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Raindrops Are Falling . . . Faster and Faster

by Chris Larson | September 2014

About five years ago, a team of atmosphere researchers published a study reporting that some raindrops were falling fast — in fact, it seemed like they were falling faster than they should be able to fall, according to theory. Science is, among other things, a process of confirmation and verification, and this finding certainly seemed to require verification.

Top: David De Lossy/Photodisc/Getty Images; Bottom: Shutterstock

"Super-terminal" raindrops—raindrops that fall faster than their terminal velocity or theoretical limit should be—are neither a spurious finding nor a misinterpretation of instrument readings. They are not even rare: small raindrops exceed their terminal velocity quite commonly.

Now, that verification has arrived, in the form of a new study accepted for publication by *Geophysical Research Letters.* The study is the work of Michael L. Larsen (College of Charleston in Charleston, South Carolina), Alexander B. Kostinski (Michigan Technological University, Houghton) and Arthur R. Jameson of RJH Scientific Inc. (based in El Cajon, California). They report that the paradoxical finding of the earlier study was indeed

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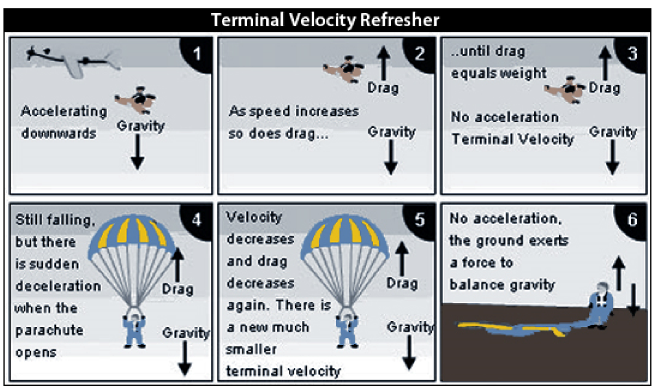
correct. So-called super-terminal raindrops — raindrops that fall faster than their terminal velocity or theoretical limit should be — are neither a spurious finding nor a misinterpretation of instrument readings. They are not even rare: small raindrops exceed their terminal velocity quite commonly. They are a fact, and of interest not just because they seem contrary to reason; the size of raindrops and the speed at which they fall and hit the ground can affect matters ranging from soil erosion to visibility to radar signals.

A Refresher on Terminal Velocity

One of the classic stories in the history of science — important for what it says about how science should be done, whether or not the story is precisely accurate historically — is of Galileo dropping two balls, one heavier than the other, from the Leaning Tower of Pisa. They both hit the ground at about the same time, showing that they had the same acceleration, in contrast to the claim of the ancient Greek philosopher Aristotle, who argued that more massive things fall faster, in proportion to their mass. The moral usually drawn is that scientific claims have to be experimentally tested, not just advanced on the basis of their supposed intrinsic reasonableness.

Of course, Aristotle probably did have some sort of experience in mind: watching a leaf flutter slowly to the ground, in contrast to the quick descent of a rock, perhaps. But Galileo's experiment certainly disposed of the notion that a more massive object will necessarily fall faster in proportion to its mass.



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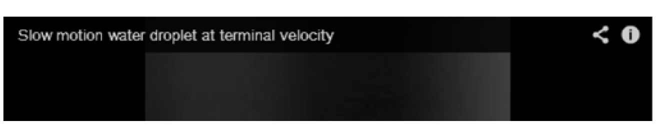
The modern understanding of how things fall near the surface of the Earth draws attention to two forces: gravity and wind resistance, or drag. (Drag is a more general term that can apply to various kinds of resistance to motion.) Near the Earth's surface, we can regard the gravitational force as constant. (As you go out into space, Earth's pull will lessen, but for the heights that raindrops fall from that change is negligible.) But drag is not a constant. The drag on a falling object will increase as it falls faster — think of walking slowly through water in a pool versus walking quickly. Since drag is a force that pushes in the direction opposite to the direction of motion, at some point the drag will have increased enough so that it exactly balances the downward-pulling force of gravity. When that happens, the falling object will no longer accelerate but will continue to fall at the same velocity: this unchanging speed, where the upward force of drag (from friction with the air, in the case of a falling object) balances the downward pull of gravity, is the terminal velocity.



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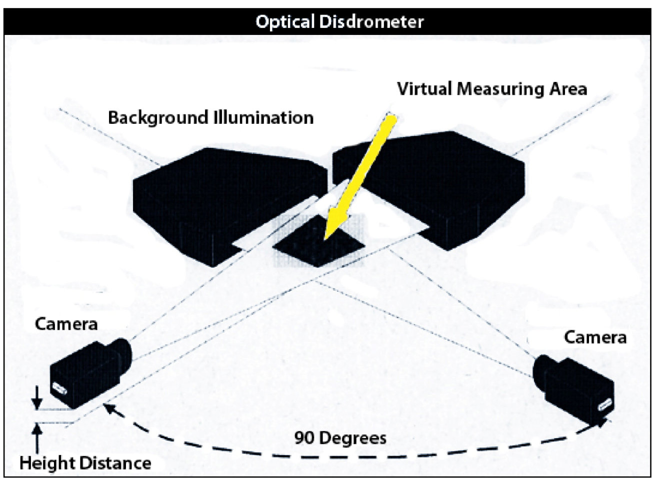
A slow motion video shows water droplets falling at terminal velocity.

Drag is a messier force to deal with than gravity. It is usually modeled as growing in proportion to the square of the velocity — that is, if the velocity goes from one meter a second to two meters a second, the drag force will grow by four, since 12 is one, but 22 is four. Also, and very importantly, different kinds of objects will experience different amounts of drag, depending on how streamlined the object is; engineers calculate "drag coefficients" to capture how different types of objects interact with the air or other mediums through which they move.

Back to Raindrops

How do you measure rainfall? Historically, this has been done with impact disdrometers. (A disdrometer is an instrument for measuring the size distribution and velocity of precipitation.) The idea is that a raindrop will hit a surface, and the force of the impact can be measured, and that force will provide a means of gauging how big the impacting drop was — but in making this calculation it is assumed that the drop is falling at its terminal velocity. If the drop in fact exceeds that velocity, then the calculation could be off. The distribution of raindrop size and speed matters in a number of ways — for example, for the same quantity of rain, big raindrops will have a different erosion impact than small raindrops.



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The researchers used optical disdrometers to measure the size distribution and velocity of precipitation. They detected particles by seeing how they obscured light: that is, the particle would pass between a light source and the detector and block it, at least partially. By keeping track of how long this obscuring lasted, the detectors could infer how fast the particle was dropping.

When the 2009 study appeared, there was some thought that the findings "of 'super-terminal' raindrops were spurious results of drop breakup occurring on instrumentation." Earlier suggestions of possible super-terminal raindrops had been met with the idea that splashing of some kind when the drops hit the detectors could lead to incorrect measurements. The 2009 study took measurements in calm atmospheric conditions, which would rule out at least some forms of splashing; however, it still seemed possible that impact with the detectors could have created raindrop fragments with various velocities, some of which could get interpreted as super-terminal.

The new study used two distinct types of disdrometers. Both were optical, meaning that they detected particles by seeing how they obscured light: that is, the particle would pass between a light source and the detector and block it, at least partially. By keeping track of how long this obscuring lasted, the detectors could infer how fast the particle was dropping. While both detectors relied on optical detection, they differed substantially in their specific design, so they could serve as checks on each other. One type of detector was actually deployed in an array of 21 units, to enable greater precision and reliability. The researchers looked at several episodes of rainfall, the better to establish whether super-terminal raindrops were common or exceptional events.

Size Matters

The study showed that "in all events [studied], a large fraction of the small drops are detected at speeds above their terminal velocity." What is small? In this case, the typical size for the smallest category of raindrops — the category for which super-terminal speed was most common — was a diameter a little less than two-tenths of a millimeter (0.1875 millimeters on average). As drop size increased, the fraction of drops that were super-terminal fell. The study looked at millions of drops, and the results did not depend on where exactly the drops fell: detectors 100 meters apart recorded similar results. Also, it wasn't a matter of a raindrop just barely exceeding the speed limit: to be counted as super-terminal a drop had to be falling 1.3 times as fast as the "terminal" speed for a drop of that size.

Alistair McClymont

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Why were these small drops so often exceeding the calculated terminal speed? The study aimed at gathering evidence that the reported phenomenon was real, not at explaining why it occurred. One theory, proposed in 2009, was that the super-terminal speed of the small drops was a consequence of large drops — which have a significantly higher terminal speed — breaking up; according to this idea, the resultant small drops would need to take some time to slow down to the terminal speed appropriate for their size, and they are measured by a disdrometer before that slowing down occurs. While not rejecting this idea, the authors of the new paper observed that other explanations are possible — there could be localized downdrafts that speed up the drops, or small drops might follow in the wake of larger ones.

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Why would large raindrops have a faster terminal speed than smaller drops? The volume — and hence the mass — of a raindrop grows in proportion to the cube of the diameter of the drop, and the mass is what gravity acts on.

(Why would large raindrops have a faster terminal speed than smaller drops? The volume — and hence the mass — of a raindrop grows in proportion to the cube of the diameter of the drop, and the mass is what gravity acts on. In a condition of perfect vacuum, with no drag, this wouldn't matter — small or big raindrops would fall at the same rate, accelerating constantly under the force of gravity. But drag changes things—drag or wind resistance will be related to the surface area of the falling drop, and area grows in proportion to the square of the diameter, while mass as observed grows in proportion to the cube of diameter; this means that drag is a bigger factor for small drops than for big ones.)

What Next?

Having established that a counterintuitive result is in fact a real phenomenon is an important step, but the authors of the study note that further research is needed—to clarify "the natural abundance" of super-terminal raindrops and to enable revisions, if necessary, to what had previously been taken as fully known. Understanding exactly how super-terminal drops occur would obviously also be desirable.

In most of the atmospheric processes that interest us, small raindrops play a less important role than larger ones, so the fact that this phenomenon is strongest with small drops may mean that not too much revision of accepted wisdom will be necessary. Still, until these fast-falling raindrops are better understood, we cannot write them off as unimportant.

Discussion Questions

Do you think the results discussed here could extend to other forms of precipitation, such as snow or hail? How would you assess that? What can skydivers do to alter their terminal velocity as they descend towards Earth?

Journal Abstracts and Articles

(Researchers' own descriptions of their work, summary or full-text, on scientific journal websites).

Larsen, M.L., A.B. Kostinski and A.R. Jameson, "Further Evidence for Super-Terminal Raindrops." *Geophysical Research Letters* (publication forthcoming): onlinelibrary.wiley.com/doi/10.1002/2014GL061397/abstract.

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