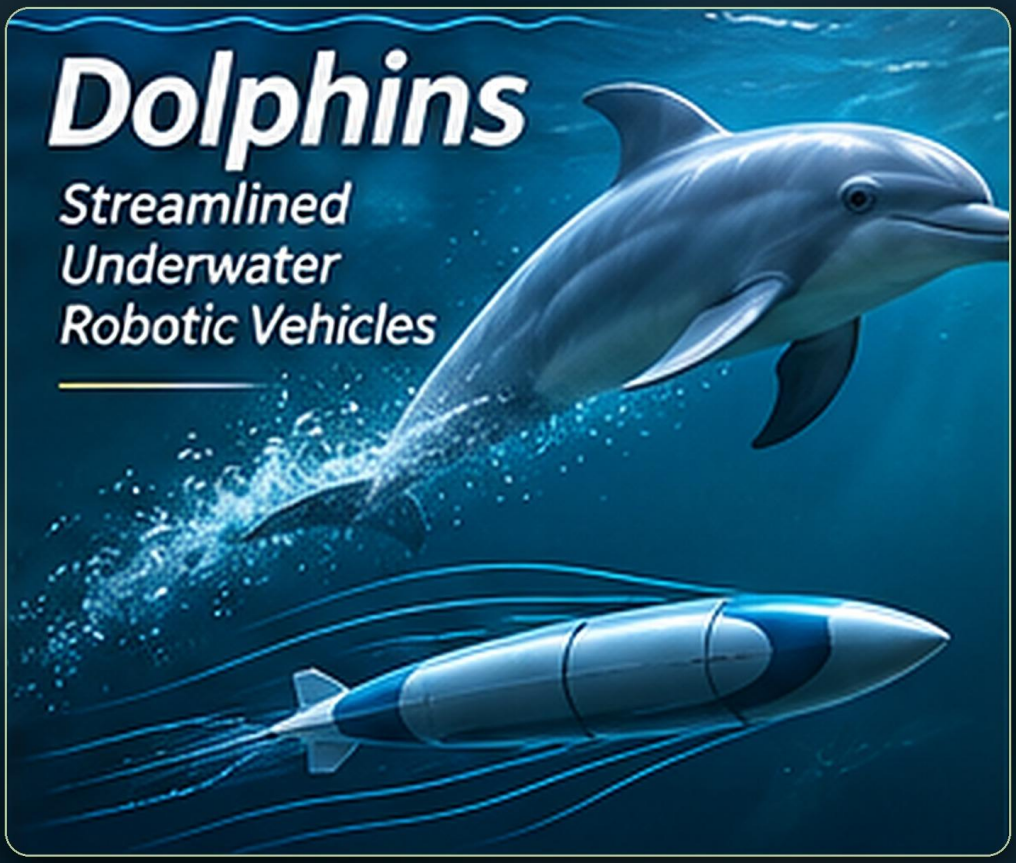
NATURE-INSPIRED INVENTIONS

WATER · VOLUME 018 / 255



From living designs to working machines

BIOMIMICRY • ENGINEERING • INNOVATION

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Dolphins

Streamlined Underwater Robotic Vehicles

Nature-Inspired Inventions

Volume 018 of 255

WealthSphere Labs

Dolphins: Streamlined Underwater Robotic Vehicles

Nature-Inspired Inventions, Volume 018

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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: The Puzzle of the Fast Dolphin

In 1936, the British zoologist James Gray did a calculation that puzzled scientists for decades. He estimated the drag on a swimming dolphin, assumed its muscles could produce about as much power per kilogram as other mammals' muscles, and concluded that dolphins should not be able to swim as fast as sailors reported. Either the dolphin's muscles were extraordinarily powerful, or its body had unusually low drag — perhaps by keeping the flow over its skin smooth and laminar.

"Gray's paradox" launched decades of research into dolphin skin, dolphin swimming and drag reduction. The eventual answer was less mysterious than Gray's alternatives: later measurements showed that dolphin muscles can deliver more power than Gray assumed, and that his speed estimates were not well matched to sustained swimming. But the research produced a wealth of knowledge about how dolphins swim efficiently: streamlined bodies, efficient oscillating flukes, energy-saving leaping, and riding the waves and wakes of others.

This volume explains how dolphins swim, the physics of their drag and propulsion, the history of dolphin research and dolphin-inspired technology, and how designers can apply dolphin principles to underwater robotic vehicles.

How this book is organized

Chapters 1 and 2 cover dolphin swimming and anatomy. Chapter 3 explains drag and oscillating-foil propulsion. Chapter 4 surveys the history of dolphin research and dolphin-inspired robots. Chapters 5 to 7 cover translation, mechanisms and control. 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 machines are rounded and typical. Worked numbers are illustrations unless a source is named.

Chapter 1: How Dolphins Swim

Dolphins and their relatives

Dolphins and porpoises are toothed whales. The bottlenose dolphin is the best studied, with adults typically 2 to 4 metres long. Other species, such as common dolphins and spinner dolphins, are smaller and faster.

Swimming style

Dolphins swim by moving their tail flukes up and down, driven by powerful muscles along the back and belly. The body bends mainly near the tail, while the front of the body stays relatively steady. This is called carangiform or, more specifically for whales and dolphins, a fluke-based oscillatory mode.

Speeds

Bottlenose dolphins cruise at a few metres per second and can sprint faster for short periods. Smaller, faster species reach higher speeds. Sustained cruising speeds are much lower than the brief maximum speeds sometimes quoted.

Porpoising

At higher speeds, dolphins often leap from the water in a series of arcs. Research by Whitlow Au and Daniel Weihs, published in *Nature* in 1980, showed that above a certain speed, leaping can save energy, because moving through air costs less than swimming close to the surface, where wave-making drag is high.

Riding waves and wakes

Dolphins ride the bow waves of ships and the waves of the ocean, gaining free propulsion. Calves swim close beside their mothers, and research by Daniel Weihs, published in 2004, analyzed how this

"drafting" lets calves save effort by using the flow around the mother's body.

Chapter takeaways

- Dolphins swim by oscillating their flukes, keeping the front body steady.
- Porpoising saves energy at high speeds near the surface.
- Riding waves and drafting reduce effort.

Chapter 2: Dolphin Anatomy

Body form

The dolphin body is fusiform, with a fineness ratio typically around 4 to 5 — in the low-drag range discussed in Volume 16. The rostrum (beak) and melon (forehead) form a smooth nose, and the body tapers to a narrow tail stock before the flukes.

Flukes

The flukes are wide, swept-back, crescent-shaped hydrofoils without bones, supported by dense connective tissue. Their shape gives a high aspect ratio and low induced drag, similar to swept wings. They pitch as they move up and down, keeping an efficient angle of attack through the stroke.

Flippers and dorsal fin

The flippers (pectoral fins) act as hydroplanes for steering and stability. The dorsal fin, present in most dolphins, adds directional stability, like an aircraft's vertical fin.

Skin

Dolphin skin is smooth, soft and continuously renewed, shedding its outer layer frequently. It has small ridges in the surface layer and a complex structure beneath. Researchers have long asked whether its softness damps turbulence and reduces drag, but this has not been clearly demonstrated in living dolphins.

Muscles and tendons

Large muscles along the spine connect through long tendons to the tail. The tendons may store and return elastic energy during each stroke.