Blackburn Trainers White Paper

Abstract

In March 2009, engineers Michael McColligan and Niko Henderson authored a comprehensive study analyzing the factors that contribute to bicycle trainer performance. Their work effectively debunks a number of longstanding myths and proposes some new ideas for trainer performance metrics.

This abstract presents some of their most important findings in a less technical format for the cycling professional and enthusiast.

Introduction

Given the competitive nature of the bicycle trainer market—not to mention of cyclists themselves—it's no wonder there would be a complex and often self-contradictory body of information in the field about which trainers perform better than others.

From a pure engineering viewpoint, it's a complex and sophisticated topic involving some highly technical elements like the fluid mechanics of shear stress, magnetic eddy currents and Lenz's Law, vacuum cavitation, impellor design, and optimized flywheel mass. But from the cyclist's viewpoint—in terms of what you get out of the trainer once you climb on and start riding—everything boils down to a handful of critical elements that directly impact the trainer experience.

One of the problems facing cyclists is that the market is full of competing claims and counterclaims about what trainers are supposed to do, how they're supposed to do it, and what they end up doing in the real world.

We applied standard engineering analyses and practices to the prevailing wisdom about trainer performance and arrived at some startling conclusions. (Specific protocols, math, and data analyses are all in the White Paper, but here's the in-the-saddle reality.)

Part One: Three Prevailing Myths About Trainer Performance

MYTH #1: ***Trainers can—and ought to—"realistically" simulate the resistance forces involved in riding a bicycle.***

Trainer manufacturer presentations generally start by showing you a power curve of how much wattage it takes to ride a bike at increasing speed. The curve itself looks like this:

Then the resistance curve for the trainer is shown to closely match the idealized power curve. This proposition sounds pretty good until you take a look at the premise their reasoning is based on.

REALITY: ***The whole idea of a "realistic" resistance curve isn't very realistic.***

Differences in rider/bike weight and the normal range of rider frontal area alone (.4-.7m^2) create huge differences in real-world resistance[1] which trainers have no means of correcting for. Factor in other uncompensated elements such as hills, crosswinds, and cornering, and it's clear that no existing trainer technology allows for this kind of variance.

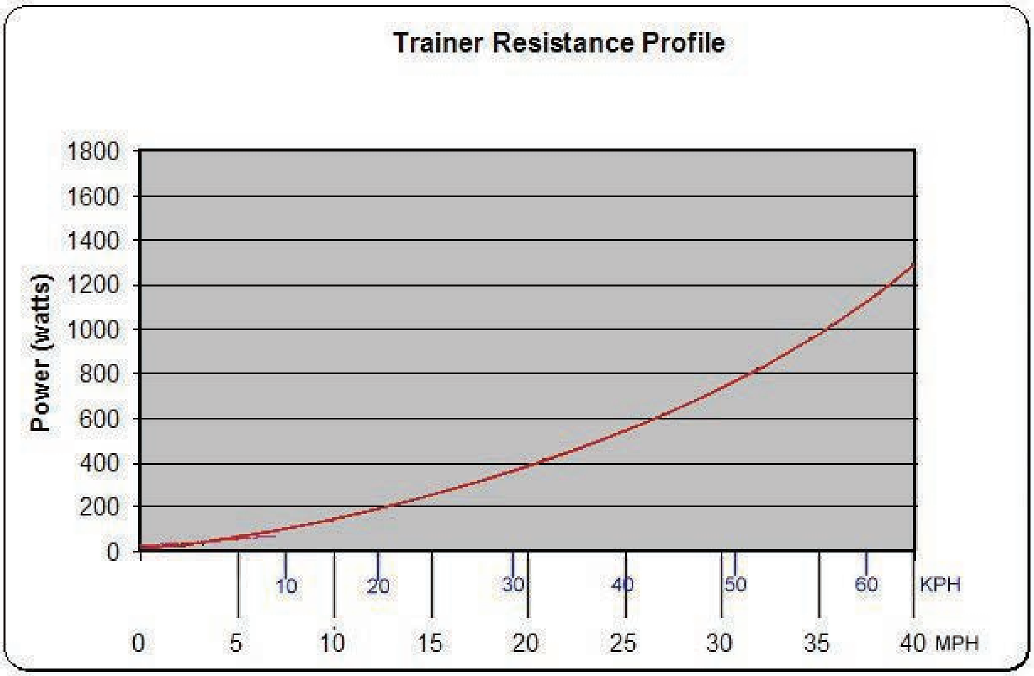


Figure 1. An idealized power curve (from the rider's point of view) or resistance curve (from the trainer's).

In terms of aerodynamics alone, the smallest-normal frontal area rider (flat course, no wind), is going to take 196 watts to maintain a speed of 11 m/s (slightly less than 40kph/25mph) But the largest-normal rider the same speed will require 318 watts of output, a 62% net difference.

Of course, trainer manufacturers (including us) try to hit a value somewhere in the middle of that range. That's only reasonable. And some

1 All speed/power calculations are done using Tom Compton's excellent Forces On Rider calculator (http://www.analyticcycling.com/ForcesPower_Page.html). This method was selected because of its analytical rigor, the general acceptance of its methodology among competing trainer brands, and because riders can easily access it and plug their own variables in. For a good discussion of the mechanics of bicycle speed/power dynamics, see http://en.wikipedia.org/wiki/Bicycle_performance, which in turn, is based largely on S.S. Wilson's groundbreaking Bicycle Technology,(*Scientific American*, March 1973) and, the venerable *Bicycling Science* (Third Edition ed.), 2004. The MIT Press. p. 126. ISBN 0-262-73154-1.) by David Gordon Wilson & Jim Papadopoulos.

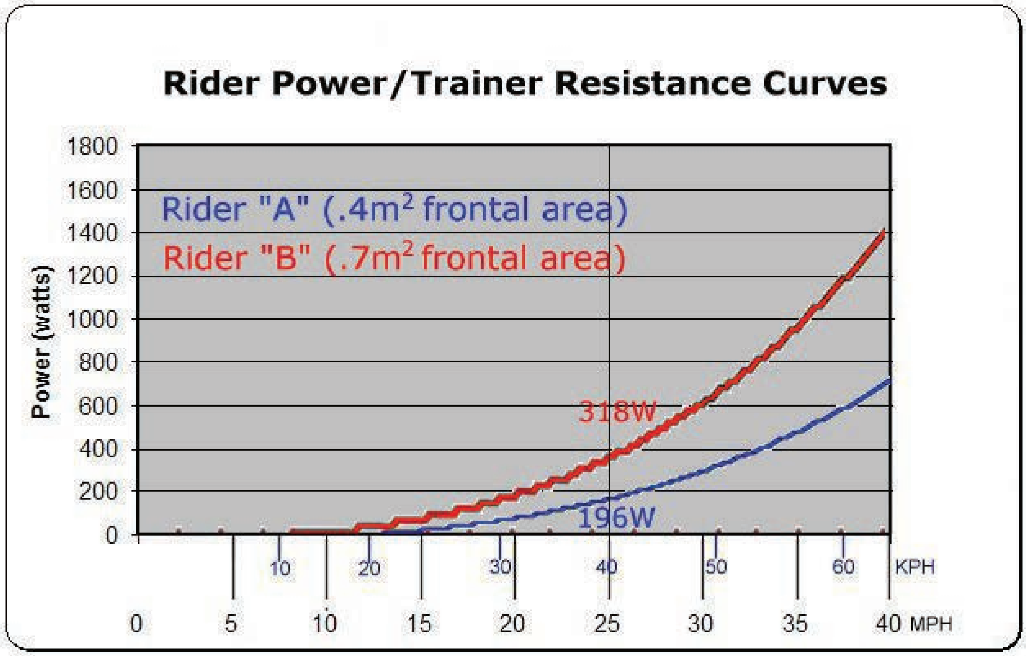


Figure 2. Power/resistance curves for two riders with typical frontal areas. As you can see, not just the wattage, but the shape of the curve itself is markedly different.

succeed better than others. But the point is, **as a cyclist, there's only one curve that matters. Yours**. And unless you happen to have exactly the combination of inputs[2] as your trainer's resistance curve (pretty unlikely), your trainer will not simulate your on-bike reality .

So **at best, a trainer can have a resistance curve that is the same general shape as a typical rider's power curve under typical conditions.** And it turns out that even that's not particularly useful, given the way cyclists actually use trainers.

MYTH #2: ***Some trainer brands are more "realistic" than others.***

This is a variation on the "accurate" resistance curve myth. A number of trainer brands generate graphs that attempt to prove this.

REALITY: It's a lot more complicated than some manufacturers would have you believe. And the likelihood of any trainer coming within 100 watts of your entire personal power curve is effectively zero.

When we actually put trainers from leading brands into the test lab[3], some interesting things come to light.

Manufacturer	Magnetic Resistance	Fluid Resistance
Elite	Crono	Primo
Kurt-Kinetic	(none)	Road Machine
Minora	Mag 850	VFS-G
Tacx	Satori	Cycle Force Flow
CycleOps	Magneto, Magneto 2006	Jet Fluid Pro
Blackburn	Tech Mag 6	Tech Fluid

2 The Forces on Rider model recognizes ten elements: Effective Frontal Area, Drag, Air Density, Rider/Bike Weight, Rolling Resistance, Slope, Speed, Pedal Cadence, Crank Length, and Effective Pedaling Range.

3 Test figures and protocols are reviewed in detail in the white paper.

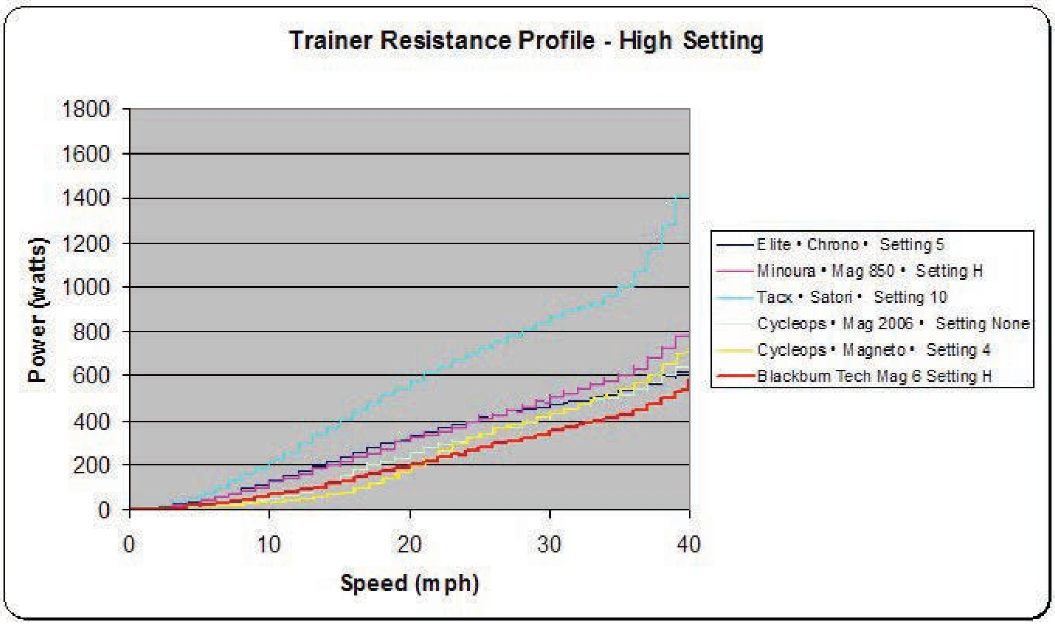


Figure 3. Magnetic-resistance trainers on their lowest and highest settings, respectively.

First let's look at test results from the magnetic-resistance trainers on their lowest and highest settings, in Figure 3 on to your left.

And the fluid-resistance[4] units (Fig. 4, following page), which have a single setting:

As you can see, the magnetic-resistance trainer curves are generally more "linear" than the fluid resistance units. However **the test data reveals some important additional conclusions:**

- **All trainers tested generally fall within the broad overall range** of predicted "real world" results.
- **None of the trainers tested reliably models any "real world" curve**. More to the point, a more expensive trainer does not deliver a 'realistic' feel.
- While different trainers and resistance technologies get closer to an idealized curve at different points in their power/resistance band, **no trainer tested consistently came within 100W of a theoretical-average power curve**, let alone the specific one for any individual rider or course.

So where does this leave the larger question of trainer performance? it turns out the answer has more to do with how cyclists use trainers than with the trainers themselves. In other words, it's all about the rider. More about that in a minute.

MYTH #3: ***Fluid resistance trainers provide a more "realistic" and "accurate" road feel overall.***

4 Note: because it uses centripetal magnets in an attempt to simulate a fluid-resistance unit's resistance curve, the CyclOps Magento is tested with both groups.

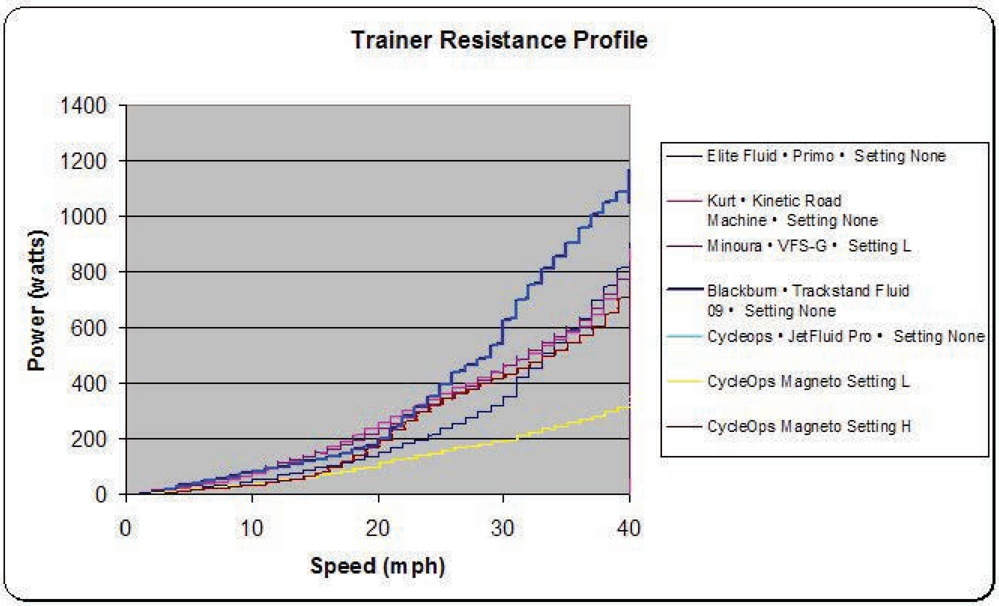


Figure 4. Fluid-resistance trainers.

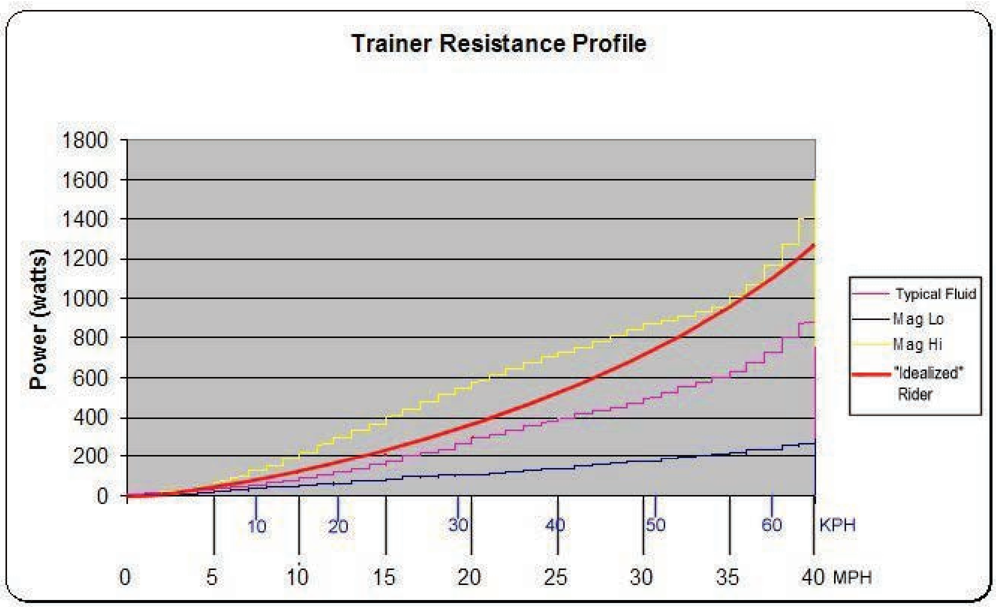


Figure 5. **Trainer power curves** *mapped against predicted "real world" rider output.*

Part of this idea speaks again to the whole "realistic resistance curve" myth; another part speaks to the fact that different trainer technologies are better at modeling different parts of an idealized curve.

REALITY: Fluid and magnetic trainers each display distinctively different resistance curve qualities; but the "most realistic and accurate road feel" is highly dependent on the end user's perception of 'real world riding,' how that rider uses the trainer, and on the rider's ultimate training goals.

- **Mag trainers display a generally linear** (and often adjustable, but still linear) **resistance curve** that simulates relatively flat roads, cruising/higher speeds, and pack riding.
- **Fluid trainers tend towards a sharper, more "progressive" resistance curve** which models climbing or riding into a headwind.
- **Mag trainers are generally more accurate for low-end resistance, fluid units typically do better in the middle of the curve.**
- **Neither technology is particularly accurate at the high end** of the resistance curve.

Note: *A few trainers attempt to hybridize both technologies (and thereby produce both linear and progressive resistance profiles) but the results show that these efforts produce no noticeable change in performance (see charts 3-4 plus footnote 4 in the previous section).*

Since it's well known that real world roads can be either hilly, or flat, or both, and that the power curves to ride them vary considerably, we can conclude that **the accuracy of a trainer's resistance profile is dependent on matching the right trainer to the rider's needs.**

In terms of which trainer is best or "most accurate," the answer will depend on what each rider uses the trainer for.

When we look at the test data it's clear that the **fluid-resistance units generally have steeper curves** which model middle- and (to some extent) high-end power output more accurately, **and are more responsive to large changes in rider input.**

Magnetic-resistance units, on the other hand, **are generally more accurate at the lower end of the resistance curve and tend to be more responsive to relatively small changes in rider input.**

Based on the data presented earlier, we can conclude that **although trainers are justly well-known for delivering any number of ergonomic benefits, accurate modeling of real-world bike behavior is not among them.**

Part Two: Four Previously Hidden Truths About Trainer Performance

Trainer Resistance

TRUTH #1: ***Different riders have different training styles.***

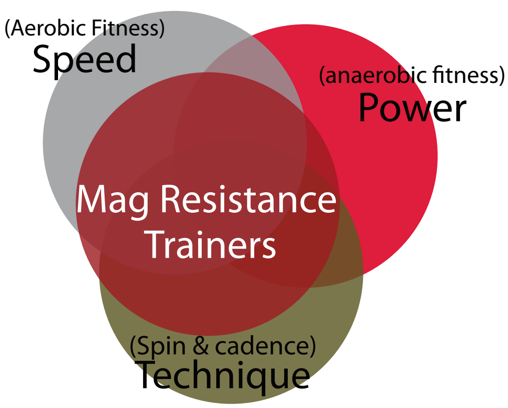
Trainers are basically good for three things:

- **Aerobic training**, to build speed and endurance.
- **Anaerobic training,** to build high-end power.
- **Technique**, to improve spin (effective pedaling range) and cadence.

Clearly, not all cyclists are interested in all three of these things in equal measure. We can expect their training styles to differ in response to their varying goals.

TRUTH #2: ***Match the trainer to the rider.***

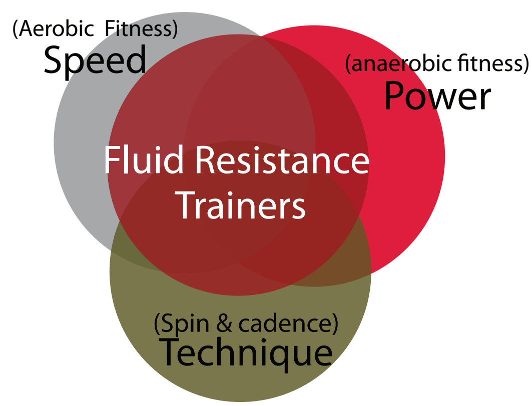
Magnetic Resistance



A **linear-resistance Speed/ Technique**-leaning trainer offers:

- ability to fine-tune resistance on the fly
- pre-race warm-up
- LSD (Long Steady Distance) at a variety of cadences
- more "realistic" response to subtle changes in rider input
- optimized to simulate pack riding/ flat courses

Fluid Resistance



A **progressive-resistance Speed/ Power**-leaning trainer is more useful for:

- a wider range of resistance
- jumps and intervals, high-intensity workouts, power training
- climbs[5]
- more "realistic" response to large changes in rider input
- optimized to simulate solo conditions on hilly or variable courses

Table 2. Mapping rider benefits to trainer technology

5 Although note the limitations previously referenced in *Myth #1*.

Mapping the training goals to what different trainer technologies do well, we hypothesize that riders will tend to prefer either magnetic or fluid trainers based on their own training style and tastes.

One technology or the other will feel more "realistic" because it actually is, at least relative to that rider's specific training style.

Table 2, above (previous page), illustrates this dichotomy:

These values clearly represent **legitimate differences in rider choice**. We also note, anecdotally, that European riders overwhelming use trainers for warm-up or steady-state cardio work, while North Americans tend to use them more for intervals or power workouts… which supports our hypothetical model.

Trainer Frame Mechanics

TRUTH #3: ***Stiffer is Better. A lot better.***

One overlooked area in the trainer literature—and one that significantly affects the rider—is how stiff the trainer is in response to rider input. In the laboratory we call this measurement *rack stiffness.*

Figure 5, below, shows the rack stiffness data for eleven popular trainer models:

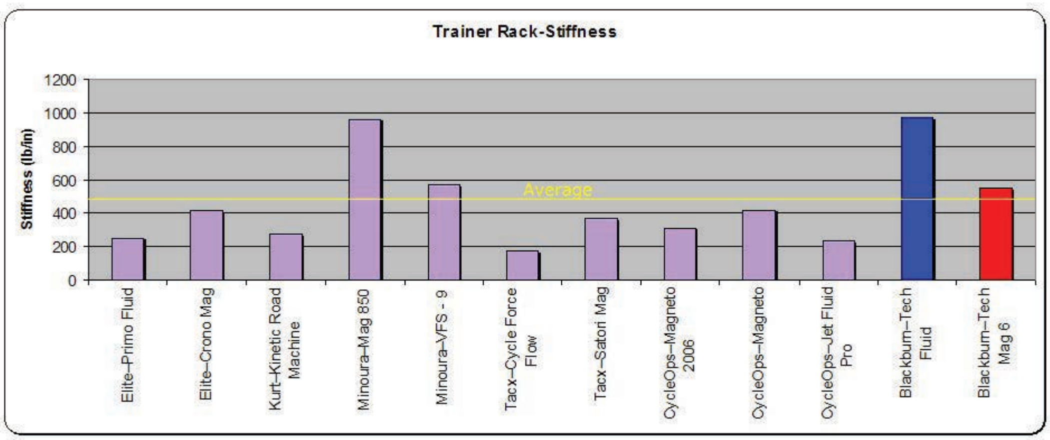


Figure 5. Rack stiffness, or how effectively a trainer resists lateral flex in response to rider input.

Since larger, stronger, or heavier riders will generate the most wattage, it is for those athletes that rack stiffness matters most.

Leaders in this respect are the Magura Mag and both Mag and Fluid Blackburn units, even though the Magura presents a third less resistance power than the Blackburn fluid unit.

Interestingly, the unit with the highest resistance wattage tested, the Tacx Satori Mag, had sub-average rack stiffness, hinting at significant issues for more powerful athletes.

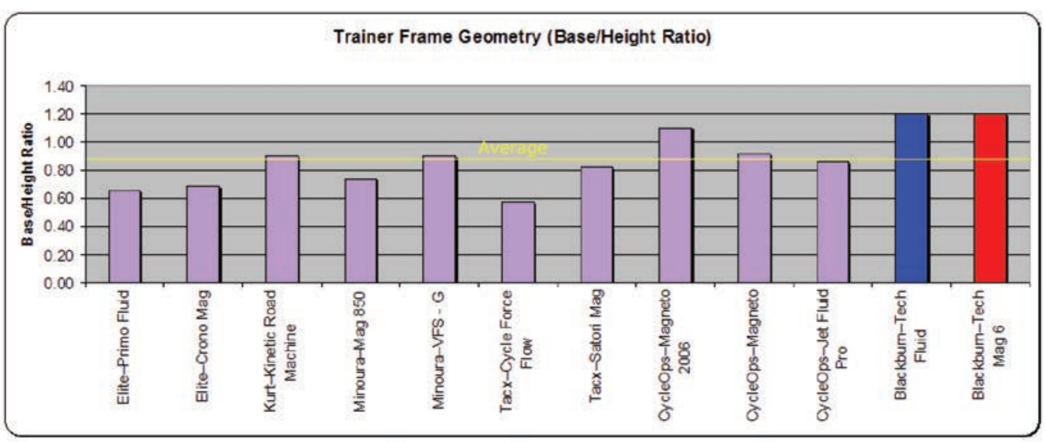


Figure 6. Trainer geometry expressed as a base/height ratio. The higher the ratio, the more stable the unit will be

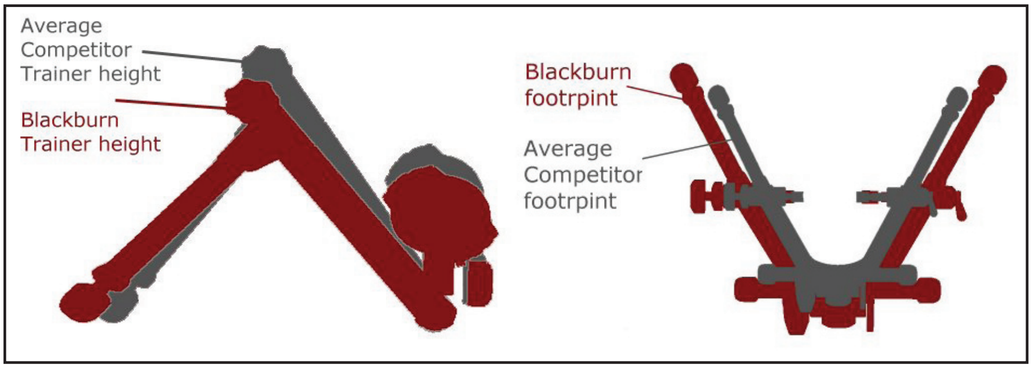


Figure 7. Relative height and footprint of Blackburn and average of competing trainers.

TRUTH #4: ***Stability is Good.***

A final unaddressed issue with trainers is that of trainer stability. This is a function of how low the trainer can place the bike relative to the ground, and how wide a footprint it presents once it's placed there.

Presenting the base/height dimensions as ratio allows us to compare trainer stability:

The most stable units tested were the two Blackburn Tech models, nearly 10% more stable than the third-ranked unit, the CycleOps Magneto.

Clearly, the more stable a trainer is, the less it will tend to tip in response to large rider inputs. So, as with stiffness, the bigger and/or more powerful the rider and the more intense the workout, the more important both stiffness and stability become.

Part Three: Summary

Myths	Realities
1. Trainers realistically simulate resistance forces.	They don't. And the whole of a "realistic" resistance curve idea isn't very realistic to begin with.
2. Some trainer brands are more "realistic" than others.	No trainer tested came within 100W of a theoretically "ideal" resistance curve.
3. Fluid resistance trainers provide a more realistic and accurate road feel overall.	Fluid and magnetic trainers each display distinctively different resistance curve qualities suited to different training style.

Truths

1. Different Riders have Different Training Styles.
2. Match the Trainer to the Rider
3. Stiffer is Better.
4. Improved Stability is Good.

Three Conclusions

A number of conclusions follow from the test data and analysis. Some are obvious, given the myths and truths shown previously and are omitted here to prevent redundancy. Others are a little more subtle, so they're presented here with a few supporting bullets for each one.

1. **Riding and training will always feel different.**
    - Trainers don't simulate riding very effectively. And that's a good thing.
    - What trainers do very effectively is stimulate certain types of riding conditions.Because they use simpler resistance curves that just about any ride, trainers can be more useful for highly structured workouts…in other words, for training.
2. **Steeper/more progressive resistance curves are not necessarily better.** Riders should select a trainer (and resistance technology) best suited to their training goals, not their riding style (the old "race your strengths/train your weaknesses" adage). As shown in Table 2 previously,
    - magnetic-resistance trainers are generally more suited to developing speed and technique, and for pre-race warm-up
    - fluid-resistance trainers are generally more suited to power workouts. However,
3. **Other factors—specifically, stiffness and stability**—have much greater impact on trainer performance than previously supposed.
    - Most trainers tested can provide more resistance than even professional racers can sustain.
    - Given the relative parity in simulating on-bike riding (summarized in the *Myths* section), a key differentiator among trainers is the quality of "on-trainer" riding…of which stiffness and stability are key components.

About the Authors

Michael J. McColligan is Director of Engineering for Blackburn Design. He has been employed by Easton-Bell Sports since 1997. In addition to his work in aerospace and transportation electronics, Michael holds two international patents and a Design Distinction Award from *I.D. Magazine* for cycling products.

Niko A. Henderson has been a Test Engineer for Easton-Bell Sports since 2001. His credits include Team Directorship of the National Science Foundation's Autonomous Mobile Robotics project and a US Patent on electro-mechanical interfaces.