NATURE-INSPIRED INVENTIONS

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Sharks

Riblet Drag-Reducing Ship Coatings

Nature-Inspired Inventions

Volume 017 of 255

WealthSphere Labs

Sharks: Riblet Drag-Reducing Ship Coatings

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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: Skin Made of Tiny Teeth

Run your hand from a shark's head toward its tail and the skin feels smooth. Run it the other way and it feels like sandpaper. Shark skin is covered in thousands of tiny, tooth-like scales called dermal denticles. Each denticle has a flattened crown, often with fine ridges running from front to back, aligned with the direction of swimming.

For decades, engineers have studied whether these ridges help sharks swim with less drag. The research led to riblets: surfaces with fine grooves aligned with the flow, which can reduce turbulent skin friction by a few percent under the right conditions. Riblet films have been tested on aircraft, used on racing yachts and trialed on commercial airliners. Shark-skin-inspired textures have also been developed to resist the growth of bacteria and marine organisms.

This volume explains shark skin, the physics of turbulent friction and riblets, the history of riblet research and applications, and how designers can apply riblet and denticle principles to ships, aircraft, pipes and surfaces — including where the evidence is strong and where claims have outrun it.

How this book is organized

Chapters 1 and 2 cover shark swimming and skin. Chapter 3 explains turbulent friction and riblets. Chapter 4 surveys the history of riblet research and applications. Chapters 5 to 7 cover translation, manufacture and practical use. 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: Sharks and Swimming

Diversity

There are over 500 species of sharks, from small deep-sea species to the whale shark, the largest fish. Fast, open-ocean sharks such as the shortfin mako are among the fastest fish, while others are slow bottom-dwellers.

Body and fins

Fast sharks have fusiform bodies, stiff pectoral fins that act like hydroplanes, and powerful, crescent-shaped tails. Their skin is tough and flexible, reinforced by the denticles and by crossed collagen fibers beneath.

Speed and efficiency

Fast sharks cruise efficiently over long distances and can sprint to catch prey. Their skin is one of many features that contribute to their performance, and its exact contribution is a subject of ongoing research.

Chapter takeaways

- Shark species vary widely; fast open-ocean sharks are the main models for drag research.
- Skin, body shape and fins all contribute to performance.

Chapter 2: Shark Skin and Denticles

Dermal denticles

Each denticle is a small structure made of the same materials as teeth: a base anchored in the skin, a neck, and a crown that lies roughly flat, overlapping its neighbors. Denticles are typically a fraction of a millimetre across.

Ridges

On many fast sharks, the denticle crowns have fine ridges running along the flow direction. The ridges on neighboring denticles line up, forming a grooved surface across the body. The spacing of ridges varies by species and by body region, and is often in the range of tens of micrometres to around 100 micrometres.

Flexibility

Denticles are attached to flexible skin and may move slightly. Some research has suggested that denticles on certain body regions can bristle up when the flow reverses, possibly affecting separation. This remains an active research area.

Antifouling

Shark skin tends to stay relatively free of fouling organisms. The texture may make it harder for organisms to settle, though mucus, skin shedding and movement may also contribute.

Chapter takeaways

- Denticles are tooth-like scales with ridged crowns.
- Ridges align with the flow and have spacings of tens of micrometres.
- Denticles may also play roles in flow separation and antifouling.

Chapter 3: Turbulent Friction and Riblets

Turbulent boundary layers

At the Reynolds numbers of ships, aircraft and fast fish, boundary layers are mostly turbulent. Turbulent friction comes from swirling motions — streamwise vortices and bursts — that sweep fast fluid toward the wall and eject slow fluid away from it.

How riblets work

Riblets are fine grooves aligned with the flow. When the grooves are small enough relative to the turbulent structures, they hinder the sideways motion of the swirling flow near the wall, keeping some of the fast-moving turbulent structures further from the surface. This reduces the momentum transfer to the wall and therefore the friction.

Wall units

Riblet size must be matched to the flow. The relevant measure is the riblet spacing in "wall units," s^+:

$$s^+ = s\,u_\tau / \nu$$

where s is the riblet spacing, ν is the kinematic viscosity and u_τ is the friction velocity:

$$u_\tau = V\sqrt{(C_f/2)}$$

with C_f the local skin friction coefficient.

The optimum

Experiments, including detailed work by Dietrich Bechert and colleagues in Germany published in 1997, found that the best drag reduction for well-made riblets occurs at around $s^+ \approx 15$ to 20, with reductions of up to about 8 to 10 percent of skin friction in carefully