

CHAPTER 18 · GENERAL NAVIGATION

Mercator Charts — Properties

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

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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.

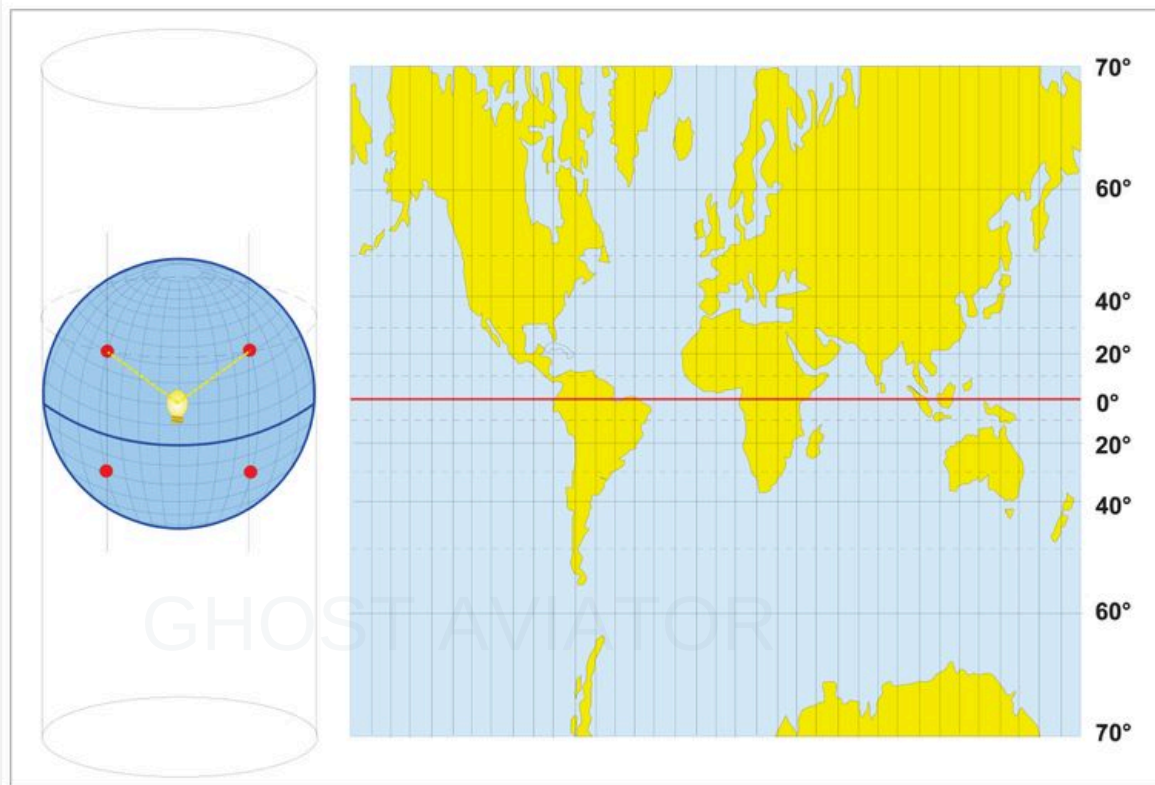


Figure 1.1 Simple Cylindrical Projection

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**.

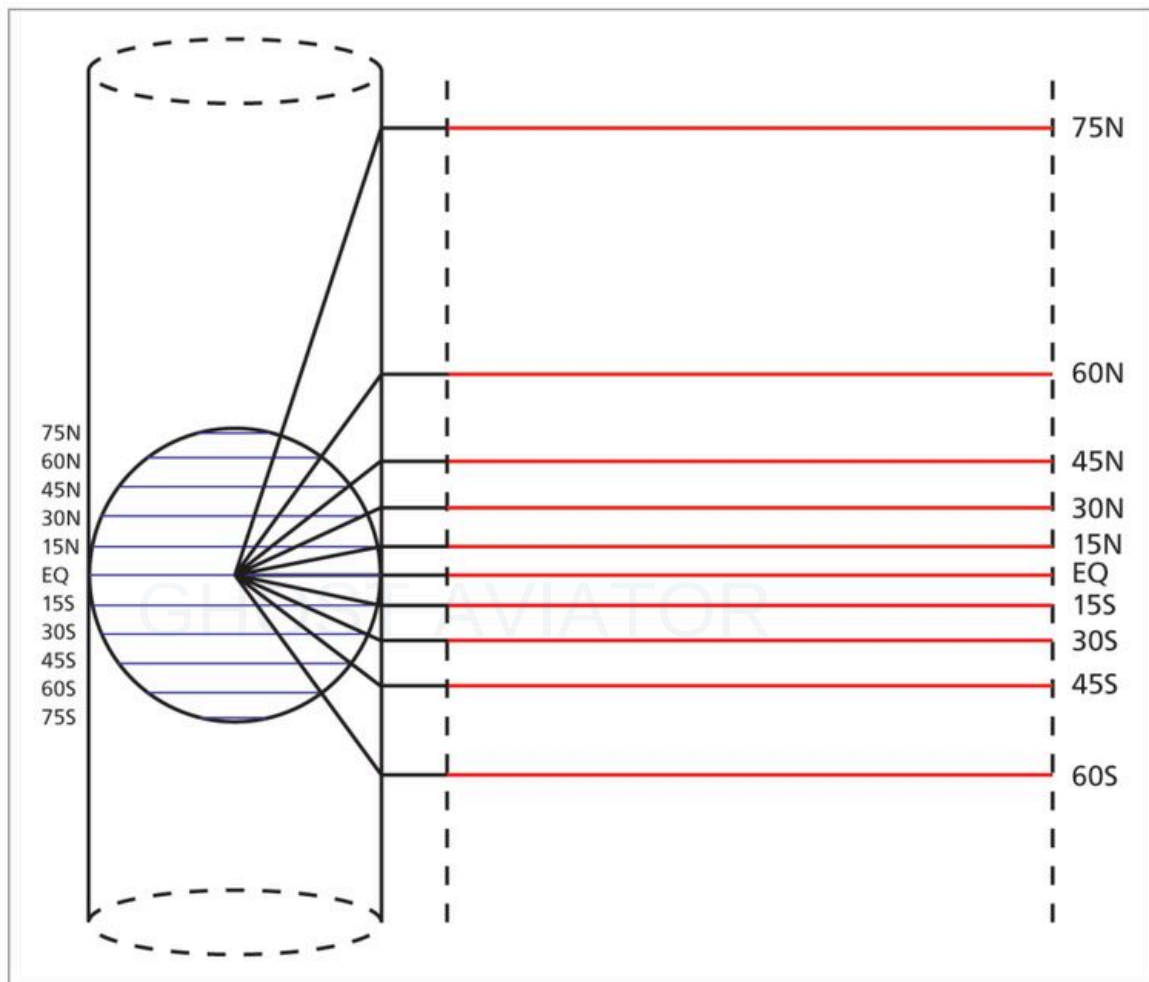


Figure 19.2 Simple Cylindrical Projection

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.

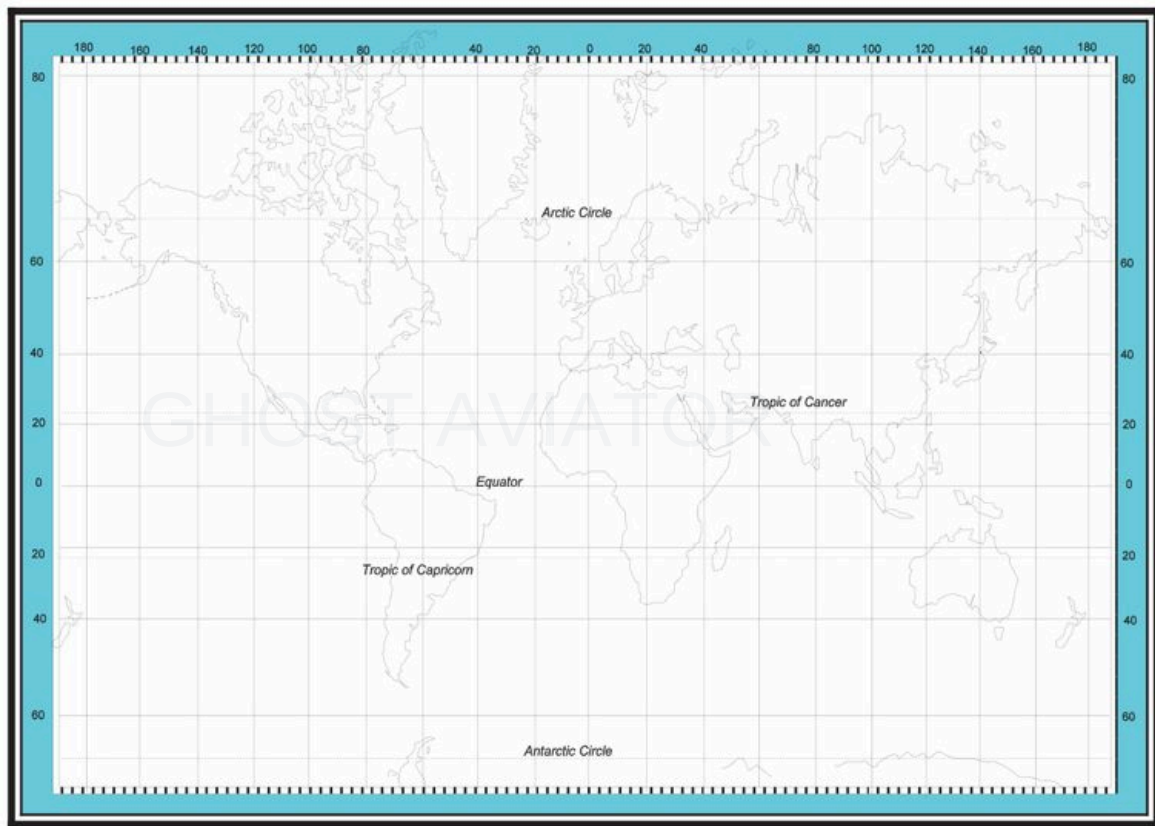


Figure 18.3 Mercator Projection

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.

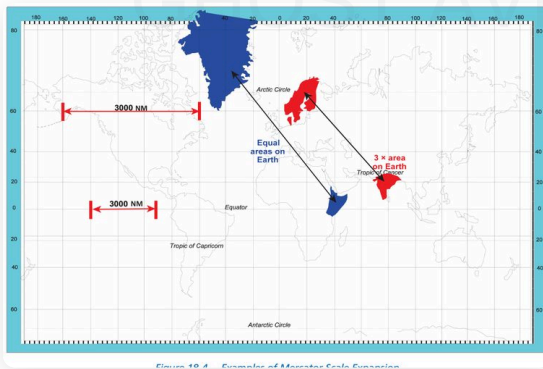


Figure 4 — Scale expansion examples on a Mercator chart — shapes in the same latitudinal band appear correct relative to each other, but are stretched compared with true scale

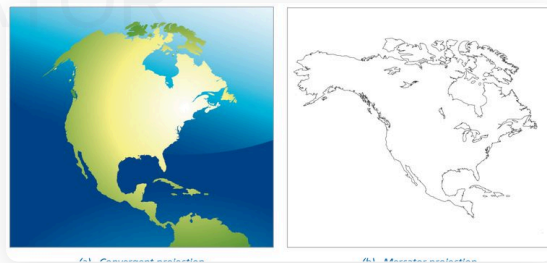


Figure 5 — (a) Convergent projection (approximately correct shape) vs (b) Mercator projection (stretched): on the Mercator all meridians are parallel vertical lines; on a convergent chart they converge toward the poles

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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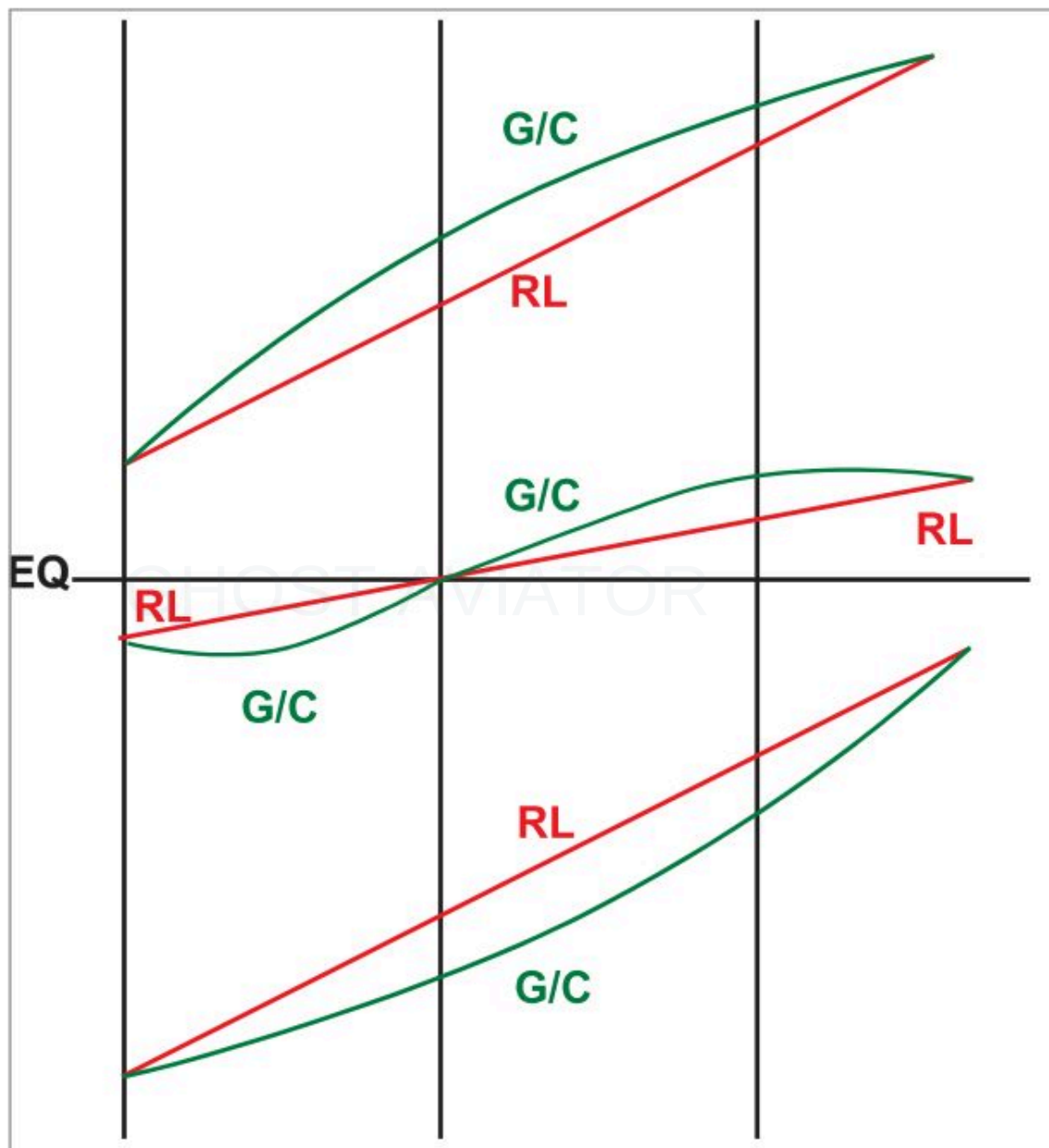


Figure 18.6 Mercator Chart, rhumb lines and Great

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**

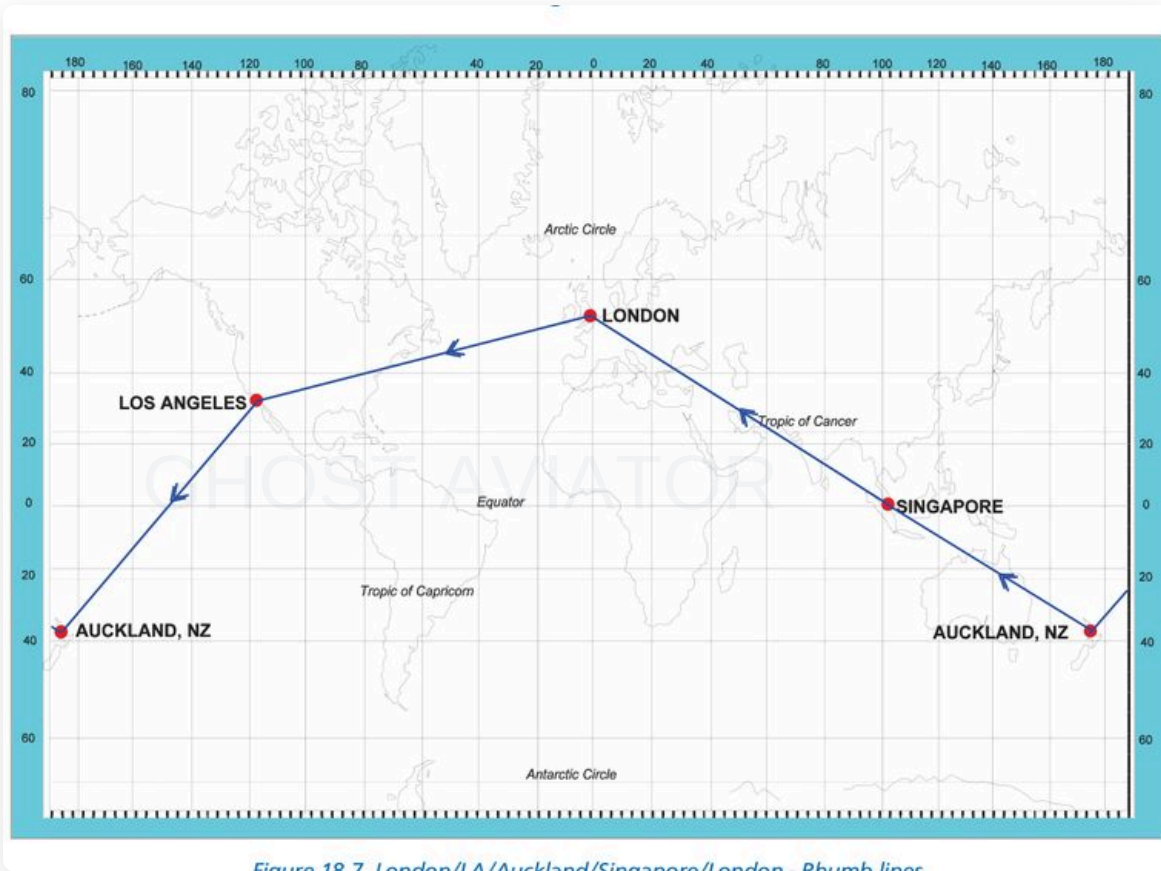


Figure 7 — Mercator chart showing rhumb lines and great circles between major cities: the RL between London and LA is approximately $257^{\circ}T$ (straight line); the GC track curves considerably northward

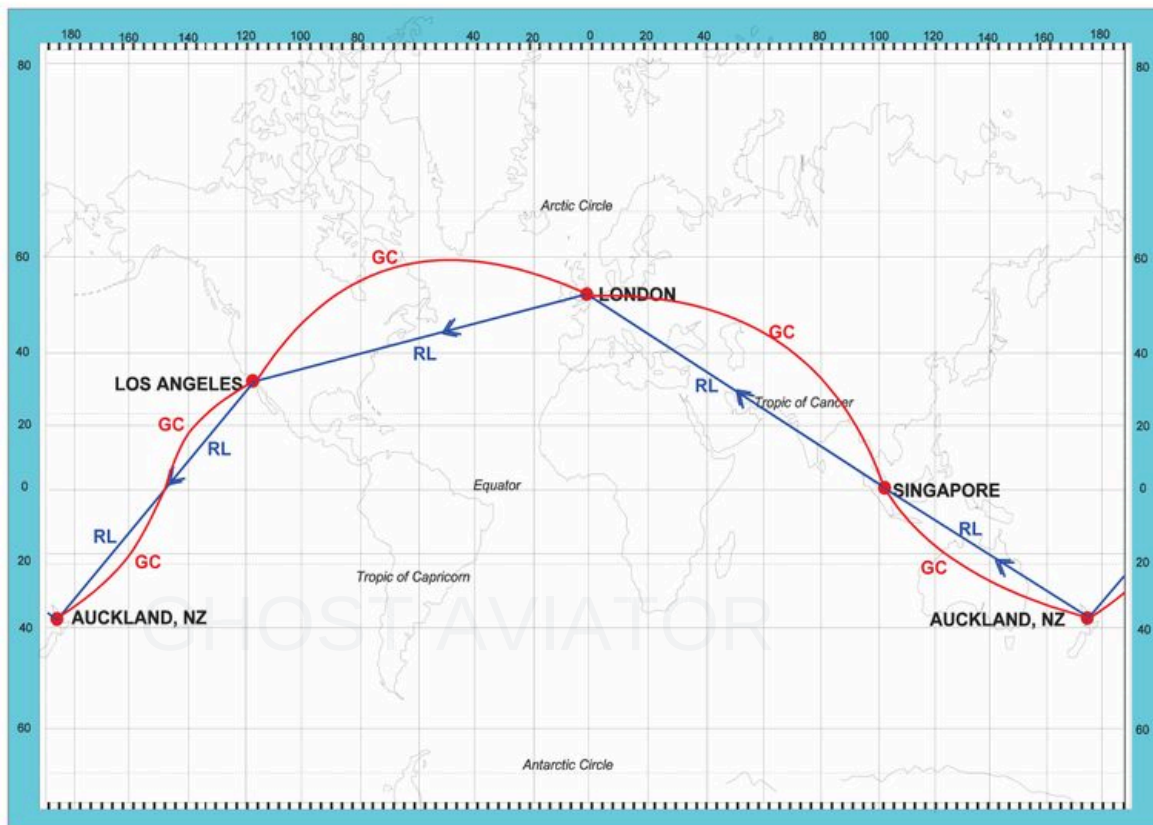


Figure 18.8 London/LA/Auckland/Singapore/London - Great circles

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 ($30\text{S } 032\text{E}$) to Perth ($30\text{S } 116\text{E}$) 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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