Glider Performance

Basic Review

Seriously, it’s just a basic review with a few technical points

January 27, 2024

Purpose and Agenda

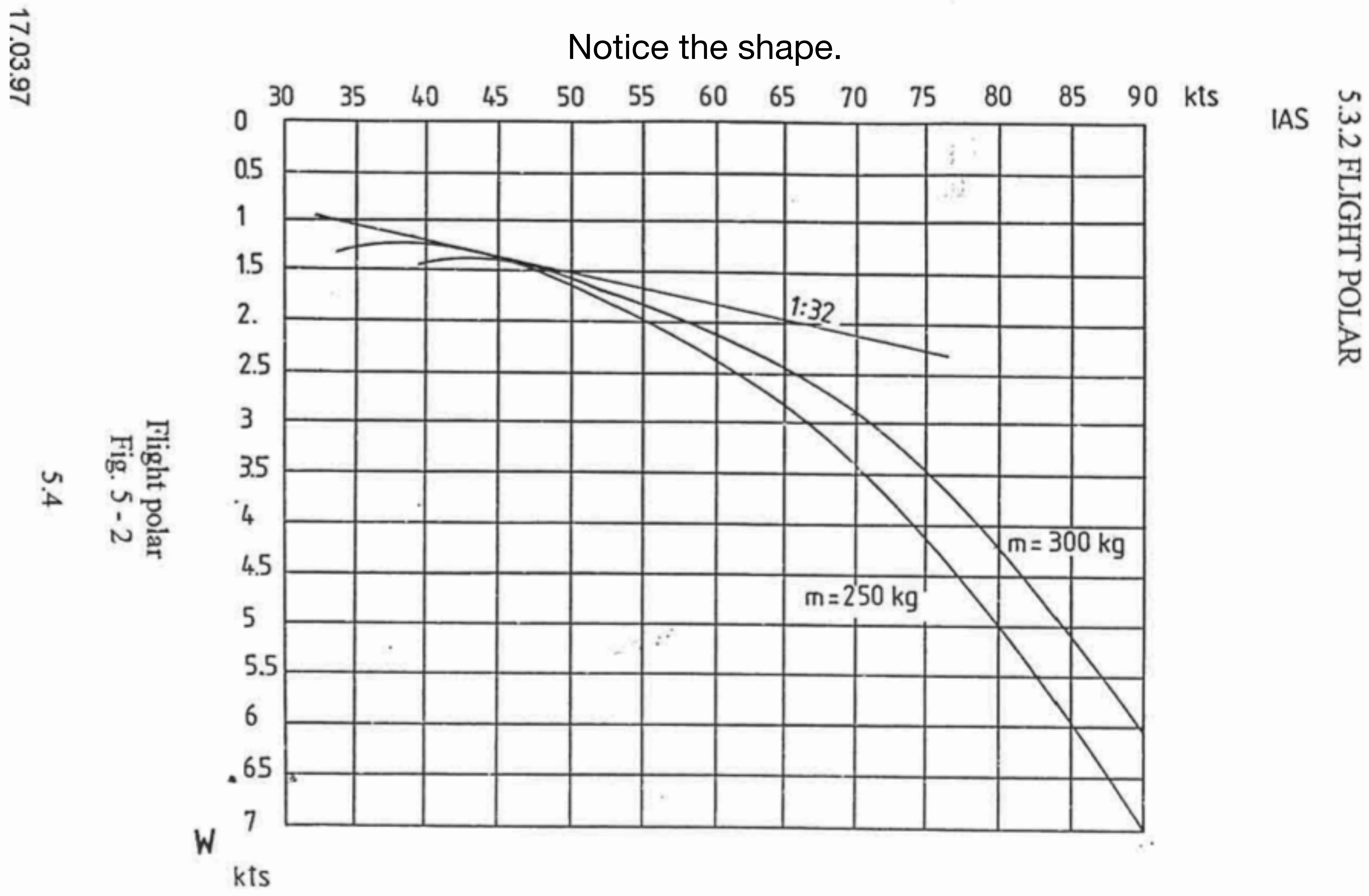
Review basic glider performance
Some stuff is important and some is just interesting.

- Flight polar — measured and approximated
- Minimum sink
- Manually calculating glide ratio
- Effects of wind and weight

The Polar

PW5 Flight Polar from Pilot Operating Handbook

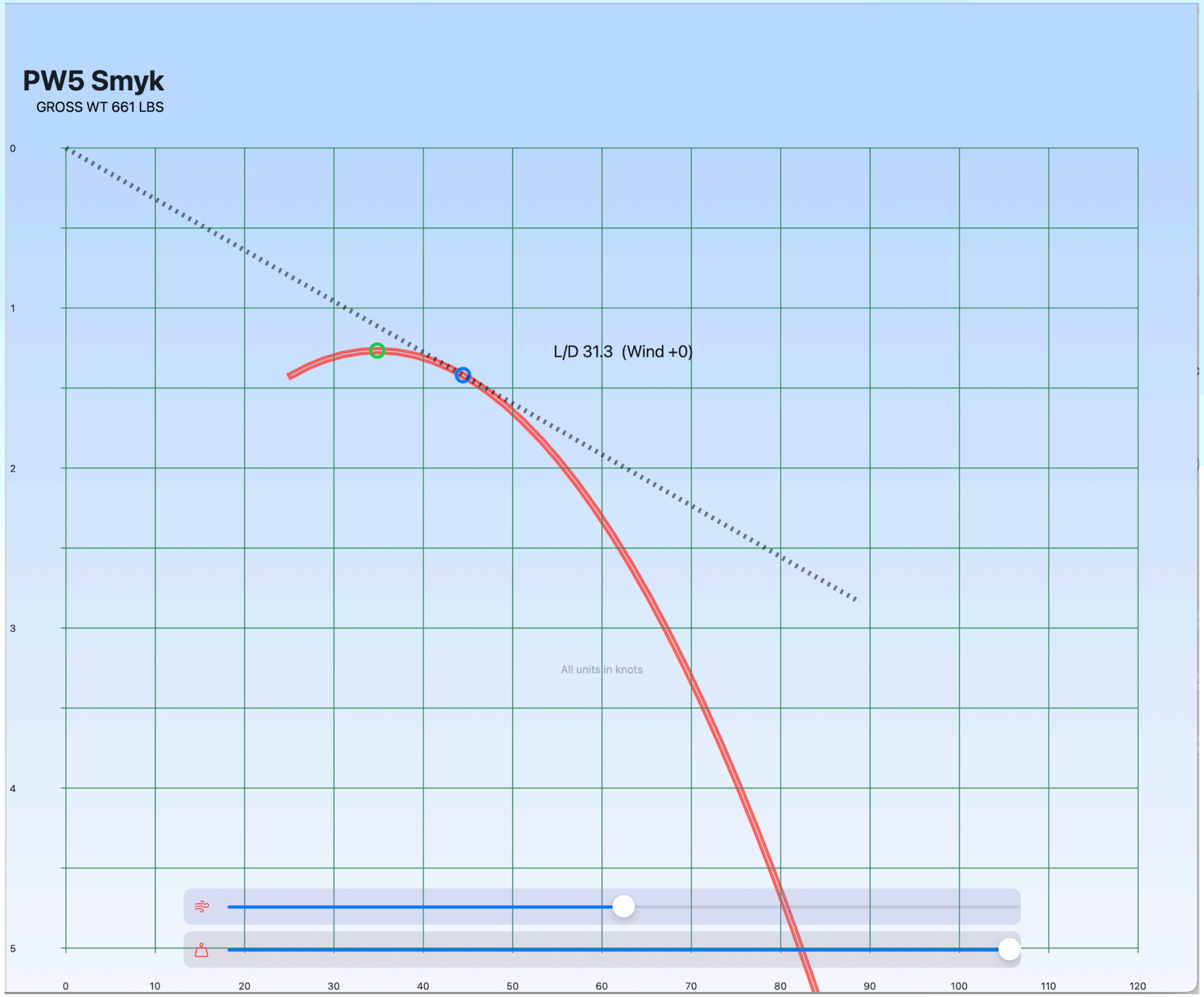
Notice the shape.



Making Sense of the Polar

It's approximated with a parabola! More on this, later.

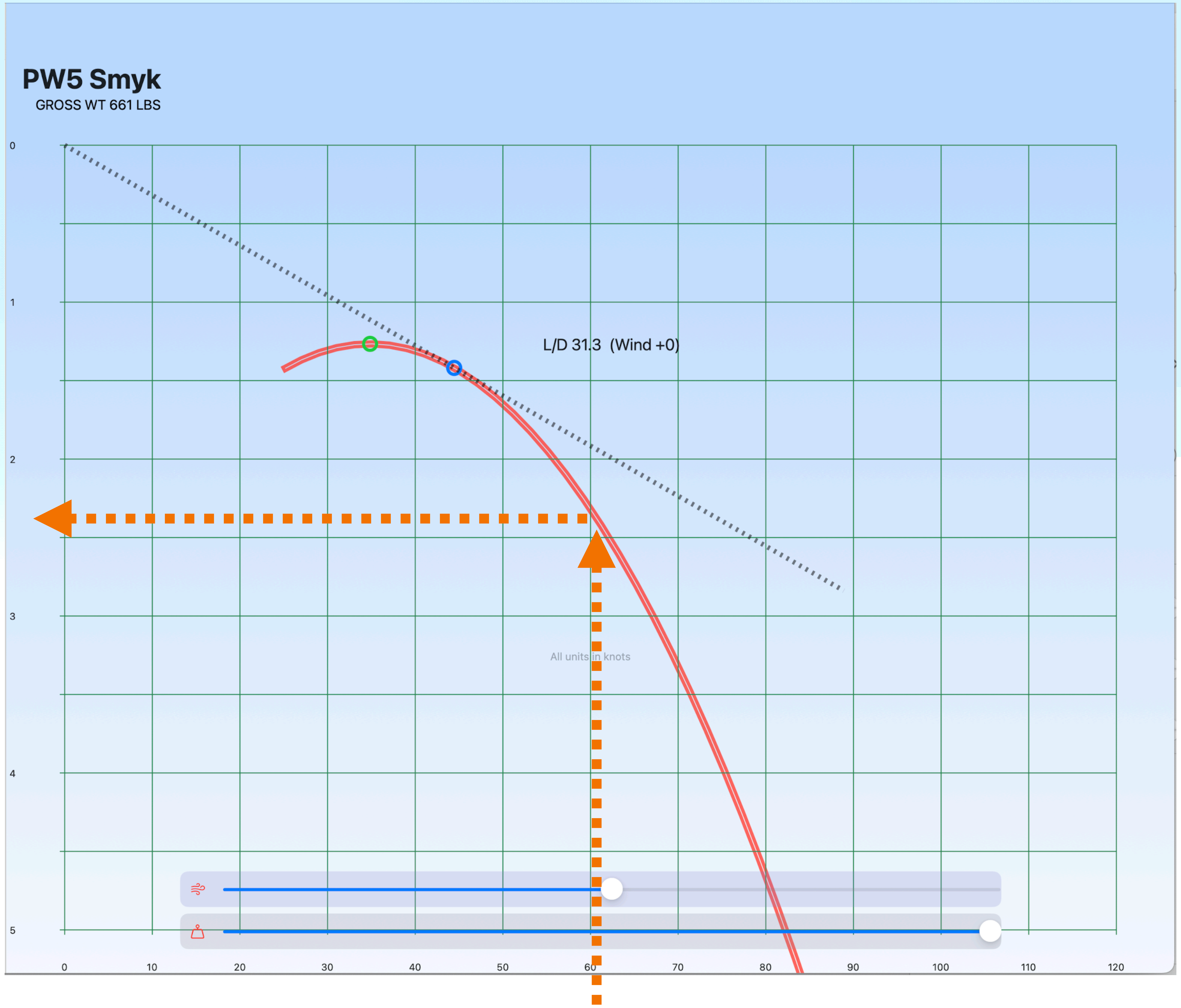
- Polar shows the glider sink rate versus airspeed (IAS) for a specific weight.
- Airspeed and Sink Rate must be the same units when calculating glide ratio.
- You'll find polars with various units (eg., knots, meters per second, etc.)
- In this presentation, the polar will be shown in knots.



Ex. Sink rate at 60 knots

661 lbs gross weight

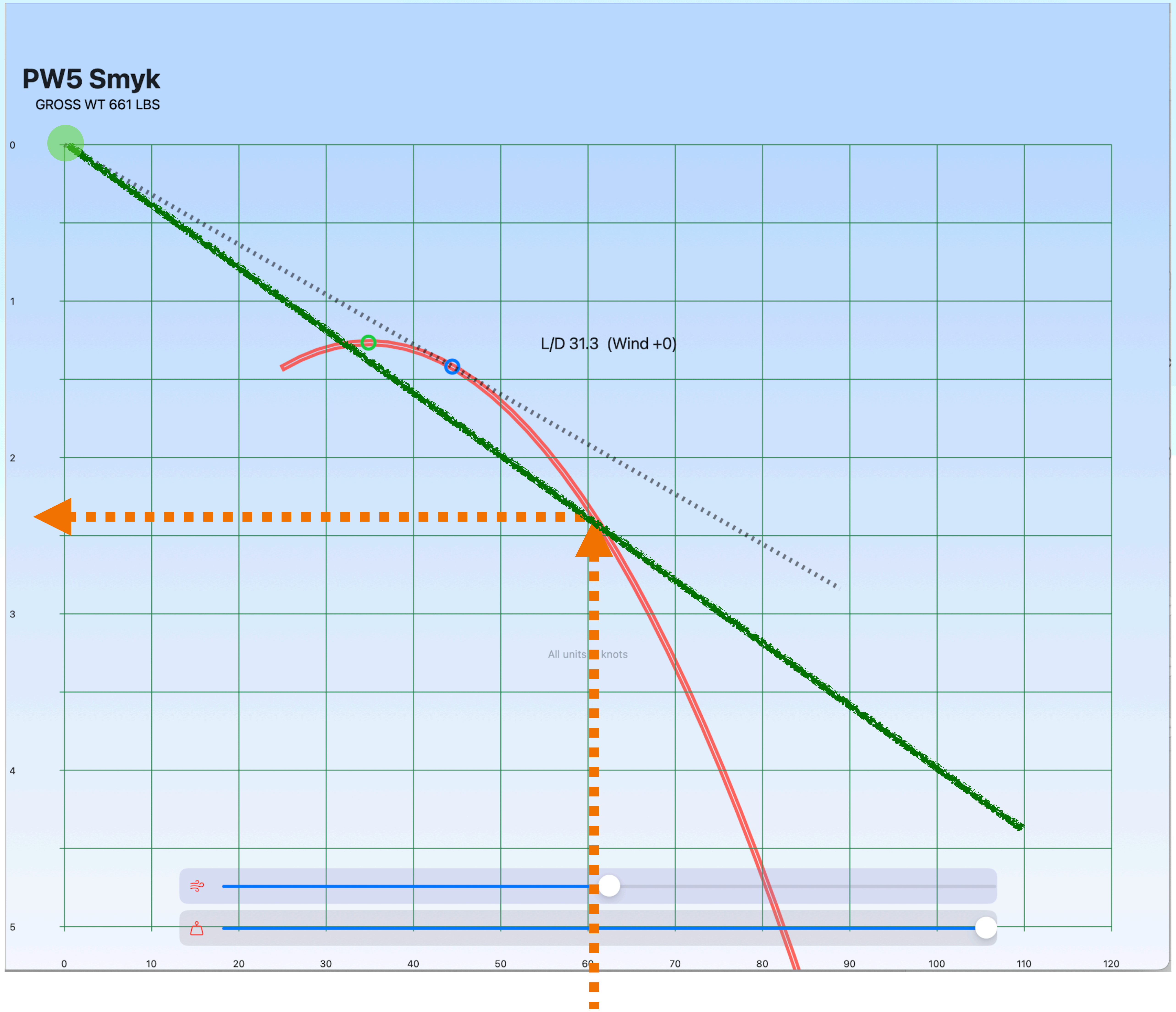
- IAS 60 knots
- Sink rate 2.3 knots
- Glide ratio (still air) 60/2.3 = 26:1
- In still air at 60 knots, 661 lbs., the glider descends 1 foot when traveling 26 feet



Glide Ratio

Math and Graphical Methods

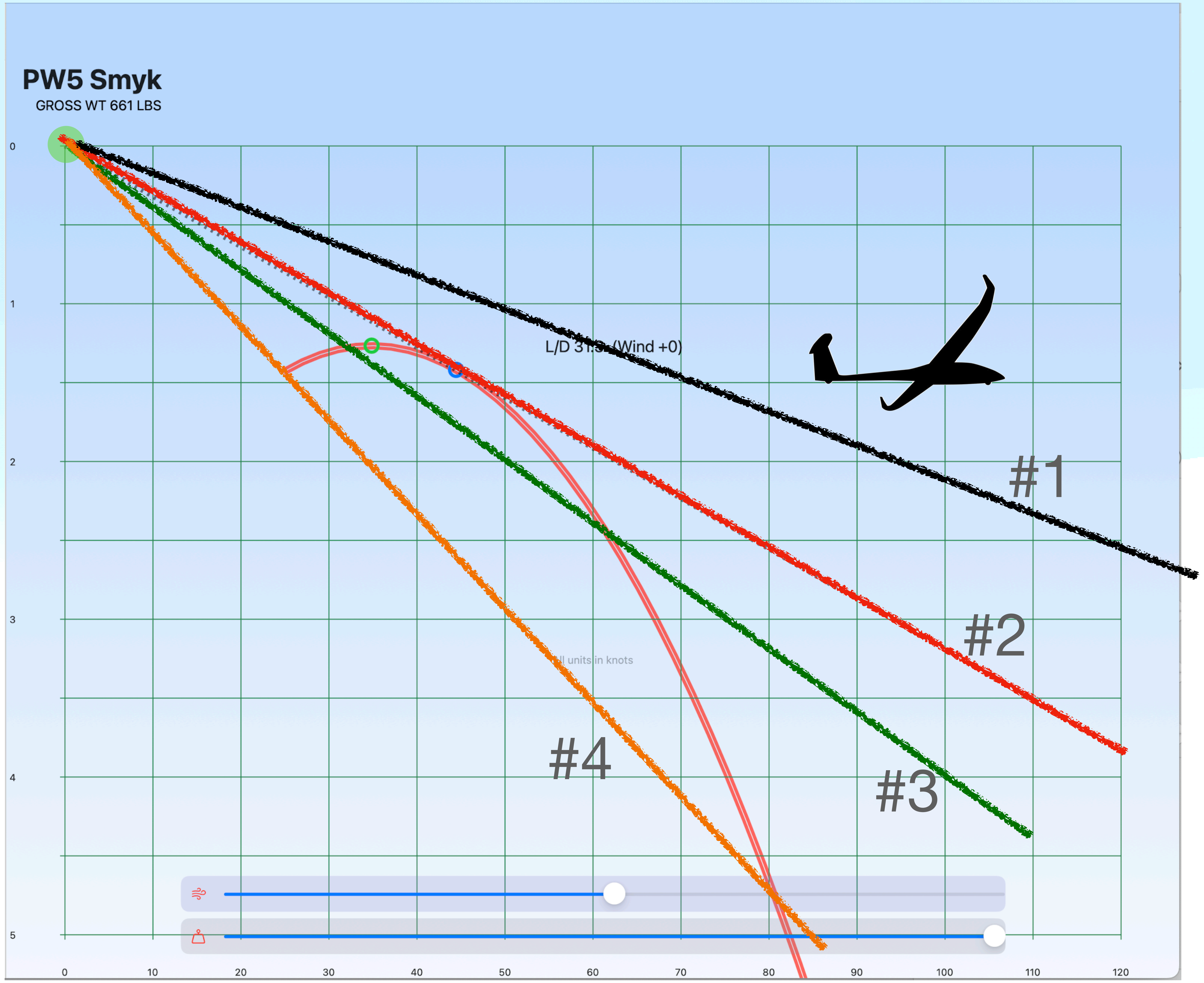
- IAS 60 knots
- Sink rate 2.3 knots
- Glide ratio (still air) 60/2.3 = 26:1
- Green line starting at origin and crossing through the polar at 60 knots represents glide ratio.
- Slope of line = glide ratio
- Notice that a 26:1 glide ratio is attained at two different airspeeds (60 and 32 knots).



Glide Ratios

More zero-wind examples

- Which glide ratios (lines #1 through #4) are possibilities?



Glide Ratios

More zero-wind examples

- Polar is used to calculate glide ratio for a range of speeds.

Maximizing Glide Ratio

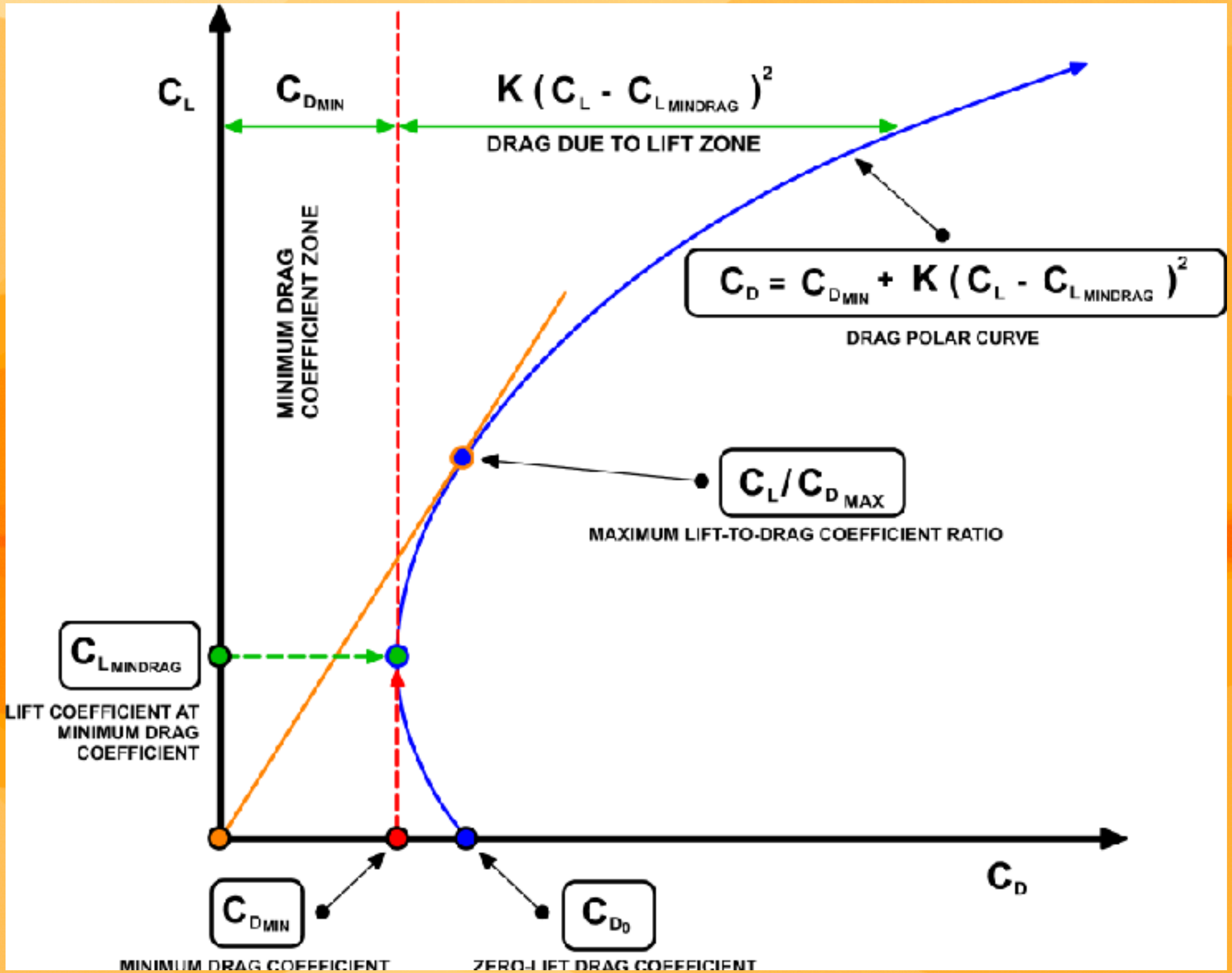
Best L/D (zero-wind example)

- Maximum glide ratio (Best L/D) is graphically shown by drawing a line from the origin to a point tangent on the polar.
- Red line is Best L/D, resulting in maximum glide ratio (approximately 31:1 for the PW5).

Terminology

"Best L/D" = Max Glide Ratio

- Clearing up some misconceptions.
- Lift is proportional to $C_L * V^2$
- Drag is proportional to $C_D * V^2$
- In short, best glide ratio occurs at maximum CL/CD, not at maximum L/D
- **"Best L/D" is NOT synonymous with maximum L/D**
- "Best L/D" refers to Max Glide Ratio
- The maximum glide actually occurs at maximum CL/CD.
- The maximum L/D is minimum drag because in unaccelerated flight L = Weight of the glider, and therefore is unchanged. In this case, D would be minimized in order to maximize L/D.
- How does the math work?
- <u>Forget everything you just saw on this slide.</u>



What?

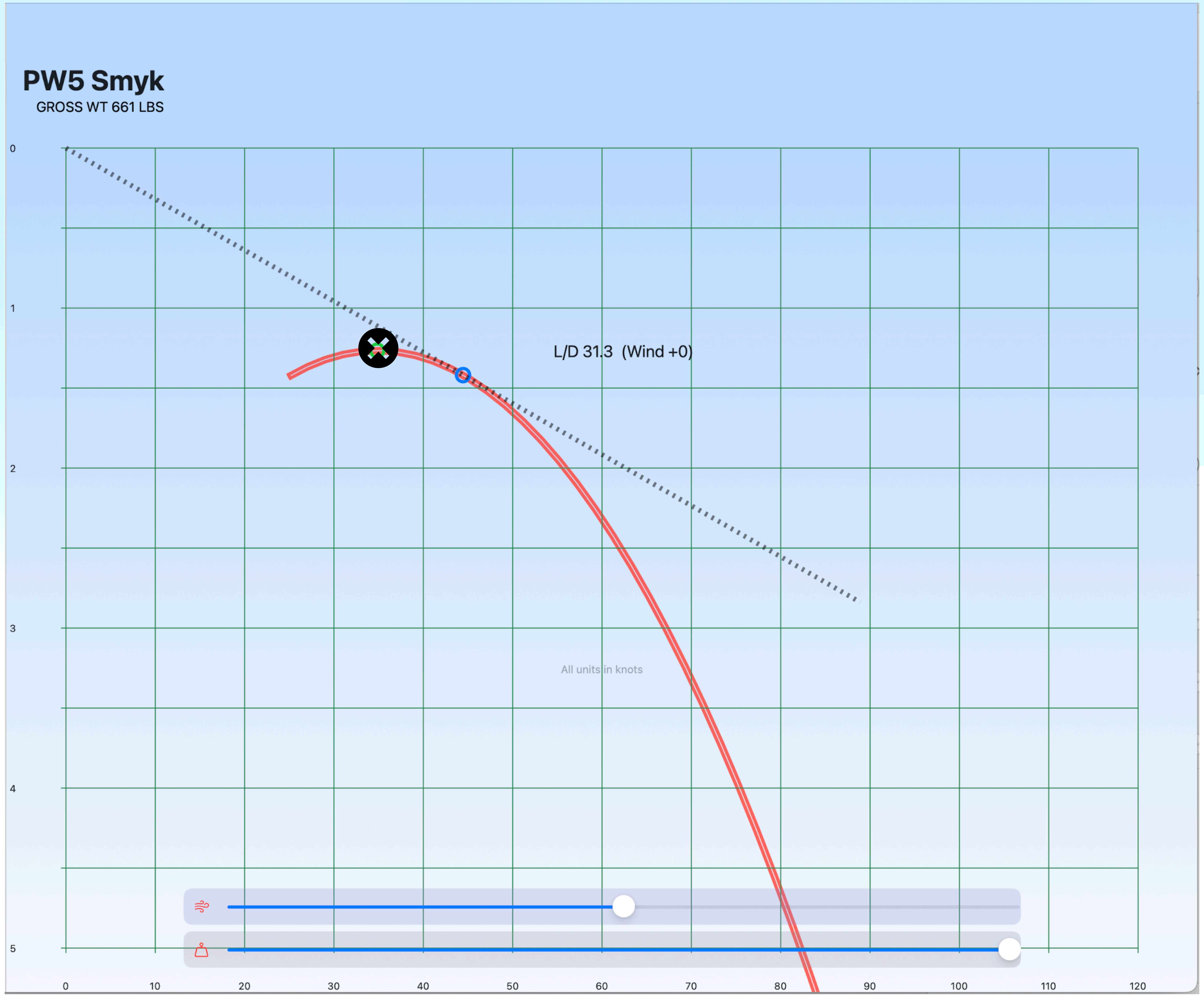
Please summarize!

- The term “Best L/D” refers to maximum glide ratio.
- Using the polar, Best L/D in zero-wind conditions is found by drawing a line from the origin to a point tangent to the polar.

Minimum Sink

Using the Polar

- Minimum sink is found at the apex of the polar.
- Minimum sink maximizes time aloft.
- Minimum sink, along with other factors, is a consideration in establishing thermaling speed.



Summary

What are the key points, so far

- Flight polar can be used to find Best L/D speed to maximize the glide ratio.
- Flight polar can be used to find minimum sink.
- <u>DEFINITION</u>: **Best L/D** results in maximum glide distance for a loss in altitude. Best L/D speed does NOT result in minimum drag.
- <u>DEFINITION</u>: **Minimum Sink** result in maximum time aloft. At minimum sink speed, the drag is also reduce to its minimum. For airplane pilots, this would typically be holding speed for minimum fuel consumption.

Manual glide calculation (no wind)

In a Perfect World

- Assumptions
  - Glide Ratio from Polar = 31:1 at 45 KT
  - Distance to airport 6 NM (nautical miles).
  - Airport elevation 500 ft MSL
  - Safety altitude 1,000 ft AGL
- A good place to start is to covert 6 NM to feet. This will enable us to work directly with feet in the altitude calculation. 6 * 6076 ft/NM = 36,456 ft.
- Next, divide the distance (36,456 ft) by the glide ratio (31) to calculate the altitude loss over 6NM. Altitude loss = 36,456/31 = 1,176 ft.
- Our goal is to arrive the airport at 1,000 ft above field elevation (500+1000 = 1,500 MSL).
- Therefore, in a perfect world one would need to be at 2,676 ft MSL in order to glide to an airport 6 NM away.

Manual glide calculation (no wind)

In the Real World

- Assumptions
  - Glide Ratio from Polar = 31:1 at 45 KT
  - **Glide Ratio used in calculations, 50% of 31:1, 15.5:1**
  - Distance to airport 6 NM (nautical miles).
  - Airport elevation 500 ft MSL
  - Safety altitude 1,000 ft AGL
- A good place to start is to covert 6 NM to feet. This will enable us to work directly with feet in the altitude calculation. 6 * 6076 ft/NM = 36,456 ft.
- Next, divide the distance (36,456 ft) by the glide ratio (15.5) to calculate the altitude loss over 6NM. Altitude loss = 36,456/15.5 = 2,352 ft.
- Our goal is to arrive the airport at 1,000 ft above field elevation (500+1000 = 1,500 MSL).
- Therefore, one would need to be at 3,852 ft MSL in order to glide to an airport 6 NM away. Let’s call it 4,000 ft MSL!

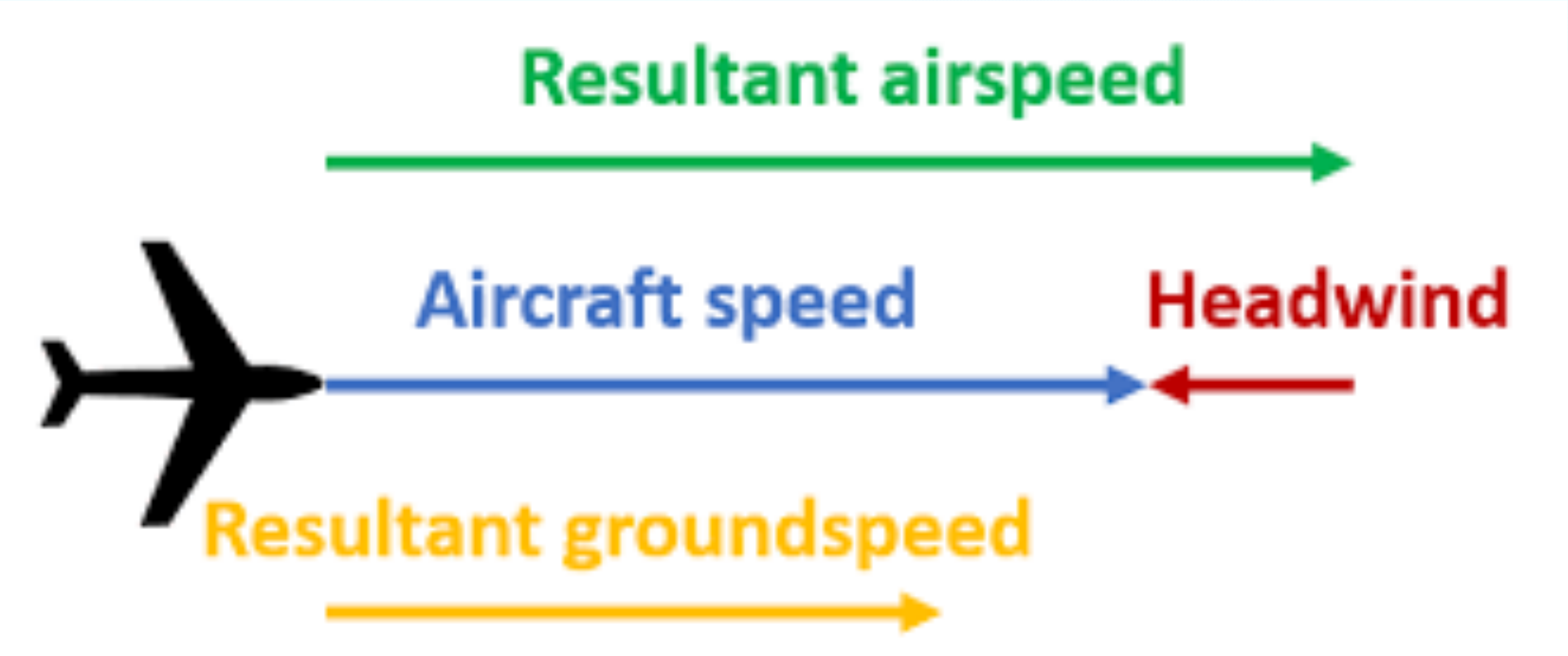
Manual glide calculation (no wind)

I can't do this and fly #$%^%$@#

- Refer back to the previous slide. A conservative (zero-wind) glide ratio of 15.5:1 was used.
- Simplify by computing the altitude loss for each NM.
- (6076 ft/NM) / 15.5 = 392 ft/NM
- Round this to something we can remember, 400 ft/NM
- With no wind, an altitude loss of **400 ft/NM** is a good approximation to use for the PW5.
- It's important to do some reasonability check and not rely solely on glide computers.

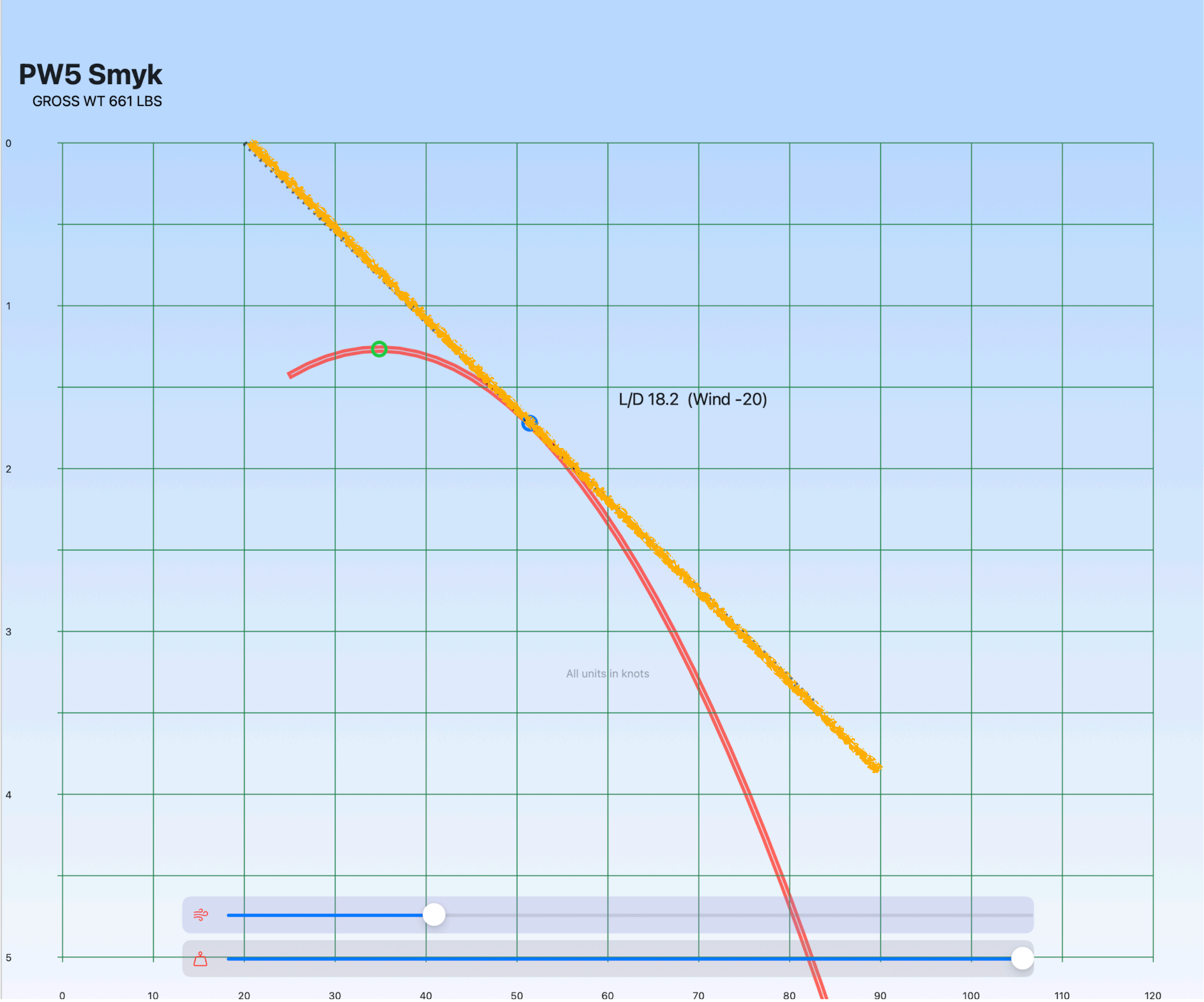
Effects of Winds

On glider performance



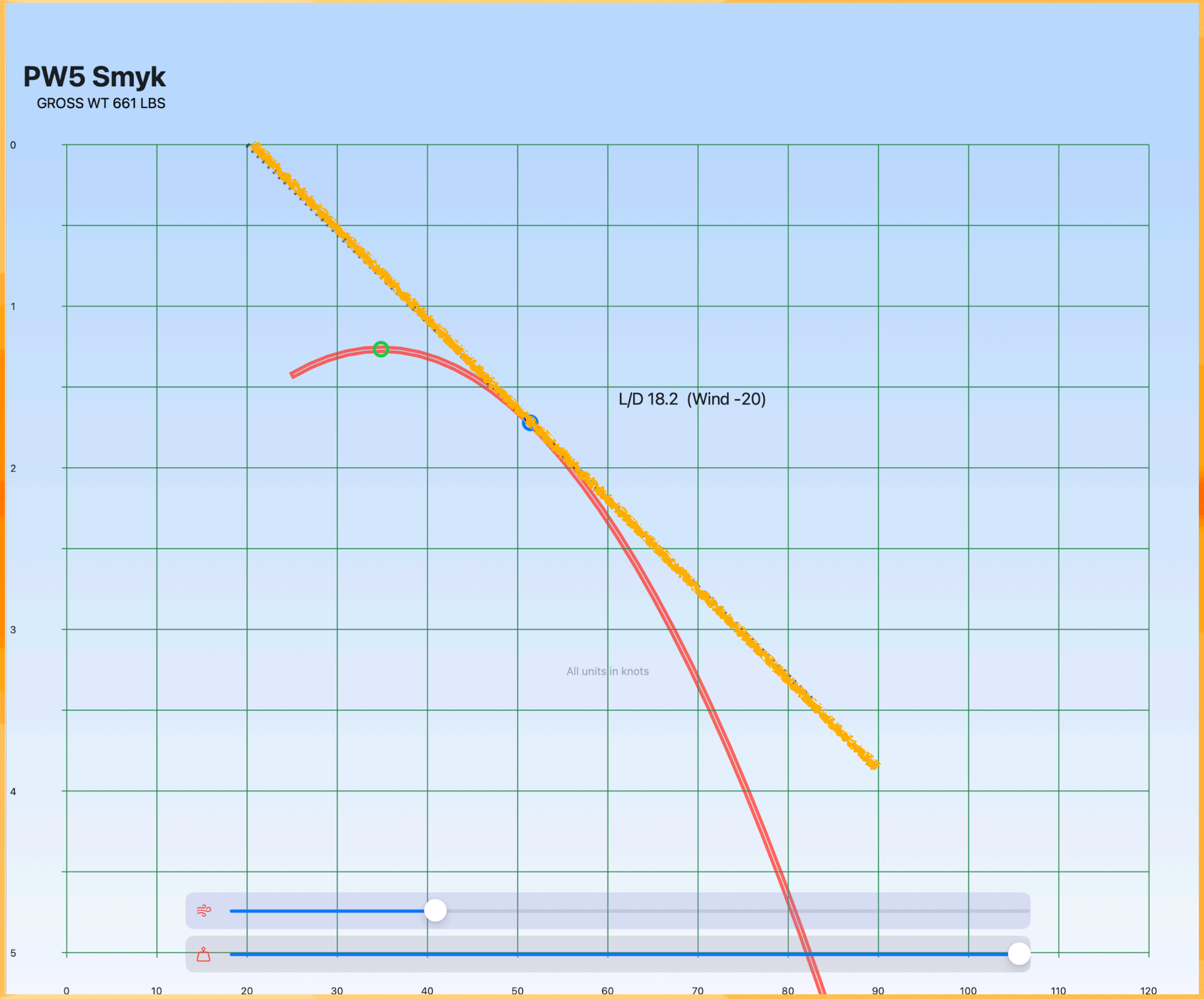
Effect of 20 knot Headwind

- Tangent line is shifted to the right from the origin.
- Notice that the Glide Ratio is significantly reduced from 31:1 to 18:1
- Also, the“Best L/D” speed is increased from 45 to 52 kt



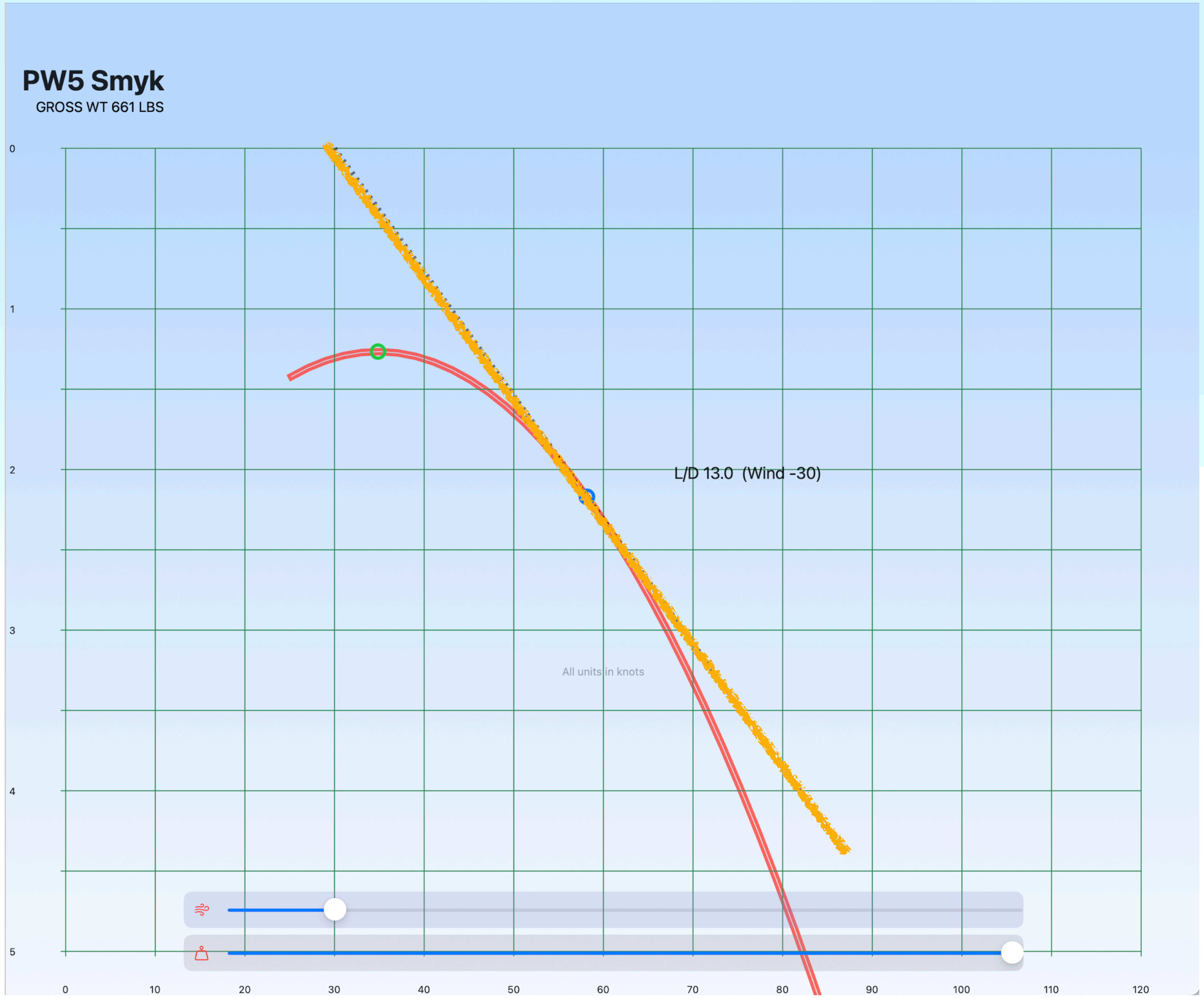
I was told to add half the headwind to the Best L/D speed to improve glide ratio.

- In the example with a 20 knot headwind, the computed “Best L/D” speed is increased from 45 to 52 kt
- Using the rule of thumb, one would fly at 55 kt.
- The 3 knot difference between the theoretical speed and the rule-of-thumb speed is insignificant.
- The rules work!



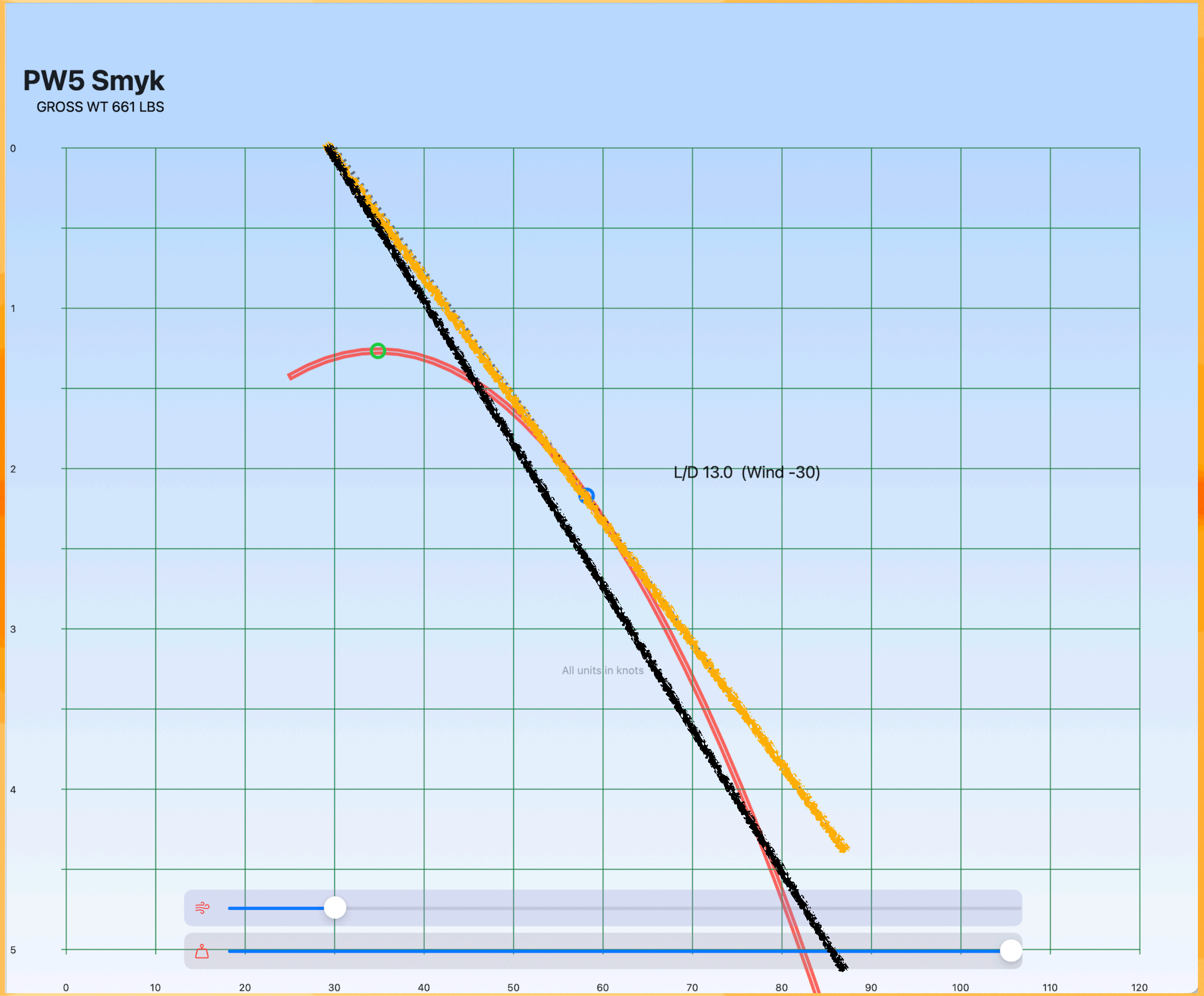
Effect of 30 knot Headwind

- Tangent line is shifted to the right from the origin.
- Notice that the Glide Ratio is significantly reduced from 31:1 to 13:1
- Also, the“Best L/D” speed is increased from 45 to 58 kt
- It would be a tough day for a cross-country.

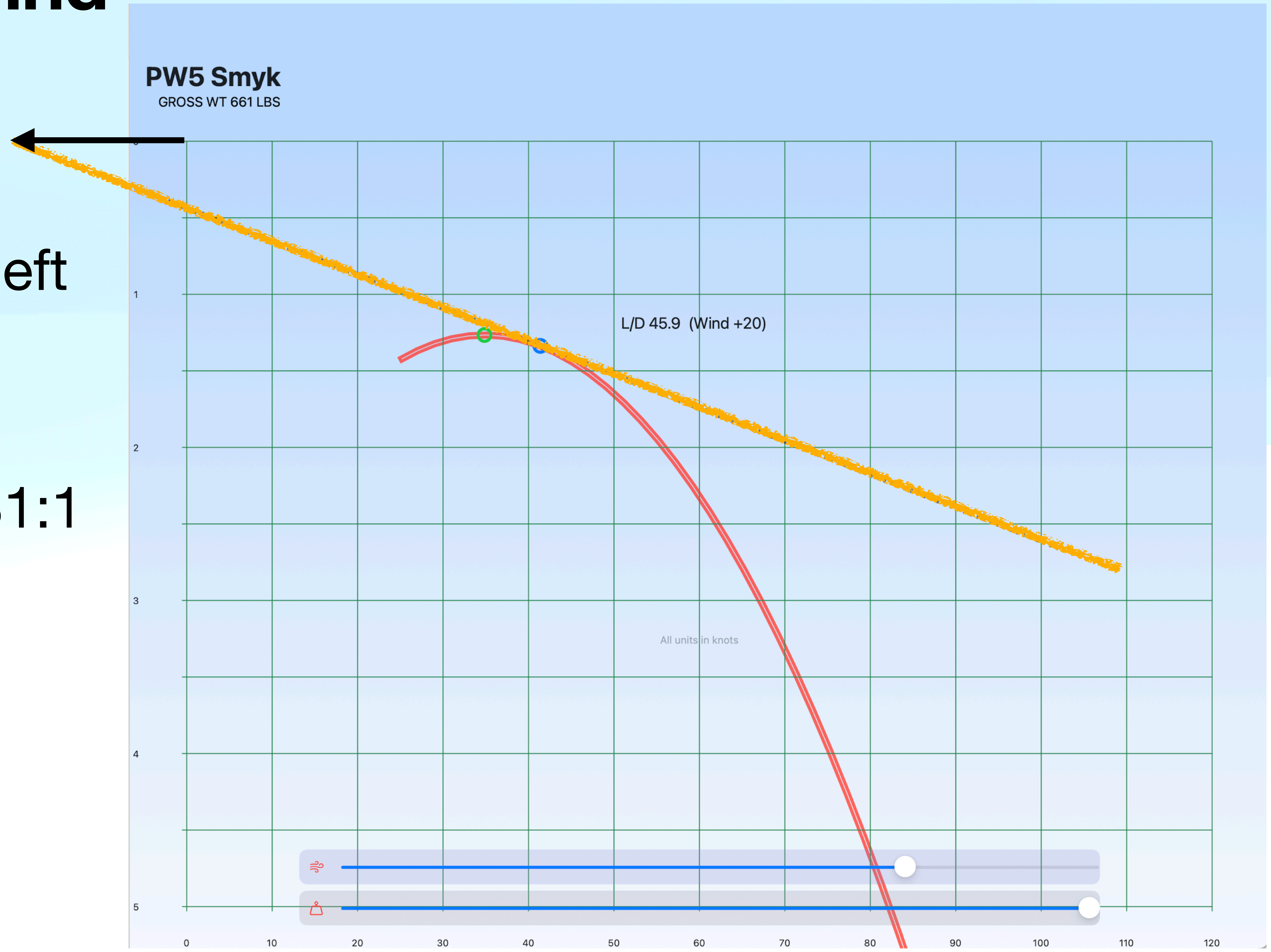


Effect of 30 knot Headwind

- Being a little fast with a strong headwind has negligible effect on glide ratio due to linearity of polar in this region.
- Better to be a little fast than slow with a strong headwind!
- If pilot elected to fly at 45 KIAS, the glide ratio would be only 10.7:1
- Calculation: (sink = 1.4 knots according to polar, GS = 45-30 = 15 kt). Glide ratio at 45 KIAS would be 15/1.4 = 10.7
- Incidentally, the same glide ratio of 10.7 would be attained at 77 KIAS, with a GS or 47 kt.
- Fly fast with a headwind!



Effect of a 20 knot Tailwind



- Tangent line is shifted to the left from the origin.
- Notice that the Glide Ratio is significantly increased from 31:1 to 46:1. This is Ventus 2C performance.
- Also, the“Best L/D” speed is reduced from 45 to 42 kt

Effect of a 20 knot Tailwind

- Being a little fast with a strong tailwind results in a significant reduction in glide ratio due to the non-linearity of the polar in this region

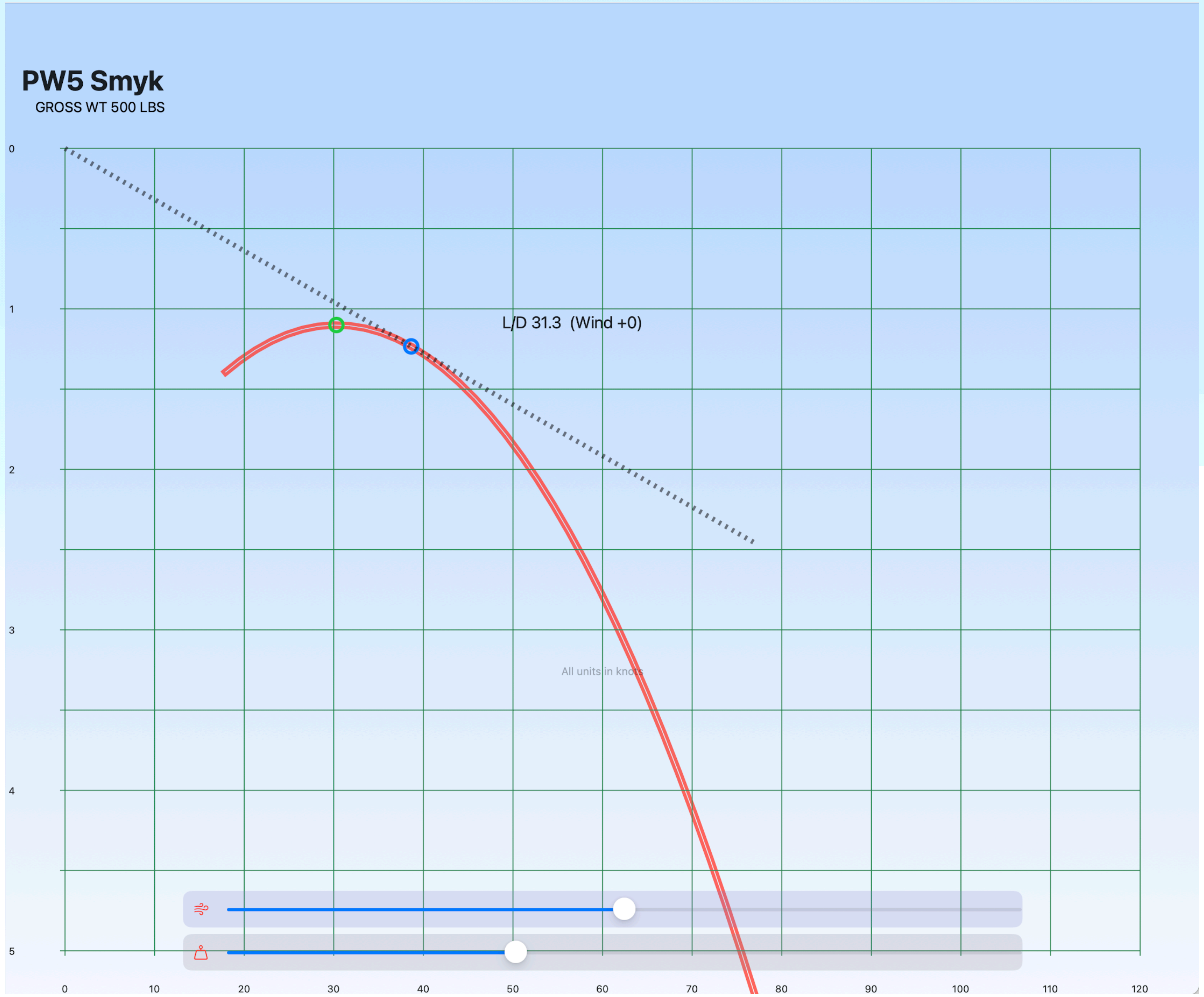
- As the tailwind increases, the Best L/D speed slowly shifts towards minimum sink.

Effects of Weight

On glider performance

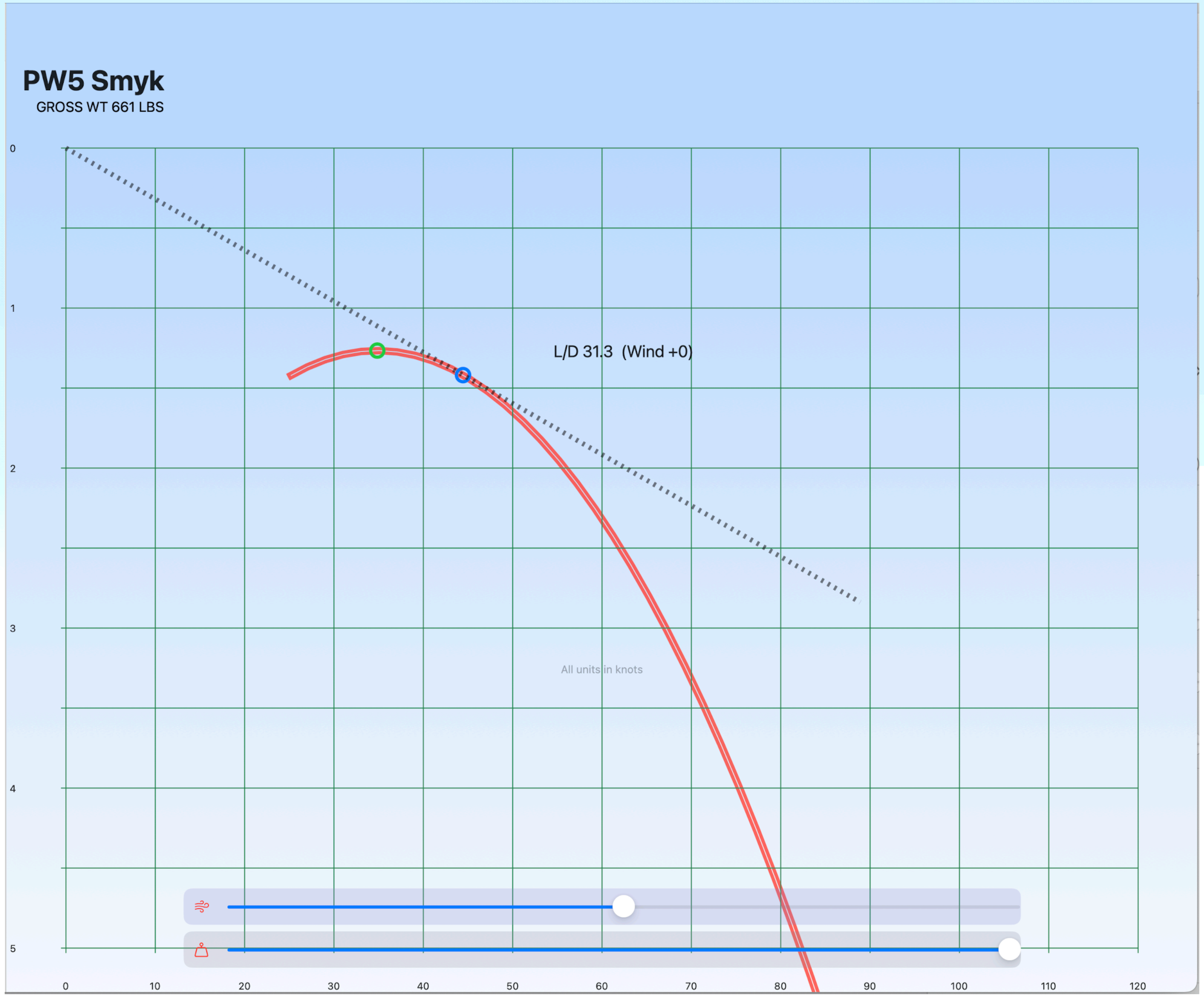
Light Weight PW5

- Minimum Sink 1.21 kt @ 30 kt
- Best L/D 31.3 (still air) @ 38 kt



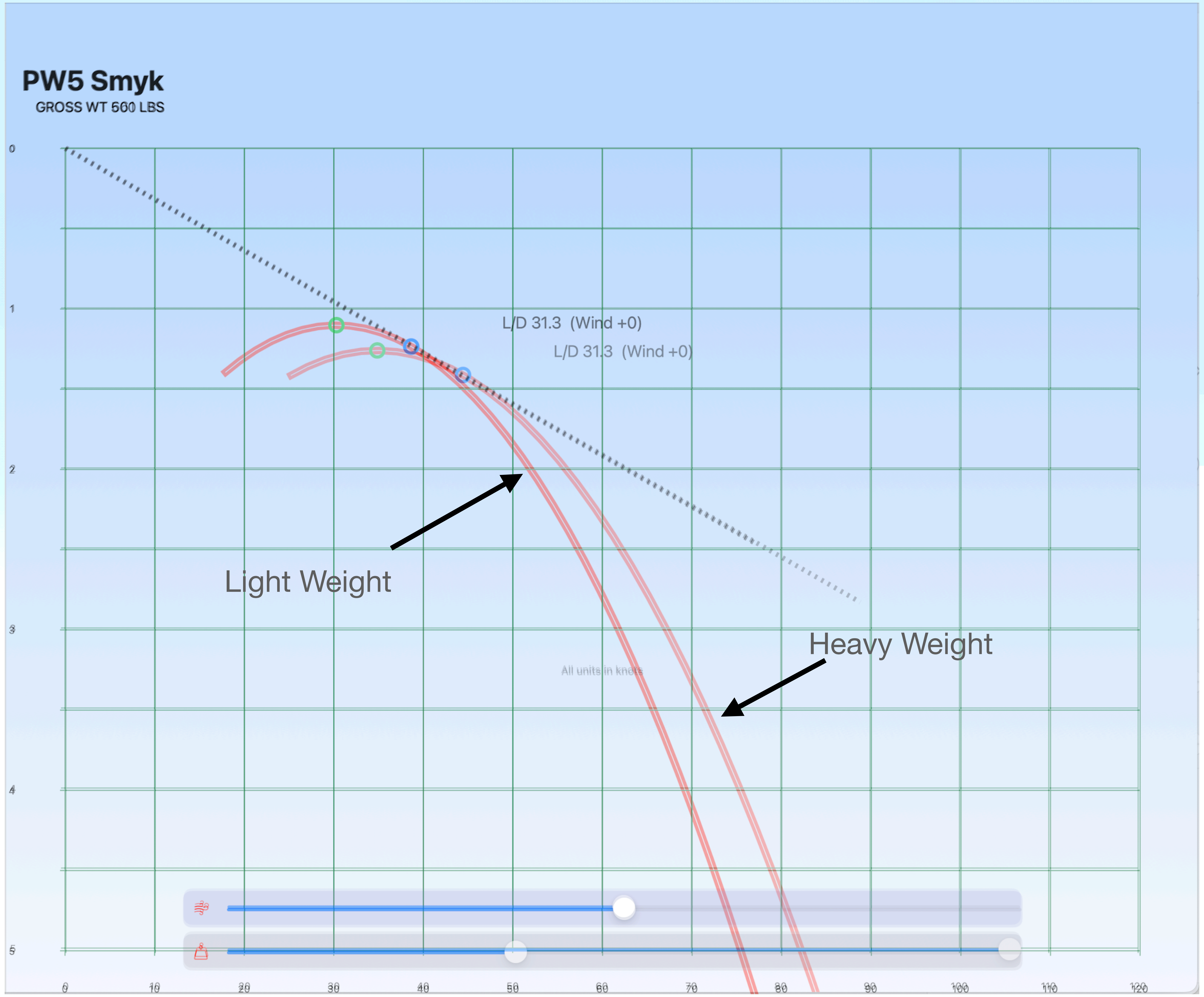
Heavy Weight PW5

- Minimum Sink 1.406 kt @ 35 kt
- Best L/D 31.3 (still air) @ 44 kt
- The maximum glide ratio remained unchanged. The Best L/D speed increased.



Summary: Effects of Weight

- The maximum glide ratio remains unchanged.
- Best L/D speed changed
- Polar keeps same shape and size, but moves.



Effect of increased weight on sink rate

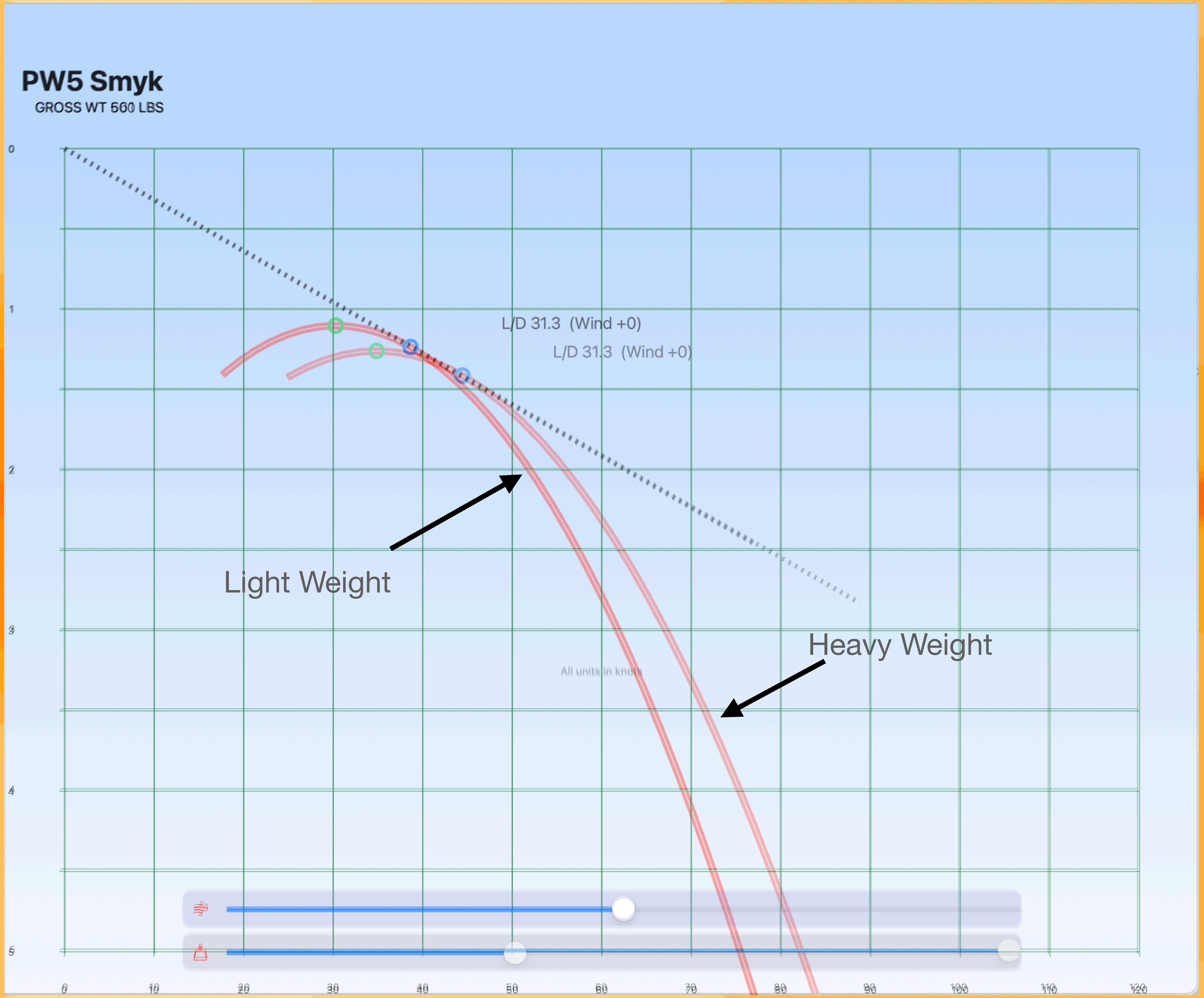
A rough analysis (ignoring other factors)

- Assumptions
  - The forecast shows 4 kt thermal day for light PW5 (meaning, light PW5 climbs at 4 kt in thermal)
  - Minimum Sink (light weight) 1.21 kt
  - Minimum Sink (heavy weight) 1.41 kt
- Heavy PW5 climbs at 4-(1.21-1.41) = 3.8 kt
- Time to climb 1,000 ft
  - Light PW5 148 seconds
  - Heavy PW5 156 seconds
  - Roughly a 5% difference in climb time
- Note: thermal speed differences and radius of turn.

Effects of weight

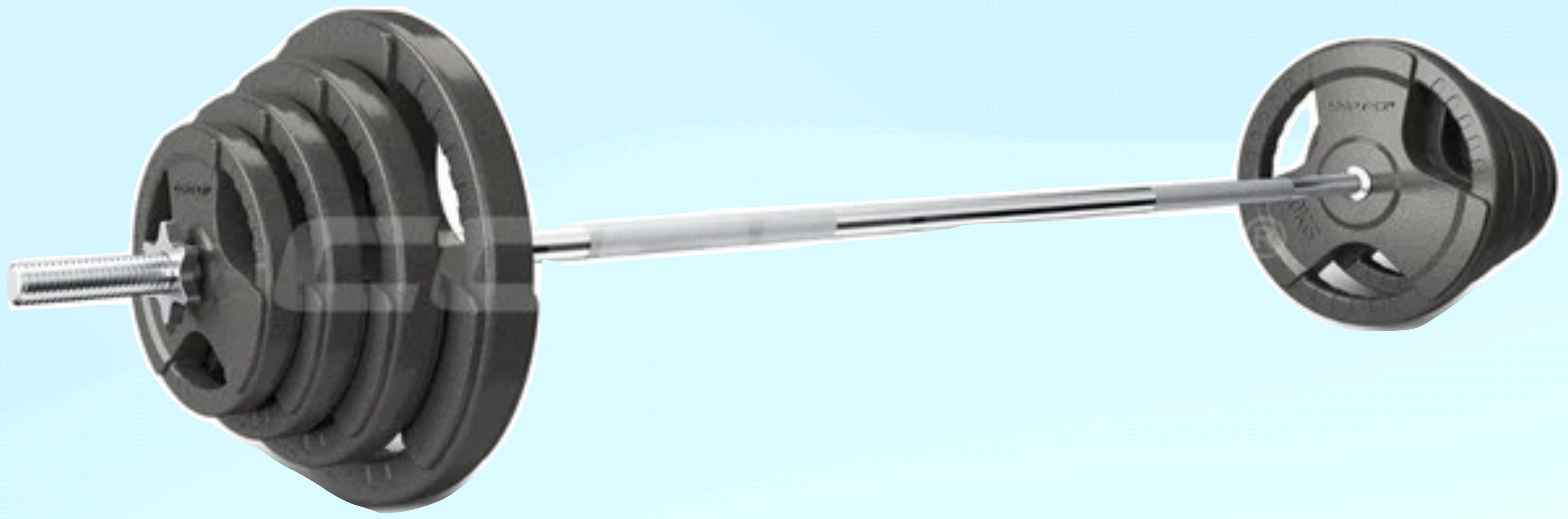
A few square roots thrown in here

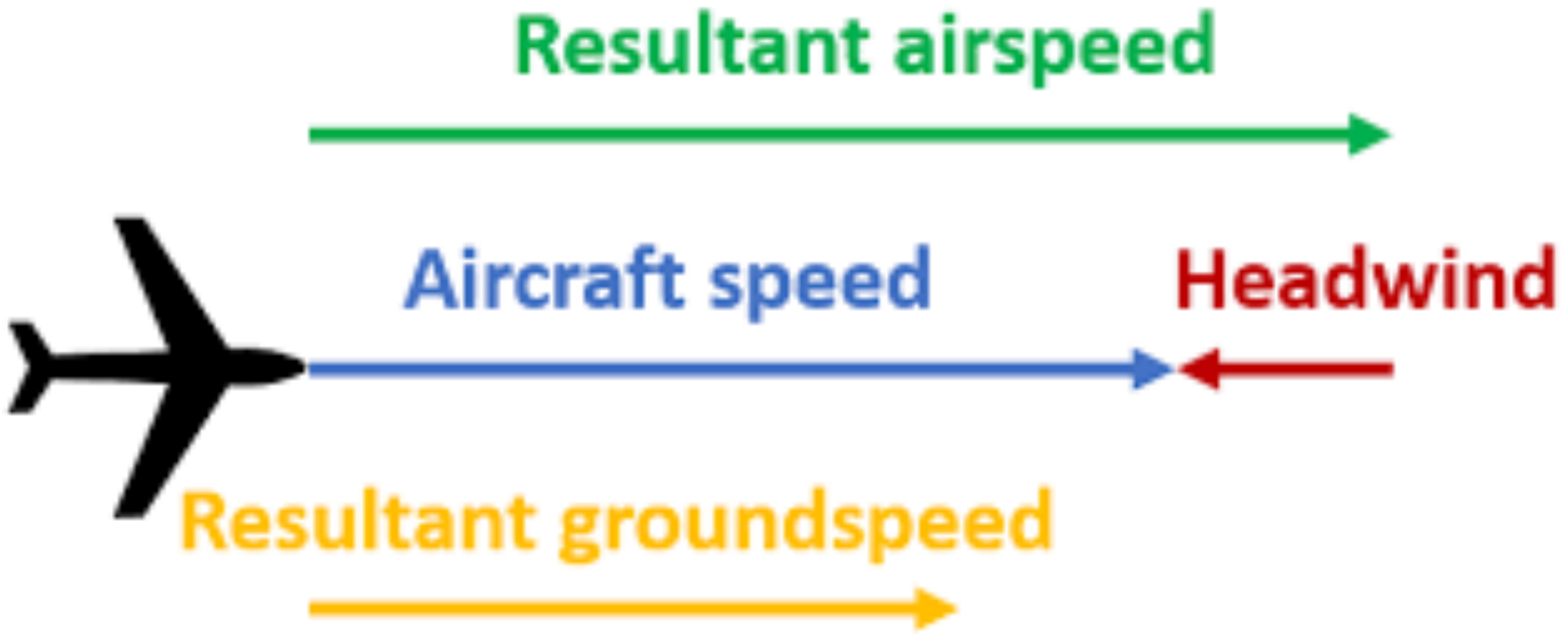
- Let W1 equal light weight PW5 (500 lb)
- Let W2 equal heavy weight PW5 (700 lb)
- Ratio = sqrt(W2/W1)
- Ratio = sqrt(700/500) = 1.18
- The heavier PW5 (at min sink) will sink 1.18 times that of the lighter PW5
- The best L/D speed will be 1.18 times greater on the heavier PW5 than the lighter PW5.
- In summary, the curve is shifted to the right and down by a factor of 1.18 at this heavier weight. This is the key to understanding why the maximum glide ratio remains unchanged.
- Interestingly, the same formula can be used to calculate the change in stall speed.
- Okay, that's enough math…



Effects of Weight and Wind

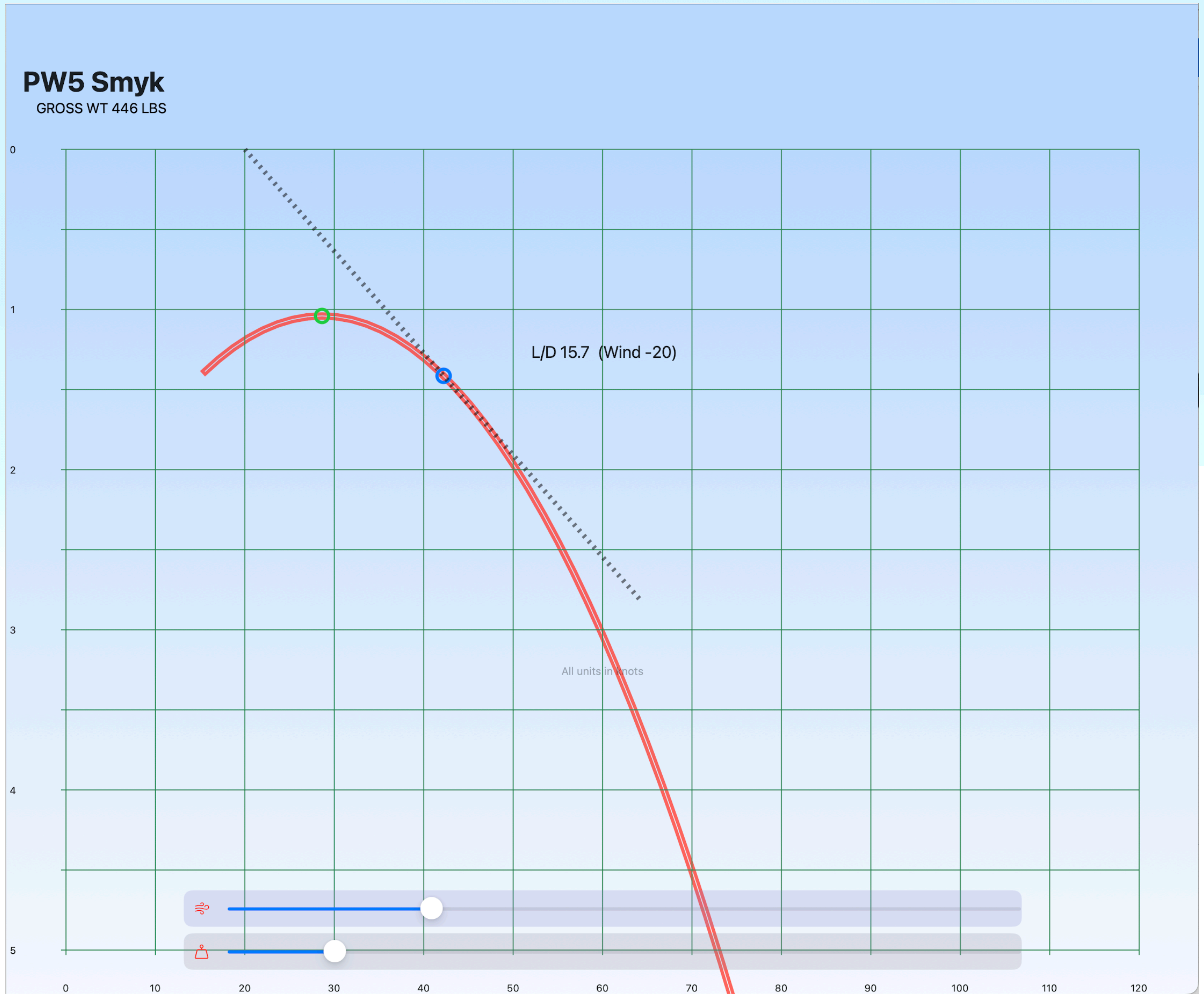
The advantage of heavier glider when operating with a headwinds





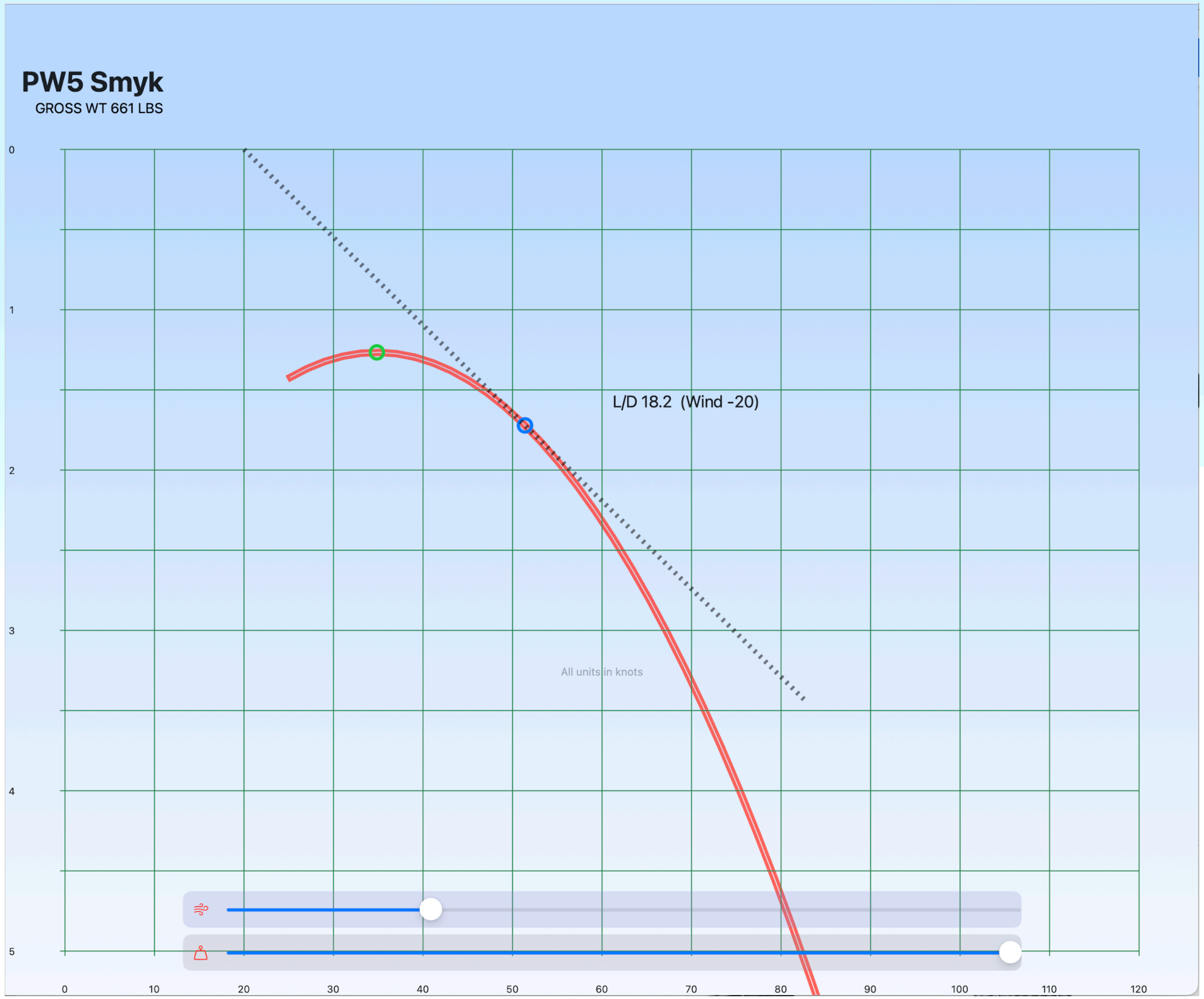
Light PW5

- 20 kt Headwind
- Best glide15.7:1 @ 42 kt IAS



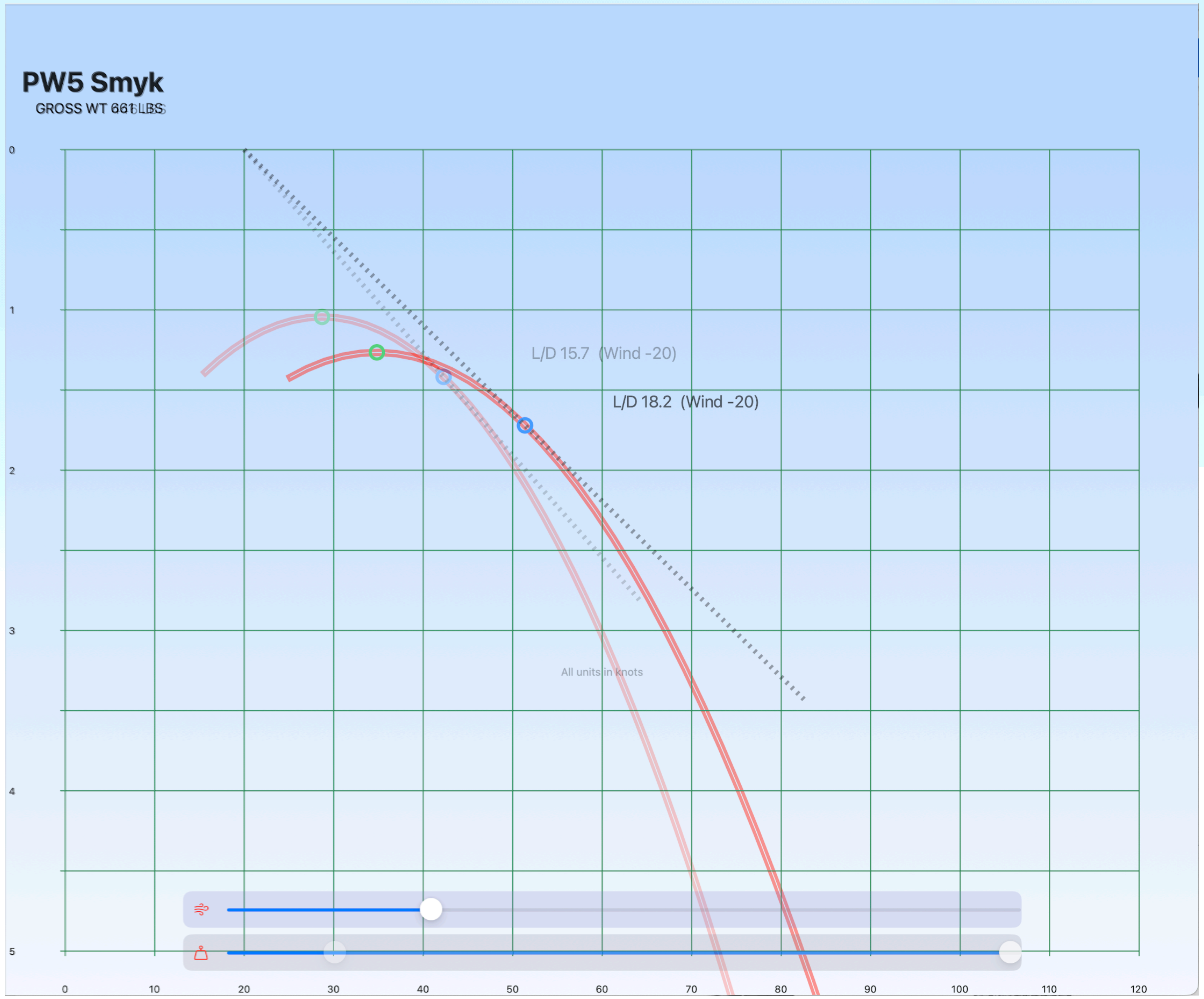
Heavy PW5

- 20 kt Headwind
- Best glide18.2:1 @ 52 kt IAS
- The light PW5 was 42 kt IAS with 15.7:1 glide ratio



Heavy PW5

- 20 kt Headwind
- Best glide18.2:1 @ 52 kt IAS
- The light PW5 was 42 kt IAS with 15.7:1 glide ratio



Effect of weight on cruise speed

20 knot headwind

- Assumptions
  - Light PW5 — Effective glide15.7:1 @ 42 kt IAS, GS = 22 kt
  - Heavy PW5 — Effective glide18.2:1 @ 52 kt IAS, GS = 32 kt
  - Leg distance into headwind 10 NM
- Light PW5 27 minutes in cruise, 3,870 ft altitude loss
- Heavy PW5 19 minutes in cruise, 3,338 ft altitude loss
- Not only will the heavy glider fly faster, it’ll also lose less altitude on the cruise leg.

Short Topics

Time permitting and the audience hasn't walked out

Short Topics Agenda

You Pick!

- Thermal Size, Best Speed in a thermal, Bank Angle Factors
- Polar Difference — Flight Computer vs. Real Glider

Thermals

- Size, Best Speed in a thermal, Bank Angle Factors

- <u>Nobody really knows because each thermal is different.</u>

- But, let make up something.

  - Assume the thermal diameter is 500 feet (Source: *Glider Flying Handbook*, FAA)

  - Airmass rising at 3 kt throughout the entire 500 ft diameter. Sure, this is highly unlikely. But, for illustration purposes, it'll do.

Table 1 Snapshot

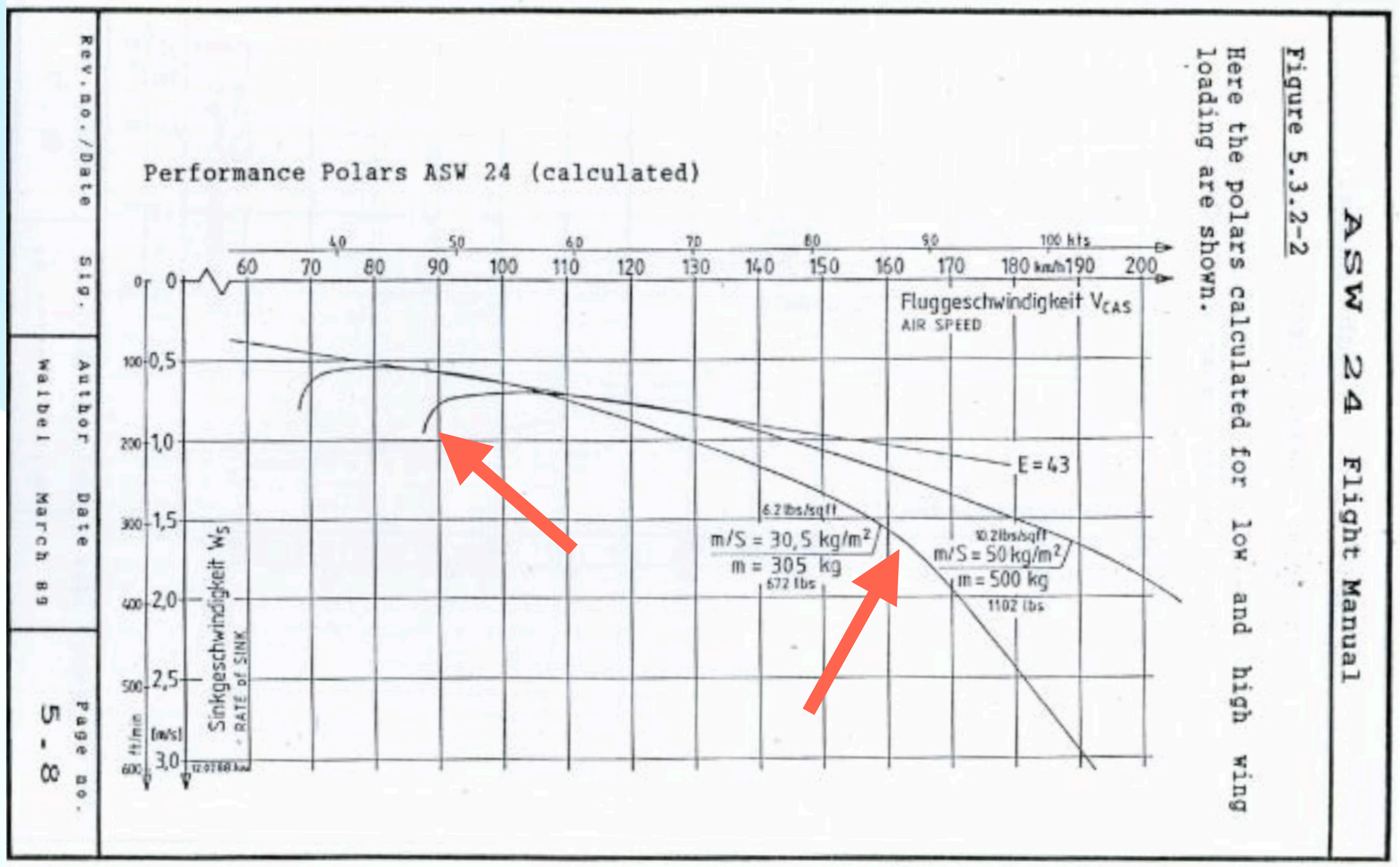
BANK ANGLE	DIAMETER (FT)	G-LOAD	SPEED (KT)	STILL AIR SINK FROM POLAR (KT)	NET CLIMB (KT) IN 3 KT AIRMASS
30	~~651~~	1.15	43	1.30	1.70
35	~~537~~	1.22	44	1.35	1.65
40	**448**	**1.31**	**46**	**1.50**	**1.50**
45	**376**	**1.41**	**48**	**1.60**	**1.40**
50	316	1.56	50	1.70	1.30
55	263	1.74	53	1.85	1.15
60	217	2.00	57	2.25	0.75

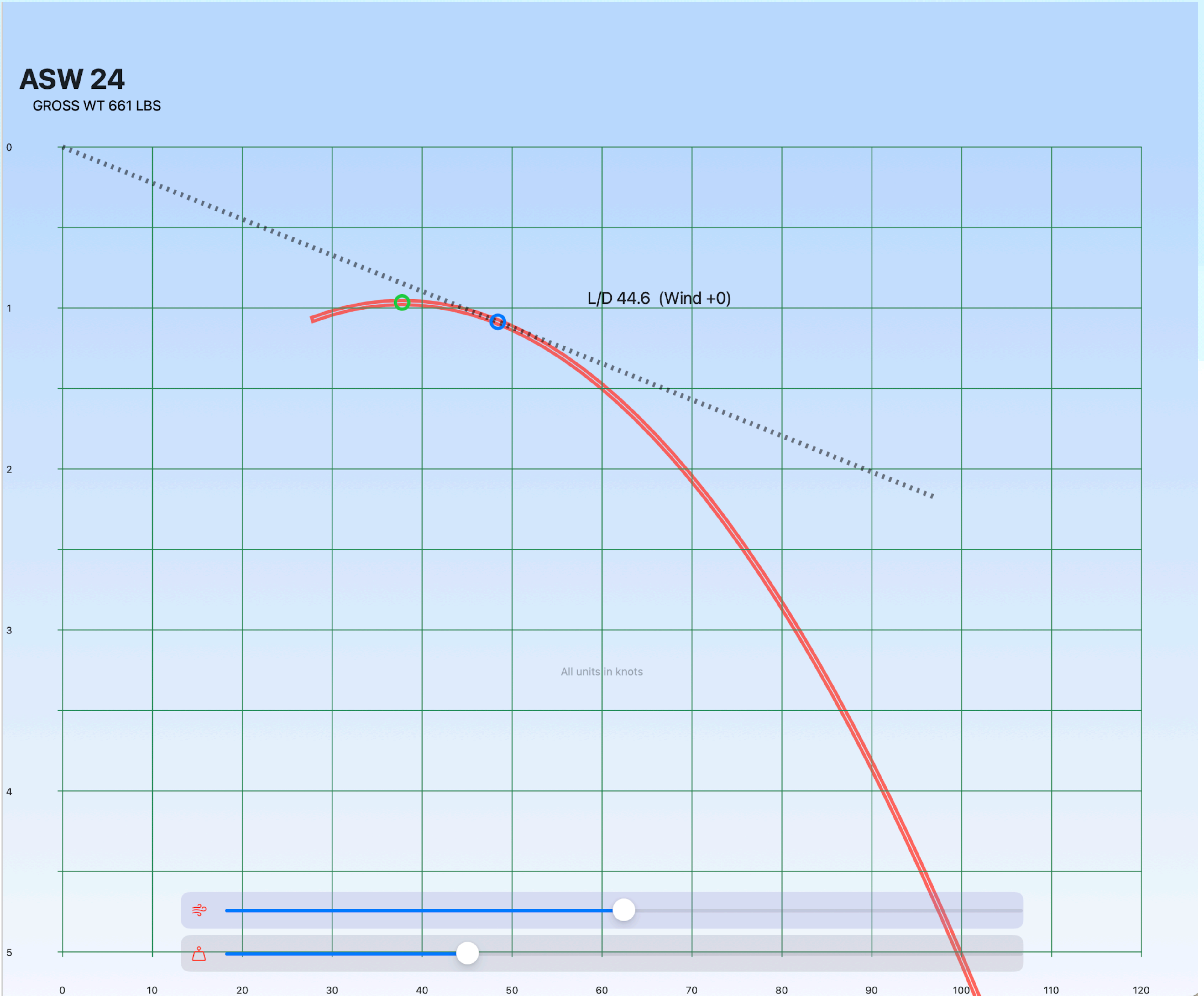
Flight Computer Accuracy

- Polar used by computers can be inaccurate
- Flight computers model the polar by using a parabola (defined by 3 coefficients). These are perfect parabolas.
- In reality, flight polars are influenced by aerodynamic factors such as air flow separation, laminar to turbulent flow, flap setting, magic, etc.
- Therefore a parabola can't possibly model the real flight polar with great precision. But, in most instances, it's not far off.

Flight Computer Accuracy

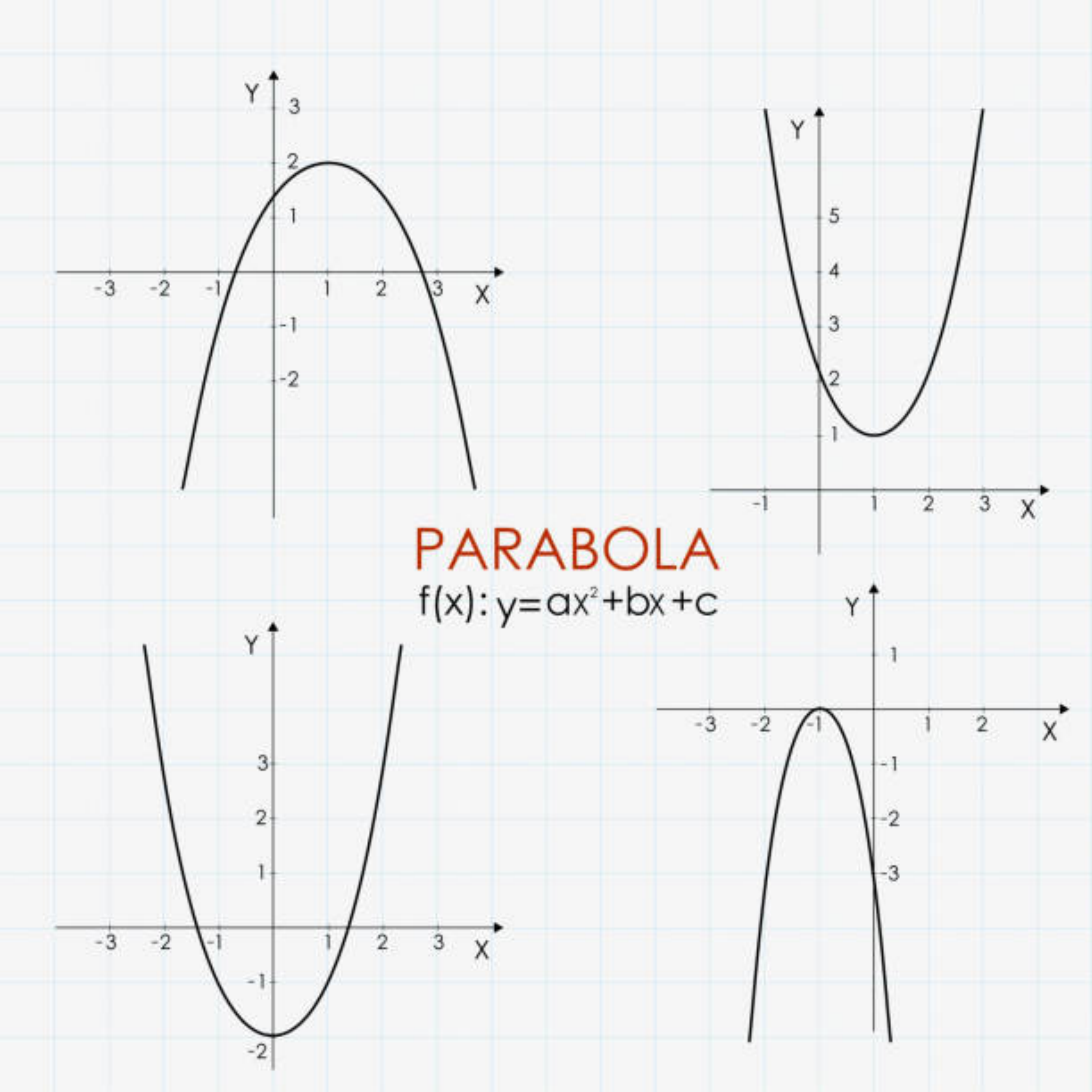
- Polar used by computers can be inaccurate





What's the advantage of approximating the polar with a parabola (quadratic equation)?

- The parabola approximation greatly simplifies and standardizes the methodology for all gliders.
- Parabolas and a little calculus makes it easy to find minimum sink, best L/D and Speed to Fly based on MacCready.
- Without parabolas, each glider would have a different methodology, and finding optimum values would require far more processing power.
- That's enough math for today…

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