

CHAPTER 17 · GENERAL NAVIGATION

General Chart Properties

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

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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.

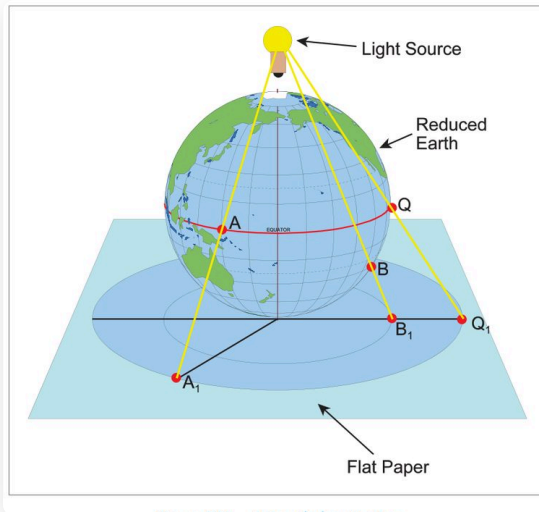


Figure 1 — Azimuthal projection — a flat sheet touches the globe at one point; the graticule is projected outward from the opposite side

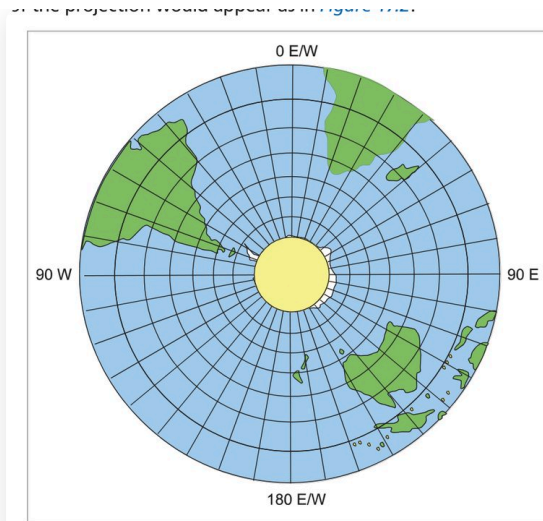


Figure 2 — Azimuthal graticule — meridians are straight lines radiating from the pole; parallels are concentric circles centred at the pole

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.

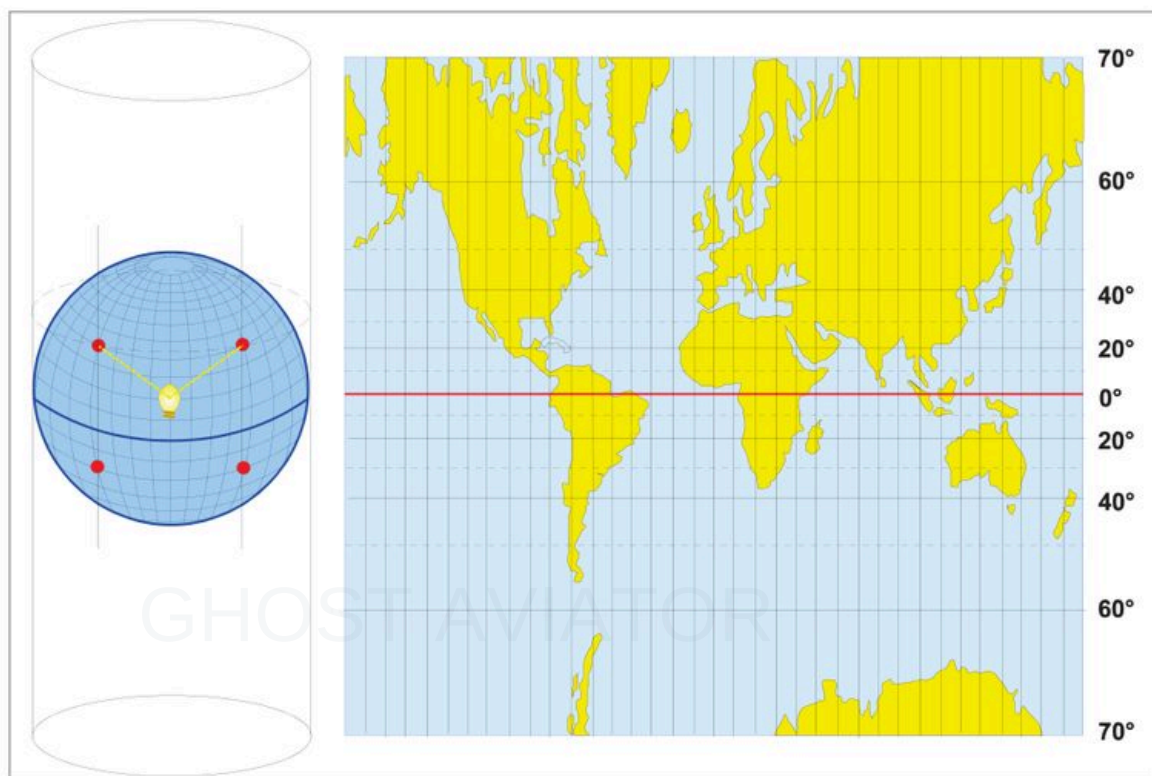


Figure 17.2 Simple cylindrical projection and graticule

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.

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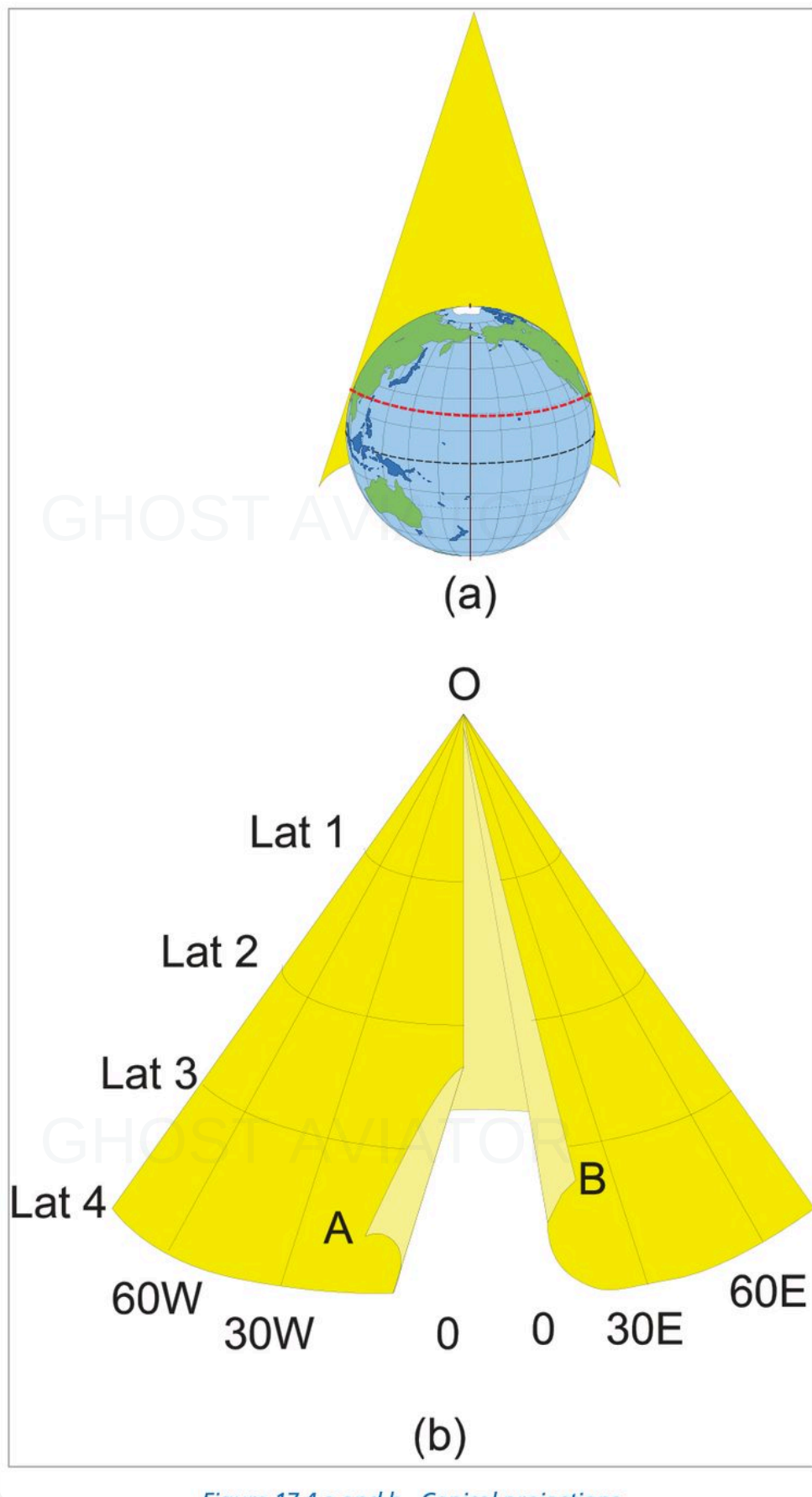


Figure 17.4 a and b. Conical projections

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

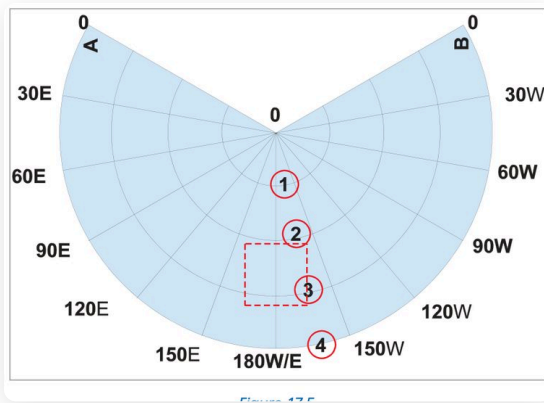


Figure 5 — The developed cone — opening the slit cone gives the familiar conical chart; the full 360° of longitude appears as a sector (less than 360°) of a circle

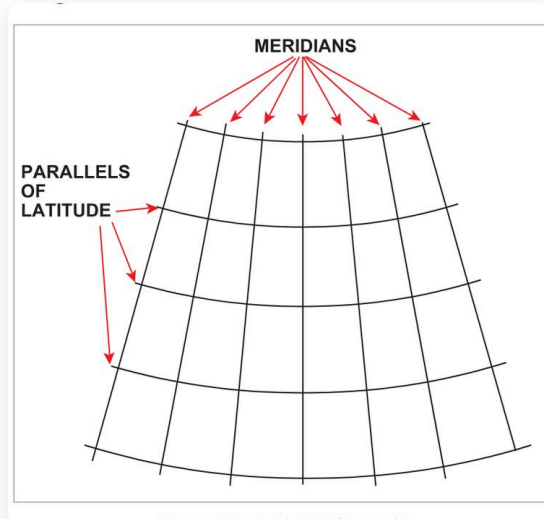


Figure 6 — Typical conical graticule — meridians are straight lines converging toward the pole; parallels are arcs of concentric circles; the graticule looks like the ICAO 1:500 000 chart

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.

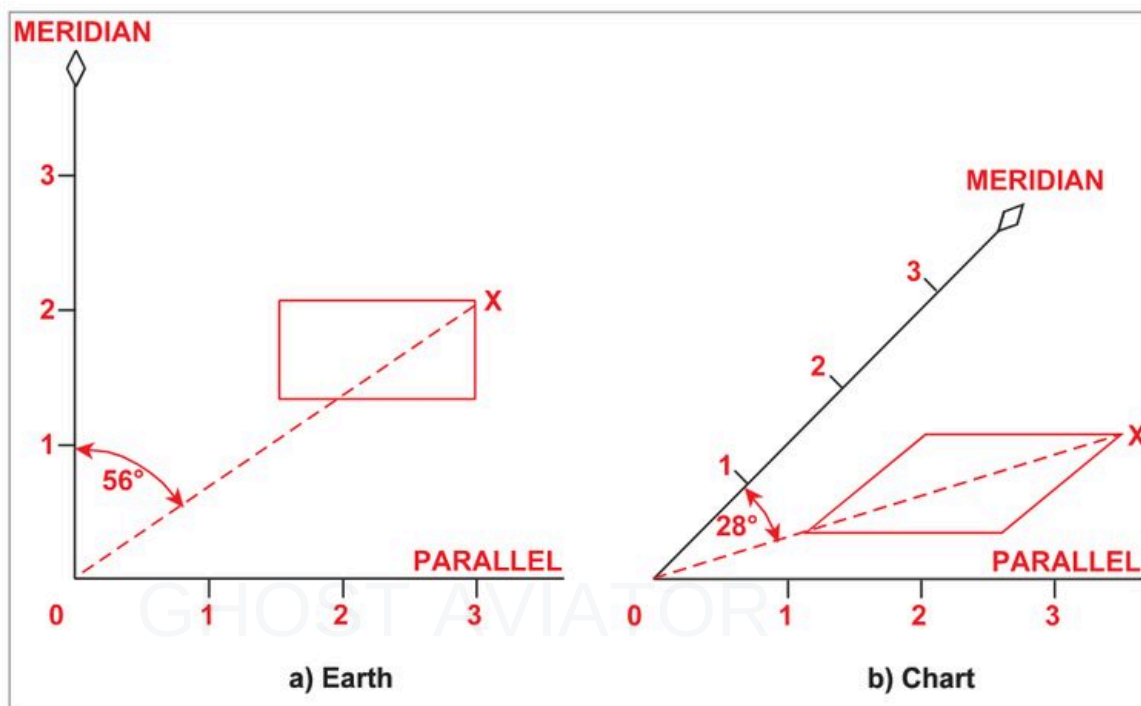


Figure 177 Orthomorphism 1

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

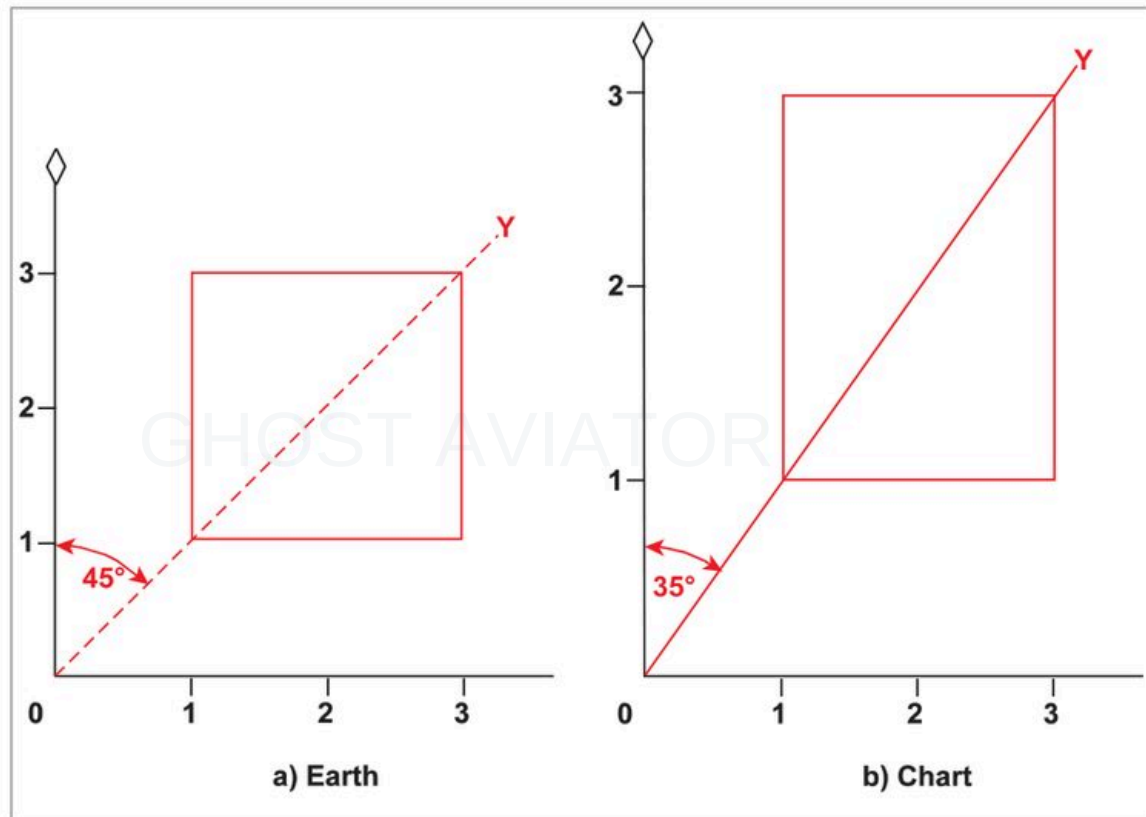


Figure 17.8 Scale at a point

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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