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Mimicking humpback whale flippers may improve airplane wing design

DURHAM, N.C. -- Wind tunnel tests of scale-model humpback whale flippers have revealed that the scalloped, bumpy flipper is a more efficient wing design than is currently used by the aeronautics industry on airplanes. The tests show that bump-ridged flippers do not stall as quickly and produce more lift and less drag than comparably sized sleek flippers.

The tests were reported by biomechanicist Frank Fish of West Chester University, Penn., fluid dynamics engineer Laurens Howle of the Pratt School of Engineering at Duke University and David Miklosovic and Mark Murray at the U.S. Naval Academy. They reported their findings in the May 2004 issue of Physics of Fluids , published in advance online on March 15, 2004.

In their study, the team first created two approximately 22-inch-tall scale models of humpback pectoral flippers -- one with the characteristic bumps, called tubercles, and one without. The models were machined from thick, clear polycarbonate at Duke University. Testing was conducted in a low speed closed-circuit wind tunnel at the U.S. Naval Academy in Annapolis, Md.

The sleek flipper performance was similar to a typical airplane wing. But the tubercle flipper exhibited nearly 8 percent better lift properties, and withstood stall at a 40 percent steeper wind angle. The team was particularly surprised to discover that the flipper with tubercles produced as much as 32 percent lower drag than the sleek flipper.

"The simultaneous achievement of increased lift and reduced drag results in an increase in aerodynamic efficiency," Howle explains.

This new understanding of humpback whale flipper aerodynamics has implications for airplane wing and underwater vehicle design. Increased lift (the upward force on an airplane wing) at higher wind angles affects how easily airplanes take off, and helps pilots slow down during landing.

Improved resistance to stall would add a new margin of safety to aircraft flight and also make planes more maneuverable. Drag -- the rearward force on an airplane wing -- affects how much fuel the airplane must consume during flight. Stall occurs when the air no longer flows smoothly over the top of the wing but separates from the top of the wing before reaching the trailing edge. When an airplane wing stalls, it dramatically loses lift while incurring an increase in drag.

As whales move through the water, the tubercles disrupt the line of pressure against the leading edge of the flippers. The row of tubercles sheers the flow of water and redirects it into the scalloped valley between each tubercle, causing swirling vortices that roll up and over the flipper to actually enhance lift properties.

"The swirling vortices inject momentum into the flow," said Howle. "This injection of momentum keeps the flow attached to the upper surface of the wing and delays stall to higher wind angles."

"This discovery has potential applications not only to airplane wings but also on the tips of helicopter rotors, airplane propellers and ship rudders," said Howle.

The purpose of the tubercles on the leading edge of humpback whale flippers has been the source of speculation for some time, said Fish. "The idea they improved flipper aerodynamics was so counter to our current doctrine of fluid dynamics, no one had ever analyzed them," he said.

Humpback whales maneuver in the water with surprising agility for 44-foot animals, particularly when they are hunting for food. By exhaling air underwater as they turn in a circle, the whales create a cylindrical wall of bubbles that herd small fish inside. Then they barrel up through the middle of the "bubble net," mouth open wide, to scoop up their prey.

According to Fish, the scalloped hammerhead shark is the only other marine animal with a similar aerodynamic design. The expanded hammerhead shark head may act like a wing.

The trick now is to figure out how to incorporate the advantage of the tubercle flipper into manmade designs, said Fish.

The research team now plans to perform a systematic engineering investigation of the role of scalloped leading edges on lift increase, drag reduction and stall delay.

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