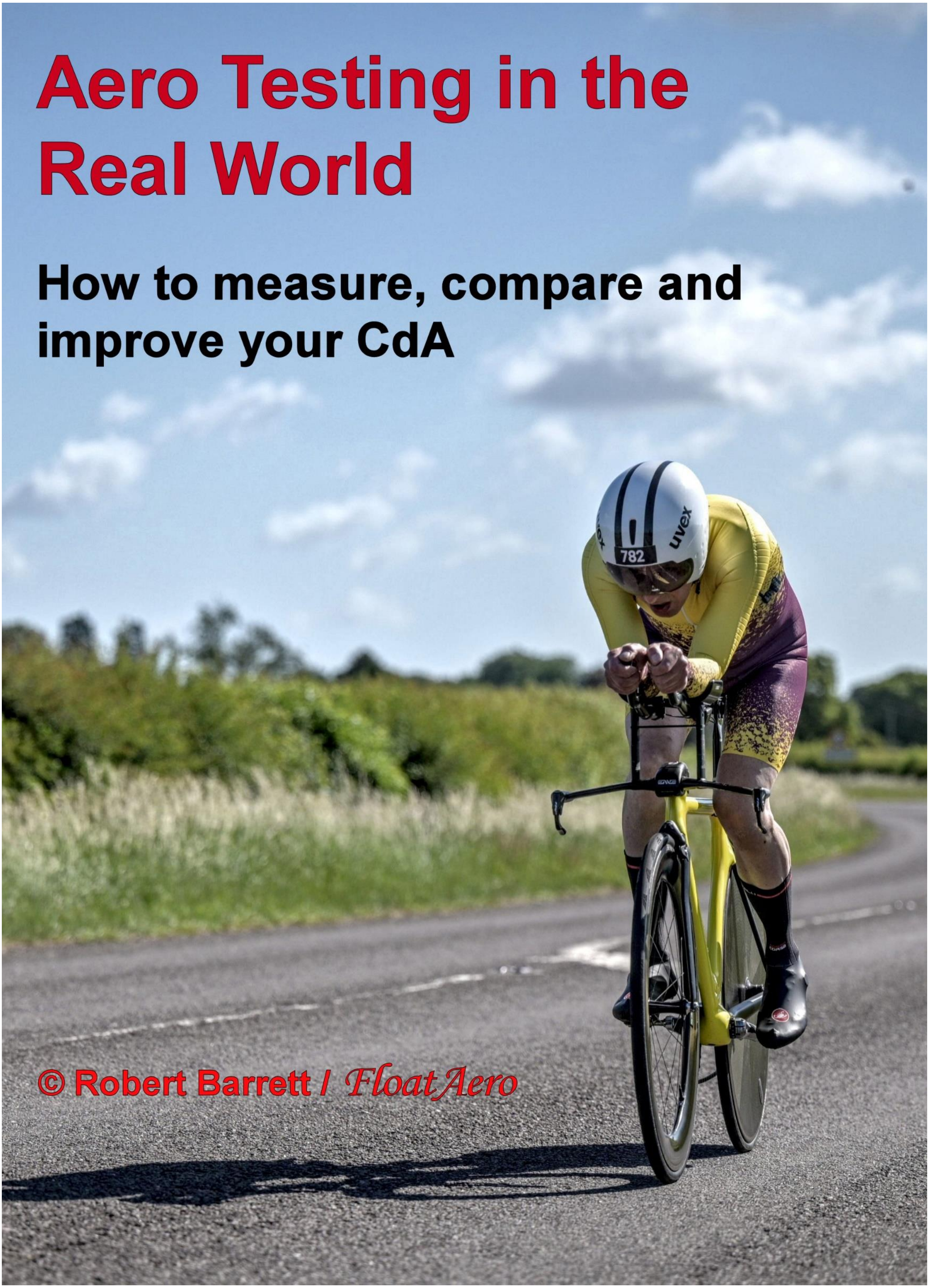
Aero Testing in the Real World

How to measure, compare and improve your CdA



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Preface

The purpose of this book is to provide the reader with the knowledge to undertake aero testing in a structured way with an awareness of the limitations of the process.

Air resistance is the enemy facing the ambitious cyclist looking for performance gains. We all know this. And we all know that most of the drag comes from the cyclist's body. We know that tucking down, riding on the hoods and keeping the elbows in makes us more streamlined, the ultimate example of this is the time trial / triathlon position.

However, when we tuck, we close the hip angle. A tucked position can impact our respiratory efficiency. Both of these can impact our ability to produce power which can negate some of the aero advantage. What we are searching for is the position where we are fully optimised in terms of power production and aero efficiency.

The core challenge, therefore, is not simply to become more aerodynamic, but to identify the position that delivers the best overall performance. This is the position where aerodynamic efficiency and power production coexist in a balance appropriate to the demands of the event. Finding that balance requires measurement, not intuition.

Armed with the techniques learnt from this book riders will be able to make informed decisions based on their own testing.

Public Edition

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Thank you, Rob Barrett

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Chapter 1: Why aerodynamics matters for every cyclist

Aerodynamics isn't just for professional racers or time trial specialists anymore. Every cyclist riding faster than at a gentle pace is fighting against the air. Understanding how to reduce that air resistance is one of the most effective ways to go faster without increasing power output.

Air resistance eats power

Above speeds of around 30 km/h (18 mph) aerodynamic drag starts to dominate. This means that small improvements in position, equipment, or clothing can yield noticeable speed gains for elite athletes, club cyclists and even recreational riders. For the elites up to eighty percent of the effort will be going into overcoming drag when achieving 50 km/h (30 mph). Improving aerodynamics can make a big difference to all categories of cyclists.

Which of these two cyclists do you think has the lower drag?

Hint: I'm the one on the left...

Why aerodynamics matters and how lowering drag helps

- Triathletes: Arrive at the run fresher, maintain bike speed with fewer watts.
- Time trialists: Gain free speed with the same power, achieve faster times.
- Club and recreational riders: Stay with faster groups and conserve energy.
- Gravel and endurance riders: Be more efficient over long distances.
- Commuters: Save energy and arrive fresher.

“Do it yourself” aero testing is now possible

With modern equipment like power meters and analysis methods like Aerolab in Golden Cheetah any cyclist can now measure and improve their CdA, their aerodynamic drag. Software like Golden Cheetah, web apps like MyWindSock, and hardware like AeroMeters, combined with a power meter, make it possible to perform accurate, repeatable testing without needing to spend significant money going to a wind tunnel or a coached velodrome session.

This book will guide you through the learning process of practical aero testing, from choosing a test venue, setting up your equipment, and to analysing your data, enabling you to make real-world comparisons and enabling you to make real performance improvements. Each chapter builds on the last, so by the end of the book, you’ll be able to plan and perform your own aerodynamic testing sessions and interpret the results.

There is a “give a man a fish, teach a man to fish” analogy here:

Go for a one-off test session, wind tunnel or velodrome, maybe you’ll find an improvement, but you probably won’t have tested its impact on your power.

Learn how to aero test yourself and the options are limitless.

This book will teach you how.

Ride smart, stay safe, but above all, get aero…

Chapter 2: Understanding CdA in simple terms

Understanding a bit of the physics behind the theory of drag helps you make sense of what you are testing and helps with the interpretation of the results. It also helps when you start to visualise how the air interacts with your body on the bike. You don't need to be a scientist to grasp the basics, you just need an idea of how air resistance affects your speed and how changes in your position or bike set-up can influence you drag. The science is effectively Fluid Dynamics with the air behaving like a very thin fluid when it hits an object, in this case the object is your body on a bike.

The power to overcome drag equation

The power required to overcome aerodynamic drag is described by the equation:

$P = 0.5 \times \rho \times CdA \times v^3$

Where:

- P = power (watts)
- ρ (rho) = air density (kg/m^3)
- CdA = coefficient of drag (Cd) multiplied by frontal area (A in m^2)
- v = velocity (m/s)

You can see from the velocity/speed term (v^3) that the power required to produce a given speed is proportional to the cube of that speed. Which means that if you want to double your speed you need eight times the power.

Unfortunately, that's true no matter how much you reduce your CdA. The relationship between power and CdA is linear. If you lower your CdA you'll need proportionately less power for a given speed.

Air density is not something that we can control but it is something that we need to be aware of when aero testing. Warm air with high humidity is less dense than cool dry air. Thin less dense air offers lower resistance than cool thicker air, so with less dense air you require less power / fewer watts to achieve the same speed.

Breaking down CdA

CdA combines two factors: how slippery your shape is through the air, your drag coefficient (Cd) and how big you appear to the air, your frontal area (A). But don't be fooled into thinking that reducing your frontal area is the magic bullet that will make you faster. Of course, it helps but there are other effects at play.

Reducing your frontal area will likely change your shape which could have a knock-on effect on your drag coefficient (Cd) and that could be a negative or positive effect. Reducing your frontal area may lead to a closing of your hip angle which may reduce the amount of power that you can sustain. Real world aero testing helps you evaluate your CdA in the context of your power so you can make changes leading to improved performance based on reliable informative results.

Other forces in the equation of motion

In addition to aerodynamic drag, cyclists also need to overcome:

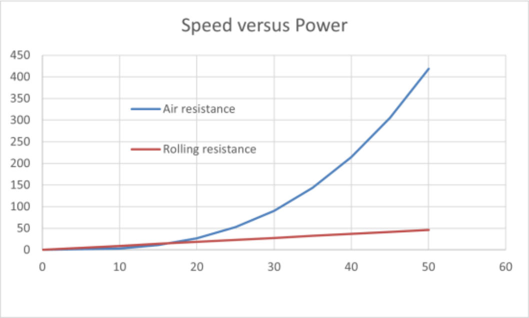
- Rolling resistance of the tyres and road surface / Coefficient of rolling resistance (Crr).
- Gravitational force, acting against when climbing and helping when descending.
- Mechanical losses, drivetrain losses and bearing / friction losses.

When riding on a flat road at higher speeds rolling resistance and gravitational forces are significantly smaller than the drag force. Gravity comes into play when riding on noticeable gradients. However, these other forces still need to be taken into account when analysing results.

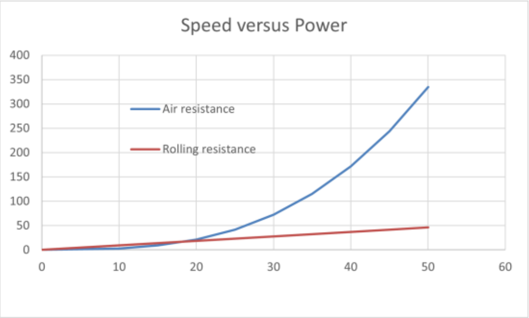
The balance between power and speed

Your speed depends on your power output and your aerodynamic efficiency. Changing your position or equipment to reduce your CdA can yield the same performance gains as increasing your power by tens of watts. However, you have to be mindful that changing your position can also impact negatively on your ability to produce power.

On the left CdA of 0.2500



On the right CdA of 0.2000



465 watts for 50km/h of which	382 watts for 50km/h of which
44 watts are to overcome Crr	44 watts are to overcome Crr
252 watts for 40km/h of which	210 watts for 40km/h of which
37 watts are to overcome Crr	37 watts are to overcome Crr

Reducing the CdA by 0.05 saves over 80 watts at fifty km/h and over 40 watts at forty km/h. You can go at the same speed with less power or go faster over the same distance if you put out the same power and take advantage of the aero gain.

If you are a Triathlete, you might choose to maintain the same speed over the bike leg distance and save energy for the run.

For time trialists it’s all about the fastest time so you would use the aero advantage to go faster.

Historically, for a seventy-five kilo road cyclist, the starting CdA would have been around 0.3000 or greater, and we'd look to reduce that to around 0.2500. With the increased focus on aerodynamics in frame and wheel design we are now seeing a starting CdA of 0.2700 and reducing that to 0.2200 or better.

Why reducing frontal area doesn't always lower CdA

Your CdA tells you how much aerodynamic drag you have in total. At first sight it might appear that reducing frontal area by making yourself smaller on the bike will make you faster, after all, a smaller frontal area means less air to push through, and that may be true, however, that assumes that the Cd part, the drag coefficient, remains constant and it may not.

Obviously, the shape travelling through the air is three dimensional, a body on a bike. Whilst it is convenient to think of the drag coefficient and the frontal area as being independent variables, unfortunately they are not.

The frontal area viewed as a silhouette doesn't tell the whole story. If we were to take cross-sections of the three-dimensional shape of the rider and the bike, we would see a different shape and area for each slice. The frontal area is made up of all those slices stacked together. We could have radically different three-dimensional shapes with the same frontal area, and each different shape will have its own value of drag coefficient.

The key point is that changing the frontal area is quite likely to have a knock-on effect of changing the drag coefficient. That change may be an increase or a decrease. The only way to know the impact of the change on the overall CdA value is to perform some aero testing.

And there is another potential catch: when you reduce your frontal area you often change the shape of your hip area, and that can affect your power output. If reducing your frontal area by going lower results in a closing of the hip angle, then that is likely to result in a reduction in the power you can sustain.

For example:

You might tuck your head down or narrow your shoulders to make yourself smaller.

But if that new position changes your overall body shape the air can behave differently, increasing your drag coefficient.

That increase in drag coefficient can sometimes cancel out or exceed the gain from your smaller frontal area.

Performance is about power and aerodynamics

It is important to measure what actually works in real world conditions.

A Simple Illustration:

For example: One rider, two positions, reducing the frontal area on a TT bike by roughly five percent by lowering the saddle and the elbow pads by 60 millimeters. In this case we are keeping the drag coefficient for the body the same as we are maintaining the same three-dimensional shape and torso angle. Lowering the saddle and the pads will close the hip angle which will likely result in a reduction in twenty-minute average power. Here are some numbers from one of my own tests.

	Frontal Area (A)	Drag coefficient (Cd)	CdA	Average 20 minute power	Power divided by CdA
Position One	0.4	0.48	0.192	190	989
Position two	0.38	0.48	0.182	174	956

In this example the CdA is reduced by 0.010. Empirically we would estimate this as being worth about eight Watts at 40 km/h. However, the closing of the hip angle in the lower position has caused a reduction in 20-minute power of 16 Watts. We know from experience that rider speed is proportional to the average 20-minute power divided by the CdA. Using this empirical rule of thumb, we can determine that position one, the higher position with the larger frontal area, is going to be faster than position two.

If the drag coefficient is increased there is a larger impact on the power / CdA quotient.

Position two	0.38	0.5	0.190	174	916

If the drag coefficient is decreased as a result of reducing the frontal area the power / CdA quotient is marginally greater than for position one.

Position two	0.38	0.46	0.175	174	994

In summary: reducing frontal area and subsequently the CdA, for example by going lower, doesn’t always mean getting faster. It’s about finding the balance between drag coefficient, frontal area and power.

This is why real-world testing of CdA is so valuable, and why you need to evaluate if changing your position has an impact on the power you can sustain for the duration of your event. You can’t just assume that a smaller silhouette is going to be better or faster. An alternative method of determining your Critical Power is outlined in Appendix Three.

Chapter 3: Selecting a suitable test venue

Choosing the place to perform your aero testing is one of the most important decisions you'll make. The venue you select directly affects the accuracy and repeatability of your results. A poor choice can introduce unnecessary variability, making it difficult to identify and isolate changes in results that are meaningful and not just quirks. A good test venue, on the other hand, gives you a consistent environment in which to measure, compare, and refine.

What makes a good test venue

A good test venue allows you to control as many external variables as possible. The following factors are critical:

- Consistent road or track surface: The rolling resistance (Crr) of your tyres depends on the surface beneath you. A consistent surface ensures that Crr remains uniform for the entire test run, helping you attribute differences in CdA to aerodynamic changes rather than random changes in surface texture.

- Low or no traffic: Passing vehicles disturb the air around you, creating turbulence and drafting effects that can make your data unreliable and alter your observed drag. Traffic-free environments are best, allowing you to focus on your performance, not having to worry about interference from vehicles.

- Shelter from the wind: Even light winds introduce variability in apparent wind angle (yaw) and wind speed. A sheltered environment reduces this effect, improving test repeatability and data confidence.

In simple terms: a venue with a smooth consistent surface, traffic free, and as sheltered as possible gives you the best possible environment for consistent testing.

Types of test venue

No single venue is perfect for every rider or every situation. The key is to balance practicality, accessibility, and data quality.

Indoor velodrome

Advantages:

- Fully controlled environment, no wind, no traffic, consistent temperature.

- Year-round usability.

- Smooth, predictable surface provides consistent rolling resistance.

Disadvantages:

- High cost of access.

- May require special permissions or scheduling around other users.

- Not always geographically accessible.

Despite the cost, indoor velodromes are unmatched for controlled repeatable testing. If precision is your priority and budget allows, this is the ideal option. You do need to monitor the air temperature and be aware of drafts that might occur when access doors are opened.

Outdoor velodrome

Outdoor velodromes are a more accessible alternative.

Advantages:

- Lower cost and easier access.
- Purpose-built for cycling, providing a consistent surface.

Disadvantages:

- Exposure to wind and changing weather conditions.
- Temperature and surface moisture can affect results.

They offer a good balance between control and accessibility but are best used in calm, overcast, stable weather conditions.

Cycle circuits

Cycle circuits can also serve as good testing venues.

Advantages:

- Traffic-free and often well maintained.
- Suitable for repeat laps.

Disadvantages:

- Usually include elevation changes or sharp corners that can influence data.
- Longer laps can mean fewer test repetitions in a given time.

Cycle circuits can work well if you can identify a flat, sheltered section for your test laps. You do need to be wary of pedestrians and animals that may have access to the circuit area.

Dedicated cycle paths

Dedicated cycle paths offer convenience but require extra care because of other users.

Advantages:

- Generally smooth surfaces with no vehicular traffic.
- Easily accessible in many areas.

Disadvantages:

- Require “out and back” testing rather than continuous laps.
- Ingress of pedestrians or animals can lead to interruptions in data collection.

Out-and-back testing can still yield useful results, particularly when combined with aerometer devices that help compensate for variations in wind effects. Most aerometers also record environmental variables. Aerometers are covered in Chapter Nine.

Public roads

Testing on open roads should be considered the last resort.

Advantages:

- Essentially available and cost-free.

- Can be suitable for preliminary or exploratory testing.

Disadvantages:

- Traffic and variable surfaces may add to data noise.

- Safety concerns can interrupt runs or restrict focus.

If you do test on public roads, choose quiet times, consistent surfaces, and repeat runs in both directions to minimise environmental influence. Aerometers can help adjust for residual wind and traffic effects.

Practical considerations

Regardless of venue, a few general principles apply:

- Test at quiet times: Early mornings often provide calmer conditions and minimal interference.

- Record surface conditions: Wet or roughened surfaces affect Crr, causing issues when comparing results between sessions.

- Note environmental factors: Wind speed and direction, temperature, and humidity. All of these factors influence air density and should be logged.

- Prioritise safety: Traffic, visibility, pedestrian access, and turning points must always be risk assessed before testing begins.

Your testing venue doesn’t have to be perfect, but it must be consistent. Consistency allows you to separate the aerodynamic effects you’re trying to measure from the noise of that can be created by changing conditions. Whether you’re in a world-class velodrome or a quiet back road the principles are the same:

- Smooth consistent surface.

- Minimal wind.

- Minimal traffic interference including other cyclists.

Chapter 4: Instrumentation for aero testing

Why the right instruments matter

The quality of your aero test results depends heavily on what instrumentation you use. You don't need lab-grade tools, but you do need instruments that are reliable, consistent, and well calibrated. Inconsistent instrumentation can introduce errors which may lead you to think a change has helped when it didn't.

This chapter shows you what instruments are essential, what are nice to have, and what you can get away with if you're on a budget.

Essential instruments

These are the minimum tools you should have, or consider investing in, to get meaningful aero testing results.

Speed sensor

If you're performing aero tests, you need to record your speed as accurately as possible.

The GPS speed that you get from a conventional bike computer / head-unit isn't accurate enough to be used for aero testing. It is particularly poor when testing on open velodromes and circuit loops. If you have ever looked at the GPS trace from a turbo session, where the bike has been static, you'll know what this means. There is another satellite system called GLONOSS which can be used. Both are unlikely to work at indoor velodromes. Some of the aero meter devices available have more precise satellite data speed estimation systems.

The better option is to use a wheel-based speed sensor. The original versions used a magnet mounted on a spoke and a sensor mounted on a fork blade or a chain stay. More recently hub mounted speed sensors have become available. These use inertia as the "tick" mechanism. Ideally you would use a magnetic based speed sensor. The inertia-based sensors can be prone to errors introduced by spurious "ticks" either caused by bumps in the road or the effect of steep banking at an indoor or short track velodrome.

When using a wheel-based speed sensor it is necessary to set the wheel circumference in the data recording device. This could be a bike computer / head-unit or a phone app. You can measure the wheel circumference with a rollout test but, of course, this is without the weight of the rider deforming the tyre, so it may not be accurate. However, this isn't critical as all speed recordings will be subject of the same systematic error. The CdA numbers will be precise but may not be accurate. The CdA results derived will still be valid for comparison purposes.

Note that if you are testing the relative performance of wheels, or different tyres on a wheel, you should mount the speed sensor on the other wheel, usually the back wheel, and this should be kept constant for consistency.

Power meter

A power meter converts your effort into wattage. It's not absolutely necessary to have a power meter to aero test but not having one restricts you to doing zero power rolldown testing, so ideally you need a power meter.

Repeatability, or more exactly precision, is very important when aero testing as the calculations rely on the data being consistent. Some power meters have automatic temperature compensation and calibration. It is important to allow time for the power meter to adapt to the environmental conditions at the test venue, and to calibrate, if necessary, prior to testing. Double sided pedal or crank based systems outperform single sided options.

Nice to have instruments

Non-contact infrared thermometer

Rolling resistance and tyre pressure vary with tyre temperature. By measuring the temperature of your tyres before and after every test run you will be aware of any differences between runs that may affect the CdA results. It's worth recording the temperature data in some way, either old fashioned pen and paper or a mobile app along with the details of what was tested in each and every run. It's worth skipping the lower cost versions and going for something with a little higher specification. You only need a range of zero to fifty degrees.

Portable weather station / air density meter

Knowing the air density on each test day is vital as it enables continuity across different days. It is also useful to be aware of any variations in air density over the duration of a test session. Your CdA doesn't change with air density. What changes is the amount of power required to overcome air resistance at a given speed. Put another way, you'll go faster with the same power if the air is thinner but your CdA will be the same.

Air density at the test venue can be calculated from three parameters, air temperature, relative humidity / dew point, and atmospheric pressure.

A pocket-sized portable weather station, like the Kestrel 5100, is an ideal tool. It also has an anemometer for measuring wind speed. It can be mounted on a tripod or handheld. Lower cost options are available.

One alternative to having your own portable weather station onsite is to rely on internet access to an open-access weather station as near as possible to your test venue. Every airport has a weather station, and many amateur meteorologists make their data available through the same weather station network.

Key point to remember about the environmental instruments

Keep them out of direct sunlight. Absorbed radiated heat will affect the accuracy of both a non-contact Infrared Thermometer and the Portable Weather Station.

Chapter 5: Testing without a power meter

Not every cyclist has access to a power meter, but that doesn't mean you can't explore aerodynamic testing. With some creativity and careful measurement, it is entirely possible to gain valuable insights into your performance without directly recording power output. This chapter explores practical techniques based on roll down and freewheel testing, providing methods that make use of simple observations to estimate drag performance.

The concept

When coasting, whether on flat ground or downhill, you know that your power equals zero because you are no longer pedalling. This key fact allows you to observe how your bike slows down under purely resistive forces, mainly aerodynamic drag but also rolling resistance. By measuring how far or how fast you coast under controlled conditions, you can create comparable test results between different setups or positions. The objective isn't to calculate the exact drag values but to establish relative differences. For example, you might compare how your bike and the rider roll with or without you wearing aero socks, or test two different handlebar positions.

Safety considerations

When performing this type of test safety must always come first. Testing on open roads, especially when coasting or descending, can expose you to risks from traffic, pedestrians, animals, or poor road surfaces.

Always:

- Choose quiet roads or better still closed environments whenever possible.

- Use a spotter or training partner if you're testing on public roads.

- Avoid overly steep or technical descents which might compromise control.

- Use bike lights, wear a helmet, and high-visibility clothing.

It's better to lose a data run than to risk an accident.

Roll down testing on a flat road

Overview

This is the simplest and most accessible method. You pedal up to a specific speed, stop pedalling at a marked point, and coast as far as possible, and measure your roll out distance. You can also analyse the data in Aerolab which is explained in Chapter Seven.

Requirements

- A bike computer with GPS speed or ideally a wheel-based speed sensor
- A clearly marked starting point
- Consistent environmental conditions (ideally low wind)

Procedure

1. Select a smooth road with a consistent road surface, minimal gradient and good visibility.
2. Mark a start line where you'll begin coasting.
3. Accelerate up to a consistent speed (e.g., 35 to 45 km/h) before the start line.
4. Adopt a consistent body position and at the mark, stop pedalling.
5. Allow the bike to roll for as long as possible.
6. Record the data file and total roll out distance.

Repeat this process multiple times, ideally five to 10 runs to account for small variations such as wind gusts or surface imperfections. Later, you can analyse these results statistically. Chapter 11 will explain how to handle your data using simple tools like Microsoft Excel to improve precision and confidence.

Downhill terminal speed testing

Overview

If you have access to a safe descent, this method uses gravity to accelerate you to a terminal velocity, the point where gravity's pull is balanced by aerodynamic drag and rolling resistance forces.

Requirements

- A bike computer with GPS speed or ideally a wheel-based speed sensor

- Consistent environmental conditions (ideally low wind)

Procedure

1. Choose a gentle, steady descent with a smooth surface

2. Accelerate to a consistent initial speed before the slope

3. Freewheel down the hill without pedalling, maintaining a stable position

4. Post test look at your maximum speed, this represents your terminal velocity for that run

5. Continue coasting beyond the hill, if safe, and record your roll out distance

What you can compare

Each test gives you two valuable metrics:

- Terminal Velocity (Vt): The maximum steady state speed achieved.

- Roll Out Distance: How far you coasted once the slope levelled out.

By comparing these two metrics between test runs with different equipment or clothing choices, you can determine differences in aerodynamic and potentially rolling resistance performance. For example, if one helmet or position consistently produces a higher terminal velocity, it's likely more aerodynamic. If one type of tyre / tube consistently produces a longer coast out distance, they likely have a lower rolling resistance.

Interpreting your results

These tests are not about pinpoint accuracy; they're about comparison under controlled conditions. Small setup changes can yield noticeable performance differences when conditions are consistent.

Keep detailed notes on:

- Rider position
- Equipment setup
- Wind direction and speed
- Surface conditions

Over time, patterns will emerge. Even without a power meter, you'll begin to develop a reliable sense of which factors have most influence on your aerodynamic drag.

In Chapter Six, we'll look at the Chung Method, and in Chapter Seven we'll look at the Aerolab implementation of the Chung Method. The Chung Method uses per second speed, power, and elevation data as the parameters fed into a mathematical model that produces an estimate of the aerodynamic drag (CdA). You can use the Chung Method in Aerolab to analyse the data from Coast Down and Terminal Speed Testing files where power equals zero.

Chapter 6: The Chung method

In Chapter 5, we explored ways to test aerodynamic drag without a power meter using simple roll down techniques. Now we move a step further with one of the most powerful and practical analysis methods available to cyclists: The Chung Method.

Also known as the Virtual Elevation Technique, the Chung Method, developed by the physicist Doctor Robert Chung, allows you to estimate your aerodynamic drag coefficient (CdA) using your ride data. No wind tunnel required. It is a method built on physics, logic, and some clever mathematics, and it has become the foundation of many modern analysis tools such as Aerolab in Golden Cheetah which we'll cover in Chapter Seven.

The principle behind the method

When you ride, your speed is determined by a balance of forces:

- Power input (from pedalling)
- Power lost to rolling resistance
- Power lost to air resistance (aerodynamic drag)
- Power lost or gained due to gravity and slopes

If you can measure speed, elevation changes, and environmental conditions, such as air density, you can reconstruct the mathematical relationship between your power and the resistive forces, on a per second basis, and estimate your CdA.

Understanding virtual elevation (simplified explanation)

Let's imagine you ride along a road and record your speed, gradient, and distance using a GPS device or bike computer. Every small change in speed tells us something about the forces acting on you, gravity when going up or down, rolling resistance from the tyres, and aerodynamic drag through the air.

The Chung Method turns this information into a virtual elevation profile, a reconstructed model of the terrain that represents how your total resistance changes with position. The remaining unknown is the effect of any variable wind force.

Here's the simple idea:

1. Start with speed and power data: you know these parameters at each second of the ride.

2. From changes in speed you can work out how much energy was used.

3. The laws of physics apply to all the forces: the method combines the forces of pedal power, gravity, rolling resistance and aerodynamic drag into one equation of motion.

4. The result is a mathematical 'virtual elevation profile' which is then aligned to the real elevation profile. This works best graphically in the Aerolab application.

When the two profiles match you've found the CdA value that best fits your ride data.

If there is an element of head wind the virtual elevation profile will be steeper that the actual elevation change. With an element of tail wind, the virtual elevation profile will be shallower. To counteract the effect of head and tail wind you can ride an out and back route, turning at a roundabout (traffic circle) without touching the brakes if possible. Those two wind effects will cancel out. Using the brakes absorbs energy. The effect of this energy loss is to create a step in the virtual elevation profile. You achieve the CdA result by matching the start and end points of identical elevation. With braking you would have to take account of the step in elevation that was introduced. This matching of elevations sounds like a fudge, but it does work. There is an example of this in Chapter Seven.

Why it works

On a flat road, when coasting or riding steadily, your changes in speed are small, so most of your power goes into overcoming drag and rolling resistance. There is little or no acceleration. In simple terms, you are estimating your aerodynamic drag by matching the virtual elevation profile (reconstructed from the ride file) to the actual elevation profile of the road. By accurately matching your virtual elevation created from your recorded data to the real elevation, the Chung Method can calculate your aerodynamic characteristics without needing a wind tunnel.

The strengths of the Chung method

- It works with data from you bike computer ride file
- It uses environmental data from real-world riding conditions
- There is a free to use implementation with unlimited usage

The Chung Method is great for comparing changes in aerodynamic characteristics, for example is helmet A better or worse than helmet B. The results are relative rather than absolute. If you are very meticulous and prepared to do a lot of test runs with the same set up it can provide you with a reasonably accurate CdA value.

Key requirements for reliable results

To get meaningful results, it’s important to:

- Use consistent testing routes with minimal wind variation
- Calibrate your power meter as required
- Ride at steady effort levels avoiding power surges
- Perform multiple passes to average out random errors

Like all experiments / tests good data discipline leads to greater confidence in your results.

Even though the calculations behind the method are quite complex, software tools have made it much easier to apply. That’s where Aerolab in Golden Cheetah comes in. It is a user-friendly graphical / visual implementation of the Chung Method. Aerolab brings the Chung Method to life making the complex physics accessible to any cyclist with a GPS bike computer, a power meter, and a speed sensor.

Chapter 7: Aerolab in Golden Cheetah

Aerolab within Golden Cheetah transforms the Chung Method into a simple to use visual tool. The calculations take place in the background with the results displayed in graphical form. Aerolab uses the same core principle of virtual elevation as the Chung Method. The CdA is determined by matching the virtual elevation and actual elevation lines on the screen by adjusting the CdA parameter. You can analyse your aerodynamic performance directly from your ride files.

In this chapter we'll explore how to use Aerolab to evaluate the ride files from your testing sessions. We'll begin by discussing how to estimate Crr, referring to Chapter Eleven on the methods of estimating rolling resistance. We'll then move on to using Aerolab itself, from importing files to fine-tuning results before finishing with three practical examples: a velodrome test session, an on-road TT event, and a roll down test.

Estimating rolling resistance (Crr)

To get the best results from Aerolab it's important to have a realistic estimate of rolling resistance (Crr) of your test track or road. Rolling resistance arises from the continual deformation of your tyres as you ride, and the characteristics of the road surfaces you ride over. Factors affecting rolling resistance include tyre and tube compounds, road surface texture, and tyre temperature.

At low speeds Crr serves as the baseline resistance. As speed increases the aerodynamic resistance starts to dominate. The value set for Crr affects how your virtual elevation curve behaves. If your Crr is too low, your CdA will appear too high, if your Crr is too high, the CdA will be appear to be lower.

A good Crr estimate sets the Aerolab system up for meaningful comparative CdA analysis. It doesn't have to be exact as we are mainly concerned with differences in CdA results, not absolute values. However, you do need to be mindful of any changes to Crr that might occur due to changes in tyre temperature in bright sunlight and other environmental changes such as air conditioning indoors.

Getting started with Aerolab

Golden Cheetah is a free, open-source performance analysis platform for cyclists and triathletes. It provides advanced tools for examining ride data, including Aerolab, which enables aerodynamic analysis using the principles of the Chung Method.

Data requirements

To use Aerolab effectively, you'll need a ride file containing:

- Speed data (set to one second recording or better)

- Elevation data (derived from GPS)

- Power data (set to one second recording or better)

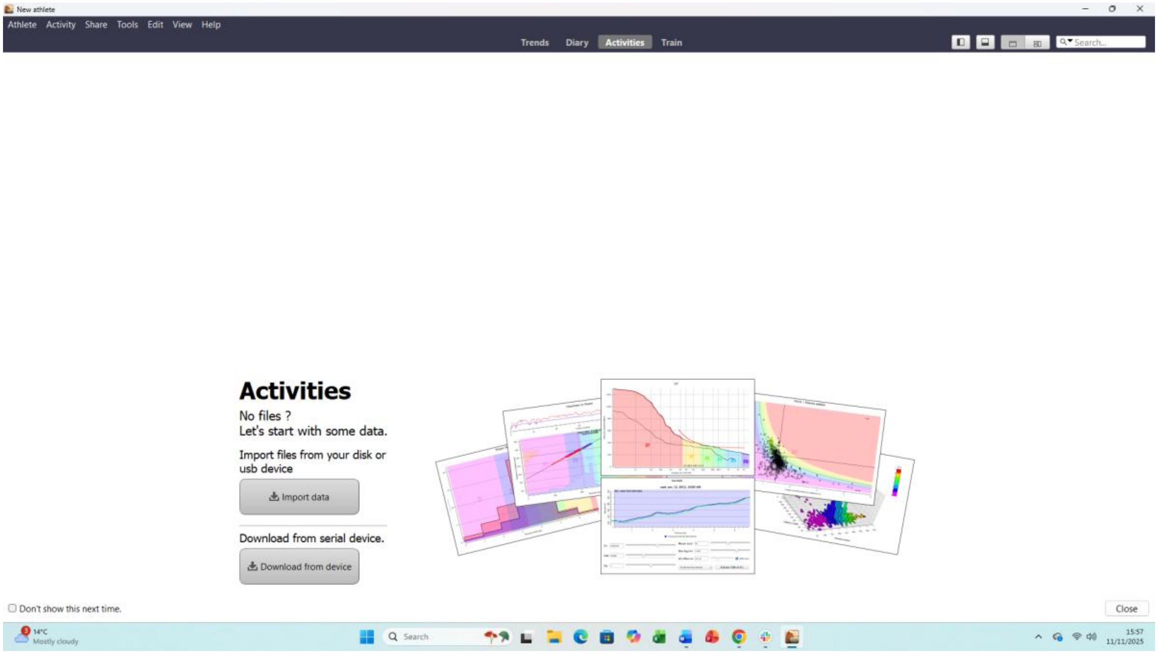
- Distance (which is normally derived from speed in your head-end)

- Environmental conditions (air density, temperature, barometric pressure, humidity)

Firstly, let's look at installing Golden Cheetah and the Aerolab tab.

The download is available from https://www.goldencheetah.org/

Once the file is downloaded and installed you get an opening screen that looks like this.



Activities

No files ?
Let's start with some data.

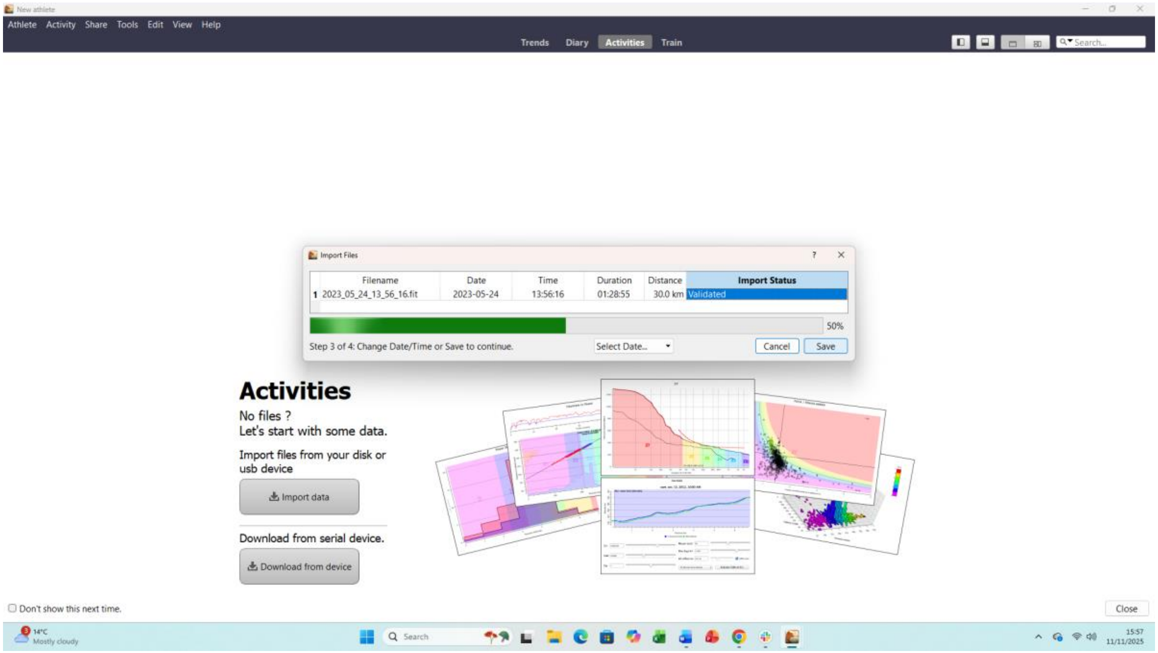
Import files from your disk or usb device

Download from serial device.

☐ Don't show this next time.

The options are Import data from locally stored ride files or Download from device such as your head-end unit.

If importing a file, the screen will look like this. Batch importing of files is supported.



	Filename	Date	Time	Duration	Distance	Import Status
1	2023_05_24_13_56_16.fit	2023-05-24	13:56:16	01:28:55	30.0 km	Validated

50%

Step 3 of 4: Change Date/Time or Save to continue.

Activities

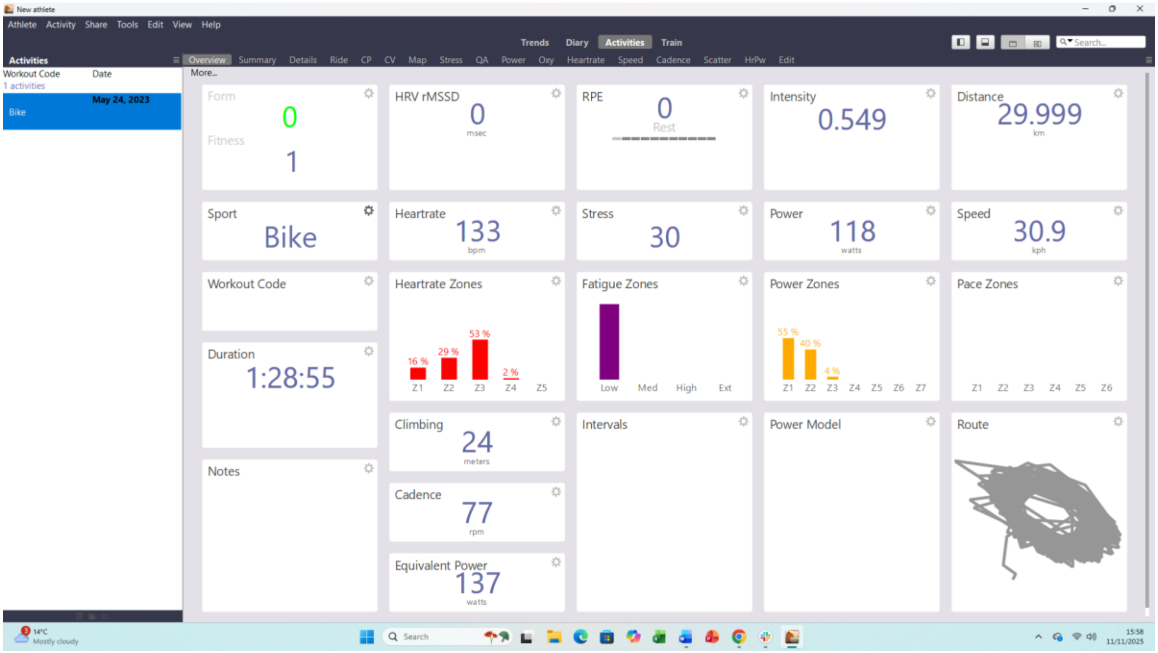
No files ?
Let's start with some data.

Import files from your disk or usb device

Download from serial device.

☐ Don't show this next time.

When the file is imported the Overview screen will be opened.

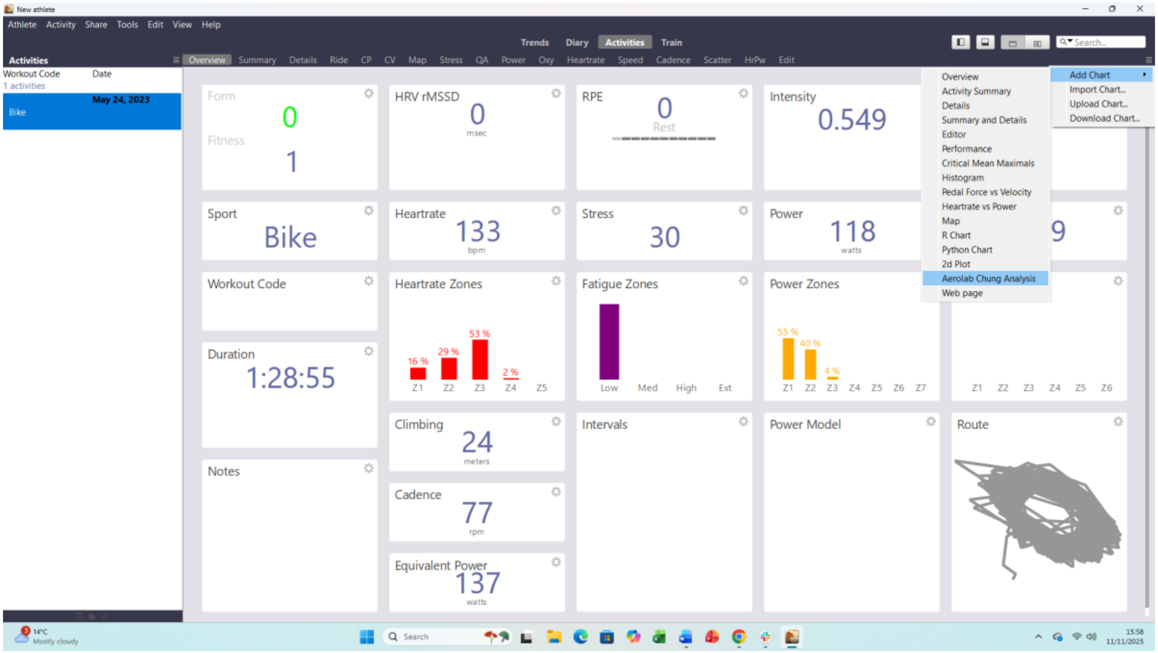


Form 0
Fitness 1
HRV rMSSD 0 msec
RPE 0 Rest
Intensity 0.549
Distance 29.999 km
Sport Bike
Heartrate 133 bpm
Stress 30
Power 118 watts
Speed 30.9 kph
Workout Code
Heartrate Zones
Fatigue Zones
Power Zones
Pace Zones
Duration 1:28:55
Climbing 24 meters
Intervals
Power Model
Route
Notes
Cadence 77 rpm
Equivalent Power 137 watts

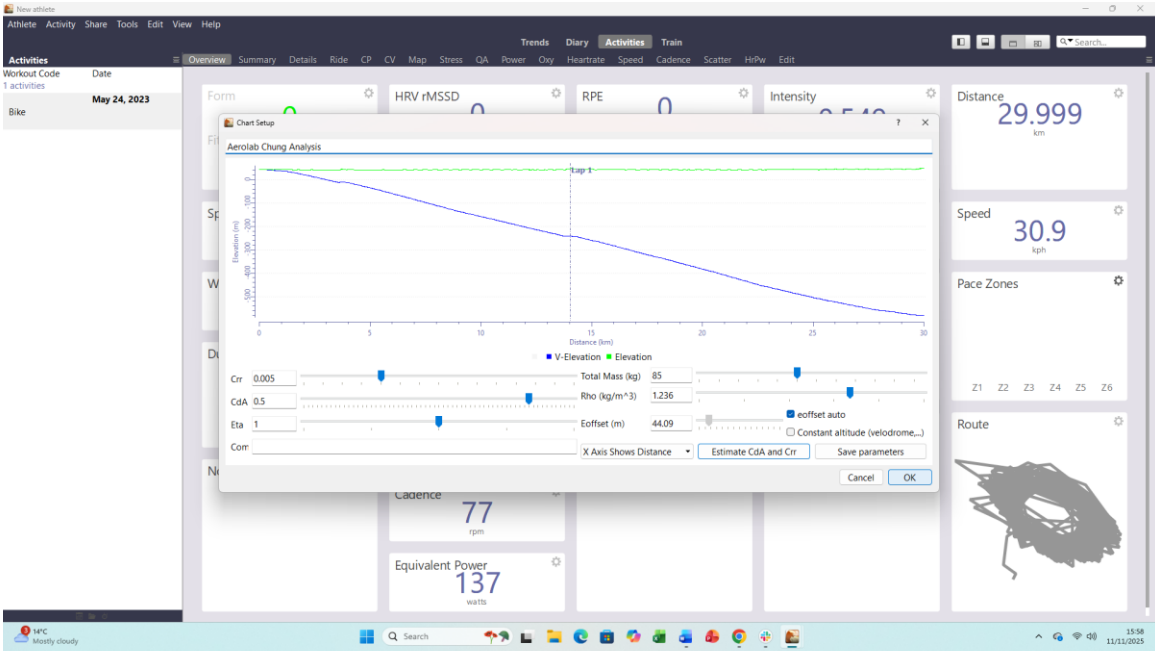
Note the section of the display showing the GPS derived route. This file is from an outdoor velodrome test. The tracking should be precise, however, the jitter on the commercial GPS signal and the time lapse reduces the resolution. The variation will have a knock-on effect on the recorded elevation profile as we will see later in the Aerolab analysis of this test file.

We then need to add the Aerolab Chung Analysis screen….

Use the dropdown from the three small dash symbol underneath the search box on the righthand side of the screen.



If you click "OK" this popup will close and an Aerolab Chung Analysis tab will appear next to "Edit" tab.



Crr 0.005

CdA 0.5

Eta 1

Com

Total Mass (kg) 85

Rho (kg/m^3) 1.236

Eoffset (m) 44.09

☑ eoffset auto

☐ Constant altitude (velodrome,...)

X Axis Shows Distance

Estimate CdA and Crr

Save parameters

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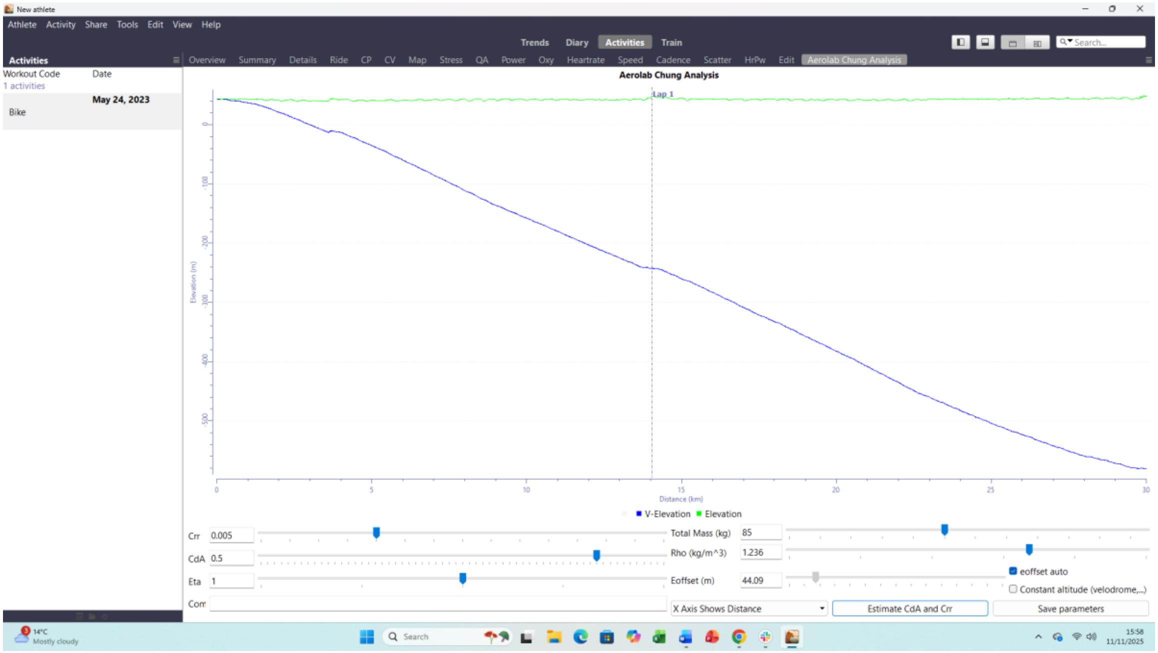
The step-by-step process

1. Import your ride file into Golden Cheetah (which we have already done).

2. Click on the Aerolab Chung Analysis tab. The full screen version looks like this:



Crr 0.005

CdA 0.5

Eta 1

Total Mass (kg) 85

Rho (kg/m^3) 1.236

Eoffset (m) 44.09

☑ eoffset auto

☐ Constant altitude (velodrome,...)

3. Set initial values:

Enter the estimated value for Crr and specify the Total Mass (kg) which is the rider and bike weight including race kit, shoes and helmet.

Change the air density / Rho number to the air density at the test venue for the date and time when the data was recorded.

Adjust the Eta (drive train efficiency): this is an estimate of the remaining power in percentage terms after the drive train loses.

4. Adjust the CdA interactive slider until your virtual elevation trace (blue) closely matches your recorded elevation trace (green).

5. Refine and compare:

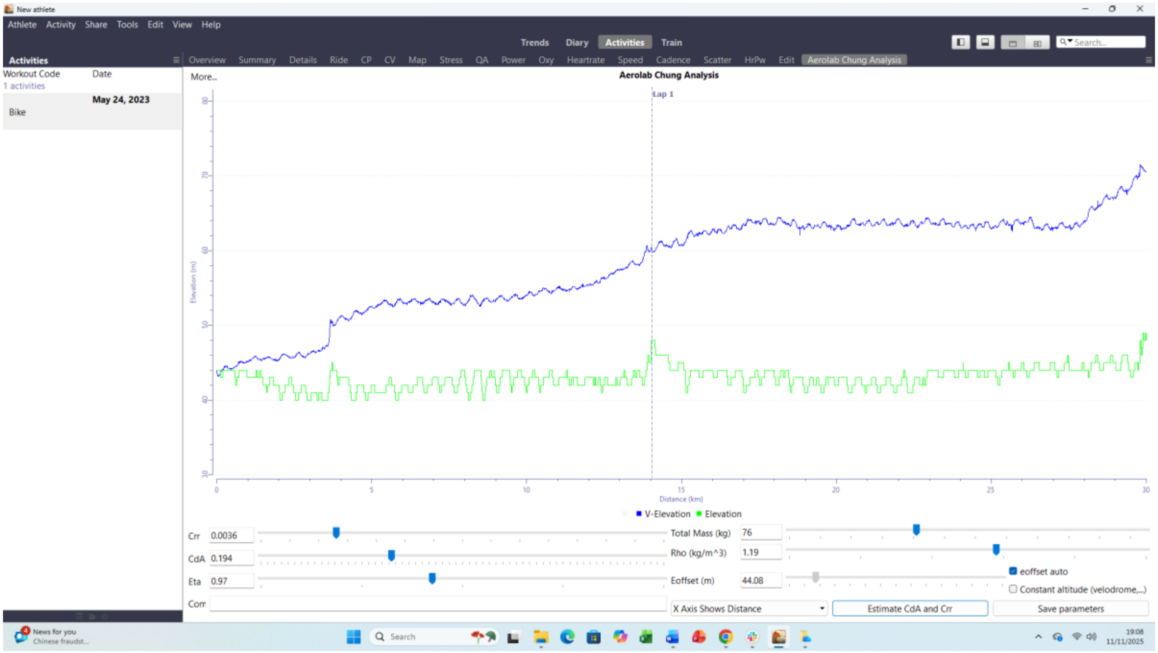
The aim is not perfection but consistency so that comparisons are meaningful. When the curves align smoothly across the section of the ride of interest, your chosen CdA and Crr are likely realistic representations of your aerodynamic drag and the rolling resistance characteristics.

Real-world examples

Example 1: Outdoor velodrome test

An outdoor velodrome offers an inexpensive venue for aero testing. It is usually possible to secure exclusive use. The consistent and hopefully smooth surface provides highly repeatable conditions even in light winds.

The next trace is from the same ride file as the trace above, with the parameters set to those of the rider and the conditions on the day. Rider and bike combined weight 76kg, Crr approximated to 0.0036 from previous testing, air density 1.190 from onsite measurement, drive train efficiency 97 percent using SRM power cranks with a clean drive train.



Crr 0.0036

CdA 0.194

Eta 0.97

Com

Total Mass (kg) 76

Rho (kg/m^3) 1.19

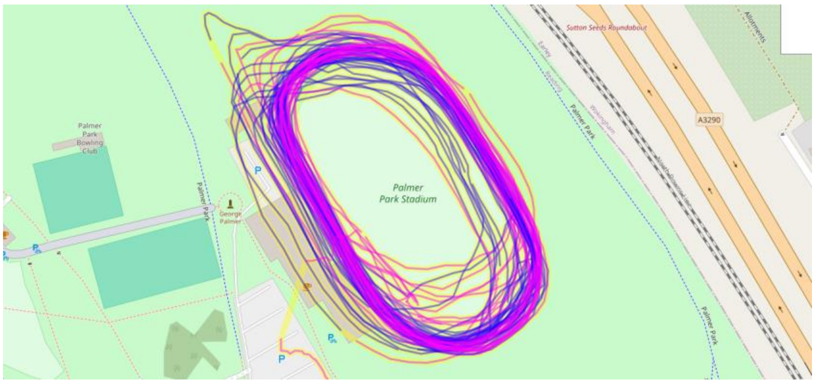
Eoffset (m) 44.08

☑ eoffset auto

☐ Constant altitude (velodrome,...)

The CdA slider has been moved to make the blue virtual elevation line roughly horizontal in the sections where the rider was holding position.

Note that the real / actual elevation line (the green line) is very jagged. This is due to the jitter on the commercial GPS signal (which is evident in the route trace) reducing the resolution. This was a velodrome test, so the “Constant altitude (velodrome...)” box is checked in the screen on the next page, and this forces the green elevation line to become horizontal.



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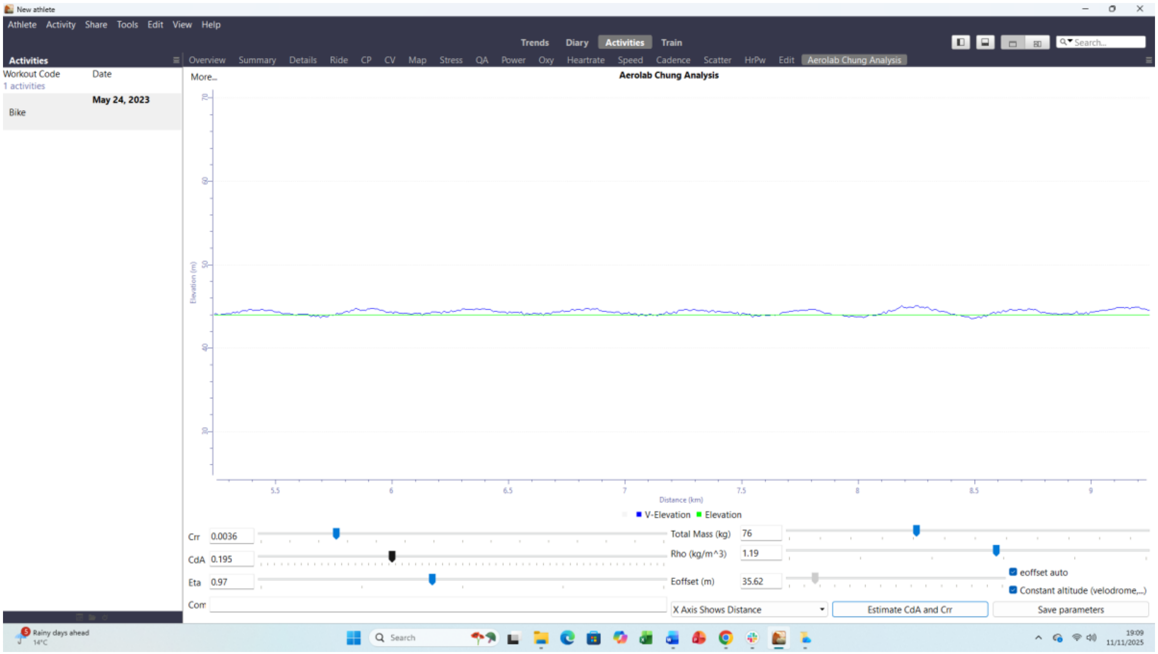
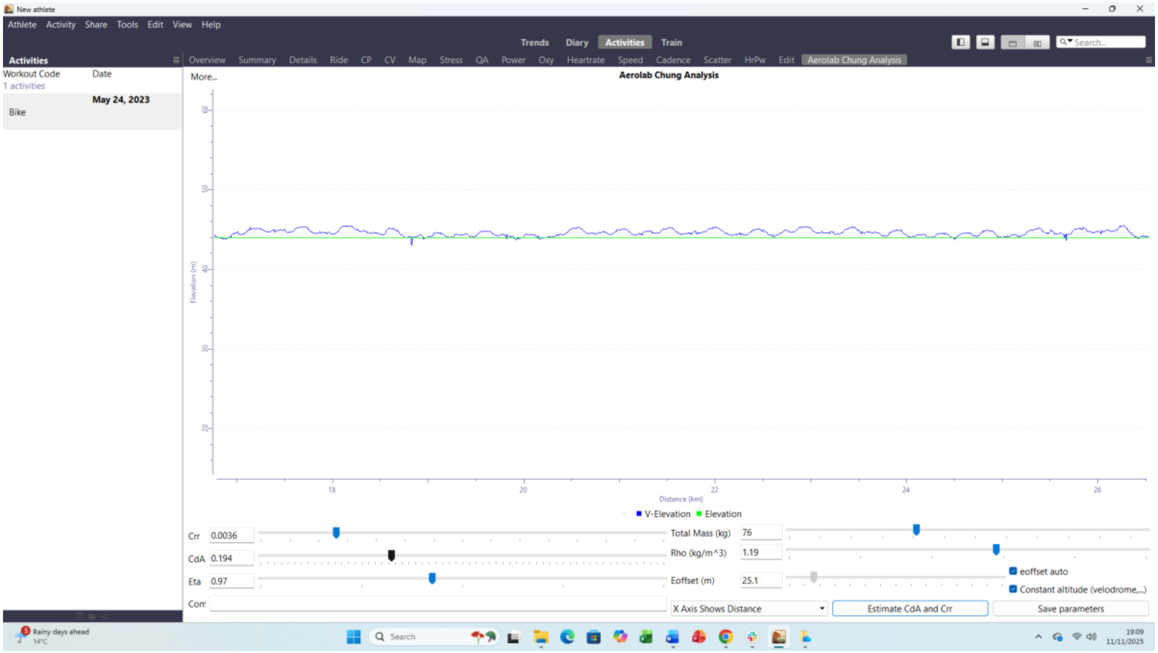
Crr 0.0036
CdA 0.194
Eta 0.97
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 44.08
☑ eoffset auto
☑ Constant altitude (velodrome,...)
X Axis Shows Distance

The next step is to look at the sections of the ride file where the rider was holding position by zooming in on the sections of interest.



Crr 0.0036
CdA 0.195
Eta 0.97
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 35.62
☑ eoffset auto
☑ Constant altitude (velodrome,...)
X Axis Shows Distance

This is the section from 5.5km to 9km. The blue line is matched to the horizontal green line as close as possible by adjusting the CdA slider. The CdA for this section is 0.195.



Crr 0.0036

CdA 0.194

Eta 0.97

Com

Total Mass (kg) 76

Rho (kg/m^3) 1.19

Eoffset (m) 25.1

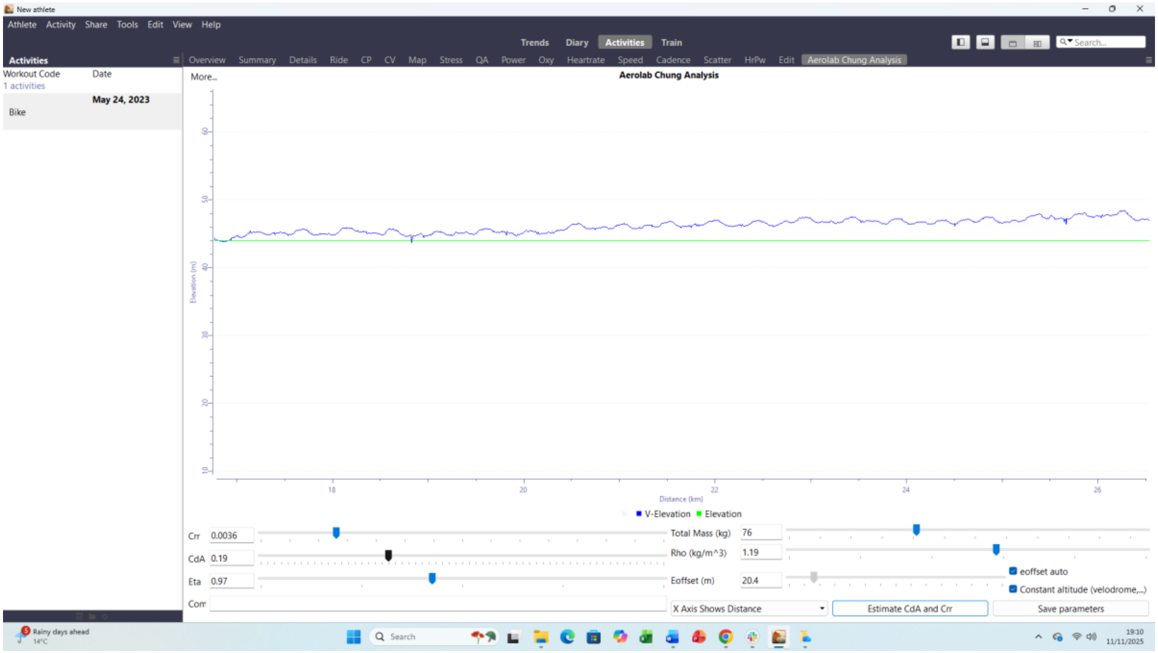
☑ eoffset auto

☑ Constant altitude (velodrome,...)

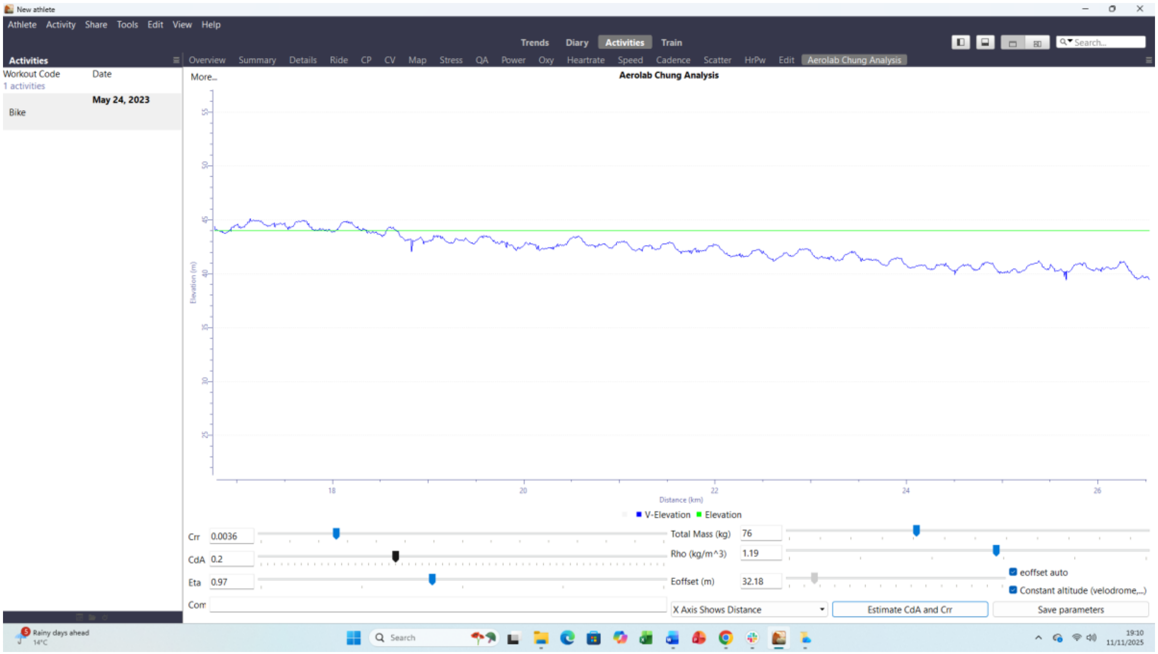
X Axis Shows Distance

This is the section from 17km to 25km. The CdA for this section is 0.194.

We can do some analogue confidence checks on the CdA estimates by adjusting the CdA number and seeing how that affects the alignment of the traces.

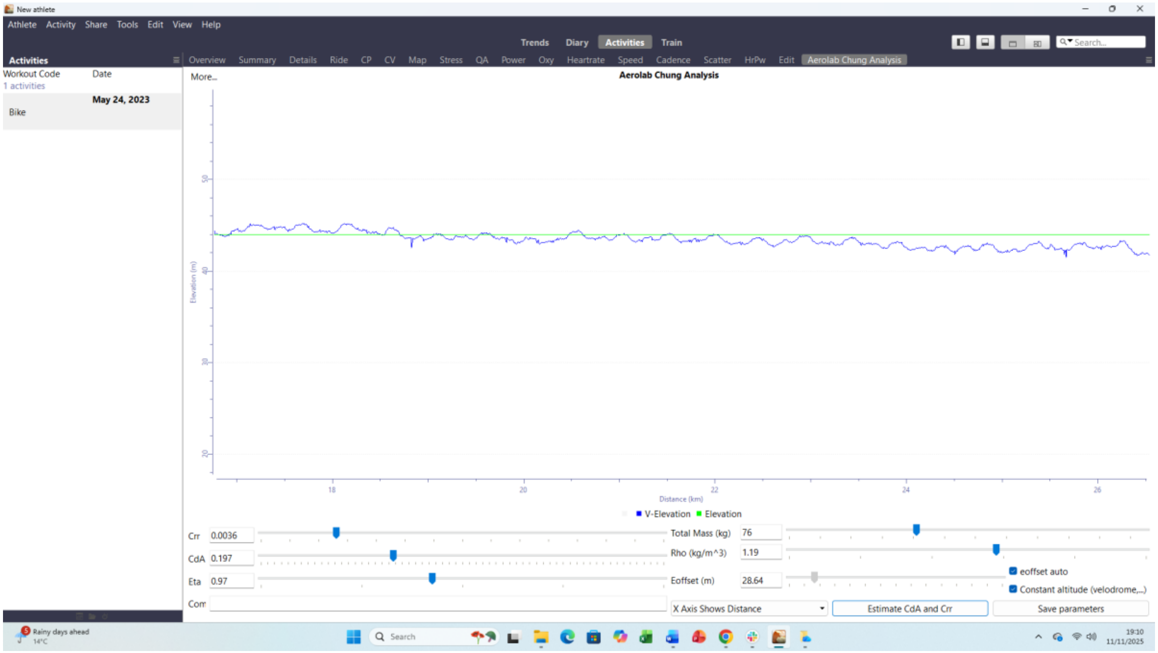


Crr 0.0036
CdA 0.19
Eta 0.97
Cor
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 20.4
☑ eoffset auto
☑ Constant altitude (velodrome,...)

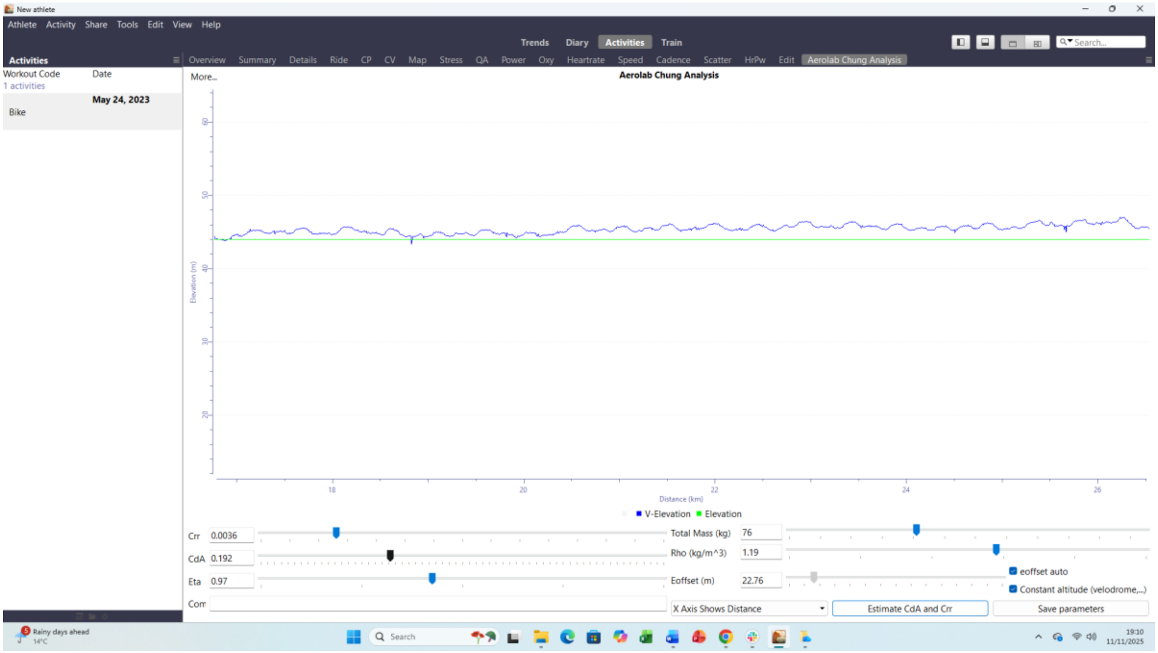


Crr 0.0036
CdA 0.2
Eta 0.97
Cor
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 32.18
☑ eoffset auto
☑ Constant altitude (velodrome,...)

We can see from these two traces that the 0.195 plus or minus 0.005 range is too wide.



Crr 0.0036
CdA 0.197
Eta 0.97
Cm
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 28.64
☑ eoffset auto
☑ Constant altitude (velodrome,...)



Crr 0.0036
CdA 0.192
Eta 0.97
Cm
Total Mass (kg) 76
Rho (kg/m^3) 1.19
Eoffset (m) 22.76
☑ eoffset auto
☑ Constant altitude (velodrome,...)

In these two traces we have narrowed the range down to 0.197 and 0.192.

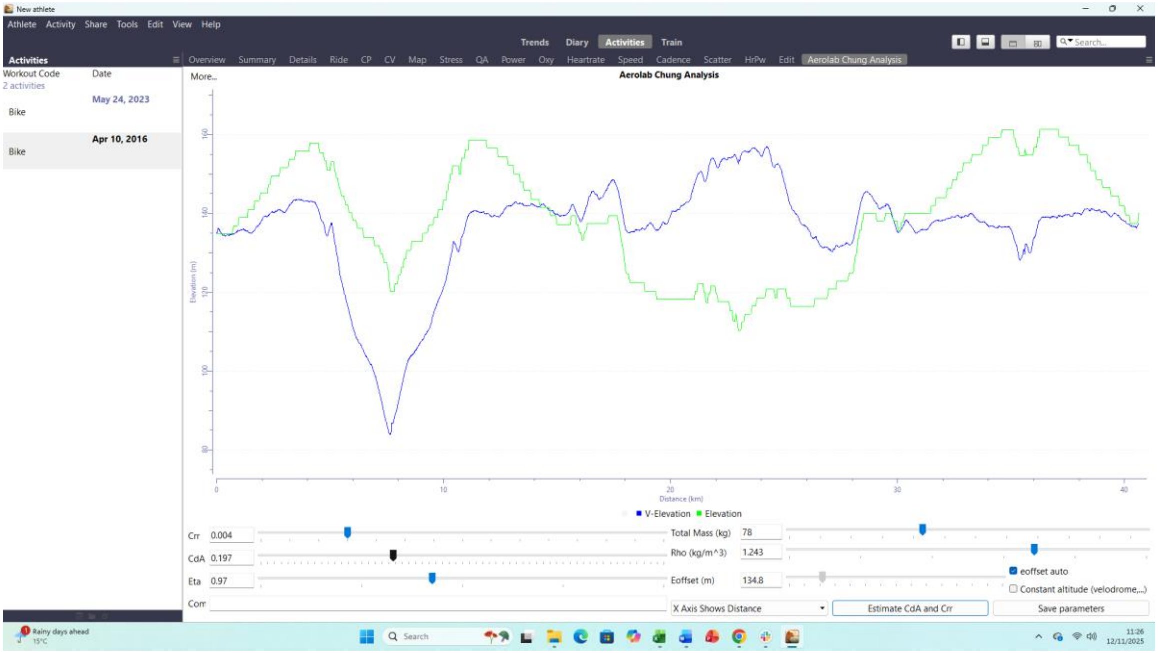
We can see from these two traces that 0.1945 plus or minus 0.0025 is a reasonable conclusion for the CdA from this test data.

Example 2: On road event

A real-world event or a road bike ride on a suitably consistent surfaces provides a more dynamic environment for analysis. You can import the ride file, focus on steady segments such as time trial sections or solo efforts, and use Aerolab to estimate aerodynamic performance under real world conditions.

This approach highlights how your apparent CdA might vary in real-world scenarios, for example, between headwind and tailwind sections, or when maintaining a particular riding position. Keep in mind that road traffic, wind variability, and power surges introduce noise into the data, so Aerolab results from on-road rides could have a wider margin of error.

This is a ride file from a 25-mile time trial. The air density was calculated using data from a nearby RAF weather station. There was a light head and tail wind.



Crr 0.004

CdA 0.197

Eta 0.97

Com

Total Mass (kg) 78

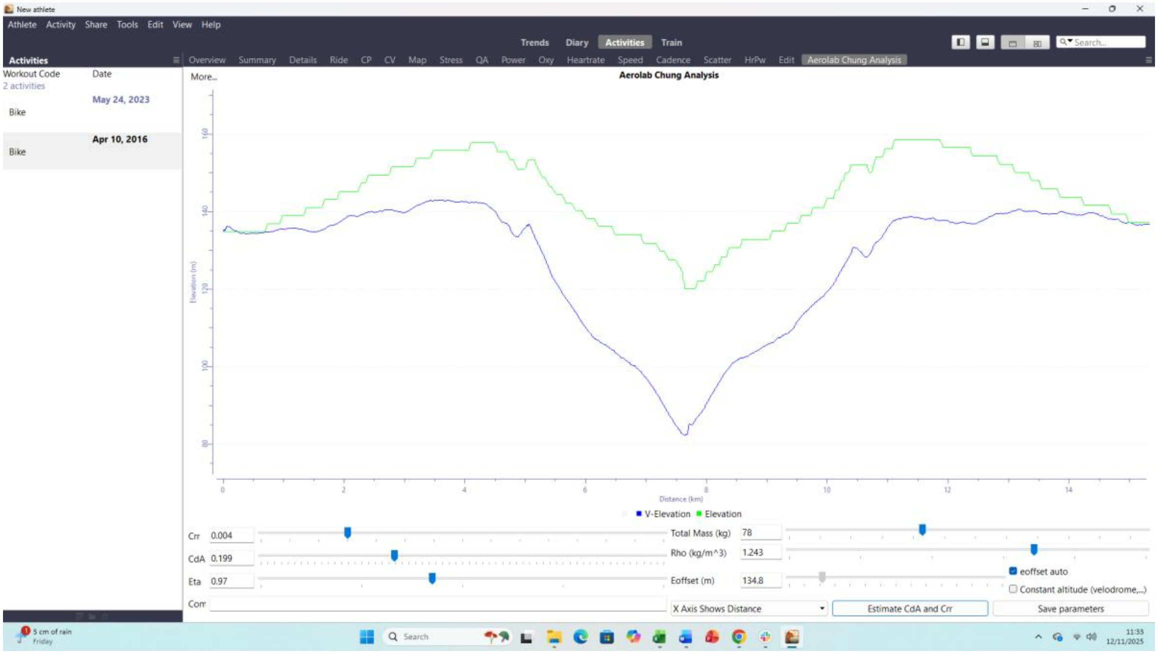
Rho (kg/m^3) 1.243

Eoffset (m) 134.8

☑ eoffset auto

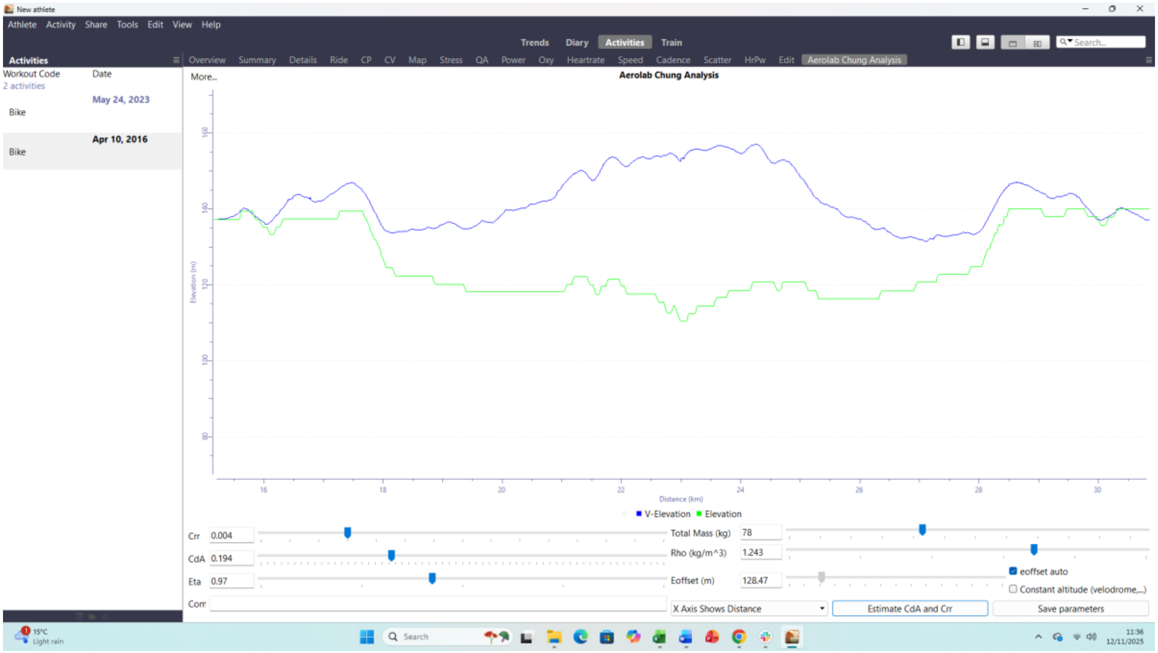
☐ Constant altitude (velodrome,...)

From the start to 15km it is “out and back” so the actual elevation at the start and finish of this section of the trace is the same.



Crr 0.004
CdA 0.199
Eta 0.97
Cor
Total Mass (kg) 78
Rho (kg/m^3) 1.243
Eoffset (m) 134.8
☑ eoffset auto
☐ Constant altitude (velodrome,...)
X Axis Shows Distance

From 15km to 30km it’s another “out and back” section.



Crr 0.004
CdA 0.194
Eta 0.97
Cor
Total Mass (kg) 78
Rho (kg/m^3) 1.243
Eoffset (m) 128.47
☑ eoffset auto
☐ Constant altitude (velodrome,...)
X Axis Shows Distance

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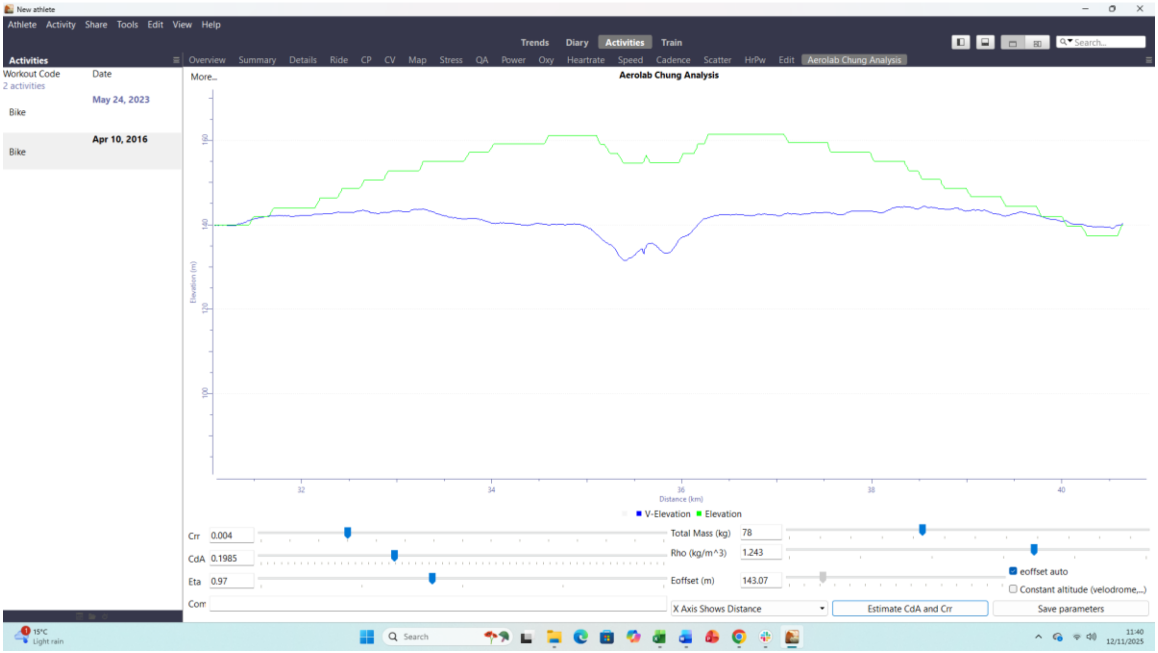
Finally, the 30km to 40km section is the same as the starting section missing out the spur by turning at an earlier roundabout.



Crr 0.004

CdA 0.1985

Eta 0.97

Com

Total Mass (kg) 78

Rho (kg/m^3) 1.243

Eoffset (m) 143.07

☑ eoffset auto

☐ Constant altitude (velodrome,...)

The CdA estimates from the three sections are 0.199, 0.194 and 0.1985, an average of 0.197. This agrees with the CdA estimated from the full length of the ride file. The conclusion would be 0.197 plus or minus 0.003.

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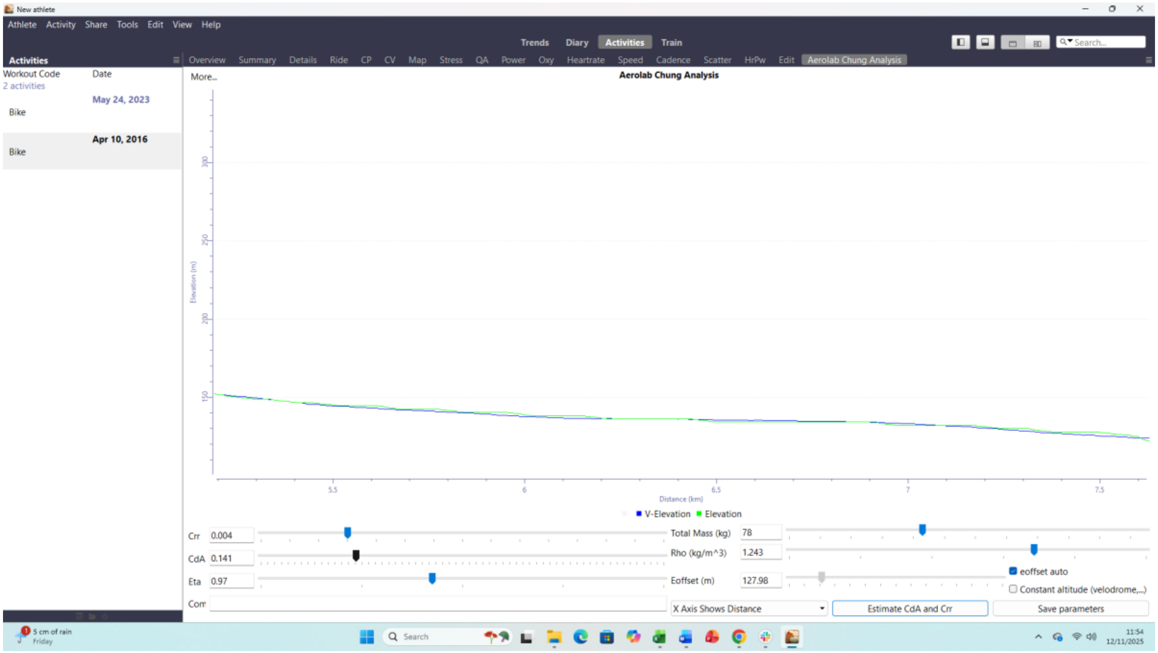
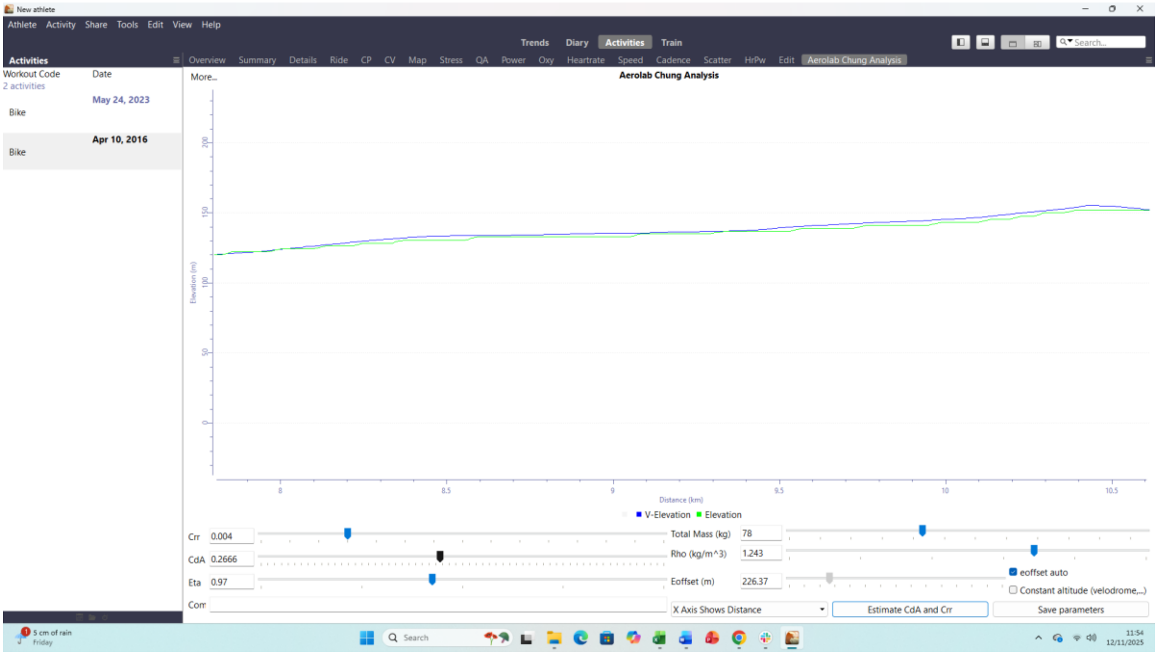
This is a good illustration of how a headwind and tailwind affect the virtual elevation line.



Crr 0.004
CdA 0.141
Eta 0.97
Total Mass (kg) 78
Rho (kg/m^3) 1.243
Eoffset (m) 127.98
☑ eoffset auto
☐ Constant altitude (velodrome,...)



Crr 0.004
CdA 0.2666
Eta 0.97
Total Mass (kg) 78
Rho (kg/m^3) 1.243
Eoffset (m) 226.37
☑ eoffset auto
☐ Constant altitude (velodrome,...)

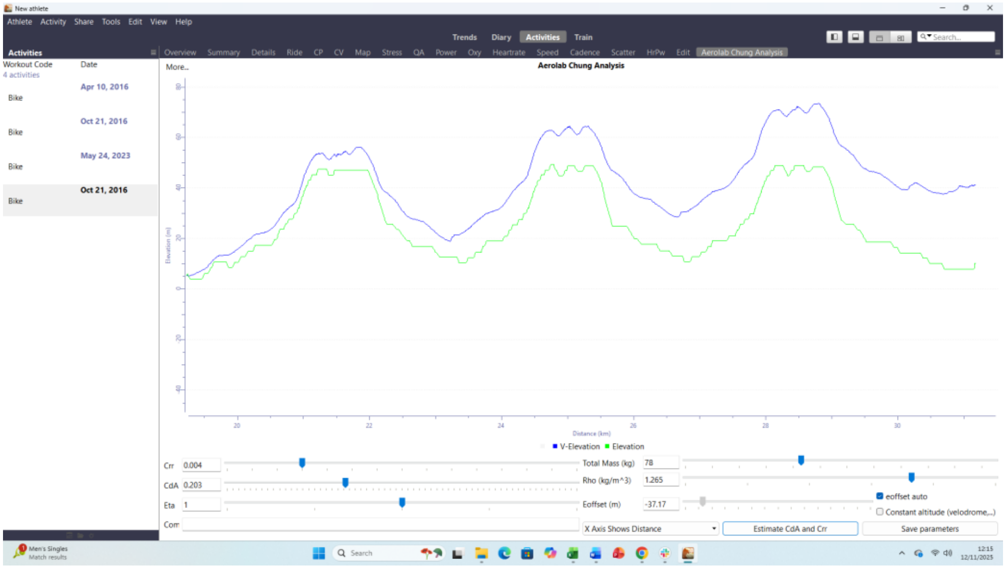
The results are 0.141 with the wind behind and 0.2666 for the headwind section, an average of 0.204. It is accepted wisdom that a rider gets less of an advantage from the tail wind even though the same air speed should be achievable in both directions of travel given equal power application.

Example 3: Roll down test

A roll down test is a simple and controlled way to use Aerolab when you don't have a power meter. If you are not pedalling your power is zero, so you have a power number for the Chung Method to apply, it just happens to be zero.

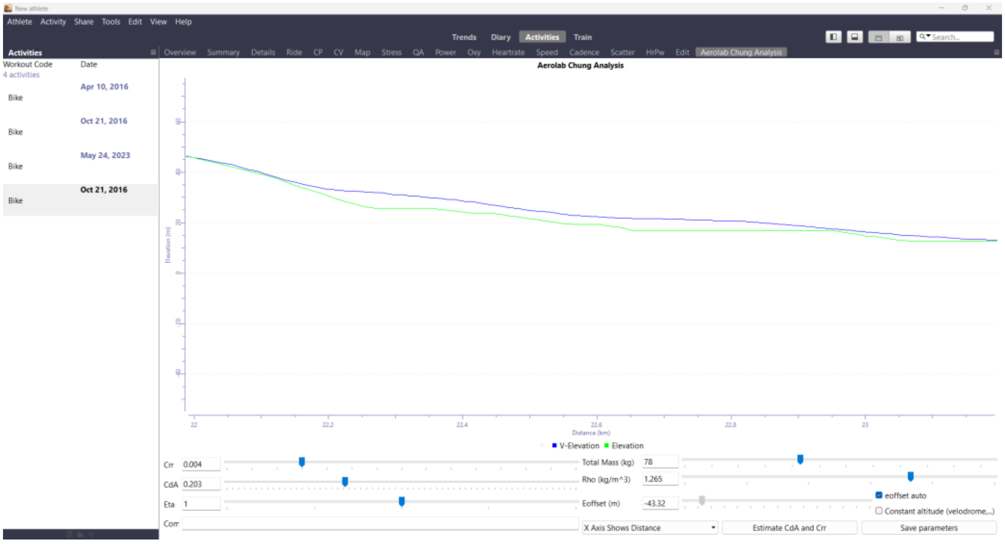
Using a quiet road, you can coast from a reasonably high starting speed and record the speed data as you slow down. You can also use a hill to coast down, but this is not to be confused with the terminal velocity test method. We still use Aerolab in the normal way to compare the virtual and actual elevation traces from these runs.

This trace is part of a ride file from Sawyers Hill in Richmond Park with three coasting sections.



Crr 0.004
CdA 0.203
Eta 1
Cmt
Total Mass (kg) 78
Rho (kg/m^3) 1.265
Eoffset (m) -37.17
☑ eoffset auto
☐ Constant altitude (velodrome,..)

This is the first section analysed by zooming in. The results from the other two sections were within the margin of error.



Crr 0.004
CdA 0.203
Eta 1
Cmt
Total Mass (kg) 78
Rho (kg/m^3) 1.265
Eoffset (m) -43.32
☑ eoffset auto
☐ Constant altitude (velodrome,..)

Interpreting the results

The strength of Aerolab lies in its visual feedback. When the virtual and actual elevation traces overlap smoothly across your ride file, it indicates that your chosen value for Crr and the resulting CdA accurately represent your aerodynamic performance.

If the virtual elevation line drifts upwards towards the right of the screen, your Crr or CdA may be underestimated. If it trends downward, they may be too high.

There is implicit averaging in the Aerolab system. The longer the duration of the test run the more data points there are for the analysis. The head-end unit is set up to record data at one second intervals, so for a three-minute run there are 180 data pairs of power and speed. For a ten-minute run there are 600. We'll look closer at sampling techniques and testing protocols in Chapter Thirteen.

Remember:

- Focus on relative comparisons not on absolute CdA values.
- Use a consistent test venue.
- Monitor conditions and environmental factors.
- Keep accurate notes of what you are testing.

Summary / conclusion

Aerolab transforms the Chung Method from theoretical mathematics into a practical hands-on tool. It empowers cyclists to analyse their aerodynamic performance using their ride files and free to use software.

By learning how to perform aero testing and analyse the results for yourself you gain the ability to assess riding positions, equipment choices, and environmental effects with clarity and confidence. Each time you test and analyse the results you deepen your understanding of how the forces of drag and resistance affect your riding performance.

In short, Aerolab is both an educational and analytical tool. One that helps you turn complex data into actionable aerodynamic insights. In the next two chapters, we'll explore two other methods of collecting and evaluating your ride data.

Chapter 8: Testing with MyWindSock

In the previous chapter we explored how to evaluate aerodynamic performance using data from a velodrome test session, a real-world event and freewheel testing. We used Aerolab in Golden Cheetah which is an implementation of the Chung Method. In this chapter we'll examine another tool based on the Chung Method that is part of MyWindSock, a web-based platform that automates much of the aerodynamic analysis process.

MyWindSock simplifies testing by automatically accounting for environmental variables such as wind speed, direction, and air density. Instead of manually matching curves or calculating virtual elevation, the software processes your ride data directly and provides estimated CdA values for each segment you test.

MyWindSock offers an easy way to obtain estimates of CdA from out and back test segments, however, it doesn't replicate the precision of carefully controlled field testing. It is a suitable method for riders looking to make initial assessments of equipment or position changes without having to use Golden Cheetah and Aerolab. The margins of error will be greater and the confidence limits wider because of the assumptions made for rolling resistance and the generalised approach to air density and other environmental effects.

How MyWindSock works

MyWindSock integrates with Strava, Garmin Connect, and other data sources to collect your data and analyse your ride files. When you upload your activity, the platform combines your recorded data (speed, elevation, power, etc.) with real-time weather data for the ride location and the ride time period.

It then applies mathematical models to estimate your CdA. The advantage is that the system handles many of the complex variables, like wind strength and direction, and air density, automatically. Rolling resistance is always treated as an approximation, so it's best to test on the same stretch of road under similar weather conditions to keep comparisons consistent.

Testing with MyWindSock

Upload your ride file

First, record your test using a cycle computer as you normally would. Once your activity has uploaded to Strava, open MyWindSock and import the ride directly from there. This process automatically links your ride data with the platform's weather database.

Set up your segments

For out and back aerodynamic testing you'll need to create two separate Strava segments, one for each direction of your test route. Match the start and end positions of the segments as closely as possible.

Evaluate your results

MyWindSock will calculate a CdA value for each segment, allowing you to average the two CdA values to offset the effects of wind or gradient bias.

For example:

- Outbound CdA = 0.171
- Inbound CdA = 0.216
- Average CdA = 0.194

This average gives you a representative measure of your aerodynamic performance.

It's important to note that the results from MyWindSock are suitable for relative comparisons where there is a significant difference in the results. The CdA numbers are not absolute values. The key takeaway is whether configuration A is faster than configuration B under similar conditions.

How to improve the quality of your MyWindSock results

The best way to evaluate the precision of your results is by repeating the test multiple times. This is particularly true when the measurement system produces a single number as the result. In the case of out-and-back testing a minimum of five runs is recommended. This helps reduce random variations caused by traffic, minor wind changes, or rider inconsistencies. There are statistical methods to assess the quality of your results which we will discuss in Chapter Ten.

With several sets of data, you can calculate averages and confidence limits. If one setup repeatedly shows a lower CdA, and both have narrow confidence limits, it's almost certainly faster. If results vary randomly, and results from A and B cover the same range, conditions may have been inconsistent or data insufficient, and you won't be able to make any meaningful comparisons.

Advantages and limitations of MyWindSock CdA assessments

Advantages

- MyWindSock handles environmental factors automatically.
- Works directly from your Strava uploads, no software knowledge required.
- Comparative insights for setup and position options.

Limitatiions

- Rolling resistance approximations. Crr may be inconsistent over the segment.
- Requires accurate and consistent segment definitions.
- Restricted to relative comparisons with limited precision.

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Practical tips for using MyWindSock

- Choose calm days with stable wind conditions.
- Use the same stretch of road for all tests.
- Avoid traffic interruptions, braking, or power surges during test segments.
- Record multiple runs for each setup to build confidence in your comparisons.
- Keep detailed notes of your tests: position, equipment, temperature, tyre pressure, etc.

The more controlled your testing, the more applicable your comparative results will be.

MyWindSock offers cyclists a user-friendly way to perform aerodynamic testing using their ride data. The automated accounting of wind and weather conditions provides comparative insights into your aero performance without requiring input of weather data or use of additional equipment.

Whilst it won't match the precision of controlled testing methods, like using Aerolab with velodrome data, MyWindSock is usable for identifying trends, verifying significant changes, and as an introduction to cycling aerodynamics.

Chapter 9: Testing with AeroMeters

The core differentiator of Aerometers, compared to other aero testing methods, is their ability to measure air speed, or more exactly the combined air speed of the cyclists and the component of air speed due to any wind. Other methods rely on ground speed alone.

The air speed measurement system is based on Pitot Tube technology. This technology originates in aviation, where it has been used for over a century to measure an aircraft's airspeed relative to the surrounding airflow. One of the first companies to use Pitot tube technology for aerodynamic measurement in conjunction with cycling was Velocomp with Notio soon following and popularising the approach. The use of Air Speed sensors marks another level of integration on top of the purely power and speed-based instrumentation.

There are two major advantages of AeroMeters

They simplify the analysis of out and back testing. Pretty much anyone can find a suitable out and back test location which opens up testing to the majority.

AeroMeters are effectively their own portable weather stations. They handle the measurements and calculations necessary to produce real time air density data for the CdA calculations.

Practical tips for testing with an AeroMeter

What you get from the AeroMeter apps is a single CdA number for the test. You don't have any calculations to do. With a single number like this you need to know how precise it is. You can't know how accurate it is, but you can know how repeatable it is. In testing we are looking for significant differences between two test set ups. To know if a difference is significant, we need to know the level of confidence in the results, and to calculate the level of confidence we need a set of results for each set up, not just a single result.

Plus you need to take into account that you are also evaluating the rider's ability to repeat their position on the bike and maintain that faithfully for the duration of the test segments. The system you are evaluating includes both the rider and the instrumentation. When you are testing alternatives, you need to know if the differences are down to the rider or the kit.

When you get an AeroMeter the first thing you should to do is evaluate for yourself how repeatable the results are and what this means for the confidence limits.

The key thing is that you need to be confident in the results. The best way to evaluate confidence is to repeat the same benchmark test over and over and see how the results compare. You need a minimum of seven repeat runs. More is better but the benefit diminishes so there isn't much to be gained after ten to twelve runs. There is some guidance on this is Chapter Ten.

Why Out-and-Back testing remains advantageous with AeroMeters

Beyond ensuring that tests start and finish at the same elevation, out-and-back protocols offer several important advantages even when airspeed is measured by an AeroMeter.

AeroMeters use air speed rather than ground speed in the calculations. In principle, this enables unidirectional testing, as the device measures the airflow experienced by the rider directly. In practice, however, ambient wind is rarely aligned perfectly with the rider's direction of travel. As a result, the measured head-on air speed is a combination of the cyclist's forward speed and the component of the wind acting in the direction of motion, which may be with or against.

Any remaining wind component acts perpendicular to the rider's direction of travel. This orthogonal, or "side-on" component does not contribute directly to head-on air speed but has important aerodynamic consequences.

Wind effects are not fully cancelled by airspeed measurement. While AeroMeters estimate the speed of the airflow relative to the bike, accurately resolving wind direction and therefore true yaw angle remains challenging in outdoor conditions. AeroMeters either attempt to calculate yaw using additional pressure sensors, or in the case of devices with a single measurement system, ignore the influence of yaw completely. Riding the same test segment in the opposite direction helps to average out asymmetries in aerodynamic response to yaw that may not be perfectly captured by the device.

Why do AeroMeters require calibration?

To understand why AeroMeters require calibration, it is useful to revisit some basic principles of fluid dynamics, specifically how the shape of an object influences the flow of a fluid and, in the case of a highly compressible and low-density fluid such as air, how it alters the surrounding pressure field.

A helpful analogy is the bow wave formed by a vessel moving through water. When a boat has a pointed bow, the bow wave forms very close to the front of the vessel. In contrast, when the front of the vessel is flat, as is the case with a barge travelling square-on to the flow, the bow wave forms some distance ahead of the vessel. The shape of the object determines not only the magnitude of the disturbance but also where that disturbance forms.

A similar effect occurs when a rider and a bike move through the air. A region of elevated pressure forms ahead of the rider, more accurately, a three-dimensional volume, typically centred around the helmet, shoulders and arms. This high-pressure region generates a pressure gradient that extends forward of the rider and bike. Importantly, this region can overlap where the AeroMeter is mounted. As a result, the air pressure experienced by the sensors is influenced not only by the freestream airflow, but also by this pressure gradient created by the rider and the bike.

The calibration procedure used by most AeroMeters relies on paired out-and-back runs. By analysing the relationship between ground speed and measured airspeed in opposing directions, a calibration factor is derived under the assumption that wind effects cancel when the two runs are averaged. This factor is then applied to subsequent measurements to correct the Pitot signal.

However, the pressure gradient in front of the rider is not fixed. It is influenced by rider position, posture, and equipment choices, most notably helmet selection. Although the calibration factor is typically assumed to be constant, it may in fact change when the rider changes helmet or position.

This presents a fundamental limitation: the very configuration changes that aero testing aims to evaluate can also alter the pressure field affecting the AeroMeter, and therefore the calibration itself. Obviously, this is a potential source of error.

In the early days of AeroMeters they were often termed random number generators. Some of this “bad press” came from the vagaries of the calibration factor which could be termed a “fudge factor” and some came from a lack of understanding of the implications of variable conditions and Crr variations that were not being taken into account by the devices.

Real time CdA with an AeroMeter

The claim that an AeroMeter can calculate real time CdA is misleading. The calculation is based on speed and average power data from a period before the calculation, so it is a pseudo real time CdA based on the average for a prior period. There is no awareness of variable road conditions. The other factor is that to observe the CdA the rider must look at the display either on a head-end or on a SmartPhone using an app. Firstly the rider should be looking where they are going and secondly if they move their head to look at the display their CdA will likely change. There is some merit in looking at comparative pseudo real time CdA in terms of maintaining the aero position in an event where a rider is likely to become fatigued and may find it difficult to hold a position.

Pitot Tube technology and AeroMeters

In its simplest form, a pitot tube measures the difference between the pressure experienced due to forward motion and the ambient atmospheric pressure. The difference between these two pressures is known as the dynamic pressure which is directly proportional to the square of the airspeed. From this relationship, airspeed can be calculated using well-established fluid dynamics equations.

In aviation applications, pitot systems operate at high Reynolds numbers and relatively high dynamic pressures, as aircraft move through air at tens or hundreds of metres per second. Under these conditions, pressure differentials are large, sensor noise is comparatively negligible, and airflow is relatively uniform across the probe.

Adapting pitot tube technology for cycling AeroMeters presents a significantly more challenging measurement environment. Cyclists typically experience airspeeds in the range of five to fifteen metres per second, producing dynamic pressures that are one to two orders of magnitude smaller than those encountered in aviation. At these lower speeds, measurement accuracy becomes highly sensitive to sensor resolution, thermal drift, vibration, and local flow disturbances caused by the bicycle and the rider. Wind conditions are also a factor as there will be a component of the wind that adds or subtracts from the air speed of the cyclist dependent on the yaw angle.

To function effectively at cycling speeds the Pitot tube geometry is optimised for low flow rates, and digital signal processing is used to filter noise and transient effects. The incorporation of additional pressure ports and proprietary probe designs are used to improve performance under yawed flow, where the effective airflow direction deviates from the bike’s direction of travel due to crosswind conditions.

Chapter 10: Accuracy and Precision

In all forms of aerodynamic testing whether it be using Aerolab, Aerometers or even a wind tunnel, every CdA value is only as meaningful as the accuracy and precision of the measurement system that created it.

CdA results are never exact. There is always a margin of error. Results are influenced by environmental conditions, sensor limitations, rider consistency, and the assumptions built into the modelling software. Understanding the two concepts of accuracy and precision, and the differences between them, is essential before making decisions about equipment or position based on your test results.

This chapter explains the difference between accuracy and precision, shows how they relate to real-world aerodynamic testing, and introduces simple statistical tools to help you interpret your test results with confidence.

Parameters that influence CdA calculations

Multiple variables affect the calculation of CdA. Some come from the rider and equipment, others from the environment.

On-bike measurements:

- Power meter accuracy is typically stated as ±1%, though the exact behaviour of the error (constant or random) is unknown.

- Speed is a function of the tyre circumference setting. This is usually measured with a roll out test without the rider being on the bike. The effective circumference can vary when the rider is on the bike (deformation), it can vary with tyre pressure and temperature which will affect casing deformation.

Environmental parameters:

- Air density which is influenced by temperature, pressure, and humidity.

- Rolling resistance which is estimated based on the surface type.

- Elevation, usually derived from GPS and calculated automatically in apps and devices.

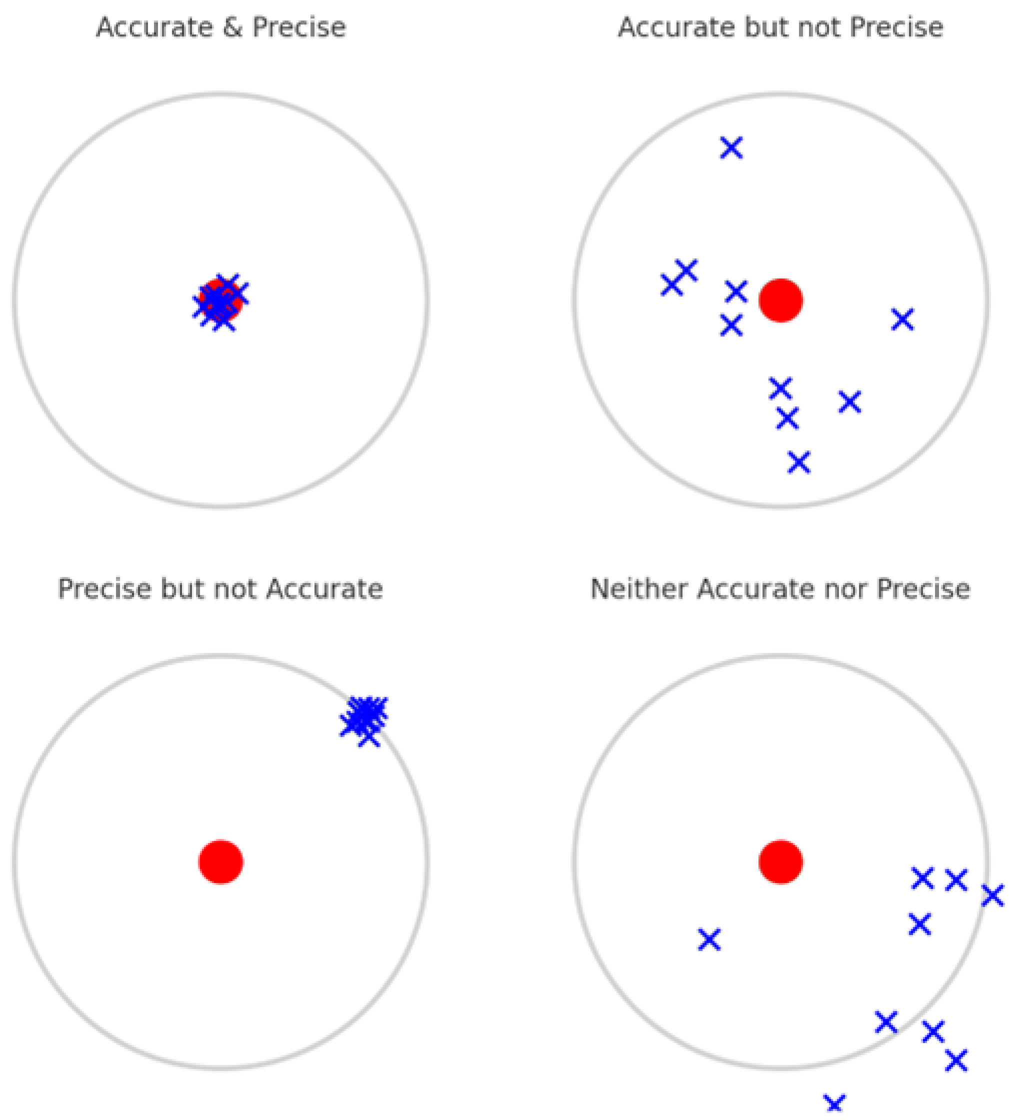
Accuracy verses Precision

A simple way to understand the difference between accuracy and precision is to imagine throwing darts at a dartboard, aiming for the bullseye and seeing how they land.

Accurate: spread of dart positions but the average of the positions is close to the bullseye.

Precise: darts land close to each other but may not be near the bullseye.

The permutations can be illustrated in four examples: accurate and precise, accurate but not precise, precise but not accurate, and neither accurate nor precise. Your field test results will typically resemble one of these patterns.



Accurate: individual results are spread but the average value of the results is probably correct. The confidence limits are quite wide because of the spread of values.

Precise: individual results are clustered, the confidence limits are quite narrow, but the average value is most likely incorrect.

Applying the analogy to CdA testing

A single CdA result can be inaccurate, imprecise, or both, you really don't know. This is why comparing results from single test runs is an invalid technique.

Accuracy is affected by incorrect assumptions such as rolling resistance, power meter bias, errors in wheel circumference, or incorrect air density. These factors are likely constant. The results will be useful for comparisons because they are precise but not accurate.

Precision is affected by wind variability, rider position inconsistencies, power fluctuations, and sensor noise. These factors are random. Results will be accurate but not precise.

Multiple test runs of the same configuration will produce a range of CdA values. How consistent they are enables you to estimate their precision. While the average value may still not be accurate, knowing the degree of precision is more meaningful when comparing alternative configurations.

Understanding your measurement system

When you measure CdA, you are using an integrated system consisting of:

1. The rider and bike
2. The instrumentation (power meter, speed sensor, aero device)
3. The environment (wind, temperature, air density, road surface)
4. The analysis software (Aerolab, MyWindSock, Aerometer tools)

Each component contributes uncertainty. Many of these factors are hidden from direct observation making it essential to understand the overall limitations of your testing system.

Improving precision through repeat testing

Precision is improved by performing multiple runs of the same setup on the same test track. This helps reduce variability caused by such things as posture changes, wind and sensor noise.

Important strategies include:

- Identical equipment setup for each run
- Dismounting and remounting for each run to test positional reproducibility
- Using steady, controlled power
- Maintaining consistent posture in the test period
- Completing at least five runs (more is better)

A simple statistical assessment

With five CdA values for a configuration, you can calculate:

- Range: highest minus lowest
- Median: the central value
- Average (mean): the sum of the results divided by total number of results
- The 95% Confidence Interval (CI): the range in which the true CdA is likely to lie with 95% certainty. You can use AI to do the statistical analysis for you.

The question is what matters to us?

In the main we are looking for differences rather than absolute CdA numbers. Is A better than B. When attempting to differentiate between A and B, accuracy doesn't matter so long as the measurements are precise.

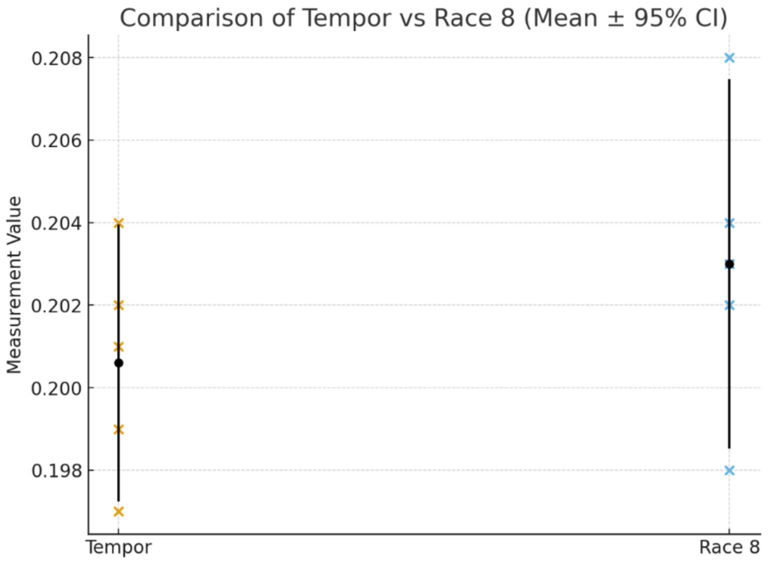
Now let’s look at the precision of some real measurements.

From a set of 10 test runs, alternating between two helmet options, we get a spread of CdA results. How those results differ from their average is an indication of their precision. We could dive into the Student T statistical test method, but we’ll keep it simple with some graphical representations and use AI to do the statistical calculations for us.

Here is an example using ChatGPT to analyse helmet test data:

Tempor	Race 8
0.204	0.204
0.201	0.208
0.202	0.202
0.197	0.198
0.199	0.203

Tempor helmet results:	Race 8 helmet results:
• Mean (Average): 0.201	• Mean (Average): 0.203
• Median: 0.201	• Median: 0.203
• Range: 0.007	• Range: 0.010
• 95% Confidence Interval: [0.199 – 0.204]	• 95% Confidence Interval: [0.199 – 0.207]



Although the Tempor helmet appears to have a lower CdA based on the average, the confidence intervals overlap. This means we cannot claim a statistically significant difference between the two helmets.

Why you need to know the limits of your measurement system

If you perform only one run per configuration, you have no way of knowing where that result lies within the true performance range. When testing equipment or position changes that have small effects on CdA, it is essential to understand the noise level (confidence interval) of your measurement system.

When we are aero testing precision (repeatability) is far more important than accuracy. Precision is an indication of how consistent your results are across repeated runs. Both accuracy and precision are affected by environmental variability, equipment calibration, modelling assumptions, and rider posture. Multiple runs, combined with simple statistical analysis using AI, allow you to evaluate equipment and positional changes with a much higher degree of confidence.

Multiple runs allow you to reduce uncertainty, define the confidence intervals, and enable you to make evidence-based decisions about which configuration is genuinely faster.

Chapter 11: Rolling resistance

When it comes to cycling speed, aerodynamics gets most of the attention but rolling resistance also plays an important role. It determines how much power is dissipated when the tyres deform as the bike moves forward as the wheels rotate. It comes into play whether you're racing, training, or just riding your bike for fun. At lower speeds rolling resistance plays a crucial role in determining how efficiently your power becomes speed.

Understanding how rolling resistance affects your riding helps you make smarter choices about tyres and tyre pressures depending on the surface and conditions, and if you are aero testing, it helps you interpret your results more accurately.

Rolling resistance explained

Rolling resistance is the energy lost when your tyres deform as they roll over a surface. Each tiny deformation absorbs energy that would otherwise help to move you forward, so the lower your rolling resistance, the more efficiently you convert your power into speed.

The coefficient of rolling resistance (Crr) quantifies this effect. A lower Crr means less resistance. Good tyres on smooth asphalt might have a Crr around 0.003, while poor tyres on rougher roads could be double that.

Factors affecting rolling resistance

- Tyre and tube type: high-quality, pliable tyres and tubes absorb less energy when deforming.

- Tyre pressure: too high can cause vibration losses on rough roads and increase the energy absorbed when deforming.

- Road surface: rough road surfaces like chip and seal dramatically increase Crr.

- Temperature: colder tyres are stiffer and increase deformation losses.

Typical Crr values

Smooth indoor track: 0.0020–0.0025

Smooth tarmac road: 0.0030–0.0040

Rough road or chip seal: 0.0045–0.0060

Switching from a basic tyre with a butyl tube to a performance tyre with a latex tube could reduce the Crr from 0.005 to 0.003 saving 10 to 12 watts at 40km/h.

Estimating Crr

If you're performing aero tests, you'll need to estimate the Crr for your test venue. You can find published tables of rolling resistance on the internet, remember that those tables are usually "per tyre". You can estimate Crr, or you can attempt to determine it experimentally.

A simple method for comparison testing is to perform a coast-down test: accelerate to a steady speed (around 16km/h), stop pedalling, and record how quickly you slow down.

You need stable conditions for this type of test. This method is good for comparing performance at different tyre pressures because the tyre pressure is easy and quick to change. Changing tyres and tubes requires time consuming effort so probably not such a practical test scenario.

A more complex method of estimating Crr is explained in Appendix 2.

How rolling resistance affects aero testing

In stable conditions and with consistent tyre pressures and temperatures the Crr should be reasonably constant when testing on a particular day. An inaccurate Crr will affect the CdA calculations, but the margin of error introduced can be ignored when comparison testing at approximately the same speed. If you are using Aerolab in Golden Cheetah, you can change the Crr by small increments and evaluate the impact of on your CdA results.

Underestimating the Crr will cause your calculated CdA results to be too high, overestimating the Crr will cause your calculated CdA results to be too low, but any significant differences in CdA will still be valid.

When performing field tests the best you can do is estimate the Crr and then measure the temperature of your tyres before and after every test run so that you are aware of any potential changes in Crr from the effects of heat that will have a knock-on effect on the results.

And most importantly, keep accurate notes of what you are testing including the tyre pressures, tyre temperatures, and weather conditions to aid consistent comparisons.

Quick reference guide

- Smooth wooden surface indoor track Crr: 0.0020–0.0025
- Typical road surface Crr: 0.003–0.004
- Rough road Crr: 0.005+
- Gravel Crr: 0.006+

Chapter 12: Air density

Understanding the effect of air density on speed

When it comes to cycling at speed, air resistance is the primary source of resistance. As speed increases air resistance increases dramatically. It is proportional to the cube of the speed. Air density is a crucial factor. Warm air is thinner than cold air. Humid air is thinner than dry air. It takes less energy to propel yourself and the bike through "thin air".

Air density influences how much drag force you experience. Lower air density means less air resistance, which is why riders often go faster on hot humid days or at altitude.

Understanding how air density influences your power and speed helps you interpret your aero testing results more accurately. The same setup will produce different results on different days if you don't account for differences in the air density on the test days.

How to calculate air density

Air density depends on three main factors: ambient temperature, atmospheric pressure and humidity. Atmospheric pressure is affected by altitude, and it is surprising how dramatic that variation is. Air density is expressed in kilograms per cubic metre (kg/m^3). At sea level, on a regular day, without a weather system in play, it is about 1.225 kg/m^3.

The simplest way to estimate air density, also called Rho (ρ), is to use an online calculator or the dropdown tool in Golden Cheetah. If you prefer to use the formula, it looks like this:

$\rho = (p / (R \times T)) \times (1 - 0.378 \times e/p)$

Where:

- p = air pressure (Pa)
- T = air temperature (Kelvin)
- e = water vapour (partial) pressure (Pa)
- R = specific gas constant for dry air (287.05 J/kg·K)

Don't worry if the maths looks intimidating, the Golden Cheetah drop down tool or online tools can handle the calculations for you. If you are trying to compare CdA results from different days you need to be aware of the air density on both of those days.

Things to be aware of:

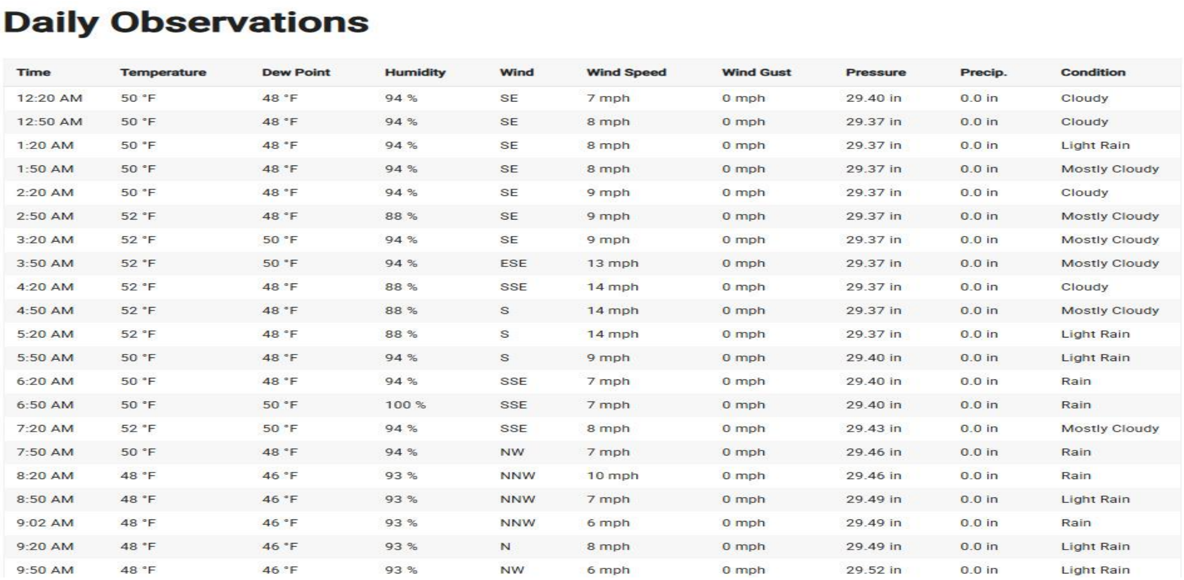
- Altitude: Air density drops roughly 1% per 100 metres of elevation.
- Temperature: Warmer air is less dense. A 10°C rise can lower air density by approximately 3%.
- Humidity: Higher humidity reduces air density, though the effect is relatively small.
- Pressure: Low-pressure weather systems reduce air density.

How to find the parameters to calculate air density

In order to calculate Air Density, you need Barometric Pressure, Ambient Temperature, and a measure of Humidity which can be expressed as Relative Humidity or as the Dew Point.

Ideally you would have a personal portable weather station with you every time you perform aero testing. If not, then you can access “wunderground/weather” on the internet.

If using wunderground you will be able to view the immediate historical data (like the table below) which updates every 30 minutes. The historical data is available for a rolling period of one year.



Daily Observations

Time	Temperature	Dew Point	Humidity	Wind	Wind Speed	Wind Gust	Pressure	Precip.	Condition
12:20 AM	50 °F	48 °F	94 %	SE	7 mph	0 mph	29.40 in	0.0 in	Cloudy
12:50 AM	50 °F	48 °F	94 %	SE	8 mph	0 mph	29.37 in	0.0 in	Cloudy
1:20 AM	50 °F	48 °F	94 %	SE	8 mph	0 mph	29.37 in	0.0 in	Light Rain
1:50 AM	50 °F	48 °F	94 %	SE	8 mph	0 mph	29.37 in	0.0 in	Mostly Cloudy
2:20 AM	50 °F	48 °F	94 %	SE	9 mph	0 mph	29.37 in	0.0 in	Cloudy
2:50 AM	52 °F	48 °F	88 %	SE	9 mph	0 mph	29.37 in	0.0 in	Mostly Cloudy
3:20 AM	52 °F	50 °F	94 %	SE	9 mph	0 mph	29.37 in	0.0 in	Mostly Cloudy
3:50 AM	52 °F	50 °F	94 %	ESE	13 mph	0 mph	29.37 in	0.0 in	Mostly Cloudy
4:20 AM	52 °F	48 °F	88 %	SSE	14 mph	0 mph	29.37 in	0.0 in	Cloudy
4:50 AM	52 °F	48 °F	88 %	S	14 mph	0 mph	29.37 in	0.0 in	Mostly Cloudy
5:20 AM	52 °F	48 °F	88 %	S	14 mph	0 mph	29.37 in	0.0 in	Light Rain
5:50 AM	50 °F	48 °F	94 %	S	9 mph	0 mph	29.40 in	0.0 in	Light Rain
6:20 AM	50 °F	48 °F	94 %	SSE	7 mph	0 mph	29.40 in	0.0 in	Rain
6:50 AM	50 °F	50 °F	100 %	SSE	7 mph	0 mph	29.40 in	0.0 in	Rain
7:20 AM	52 °F	50 °F	94 %	SSE	8 mph	0 mph	29.43 in	0.0 in	Mostly Cloudy
7:50 AM	50 °F	48 °F	94 %	NW	7 mph	0 mph	29.46 in	0.0 in	Rain
8:20 AM	48 °F	46 °F	93 %	NNW	10 mph	0 mph	29.46 in	0.0 in	Rain
8:50 AM	48 °F	46 °F	93 %	NNW	7 mph	0 mph	29.49 in	0.0 in	Light Rain
9:02 AM	48 °F	46 °F	93 %	NNW	6 mph	0 mph	29.49 in	0.0 in	Rain
9:20 AM	48 °F	46 °F	93 %	N	8 mph	0 mph	29.49 in	0.0 in	Light Rain
9:50 AM	48 °F	46 °F	93 %	NW	6 mph	0 mph	29.52 in	0.0 in	Light Rain

The first thing of note is that you get both Relative Humidity and Dew Point, so you don’t have to worry about a conversion. The pressure units are inches of mercury which you may need to convert to millibars. Also, because the benchmark for atmospheric pressure is sea level, you will need to adjust the pressure for the altitude of your test location.

To calculate the air density, plug the parameters, in the appropriate units, into the calculator available with Golden Cheetah or use one of the online calculator resources.

Summary

Understanding and accounting for the air density on test days is essential if attempting to make comparisons across different test days. You may see air density variations within test periods on the same day. These are usually due to changes in temperature rather than pressure or humidity. Being aware of the air density makes your aero testing results more reliable and more meaningful.

Appendix 1: Evolution of a time trial position

My interest in time trialing was reawakened after I had competed in a few rowing triathlons. Rowing because the local Marlow Rowing Club organized an event called The Rowers' Revenge. I am a very poor swimmer so real triathlons are a non-starter for me.

These pictures span from 2011 to 2022.

In the 2011 picture I look like a 60-year-old man on a bike.

From around 2019 I start to look like a time trialist.

Things to note from this 2022 picture:

Non-UCI position as UCI rules do not apply to English CTT events.

Front and rear lights, a requirement of the CTT regulations. Timing chip on the ankle.

No air gap between the forearms and the extensions. This is the main aero advantage of the new generation of "super extensions", although the ones I am using here are bent pipe with a balsa wood filler held in place with heatshrink.

Essentially a "V" shape for the forearms and upper arms. Arms are essentially cylinders. By having the arms at forty-five degrees I am turning their cross section into an ellipse rather than a circle.

POC Tempor without a visor. Ideally, I wouldn't have the gap between the tail and my back.

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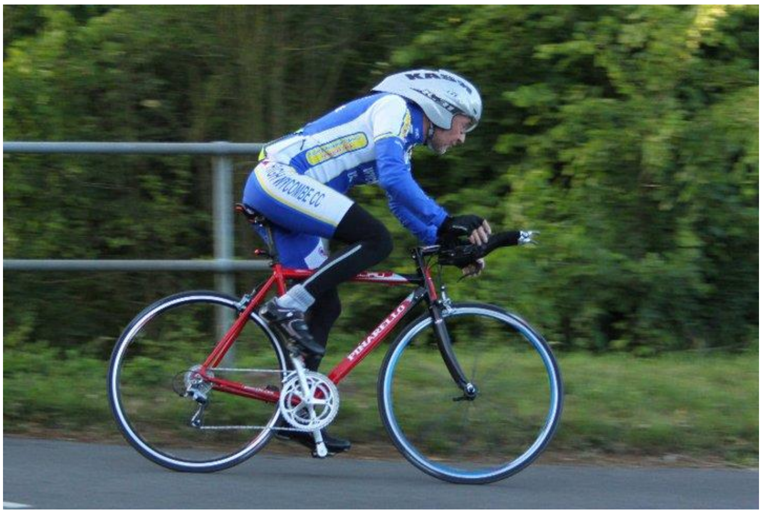

11th June 2011

HWCC club circuit TT, two laps of 11 miles.

I bought this frame as a road bike, mainly to use as a training bike. It's a 54cm whereas my Madone was a 56cm. I set it up with a set of "King Cycle" Tri-bars that I bought from eBay. Those bars had an integrated stem like Ventus II, quite advanced for the time. This low-end Pinarello frame became my turbo bike.

The only other concession to a TT style is the Kask K-31 helmet. The kit looks more like I'm dressed for an early season event rather than one approaching midsummer's day.

Note the silver line on the leg warmers which is actually the flap that covers the zip. I used leg warmers because I had discovered through aero testing that I was faster with leg warmers than without. On further testing with other leg warmers, I discovered it was the zip cover that was making the difference as it was acting as a "trip" for the airflow. We then saw the appearance of "trip strips" that you stuck on the shins, made from kinesiology tape. These evolved into the "calf guards" and "trip socks" that we see today with claims of a 15-Watt saving. Who would have thought that such a simple idea would produce such a significant aero advantage.

Two benchmark 25TTs from 2011:

H25/2	15th May 2011	25TT	72:10:00
H25/2	2nd October 2011	25TT	71:17:00

I bought a pair of SRAM S60 wheels before the 2012 season but the rest of the bike remained the same. I don't have any pictures from the 2012 season.

I bought a FFWD disk wheel (eBay) and used that on the back for the 2012 May 13th 25TT. I'd also invested in SRM power cranks. Average power was 168 watts.

H25/2	13th May 2012	25TT	68:02:00

I bought this Felt B12 entry level TT bike in 2013. I'm using the S60 front wheel and Zipp Super 9 on the back. I probably had one of the first Super 9 disk wheels in the country. Kask Bambino helmet replacing the K-31, Castelli overshoes and a club skin suit. Still using the aero leg warmers...

30th June 2013

Richmond Park TT

31:37

You can see the SRM power cranks in this picture. I don't have a meaningful average power figure for this course as it was a Hilly (in so much as there are any hills in Richmond Park). The average power for a 25TT a few weeks earlier was 172 watts.

H25/2 2nd June 2013 25TT 65:42:00

Roughly two and a half minutes faster than my 2012 time with only four watts more average power. This could have been partly down to conditions and partly down to having a more aero set up.

H25/2 6th October 2013 25TT 61:39:00

Four minutes faster with an additional six watts average power of 178 watts. Fewer minutes for a 25TT than my age in years, which was one of my goals.

I bought a used 2009 P3C in the spring of 2014. It had an SRM power meter which I later found out was water damaged, probably from pressure washing. It came with some wheels with Zipp 404 decals that were actually knock-off imports. The seller did make me aware that they weren’t the real deal.

This 25TT was on H25/4 which is a slower course than the H25/2. I had an average power of 175 watts.

16th March 2014

West London Combine 25TT

67:17:00

April / May 2014 and what you can see in this picture is that I've put a Tririg Omega brake caliper on the front and fitted a Vision Bayonet basebar, the same as the one that was factory fitted on the Felt B12. I'm using an original Zipp 808 on the front instead of the SRAM S60.

HWCC Good Friday 10TT first time under 24 minutes

H10/22 18th April 2014	10TT	00:23:55	Average power 192
H25/2 4th May 2014	25TT	61:40:00	Average power 174
H25/2 18th May 2014	25TT	59:47:00	Average power 183

I'm riding a very low position with a CdA or around 0.1800. I'd trained in the low position on the turbo for six months prior to the start of the 2014 season, always in a TT position on the extensions.

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You can see from the Cervelo logo on the seat post how low the saddle is. With the basebar as low as it will go, I only have a drop of about 60mm at most. I picked up the Uvex FP1 helmet for £30.00 (eBay). I was advised by one of my aero TT friends that it was a "fast helmet".

14th June 2015

Westerley CC Wednesday evening 11 lap circuit TT Minet Park

I've gone Di2, so no gear cables entering the downtube. You can also see that I am still using a conventional brake caliper on the back.

I didn't do any events on H25/2 or H10/22 (the A404 courses) after 2014, because of safety concerns.

In this 2016 picture you can see that I've gone "single ring", fitted a Tririg Omega brake at the back, and changed the basebar to a Ventus II set up. From the position of the Cervelo logo on the seat post you can see that the saddle is about 30mm higher, and I'm using 30mm of risers at the front to maintain the same "drop".

14th April 2016

Aero Testing at Palmer Park Velodrome

Same year, and from the position of the Cervelo logo on the seat post you can see that I've gone back to the lower riding position. I'm testing out a Giro AeroHead (borrowed from the client on the day) against the Bambino and the Uvex FP-1.

I was also testing the 808 NSW against an ENVE 7.8 front wheel (borrowed from the same client). It wasn't a particularly windy day. The ENVE 7.8 was rock solid when cornering whereas the 808 NSW was very twitchy. Consequently, I bought an ENVE 7.8 front wheel in 2017.

3rd September 2016

Aero testing at Redbridge Circuit

The other noticeable change is that I am using Zipp 110mm extensions rather than conventional S-bends.

I rode a 25TT in the autumn on the "fair test" H25/1 course, on the A4 at Pangbourne / Thatcham, which includes part of the original "Bath Road" 25 TT course. Power was a bit down compared to previous efforts. If I look back at my training diary there is probably a simple explanation for that.

H25/1 2nd October 2016 25TT 62:12:00 Average power 174

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Still using the 808 NSW in this picture. Much higher position. Aero SpeedPlay pedals and cleats. Di2 (10 speed) replaced with eTap (11 speed). Same Zipp 110 extensions, AeroHead helmet (obviously).

27th July 2017

Westerley Wednesday evening 11 lap circuit TT Minet Park

2019 saw the launch of “aero extensions”. The key difference being the elimination of the gap between a round extension pipe and an essentially round forearm. Rather than pay out a thousand pounds or more, I had a friend bend some 22mm pipe for me to mimic the style. I also adopted a much higher riding position. The aero loss was more than offset by the power gain from a more open hip angle.

15th May 2019

Westerley Wednesday evening 11 lap circuit TT Minet Park

Apart from the custom paint job on the P3C the other changes in this picture are the ENVE basebar and riser stack, with a bridge for stability; the Uvex Race 8 helmet, which, when tested at the Boardman wind tunnel (October 2018), proved to be as good as the AeroHead, but has the advantage of much better forward visibility; the Huub skin suit, which proved faster than both my club skin suit and my original NoPinz “trip” skin suits; aero calf guards; and finally the ENVE 7.8 front wheel.

This is my favourite picture of me on a bike. The cranks are in the right position, the valve cover on the disk is at the bottom and the valve on the ENVE 7.8 at the top. The evening sun is at the right angle to highlight the wheels. For those that are familiar with the Minet

Park Cycle Circuit I'm just cresting the rise out of the dip after the hairpin and about to take the 180 degree turn to the left.

Essentially the same set up as the previous picture except I've changed the stem from a Profile Design to the ENVE aero stem. The basebar had slipped in the Profile stem when I was doing a 25TT on H25/1.

20th October 2019

CTT National Closed-Circuit Championship Thruxton

29:36 Timing chip on the wrist

H25/1 7th July 2019 25TT 60:00:36 Average power 190

Without my basebar being tilted down by ten or so degrees for the final five miles, after hitting a pothole, I might have just squeezed a 59:59. At Thruxton my average power was 180 watts.

Switched to the Ventus II basebar, NoPinz “Flow” skin suit (riding with AS Test Team), NorthWave shoes, without covers as no advantage found.

Other than that, essentially the same set-up, except for the 3D printed additions to the extensions. The additions helped with comfort, but the aero difference was negligible.

13th September 2020

VTTA 10TT H10/3A 24:59

I acquired a Cervelo P4 and used it at the CTT National Championship at Thruxton. Same riding position but reverting to the Zipp 110 extensions. I later tested the Zipp 110 extensions against my “bent pipe” extensions and the difference was massive. I would probably have been a minute faster if I had been using those.

11th October 2020

CTT National Closed-Circuit Championship Thruxton

Top end of my age group 30:19

Average power for this event was 185 watts. With the set up on the next page, with the bent pipe extensions I was a minute faster with an average power of 178 watts.

NoPinz “Flow” skin suit in FloatAero Race Team livery. Castelli overshoes with integrated calf guards. Tri-spoke, front and rear tyres are Veloflex 23c with Michelin latex tubes. I wouldn’t use that tyre on an open road course.

10th October 2021

CTT National Closed-Circuit Championship Thruxton

First place in CTT 70+ age group 29:13

Average power 178 watts (I won by less than a single second)

CTT National Closed-Circuit Championship Thruxton 2022. Back to the P3C as the P4 was away for a paint job. NoPinz "Flow" skin suit in FloatAero Race Team livery. Castelli overshoes with integrated calf guards. Tri-spoke, front and rear tyres are Veloflex 23c with Michelin latex tubes.

9th October 2022

CTT National Closed-Circuit Championship Thruxton

Second place in CTT 70+ age group 28:33

Average power 181 watts (five seconds too slow)

Appendix 2: How to estimate Crr from speed and power

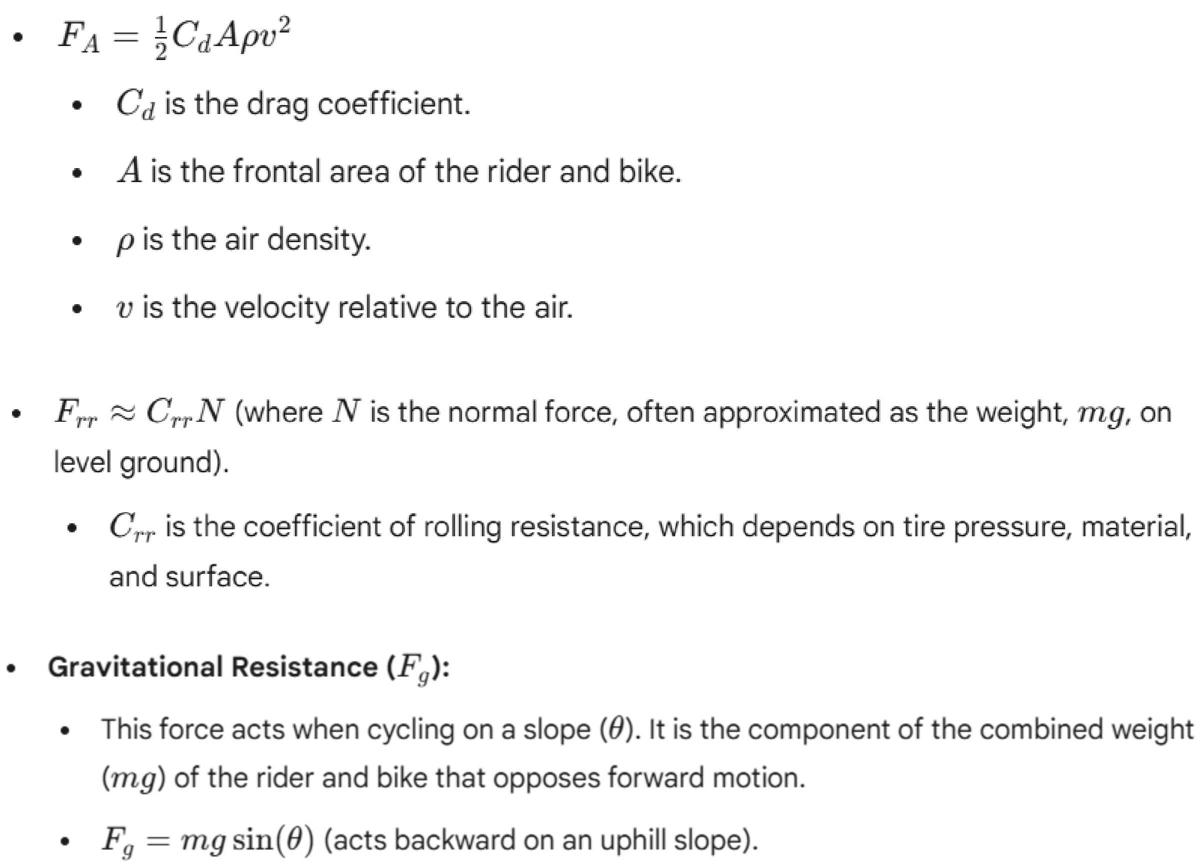
The first thing to say is that if you want to delve into the detailed explanation of Newton's second law of motion with respect to powering a bike then ask your favourite AI engine.

The Aerolab sub-system in Golden Cheetah, which is based on the virtual elevation Chung method, is an application of Newton's second law. You can use the Aerolab graphical screen as an analogue method to estimate Crr from a similar data set to the one used in the example that follows. There is a tool in the Aerolab screen for estimating Crr and Cda but I have never seen this work properly, probably due to the ride data being unsuitable with too many stops and starts. I have tried cutting down my test file to just the relevant section, and then retrying the Aerolab Crr / CdA tool, but that was no better.

The resistive forces working against a cyclist are air resistance and rolling resistance. In addition, gravity may be helping or hindering.

If the bike moves at a constant speed the propulsive force must exactly balance the total resistive forces:

Force = force(F_A) proportional to CdA + force(F_{rr}) proportional to Crr + and gravitational forces(F_g)



- $F_A = \frac{1}{2} C_d A \rho v^2$
  - C_d is the drag coefficient.
  - A is the frontal area of the rider and bike.
  - ρ is the air density.
  - v is the velocity relative to the air.

- $F_{rr} \approx C_{rr} N$ (where N is the normal force, often approximated as the weight, mg, on level ground).
  - C_{rr} is the coefficient of rolling resistance, which depends on tire pressure, material, and surface.

- **Gravitational Resistance (F_g):**
  - This force acts when cycling on a slope (θ). It is the component of the combined weight (mg) of the rider and bike that opposes forward motion.
  - $F_g = mg \sin(\theta)$ (acts backward on an uphill slope).

The propulsive force is provided by the power exerted by the cyclist (pedal force).

Now we come to the first convenient assumption: If we are on a velodrome we can assume that gravitational forces balance themselves out as we are always starting and finishing at the same altitude. The same can be said of a level test venue.

If we are taking it as true that the gravitational forces balance themselves out, we are left with only the CdA and Crr terms on the right-hand side of the equation.

The dot notation "." is mathematical shorthand for "times" usually represented by "x" when doing numerical arithmetic. This avoids "times" being confused with the use of "x" as a variable when doing algebra.

Power = (CdA.Rho.V^3)/2 + Crr.m.g.V

This is where we do a bit of mathematical trickery by converting what looks like the need to solve a cubic equation into a much easier to solve linear equation.

First step divide both sides by V:

Power/V = (CdA.Rho.V^2)/2 + Crr.m.g

You will hopefully recall that the general form of a linear equation is Y = aX + b, or for those of a certain age Y = mX + c.

Our Y here is Power/V and our X is V^2 (V squared)

So, if we plot our data as Power/V against V^2 we will get a straight line. The slope (the a value) will be (CdA.Rho)/2 and the intercept (the b value) will be Crr.m.g

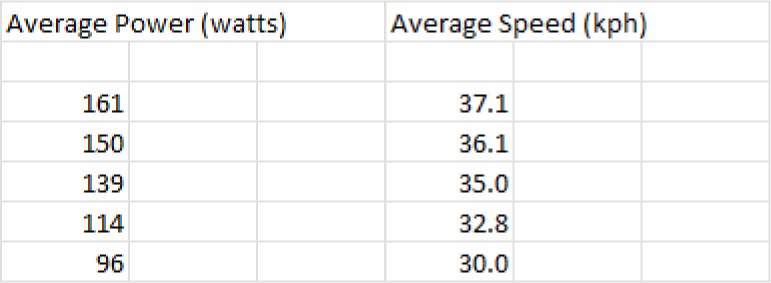
Rearranging those expressions for CdA and Crr

CdA = (2.a)/Rho

Crr = b/(m.g)

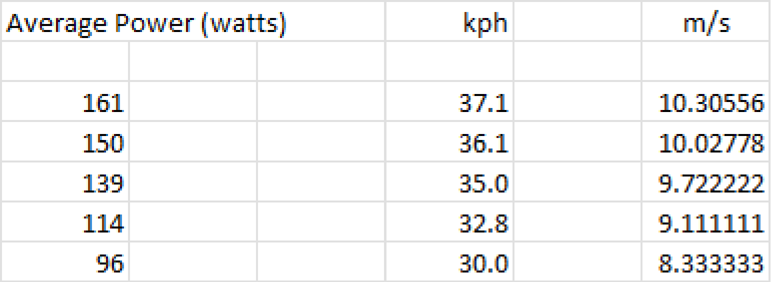
All we need now is the data which is derived from the average power and the average speed data from a set of test runs.

On a velodrome you would ride sets of laps at different speeds. Indoor velodrome 12 laps taking data from the middle 10, outdoor velodrome seven laps taking data from the middle five. What you end up with is a table of data pairs, average power and average speed. Ideally the sample would include data at higher power and speeds. This data is from one of my tests.



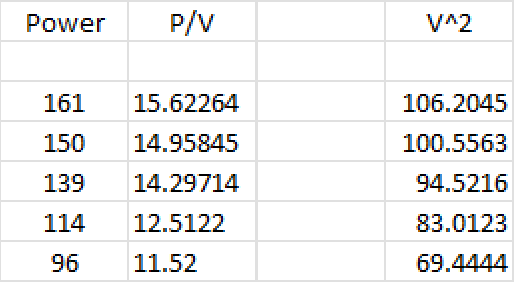
Average Power (watts)	Average Speed (kph)
161	37.1
150	36.1
139	35.0
114	32.8
96	30.0

To keep the units of measurement consistent we need to convert the speed data from kilometres per hour to metres per second (1000/3600).



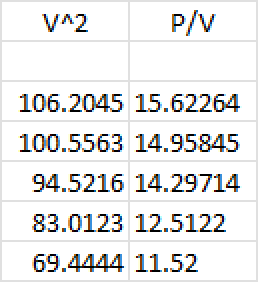
Average Power (watts)	kph	m/s
161	37.1	10.30556
150	36.1	10.02778
139	35.0	9.722222
114	32.8	9.111111
96	30.0	8.333333

And now we have to create the data set of average power divided average speed and average speed squared…



Power	P/V		V^2
161	15.62264		106.2045
150	14.95845		100.5563
139	14.29714		94.5216
114	12.5122		83.0123
96	11.52		69.4444

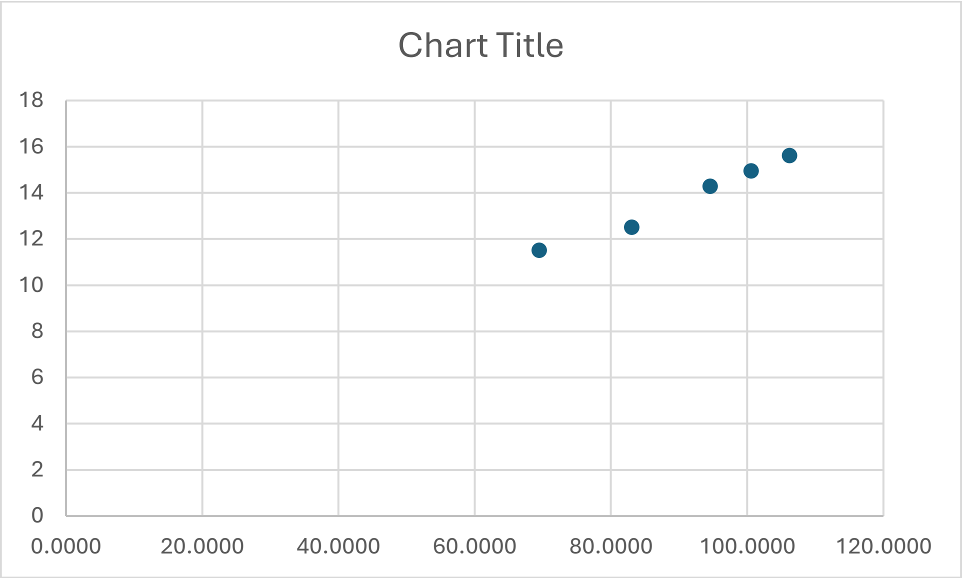
In our linear equation the x-axis is V squared and the y-axis is power divided by V



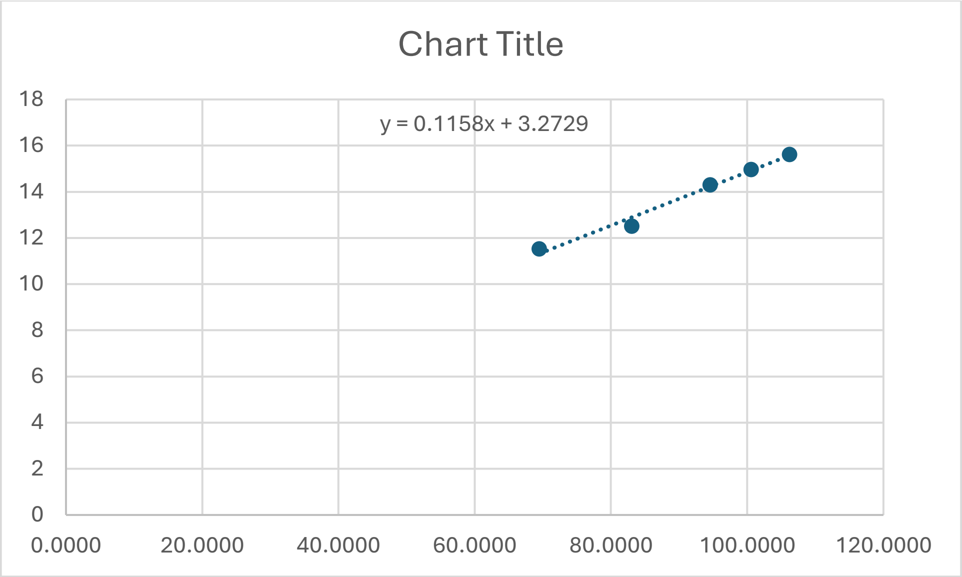
V^2	P/V
106.2045	15.62264
100.5563	14.95845
94.5216	14.29714
83.0123	12.5122
69.4444	11.52

Next, we create a scatter graph from this data using the insert chart tool in Excel.

Screenshots of this method, including the trendline aspects, are detailed in Section Two.



Then we use the Trendline tool to fit a linear equation to this data.

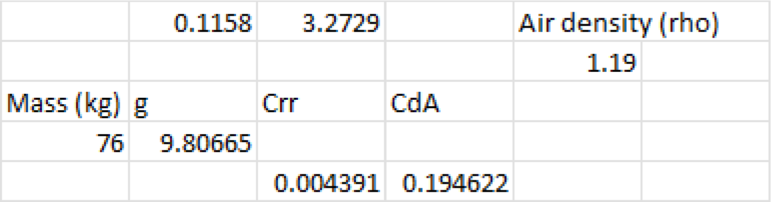


The trendline equation gives us a value for “a” of 0.1158 and a value for “b” of 3.2729

Crr = b (3.2729) divided by mass (76kg) and the force of gravity (9.80665) = 0.004391

Mass here is the combined mass of the bike and the rider.

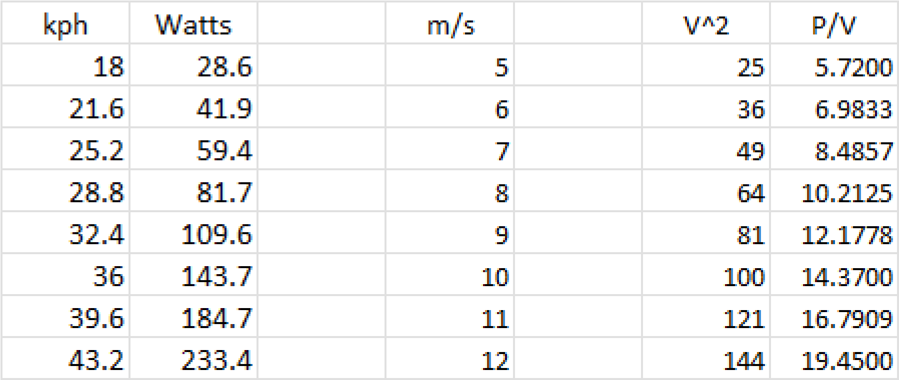
CdA = two times 0.1158 divided by air density (1.19)



	0.1158	3.2729		Air density (rho)	
				1.19	
Mass (kg)	g	Crr	CdA		
76	9.80665				
		0.004391	0.194622		

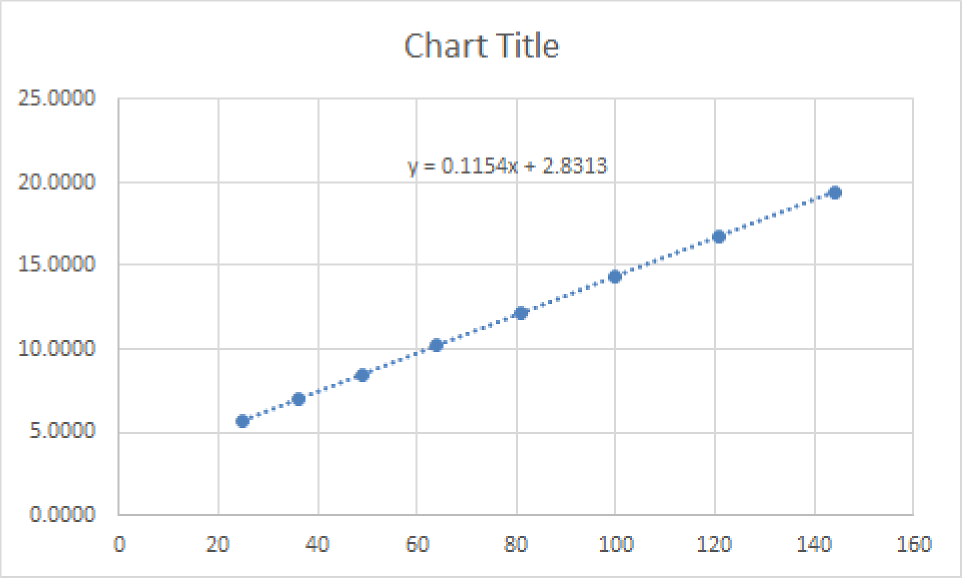
The CdA of 0.195 is a good match to the result produced by Aerolab using the original file from which the example data was extracted. The Crr result is higher than my estimate of 0.0036.

My next thought was to “ask” Gemini to work things backwards. Calculate the power and speed data pairs that would produce a result of 0.194 and 0.0036 from this method.



kph	Watts		m/s		V^2	P/V
18	28.6		5		25	5.7200
21.6	41.9		6		36	6.9833
25.2	59.4		7		49	8.4857
28.8	81.7		8		64	10.2125
32.4	109.6		9		81	12.1778
36	143.7		10		100	14.3700
39.6	184.7		11		121	16.7909
43.2	233.4		12		144	19.4500

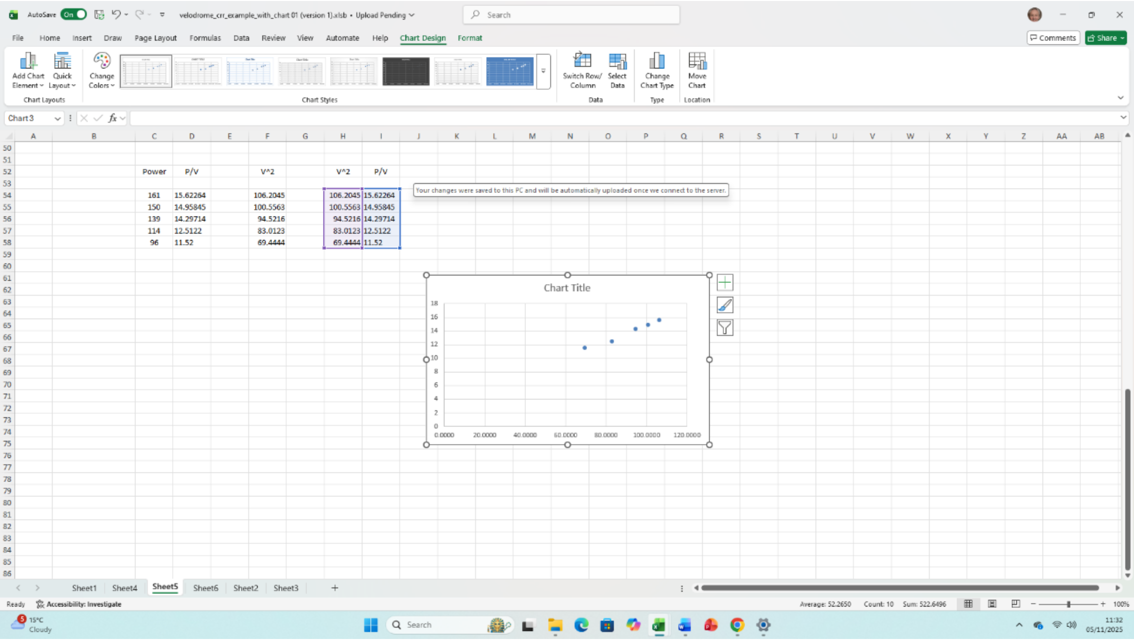
The key takeaway from this is that you need a larger sample over a wider range of speeds to get a more significant result for the Crr. Unfortunately, I am not in a position to return to the velodrome to undertake such a test.



The trendline equation gives us a value for “a” of 0.1154 and a value for “b” of 2.8313 compared to a value for “a” of 0.1158 and a value for “b” of 3.2729 from the ride data.

Section Two: Screenshots

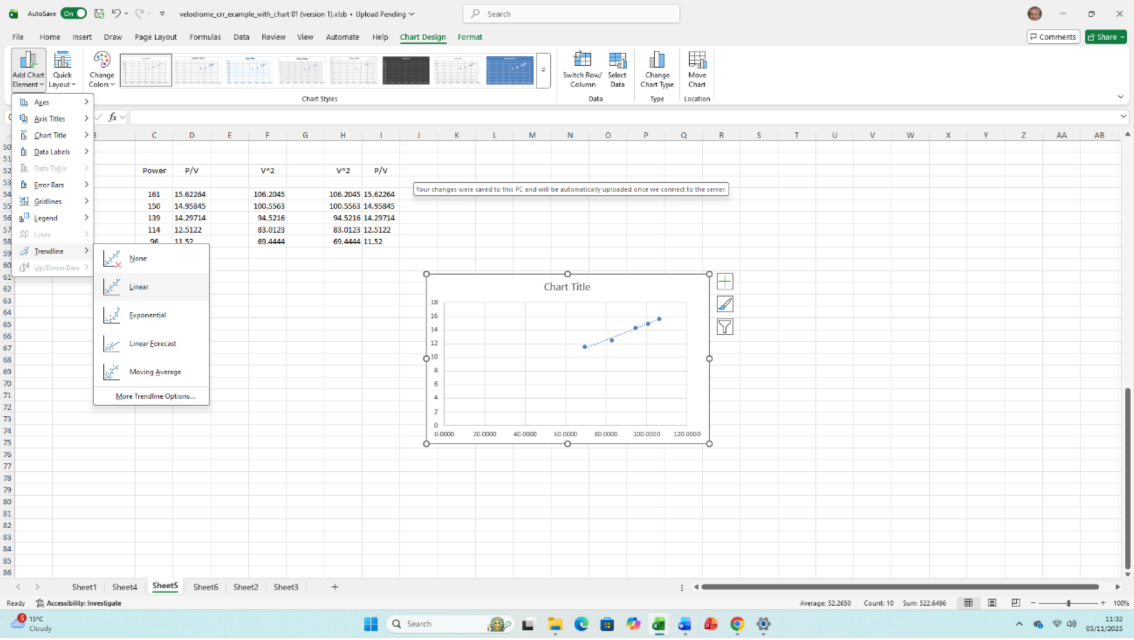
Note that there are two ways to access the Trendline functions in Excel. After inserting the chart there is a toolbar available with the “Add Chart Element” tool.



Power	P/V	V^2	V^2	P/V
161	15.62264	106.2045	106.2045	15.62264
150	14.95845	100.5563	100.5563	14.95845
139	14.29714	94.5216	94.5216	14.29714
114	12.5122	83.0123	83.0123	12.5122
96	11.52	69.4444	69.4444	11.52

Your changes were saved to this PC and will be automatically uploaded once we connect to the server.

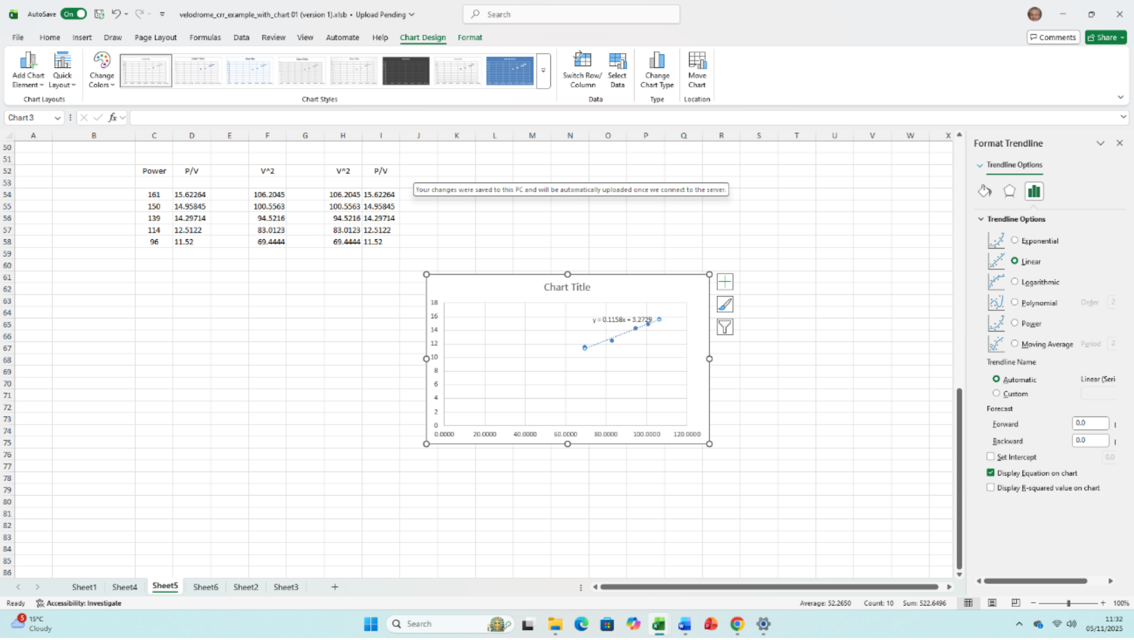
From the dropdown select “Trendline” and in this case “Linear” to produce the line.



Power	P/V	V^2	V^2	P/V
161	15.62264	106.2045	106.2045	15.62264
150	14.95845	100.5563	100.5563	14.95845
139	14.29714	94.5216	94.5216	14.29714
114	12.5122	83.0123	83.0123	12.5122
96	11.52	69.4444	69.4444	11.52

Your changes were saved to this PC and will be automatically uploaded once we connect to the server.

Selecting "more options" enables the "Format Trendline" panel. Select the three vertical bars tab and then select "Display Equation on Chart" to see the coefficients required to perform the Crr and CdA calculations.



Power	P/V	V^2	V^2	P/V
161	15.62264	106.2045	106.2045	15.62264
150	14.95845	100.5563	100.5563	14.95845
139	14.29714	94.5216	94.5216	14.29714
114	12.5122	83.0123	83.0123	12.5122
96	11.52	69.4444	69.4444	11.52

Your changes were saved to this PC and will be automatically uploaded once we connect to the server.

Format Trendline

Trendline Options

- ○ Exponential
- ● Linear
- ○ Logarithmic
- ○ Polynomial
- ○ Power
- ○ Moving Average

Trendline Name

- ● Automatic Linear (Seri
- ○ Custom

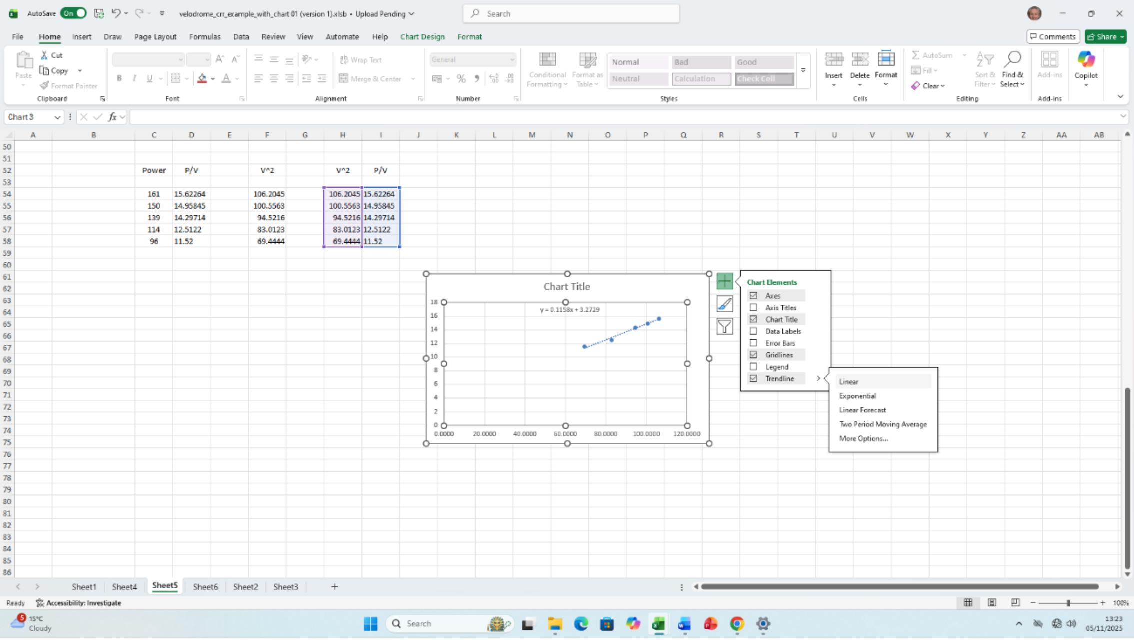
Forecast

Forward 0.0

Backward 0.0

- ☐ Set Intercept
- ☑ Display Equation on chart
- ☐ Display R-squared value on chart

The alternative way of accessing the Trendline functions is from the Chart Elements popup that is accessed from the "+" icon that appears when you select the chart.

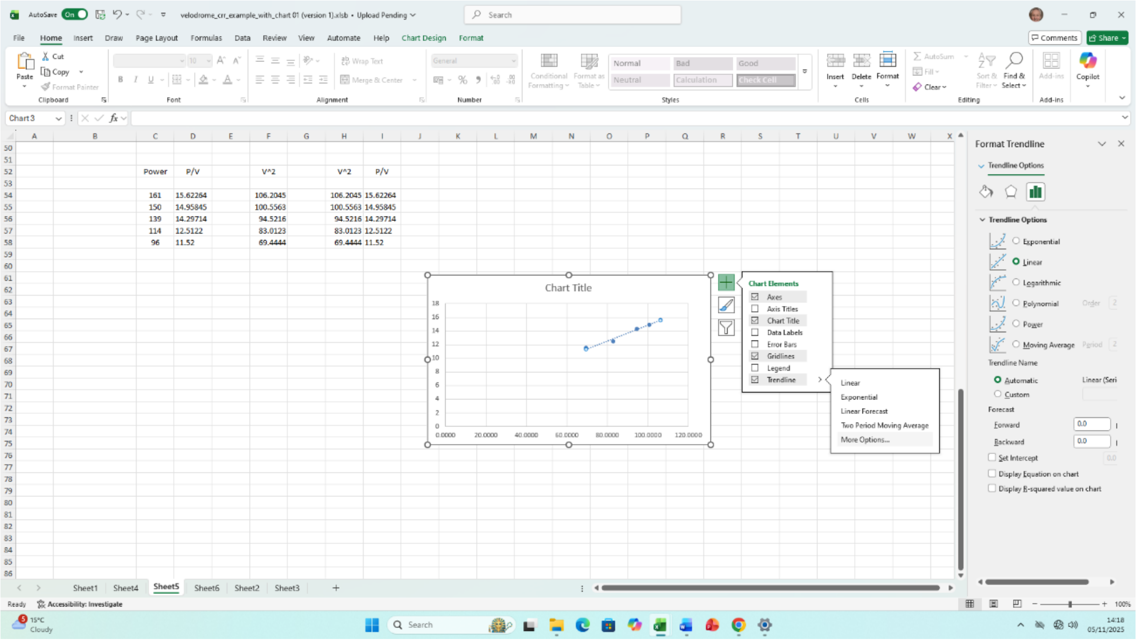


Power	P/V	V^2	V^2	P/V
161	15.62264	106.2045	106.2045	15.62264
150	14.95845	100.5563	100.5563	14.95845
139	14.29714	94.5216	94.5216	14.29714
114	12.5122	83.0123	83.0123	12.5122
96	11.52	69.4444	69.4444	11.52

Chart Elements

- ☑ Axes
- ☐ Axis Titles
- ☑ Chart Title
- ☐ Data Labels
- ☐ Error Bars
- ☑ Gridlines
- ☐ Legend
- ☑ Trendline

Similarly, selecting “more options” enables the “Format Trendline” panel.



Power	P/V	V^2	V^2	P/V
161	15.62264	106.2045	106.2045	15.62264
150	14.95845	100.5563	100.5563	14.95845
139	14.29714	94.5216	94.5216	14.29714
114	12.5122	83.0123	83.0123	12.5122
96	11.52	69.4444	69.4444	11.52

Chart Elements

☑ Axes
☐ Axis Titles
☑ Chart Title
☐ Data Labels
☐ Error Bars
☑ Gridlines
☐ Legend
☑ Trendline

Format Trendline

Trendline Options

○ Exponential
● Linear
○ Logarithmic
○ Polynomial Order 2
○ Power
○ Moving Average Period 2

Trendline Name
● Automatic Linear (Seri
○ Custom

Forecast
Forward 0.0
Backward 0.0

☐ Set Intercept 0.0
☐ Display Equation on chart
☐ Display R-squared value on chart

Appendix 3: An alternative critical power test

The definitive way to find your FTP is to do a steady state ride of 60 minutes duration at your maximum sustainable effort. That's easier to do on the turbo than it is on the road, however, both will produce quite a bit of fatigue and potentially mess up your training programme.

Historically, if that's the correct expression for the way it was done 40 years ago, coaches would have used a ramp test, either linear, like the King Cycle used by British Cycling, or a step ramp test, where the athlete rides at a near steady state power for each ramp interval, and the power is increased in a step at the end of each ramp interval. FTP is approximated by taking a percentage of the average power for the final minute of the test, known as the Maximal Aerobic Power or MAP for short, usually 70 percent of the MAP number. I was never quite sure why it was called maximal aerobic power as in the final minute the athlete is decidedly anaerobic. This style of test, going to the athlete's absolute limit, can be even more fatiguing than the 60-minute test.

More recently coaches have started using a 20-minute test, known as the CP20 or Critical Power 20-minute test. In this test the athlete follows a specific warm up routine and then rides for 20 minutes at their maximum sustainable power. FTP is calculated as 95 percent of the 20-minute average power.

I have found that pacing the 20-minute test can be quite tricky, so I have devised an alternative shallow step ramp test.

Most people have a pretty good idea of what their CP20 power number should be, within a margin of five percent either way, so we use that number to set the power levels in the shallow step test. I start with a four step test with the first five-minute step at 92.5 percent of the estimated CP20, the next at 97.5 percent, the next at 102.5 percent and the next at 107.5 percent.

So how is this better than a conventional CP20?

If FTP is 95 percent of the CP20 power, then 92.5 percent is slightly lower than FTP. This five-minutes should be easy to accomplish. The heart rate will probably be a little below what would be a "normal" functional threshold heart rate. It can be seen as the final part of the warm-up.

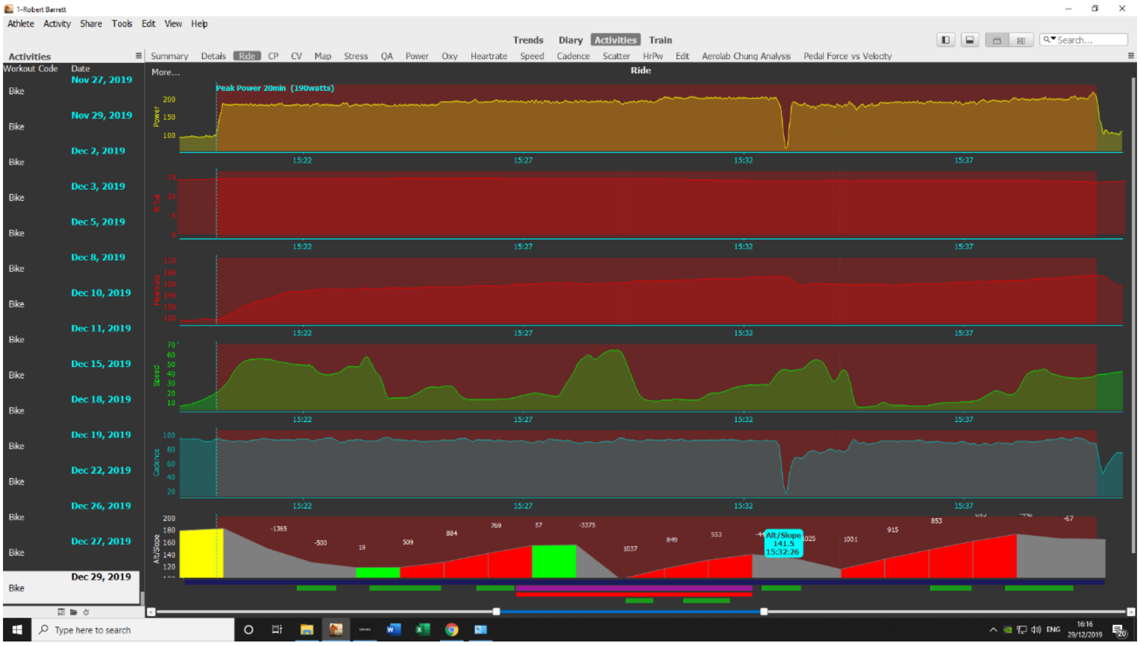
Moving on to the 97.5 percent, this is above the nominal FTP but below the CP20 power. The heart rate should go up a little but stabilize after the first two or three minutes.

Now we come to the 102.5 percent section. Again, heart rate should go up a little. If it goes up a little and stabilizes after two or three minutes, then you can say you are doing well. If it continues to climb and you start to feel the lactate build up in your legs, then you can start to think that you are now at a power level above your CP20 power.

In some cases, you will need to back-off or stop the test at this point if the starting assumption about CP20 power has been too high.

If we get to the 107.5 percent section and heart rate stabilizes after two or three minutes, then you can start to think that the initial assumption about CP20 power was too low. More often than not you will find that this a tough five minutes and struggle to finish it. You can always stop this test short as you have enough data to get a good estimate of your CP20 power and calculate FTP as 95 percent of that number.

I did one of these on the 29th December 2019, in my TT position, as my end of year test.



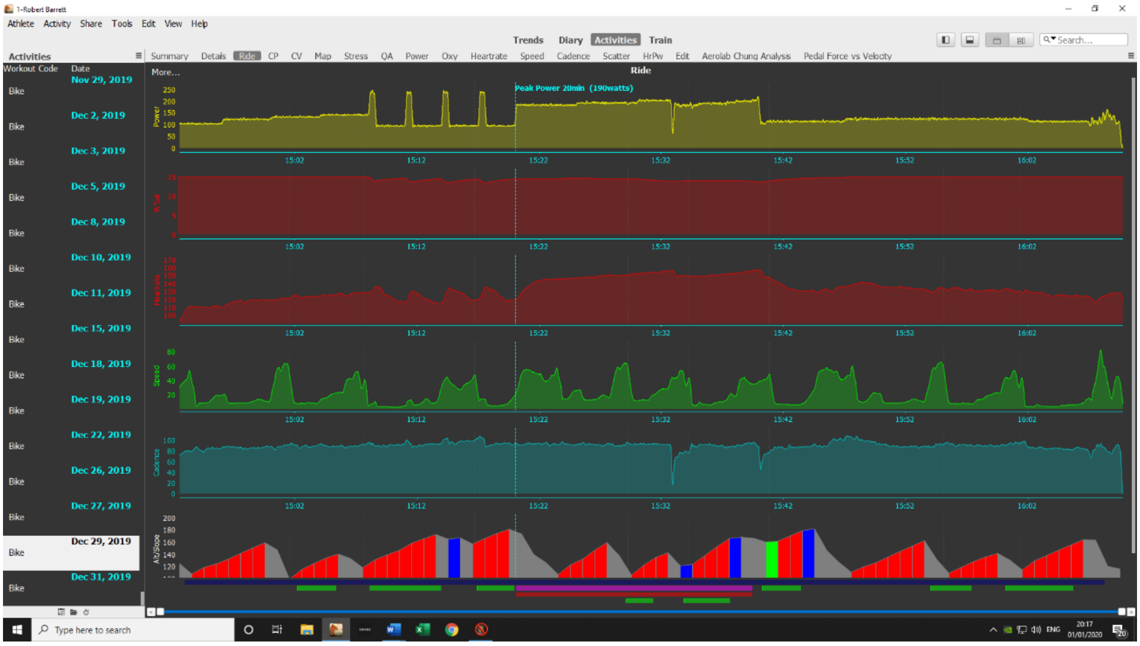
You can see that at the start of the test it took around two minutes for my heart rate to get to around 95 percent of my functional threshold heart rate (around 155 +/- 2).

You can also see, from the power curve, that I got to just short of 3 minutes into the 205-watt interval of the test before I blew up.

I was able to continue the workout after around 15/20 seconds of recovery, and after backing off the power demand by 10 percent. I was using a Neo turbo with an ERG workout in Zwift.

Once you have a better estimate of your CP20 you can reduce the size of the steps to 95/97.5/102.5/105 or start higher using 97.5/100/102.5/105.

This is the full session profile with the warm-up and cool down.



Workout Code	Date
Bike	Nov 29, 2019
Bike	Dec 2, 2019
Bike	Dec 3, 2019
Bike	Dec 5, 2019
Bike	Dec 8, 2019
Bike	Dec 10, 2019
Bike	Dec 11, 2019
Bike	Dec 15, 2019
Bike	Dec 18, 2019
Bike	Dec 19, 2019
Bike	Dec 22, 2019
Bike	Dec 26, 2019
Bike	Dec 27, 2019
Bike	Dec 29, 2019
Bike	Dec 31, 2019

Although I went to the max in this test it was for a very short time and didn't build up any significant fatigue.

Obviously, my power numbers and functional threshold heart rate look a bit low compared to most, however, my FTHR was the same as it was 20 years prior, and my power was 30 percent greater than it was 10 years prior.

The point here is that you can use this test to evaluate the impact of changing your riding position on your power production, and because this test doesn't create much fatigue you can easily do two or three of them on the same day.

You can train into a position with a tighter hip angle but there will always be a limitation and the adaption period is going to be six to eight weeks at best.

Next page: Zwift workout file

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About the Author

I am Rob Barrett, a lifelong enthusiast with a background in maths, physics, and business. I was a keen competitive cyclist until my unfortunate injury.

After obtaining a degree in Molecular Physics, my early career was spent in sales and marketing for a scientific instrument company before I progressed into micro-computing and networking. I started my own business in 1990, focused on internetworking, and ran that for 15 years.

That experience of analytical thinking and real-world problem solving continues to shape how I approach performance today.

After a gap of 20 odd years, I returned to cycling in 1990, firstly off-road, then leisure road cycling.

My return to competitive cycling was through participation in rowing triathlons which led to me rediscovering time trials. What began as a semi-social club activity quickly developed into an obsession with understanding how aerodynamic drag affects cycling performance.

In the off season of 2013/14, I completed a structured training program, specifically in my time-trial position, and increased my physical power output by 40 watts.

More significantly, I reduced my drag, my CdA, from 0.235 to 0.175, the equivalent of around 60 watts of aerodynamic gain, or “AeroWatts” saved. Those savings were achieved from a combination of position optimisation and equipment upgrades plus many hours of aero testing.

That on-going combination of physiology and aerodynamic gains culminated in a milestone age group win in 2021. This book reflects my belief that aerodynamics should be understandable, testable, and usable by all cyclists, not locked away behind jargon, guesswork, and resources only available to the elite.

Rob Barrett

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