Should I wear an aero helmet?

This is a great question and one on hand, the answer is easy: Yes, buy any equipment that will reduce air resistance during cycling. On the other hand, the answer is more complicated because money may be better spent (or saved!) in other ways.

Let’s go through the mechanics of air resistance – that way we can understand why an aero helmet may be a good option for someone.

A good way to understand air resistance is to consider ‘terminal velocity’ of an object dropped from a high height and falling through the air. Let’s consider a situation where gravity is the only force acting on the object. When dropped, the object has 0 m/s velocity and will start accelerating at a rate of -9.8 m/s/s (the acceleration due to the force of gravity). That means, after 1-second, the object would be traveling -9.8 m/s (remember … velocity is a vector and has magnitude and direction … in this case the magnitude of velocity is 9.8 m/s and the direction is negative (or downward)). After 2-seconds, velocity would be -19.6 m/s (i.e., velocity is increasing at a rate of -9.8 m/s every second while the object is moving downward).

The object would continue to accelerate (i.e., speed up while moving downwards) as long as gravity is the only force acting on the object. In the real-world, there is another force acting on the object … air resistance. Air resistance is a force applied to an object based upon these factors:

- Velocity of the air moving over the object (v)
- Density of the air (ρ)
- Frontal area of the object (A)
- Coefficient of drag (C_d)

In general, we talk about air resistance as a force that opposes the direction of movement. However, there are situations where air resistance aids movement … for example a tail wind during cycling (which is faster than the speed of the cyclist). Another example would be sail boats or wind surfing … in these cases, the air resistance is providing the propulsive force causing velocity. However, for our discussion of air resistance during sports like cycling and running, we will focus on air resistance as a force opposing direction of movement.

Let’s get back to terminal velocity … When dropping an object, that object will increase velocity until the point that the air resistance force matches the force due to gravity. At that point, velocity becomes constant and the acceleration of the object is 0 m/s/s. Below is a figure illustrating the two forces acting on the object as it is traveling downward: Gravity (pulling down) and air resistance (pushing up). We will start by using Newton’s 2nd Law of Motion.
\[ \Sigma F = ma \]
\[ F_{\text{air}} - F_g = ma \]

- \( F_g = F_{\text{air}} \) at terminal velocity
- Therefore, \( a = 0 \) m/s/s

\[ F_{\text{air}} = F_g \]

We can calculate the air resistance force using this equation:

\[ F_{\text{air}} = \frac{1}{2} \rho v^2 C_d A \]

Let’s put that in the equation (remember \( F_g = mg \))

\[ F_{\text{air}} = F_g \]
\[ \frac{1}{2} \rho v^2 C_d A = mg \]
\[ v = (2mg/\rho C_d A)^{0.5} \]

Where ‘v’ is the terminal velocity of the object. Using this equation, that means that terminal velocity is a function of

- Mass
- Acceleration due to the force of gravity (i.e., -9.8 m/s/s on Earth)
- Air density
- \( C_d A \) – coefficient of drag and frontal area

That equation tells us something we already know. Consider two objects, both of the same size and shape but one has more mass than another (below) … something like a soccer ball vs. a bowling ball. The bowling ball will have a greater terminal velocity than the soccer ball.
Likewise, if we take two objects of different shapes, the one that ‘looks’ more aerodynamic will have a greater terminal velocity than the non-aerodynamic shape. The shape of the object is represented in the equation by the term ‘$C_dA$’. Again, this is easy to understand that the air resistance of a big truck is more than a small car simply due to the shape being moved through the air.

The point of going through terminal velocity is that we can see how easy we can link the velocity of the object to the air resistance force. The less air resistance force, the greater the terminal velocity. Now, let’s go through each of the parameters in the equation to calculate air resistance.

**Velocity ($v$)**
Velocity represents how fast the air is moving over the object. Consider running into a head wind, the velocity of the air moving past you would be dependent on how fast you are running and how fast the wind is blowing. To simplify the discussion, we often just talk about situations where there is no wind … then we can talk about velocity relative to the ground. Velocity has units of m/s and when calculating the force of air resistance, we take the square of velocity. That means that air resistance changes a lot based upon how fast the object is moving. If you double the velocity, you increase air resistance by four times!

**Density of air ($\rho$)**
Air has mass … if we weigh a cubic meter (m$^3$) we would have about 1.2754 kg of air (at sea level). When we talk about density, we use units of mass per volume, so air density would be 1.2754 kg/m$^3$. This can change based upon elevation … the higher the elevation, the less dense air is. Temperature also influences air density … the higher the temperature, the lower the air density. Likewise, the amount of water vapor present in air (i.e., humidity) influences air density … the more humid, the less dense air is.

**Coefficient of Drag ($C_d$)**
This parameter describes how well air moves over an object. It is a function of skin and form drag where skin drag represents how easy air moves over a surface and form drag is based upon the object’s shape. An object that is more aerodynamically shaped has a lower form drag.
**Area (A)**

In this equation, the Area (m²) parameter represents the frontal area of the object being moved through the air. This is different than form drag since form drag is based upon the overall shape of the object. In the case of Area, it is determined only by the frontal area of the object. In the picture below, the Area would be getting smaller when looking at the pictures from left to right.

![Area Image]

Many references will combine Coefficient of Drag and Area into one term (C₉A) because this then describes the overall influence of the shape being moved through air.

Ok … now let’s talk about cycling. Let’s start with a kinetic analysis of cycling … that is, let’s identify all the forces (pushing and pulling) acting ON the bike/rider system. In the picture below, there seems like a lot of arrows … but let’s reduce them to these:

- Forces opposing motion:
  - Air resistance (Fair)
  - Bearing resistance (Fb)
  - Rolling resistance (Fr)
  - Slope (this will be explained more below) (Fs)

- Force causing motion:
  - Propulsion (Fp)

![Cycling Image]
Let’s go through each of these parameters.

**Air resistance (\(F_a\))**
This was covered above in the discussion of terminal velocity … same force. The important part here is to recognize that the term \(C_d A\) is influenced by position of the cyclist as well as the helmet, clothing, frame shape, and placement of water bottles. A more upright rider will have greater air resistance than a rider in an aero position, for example.

**Bearing resistance (\(F_b\))**
This is the resistance of the bearings that allow the wheels to spin. Consider just holding the bike off the ground and giving a wheel a spin … eventually the wheel will stop rotating. The resistance that causes the rotation to stop is referred to as Bearing Resistance. This is not that big of a force as compared to some of the other forces. Nevertheless, cyclists will often pay close attention to the ‘hubs’ that a bike has in order to reduce the bearing resistance.

**Rolling resistance (\(F_r\))**
This is the resistance that comes from the tire rolling along the ground. It’s not hard to imagine that biking in sand is harder than biking on a paved road. The difference in this is because of rolling resistance. As the tire rotates and comes into contact with the ground, the tire deforms. As the wheel continues to rotate, the tire rebounds … but there is always energy lost in this process. Rolling resistance is calculated using this formula: \(F_r = C_r N\) … where \(C_r\) is called the ‘Coefficient of rolling resistance’ and ‘\(N\)’ is the normal (i.e., vertical) force.

\(C_r\) is a dimensionless parameter and describes how well a tire rolls over the ground. A tire with a low \(C_r\) does not roll very easily. When a cyclist purchases tires, he/she will often ask what is the \(C_r\)? You can also see from the equation that the \(F_r\) is influenced by bike/rider weight (i.e., \(N\)). This is one reason why cyclists try to keep their bike and rider weight as low as possible.

The test of \(C_r\) is done on a smooth surface. However, \(F_r\) can be increased if we are riding on a bumpy surface. The tire may or may not deform over the bump. If it does, energy can be lost in the deformation-recoil process. If it does not, the wheel is lifted vertically – which influences the resistance of rolling forward. Some references develop a separate term for ‘bumps’ whereas others include it in \(F_r\).

![Image of rolling resistance](image)

**Slope**
We all know cycling uphill is harder than cycling on a flat road. The reason for that is that when we ride up a slope, a component of gravity ends up opposing the direction of motion (or, if you are riding downhill, the component of gravity aids motion). We calculate slope force using this equation: \(F_s = (mg) \sin(\theta)\)
where ‘mg’ is the weight of the rider/bike system and θ is the angle of the slope. This is another reason cyclist try to keep the rider/bike weight low … the bigger this weight (i.e., mg), the harder it is to ride up hills.

**Propulsive force (Fp)**

This is the force that makes the bike go … this is a result of the cyclist pushing on the pedals. That turns the cranks, which causes the chain to pull on the rear wheel, which then pushes on the ground to cause propulsion. Even though there are a lot of places that energy can be lost between what the rider does and the point where the wheel causes propulsion, we can consider that Fp is caused by the rider (the efficiency of bike transmissions may be about 80-95% … which is pretty good!).

**Thinking like a Biomechanist**

Now let’s pull together the different pieces and try to see the basis for an answer to the question: Should I buy an aero helmet? Once again, we start with Newton’s 2nd Law of Motion:

\[ \sum F = ma \]

Fp + (-Fair) + (-Fr) + (+Fb) + (-Fs) = ma

- Propulsion from wheel (Fp)
- Air resistance (Fair)
- Rolling resistance (Fr)
- Bearing resistance (Fb)
- Slope resistance (Fs)

Consider riding at constant velocity (which is what we are trying to do during an endurance event), then a = 0 m/s/s … therefore:

Fp = Fair + Fr + Fb + Fs

Now we see that the propulsion force is a function of the resistance forces. That is, the rider needs to create more propulsion force in order to overcome a greater air resistance, riding up hill, or greater rolling and bearing resistance.

Should a cyclist buy an aero helmet? The easy answer is yes … the cyclist should buy anything to reduce the resistive forces. The more complicated answer is that if a rider purchased every piece of available equipment to reduce those forces, the bike would likely cost over $15,000. Riders need to make informed choices and match the equipment with his/her capabilities.