Penguin physics: Understanding the mechanisms of underwater turning maneuvers in penguins

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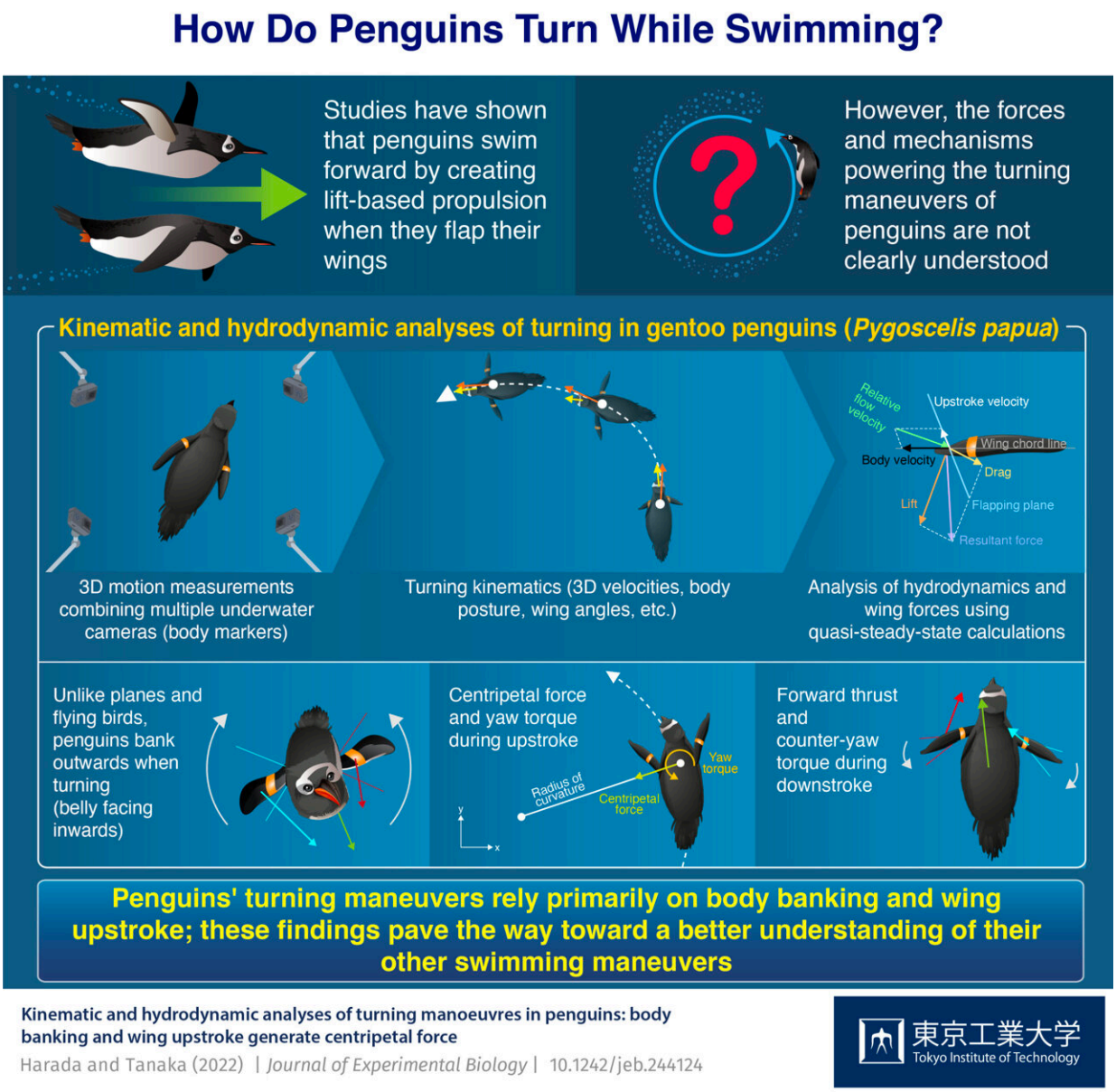

Credit: Tokyo Tech

Penguins constitute a fascinating family of flightless birds, that although somewhat clumsy on land, are extremely talented swimmers. Their incredible maneuverability in water has captivated biologists for decades, with the first hydrodynamic studies on their swimming dating back to the 1970s.

Although a rare few studies have clarified some of the physics behind penguins' dexterity, most of them have focused on forward swimming rather than turning. While one may argue that existing studies on the turning mechanisms of flying birds could shed some light on this topic, water is 800 hundred times denser than air, and thus the turning mechanisms employed are presumably very different between these media.

In an effort to bridge this knowledge gap, a pair of Japanese scientists from Tokyo Institute of Technology (Tokyo Tech), including Associate Professor Hiroto Tanaka, recently conducted a study. The main goal of this work, which was published in *Journal of Experimental Biology*, was to gain a better understanding of the three dimensional (3D) kinematics and hydrodynamic forces that enable penguins to turn underwater.

Using a dozen or more underwater cameras, the researchers recorded two sessions of gentoo penguins (Pygoscelis papua) freely swimming in a large water tank at Nagasaki Penguin Aquarium, Japan. Then, thanks to a technique called 3D direct linear transformation, they were able to integrate data from all the footage and conduct detailed 3D motion analyses by tracking various points on the penguins' bodies and wings.

Armed with these data, the researchers then established a mathematical 3D body model of the penguins. This model covered the orientation and angles of the body, the different positions and motions of the wings during each stroke, the associated kinematic parameters and hydrodynamic forces, and various turning metrics. Through statistical analyses and comparisons with the experimental data, the researchers validated the model and gained insight into the role of the wings and other body movements during turning.

The main findings of the study were related to how penguins generate centripetal force to assist their turns. They achieve this, in part, by maintaining outward banking, which means that they tilt their bodies such that their bellies face inward. In powered turns—those in which the penguin flaps its wings—the majority of changes in direction occur during the upstroke, whereas the forward thrust occurs during the downstroke. In addition, it turns out that penguins flap their wings with a certain asymmetry during powered turns.

"We found contralateral differences in wing motion; the wing on the inside of the turn becomes more elevated during the upstroke than the other," explains Assoc. Prof. Tanaka, "Quasi-steady calculations of wing forces confirmed that this asymmetry in wing motion with the outward banking contributes to the generation of centripetal force during the upstroke. In the following downstroke, the inside wing generates thrust and counter yaw torque to brake the turning."

Overall, these findings contribute to a greater understanding of how penguins turn when swimming, which is relevant from both biological and engineering standpoints. However, Assoc. Prof. Tanaka remarks that these findings bring but one piece to the puzzle: "The mechanisms of various other maneuvers in penguins, such as rapid acceleration, pitch up and down, and jumping out of the water, are still unknown. Our study serves as the basis for further understanding of more complex

maneuvers."

More information: Natsuki Harada et al, Kinematic and hydrodynamic analyses of turning manoeuvres in penguins: body banking and wing upstroke generate centripetal force, *Journal of Experimental Biology* (2022). DOI: 10.1242/jeb.244124

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