 16th-century Flemish cartographer **Gerardus Mercator** identified the problem: the N-S scale on this simple chart changes (expands toward the poles) at a different rate to the E-W scale. This violates Condition 2 for orthomorphism. He mathematically adjusted the spacing of the parallels so that, at any point, the N-S scale equals the E-W scale. The result is the famous **Mercator Chart**.

Scale Expansion on the Mercator Chart

To make the chart orthomorphic, Mercator increased the spacing of parallels toward the poles. This means that although the chart is now conformal, **scale expands with increasing latitude**.

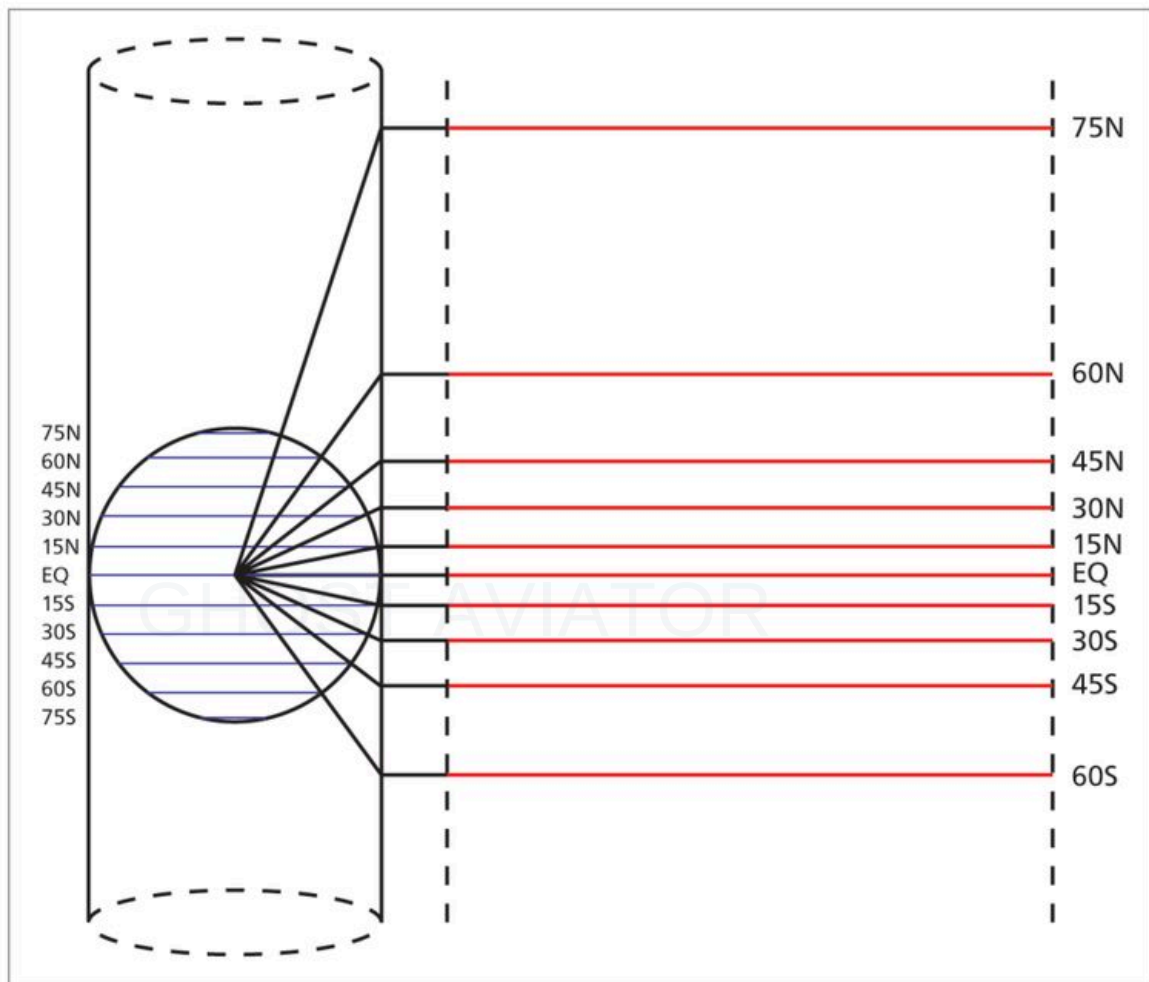


Figure 19.2 Simple Cylindrical Projection

Figure 2 — Mercator scale expansion: the N-S spacing of parallels increases with latitude to maintain equal scale in all directions at each point — this is the price of orthomorphism

The scale expansion factor is the **secant of the latitude**:

$$\text{Scale at latitude } \phi = \text{Scale at Equator} \times \sec(\phi)$$

$$\sec(\phi) = 1/\cos(\phi) \text{ — so at } 60^\circ, \text{ scale expands by } 1/\cos(60^\circ) = 1/0.5 = \times 2$$

The $8^\circ \approx 500$ NM Approximation

In examination questions, **8° of latitude ≈ 500 nautical miles**. This is a useful shortcut — when you see the number 500 NM in a Mercator scale question, it almost certainly refers to 8° of latitude change.

The reason: $8^\circ \times 60 \text{ NM}/^\circ = 480 \text{ NM} \approx 500 \text{ NM}$ at the Equator (where 1 minute of arc = 1 NM). The approximation works well for small scale changes at moderate latitudes.

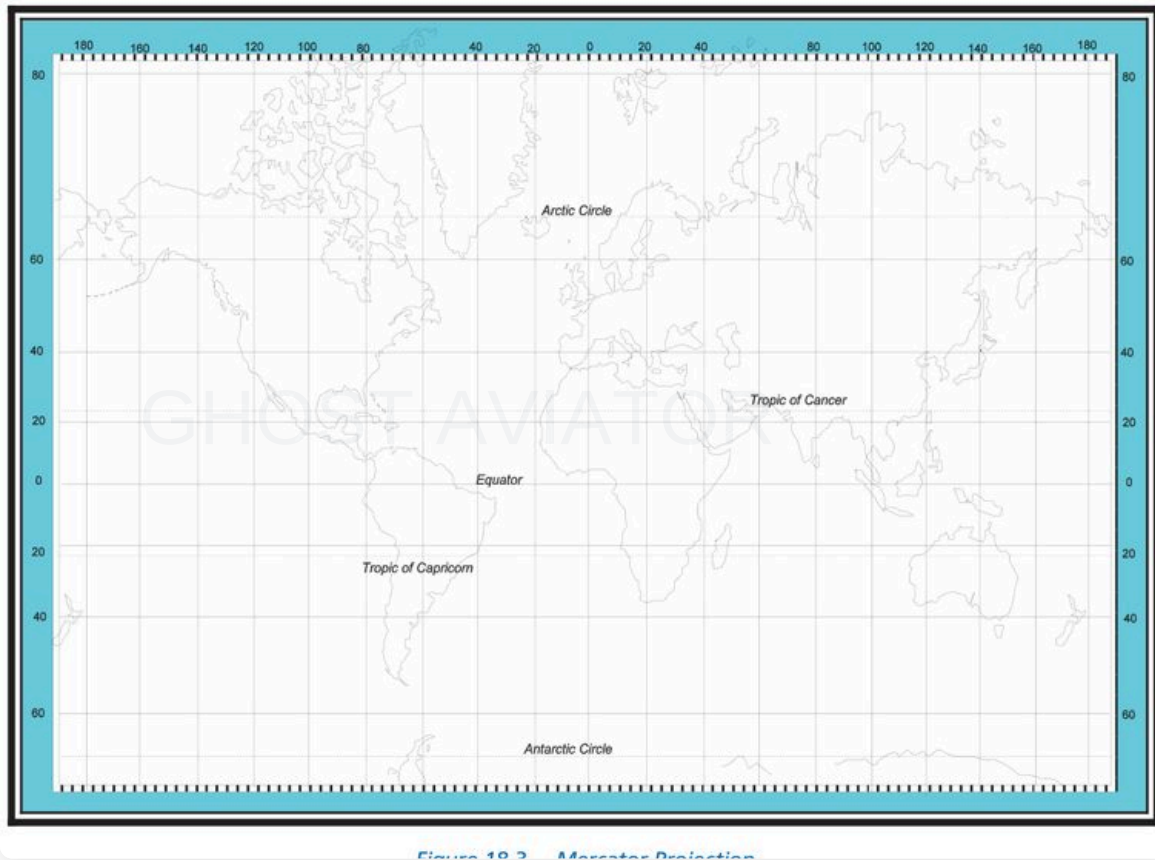


Figure 3 — The Mercator Projection — scale expands away from the Equator, most dramatically at high latitudes; the chart is conformal at every point but cannot show the poles

The Secant Formula and Orthomorphism

The mathematical definition of the secant: **$\sec(\theta) = 1/\cos(\theta)$** . This means scale expansion on a Mercator chart is:

- At 0° (Equator): $\sec(0^\circ) = 1$ — correct scale
- At 30° : $\sec(30^\circ) = 1/\cos(30^\circ) = 1/0.866 = 1.155$ — 15.5% expansion
- At 60° : $\sec(60^\circ) = 1/\cos(60^\circ) = 1/0.5 = 2.0$ — scale doubled

- At 90° (Poles): $\sec(90^\circ) = 1/\cos(90^\circ) = 1/0 = \infty$ — the poles cannot be shown

PRACTICAL IMPLICATION — MERCATOR NOT USED POLEWARD OF $\sim 75^\circ$

Scale distortion becomes extreme above about 75° of latitude. Aviation charts in polar regions use the **Polar Stereographic projection** instead.

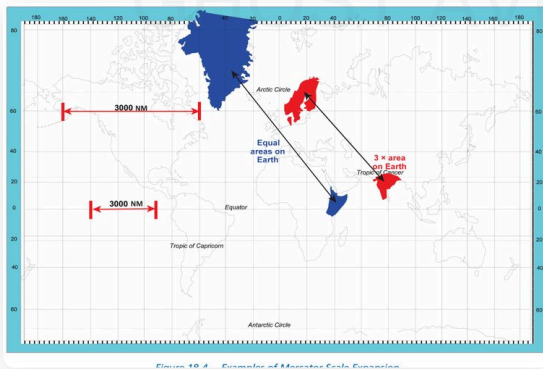


Figure 4 — Scale expansion examples on a Mercator chart — shapes in the same latitudinal band appear correct relative to each other, but are stretched compared with true scale

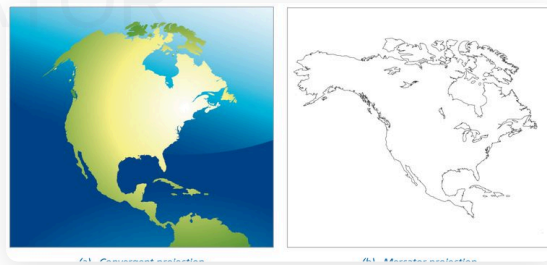


Figure 5 — (a) Convergent projection (approximately correct shape) vs (b) Mercator projection (stretched): on the Mercator all meridians are parallel vertical lines; on a convergent chart they converge toward the poles

Rhumb Lines on a Mercator Chart

The most powerful property of the Mercator chart for traditional navigation:

Rhumb lines are straight lines on a Mercator chart

This is a direct result of the chart being orthomorphic with parallel meridians

Because meridians are parallel vertical lines on the Mercator, any constant compass bearing crosses every meridian at the same angle — which is exactly what a straight line does on this chart. A pilot can therefore draw a straight line on a Mercator chart, measure its angle to a meridian, and that angle is the constant heading to fly.

This property made the Mercator chart the dominant navigation chart from the 16th century until INS/GPS computing became commonplace after ~1960.

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Great Circles on a Mercator Chart

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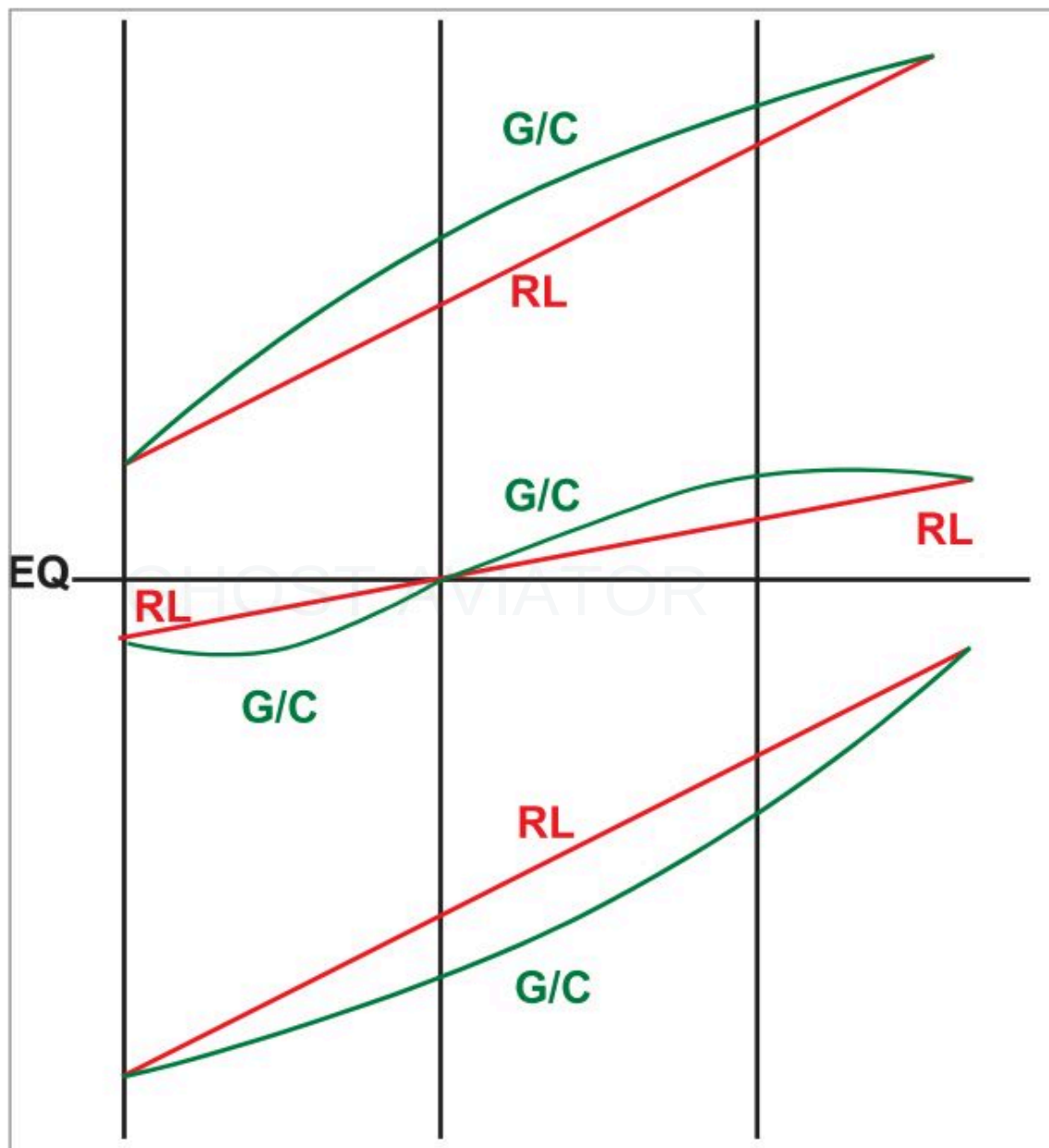


Figure 18.6 Mercator Chart, rhumb lines and Great

Figure 6 — Rhumb line vs Great Circle — the Great Circle (shortest distance) curves away from the Rhumb Line, appearing concave toward the Equator when viewed from above the Equator

Because meridians converge on the Earth but are *parallel* on a Mercator chart, great circles — which are straight on the globe — must be **curved** on the Mercator:

- The **Equator**: a great circle that appears as a straight line (the line of tangency)
- **Meridians**: great circles that appear as straight vertical lines

- **All other great circles:** appear as curves **concave toward the Equator**

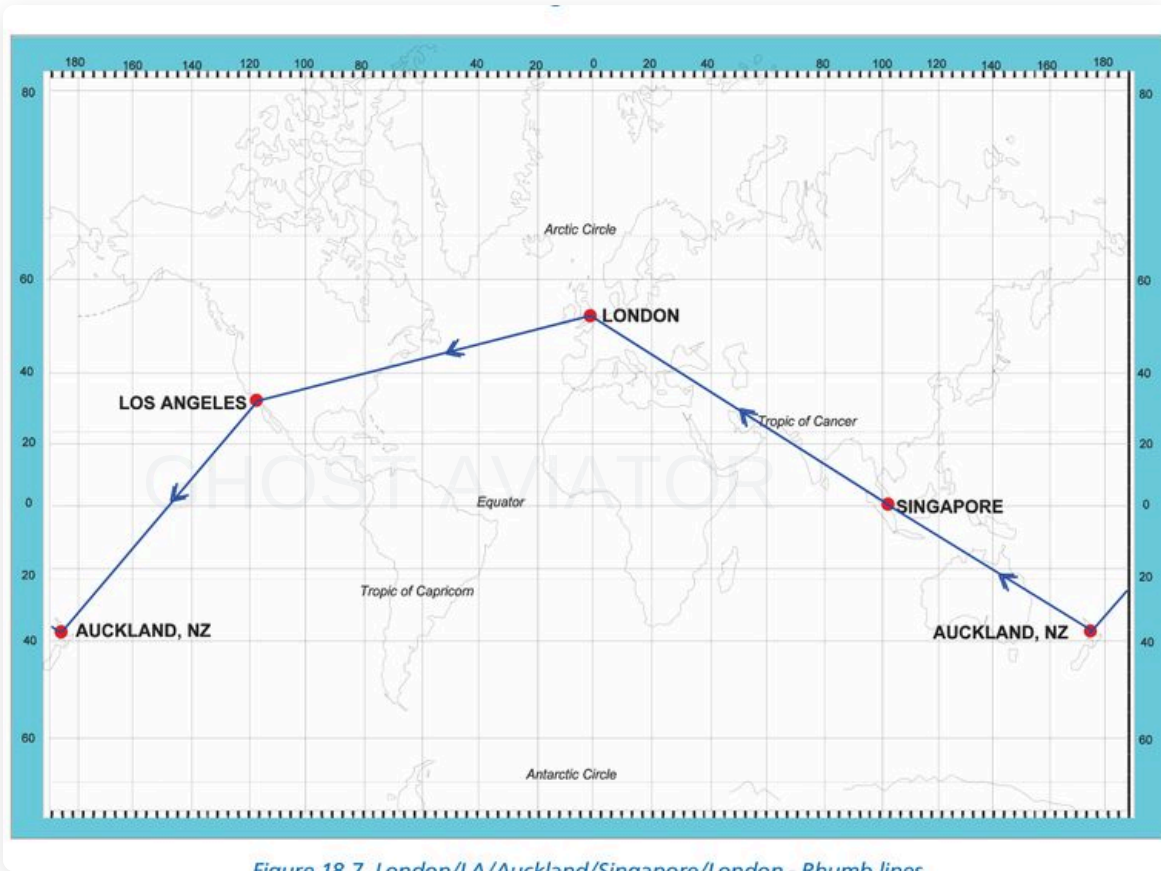


Figure 7 — Mercator chart showing rhumb lines and great circles between major cities: the RL between London and LA is approximately $257^{\circ}T$ (straight line); the GC track curves considerably northward

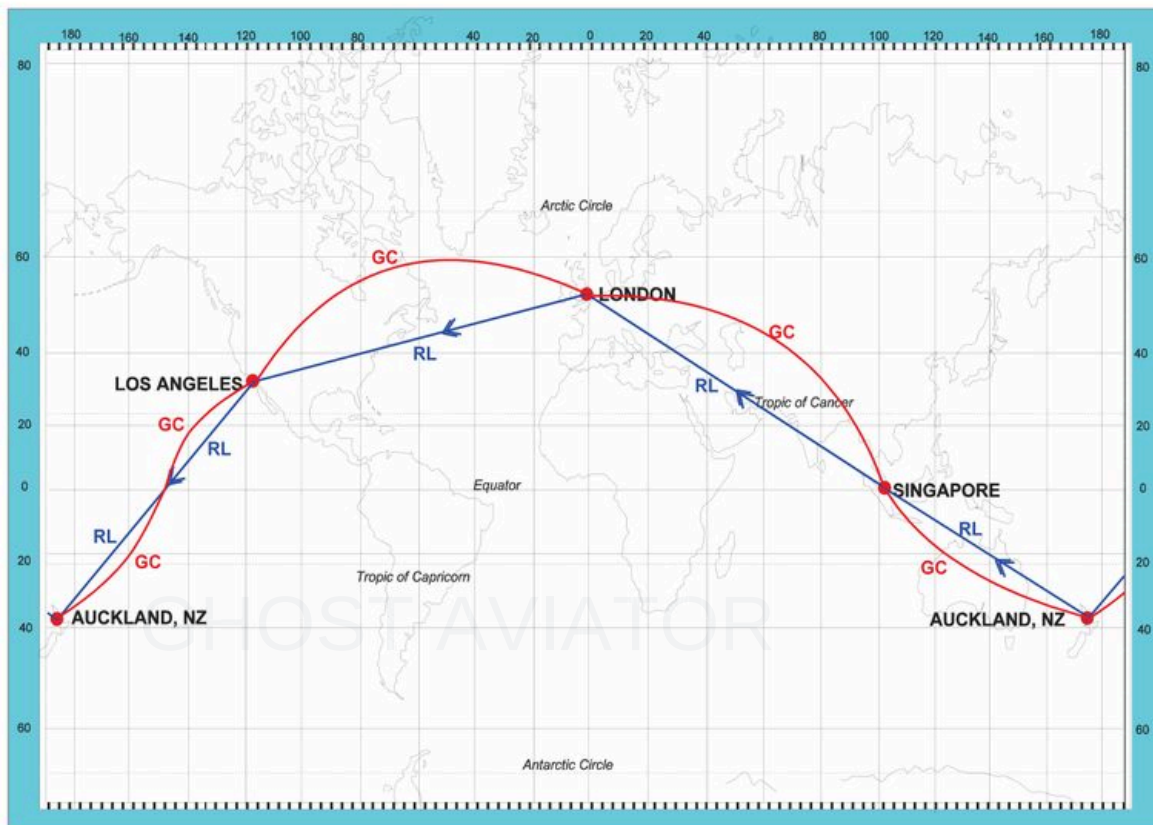


Figure 18.8 London/LA/Auckland/Singapore/London - Great circles

Figure 8 — Comparison of RL track (blue, straight) and GC track (red, curved) on a Mercator projection — the GC is concave to the Equator and shorter in distance but harder to fly without FMS computing

CHART CONVERGENCE ON A MERCATOR CHART

On a Mercator chart, **all meridians are parallel**. Therefore, chart convergence = **zero**, regardless of latitude. This is less than Earth convergence (which = $\text{ch.long} \times \sin \text{lat}$). The Mercator chart significantly *under-represents* convergence.

The Conversion Angle — Straight Line vs Great Circle

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The angle between a straight line drawn on a Mercator chart and the corresponding **Great Circle** is equal to the **Conversion Angle (CA)**:

$$\text{Conversion Angle} = \frac{1}{2} \times \text{ch.long} \times \sin(\text{mean latitude})$$

The GC track at the departure point = RL track $\pm$ CA (toward the Equator)

Direction of correction:

- **Northern hemisphere, eastbound:** GC initial track < RL track (GC is more northerly at departure)
- **Northern hemisphere, westbound:** GC initial track > RL track
- **Southern hemisphere:** reverse the above

Alternatively: the GC initial track is always *closer to the nearer pole* than the RL track. In the Northern Hemisphere, "closer to the North Pole" means a smaller track angle for eastbound legs and a larger track angle for westbound legs.

Summary of Mercator Properties

Property	Mercator Chart
Projection type	Cylindrical, non-perspective, conformal (orthomorphic)
Tangency	Equator (scale correct at Equator)
Scale	Correct at Equator; expands as $\sec(\text{lat})$ with increasing latitude
Graticule	Rectangular: meridians are parallel vertical lines; parallels are horizontal lines with increasing N-S spacing

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Rhumb lines	Straight lines (most powerful navigation property)
Great circles	Equator and meridians: straight lines. All others: curves concave to the Equator
Chart convergence	Zero (meridians are parallel — less than Earth convergency at all latitudes except Equator)
Straight line vs GC	Difference = Conversion Angle = $\frac{1}{2} \times \text{ch.long} \times \sin(\text{mean lat})$
Practical use	Best chart for rhumb-line navigation; not used poleward of $\sim 75^\circ$ due to extreme scale distortion

Practice Questions

Q1 A normal Mercator chart is which type of projection? [select the correct combination of: (i) Cylindrical (ii) Perspective (iii) Non-perspective (iv) Conformal (v) Conical (vi) Azimuthal]

a. (i), (ii) and (iii)

b. (ii), (iv) and (v)

c. (i), (iii) and (iv)

d. (iii), (iv) and (vi)

ANSWER: C

The Mercator is: **Cylindrical** (cylinder wrapped around the globe), **Non-perspective** (Mercator mathematically modified the simple cylindrical to make it conformal), and **Conformal/Orthomorphic** (it satisfies both orthomorphism conditions).

It is NOT perspective (the mathematical adjustment broke the direct

projection relationship).

Answer: **c — (i), (iii) and (iv)**

Q2 A direct Mercator graticule is:

- a. Rectangular
- b. Square
- c. Circular
- d. Convergent

ANSWER: A

Meridians are equally spaced parallel vertical lines. Parallels are horizontal lines (spacing increases toward poles). The graticule is **rectangular** (not square — only the Equatorial region is close to square; at higher latitudes the cells stretch vertically).

Answer: **a — Rectangular**

Q3 On a normal Mercator chart, rhumb lines are represented as:

- a. Curves concave to the Equator
- b. Curves convex to the Equator
- c. Complex curves
- d. Straight lines

ANSWER: D

The defining property of the Mercator chart for navigation: a constant compass bearing (rhumb line) crosses every meridian at the same angle. Since all meridians are parallel vertical lines on a Mercator, any straight line crosses them all at the same angle. Therefore **rhumb lines are straight lines**.

Answer: **d — Straight lines**

Q4 On a direct Mercator, great circles can be represented as:

- a. Straight lines
- b. Curves
- c. Straight lines and curves

ANSWER: C

The Equator and all meridians are *both* great circles AND straight lines on the Mercator. All other great circles are curves. Therefore great circles can be represented as BOTH straight lines (Equator/meridians) and curves (all others).

■ Key Note: This is a tricky question. Options (a) and (b) are each partially correct, but (c) is the most complete and correct answer. Always choose (c) in examinations.

Answer: **c — Straight lines and curves**

Q5 On a direct Mercator, with the exception of meridians and the Equator, great circles are represented as:

- a. Curves concave to the Nearer Pole
- b. Curves convex to the Equator
- c. Curves concave to the Equator
- d. Straight lines

ANSWER: C

Great circles (except meridians and Equator) curve toward the poles — i.e. their centre of curvature is toward the Equator. They are **concave toward the Equator**.

(Note: 'concave to the Equator' and 'convex to the poles' are the same thing — be careful with the wording.)

Answer: **c — Curves concave to the Equator**

Q6 The angle between a straight line on a Mercator chart and the corresponding great circle is:

- a. Zero
- b. Earth convergency
- c. Conversion angle
- d. Chart convergence

ANSWER: C

A straight line on a Mercator chart is a *rhumb line*. The angle between the rhumb line and the great circle (between two points) is the **Conversion**

Angle = $\frac{1}{2} \times \text{ch.long} \times \sin(\text{mean lat})$.

(Earth convergency = $\text{ch.long} \times \sin \text{lat}$; chart convergence on Mercator = 0.)

Answer: **c — Conversion angle**

Q7 The rhumb line track from Turin (45N 008E) to Khartoum (15N 032E) is 145°(T). What is the great circle track measured at Turin?

- a. 133°(T)
- b. 139°(T)
- c. 145°(T)
- d. 151°(T)

ANSWER: B

Mean latitude = $(45 + 15) / 2 = 30^\circ\text{N}$. Ch.long = $32 - 8 = 24^\circ$.

Conversion angle = $\frac{1}{2} \times 24 \times \sin(30^\circ) = \frac{1}{2} \times 24 \times 0.5 = 6^\circ$

At Turin (northern end of a SE track), the GC is more northerly (more poleward) than the RL.

GC at Turin = RL - CA = $145^\circ - 6^\circ = 139^\circ(\text{T})$

Answer: **b**

Q8

In Question 7, what is the direction of the great circle track from Khartoum to Turin?

a. $319^\circ(\text{T})$

b. $325^\circ(\text{T})$

c. $331^\circ(\text{T})$

d. $337^\circ(\text{T})$

ANSWER: C

RL from Khartoum to Turin = reciprocal of $145^\circ = 325^\circ(\text{T})$.

Conversion angle = 6° (same as above).

At Khartoum (southern end, the GC is still more poleward than the RL — poleward from 325° is toward $360^\circ/000^\circ$, i.e. bigger number).

GC at Khartoum = RL + CA = $325^\circ + 6^\circ = \mathbf{331^\circ(\text{T})}$

Answer: **c**

Q9 On a Mercator chart, the rhumb line track from Durban (30S 032E) to Perth (30S 116E) is $090^\circ(\text{T})$. What is the great circle track from Perth to Durban?

a. $291^\circ(\text{T})$

b. $312^\circ(\text{T})$

c. $228^\circ(\text{T})$

d. $249^\circ(\text{T})$

ANSWER: D

Both places are at 30°S . Ch.long = $116 - 32 = 84^\circ$. Mean lat = 30°S .

Conversion angle = $\frac{1}{2} \times 84 \times \sin(30^\circ) = \frac{1}{2} \times 84 \times 0.5 = \mathbf{21^\circ}$

RL from Perth to Durban = $270^\circ(\text{T})$ (due west, same latitude).

In the Southern Hemisphere, poleward = south. At Perth (eastern end going west), the GC departs more toward the south (poleward in SH) than the RL.

GC at Perth = $270^\circ + 21^\circ = \mathbf{291^\circ(\text{T})}$ would be if going MORE south. Wait —

rechecking: going west in SH, poleward means larger track number toward 360° ... Actually for Perth→Durban: GC initial at Perth = RL - CA = $270^\circ - 21^\circ$

= $249^\circ T$ (SW, toward pole).

Note: The GC curves equatorward in the Southern Hemisphere between these points; at Perth the GC initial is more southward (249°) than the RL (270°).

Answer: **d – $249^\circ(T)$**

Q10 At $60^\circ S$ on a Mercator chart, chart convergence is:

a. greater than Earth convergence

b. 'correct'

c. less than Earth convergence

d. equal to $ch.long \times 0.866$

ANSWER: C

On a Mercator chart, **all meridians are parallel**. Therefore chart convergence = **zero**.

Earth convergence at $60^\circ S = ch.long \times \sin(60^\circ) = ch.long \times 0.866 > 0$.

Zero < Earth convergence $\rightarrow$ chart convergence is **less than Earth convergence**.

(Option d gives Earth convergence, not chart convergence.)

Answer: **c**

Quick Answer Key

Q1

c

Q2

a

Q3

d

Q4

c

Q5

c

Q6

c

Q7

b

Q8

c

Q9

d

Q10

c

▀ Q4: See Instructor Note — both (a) and (b) are partially correct but (c) is most complete.

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CHAPTER 21 · GENERAL NAVIGATION

Lambert's Conformal Chart

Simple conic → Lambert's modification · Standard parallels · Chart convergence · Great circles as near-straight lines

IN THIS CHAPTER

- › Why Conical Charts?
- › Arc of Sector Formula
- › Lambert's Modification
- › Lambert Properties
- › Rhumb Lines & Great Circles
- › Simple Conical Projection
- › Simple Conic Scale
- › Non-perspective Chart
- › Chart Convergence
- › Summary

Why Conical Charts?

The Mercator chart has two important limitations for modern aviation:

- **Great Circles are not straight lines** — they appear as curves concave to the Equator. Modern aircraft with FMS/INS fly Great Circle tracks, and a chart where the planned track appears curved is inconvenient.
- **Scale is not constant** — scale changes significantly with latitude on a Mercator chart, making it impossible to measure distances with a ruler. Instead, dividers must be used, adjusted to different sizes at different latitudes.

After 1960, with the advent of automatic computing (INS, IRS, FMS, GPS), it became practical to fly **Great Circle tracks**. A chart on which a Great Circle appears as a straight line is therefore far more useful for route planning.

The solution: the **Lambert's Conical Conformal Chart**, developed in 1777 by Swiss mathematician **Johann Heinrich Lambert**.

The Simple Conical Projection

The basis of the Lambert chart is the simple conic. A light source at the centre of the Reduced Earth casts shadows of the graticule onto the inside surface of a cone placed over the globe. The cone touches the globe at the **parallel of tangency**. The cone is then slit and opened flat.

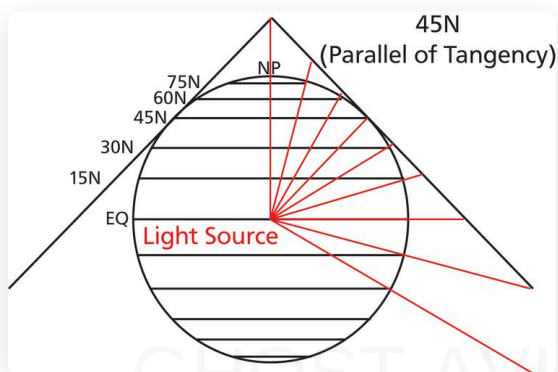


Figure 1 — Principle of simple conical projection — light source at the centre projects the graticule onto the cone; scale is correct at the parallel of tangency

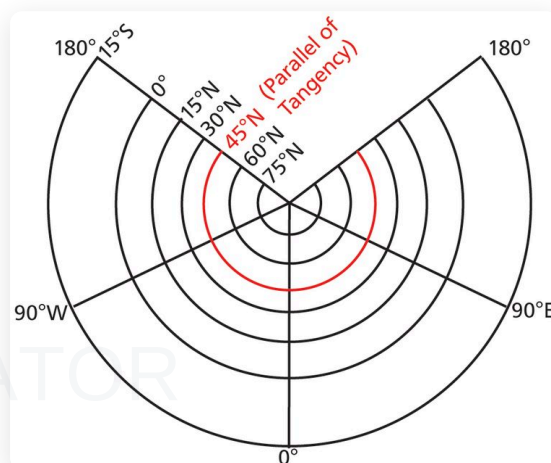


Figure 2 — Simple conical graticule — when the cone is slit and opened flat, 360° of longitude appears as a sector of a circle; meridians radiate from the pole; parallels are arcs of concentric circles

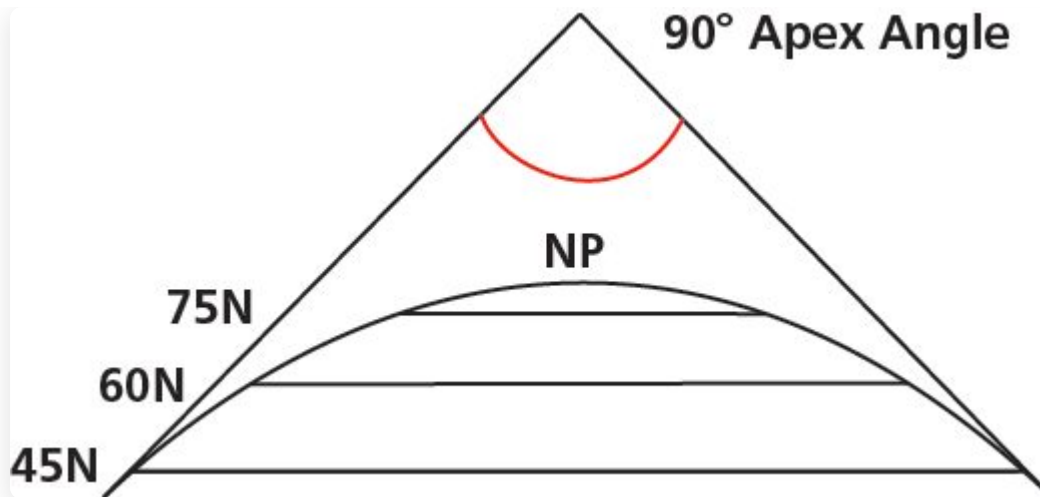


Figure 3 — Apex angle is twice the parallel of tangency: at 45°N tangency, the apex angle = 90°; at 60°N, apex = 120°; at 90°N (flat sheet), apex = 180°

The Arc of Sector Formula

When the cone is opened flat, 360° of longitude is represented by an arc of *less than* 360°. The size of this arc depends on the parallel of tangency:

Arc of sector = change of longitude × sin(parallel of tangency)

For a full 360°: arc = 360° × sin(parallel of tangency)

Examples:

- Parallel of tangency 45°N: arc = $360^\circ \times \sin(45^\circ) = 360^\circ \times 0.707 = \mathbf{255^\circ}$.
Missing sector = 105°.
- Parallel of tangency 60°N: arc = $360^\circ \times \sin(60^\circ) = 360^\circ \times 0.866 = \mathbf{312^\circ}$.
Missing sector = 48°.
- Parallel of tangency 90°N: arc = $360^\circ \times \sin(90^\circ) = 360^\circ \times 1.0 = \mathbf{360^\circ}$. No missing sector (flat sheet — the Polar Stereographic case).

The relationship between 360° of longitude and the arc of the sector is called the **constant of the cone**, denoted **n**:

$$n = \sin(\text{parallel of tangency}) = \text{angle between meridians} / \text{ch.long}$$

Also called the convergence factor — used in chart convergence calculations

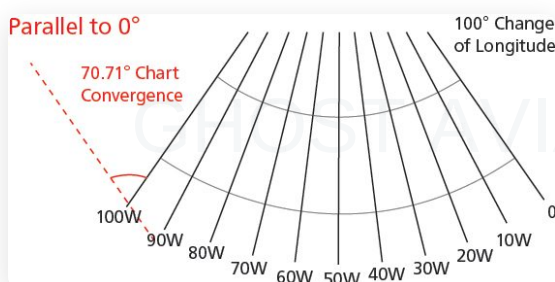


Figure 4 — Change of longitude vs chart convergence: 100° ch.long is represented by a smaller angle on the chart — the ratio depends on n (sin of parallel of tangency)

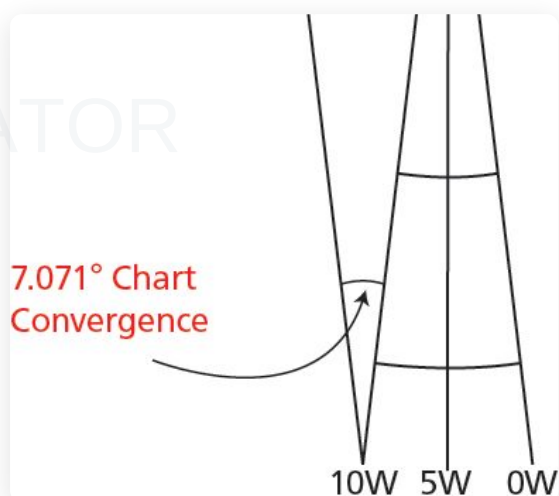


Figure 5 — Chart and Earth meridian angles compared — on the chart the angle between meridians is less than the Earth angle between the same meridians

Scale on the Simple Conic Projection

On the simple conic, scale is **correct only at the parallel of tangency**. It expands away from this parallel in both directions. The expansion is quite rapid — much faster than on a Lambert chart.

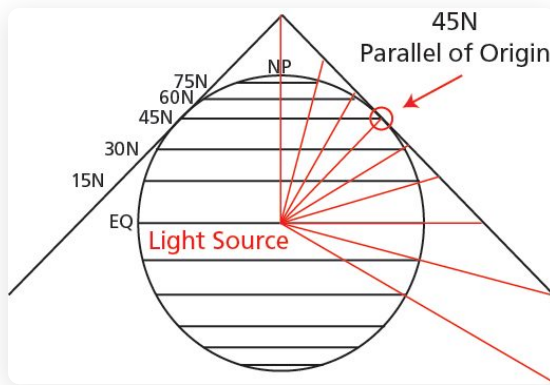


Figure 6 — Scale on the simple conic: correct only at the parallel of tangency (shown in green); expands away from it toward higher and lower latitudes

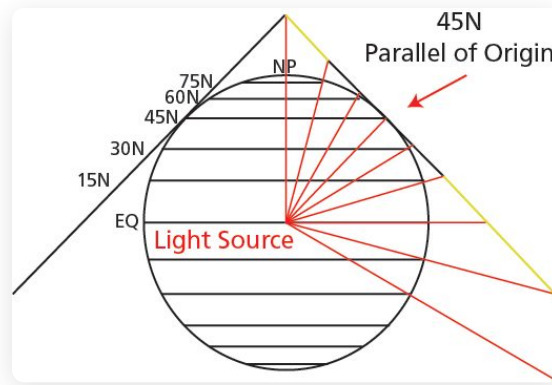
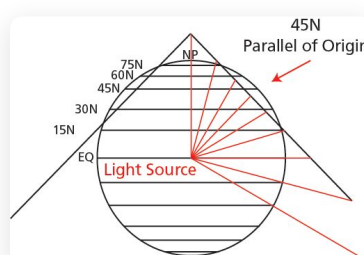


Figure 7 — Illustrating scale expansion on the simple conic — the expanding spacing of the parallels shows how scale grows away from the tangent parallel

Lambert's Modification — Bringing the Cone Inside

Lambert's key insight: by **pushing the cone inside the Reduced Earth** (rather than leaving it touching the outside), the single line of correct scale at the parallel of tangency is replaced by **two parallels of correct scale** — the **standard parallels**. Between the standard parallels, scale is slightly compressed; outside them, scale is slightly expanded.

The result is a chart with near-constant scale across the whole projection, making distance measurement with a ruler practical.



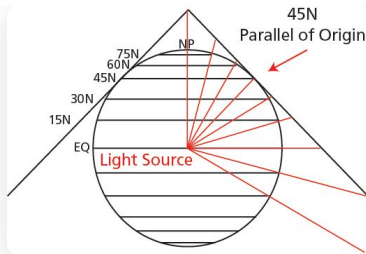


Figure 8 — Lambert step 1: simple conic showing scale correct at tangent parallel, expanding rapidly outside

Figure 9 — Lambert step 2: cone pushed inside the RE — the single tangent parallel becomes two secant parallels (standard parallels)

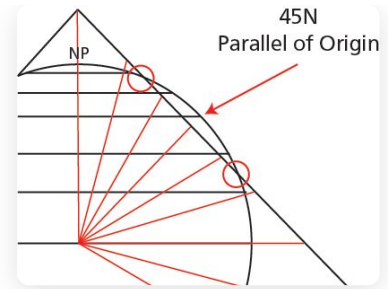


Figure 10 — Lambert modification — the cone now intersects the Reduced Earth at two latitudes (standard parallels) rather than touching at one

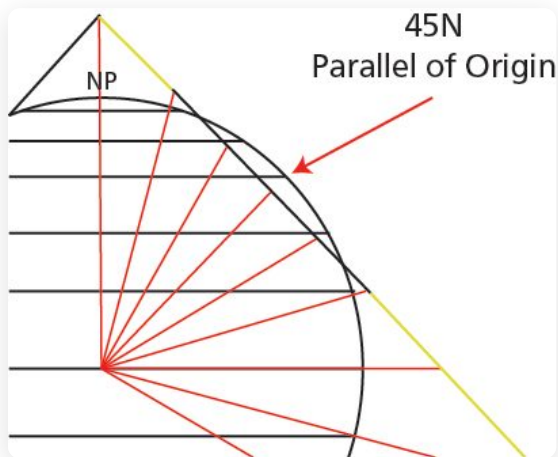


Figure 11 — Lambert scale zones: scale contracts between the standard parallels (blue, scale < 1), is correct AT the standard parallels (green), and expands outside (yellow/red)

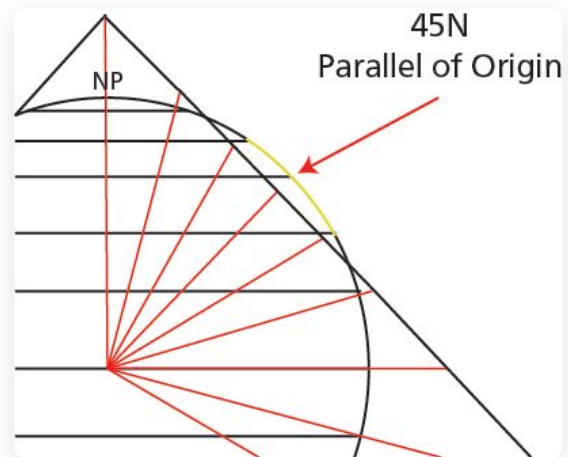


Figure 12 — Lambert scale zones continued — the expanded and contracted zones are exaggerated here to show the principle; in practice the variation is tiny across the chart

Non-perspective Chart

Having brought the cone inside the Reduced Earth, Lambert made mathematical adjustments to ensure the chart is **orthomorphic**. The result is that the Lambert chart is a **non-perspective chart** — it cannot be produced by a simple optical projection. It is constructed mathematically.

This is the same situation as the Mercator: the mathematical modification required to achieve conformality removes the direct optical projection relationship.

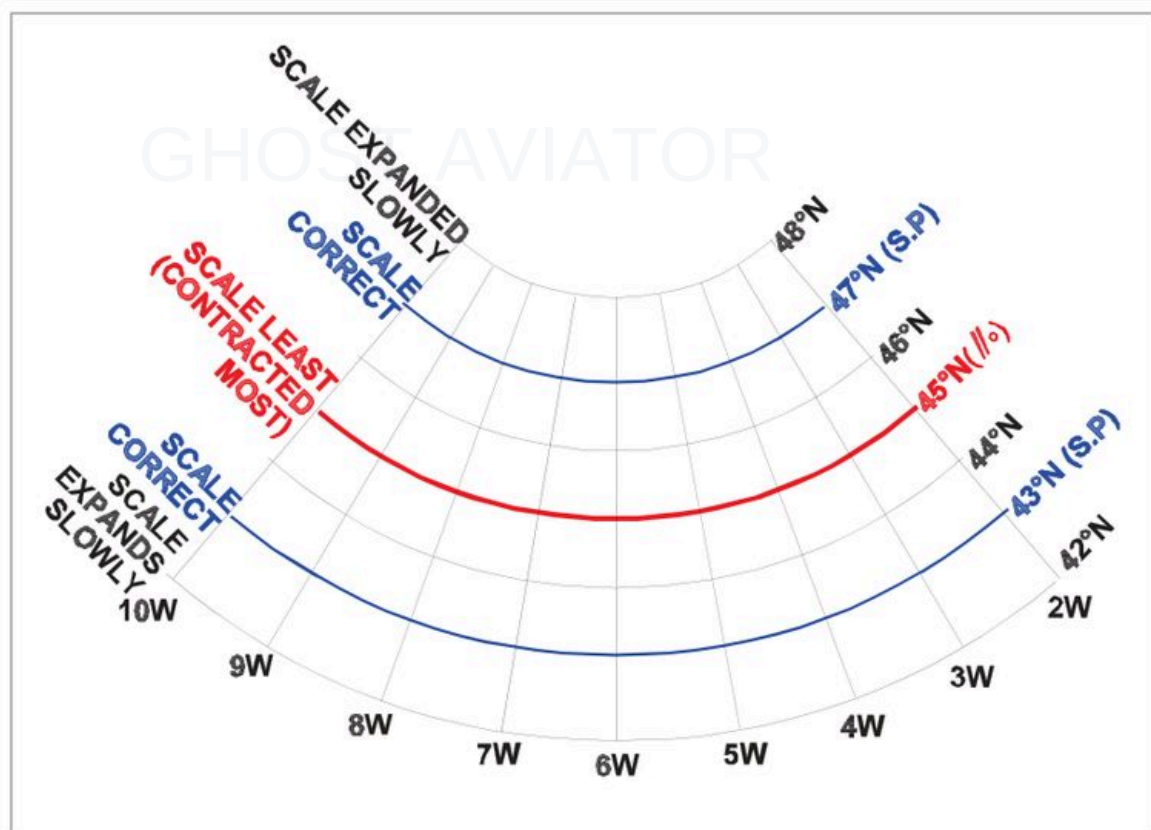


Figure 13 — Part of a Lambert conical orthomorphic chart — the familiar look of the ICAO 1:500 000 or 1:250 000 aeronautical chart; note slightly curved parallels and converging meridians

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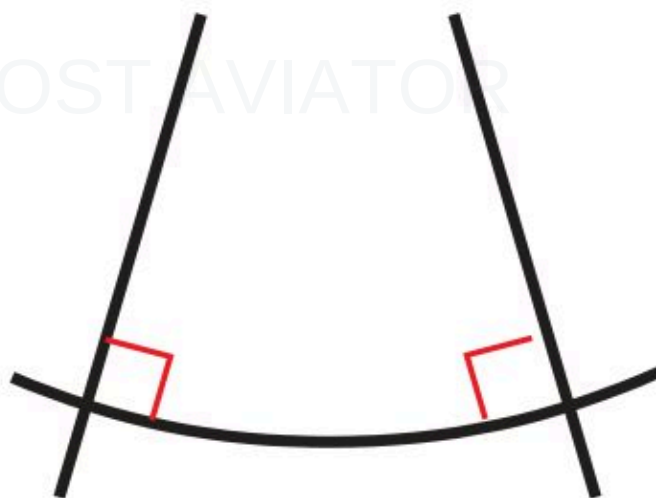


Figure 14 — *Orthomorphism on the Lambert chart: meridians converge (left) and parallels curve (right), but when combined they intersect at exactly 90° — satisfying both orthomorphism*

Lambert Chart Properties

Scale

Scale is **least at the Parallel of Origin** (between the two standard parallels). It increases outward, reaching the correct value at the two **standard parallels**. Scale is **greatest at the top and bottom parallels** of the projection.

Parallel of Origin

The **Parallel of Origin** is the mathematical basis of the projection. It is assumed to be halfway between the two standard parallels. Its sine is the **constant of the cone (n)**:

$$n = \sin(\text{Parallel of Origin})$$

The parallel of origin defines chart convergence and is approximately the mid-parallel of the chart

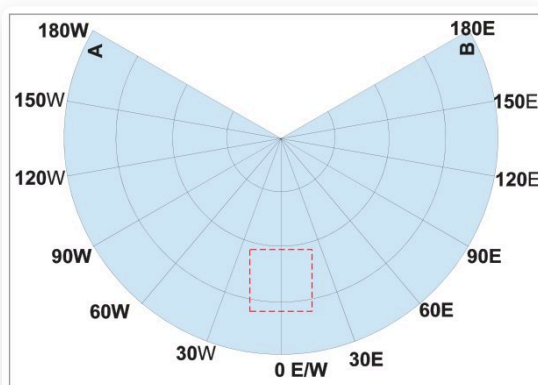


Figure 31.13

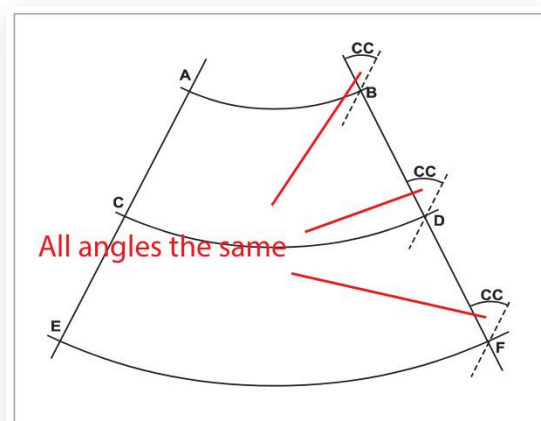


Figure 31.14 Chart convergence

Figure 15 — *The Parallel of Origin — the mathematical basis of the Lambert projection; it lies halfway between the two standard parallels and defines the convergence factor n*

Figure 16 — *Chart convergence on the Lambert chart is constant across the whole chart — all meridians incline at the same angle to each other*

Graticule

- **Meridians:** Straight lines radiating from the pole (pole is usually off the map)
- **Parallels:** Arcs of concentric circles centred at the pole
- Meridians and parallels intersect at 90°

Chart Convergence

Since the meridians on the Lambert chart are **straight lines**, the angle between any two given meridians does *not* change with latitude — unlike on the real Earth where meridians converge increasingly toward the poles.

$$\text{Chart Convergence} = \text{ch.long} \times \sin(\text{Parallel of Origin})$$

This is constant everywhere on the Lambert chart for any given ch.long

This is different from Earth convergency which $= \text{ch.long} \times \sin(\text{latitude})$ and changes with latitude. Chart convergence on the Lambert is *correct only at the Parallel of Origin*. Above the Parallel of Origin, chart convergence $<$ Earth convergency; below it, chart convergence $>$ Earth convergency.

Rhumb Lines and Great Circles

Rhumb Lines

Except for meridians (which are straight lines), rhumb lines on a Lambert chart appear as **curves concave to the pole** (i.e. they curve in the same direction as the parallels of latitude). The curvature is considerable.

Great Circles

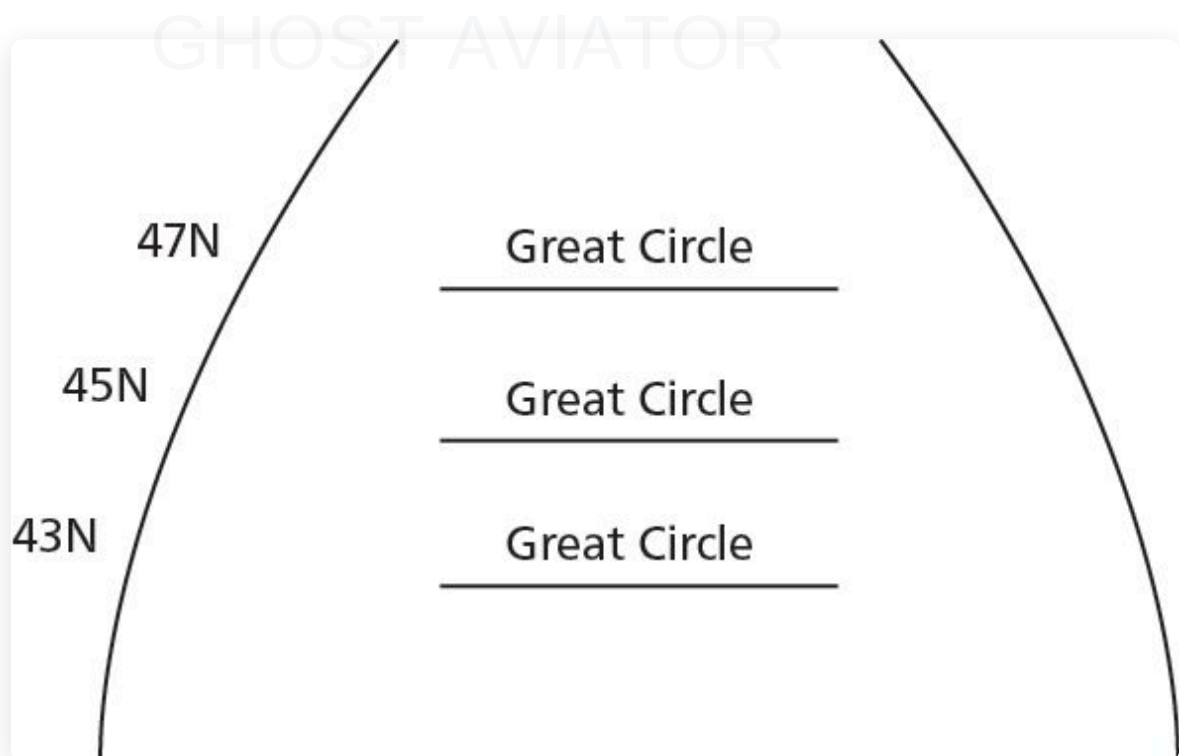


Figure 17 — Great circles on the real Earth — three Great Circle tracks at different latitudes, shown as straight lines across the globe

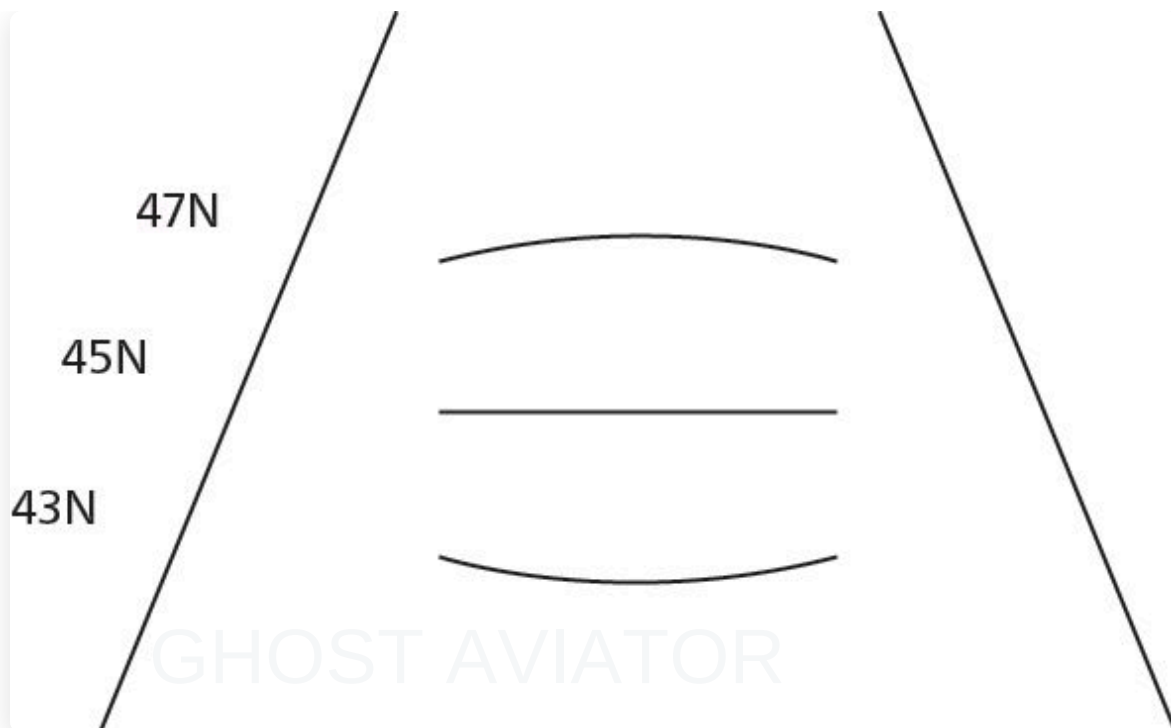


Figure 18 — *Great circles on a Lambert chart — when Earth meridians are straightened to parallel-line chart meridians, the formerly straight GCs become slightly curved; the curvature is concave to the Parallel of Origin*

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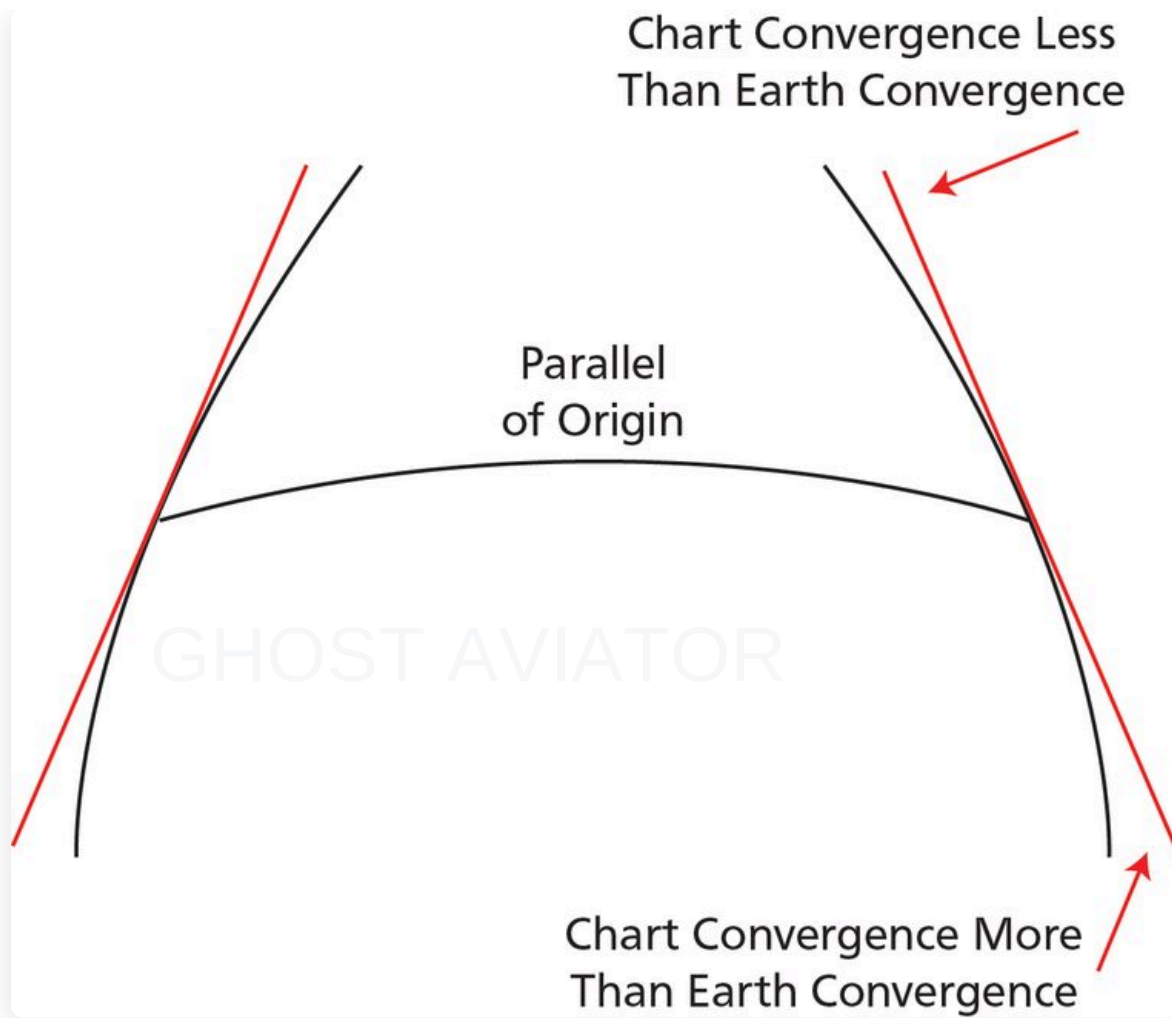


Figure 19 — Earth convergence vs chart convergence — the Lambert chart convergence is fixed at the Parallel of Origin value; at the Parallel of Origin, chart = Earth, and a Great Circle is a straight line

THE KEY RULE FOR GREAT CIRCLES ON LAMBERT CHARTS

A Great Circle is a straight line *only* at the Parallel of Origin. Elsewhere it curves concave to the Parallel of Origin. However, the amount of curvature is very small — much less than a Rhumb Line — and for **all practical purposes including plotting, Great Circles on a Lambert chart may be treated as straight lines.**

Summary — Properties of a Lambert Conformal Chart

Projection type	Conical, non-perspective, orthomorphic (conformal)
Scale	Correct at the two standard parallels. Contracted between them (least at Parallel of Origin). Expanded outside them.
Graticule	Meridians: straight lines from pole. Parallels: arcs of circles centred at pole.
Parallel of Origin	Mathematical basis of projection. $n = \sin(\text{PO})$. Halfway between standard parallels.
Chart Convergence	Constant: $\text{CC} = \text{ch.long} \times \sin(\text{Parallel of Origin})$. Correct only at PO.
Rhumb Lines	Meridians = straight. All other RLs = curves concave to the pole.
Great Circles	Meridians = straight. At PO = near-straight. Elsewhere = curves concave to PO (but very slight). Treated as straight lines for plotting.

Ghost Aviator Study Notes · General Navigation Chapter 21 · For DGCA CPL/ATPL Examination Preparation

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CHAPTER 23 · GENERAL NAVIGATION

The Polar Stereographic Chart

Geometric projection · Scale $\sec^2(1/2 \text{ co-lat}) \cdot n = 1$ · Straight-line track problems

IN THIS CHAPTER

- › Introduction
- › Scale Expansion
- › Chart Properties
- › Rhumb Lines & Great Circles
- › Summary
- › The Co-latitude
- › Scale Zones
- › Chart Convergence ($n = 1$)
- › Straight-line Track Problems

Introduction — A True Perspective Projection

Of all the chart projections studied in this course, the **Polar Stereographic** is the only *true geometric (perspective) projection*. It is constructed by placing a flat sheet of paper touching the **North Pole** (the point of tangency), with the light source at the **South Pole** (diametrically opposite).

The graticule is cast by straight light paths from the South Pole through the globe and onto the flat sheet, producing the characteristic circular parallel / radial meridian graticule.

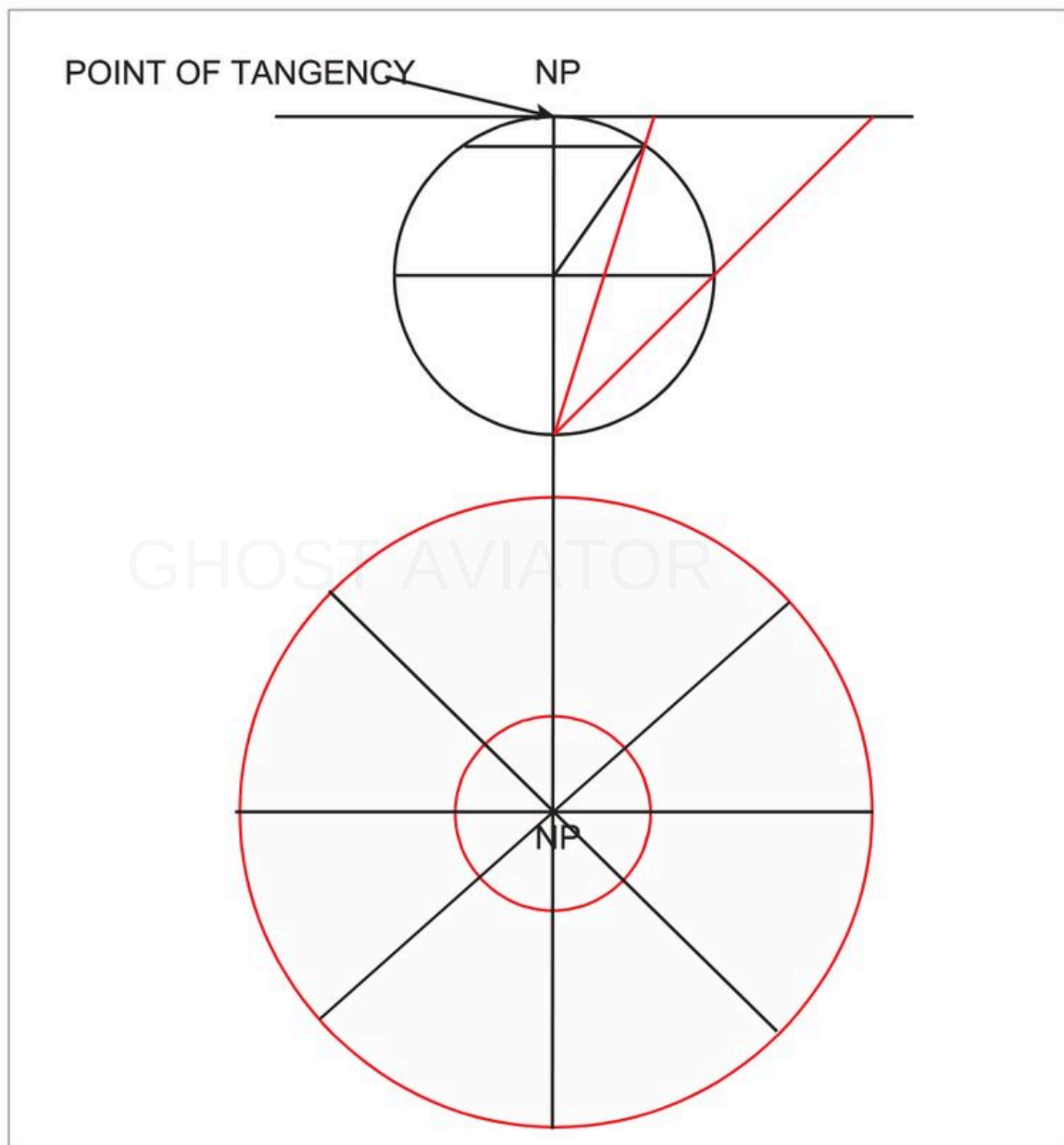


Figure 331 — A Polar stereographic projection

Figure 1 — Polar Stereographic projection construction: flat sheet touches the North Pole; light source at South Pole; the graticule is projected geometrically outward from the pole

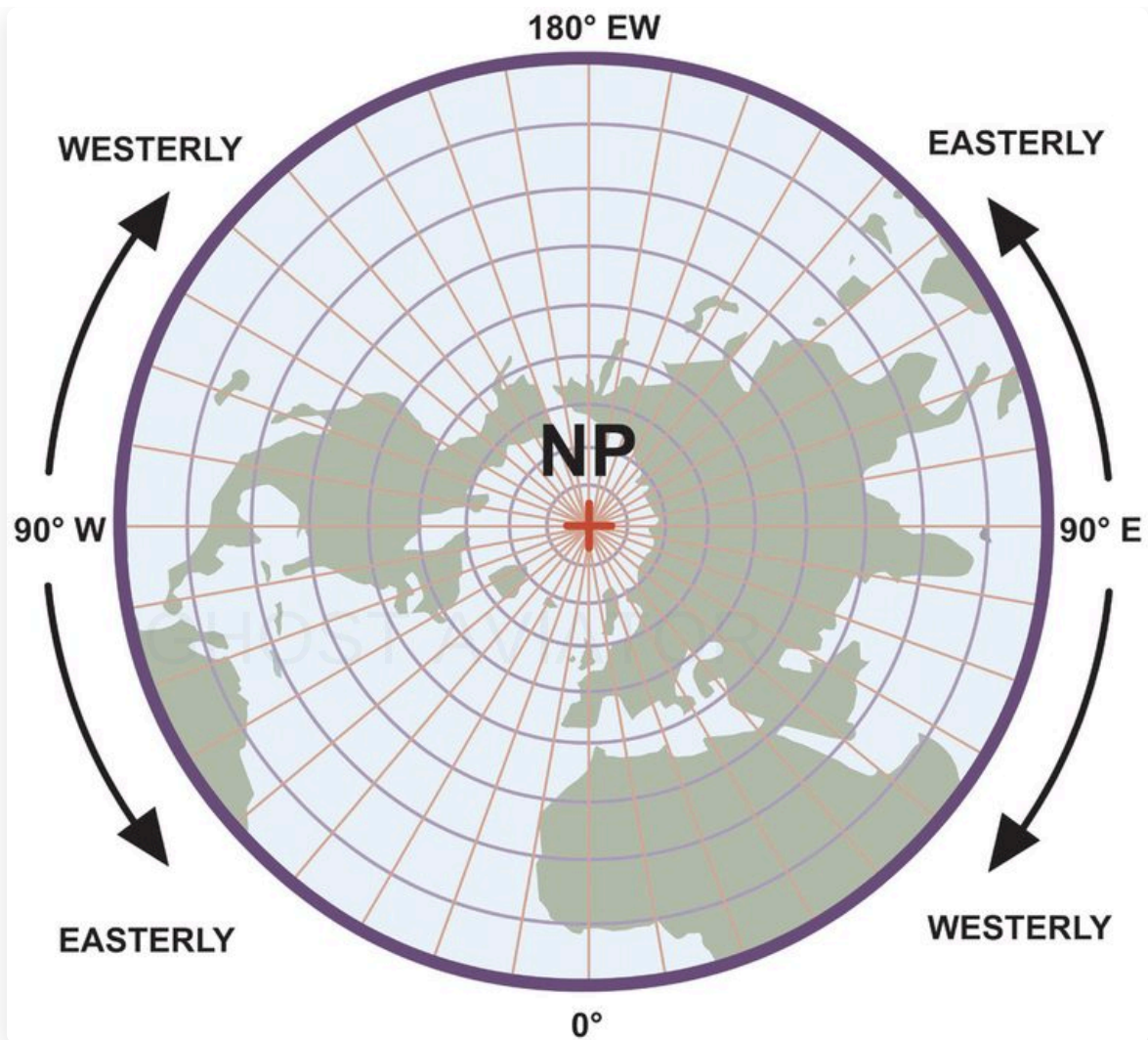


Figure 2 — Polar Stereographic graticule: meridians are straight lines radiating from the pole; parallels are concentric circles; the spacing between parallels increases with distance from the pole

The Co-latitude

The co-latitude is a key concept for polar chart calculations:

$$\text{Co-latitude} = 90^\circ - \text{latitude}$$

It measures the angular distance from the pole (rather than from the Equator)

Examples:

- Latitude 90°N (the North Pole): co-latitude = 0°
- Latitude 78°N: co-latitude = 12°
- Latitude 70°N: co-latitude = 20°
- Latitude 60°N: co-latitude = 30°
- Latitude 0° (Equator): co-latitude = 90°

The co-latitude is used because polar chart properties (scale expansion, distance from the pole) are measured from the pole rather than the Equator.

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Scale Expansion

Scale is **correct at the Pole** (the point of tangency). Elsewhere it expands with increasing co-latitude (i.e. with decreasing latitude / distance from the pole):

Scale at latitude ϕ = Scale at Pole $\times \sec^2(\frac{1}{2}$ co-latitude)

Where: co-latitude = $90^\circ - \phi$; $\sec(\theta) = 1/\cos(\theta)$

Worked Example — Scale at 78°N

If scale at Pole = 1:1 000 000:

Co-latitude of 78°N = $90^\circ - 78^\circ = 12^\circ$. Half co-lat = 6° .

Scale at 78°N = $(1/1\,000\,000) \times \sec^2(6^\circ) = (1/1\,000\,000) \times (1/\cos 6^\circ)^2 = (1/1\,000\,000) \times (1/0.9945)^2$

= $(1/1\,000\,000) \times (1.00554)^2 \approx (1/1\,000\,000) \times 1.011 = \mathbf{1/989\,074}$

→ Scale change from 90°N to 78°N: less than 1%. Chart is within 1% of correct scale.

Scale Zones

The near-constant scale near the pole makes this chart ideal for polar flying:

- **90° to 78°N:** Scale within 1% of correct (Pole scale)
- **78° to 70°N:** Scale within 3% of correct
- **Below 70°N:** Scale error exceeds 3%; the chart becomes less suitable

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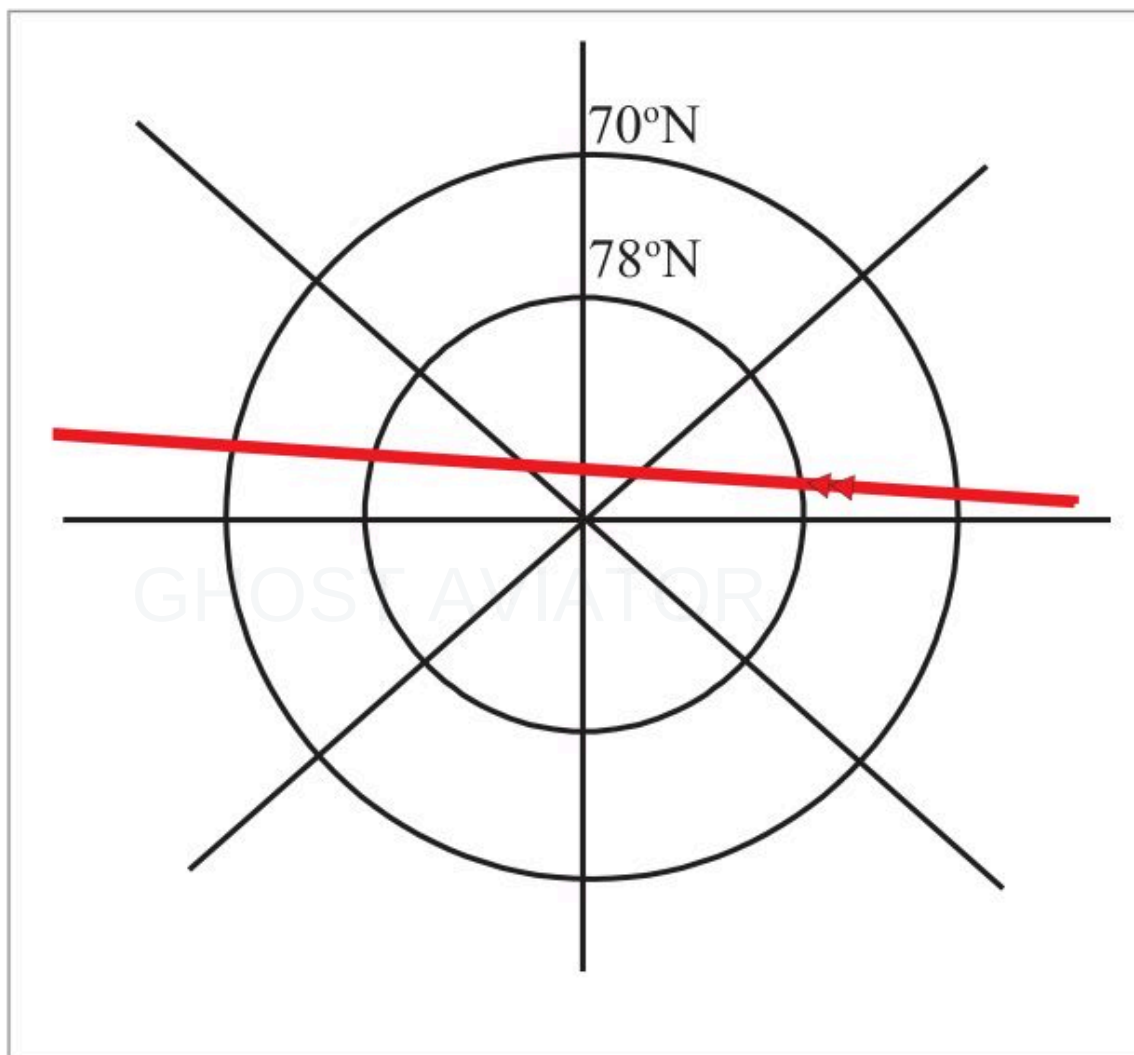


Figure 22.2 Track near Pole

Figure 3 — Scale zones on the Polar Stereographic: the 78°N parallel marks the 1% boundary and the 70°N parallel marks the 3% boundary — this 1% zone covers about 720 NM radius from the pole

The practical significance: the 1% scale zone extends from the Pole to 78°N.

The distance from Pole to 78°N = $12^\circ \times 60 \text{ NM} = \mathbf{720 \text{ NM}}$. An aircraft crossing the polar region (entering on one side, exiting the other) travels about 1 400 NM in the 1% zone — approximately 3 hours at typical jet speeds. A chart useful for 3 hours of polar flying with minimal scale error is extremely practical.

Chart Properties

Property	Detail
Projection type	Azimuthal (plane), geometric (perspective), orthomorphic
Orthomorphism	Yes — meridians radiate from pole, parallels are concentric circles; expansion is equal in all directions from any point, satisfying both orthomorphism conditions
Scale	Correct at Pole. Expands as $\sec^2(\frac{1}{2} \text{ co-lat})$. Within 1% from 90°N to 78°N; within 3% from 78°N to 70°N
Graticule	Meridians: straight lines from pole. Parallels: concentric circles centred at pole (uneven spacing — wider apart with distance from pole)
Shape distortion	Shapes and areas become increasingly distorted away from the pole
Practical use	Polar route planning and plotting; ETOPS operations over polar areas; some meteorological charts

Chart Convergence — $n = 1$

On the Polar Stereographic chart, the meridians converge at the pole at exactly the same rate as they do on the Earth's surface. This gives the chart a **convergence factor $n = 1$** :

Chart Convergence = change of longitude $\times 1 =$ **ch.long**

This is CONSTANT across the whole chart and CORRECT at the Pole only

On the real Earth, convergency = $\text{ch.long} \times \sin(\text{latitude})$. At the Pole, $\sin(90^\circ) = 1$, so Earth convergency = ch.long . Chart convergence (always = ch.long) equals Earth convergency only at the Pole. Elsewhere, chart convergence $>$ Earth convergency (since $\sin(\text{lat}) < 1$ at any latitude other than the Pole).

N = 1: THE KEY NUMBER FOR POLAR STEREO PROBLEMS

For any two meridians on a Polar Stereographic chart, the angle *between* them on the chart = their difference in longitude. This is the starting point for all straight-line track problems on this projection.

Rhumb Lines and Great Circles

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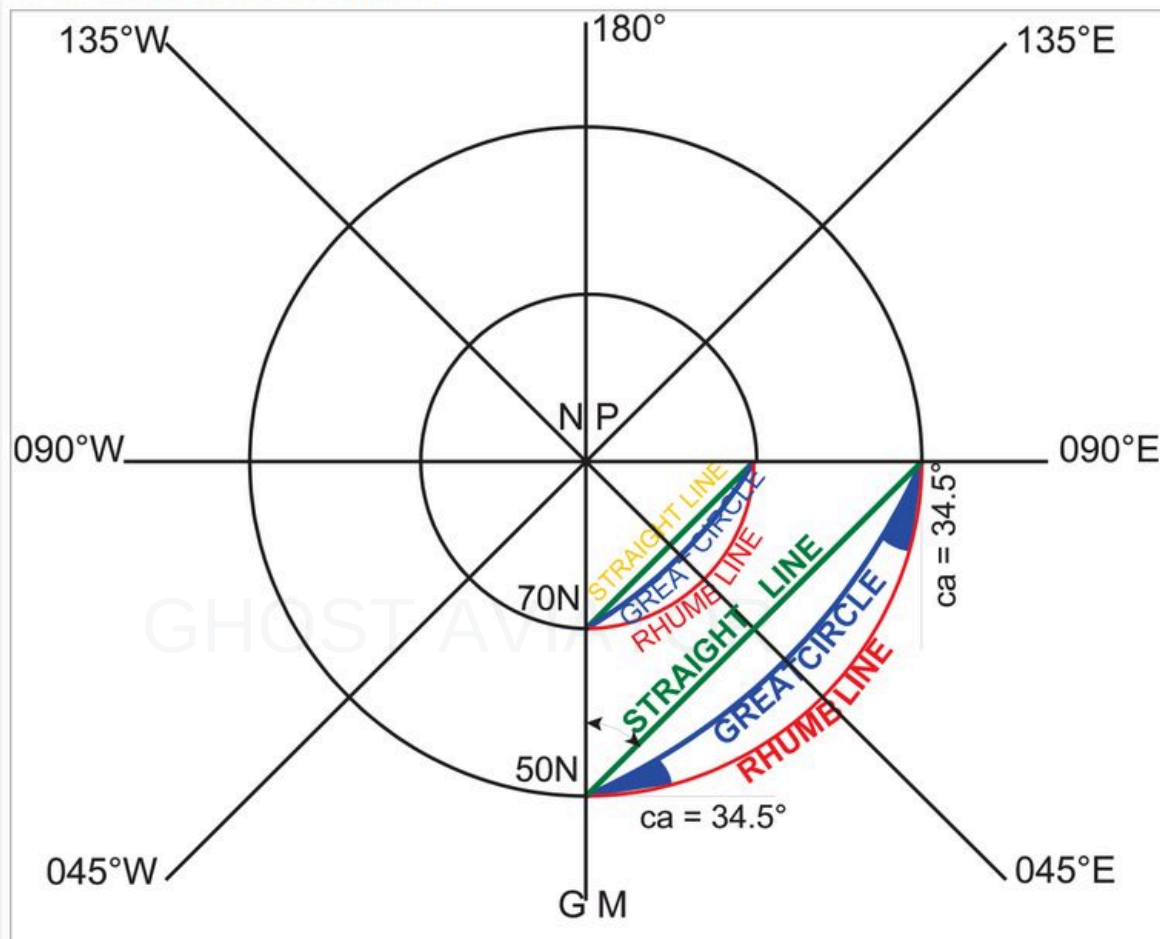


Figure 33.4 — Great circle, rhumb lines and straight lines

Figure 4 — Great circles, rhumb lines and straight lines on a Polar Stereographic chart between two meridians (000°E and 090°E) at 50°N and 70°N — the straight line on the chart sits between the RL and GC in terms of curvature

Rhumb Lines

Rhumb lines are curves **concave to the Pole** (same as on the Lambert chart, but here the "Parallel of Origin" is the pole itself). The curvature is considerable.

Great Circles

Great circles are also curves **concave to the Pole**, but with **less curvature than Rhumb Lines** in the same hemisphere.

Straight Lines vs Great Circles at Different Latitudes

The difference between a straight line on the chart and the corresponding Great Circle can be calculated:

- **At 50°N, 90° ch.long:** Angle between straight line and RL = $\frac{1}{2} \times \text{chart convergence} = \frac{1}{2} \times 90^\circ = 45^\circ$. Conversion angle = $\frac{1}{2} \times 90 \times \sin(50^\circ) = 34.5^\circ$.
Difference = $45^\circ - 34.5^\circ = 10.5^\circ$. Too large to treat as equal.
- **At 70°N, 90° ch.long:** $\frac{1}{2} \text{ CC} = 45^\circ$. Conversion angle = $\frac{1}{2} \times 90 \times \sin(70^\circ) = 42.3^\circ$.
Difference = $45^\circ - 42.3^\circ = 2.7^\circ$. Acceptably small.

RULE OF THUMB

At latitudes above **70°N** (or 70°S), a straight line on a Polar Stereographic chart may be taken as a Great Circle. Below 70°N, the approximation breaks down.

Straight-line Track Problems

These are the most common exam questions on this chapter. Two methods work:

- **Triangle geometry:** Draw the triangle formed by the Pole, point A, and point B. Use the fact that the angle at the Pole = ch.long (since $n = 1$). Solve the triangle (isosceles if A and B are at the same latitude).
- **Rhumb Line method:** Find the RL track (easy — same latitude means 090° or 270°). Then subtract half chart convergence to find the initial straight-line track.

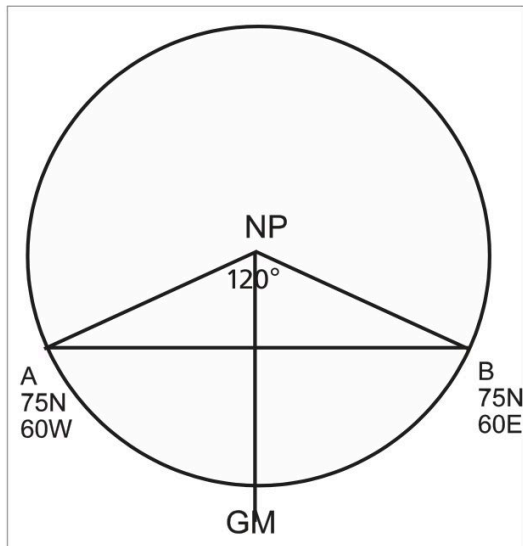


Figure 5 — Example 1 diagram — isosceles triangle A(75N 60W)–Pole–B(75N 60E); apex angle = 120° (ch.long); base angles each = 30°

or way of solving this problem by use of the Rhumb Line method. If A is at 75N then the Rhumb Line track between them is the parallel of latitude. It must have a Rhumb Line track of $090^\circ(T)$.

Divergence between 60W and 60E is 120° . Therefore half chart convergence is 60° . The difference between the Rhumb Line and the straight line. Therefore the Rhumb Line track of $090^\circ(T)$ gives us an initial straight-line track

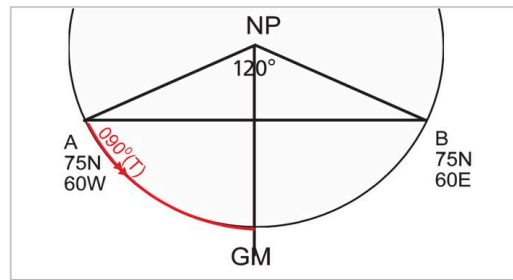


Figure 6 — Example 1 using the RL method —

RL track = $090^\circ(T)$; half chart convergence = 60° ; straight-line track at A = $090^\circ - 60^\circ = 030^\circ(T)$

Example 1: Initial straight-line track from A (75N 60W) to B (75N 60E)

Method 1 — Triangle: A and B are both at $75^\circ N$ (co-lat = 15° each). Angle at Pole = ch.long = 60W to 60E = 120° . Isosceles triangle: two equal co-lat sides of 15° . Internal angles sum to 180° : angles at A and B = $(180^\circ - 120^\circ)/2 = 30^\circ$ each.

Direction from A to North Pole = $000^\circ(T)$. Straight-line to B is 30° to the right = **$030^\circ(T)$** .

Method 2 — RL: A and B are both at $75^\circ N \rightarrow$ RL track = $090^\circ(T)$. Chart convergence = 120° . Half CC = 60° . Subtract: $090^\circ - 60^\circ =$ **$030^\circ(T)$** ✓

Initial straight-line track A $\rightarrow$ B = $030^\circ(T)$

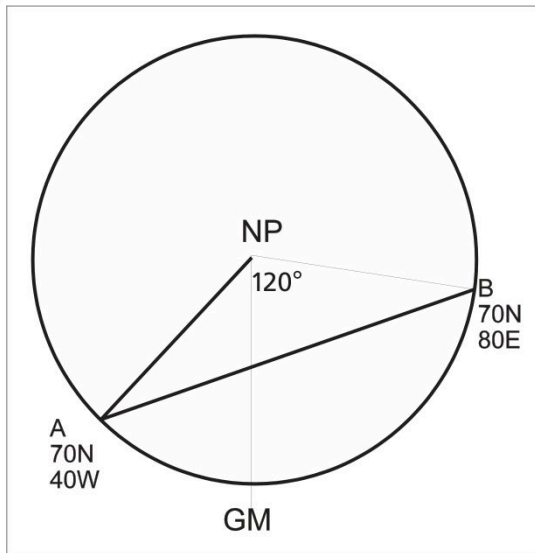


Figure 22.7 — Polar stereographic situation

Figure 7 — Example 2 — vertex longitude: the highest latitude on a straight line between two points occurs at the shortest distance from the Pole, where the perpendicular from the Pole meets the line

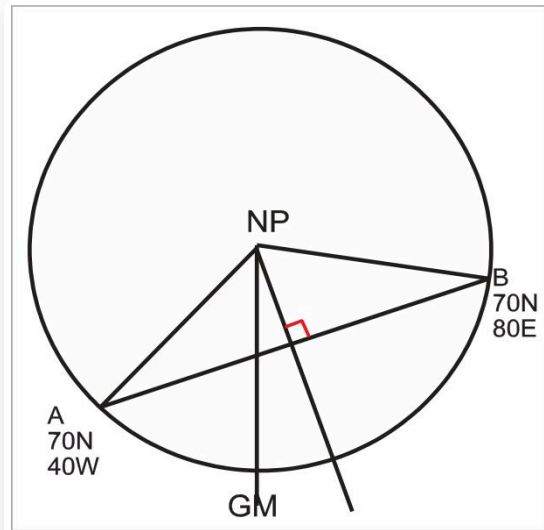


Figure 22.8 — Right angles to track

Figure 8 — Example 2 — perpendicular from Pole to track meets at mid-meridian (020°E = mid-point of 40°W and 80°E)

Example 2: Highest latitude on straight-line from A ($70^{\circ}\text{N } 40^{\circ}\text{W}$) to B ($70^{\circ}\text{N } 80^{\circ}\text{E}$)

A and B are both at 70°N . Pole–A–B is an isosceles triangle.

The highest latitude (shortest distance from Pole) is where the line is closest to the Pole. By symmetry, this must be at the **perpendicular bisector** from the Pole.

Mid-meridian between 40°W and 80°E = $(-40 + 80)/2 = 20^{\circ}\text{E} \rightarrow$
 020°E .

Highest latitude at longitude 020°E

Figure 9: Right-angled triangle.

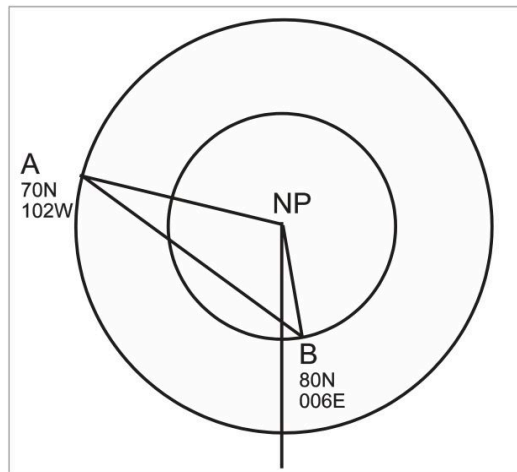


Figure 23.9

Figure 9 — Example 3 setup — A (70N 102W) and B (80N 006E) at different latitudes; highest latitude along the line is at 035°W

Right-angled triangle, between A, the North Pole, and the point C (035°W). The difference between 102°W and 035°W, so it is 67°. Angle c is the angle at the North Pole. The angle must add up to 180°. So angle a must be 23°.

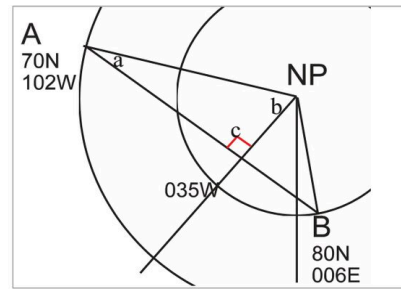


Figure 23.10

Figure 10 — Example 3 solution — the perpendicular from the Pole to the highest-latitude point creates a right-angled triangle; angle $b = 102^\circ\text{W} - 035^\circ\text{W} = 67^\circ$; angle $a = 180^\circ - 90^\circ - 67^\circ = 23^\circ$

Example 3: Initial track from A (70N 102W) to B (80N 006E) — highest latitude at 035°W

A and B are at *different* latitudes, so there's no isosceles triangle. Use the highest-latitude (vertex) information instead.

Draw the right-angled triangle: Pole $\rightarrow$ vertex (at 035°W) $\perp$ to the straight line. The angle at the Pole (angle b) = difference between A's longitude (102°W) and vertex (035°W) = **67°**.

Angle at vertex = 90° (perpendicular by definition). Angle at A = $180^\circ - 90^\circ - 67^\circ = \mathbf{23^\circ}$.

Direction from A to Pole = 000°(T). The 23° is measured to the RIGHT of north (east of north, toward B). Initial straight-line track = **023°(T)**.

Initial straight-line track from A = 023°(T)

Summary — Properties of a Polar Stereographic Chart

Projection type	Azimuthal (flat sheet), geometric/perspective, orthomorphic
Scale	Correct at Pole. Elsewhere expands as $\sec^2(1/2 \text{ co-lat})$. Within 1%: $90^\circ \rightarrow 78^\circ$. Within 3%: $78^\circ \rightarrow 70^\circ$.
Graticule	Meridians: straight lines from Pole. Parallels: concentric circles (uneven — increasingly spaced).
Orthomorphic	Yes — equal scale expansion in all directions at any point.
Chart Convergence	= ch.long. Constant everywhere. Correct only at the Pole. $n = 1$.
Rhumb Lines	Curves concave to the Pole (except meridians).
Great Circles	Curves concave to the Pole, but with less curvature than RLs. Treated as straight lines above 70° .
Straight-line track	Initial track at A = $000^\circ(\text{T to Pole}) \pm \text{angle from isosceles/right-angle triangle}$. Or: $\text{RL} \pm \text{half CC}$.

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