BULLET PROOF

What it Takes to Make the World's Most Durable Racing Wheelsets

A CASE STUDY BY EASTON CYCLING

EASTON
TECH MANUAL

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Introduction

What makes a bicycle wheel durable? It's an excellent question, but one without a simple answer, and with good reason: a wheel is not a simple component, but rather an amalgamation of several distinct components, each of which must be perfectly optimized, matched and assembled in order for a wheel to prove durable.

Or to put that more simply, there is no such thing as an "unimportant" component when your job is to create a performance wheelset.

Seemingly trivial details—from the pitch of a nipple thread to the viscosity of the grease coating the hub bearings—can spell the difference between years of reliable service and being stranded on the side of the road.

While we are justifiably proud of our past wheelsets (wheels that have rolled to victory in every cycling discipline, from the Tour de France to the World Championships), we are never satisfied. Our job is to make each product better than the one before it...which is why we approached our latest project as a ground-up reinvention of the road wheel.

Every single component of these wheelsets was thoroughly re-thought and re-designed—from the shape of the rim to the bevel on the hub flange spoke holes. We started from scratch because it wasn't enough to make a light wheelset or an aerodynamically "fast" wheel. We wanted this all-new wheel to be the most durable road wheelset ever produced.

That's a tall order.

Our EC90 and EA90 wheels are the ultimate, do-it-all wheelsets. Road racing? Absolutely. Giro d'Italia, Kona's Ironman, your local Wednesday night crit—if it involves speed and asphalt, these are your weapons. But unlike typical "race day" wheelsets these are also wheelsets you can train on. Every day. In all conditions. They are that durable and it's no coincidence that these wheelsets wound up that way.

We've purposely designed the EC90 and EA90 wheels to stay true and roll smoothly as long as possible. And when it does require maintenance (as all products eventually do), riders will find that we've also engineered these wheelsets to be the simplest set of hoops to work on. No degree in engineering required. No specialized tools. No headaches.

In making these wheels, we've re-thought every single component, challenged every preconception we had about durability and design, and then obsessed over the details to an almost absurd level. This new line of road wheelsets represents a radical departure from Easton's previous designs. These new wheels are packed with several technologies that are entirely new to cycling. These are wheelsets Eight years in the making. And that, in a nutshell, is why we've created this document. We've put too much time into this project to simply roll out a slick ad with a snappy slogan.

We're going deeper than that.

Read on and you'll find a thorough review of the fundamentals of bicycle wheel design as they relate to durability. We'll examine the facts, de-bunk a few myths along the way and explain our own approach to creating the most durable wheel of its kind on the market.

At the end of the day, engineering is a matter of trade offs: you gain one thing and you give up another. It's all a matter of achieving the best balance of traits and features. We're confident, with this new line of road wheels, that we've taken the best, most rigorously tested and researched approach possible.

This is the story of the decisions we made, why we made them and how they all add up to a wheel that has no equals when it comes to standing the test of time.

What's Happening to Your Wheel As You Ride?

Before we get too deep into this discussion on durability, we need to set the stage by taking a brief look at the three types of stresses a bicycle wheel actually experiences out there on the road.

Radial Loads

The weight of a rider balancing atop the bike subjects a wheel to radial loads. The rider's weight flattens (so slightly that it's not visible to the human eye) the section of the wheel contacting the ground, which causes the spokes in that section of rim to partially de-tension, and the opposing spokes to tighten, minutely. As the wheel rolls, each wheel undergoes a constant fluctuation of spoke tension. Each spoke experiences a load/unload cycle with every revolution of the wheel. Thus, a wheel with 24 spokes undergoes 24 million load cycles over the course of 1,242 miles of riding. It's not surprising then, that radial loads impact the durability of key wheel components (particularly spokes). Radial loads are unavoidable and are the primary source of stress experienced by a wheel.

Lateral Loads

Sometimes called "side loads" lateral loads occur when a rider leans the bike aggressively in a corner or stands on the pedals and leans the bike from side to side (think of a sprint finish during a race). These lateral loads are relatively small (when compared with radial loads) and generally do not cause wheel failure.

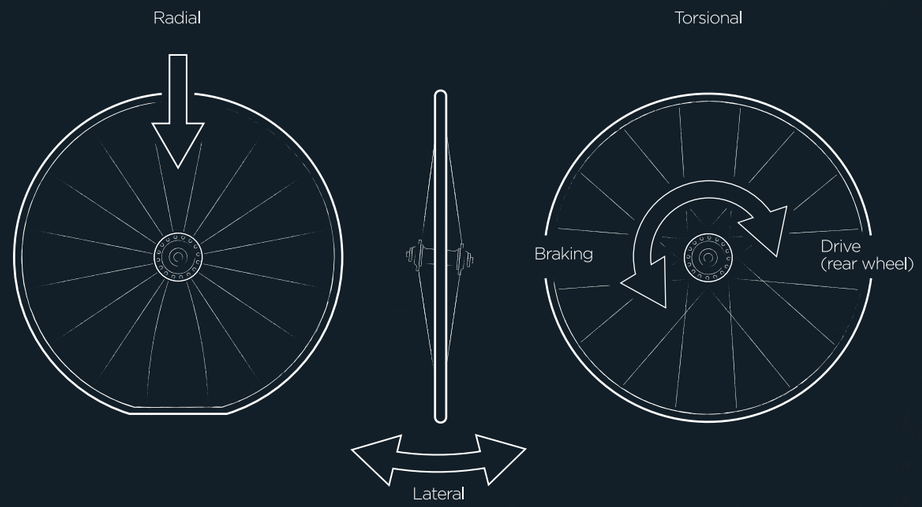
Wheels experience more significant lateral loads when knocked sideways while the rider is traveling at speed. On a road bike, this kind of situation can occur during a loss of control and often results in a crash. These kinds of lateral loads occur with greater frequency during mountain biking, which inherently involves jumping, being deflecting off of rocks, and, in some cases, crashing.

Torsional Loads

Torsional loads are created by both pedaling forces and by the use of disc brakes. As a rider pedals, the chain turns the freehub and this action exerts torque on the hub, which is transmitted through the spokes (causing some spokes to tighten and others to loosen minutely). The use of disc brakes (a fixture in mountain biking and of growing importance for road bikes) also creates torsional loads. On the whole, torsional loads have less of an impact on durability (assuming appropriate spoke-lacing patterns) than radial loads.

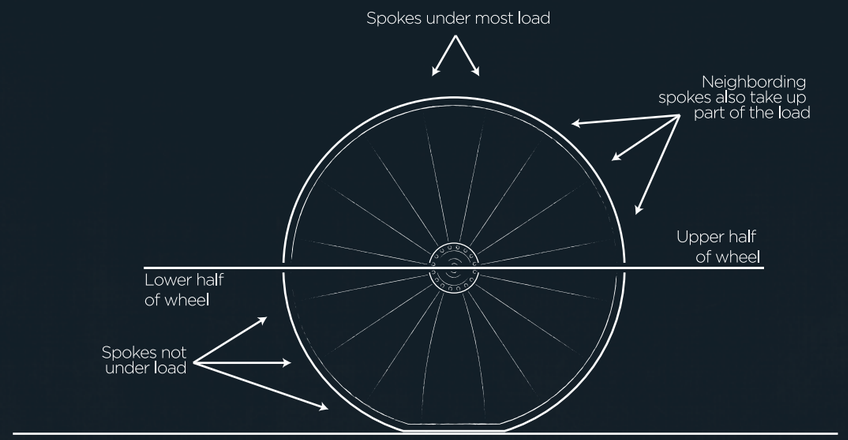
THE THREE TYPES OF LOADS

The three types of loads that stress bicycle wheels. Radial loads are the primary source of fatigue-related failure in bicycle wheels.

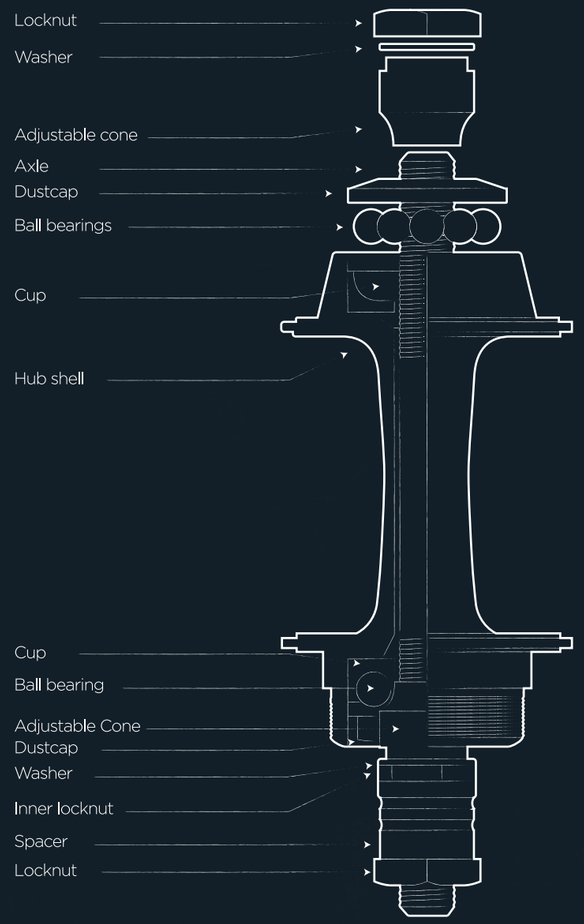


RADIAL OVERLOAD

At the bottom of a wheel's rotation, the bottommost spokes are de-tensioned as the hub tries to meet the ground. At the same moment, the spokes 180-degrees opposite are tensioned. The only thing that keeps wheels from imploding is that all the spokes are laced together and held in tension, so that when these moments of loading and unloading occur, the other spokes can share and dissipate the burden.



CUP-AND-CONE HUB



Cup-and-Cone Pros:
- Completely rebuildable: tools required are limited to cone wrenches.
- Inherent ability to withstand lateral loads.
- Grade 25 bearings are inexpensive to replace (less than 20 cents per ball bearing).

Cup-and-Cone Cons:
- Loose ball bearings easily roll off of bench tops into the darkest corners of your workshop, lost forever.
- Attention must be paid to achieving proper adjustment of the cone—otherwise the hub can be damaged.
- Weight: Cup and Cone systems are generally heavier than cartridge bearing systems.
-Once the race is damaged, the hubs are ruined.

At the Center of it All: Hubs and Bearings

Often overlooked, hubs are nevertheless the foundation of a wheel. Hubs house the bearings that allow a bike to move and they are the epicenter—the base structure—of the wheel itself.

Bicycle wheels roll on either cup-and-cone bearing systems or "sealed" cartridge bearings. Both systems have their pluses and minuses. Here's a quick review of the two systems and their relative merits.

Cup-and-Cone Hubs
Today, only Shimano and Campagnolo employ high end cup and cone hubs, but for decades nearly all bicycle hubs relied on the cup and cone. Here's how it works: loose ball bearings are sandwiched and roll between two races: the "cup" or inner race, which is forged or press fit into the hub shell itself, and the "cone", a conical nut that threads onto the axle and acts as the outer race. Bearing tension is adjusted by threading the cone down on the axle, and locking it in place with the locknut. If that sounds confusing, refer to the image at left.

As the picture illustrates, a cup and cone bearing is fairly simple. Tools required to conduct an overhaul amount to nothing more than a few, thin cone wrenches. Overhauling this system simply requires loosening the locknuts and cones, withdrawing the axle, and replacing the bearings and grease. Most cup-and-cone hubs utilize Grade 25 steel ball bearings. Front hubs tend to use 3/16-inch ball bearings (10 per side). Rear hubs often contain ball bearings (nine per side). Grade 25 bearings are widely available at bike shops and sell for as little as twenty cents a piece. A home mechanic might spend between $8 to $10 on new bearings when overhauling their cup-and-cone hubs.

Upon reassembly, however, you must pay keen attention to the adjustment of the cone. If the cone is screwed on too far, it places excessive pressure on the bearings, leading them to wear out prematurely. This may also pit or mar the cup itself, which would necessitate replacing the hub altogether. Similarly if the cone is set too loose, play develops, which also leads to premature bearing failure and, potentially, damage to the hub itself.

One of the positive aspects of the cup and cone system is that the manner in which the cup and cone nestle together acts to cradle and support much of the bearing's surface area. The contact points for the ball bearings are angled, rather than radial and this helps the bearing withstand both radial and lateral loads. Thus, a cup-and-cone bearing can be considered a type of angular contact bearing.





At left you can see the loose ball bearings cradled in the "cup". The cup or outer race is built into the hubshell. At right you can see the inner race or "cone".

Cartridge-Bearing Hubs

In the 1970s, manufacturers began moving away from loose ball bearings, opting instead to equip their hubs, bottom brackets and headsets with bearings housed in "sealed" cartridges. The upside for many consumers was obvious—no more messing around with loose ball bearings and, since many cartridge bearings are non-adjustable, no need to fret over hub adjustment (Note: some cartridge bearing hubs do, in fact, feature preload adjusters). Overhauling a cartridge bearing-equipped hub generally entails pressing out the old cartridge and pressing in a new one. Most manufacturers do not recommend rebuilding their cartridge bearings.

From a manufacturer's standpoint, cartridge bearings were also attractive. Cartridge bearing hubs are less labor intensive. True, manufacturers still need the bore in their cartridge-bearing hubs to meet high tolerances, but that process tends to be less expensive than that of forging a steel cup and cone, heat treating both products, polishing them and then press fitting the cup within an aluminum hub shell (as required in a cup-and-cone system).

Many consumers assume that cartridge bearings are better sealed than cup-and-cone bearings since the cartridge is a self-contained unit. This isn't necessarily true. Cup and cone systems often include robust sealing systems consisting of both a dust shield and a labyrinth seal. Some cartridges are well sealed, others are not. Better-quality bearings contain more robust seals.

Downsides to the cartridge bearing? Some consumers and mechanics prefer to re-pack hubs—tossing out the cartridge bearing mechanism with every overhaul may seem a waste. Similarly, many cartridge bearings situate the bearings radially within the cartridge and thus are designed to only accommodate radial (up and down) loads. Lateral loads prematurely wear out such bearings. Some manufacturers attempt to address this by equipping their radial cartridges with bigger ball bearings (which have greater load capacity than smaller bearings), though this adds weight to the system.

Fortunately, there are also angular-contact cartridge bearings (see image below), which possess the convenience of cartridge bearings and the angular contact of a cup-and-cone bearing. Such bearings are often found in head-sets, full-suspension mountain bike frames and some hubs. While more expensive than radial cartridge bearings, angular contact bearings are well suited to use in bicycle hubs and bottom brackets.



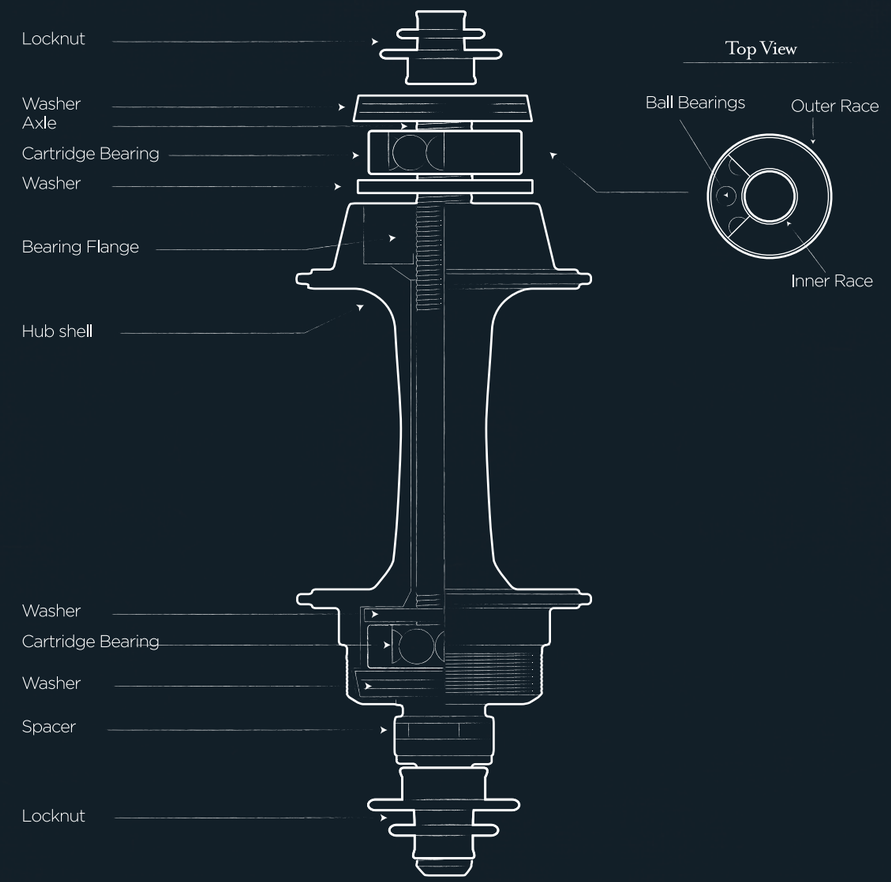


A side-by-side comparison of the two primary styles of bicycle hub: cartridge bearing on the left and loose-ball bearing (cup-and-cone) at right.



Angular Contact Bearings

CARTRIDGE-BEARING HUB



Cartridge Pros:

- Simple to work on: press out old cartridge. Press in new one.
- No loose ball bearings to hassle with in your dimly-lit garage.
- Less-expensive to manufacture.
- Generally lighter than cup-and-cone systems.
- Can feature adjustable bearing preload.

Cartridge Cons:

- Radial versions do not withstand lateral loads as well as cup-and-cone hubs.
- Some hubs require specialized tools (drifts) to properly remove/install cartridge bearings. Misaligned cartridge bearings will wear out prematurely.
- Not rebuildable.
- Cartridge bearing are more expensive to replace than loose ball bearings.
- Easy to mis-adjust preload (with designs that include adjustable preload).

Bearings—Old Faithful versus New Technology

For more than a hundred years, bicycle bearings were steel. End of story. More recently, however, ceramic bearings have made headway in the cycling industry. Though ceramic bearings are considerably more expensive than their steel counterparts, they do have definite strengths.

Ceramics: Worth the hype?
Friction is the bane of any bearing—it leads to wear and forces the rider to work harder to maintain speed. Ceramic (technically, silicon nitride) bearings produce less friction than their steel counterparts because they are up to three times harder than a Grade 25 steel bearing, which means they are less prone to pitting should contaminants work their way past your hub's seals. Ceramic bearings also can be made rounder than steel bearings, won't corrode and are lighter than steel bearings. All good things.

Admittedly, It's a Bit More Complicated Than That....
Ceramic bearings offer undeniable benefits, but there are also a few caveats. First there is the issue of cost. A steel bearing-equipped external bottom bracket, for instance, might retail for $40 whereas a nearly identical version equipped with ceramic bearings can easily cost three times as much.

Ceramic bearings are also not as universally friction-free and durable as some suggest. In a hybrid ceramic cartridge bearing, for instance, the ceramic ball bearings are housed in steel races, which can corrode when exposed to water (thereby adding friction to the bearing). What's more, since ceramic ball bearings are harder than the steel races that house them, ceramic bearings have a tendency to wear the steel races, which again adds friction and wear and tear to the system.

Finally while it's easier to make a rounder bearing from silicon nitride (ceramic) than from steel, this doesn't mean that all ceramic bearings are inherently rounder than all steel bearings. The old adage, you get what you pay for applies here. If you want the benefits of ceramic bearings (and they do, indeed, have their benefits), you'll need tc pay for high quality versions.



Easton's Approach: The Echo Hub

All EC90 and EA90 wheels are equipped with Easton's all new Echo hub. **Every single component of the Echo was designed and redesigned several times over in an effort to increase stiffness, improve bearing life and cut weight, while also giving builders and mechanics an intuitive and easy hub to maintain and build.**

We rethought and re-engineered every component when making the Echo. Everything from the bearing architecture to the machining methods, spoke configuration, drive-ring engagements, the angular contact bearings, the sealing methods, grease—every aspect of hub design was challenged and then challenged again. We contested every notion, idea, preconception and bit of wheel building folklore that we knew. We even redesigned the quick release skewers because what was out there just wasn't cutting it. We pushed our manufacturing partners. We pushed our bearing supplier. We pushed our forger, our machinists, our managers, our budgets, our relationships with one another—if we thought we could make it better, we pushed it.



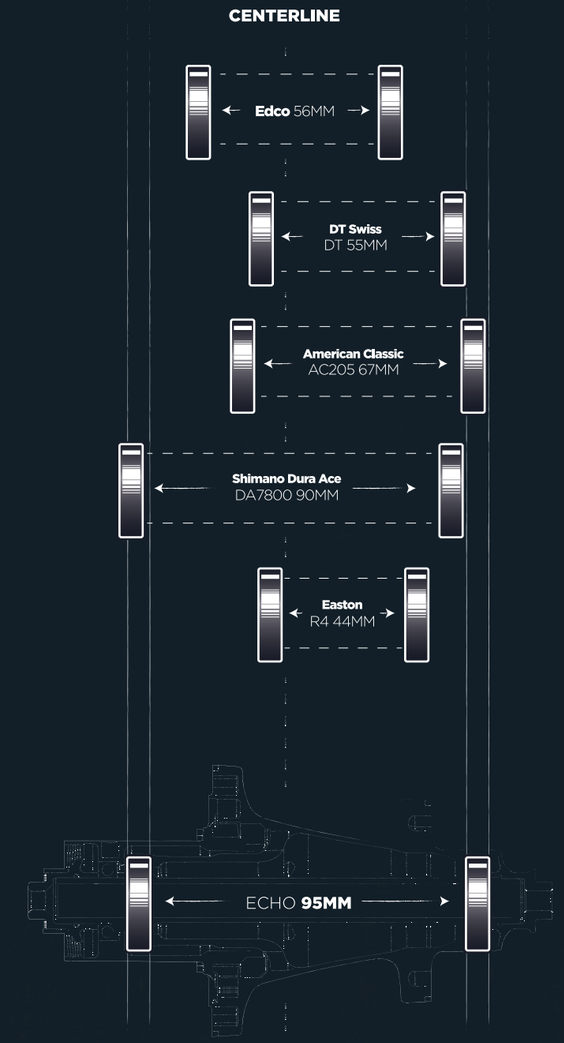
Angular Contact Bearings
Our R4 and R4SL hubs contain radial cartridge bearings with adjustable preload—an excellent choice and perhaps the best option at the time. But with the Echo, we've gone one better and equipped the hub with angular contact cartridge bearings that prove just as smooth as before and even more resistant to side loads.

While the new angular contact bearings are absolutely premium grade, we purposely equipped the Echo with readily-available bearings—these are not hard-to-find, hard-to-service bearings. Working on the Echo hubs won't require that you scour the Internet and pound the pavement in search of proprietary parts.

More Durable Bearing Architecture
One of the downsides of adding gears (first 5, then 6, 7, 8, 9, 10 and now 11-speeds) to bicycle drivetrains is that hub drive bearings have been getting squished closer and closer to one another. That's bad for bearing life. Basic physics tells us that the closer the drive-side bearing is to the center of the hub shell, the more stress it will see. That bearing is essentially a fulcrum and the axle is the lever. The further inwards the bearing sits on the axle, the longer that lever arm grows... and a long lever exerts an ungodly amount of force on a bearing.

With the Echo, we've turned the tables completely and given the hub an extra-wide bearing stance that has massively increased the lifespan of the hub bearings. We pushed the two main drive bearings as far apart as possible—50 millimeters further apart than the R4. With a span of 95 millimeters between the two bearings, the bearing stance on the Echo is considerably wider than that of the majority of hubs on the market today. The end result? Longer, smoother and more consistent bearing performance.

COMPARATIVE BEARING SPANS



EASTON ECHO
FASTER, STIFFER, LIGHTER





No Adjustments. No Hassle.
Many top-tier road wheels utilize cartridge bearings with preload adjusters. Previous to our 2014 product line, our best road wheels utilized the R4 and R4SL hubs. Those hubs are light, quick-engaging and they help create a wheel that stays true in the harshest of conditions. They also feature bearing preload adjusters, which have their pros and cons.

Let's start with the pros: preload adjusters allow you to adjust your hubs as the bearings wear. Most riders really like the idea of adjustability—bells and whistles are loved by all, plus adjustable preload can prolong bearing life and decrease drag in the hub. Cranking down bearing preload is a good way to "cheat the system" and score a few more weeks out of worn out bearings.

That adjustability, however, requires that you routinely check your wheels and add preload when play develops in the hub. It's an excellent feature, but it requires vigilance. The feedback we've received from consumers, however, is clear: they don't want to be vigilant—they just want to ride. Fair enough. That's why we designed a bearing system for the new Echo hub that required no preload adjustments. **No more checking the bearings. Just ride.**





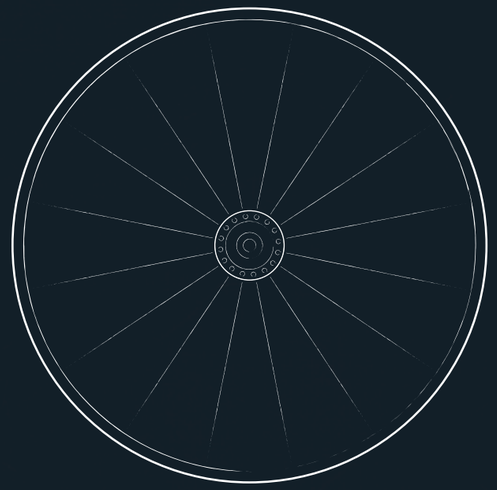
Faster, Stiffer and Lighter
Our primary goal with the Echo was to create long and reliable bearing performance. That meant redesigning the hub shell and driver engagement that Easton had previously used. A bigger hub shell allowed us to use thinner walls and change the drive-ring and pawl orientation.

By reversing the drive mechanism (the pawls are attached to the hub shell and the drive ring is on the cassette body) we were able to give the Echo a quicker, 7-degree engagement (as opposed to our old 12-degree design). This also distributes the drive forces in a more tangential direction directly underneath the crossed drive-side spokes, resulting in a tighter, torsionally-stronger wheel. Finally, redistributing those drive forces enabled us to also cut the axle weight down by 77-percent.

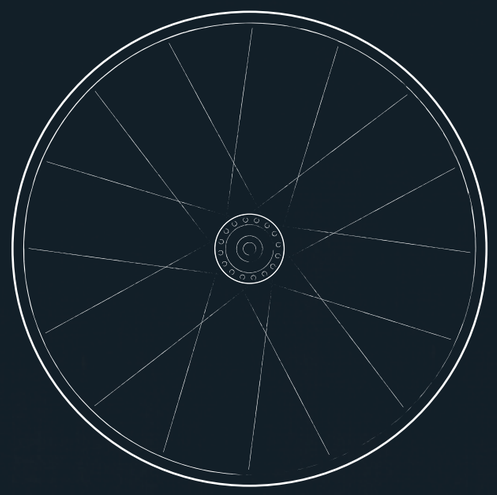
Or in plain English: faster, stiffer and lighter.



Radial Lacing



Cross Lacing





Strengthening the Connection: the Spokes

Spokes may be the most under-appreciated component in a wheel. With every revolution, the wheel undergoes tremendous strain, as forces yank and pull on each spoke. In the simplest terms, here's how it works: At the bottom of a wheel's rotation, with all a rider's weight pushing down towards the ground, the bottommost spoke is partially de-tensioned as the hub tries to meet the ground. At the same moment, the spoke 180-degrees opposite experiences an increase in tension, since the hub is trying to pull away from the top of the rim. The only thing that keeps wheels from imploding is that all the spokes are laced together and held in tension, so that when these moments of loading and unloading occur, the other spokes can share and dissipate the burden. That's why high quality spokes and an exceptional wheel build are the foundations of wheelset durability.

What Are Spokes Made of?
For decades, the best spokes were made of stainless steel, and with good reason—stainless steel is light, resists fatigue well and doesn't corrode. Spokes, however, also can be made from materials such as aluminum, titanium and carbon fiber. Mavic, for example, has long employed an aluminum alloy in their spokes. Titanium spokes are available, but are rarely used because they cost a bundle, can be a challenge to build with, and only offer minimal weight savings. Ultra-light composite (carbon fiber) spokes have been in use for more than a decade now on both road and mountain bike wheels and are steadily gaining traction. Even with all of these advancements, stainless steel is still the shining star of spoke materials.

Bent or Straight?
Spokes generally come in two basic flavors: J-bend and straight-pull. J-bend spokes feature a bend at the head where they seat into the hub flange. Straight-pull spokes have no bend or "elbow" and require different hub flanges than J-bend spokes.

Which type of spoke is superior? There was a time when advocates of J-bend spokes argued that their spoke was superior because it was so readily available. Nowadays, however, straight-pull spokes are just as easily purchased at any bike shop. Straight-pull spokes have the additional benefit of not having been bent and fatigued during fabrication (which is precisely what is required to create a J-bend spoke).

Lacing Patterns: Pros and Cons
There are two primary ways to lace a wheel: cross lacing and radial lacing. In cross-laced wheels, each spoke crosses one, two, three or four other spokes as it travels from the flange to the rim. In wheels with a radially-laced pattern, each spoke radiates directly from the flange to the rim, never crossing another spoke.

Radial lacing can help shave a few grams of weight from a wheel build because it requires shorter spokes and therein, less material. While radial lacing is quite common on rim-brake front wheels, it's less common on rear wheels because radially-laced spokes have a hard time withstanding the fore-and-aft pull of torsional loads, sometimes called "wind-up," which is created by disc brakes or pedaling forces. This is why radial lacing is only rarely employed on the drive side of a rear wheel and why it shouldn't be used with disc brakes.

Cross lacing, on the other hand, is well suited for handling the torsional loads created by disc brakes and pedaling forces.

Spoke Tension—Sharing The Load

Rims, as they come out of the box, are basically very round and very straight. There may be some inconsistencies or variances in manufacturing, but any modern rim of decent quality is basically round. If we were building basic wheels, we'd take this round rim and lace it to a hub with 32-spokes. Tensioning these spokes fairly evenly will result in a pretty straight, basic wheel that will probably work for a few years. Basic wheels like these are pretty simple to build. In fact, robots build thousands of these wheels worldwide on a daily basis (ever heard the term "machine built"?).

The thing is Easton Cycling isn't interested in building another run-of-the-mill 32-spoke, basic road wheel. We want to build lightweight, racing wheelsets that offer responsive ride quality—the sort of wheels that accelerate when you push the pedals and carve turns with authority.

One of the biggest things that you, the bike rider, are looking for in a racing wheel is minimal weight. The other big consideration is ride quality. Building a wheel with fewer spokes decreases weight and can contribute to better handling, but as you can imagine, it also complicates the build. You can't just take out half of the spokes and expect your basic machine assembly procedure to perform for years and years of hard riding. With fewer spokes, it is absolutely critical that those spokes are tensioned evenly.

As you ride, your weight—plus the weight of your bike—is being carried by the spokes in the top half of each wheel. As mentioned on page 4, the spokes in the lower half of the wheel are detensioned. These increases and decreases are imperceptible to the rider but this cyclical variation in tension is the reason that wheels lose their straightness and roundness over time and the reason spokes eventually fatigue and break.

Now imagine if just one of those spokes is at a higher tension than its neighbors. The wheel can still be straight and round but that one spoke is overtensioned and the two neighboring spokes are undertensioned. This means that with every rotation, the two low-tension spokes are being partially detensioned to a greater extent and will fatigue more quickly. This is a common situation with machine built wheels and is a major contributing factor for wheels needing to be periodically "re-tensioned". In wheels with lots of spokes the variance between spoke tension is less important because there are still plenty of remaining spokes to share the load. But remember, we want race wheels, and those extra twelve or sixteen spokes add weight and increase aerodynamic drag.

We need to get all sixteen or twenty spokes pulling the exact same tension and all working together; there's no room for slackers here. When all the spokes are working together a wheel can run for years and years on rough, potholed roads and never need to be trued because all of the parts are fatiguing slowly and evenly.

Machine built wheels can't achieve the even tension required, and robots cannot account for the slight variances caused by rim, spoke, and hub manufacturing tolerances. That's why Easton Cycling employs wheel technicians to lace, tension and true wheels by hand. In addition, our technicians acoustically tune each wheel during the tensioning/truing process. Tensiometers are also used throughout the process—we'll get into that in a moment—but we believe our systematic approach sets the standard for racing wheels that stand the test of time.

Do You Trust Your Tensiometer?



Tensiometers are tools used to measure spoke tension. There are a variety of tensiometers available for bicycle spokes, but even the best (and most expensive) need to be calibrated regularly and can be tricky to read. And here's the kicker—they don't actually measure spoke tension at all.

Spoke tensiometers work by holding the spoke at three points and placing a known and consistent side load on a short section. Depending on the amount the spoke deflects under this load, the tensiometer will give you a number. The number on the tensiometer is not actually the tension or even a measurement—it is just a number. For example, if my tensiometer reads 139 on a Sapim CX Race spoke, I have to correlate that number to an actual tension by referring to a calibration chart. So here's how we create a calibration chart—we need a well-calibrated force gauge and a spoke from the batch that we're using. By some mechanism we can add a load to the spoke and the force gauge will show the exact load being experienced by the spoke at that moment. Measuring that spoke with the tensiometer will give me a tensiometer reading which directly correlates to a given force. Repeat this a few times with different forces and you can build a calibration chart specifically for that tensiometer and that spoke.

We have found that for the most consistent performance, spoke tensiometers should be calibrated to each new batch of spokes and should not be completely trusted. The reason for this is that spokes can vary in thickness between batches and even within a batch. A double butted spoke which proclaims to be 2.0-1.8-2.0 may actually vary between spokes in a batch. One spoke might be 1.78-millimeters thick in the middle section and another might be 1.81 millimeters. This difference of .03 millimeters may not seem like much but it's enough that it can affect the readings on the tensiometer. These two spokes can give the same reading only if the thicker spoke is at a lower tension.

By referring to my calibration chart, I can see that a tensiometer number of 139 equates to 118 kilograms. By this method I can guarantee that all the spokes in the wheel are near the target tension. We still aren't done, though, some of these spokes may be different thicknesses. And if we're expecting this wheel to last for years, we simply cannot allow this type of variance.

That's why acoustic tuning plays such a large role in the Easton process. It's nothing new, and far from high tech. We literally pluck the spokes with a guitar pick. This often reveals different tones from spokes that show the exact same reading on the tensiometer. By using acoustic tuning, we can tease out those slight variations in thickness and be confident that we are building the most durable wheel possible.

Spoke Tension - Like A Marine's Haircut

Building durable, low spoke count race wheels requires more than even spoke tension. The tension also needs to be a lot higher than traditional, 32-spoke wheels.

High tension is important, but how much is too much? If you just continue turning the nipples tighter and tighter you'll eventually reach a point at which you can't tighten them any more without rounding off the square wrench flats. On good quality alloy nipples this usually happens at about 125 Kg. So there's one limit. But we don't want to build wheels like that because we'll have a devil of a time during final balancing if all the nipples are stripped.

Because front hubs are symmetric, we target the spoke tension for front wheels at just below this threshold.

Rear wheels need to accommodate the gears on the right side of the hub and this means that the right spokes are pushed further inboard. This offset of spoke flanges is called 'dish' (see page 21). Dish requires the tension between left and right spokes to be different from each other. This is because the increased distance to the left flange gives the left side spokes a greater mechanical advantage.

If we were to simply tighten all the spokes at the same time we would top out on the right side first at about 125 Kg before the nipples begin to strip. In reality the sweet spot for the right side spokes in a low spoke count wheel is somewhat higher than 125Kg. The question is, how do you achieve that high tension without rounding off the nipple flats?

Easton Cycling employs a procedure called "pull-over wheel building" that has a number of advantages—higher right side tension, greater ease in balancing tension, and higher left side tension. These are all things that add to long term wheel durability.

Starting with a wheel which has been laced (but is not yet tensioned) we slowly and evenly add tension only to the spokes on the right side. We will slowly and evenly add tension to all the spokes on the right side until we reach a specific target or 'pull-over' tension, usually about 60-percent of the final tension. Because this is still a relatively low tension, fine adjustments required to achieve perfectly even spoke tension are very easy.

Once we balance spoke tension on the right side, we will not touch the right side spokes again. Instead, we'll add tension only to the left side. In this manner we will pull the rim over to the left. This move adds tension to both sides and trues the wheel laterally. When the rim is centered over the hub we have a wheel with a high and even spoke tension which is perfectly balanced.

The Importance of Spoke Count

Building wheels is just like achieving a happy, fulfilling life: it's all about balance. Spokes give wheels their structural strength. Aside from suspending the hub in the rim to counter radial forces, spokes must also resist the lateral forces of riding and cornering. Adding spokes adds strength to the wheel, but also adds weight and aerodynamic drag. In the case of racing wheels we want to choose the lowest number of spokes which can still resist all of the forces involved.

A traditional wheel with thirty-two spokes can easily resist all these forces even when built with uneven spoke tensions, this is because even though some of the spokes may be a little looser or tighter than the others there are still plenty of spokes at close enough tensions to share the load.

To compensate for that loss in strength, manufacturers generally have to add material to the rim to increase its structural integrity. Most manufacturers increase rim strength by using heavier, deeper-profile rims and lacing the spokes under extremely high tension.

There is, however, a trade off here: adding extra material in the rim adds rotational weight and can creates a sluggish feel when accelerating. Proponents of low spoke-count wheels, however, are usually content with that tradeoff. They might, for instance, contend that the difference in rim weight is negligible, and that by adding strength to the rim, they are effectively creating a more rigid and stable structure for the spokes to pull from. This in turn leads to longer spoke life because the rim isn't trying to flex and overload the spokes.

Again, it's all a matter of tradeoffs.

Why Spokes Break

There are two main reasons that spokes break:
- Play between the hub flange and the spoke head.
- And low or uneven spoke tension.

Since a spoke is constantly being loaded and unloaded, even the slightest amount of play between the spoke and the hub flange will cause the spoke to jerk back and forth in the flange, which widens the spoke hole (continually exacerbating the problem) and causing the spoke to fatigue and become brittle.

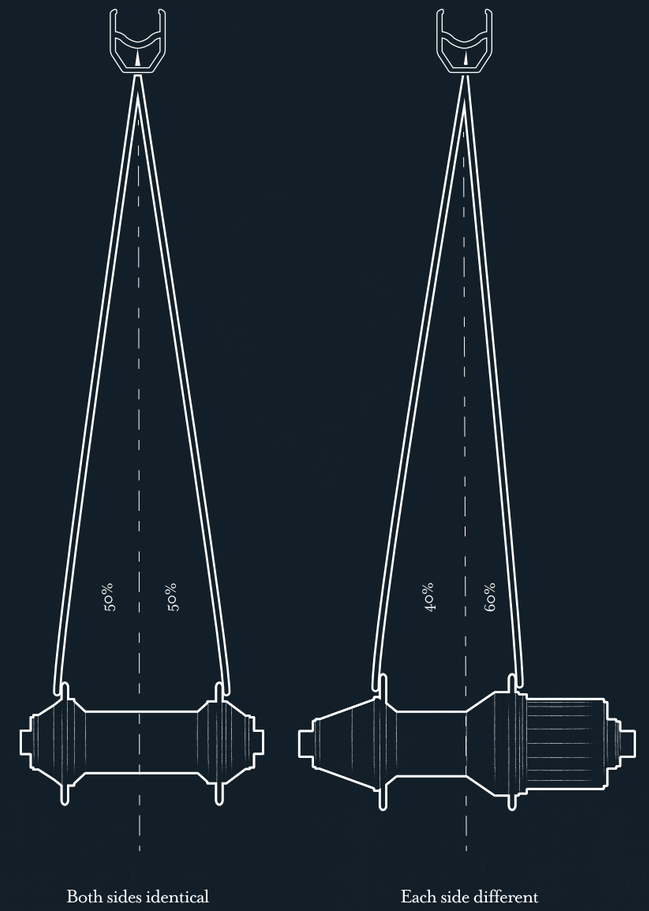
We've fatigue tested countless (literally thousands upon thousands) of different spokes and have found that J-bend spoke are particularly prone to shearing at the bend or "elbow" since that section of the spoke was already weakened when fabricators first cold-worked the bend into the spoke.

Loose spokes also lead to spoke failure, which may seem counter-intuitive. If you've never built a wheel, you might think that high spoke tension would fatigue spokes, but loose spokes bend more than highly-tensioned spokes and fatigue more quickly than highly-tensioned spokes. They also require adjacent spokes to shoulder more of the stress than they were designed to handle. In this way, even a single loose spoke accelerates the demise of properly tensioned spokes in the wheelset.

The key to a durable wheel is to lace it with highly and evenly tensioned spokes. This, however, is easier said than done, particularly on the rear wheel due to rear wheel dish. What exactly is "dish"? Dish is a term used to describe the angle of spokes on rear wheels when viewed in cross-section from the hub to the rim. The image at right illustrates this.

To make room for the bike's gears, the spoke flange on the drive side of the hub must be pushed inwards (about 10 millimeters) towards the hub center. Consequently, the spokes originating from that drive-side hub flange must travel to the rim at a steeper angle than the spokes on the non-drive-side. This, in turn, means that wheel builders must use shorter, higher-tensioned spokes on the drive side of the wheel than on the non-drive side. In fact, non-drive side spokes are usually only tightened to about 60 percent of the tension of the drive-side spokes. The uneven spoke tension greatly weakens the rear wheel. Making matters worse, a rider's weight is biased towards the rear of the bicycle, which means rear wheels also see greater radial loads than front wheels. All of this helps explain why broken spokes occur more frequently on the rear wheel.

WHEEL DISH



Both sides identical

Each side different

Easton's Approach:
Premium Materials, Durable Design & Unrivaled Build Quality

Premium Materials
Easton's 90-level wheels are laced with the highest quality steel spokes available: double-butted, straight-pull Sapim spokes. These time-proven spokes save weight and handle loads exceptionally well. While we do use J-bend spokes on some of our more entry level wheel models, countless in-house fatigue tests and field trials have proven that straight pull spokes have a much higher fatigue life. The bending process that creates J-bend spokes stresses and fatigues the spoke before it ever hits the road.

Exceptionally Stiff and Reliable Spoke Configuration
While spoke configuration may not sound terribly sexy, it's absolutely critical to rear-wheel durability, which is why we spent an inordinate amount of time testing different lacing patterns when developing our road wheels. On our top-tier EC90 wheels, the front wheel features 16 radially-laced spokes, which keeps weight to a minimum. The rear, however, features cross-laced spokes... on both sides of the rear wheel: single-cross on the non-drive side and two-cross on the drive side.

The 20 cross-laced spokes on the rear wheel will withstand the torque of pedaling and the most brutal riding conditions possible. This lacing pattern, however, also provides a tangible improvement in ride quality and power transfer. The moment you stand on the pedals, there's an immediate "snappiness". It's a difference that's noticeable to the rider and it's been proven in testing.

100% Hand Built to the Highest Standards
You can use the best materials possible, but if your wheel build isn't equally precise, you might as well build your wheel from popsicle sticks and bat guano. There are plenty of "machine built" wheelsets on the market. Some of these wheels may come out of the box and spin perfectly straight and true. However, any difference in spoke tension will become evident over the first few rides. The end result? Wheels that come out of true easily and, eventually, fail and let the rider down. This is why so many riders still pay a premium to have their wheels built by a master wheelsmith. They want their wheels to last. That's also why we, at Easton, build our wheels—from our entry-level models on up—entirely by hand.

Each of our wheels is 100-percent hand built and acoustically tuned by Easton-trained builders. This is not the fastest or least expensive way to build and sell wheels. But we believe that this painstaking process makes a difference in keeping Easton wheels spinning straight and true much longer. Easton's systematic approach to precision tensioning and truing sets the standard in the bike industry.

Hassle-Free Maintenance
We designed our 90-level wheels for maximum performance and style, but we were not willing to sacrifice durability or serviceability in the process. These wheelsets stay true and stand the test of time, but naturally, all wheels will need some maintenance over the course of their lives. Just as with the bearings in the new Echo hub, we purposely equip all of our wheels with readily-available parts. No special tools. No hassles..



Where the Wheel Meets the Road: The Rims

It goes without saying; rims have a massive impact on a wheel's performance. Weak rims deform excessively and place massive strain on the spokes, leading to premature failure. Likewise, heavy rims will transform an expensive bike into a plodding beast of burden. Rims with poorly-designed profiles can feel unstable in cross winds and add significant aerodynamic resistance to your ride. Clearly, a lot hangs on the design and execution of your rims.

The Shape of Things:
Rim Profiles and Their Impact on Performance

Like every other wheel component, rim profiles are frequently in flux. The shape of performance rims have morphed from low-profile, box-section varieties to decidedly more aerodynamic profiles. All things being equal, triangulated "aero" rim profiles offer better strength and stiffness than box-section rims. This is why these rims are popular in low-spoke-count wheels, which lack the strength supplied by a greater number of spokes and, thus, require a stronger rim. In the past, these taller, more aerodynamic rims also weighed more than their rectangular counterparts. Advances in material technology, however, have made this less true.

Early Rim Materials

From the mid-to-late 19th century until about the 1940s, premier road racing bikes featured wooden rims. These rims provided a smooth ride, with great vibration damping characteristics. But as rim brakes became more commonplace, steel quickly took center stage. By the 1980s steel rims were relegated to inexpensive "department store" bikes, and aluminum was the de facto material for premier wheels—in road and mountain bikes.

Aluminum can be an excellent material for bicycle rims. To make a rim, manufacturers extrude semi-molten aluminum through a die, which they cut and then shape into hoops by pinning, gluing or welding the ends into place (sometimes they are pinned and glued, sometimes pinned and welded). Quality rims feature a hollow cross-section underneath the nipple bed created during the extrusion process. These double and triple-wall rims boost strength without adding much weight.



Carbon Fiber Rims: Potential Benefits
In recent years, carbon fiber has become a popular material from which to build rims—and with good reason. Carbon fiber components can be made incredibly strong. Carbon fiber has an almost unlimited fatigue resistance, which makes it an excellent option for components, such as rims, that undergo constant fatigue cycles.

While carbon fiber once had a reputation for a lack of toughness (which is different than strength—think of it as "impact resistance"), advances in resins over the past few years have enabled carbon fiber frames and wheels to surpass aluminum in terms of its ability to withstand impact. Five years ago people would have scoffed at the notion of carbon fiber for aggressive trail riding and yet today the Easton Haven Carbon wheelset has proven to be the strongest option on the market. In fact this virtually indestructible wheelset even carries a two-years-no-questions-asked warranty. From a durability perspective, properly constructed carbon components easily outshine their aluminum counterparts.

So... lightweight, strong and tough...Carbon has a lot going for it. But there's still more weighing in its favor. Engineers can design carbon structures to flex in certain planes and remain rigid in others, all by meticulously tailoring the schedule of the composite plys during fabrication. They can, in essence, tailor a distinct feel into a carbon wheel that makes for a better ride.

What makes a great rim? Though Jobst Brandt clearly wasn't thinking of carbon back in 1981 when he penned, The Bicycle Wheel, his seminal book on wheel building, his description of the ideal rim presciently describes the benefits of a carbon rim. "They [rims] must be elastic enough to absorb shock loads, yet stiff enough to distribute loads over several spokes; and they must be strong radially, laterally and in twist."

Carbon Rims: Potential Drawbacks
The Expense
There's no denying it—carbon rims are expensive. Despite the space-age appeal of carbon fiber as a building material, it requires an incredibly labor-intensive production process. Each ply must be perfectly aligned if carbon has to fulfill on its promise of strength and ride quality. Carbon components are truly hand built. The incredible attention to detail and sheer manpower required to make a product out of carbon raise the sticker price on carbon components.

Braking/Heat Dissipation
To date, some carbon clincher wheels have performed poorly and, at times, dangerously due to their inability to cope with the heat created by braking forces. Most road bikes still rely on caliper brakes, which slow the bike down by clamping the brake pads against the rim's sidewalls. On long descents that require prolonged braking, the friction of the pad against the rim can lead to high temperatures on the rim. Higher temperatures lead to thermal expansion—the air pressure in the inner tube increases—which further stresses the clincher. You have two opposing forces: expanded air pushing the rim's sidewalls apart and brake calipers pushing the sidewalls together. To make matters worse, some inexperienced rim manufacturers utilize subpar carbon fiber with resin that softens at the temperatures experienced in long, sustained braking.

If that sounds scary to you, well, it should.

Easton carbon clinchers perform remarkably well in terms of durability and heat dissipation. We've taken extraordinary steps to ensure that our carbon clincher rims perform as well under high heat conditions as any aluminum rim. How exactly did we do that? We'll get into detail about that soon....



Easton's Approach:

The Fantom Rim: Shaped by Years in the Wind Tunnel & the Torture Chamber

If your wheelset won't allow you to stop your bike on a dime or threatens to spit your tire off the rim, you've got serious problems. Despite the fact that Easton is a pioneer in composite cycling components, we weren't the first company on the block with a carbon clincher wheelset. Or the second. Or the third. And there's a reason for that—we weren't willing to put a carbon wheel under riders that we weren't 100 percent confident in. The stakes are just too high.

In fact Easton Cycling spent six years creating the technology required to make carbon clinchers perfectly safe under extreme and extended braking; doing so required, for starters, that we invent a testing fixture and protocol designed to simulate hard, prolonged braking on long, steep descents.

In our text fixture, a wheel (with tire mounted) is driven forward with brake caliper loads adjusted to maintain constant pressure. During testing, we monitor the temperature of the rim surface as it exits the brake pads on both sides. All loads and temperatures are recorded with one sample per second. We also measure rim width dynamically throughout the test.

Once we built the perfect torture test (and let's be clear, it absolutely mangles wheels), we needed to create technologies that would enable our wheels to actually survive the tests.

The results are a proprietary, carbon laminate that pulls heat through the system and a unique brake-track surface treatment that improves braking performance and reduces the effect of heat on carbon sidewalls. Most carbon rims perform poorly under braking. Easton carbon rims, however, offer the best braking, heat dissipation and durability of any carbon clinchers.

We don't make that claim lightly—we've tested plenty of our competitors' wheels and all, with the exception of our EC90 Aero wheel and Zipp's 404, have failed before making it to the test's two-mile end point. Our EC90 Aero 55, by contrast, is so good that it routinely withstands this punishing test twice and remains in ride-worthy condition.

The EC90 Aero 55 is literally twice as durable as the strongest carbon clinchers in the world

Shaped for Speed & Stability
We've spent five years working with world-renowned aerodynamicist, Len Brownlie, at the San Diego Low Speed Wind Tunnel. During that time we benchmarked our competitors best wheelsets, tested and scrapped dozens of our own rim concepts and chased every detail in the process of finding the most truly aerodynamic wheel on the market. The EC90 Aero 55 is the result.

The EC90 Aero 55's Fantom rim is 55 millimeters deep, 19-millimeters wide (internal) and meticulously shaped. The end result? The Fantom is the fastest rim on the market—and not just at one random yaw (wind) angle. The Fantom is, on average, the most aerodynamic road rim in the world and we have the data to prove it. What's more, we tailored the Fantom's shape so that it also offered incredible stability in the fiercest of cross winds.

The Only Fully-Sealed, Certified Tubeless Carbon Clincher
Tubeless wheels offer legitimate benefits, not the least of which are improved ride comfort and protection against flats. Resorting to shoddy rim strips to create that air tight seal, however, doesn't cut it. All of Easton's 90-level clincher wheels are certified road tubeless right out of the box—no rim strips or conversion kits are necessary. We are proud to say that even our EC90 Aero 55 is road tubeless certified, making it the only fully-sealed, certified road tubeless carbon clincher wheelset available. The EC90 Aero 55 is easy to set up tubeless and provides absolutely problem-free performance.



Choosing The Right Wheel For Your Needs

The intention of this document is to shed some light on the myriad options in road racing wheels. Hopefully you learned a few things, like why Easton Cycling chooses angular cartridge bearings and a low spoke count. This document is not intended to be a sales piece. We're not trying to tell you that the EC90 Aero55 tubular is what you need to buy. It might not be.

What we mean to say is this: you have options. Easton Cycling's 2014 road line alone has seven different wheelsets, with aluminum or carbon rims, clincher or tubular, tubeless or standard. We honestly feel like we offer the best range of performance road wheels. But perhaps you value ease-of-maintenance over performance. In that case, an old-fashioned box section rim and 32 spokes might be perfect for your needs. We really just want to arm you with all of the information necessary to make an educated decision.


EASTON
TECH MANUAL