Researchers count the kinks in a ring, predict their stability

Enlarge / Two rings buckling under the pressure of a soap film. The top ring is a narrow band (compared to its diameter), so it buckles inward. The bottom ring has wide walls. It wrinkles out of plane as it collapses inward.

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I once had a PhD student who joined our research program thinking he was going to be studying a mixture of plasma physics and gas diffusion. To his surprise, he ended up having to understand the mechanics of buckling. At the time, I decided that if I never saw the fourth derivative of deflection again, it would still be too soon. Unfortunately, the physics of buckling and wrinkling is especially beautiful, so I found myself unable to resist a study on how a ring is deformed and buckled by soapy water.

Release the ring

The experiment is very simple. A ring made from a soft material is gently placed on a soap film that is suspended across an opening. The mass of the ring causes the soap film to stretch downward but then everything stabilizes. The tension applied by the soap on the inside of the ring, which would normally pull it inward, is balanced by the tension of

the soap between the ring and the opening. Then, the soap film outside the ring is destroyed by poking it with a pin.

The ring starts to fall. At the same time, the surface tension of the film tries to pull the ring inward. This pull would be resisted by the stiffness of the ring, but we used a soft ring, so there's not much stiffness there. It buckles and collapses, and the researchers filmed that collapse with a high-speed camera.

So what physics is at play here?

The flexibility of the ring is determined by its size: the larger the diameter, the easier it is to deform. But its thickness also plays a role. The thicker the wall of the ring, the more difficult it is for the wall to bend inward, although it can still bend upward or downward (referred to as out-of-plane). Then you need to stir in the mechanical properties of the material. How much pressure does it take to deform the material the ring is made from (a measure called Young's modulus)?

When all these factors are considered, the researchers show that wide rings with thin walls will see the rings buckle inward. This is visible in the top row of photos below, where the ring (the dark band) can be seen to kink inward. But if the walls are relatively thick, the ring buckles upward and downward. This can be seen in the bottom row of photos where the ring wrinkles rather than buckles.

The (surface) tension rises

Observation was only the start, though. The researchers also created a model to predict the ring's buckling. This kind of dynamic behavior is often described by what are called "modes." In this case, a mode will be a kink or wrinkle in the ring. But there aren't a fixed number of modes, as the number will grow as the ring buckles further. The researchers were

interested in seeing how the mode number grew with time and whether their model could predict that information. They showed that they could predict a final mode number for both in-plane and out-of plane modes relatively well (bearing in mind that logarithmic scales hide a multitude of sins).

I suspect that counting the mode number over time is problematic, since you have to decide when a deformation is really there. Instead, it's easier to measure the area of the ring, which can be translated to an instability growth that depends on the number of modes. The researchers showed that the instability growth also followed their model.

An interesting side note here is that inertia doesn't seem to matter. Compared to the soap film, the ring has more mass. Once pulled into motion (as in the wall kinks), inertia should make it difficult for the puny soap film to change that motion. But everything happens so fast that inertia does not have a chance to dominate. Instead, everything is driven by the shape of the ring and the mechanical properties of the material the ring is made from.

According to the researchers, this finding provides insight into how to guide buckling. Elastic buckling—the sort that was studied here—may be controlled as long as the process is slow enough that inertia can be used to guide it. So where would that be used? Well, I suspect that anyone who actually studies buckling can name several potential applications. But at this point, I'm in the camp that doesn't care about applications. This is a beautiful bit of physics that helps us explain complicated real-world behavior.

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