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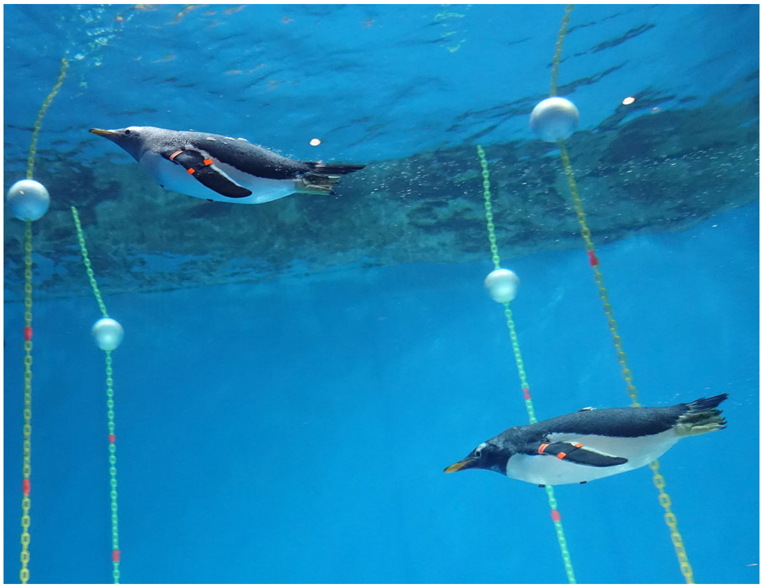
INSIDE JEB

Flexible wings take the effort out of swimming for diving penguins



Two penguins at Nagasaki Penguin Aquarium, Japan, swimming around the observation area in their tank. Photo credit: Hiroto Tanaka.

Swimming with penguins in the wild is a mind-blowing experience. When the ‘mini torpedoes’ hurtle past, you can barely make out the animals’ shape, let alone their movements. This was the problem faced by Hiroto Tanaka and colleagues from the Tokyo Institute of Technology, Japan, as they tried to understand how penguins swim; their movements are supremely swift. And even though researchers have a sense of how penguins overcome buoyancy, no one had successfully visualised how the birds use their wings to propel themselves through water; do they flap like inflexible paddles, or flex and bend as they sweep through the water? Intrigued by this mystery, Tanaka, Natsuki Harada, Takuma Oura and Masateru Maeda travelled to the Nagasaki Penguin Aquarium, Japan – home to nine species ranging in size from king penguins to little penguins – to find out how gentoo penguins (*Pygoscelis papua*) move beneath the waves.

‘Working with real penguins at the aquarium was so exciting but demanded a lot of effort to find the appropriate setup for video recording; it took several years’, explains Tanaka, who equipped the penguins’ 4 m deep tank with up to 14 waterproof cameras trained on a rectangular region in the centre of the tank to capture their manoeuvres in 3D. Then, Harada and Oura gently attached tape markers to three points on the wings of three penguins, in addition to markers on the birds’ bellies and backs, to keep track of their motions as they plunged freely through the water. ‘I was so glad and relieved to see the penguins swim comfortably inside the measurement space’, says Tanaka, who recorded over 28 h of movies as the birds darted around the tank at speeds ranging from 0.83 to 2.07 m s^{-1}. Then, Harada and Oura meticulously analysed the birds’ manoeuvres, identifying 40 complete wingbeats to dissect in fine detail.

By dividing each wing into a lozenge shape – composed of two triangles joined at their bases, where the triangle at the wing tip could hinge up and down as the wing bent at the penguins’ wrists – to conceptualize each wing beat, the team could see that the wing tip led the penguin wing beat, bending downward (with an angle larger than –20 deg) while sweeping upward and producing a shallower upward bow (~10 deg) as the wing swept down. Most importantly, the team recorded that the penguins surged forward during both the up- and downstrokes, accelerating more during the upstroke, in contrast to other diving birds, which accelerate more during the downstroke.

But how much benefit were the penguins reaping from the flexibility of their wings? After scanning the extended right wing of a penguin, Yayi Shen (Tokyo Institute of Technology) printed a 3D model of the limb before tilting it at various angles in water flowing at 2 m s^{-1} to measure the lift and drag exerted on the model. Harada then used the values to calculate the forces exerted on a flat and bent wing as the penguin swam and realised that swimming with flat paddle-like wings was less efficient than when the wing bent. In other words, bending the wing reduces the amount of effort penguins have to invest in swimming, improving their efficiency.

So, wing flexibility is a key component of the penguin’s effortless agility, and Tanaka is eager to measure the wing motions of gentoos as they twist and turn at extremely high speeds in the aquarium. He also dreams of observing their manoeuvres in the wild, ‘but I have no idea how to do that for now’ he smiles.

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Harada, N., Oura, T., Maeda, M., Shen, Y., Kikuchi, D. M. and Tanaka, H. (2021). Kinematics and hydrodynamics analyses of swimming penguins: wing bending improves propulsion performance. *J. Exp. Biol.* **224**, jeb242140. doi:10.1242/jeb.242140.

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