How do birds flock? Researchers do the math to reveal previously unknown aerodynamic phenomenon

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Motivating examples of quasi-linear flight formations of birds. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-47525-9

In looking up at the sky during these early weeks of spring, you may very well see a flock of birds moving in unison as they migrate north. But how do these creatures fly in such a coordinated and seemingly effortless fashion?

Part of the answer lies in precise, and previously unknown, aerodynamic interactions, reports a team of mathematicians in a newly published study. Its breakthrough broadens our understanding of wildlife, including fish, who move in schools, and could have applications in transportation and energy.

"This area of research is important since animals are known to take advantage of the flows, such as of air or water, left by other members of a group to save on the energy needed to move or to reduce drag or resistance," explains Leif Ristroph, an associate professor at New York University's Courant Institute of Mathematical Sciences and the senior author of the paper, which appears in the journal *Nature Communications*.

"Our work may also have applications in transportation—like efficient propulsion through air or water—and energy, such as more effectively harvesting power from wind, water currents, or waves."

The team's results show that the impact of aerodynamics depends on the size of the flying group—benefiting small groups and disrupting large ones.

"The aerodynamic interactions in small bird flocks help each member to hold a certain special position relative to their leading neighbor, but larger groups are disrupted by an effect that dislodges members from these positions and may cause collisions," notes Sophie Ramananarivo, an assistant professor at École Polytechnique Paris and one of the paper's authors.

Previously, Ristroph and his colleagues uncovered how birds move in groups—but these findings were drawn from experiments mimicking the interactions of "two" birds. The new *Nature Communications* research expanded the inquiry to account for many flyers.

To replicate the columnar formations of birds, in which they line up one directly behind the other, the researchers created mechanized flappers that act like birds' wings. The wings were 3D-printed from plastic and driven by motors to flap in water, which replicated how air flows around bird wings during flight.

This "mock flock" propelled through water and could freely arrange itself within a line or queue.

The flows affected group organization in different ways—depending on the size of the group.

For small groups of up to about four flyers, the researchers discovered an effect by which each member gets help from the aerodynamic interactions in holding its position relative to its neighbors.

"If a flyer is displaced from its position, the vortices or swirls of flow left by the leading neighbor help to push the follower back into place and hold it there," explains Ristroph, director of NYU's Applied Mathematics Laboratory, where the experiments were conducted. "This means the flyers can assemble into an orderly queue of regular spacing automatically and with no extra effort, since the physics does all the work.

"For larger groups, however, these flow interactions cause later members to be jostled around and thrown out of position, typically causing a breakdown of the flock due to collisions among members. This means that the very long groups seen in some types of birds are not at all easy to form, and the later members likely have to constantly work to hold their positions and avoid crashing into their neighbors."

The authors then deployed mathematical modeling to better understand the underlying forces driving the experimental results.

Here, they concluded that flow-mediated interactions between neighbors are, in effect, spring-like forces that hold each member in place—just as if the cars of a train were connected by springs.

However, these "springs" act in only one direction—a lead bird can exert force on its follower, but not vice versa—and this non-reciprocal interaction means that later members tend to resonate or oscillate wildly.

"The oscillations look like waves that jiggle the members forwards and backwards and which travel down the group and increase in intensity, causing later members to crash together," explains Joel Newbolt, who was an NYU graduate student in physics at the time of research.

The team named these new types of waves "flonons," which is based on the similar concept of phonons that refer to vibrational waves in systems of masses linked by springs and which are used to model the motions of atoms or molecules in crystals or other materials.

"Our findings therefore raise some interesting connections to material physics in which birds in an orderly flock are analogous to atoms in a regular crystal," Newbolt adds.

More information: Joel W. Newbolt et al, Flow interactions lead to self-organized flight formations disrupted by self-amplifying waves, *Nature Communications* (2024). DOI: 10.1038/s41467-024-47525-9

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