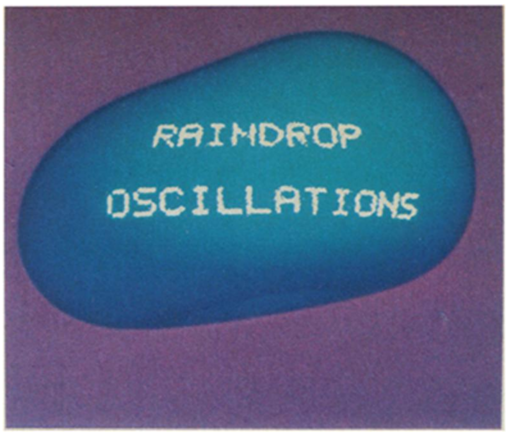


Raindrops do more than just fall; they also appear to oscillate during their downward plunge

By IVARS PETERSON

Jiggling like tiny, dimpled hamburger buns made of jelly, raindrops rapidly change shape as they fall. Stretching and thinning, bulging and swelling, they oscillate from one transient form to another.

This is the picture of raindrop behavior that is starting to emerge from recent computer models and photographic studies of water drops in wind tunnels and raindrops during storms. Much of the research is aimed at providing a better understanding of the way in which rain scatters microwave signals, so that meteorologists can produce better radar estimates of rainfall rates and radio engineers can predict when interference between adjacent communications channels is likely to occur.

Most people still imagine that raindrops take on a teardrop shape when they fall — a notion perpetuated by innumerable cartoonists and commercial artists. Yet, for more than 80 years, scientists have known that falling water drops are flattened rather than elongated. This shape is the result of a delicate balancing act that involves the force of gravity, the liquid's surface tension and the pressure of air rushing past the drop.

More recent laboratory studies have revealed that the shape of a falling drop also depends on its size. Drizzle drops, those less than 0.5 millimeter across, are essentially spherical. In contrast, a drop more than 5 millimeters in diameter is distinctly flattened and may even begin to show a dimpled lower surface. This squat object resembles nothing so much as a hamburger bun.

Moreover, there is evidence that raindrops can take on other shapes and that they actually oscillate from one shape to another while they fall. Under the right conditions during a heavy, nighttime rainstorm, anyone can see the effects of these oscillations, says Kenneth V. Beard, a meteorologist with the Illinois State Water Survey and a professor at the University of Illinois at Urbana-Champaign. Beard has been studying the shape of raindrops for more than 10 years. Beard's colleague, atmospheric scientist David B. Johnson, joined the research project a few years ago to investigate the factors that cause raindrops to shake.

"Illumination of rain at night reveals scintillations in the light reflected from the falling drops," says Beard, "with the drops often appearing as dashed streaks." Each raindrop behaves like a little falling lens. Light from, say, a floodlight shining against a dark background bends as it enters each droplet and is reflected back out. As the lens oscillates, the light is reflected in different directions. Thus, a stationary observer sees the bright, reflected light only for brief intervals, when the light happens to go in the viewer's direction. This creates the illusion of broken streaks of light.

"This is very easy to see if you watch drops dripping off a tree or the edge of a building," says Beard. In this case, the drops are larger, and they fall more slowly. In the daytime, similar streaks are visible in a jet of water from a garden hose when the drops are viewed in backscattered sunlight, he adds.

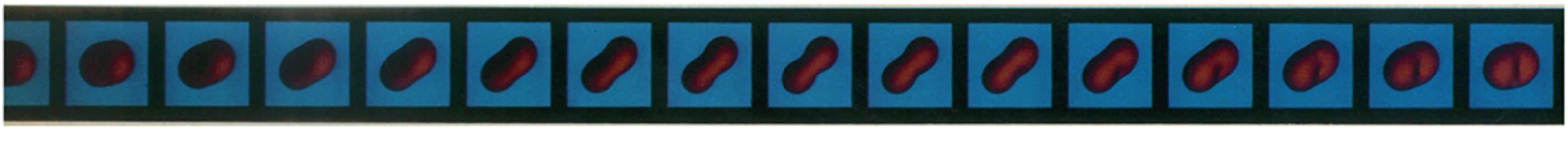
The idea that raindrops oscillate was reinforced by measurements of raindrops frozen in photographs taken many years ago at several locations in Illinois. Researchers found a wide variation in the ratios of the raindrops' dimensions, hinting that the drops were caught at different stages during their oscillations.

Beard and Johnson suspect that these oscillations are the result of collisions between drops. Larger drops, as they fall, reach a higher terminal velocity or constant speed (when the air's drag balances the gravitational force on the drop) than smaller droplets. These large, speeding raindrops readily overtake smaller, slowly falling drizzle droplets.

A collision produces large oscillations in the newly coalesced drop, says Beard, or in the fragments created if the collision causes a breakup. "So it's important that you don't have just big raindrops all by themselves," he says. "You have to have a kind of drizzle drop, which happens in very intense showers where there is lots of mist.

"Calculations indicate that in heavy rainfall each raindrop experiences collisions with other raindrops every few seconds," Beard says. "If you've got small drops around, they'll get in the way of the large drops often enough to keep them oscillating." Last year, Johnson showed theoretically that a significant fraction of raindrops in heavy showers should be oscillating noticeably.

Wind tunnel studies, in which water drops are suspended in airstreams, also show that these drops oscillate. Although here the oscillations are induced by turbu-



lence rather than by collisions, the effects are similar to those observed in nature, says Beard. The frequency of the oscillations depends strongly on the size of the drops. Small water drops shake at a few hundred cycles per second; large ones oscillate at 20 cycles per second.

One puzzle, however, involves how a droplet "decides" whether it should oscillate in a vertical, horizontal or transverse mode. Drop collisions should excite vertical oscillations, says Beard. But why small drops prefer to oscillate vertically and large drops horizontally is a mystery.

"What is lacking is direct evidence of raindrop oscillation shapes," says Beard. "All we have are frozen pictures of drops that tell us their shapes. We don't really have a time sequence for natural drops."

Beard is now planning an experiment that involves firing water drops of various sizes down a seven-story shaft to see what the natural modes of oscillation are and how they die out. "The hypothesis for the experiment is that raindrops or drops falling in air have natural aerodynamic feedback that tends to reinforce oscillations into certain modes," he says. "This would explain why drops of certain sizes prefer certain modes." It's not the way that a drop is excited initially so much as the air pressure and acceleration experienced by a drop that keep it oscillating in a certain way, Beard suggests.

Computer modeling also plays a role in this research. "We'll get the overall picture from the laboratory experiments," says Beard. But calculations showing what effect factors like changes in air resistance have on the oscillations will help the researchers interpret the experimental data.

Another aspect that needs checking is how raindrop oscillations get started in the first place. Next summer, Johnson is coordinating a study in Hawaii that involves aircraft measurements to determine the size and number of raindrops in a typical shower. Johnson's theoretical calculations indicate that raindrops slightly smaller than a millimeter across contribute most to a drop's oscillations.

"There's a rather delicate size range there because if the small raindrops are too small, they don't impart enough energy when they hit a big raindrop," says Johnson. "This led us to look more closely at the size range of raindrops in nature."

"Another thing we want to look at in our experiment in Hawaii is to trace how drizzle drops come out of a cloud base," says Beard. "Do they come from the bursting apart of drops as they collide and rupture, or do they actually fall down on their own? They are the key to the source of the oscillations."

This work on raindrop oscillations may influence the way data from new weather radars are interpreted. These systems send out microwave signals that are alternately polarized horizontally, then vertically. If raindrops are not spherical, then slightly different amounts of scattering will occur for the two directions of polarization. By taking into consideration the shape of raindrops, this measurement potentially provides a more precise way of determining the rainfall rate during a rainstorm.

Some meteorologists assume that oscillations do not change the average shape of raindrops as seen by radar. Beard and Johnson contend that oscillations cause raindrops, on the average, to appear more spherical. As a result, there would be a smaller difference between the amounts of electromagnetic radiation scattered by microwaves polarized in two different directions.

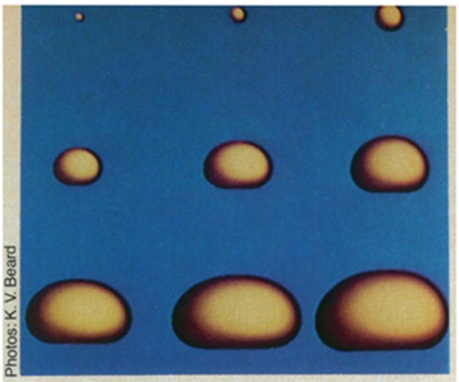
"The data analysis techniques should be generalized to allow for transient shapes," says Beard. "The way [raindrops] oscillate determines what their average shapes are for scattering calculations."

"We think we've established that a large fraction of raindrops are oscillating," says Johnson. "The question of whether or not that means their average shape is different depends rather critically on what mode the oscillations are being forced into as well as how quickly these oscillations are damped. It's still a bit of an open question."

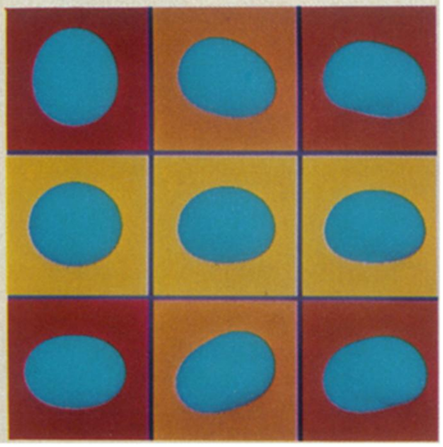
Communications engineers have also been interested in the shape of raindrops because a heavy shower can affect microwave links by shifting the direction of polarization of the electromagnetic radiation. This sometimes leads to bothersome "crosstalk" between adjacent communications channels that happen to be very close together in frequency but polarized in different directions. Although the studies of Beard and Johnson won't help eliminate the problem, their research may allow engineers to estimate when and how often rainfall causes a problem.

In general, says Beard, "An improved understanding of transient shapes and their causes will result in better models of scattering in rain."

"The whole thing is fascinating to me," says Johnson, "because it takes you from the simple to the complex — from the shape of a raindrop . . . to microwaves and state-of-the-art aircraft instruments." ☐



Photos: K. V. Beard



Larger and larger raindrops look more and more like hamburger buns, as shown in the top, computer-generated sequence of images. The middle photograph captures a giant water drop, about 8 millimeters across, suspended in a wind tunnel's airstream. In the next sequence of images, third from top, each column illustrates the preferred oscillation shapes for drops of a particular size, ranging from 2 mm in diameter on the left to 6 mm on the right (not drawn to scale). The strip, below, shows the rotation of one raindrop oscillation shape.