

STUDY AID — PENDING INDEPENDENT AUDIT

These notes are study aids for DGCA examination preparation. They are PENDING INDEPENDENT AUDIT and must not be used for operational flight planning. Always verify procedures against current AIPs, NOTAMs, and your operator's manuals.

GENERAL NAVIGATION • THE NAVIGATION COMPUTER

Chapter 7

The Triangle of Velocities

An aeroplane almost never goes where it is pointing. This chapter is the geometry of the difference — and it is the one piece of this module that the electronic computer lets you skip, and therefore never learn.



Figure 7.11 — Short final, strong crosswind. The nose is pointing well off the centreline and the aeroplane is tracking straight down it. Nothing is wrong. This is what competence looks like.

■ where the nose points — heading

■ where the aeroplane goes — track

■ what makes them differ — wind

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SIXTY SECONDS IN THE COCKPIT

You are cruising at 100 knots true airspeed on a heading of **000°** — due north, dead steady, wings level. The compass has not moved in twenty minutes.

You are travelling **012°**, at **118 knots**.

Nothing has failed. The aircraft is doing exactly what you asked. But a 30-knot wind from the south-west has been quietly carrying the whole air mass — and your aeroplane with it — sideways and forwards the entire time. Fly that heading for an hour believing you are going north and you will be **12 nautical miles** east of where you planned.

The instruments are not lying to you. They are answering a different question.

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1 • Six words, used precisely

This chapter is unusually strict about vocabulary, and the strictness is not pedantry. Every one of these words has been the wrong answer to an exam question because a student used it loosely.

Heading

The direction the aircraft's **fore-and-aft axis is pointing**. Where the nose is aimed. It can be measured from True, Magnetic or Compass north — so it is always written with a qualifier: 000°(T), 000°(M).

Heading is not where you are going. It is only where you are pointing.

Track

The direction of the aircraft's **path over the ground**. Where you are actually going. Measured from True or Magnetic north — but never from Compass north, because the ground does not care about your compass.

Drift

The angular difference between heading and track. **You always drift from your heading to your track** — that phrase is the whole definition and it fixes the direction of the subtraction.

Heading 090°, track 097°: you have drifted from 090 to 097, so **7° of starboard (right) drift**.

Heading 030°, track 026°: from 030 to 026, so **4° of port (left) drift**.

Wind Correction Angle — the same number, the opposite sign

WCA is drift's mirror. Same magnitude, applied the other way.

Carry this forward carefully. Chapter 8A solves for the heading with $\sin^{-1}(W \cdot \sin \theta \div \text{TAS})$, and the number that formula returns is the *drift*, not the WCA — so it is *subtracted* from the track. Put a signed WCA into that subtraction instead and you will aim twice the angle, on the wrong side. **Compute with drift; report WCA.**

Drift is applied to *heading* to give *track*: it tells you what the wind *did* to you.

WCA is applied to *track* to give *heading*: it tells you what to do *about* the wind.

Heading 090°, track 097° means drift is +7° and WCA is −7°. Same seven degrees, opposite sense, and an exam will happily ask for either.

Port and starboard

Port is left. Starboard is right. British and DGCA documents use them freely; American ones say left and right.

The memory aid that never fails: **"port" and "left" both have four letters.**

"Course" — the word we will not use

British usage before about 1950 meant *heading*. Much current American usage means *track*. Two respectable traditions, opposite meanings, same word.

This module never uses it. Everything is heading or track, and there is no ambiguity. Be aware that an examination paper may still use "course" — when it does, it almost always means **desired track**.

2 • Why a boat explains this better than an aeroplane

Newcomers find it hard to believe that something as insubstantial as wind can shove a 400-tonne aircraft sideways. So we will start with something you can see.

Imagine a river ten nautical miles wide, flowing at five knots.

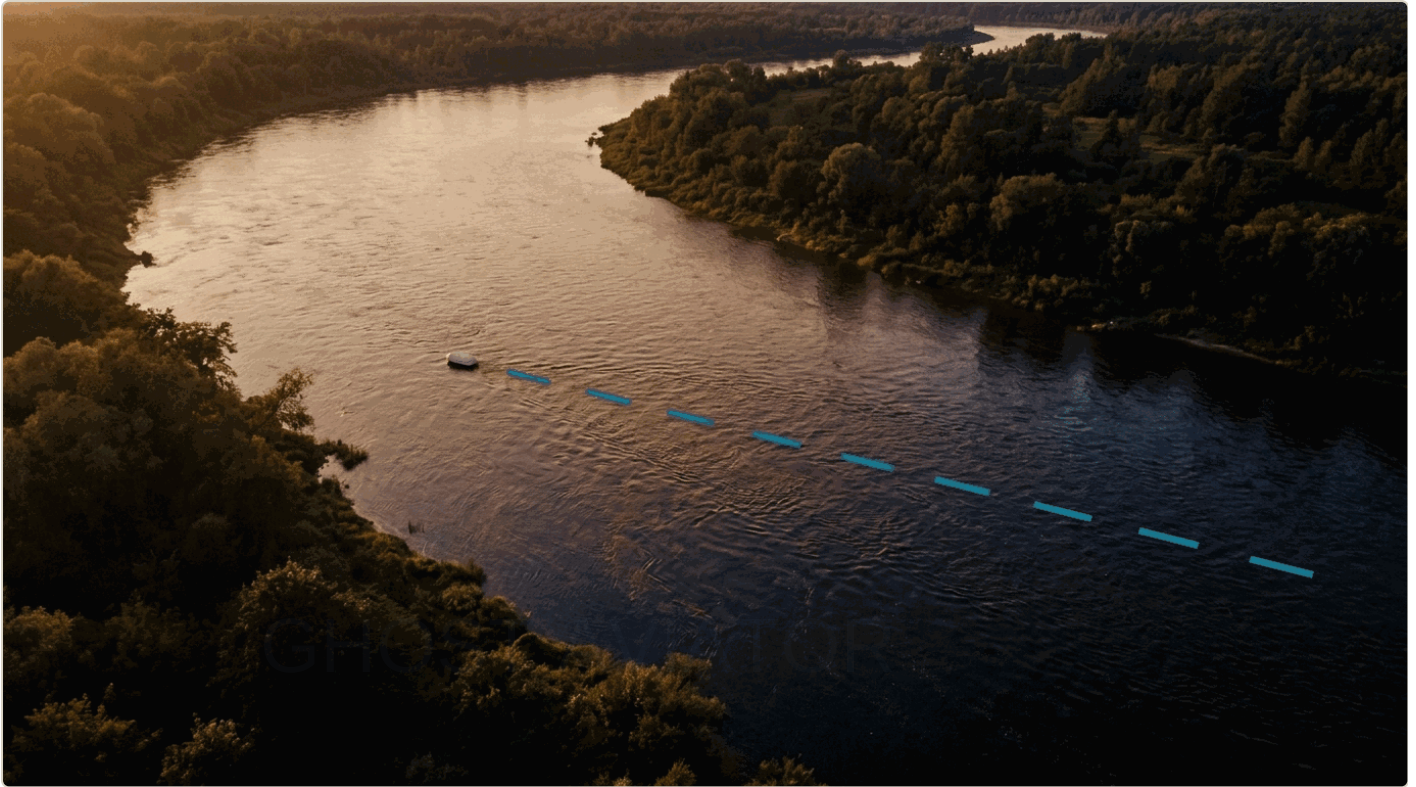


Figure 7.1 — Throw a stick in at the near bank. An hour later it is five nautical miles downstream, and it never moved under its own power at all. **The medium itself is travelling.**

■ the current — where the water goes

First, dam the river

Now the river is a still lake. You have a boat that does ten knots through the water. You point it straight at the far bank and open the throttle.

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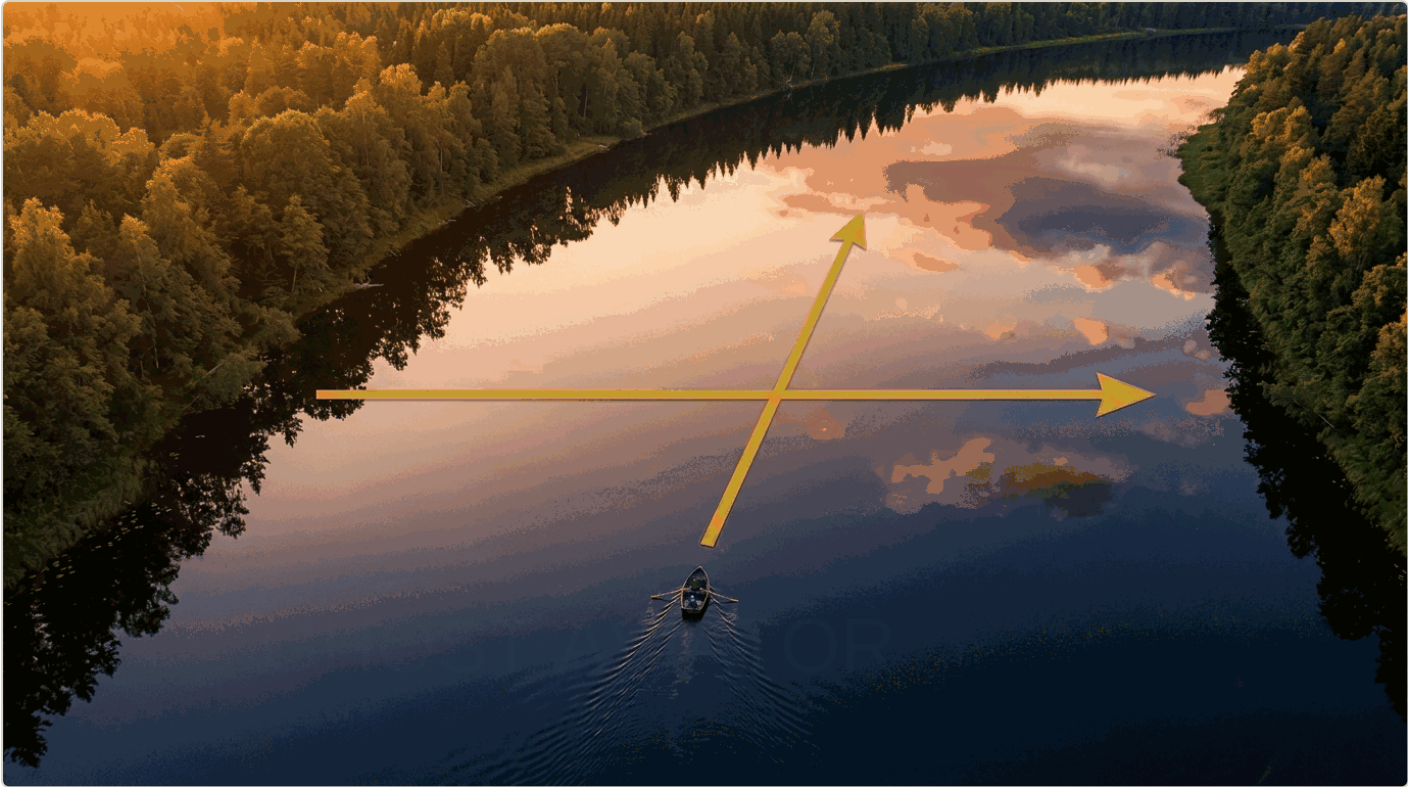


Figure 7.2 — Still water. One hour later you are ten miles across, directly opposite where you started. **Track equals heading, because nothing moved the water.** This is the calm day — and we get about six of those a year.

■ heading — where the boat points

Now let the river run again

Same boat, same heading, same throttle. But the current is back.

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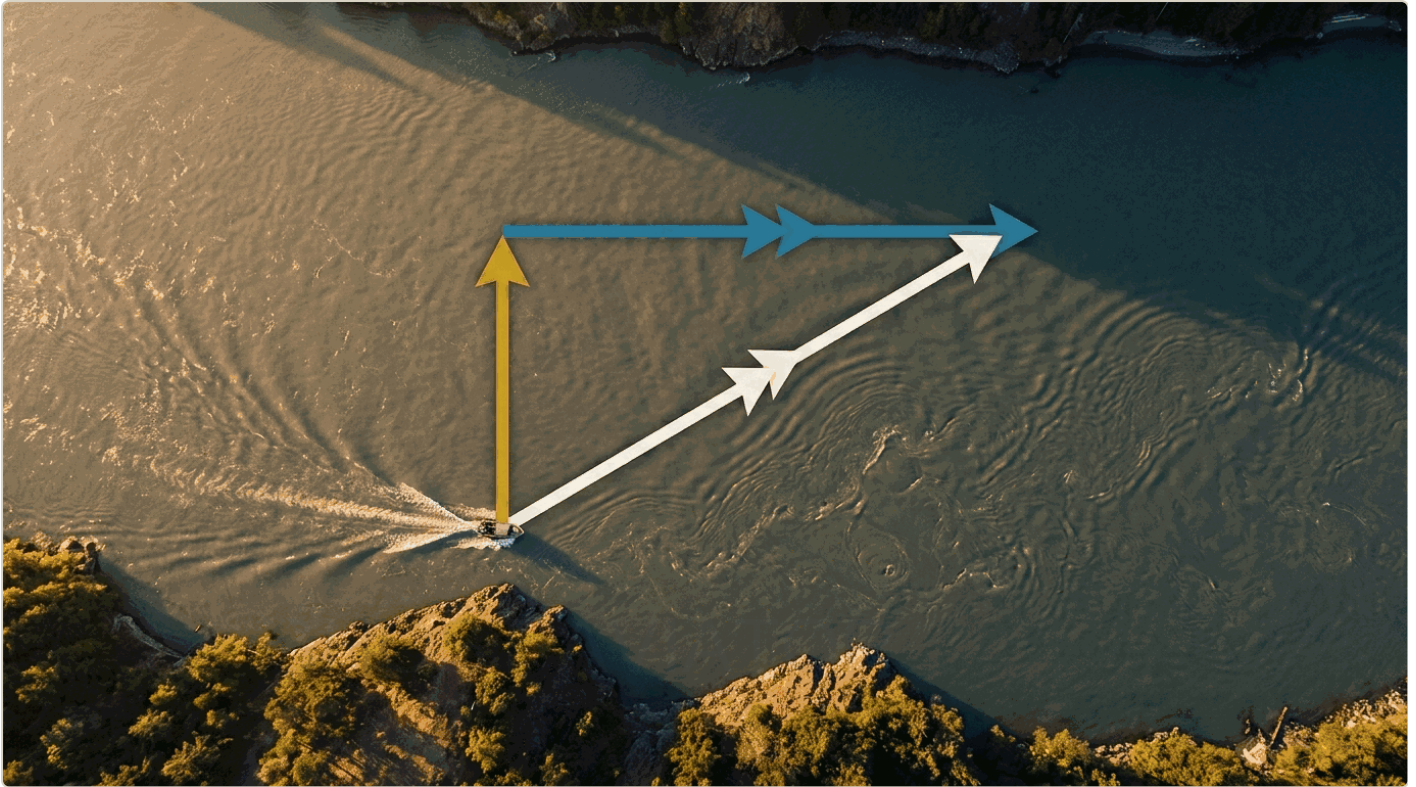


Figure 7.3 — You still point straight across and you still make ten miles across in the hour — but you also go five miles downstream, because the water took you there. You arrive **five miles below** the point you aimed at.

■ heading — one arrowhead
 ■ the current — three arrowheads
 ■ track — two arrowheads

Two things worth noticing before we go further

It is continuous, not sudden. After 12 minutes you are two miles across and one mile down. After 24 minutes, four across and two down. The boat is being carried the whole time, smoothly, along one straight resultant path.

You can fix it by aiming off. If you want to arrive directly opposite, point the boat *upstream* of your destination. That is the Wind Correction Angle, three hundred years before anyone put it on an aeroplane. It is Chapter 8's whole subject.

The step that matters: the air is the river

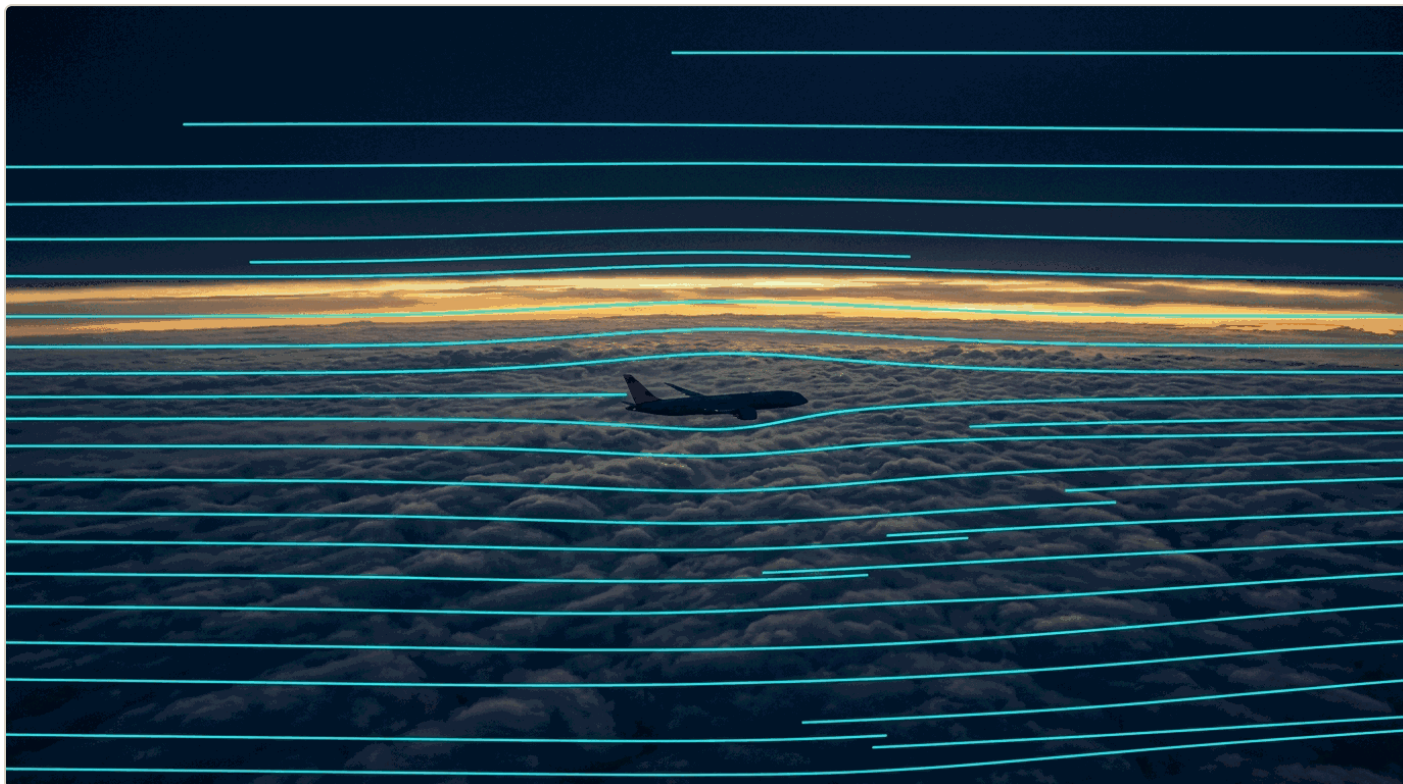


Figure 7.4 — Wind is not gusts. Wind is an **air mass** — a single coherent body of air, rarely smaller than 60 by 60 nautical miles, travelling across the ground exactly as the river travels past its banks.

■ the air mass in motion

This is the sentence the whole chapter rests on

Your aircraft is **supported by** that air mass. It is not fighting it, not pushing through it, not being buffeted by it. It is *floating in it*, exactly as the stick floats in the river — and it is carried with it, completely, whether it is a Cessna or a 747.

A 747 is no more able to resist a moving air mass than a stick is able to resist a moving river. Mass has nothing to do with it.

3 • Three vectors, and how to tell them apart

A vector is just an arrow that carries two pieces of information at once: a **direction** and a **magnitude**. Every navigation problem in this module is three of them arranged into a triangle.

The Air Vector

ONE ARROWHEAD • GOLD

Heading and TAS. Where the nose points, and how fast you move through the air. This is the speed you would make over the ground if the air were still.

The Wind Vector

THREE ARROWHEADS • CYAN

W/V — wind direction and speed. Where the air mass is going, and how fast. Always named by where it comes *from*.

The Ground Vector

TWO ARROWHEADS • WARM WHITE

Track and ground speed. The resultant — what you get when you join the air vector to the wind vector. Where you actually go.

The arrowheads are not decoration — learn to count them

Air = 1. Ground = 2. Wind = 3.

An exam will hand you an unlabelled triangle and ask which side is which. The arrowheads are the answer, and they are the only answer, because the colours will not be there.

The order is easy to hold: they run **1, 2, 3** in the order the words appear in "**air, ground, wind**" — alphabetical.

4 • The convention that costs the most marks

Wind direction is where it comes FROM. Never where it goes TO.

A wind written **330/30** is a wind blowing *from* 330° at 30 knots. On a diagram, its arrow **points toward** 150° — the exact opposite of the number in its name.

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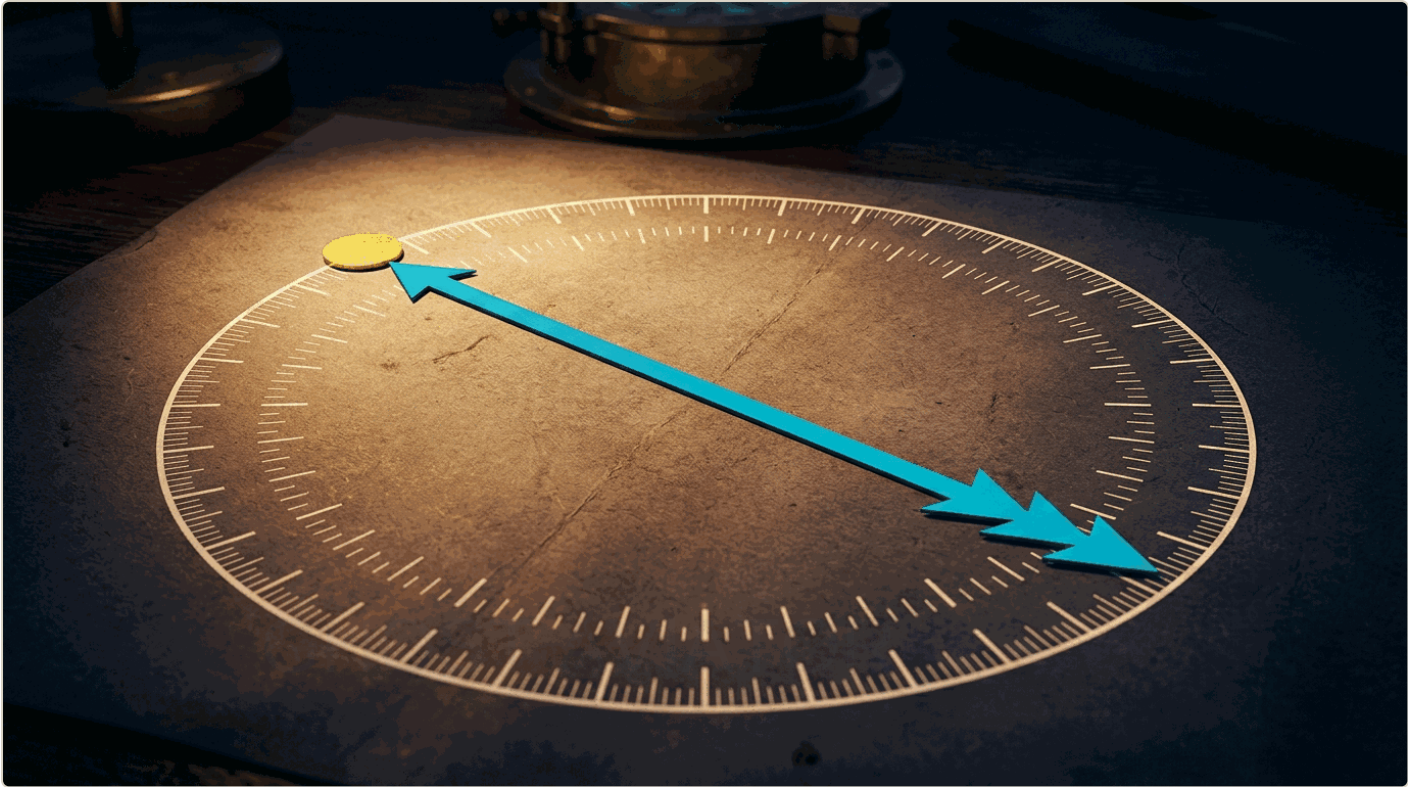


Figure 7.5 — The name of the wind is at the *tail* of the arrow, not the head. A 330 wind starts at 330 and travels away toward 150.

■ where the wind comes FROM — its name ■ where the air actually travels

And this matches how you already talk about weather

You already use this convention without thinking. A *southerly* is warm because it has come up from the south. A *westerly* is wet because it has crossed the Atlantic. Nobody has ever meant "a wind heading south".

The aviation convention is the everyday one. It only feels strange when you start drawing arrows.

Where students lose the mark

Add 180° before you draw, never after. Convert the W/V into a direction the arrow actually points, write that number down, and then draw. Students who try to hold the reversal in their head while also managing heading and drift are the ones who lose it.

Wind 240/30? The arrow points **060**. Write "060" on your scrap paper and work with that.

5 • The triangle of velocities

Three vectors. Two you know, one you want. Join them nose to tail and the answer is the side that closes the shape.

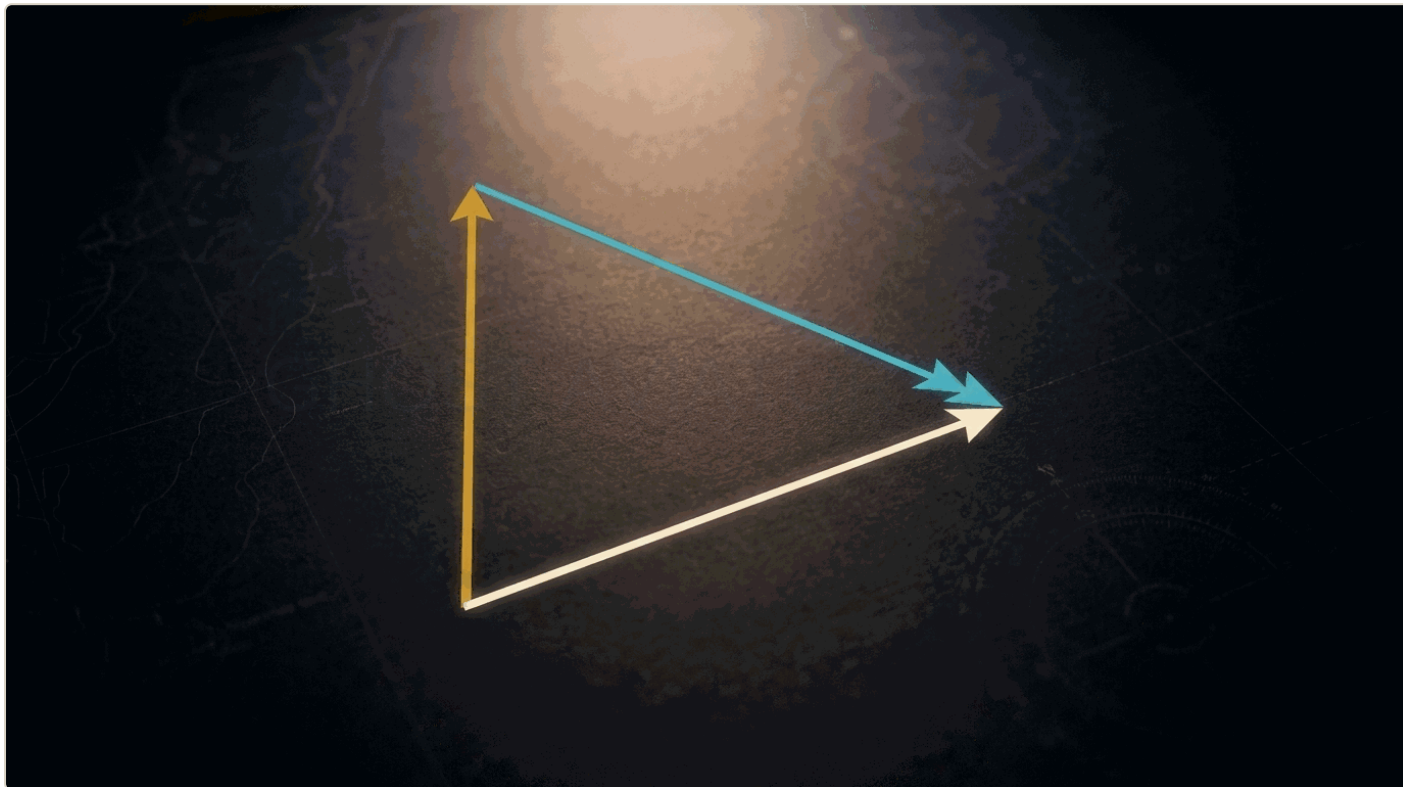


Figure 7.6 — The triangle of velocities. Come back to this page whenever the next two chapters stop making sense; everything in them is this shape wearing different numbers.

- air vector — heading & TAS — 1 arrowhead
- wind vector — W/V — 3 arrowheads
- ground vector — track & GS — 2 arrowheads

What the flight computer is really doing

Pilots do not draw this on graph paper in the cruise. They solve it on a computer — and the old slide-rule wind face was nothing more than **a machine for producing this scale drawing quickly**. It was literally drawing the triangle for you, on a rotating disc.

The CX-3 does the same job with trigonometry instead of geometry. **The triangle has not gone anywhere**. It is still what is being solved — you just no longer see it happen, which is exactly why you have to understand it now.

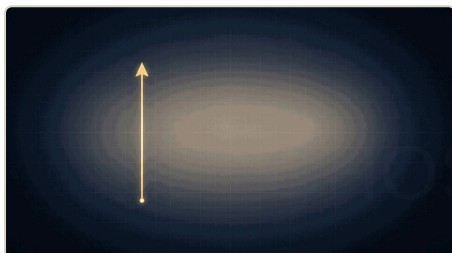
6 · Building the triangle, one vector at a time

The problem we will solve three ways

You are in a Warrior PA-28. TAS **100 knots**. Steady **heading 000°(T)**. Forecast **W/V 240/30**.

What will your track and ground speed be?

STAGE 1 — WHAT YOU KNOW



7.7 — The **air vector**. Direction 000°, length 100 units. One arrowhead.

STAGE 2 — ADD THE WIND



7.8 — From its tip, the **wind vector**: 30 units, pointing toward 060°. Three arrowheads. Still open.

STAGE 3 — CLOSE IT



7.9 — Join start to finish and read the **ground vector**: track 012°, ground speed 118 knots.

Read the three frames again, in order

Nothing moves between them. The gold vector you drew first is still exactly where it was in the last frame. All that happens is that information gets *added* — and on the third frame the shape closes and the answer simply appears.

That is what "solving" a triangle of velocities means. There is no calculation in the drawing. There is only the closing side.

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Worked example 7.1 — both methods, side by side

Problem. TAS 100 kt, heading 000°(T), W/V 240/30. Find track and ground speed.

METHOD 1 — THE ARITHMETIC

resolve into components, then recombine

1. Turn the wind round. From 240 means it points toward **060°**.

2. Break both vectors into east and north parts:

$$E = 100 \cdot \sin 0 + 30 \cdot \sin 60 = 25.98$$

$$N = 100 \cdot \cos 0 + 30 \cdot \cos 60 = 115.0$$

3. Ground speed is the hypotenuse:

$$\sqrt{(25.98^2 + 115.0^2)}$$

4. Track is the angle:

$$\tan^{-1}(25.98 \div 115.0)$$

Track 013° · GS 118 kt

METHOD 2 — THE CX-3

and there is a catch — read the note below

1. **FLT** → **Wind Correction**.
2. This function takes **GS**, **TAS**, **TCrs** and **THdg** — and solves for the **wind**.
3. It runs the *opposite* way to this question.
4. **And nothing else on the machine does either.** **PLAN** takes **TCrs** — the track — as an *input* and returns **CHdg**. It solves the opposite problem: known track, find heading.
5. So **this case is trigonometry**, on the **CALC** keypad. Four lines, and it is exact.

Track 012° · GS 118 kt

Which do you use? For a single triangle in an exam, the trigonometry is fast and it always works. The **PLAN** menu earns its keep on a multi-leg flight plan, which is Chapter 8B. **Know both, because the CX-3's Wind Correction function does not answer this question — it answers the reverse one, and reaching for it here is a genuine trap.**

Sanity check — do this one in your head first. The wind is behind you and off to the left, so it must push you forward and right. Ground speed should therefore be more than 100, and track should be east of 000. Both are true: 118 knots, tracking 012. If you had got 89 knots and 343°, you would have applied the wind backwards.

Why the two methods differ by one degree

The trigonometry gives 12.7°, which rounds to 013. The published answer is 012, read off a rotating disc to the nearest degree.

Neither is wrong to any degree that matters — a degree of track over 100 nautical miles is under two miles. **But when exam options are one degree apart, trust the arithmetic.** It is exact, and it is reproducible.

7 • Which way did it push you?

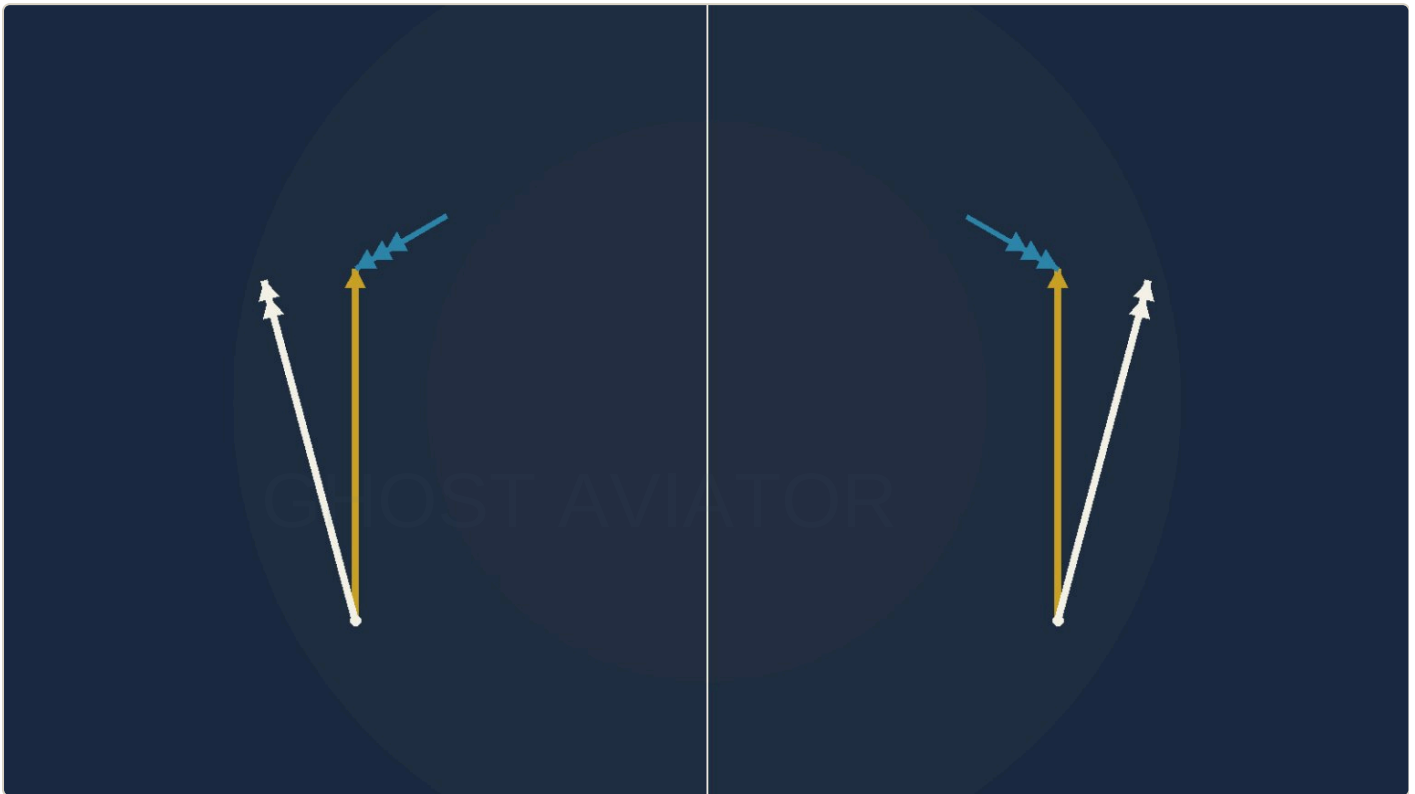


Figure 7.10 — The wind always pushes you away from where it comes from. Wind from the right pushes you left; wind from the left pushes you right.

■ heading ■ track ■ wind

The one-line rule that settles every drift question

Track = Heading + Drift, with starboard drift positive and port drift negative.

Heading 000 with 12° starboard drift gives track 012.

Heading 090 with 4° port drift gives track 086.

And the reverse, for Chapter 8: **Heading = Track – Drift**.

Where students lose the mark — the 360/000 boundary

Heading 005° with 8° of port drift is **not** track –003°. It is track **357°**.

Anything at or below zero, add 360. Anything at or above 360, subtract 360. Do it as a reflex, before you look at the answer options — because one of those options will be the number you get if you forget.

Questions

What you are given, and what you are finding

Every row gives you a **heading**, a **W/V** and a **TAS**. Find the **track** and the **ground speed**.

That is the triangle with the air vector and wind vector known, solving for the ground vector — exactly Figure 7.9. Thirty of them. Answers follow the second table.

Q1 • Eleven rows

#	HDG°(T)	W/V	Track°(T)	TAS	GS
1	273	230/40		150	
2	181	150/30		90	
3	054	350/28		88	
4	084	255/55		210	
5	141	280/35		190	
6	274	030/40		150	
7	213	060/35		150	
8	029	090/40		170	
9	305	350/16		100	
10	187	270/60		110	
11	310	045/45		320	

Q2 · Nineteen rows, and the speeds get serious

#	HDG°(T)	W/V	Track°(T)	TAS	GS
1	138	125/50		390	
2	253	180/70		415	
3	131	210/40		485	
4	100	315/55		480	
5	270	315/55		110	
6	200	125/50		210	
7	180	210/40		135	
8	140	180/70		170	
9	093	045/45		210	
10	103	060/35		240	
11	237	270/60		205	
12	343	030/40		350	
13	030	350/16		390	
14	315	280/35		375	
15	145	090/40		420	
16	290	255/55		490	
17	191	150/30		480	
18	257	350/28		475	
19	157	230/140		460	

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Answers

How these were produced

Every row was solved by resolving both vectors into east and north components and recombining — the exact method in Worked Example 7.1. Tracks are rounded to the nearest degree, ground speeds to the nearest knot.

All thirty agree with the published key within one degree and three knots. Unlike Chapters 5 and 6, there is nothing to flag here — this chapter's answers are sound throughout.

The **drift** column is not in the original question. It is added so you can check your *reasoning*, not just your answer.

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A1

Row 1 in full. HDG 273°, W/V 230/40, TAS 150.

METHOD 1 — THE ARITHMETIC

1. Wind from 230 points toward **050°**.

2. Components:

$$E = 150 \cdot \sin 273 + 40 \cdot \sin 050 = -119.2$$

$$N = 150 \cdot \cos 273 + 40 \cdot \cos 050 = 33.6$$

3. $GS = \sqrt{(119.2^2 + 33.6^2)}$

4. $\text{Track} = \text{atan2}(-119.2, 33.6)$

Track 286° · GS 124 kt

METHOD 2 — THE REASONING CHECK

do this before you trust any answer

Heading 273 is roughly west. The wind is from 230 — the south-west — so it is coming over your **left shoulder**.

A wind from the left must push you **right**, so track should be *more* than 273.

It is also partly behind you, so ground speed should be *less* than TAS — no: partly behind means *more*. Check the geometry: from 230 onto a 273 heading is close to abeam, slightly behind.

expect track just right of 273, GS near 150 or below

286 and 124. Track moved right as predicted. The ground speed came out well below TAS because the wind, resolved along the track, is mostly a headwind component. The reasoning got the direction right and that is all it has to do.

Rows 2–11 are the identical four steps: reverse the wind, resolve, recombine, read.

#	HDG°(T)	W/V	Track°(T)	TAS	GS	drift
1	273	230/40	286	150	124	<i>13°S</i>
2	181	150/30	195	90	66	<i>14°S</i>
3	054	350/28	072	88	80	<i>18°S</i>
4	084	255/55	082	210	264	<i>2°P</i>
5	141	280/35	135	190	218	<i>6°P</i>
6	274	030/40	262	150	171	<i>12°P</i>
7	213	060/35	218	150	182	<i>5°S</i>
8	029	090/40	016	170	155	<i>13°P</i>
9	305	350/16	298	100	89	<i>7°P</i>
10	187	270/60	157	110	119	<i>30°P</i>
11	310	045/45	302	320	327	<i>8°P</i>

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Row 19 in full — and read the wind speed twice. HDG 157°, W/V 230/140, TAS 460.

METHOD 1 — THE ARITHMETIC

1. Wind from 230 points toward **050°**.
Speed **140 knots**.

2. Components:

$$E = 460 \cdot \sin 157 + 140 \cdot \sin 050 = 287.0$$

$$N = 460 \cdot \cos 157 + 140 \cdot \cos 050 = -333.4$$

3. $GS = \sqrt{287.0^2 + 333.4^2}$

Track 139° · GS 440 kt

METHOD 2 — IS 140 KNOTS EVEN REAL?

yes, and this is why the row is here

140 knots of wind looks like a misprint. It is not.

At the levels where a 460-knot TAS lives, the **jet stream** routinely runs 100 to 200 knots.

Check it: at 40 knots this row would give track 152 and GS 450. The published answer is 139 and 440 — which only works at 140.

the wind really is 140 kt

Look at what that wind did. *It bent the track 18 degrees and took 20 knots off the ground speed. Over a three-hour sector, ignoring it puts you the better part of two hundred miles from where you meant to be. This is why the jet stream is a flight-planning subject and not a curiosity.*

Rows 1–18 use the same four steps. The only thing that changes is how hard the wind is working.

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#	HDG°(T)	W/V	Track°(T)	TAS	GS	drift
1	138	125/50	140	390	341	2°S
2	253	180/70	263	415	400	10°S
3	131	210/40	126	485	479	5°P
4	100	315/55	103	480	526	3°S
5	270	315/55	241	110	81	29°P
6	200	125/50	214	210	203	14°S
7	180	210/40	169	135	102	11°P
8	140	180/70	119	170	125	21°P
9	093	045/45	104	210	183	11°S
10	103	060/35	109	240	216	6°S
11	237	270/60	225	205	158	12°P
12	343	030/40	338	350	324	5°P
13	030	350/16	032	390	378	2°S
14	315	280/35	318	375	347	3°S
15	145	090/40	150	420	398	5°S
16	290	255/55	294	490	446	4°S
17	191	150/30	193	480	458	2°S
18	257	350/28	254	475	477	3°P
19	157	230/140	139	460	440	18°P

Two patterns worth spotting in that table

Drift shrinks as TAS grows. Compare row 5 (TAS 110, drift 28°) with row 3 (TAS 485, drift 5°) — similar winds, wildly different drift. The faster you go, the less time the wind has to work on you.

Ground speed can beat TAS by a long way. Row 4: TAS 480, ground speed 525. That is 45 knots of free progress — and on the reciprocal it would be 45 knots against you. The same air mass gives and takes.

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90-second speed drill

No computer needed for most of these. 90 seconds. Go.

1. Heading 090°, track 084°. How much drift, and which way?
2. Same aircraft. What is the wind correction angle?
3. A wind is given as 270/25. Which way does its arrow point on a diagram?
4. How many arrowheads on the wind vector? On the ground vector?
5. Heading 355° with 10° of starboard drift. What is the track?
6. Heading 010° with 15° of port drift. What is the track?
7. Which vector is gold in every diagram in this module?
8. Wind from directly behind you. How much drift?
9. Wind from directly ahead. Is ground speed more or less than TAS?
10. Two aircraft, same wind. One at 120 kt TAS, one at 480. Which drifts more?

ANSWERS

1. From 090 to 084 — **6° port (left)**
2. **WCA +6°** — same size, opposite sense
3. Toward **090°** — from 270 means it blows to 090
4. Wind **three**. Ground **two**. (Air is one.)
5. $355 + 10 = 365$, so **005°** — subtract 360
6. $010 - 15 = -5$, so **355°** — add 360
7. The **air vector** — heading and TAS
8. **None**. A pure tailwind adds speed and bends nothing
9. **Less**. Straight headwind subtracts from ground speed
10. The **120-knot** aircraft — less speed, more time for the wind to act

Quick reference — Chapter 7

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Thing	What it is	How to remember it
Heading	Where the nose points	Gold vector · 1 arrowhead
Track	Where you actually go	Warm white vector · 2 arrowheads
W/V	Where the air comes from, and how fast	Cyan vector · 3 arrowheads
Drift	Heading to track	Track = Heading + Drift (starboard +)
WCA	Track to heading	Same number as drift, opposite sign. The Ch 8A formula returns <i>drift</i> — subtract it.
Port / starboard	Left / right	"port" and "left" — four letters each
Wind direction	Where it comes FROM	Arrow points to W/V + 180°
Track & GS from a known wind	The Chapter 7 problem	Trigonometry — no CX-3 function does this
FLT → Wind Correction	Solves for the <i>wind</i>	Not this chapter's problem — it runs backwards

The five things to carry out of this chapter

- **You float in the air mass.** A 747 drifts exactly like a stick in a river
- **Air 1, ground 2, wind 3** — arrowheads, alphabetical
- **Wind direction is where it comes FROM** — add 180° before you draw
- **Track = Heading + Drift**, starboard positive
- **Faster aircraft drift less** — the wind has less time to work

Chapter 7 — The Triangle of Velocities

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*Next: **Chapter 8A — Calculation of Heading and Ground Speed**, where the triangle runs the other way — you know the track you want, and you solve for the heading that gets you there.*

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