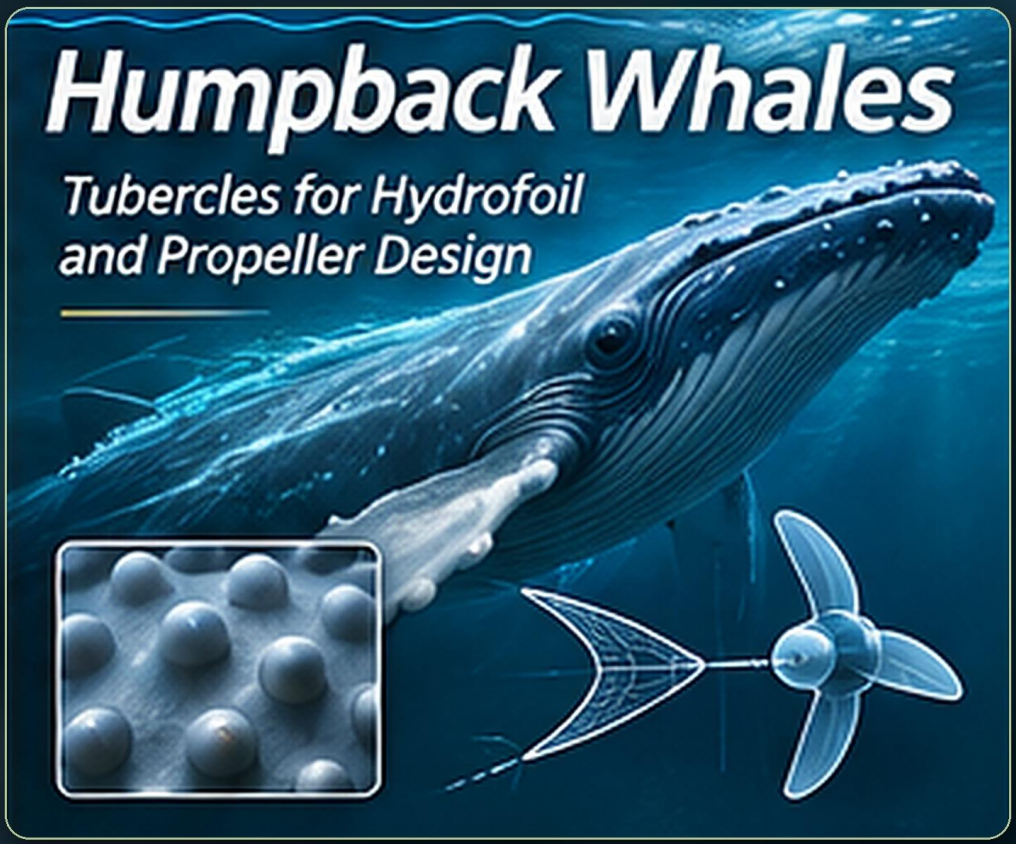
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Humpback Whales

Tubercles for Hydrofoil and Propeller Design

Nature-Inspired Inventions

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WealthSphere Labs

Humpback Whales: Tubercles for Hydrofoil and Propeller Design
Nature-Inspired Inventions, Volume 020

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About this book. This is an educational guide to biologically inspired engineering. The invention concepts in it are design ideas for study and experimentation, not tested or certified products. Worked numbers illustrate methods unless a source is named. Nothing here is engineering certification, legal advice on patents, or a substitute for qualified professional review of anything that will carry people, loads or risk.

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Introduction: Bumps That Help a Giant Turn

The humpback whale is one of the largest animals on Earth, often 12 to 16 metres long and weighing tens of tonnes. Yet it is surprisingly agile. Humpbacks feed by swimming in tight circles beneath schools of fish, blowing curtains of bubbles to trap them, then lunging up through the trapped prey. To turn tightly, they rely on their enormous flippers — the longest of any whale, up to about a third of their body length.

Look closely at a humpback flipper and you will see something unusual: its leading edge is not smooth but lined with large, rounded bumps called tubercles. For years these were assumed to be irregular growths. In the 1990s, biologists and engineers began to ask whether the bumps had a hydrodynamic function. Wind-tunnel and water-tunnel tests showed that tubercles can delay stall and soften its onset, letting a fin or wing work at higher angles before losing lift.

Tubercle-inspired leading edges have since been tested and applied on fans, wind turbine blades, propellers, surfboard fins and aircraft components. This volume explains humpback flippers, the physics of tubercles, the research and applications so far, and how designers can apply tubercle leading edges — including where they help and where they do not.

How this book is organized

Chapters 1 and 2 cover humpback feeding and flipper anatomy. Chapter 3 explains how tubercles change the flow. Chapter 4 surveys research and applications. Chapters 5 to 7 cover translation, geometry design and manufacture. Chapter 8 presents ten design concepts. Chapters 9 to 13 cover testing, failure modes, approval, a workbook and a case study.

> Figures for real animals and products are rounded and typical. Worked numbers are illustrations unless a source is named.

Chapter 1: Humpback Whales and Agile Feeding

The humpback whale

Humpback whales live in all major oceans and migrate between cold feeding grounds and warm breeding grounds, some covering several thousand kilometres each way. They are baleen whales, filtering small fish and krill from the water.

Bubble-net feeding

Groups or individuals swim in spirals beneath prey, releasing bubbles that rise in a ring or net, concentrating the prey. The whales then lunge upward through the center with their mouths open. This requires tight turns at relatively low speeds — exactly the conditions where a fin is close to stalling.

Maneuverability for a large animal

Large animals are usually less maneuverable than small ones. Humpbacks are unusually agile for their size, and their long, mobile flippers are central to that agility, acting like the wings of a banking aircraft.

Chapter takeaways

- Humpbacks feed by tight, spiral maneuvers.
- Tight turns at low speed demand high lift without stalling.
- Long flippers provide the turning forces.

Chapter 2: The Humpback Flipper

Shape

The humpback flipper is long, narrow and wing-like, with a high aspect ratio. In cross-section it resembles a symmetric hydrofoil, thick near the leading edge and tapering toward the trailing edge.

Tubercles

Along the leading edge are a series of rounded bumps. Frank Fish and Juliann Battle described the flipper's shape and tubercles in the *Journal of Morphology* in 1995, suggesting that the tubercles might improve hydrodynamic performance by acting as lift-enhancing devices. The tubercles are larger near the root and more closely spaced toward the tip in some descriptions, and vary between individuals.

Other features

The flipper's trailing edge is also uneven in places. The flipper is flexible to a degree and can be swept, twisted and angled through a wide range.

Chapter takeaways

- The flipper is a long, high-aspect-ratio hydrofoil.
- Leading-edge tubercles were proposed as lift-enhancing features in 1995.

Chapter 3: How Tubercles Change the Flow

Stall on a smooth foil

As angle of attack increases, a smooth foil produces more lift until the flow separates from the upper surface. Lift then falls, sometimes abruptly. This is the stall.

The tubercle effect

Tubercles produce a pattern of flow that varies along the span:

- Between tubercles (in the troughs), the local flow is accelerated and the pressure gradients differ, so separation tends to start there first.
- Behind each tubercle, the flow stays attached longer.
- The tubercles generate pairs of streamwise vortices, similar to those from vortex generators, which carry high-momentum fluid toward the surface and delay separation.

The result is that separation does not spread across the whole span at once. Instead, the foil stalls in patches, and lift falls gradually rather than abruptly.

Measured effects

Research by David Miklosovic, Mark Murray, Laurens Howle and Frank Fish, published in *Physics of Fluids* in 2004, tested scale models of humpback flippers with and without tubercles in a wind tunnel. The model with tubercles stalled at a substantially higher angle of attack — about 40 percent higher in their tests — with higher maximum lift and lower drag in the post-stall region.

Later research on two-dimensional foils (with tubercles along an infinite span), such as work by Hamid Johari and colleagues published in the *AIAA Journal* in 2007, found a more mixed picture: tubercles reduced the abruptness of stall and improved post-stall lift,