

Why Meteors Strike Earth Faster Than Terminal Velocity

By TJ Tryon

Each October, the Orionid Meteor Shower dazzles the night sky as Earth passes through a trail of dust left by Halley's Comet. Tiny particles of rock and ice vaporize in our upper atmosphere, leaving brilliant streaks of light we call shooting stars.

During this year's Orionids, someone in a discussion group I belong to asked a thoughtful question:

"How can a meteor hit Earth many times faster than terminal velocity?"

It's a great question because it connects a familiar Earth-bound concept—terminal velocity—with the vast speeds of space. Understanding why meteors travel far faster than terminal velocity requires exploring Newton's Laws of Motion, air drag, and how an object's surface-area-to-mass ratio determines whether the atmosphere can slow it down.

1. What Terminal Velocity Really Means

When an object begins to fall through Earth's atmosphere, two main forces act on it: the force of gravity pulling downward and the force of air pressure (drag) pushing upward. As the object accelerates downward, drag increases. Eventually, these two forces become equal in magnitude and opposite in direction.

At that instant, the net force on the object is zero, so it stops accelerating and continues to fall at a constant speed—its terminal velocity.

This is a direct demonstration of Newton's First Law of Motion, which states: "An object in motion will remain in motion at a constant velocity unless acted upon by a net external force."

In mathematical terms, Newton's Second Law ($F = ma$) tells us that if the total (net)

force F equals zero, then acceleration a must also be zero. Near Earth's surface, the acceleration due to gravity, g , is approximately 9.8 meters per second squared (9.8 m/s^2). That means that every second an object is in free fall (without air resistance), its speed increases by about 9.8 m/s—until air pressure grows strong enough to oppose it equally.

When gravity and drag become equal and opposite, the object no longer speeds up; it simply keeps moving at a steady rate. A skydiver, for example, typically reaches a terminal velocity of about 120 mph. A heavier rock might fall at several hundred miles per hour before drag and gravity become equal and opposite. Beyond that point, acceleration stops.

2. Why Small Meteors Reach Terminal Velocity but Large Ones Don't

This principle explains everyday falling objects, but meteors add complexity because of their speed and mass.

A small meteor—like those producing the Orionid streaks—has a high surface-area-to-mass ratio. That means it offers a lot of area for air to push against relative to its weight. As it enters the atmosphere, air molecules collide with it, rapidly increasing drag until that drag force becomes equal and opposite to gravity.

At that point, the meteor reaches its terminal velocity, which can be surprisingly low—sometimes around 100 mph, only a bit faster than a baseball pitcher's fastball. Because of their small mass, these particles also heat up quickly and almost always burn away completely high above the ground. The glowing line we see is caused by ionized air and vaporized rock, not the meteor itself hitting Earth's surface.

By contrast, a large meteor or asteroid has a low surface-area-to-mass ratio. Its enormous mass means gravity's pull—accelerating it at 9.8 m/s^2 —far outweighs the opposing drag. Even though air resistance increases as it descends into denser layers of atmosphere, the drag never becomes large enough to be equal and opposite to gravity. The atmosphere simply cannot generate enough opposing pressure to counteract such momentum.

As a result, a large meteor never reaches terminal velocity; it remains far above it and keeps incredible speed all the way to impact. The same physical laws still apply, but the scale of the forces is vastly different.

3. Starting Speed: The Cosmic Advantage

The other key difference is where meteors begin their motion. Objects dropped on Earth start from rest and accelerate under gravity at 9.8 m/s^2 until drag and gravity become equal and opposite. Meteors, however, don't start from rest—they're already moving at cosmic velocities when they encounter Earth.

Both small and large asteroids typically travel between 20 and 70 kilometers per second, or 20–70 times the speed of sound (roughly 45,000 to 155,000 mph). These immense speeds come from their orbital motion around the Sun. Earth and the meteoroid each follow their own solar orbits; when those orbits intersect, their relative velocity can be astonishingly high.

When a meteor slams into Earth's atmosphere, gravity adds only a small fraction to its overall velocity— 9.8 m/s^2 is tiny compared to tens of kilometers per second. The meteor is already moving at such a high speed that air resistance can only slow it slightly before it burns or impacts. For smaller meteors, that brief encounter with air is enough to destroy them; for larger ones, it's barely a speed bump.

Thus, while terminal velocity might limit a skydiver or a falling rock, it does not limit a cosmic object that begins its plunge at tens of kilometers per second. The term “terminal velocity” applies only after an object has spent enough time in the atmosphere for drag and gravity to become equal and opposite—a condition that never occurs for a large, fast-moving asteroid.

4. Why Big Meteors Stay Fast

Large meteors stay fast for two related reasons: momentum and surface-area-to-mass ratio.

First, their momentum—mass multiplied by velocity—is enormous. Even though the atmosphere exerts tremendous drag, the meteor's huge mass means that force changes its speed only slightly. Imagine throwing a ping-pong ball and a bowling ball through water: the same drag acts on both, but the heavier ball plows through almost unaffected.

Second, large meteors have far less surface area per unit of mass than small ones, leaving less area for air pressure to act upon. Together, these factors allow big meteors to retain the majority of their original velocity. While a skydiver might move at 120 mph and a small meteorite might strike at 100–200 mph, a large asteroid can hit Earth at 45,000 mph or more—hundreds of times faster than any terrestrial terminal velocity.

5. A Real Example: The Chicxulub Impact

The best-known example of such a colossal impact is the Chicxulub asteroid, which struck Earth about 66 million years ago, near the Yucatán Peninsula in Mexico.

- Diameter: roughly 10 kilometers (6 miles)
- Impact speed: ~20 km/s (12 mi/s) — about 58 times the speed of sound
- Energy released: $\approx$ 4.5 billion Hiroshima-sized atomic bombs

The consequences were devastating: global fires, massive tsunamis, a dust-filled sky, and yes—the end of the dinosaurs.

Because the asteroid was so massive and moving so quickly, the atmosphere barely slowed it at all. Its drag force never became equal and opposite to gravity, so it struck the surface at nearly its original cosmic speed.

6. Connecting Back to the Orionids

The glowing meteors we see in the Orionid Meteor Shower are the other extreme. These are minuscule dust grains from Halley's Comet, yet they enter Earth's atmosphere at similar cosmic speeds—about 66 km/s. Their small size gives them a high surface-area-to-mass ratio, so they quickly reach the point where drag and gravity become equal and opposite. That rapid deceleration causes them to heat up and disintegrate dozens of miles above the surface.

Every streak we see is the result of this delicate interaction: air molecules pushing back as gravity pulls forward. Even so, the meteors' starting speeds are so immense that the brief flash of light represents energy far beyond what any object accelerating only at 9.8 m/s^2 could ever achieve.

Conclusion

The concept of terminal velocity describes what happens when drag and gravity become equal and opposite, eliminating net acceleration. It applies beautifully to skydivers, falling debris, and raindrops—objects that begin at rest within Earth's atmosphere and accelerate at 9.8 m/s^2 until drag halts that acceleration.

But meteors are different. Small meteors slow quickly because they have lots of surface area for their mass. Large meteors don't, because they possess immense momentum and too little surface area for air pressure to oppose effectively. Both small and large meteors enter the atmosphere already moving tens of kilometers per second, speeds set by orbital mechanics rather than Earth's gravity.

Next time you watch the Orionid Meteor Shower, remember that every flash of light you see is a tiny piece of Halley's Comet colliding with our atmosphere at cosmic speeds—tens of miles per second faster than anything that could ever fall under gravity alone.