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FASTER

DEMYSTIFYING THE SCIENCE OF TRIATHLON SPEED

JIM GOURLEY

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PREFACE

I've been a technologist and an engineer almost all of my life, a path that might have started with an obsession with Legos as a young child. From that time on, I've had jobs that focus on how to improve the way man-made objects interact with the physical world. As a cadet at the United States Air Force Academy, I helped assemble a satellite that was eventually launched into space and operated some of the first unmanned surveillance aircraft in the U.S. Army. So although I initially got into triathlon as a purely physical endeavor, it wasn't long before my natural inquisitiveness led me to approach it as exercise for my brain as well.

I did my first triathlon in 2004 and finished my first Iron-distance race four years later. Like most triathletes, I quickly developed a passion for the sport and sought all the information I could find to become a better athlete. I was surprised to discover the amount of research and development invested in triathlon equipment, training, and nutrition. From the shoes we wear to the bikes we ride to the techniques taught to us, our knowledge of the sport is furthered by discoveries made with the help of cutting-edge technology. My personal fascination with triathlon and science ultimately led me to a new profession.

I've written about the latest products and technological developments in cycling and triathlon for *LAVA*, *3/GO Triathlon*, *220 Triathlon*, *Triathlete*, *Inside Triathlon*, *Peloton*, and *Bicycle Times*. Through research and personal experience, I've learned some interesting things about the cultural and technological dynamics of triathlon. It takes extraordinary dedication and discipline for an athlete to compete in multiple races every year or to take the start line of an Iron-distance race. You train hard. You set high standards for yourself. You want to achieve your full potential. You want to go faster.

To serve triathletes like you, product manufacturers, coaches, and instructors push the technological boundaries of racing equipment and training methodologies far beyond what was thought possible a decade ago, and they continue to make new advances each year. The amount of scientific research that goes into endurance sports equipment today is staggering. This is a boon to dedicated athletes, but it has consequences as well. It's easy to become overwhelmed by the vast array of products advertising sophisticated research and technology. Meanwhile, there is very little information explaining the fundamental concepts underlying the rationale and development of these items. Additionally, as manufacturers make new discoveries at the cutting edge of aerodynamics and material science, it becomes ever more challenging for them to explain the value of their developments to athletes who do not have the requisite foundation in scientific knowledge. This has led to the emergence of gimmicks that market themselves with pseudoscience and obscure their effectiveness with double-speak. Consequently, triathletes become frustrated, unable to maximize their gains in training and racing.

Triathletes need an understanding of the fundamental principles of racing technology, which can only be found piecemeal, buried in reams of advanced-level publications and journal articles. Instead of sorting through all this high-end data, they spend a significant amount of time searching the Internet to research products that will deliver performance—time they would rather spend swimming, cycling, or running. Often, they can't find a satisfactory answer online, leaving them to simply choose one of several expensive options without any guarantee of superior quality.

In short, it's hard for athletes to understand what makes the good stuff so good, and it's very easy for people making junk to fool you into thinking it's good. If triathletes could only find a way to capitalize on the scientific principles that are most beneficial to racing faster, they would likely discover that the good stuff is often the least expensive. There are endless magazine articles titled "Speed for Sale," and precious few with the title "Speed for *Free*!" Make no mistake. ***Free speed does exist. You just have to know where to find it.*** This book shows you some great places to look.

Faster bridges the technology gap for triathletes and points them to some non-equipment-based answers. Whether you're a newcomer to the sport, a gear hound who wants to get more educated about what goes into your equipment, an athlete on a budget looking to do more with less, or a serious competitor who wants to get every possible edge out of your training and gear, this book lays out the information you can use to obtain tangible results.

It's not as hard as you think. The prevailing myth in triathlon is that the science of speed is extremely complicated and difficult to understand. So triathletes go about their training neglecting the technological aspects of a sport that seem inaccessible. It's my goal to break down these concepts and make them easier to understand. Having spoken to many of the top product engineers and sports scientists around the world, I know that they can get carried away and quickly leave you behind with advanced ideas before establishing the fundamentals. Having taught high school math and science, I also know that the very idea of doing math and science is intimidating to some people. Let me reassure you, this isn't an attempt to make complicated things simple. The concepts aren't complicated in the first place. I have literally studied rocket science, and you have my professional assurance that ***this is not rocket science***.

For all the blood, sweat, and tears you put into your training so you can race harder, you owe it to yourself to do the homework that will help you race smarter. Don't let what you don't know hold you back from reaching your full potential. Instead, take a deep breath, grab your favorite recovery snack, give your legs a break, and get ready to pick up a few minutes on your finishing time by grabbing some scientific knowledge. Empower yourself to make smart choices in your equipment, training, and racing.

It's time to think about how you can go *faster*.

CHAPTER 1

PHYSICS & THE TRIATHLETE

Before we begin in earnest, let's review some basic physics. The beginning of each chapter will refer back to these fundamental principles to get you into the right mind-set and help you see how science factors into swimming, cycling, and running.

BATTLE AGAINST THE UNIVERSE: FORCES AND HOW THEY RELATE TO YOU

Whether you're swimming, biking, or running, ***there will always be two things involved: a body and a medium***. Though you might not have ever thought of it this way, your race is actually a battle against the universe. From the resistance of the water and the air to the earth's gravitational pull, *everything* is trying to keep you from moving forward. We cross finish lines all the time, and most of us hardly ever think about the fact that we've literally conquered heaven and earth to get there. But if you did think about it, you might find that you've been making things harder for yourself than they have to be.

Let's start by thinking about the human machine at rest. You are the **body**. On a bike, you and the bike are the body. You are surrounded by air. If you were to stand on the bottom of a pool, you'd be surrounded by water. As a swimmer in a triathlon, you are surrounded by a combination of air and water. In each case, you have to move through the air or the water. The **medium** is whatever the body moves through.

Your body has several scientific properties. You have a certain height, width, and depth. You have volume and surface area. You also possess a certain amount of mass, though this changes throughout the day according to your nutritional intake and conversion of that nutrition into energy. Let's describe a few of these physical properties in detail, beginning with mass.

Many people confuse the concept of mass with weight. **Mass** is a measurement of how much actual matter is in an object. Weight is a measurement of gravity's influence on that mass. To understand the difference, think of an astronaut orbiting the earth. She is weightless in space, but she still has the same mass. ***Mass is matter, and weight is force.***

Next in order of importance to triathletes is **surface area**. Surface area is a major factor in aerodynamics, whether you are riding your bike or moving through the water. It also has a strong influence on an athlete's ability to dissipate heat during training and competition. If you inflate a balloon, the air entering the balloon will cause it to expand, increasing the total surface area. Oftentimes scientists deal with a specific region of an object's surface area, referred to simply as the **frontal area**. In aerodynamics, the frontal area is that part of the surface that first comes into contact with the fluid medium as it moves forward. There are other ways to change the surface and frontal area of an object. Hold your hands flat out in front of you. Now lay one over the top of the other. Notice how the palm of one hand is covering the back of the other, keeping both from being exposed to the air. You've just decreased the total surface area of your hands by almost half. Though human beings can only make slight adjustments to their surface area (not counting extreme weight loss), ***they can make extraordinary changes by changing their body position***.

There's a further distinction that plays into aerodynamics in the water and on the bike. Although drag occurs across the entire surface area of a body, it is particularly influential on that part of your body that comes into contact with the air first, which we specified as the frontal area. Think of air molecules as paintballs. Would you rather be hit smack in the middle of your chest or have the ball break as it grazes your arm or hip? It's a lot less painful when the paintball skips off your skin, right? It's the same with wind and water, just on a much smaller scale. The best strategy is to duck down and make yourself as small as possible so fewer microscopic paintballs smack you straight on and more of them roll down your back. In fact, the most aerodynamic position you assume during a triathlon is in the water. Your frontal area is reduced to your head and shoulders, and a portion of your arms. Your torso and legs "draft" behind the rest of your body. It's why Superman flies head first. With that huge cape adding so much drag, he needs to be as efficient as possible! The most common way to reduce your frontal area is to lean farther over the aerobars on the bike or improve your streamline position in the water. Coaches and bike fitters go to great lengths to emphasize this, because ***unnecessary frontal area significantly compromises performance***.

The property of **volume** and the associated principle of density become especially important in swimming performance. Think of your body as a giant container. If we filled it up with a given substance, how much would it hold? We could measure its capacity, or volume, in gallons, liters, or cubic inches. Now let's think back to the analogy of inflating a balloon. If you fill the balloon with helium, it will float up into the air. If you simply fill a balloon with air to make it the same size as the helium balloon, it will fall to the ground but float on water. Fill the balloon with sand, and it will sink in water. Helium, air, and sand have very different masses per unit of volume. When you divide an object's mass by its volume, you discover its **density**.

These are the fundamental physical properties of the body. The medium has the same properties, but because things like oceans and atmospheres are so large, we don't think of them in terms of their mass and volume. Instead, we are more concerned with the properties that influence bodies moving through them: viscosity, density, and the coefficient of friction. To get acquainted with these, let's take a closer look at how the body interacts with the medium.

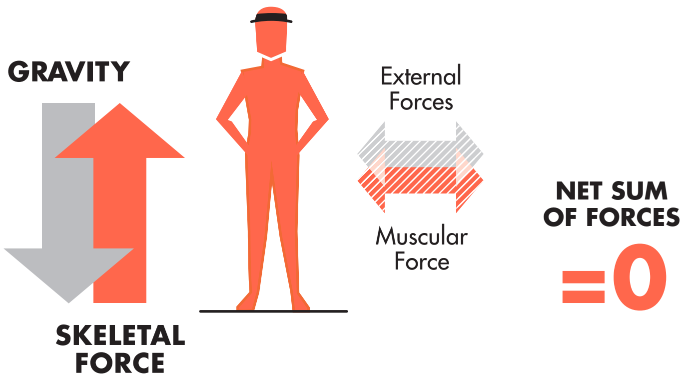
Standing still is a pretty easy task, and we often take that simplicity for granted. But just because you're not moving doesn't mean your body is not exerting any effort. Gravity pulls down on you, and you have to exert a force to keep it from yanking you down onto the floor. If the wind blows or a current moves through the water, it will push you sideways until you exert another force to resist it. Forces like these are continually acting on us, and we exert a force against them, even when we are standing as shown in the figure on page 5. From this we can conclude two very important things about a body at rest:

– All forces act in direct opposition to each other.

– The forces combine to cancel each other out, and no net force results to move the object.

These two conditions are especially important to remember because they help us answer the triathlete's most-asked question: Why am I not going faster? All of this is summed up best in Newton's first law of motion: ***A body at rest or in motion will tend to stay at rest or in motion unless a force acts on it.***

If your body didn't provide enough force to resist gravity, you'd fall to the ground. If there were no gravity, you'd remain still until you pushed down on the ground, and then you'd fly up into space. The same holds true for an object in motion. If you threw a baseball and no force of gravity or air resistance acted against it, it would keep going forever.



Whether we're running or standing still, forces are constantly acting on us.

Let's examine the situation in more detail. Gravity exerts a force on you, pulling you down against the earth's surface. The surface itself holds you up when at rest and stops you cold whenever you fall, meaning it exerts a force in opposition to gravity. We all know but often forget that the skeleton exerts a force, too. Your foot bone is pulled down by gravity and pushed up by the ground; your leg bone is pulled down by gravity and pushed up by the foot bone; and the knee bone is pulled down by gravity and pushed up by the leg bone. So by singing the old "x-bone is connected to the y-bone" song and including forces, we see that the skeleton is an engineering marvel. At each point from the ground to the top of your head, wherever two surfaces come into contact, forces must be exerted to resist gravity. The earth's force is called the **gravitational force**. The force a body exerts against the surface upon which it rests is called the **normal force**. The normal force is always perpendicular to the surface and is equal to the force the object exerts directly against it. Whether it's bones, bike tires, or shoes, the same principle applies, and we'll see it constantly throughout this book.

The force the earth exerts on your skeleton is defined by the equation:

F = ma

*Where **F** is force, **m** is your body's mass (measured in kilograms, not pounds), and **a** is the rate of acceleration. For Earth's gravity, acceleration is 9.81 meters per second squared, or m/s^2.*

And with that equation explained, we now understand Newton's second law of motion: ***The sum of the forces is equal to the mass of the body multiplied by its acceleration.***

In addition to force, you might recall that we have defined weight as a product of mass and gravity. In more rigorous terms, units of measurement such as pounds and ounces are measuring force. This is why you often see measurements of pressure or force in industrial equipment expressed in pounds. For consistency, we'll use the metric system throughout the book, though conversions are often noted to help you reference the units used on the racecourse. The metric unit of force, the newton (N), is, appropriately enough, named after the man who characterized it.

It may seem odd that it's your skeleton, not your muscles, doing the work to hold your body up, but it's true. That doesn't mean your muscles aren't also exerting a force. Quite the contrary, they're constantly making little twitches and gentle contractions to keep your skeleton perfectly balanced, just like you might use a finger to keep a house of cards balanced. It's the cards that are rigid enough to maintain an upright position, but it's your finger that prevents them from leaning one way or the other too much. That's an important distinction for triathletes, because as your muscles exert forces to move you, they change the amount of force placed on your bones and joints. The force is not always the same, and it's a big reason why some people tear muscles and others sprain ankles. Through the complicated interplay between muscles, tendons, and the impact of your foot against the ground, one force becomes too great for the others to compensate. Something's got to give, and in battles against Mother Nature we usually wind up on the short end of the stick. That brings us to Newton's third and final law: ***For every action, there is an equal and opposite reaction.***

Problems arise when triathletes take Newton's third law for granted. Just to illustrate that point, consider this: You've never run a step in your life by pushing yourself. It's been the earth pushing you all this time.

Let's say a triathlete starts out at a run. *Wham!* His foot slams down on the pavement and his quads and glutes fire with maximum intensity. Watch the earth go! That's right, the earth. That's what our triathlete is trying to move, isn't he? He's exerting a muscular force, pushing down on our planet. Didn't see it move much, did you? The earth is obeying Newton's first law: The force exerted against it isn't sufficient to disturb it from its original motion. However, that doesn't excuse it from adhering to Newton's third law. A force has been exerted on it. It has to return the favor. If the earth won't be pushed down, then the triathlete must be pushed up. The triathlete gets just about all of his muscular energy returned to him in the form of forward motion. *Boom!* He's off and running.

The same goes for cycling, though the force the leg applies is transferred a few times before reaching the ground. The wheels on our bikes go round and round, but the earth continues to spin on its axis without interruption. Down the road we go.

GET A GRIP: THE IMPORTANCE OF FRICTION

We take it for granted that we don't slip and fall every time we step out on a run or roll out on our bikes. There's a very important physical principle that prevents us from eating pavement. Strangely enough, as helpful as it is, we're constantly trying to find new ways to beat it. That physical principle is called **friction**.

Friction isn't a thing, it's an interaction between two things. When your shoe or tire hits the pavement, the two surfaces rub and scrape against each other, and not just in terms of your tread pattern on gravel. Although the visible texture of the two surfaces matters, friction actually occurs at the molecular level. That's why we use highly polished metal skates to slide along ice, and pedal extra carefully along rainy streets. Several factors influence just how much friction we experience: material composition, temperature, and the physical state of the matter. All of this is measured experimentally and can then be summed up in one number, called the coefficient of friction (expressed by the Greek letter μ). There are no units for the coefficient of friction. It is said to be dimensionless. As a general rule, it's best to keep the coefficient of friction as low as possible. Scientists have done enough research over time to create a list of coefficients of friction for different materials. For instance, bicycle tires typically have a value between 0.0025 and 0.005.

The biggest factor influencing terrestrial friction is the mass of the object in contact with the ground. We see this relationship in the equation for friction:

$$F_f = \mu mg$$

Where ***m*** *is the mass of the object,* ***g*** *is the force of gravity and* ***μ*** *(pronounced "mew") is the coefficient of friction.*

The **coefficient of friction** describes just how much two materials (like rubber and asphalt) will want to resist moving past each other. The actual friction depends on how they're applied to each other. Since normal force is equal to mass multiplied by gravity, we simply say

$$F_f = \mu F_N$$

Where F_N equals normal force.

This equation will become important when we talk about the relative value of saving weight on bicycle components in Chapter 3.

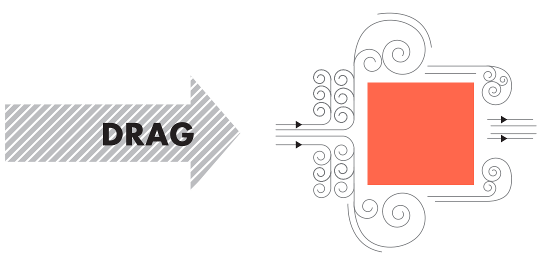
FEEL THE FLOW: AN INTRODUCTION TO AERODYNAMICS

You may have heard the phrase "Nature abhors a vacuum." That's why it's filled with things like air and water. Every time you pour on the steam in a race, you're performing the equivalent of shoving your way through a subway crowd of microscopic molecules. Oxygen, hydrogen, carbon, and nitrogen are all in your face, and as good as it might feel to have them blowing through your hair, they're actually shoving back against you. You start to press your way through the crowd without so much as an "Excuse me." As you pass by them, they turn around and pull on you. Push, scrape, and pull: Those molecules catch you in three different ways, and the faster you try to go, the harder they're going to resist. This is what we call **drag**. Product manufacturers are constantly selling revolutionary technologies to help you beat drag. However, there's a lot you can do to cut down on drag without spending a dime, and there are even a few things you can do to take advantage of drag. We'll get into that in more detail as we hit the specifics of each discipline within the sport, but for now let's get a handle on the concept of drag.

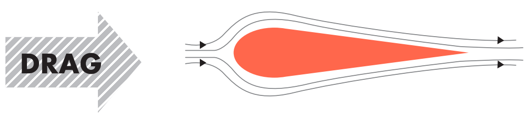
Depending on who you are and how you move through that subway car, you'll get different reactions from the people you pass. People step aside politely for a pregnant woman, shove back against an angry linebacker trying to throw his weight around, and reach out and grab a thief by his large jacket or the purse he just stole. The size, speed, and shape of these folks is a very good analogy for aerodynamics, because air doesn't react the same way to all objects.

Because the atmosphere acts on different bodies in different ways, knowing the different kinds of drag will help us guess which ones will act on feathers, hammers, and triathletes. Meet the Drag family:

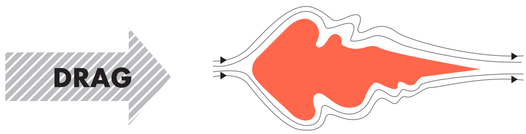
Pressure drag (also called form drag) is the version we are most familiar with. You try to move forward and occupy the space taken up by air molecules. The easiest thing for them to do would be to back away from you, except for the fact that there are miles and miles of other molecules behind them. What happens is a big mashup, and the molecules are forced to push up against you. The faster you try to move, the more molecules get pressed against the crowd behind them, and the more resistance they encounter from all the molecules behind them. All this pushing and shoving generates a lot of pressure, so the only option you leave these poor molecules is to squeeze around you to let you by. As you go past them, those molecules are desperate to return to their previous position. So they rush back in and fill the vacuum behind you. Because there are millions of these molecules, it's a very chaotic scene and they swirl about in all directions, creating a phenomenon known as a **vortex**.



In your case, they create several vortices. These vortices are like tiny tornadoes, sucking in anything near them, including you. You're stronger than these tornadoes, of course, but you still feel the effect. Remember how molecules shoving against your frontal area created a region of high pressure? The vortices are a region of *low* pressure. That pressure difference means air is pushing *and* pulling you backward. The faster you try to go, the harder it gets because you've got more molecules working on you at once. Since this type of drag is the result of a collision between the front of your body and the air, it stands to reason that the bigger your frontal area, the more drag you'll face. On the subway, the bigger our linebacker is, the more people he's going to shove as he moves through the car. There's a direct relationship between his size and the resistance he faces. It's the same for you and those air molecules. It's kind of tough to get smaller, but there are still ways to beat pressure drag. Those ways are best exemplified by our pregnant woman. As soon as she steps into the subway car, people take notice and move aside for her. She doesn't have to say, "Excuse me, I'm pregnant." The shape of her belly tells everyone all they need to know, and they react politely to that shape by offering less resistance. Air is the same way. Certain shapes get a more "polite" reaction from air molecules. The teardrop design of time trial helmets says "Pardon me" to the atmosphere, and the molecules bend less chaotically around it and create fewer vortices. More on that later.

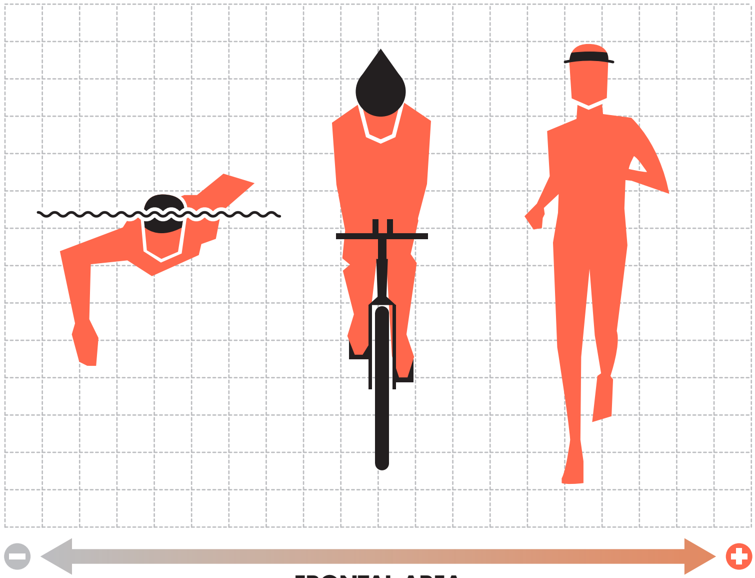


Skin friction drag describes the resistance you encounter as those air molecules move around you. Typically in triathlon we don't have to worry about this too much: Engineers consider the influence of skin friction drag on highly polished bikes and skin-tight jerseys negligible. However, let's briefly explore it for the sake of being thorough. Imagine that our thief tries to run through the subway car as someone shouts, "Stop that man!" If the thief is clutching the purse he just stole to his chest, then the purse adds to his pressure drag. We essentially consider the purse a part of his frontal area. But what if he's carrying it by the shoulder strap? That bag is flapping all over the place, just begging to be grabbed by one of the passengers. It's the same way with your own equipment. Wear a baggy running shirt, unzip your jersey, or attach your race number to your bike carelessly, and they flap around. All these little odds and ends hanging off you don't necessarily add much to your surface area, but they give air molecules a little something extra to grab on to.



Induced drag takes into account how you approach the air. Whereas with pressure drag and skin friction drag we were focused more on size and texture of our surface area, here we consider how our orientation changes our frontal area. This is no small consideration for triathletes, since we gradually change that orientation throughout the course of a race. We begin the swim completely horizontal, almost flying through the water like Superman flies through air (if only that were true!). We spend our time on the bike sitting in a hunched-over position, and then we finally stand fully upright to run. Our orientation to our direction of motion, and consequently the direction of air or water flow, goes from parallel to perpendicular in the span of two transition areas. The change in that orientation changes the relative surface area of our bodies that is exposed to the elements, as shown in the figure on page 13. Aerodynamicists refer to that orientation as **angle of attack**. At a higher angle of attack, you expose a greater percentage of surface area to the air or water, and this can induce a greater amount of pressure drag. That's why we call it induced drag.[1]

THE TRIATHLETE'S CHANGING ANGLE OF ATTACK



During the course of the race, an athlete's angle of attack increases, exposing more area to air resistance.

We know that an object's size, speed, shape, orientation, and the density of the medium it moves through will all affect how fast the object is able to move. Scientists have taken those variables and used them to create a formula for describing just how efficiently an object will move through the air or water. That relative efficiency is called the **drag coefficient (C_d)**, and it's expressed by the following equation:[2]

$$C_d = \frac{D}{\rho \times v^2 \times \frac{A}{2}}$$

*Where **D** is the observed drag, **ρ** is the fluid field density, **v** is the object's velocity, and **A** is the frontal surface area.*

Given that we're talking about velocity and an observed level of drag, some experimentation in the lab is necessary to figure out an object's drag coefficient. Thankfully, the good folks at NASA and other research institutions have been performing these kinds of experiments for years, and so we have data on a wide range of shapes. Here are a few:[3]

OBJECT	C_d
Flat Plate	1.28
Runner	0.8–0.9
Prism	1.14
Cyclist on a Bike	0.5–0.7
Sphere	0.5
Elite Swimmer	0.4–0.5
Airfoil	0.045

We can see that flat, wide objects have a higher drag coefficient and tapered, narrow objects have a lower coefficient. Because of our relative size and shape, triathletes are on the higher end of the spectrum, but we can adapt our positioning and accessories to overcome some of that. From swimming to running, you make a change in your angle of attack by almost 90 degrees, and it just about doubles your cost in drag.

That about wraps up our introduction to the science of your race. There will be a few other concepts we'll introduce along the way, but these are the fundamental principles that apply to just about every discipline of your triathlon effort. Nothing can be overly complicated so long as you remember how scientists unlocked these principles of physics in the first place—by reducing the problems to their most basic forms and observing things one step at a time. If you feel like some of the items discussed here were oversimplified, don't sweat it. Developing the most beneficial relationship between yourself and the physical universe involves several factors, and there is no end of tips and tools being offered to triathletes by the endurance sports market. Using the most effective tools and methods requires a solid understanding of the basics. Now that we have the fundamentals in hand, it's time to see how we can apply them to our advantage. Knowing the ways your body and the earth's medium work in relation to each other is the surest way to get the two interacting in smoother—and faster—fashion. Having sized up all that's working against you, we're ready to develop a strategy to overcome it.

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ABOUT THE AUTHOR

Jim Gourley is a successful triathlete, four-time Ironman finisher, and part of a four-man-division team that finished the Race Across America, one of the most difficult endurance races in the world. Gourley earned a degree in astronautical engineering from the United States Air Force Academy and has written on the scientific and technological developments in sports for the last four years. His articles have appeared in *Triathlete*, *Inside Triathlon*, *LAVA*, *220 Triathlon*, and *3/GO* magazines, as well as in *Peloton* and *Bicycle Times*. This is his first book.

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speed = athlete ∑ knowledge

EVERY TRIATHLETE WANTS TO GET FASTER. But while training delivers big gains early on, eventually hard work only maintains the status quo. You can try to buy speed with gear upgrades, but costly high-tech equipment doesn't always deliver the results you're chasing.

Faster puts free speed at your fingertips. Aerospace engineer and seasoned triathlete Jim Gourley teaches athletes how to turn knowledge into power by exploring the forces that matter most in triathlon. You will find out how to get the most out of training, gear upgrades, and technology.

Even the fittest triathletes are subject to the laws of physics—like drag, friction, and rolling resistance. By understanding the forces that act on you and your gear in swimming, cycling, and running, you can build up a real advantage on race day. You'll also get the truth behind the latest trends and fads in technique, training tools, and product design. And, with science on your side, you can make the smart calls to become a better, *faster* triathlete.

Jim Gourley is a teacher, a writer—and yes, a rocket scientist. His articles on the science and technology of triathlon and cycling have been widely published in *Triathlete*, *Inside Triathlon*, *LAVA*, *Peloton*, and *Bicycle Times* magazines.

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