Biomimetic Rotary Cutting Blade Design
Humpback-Inspired Leading-Edge Geometry for Improved Flow Control

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Abstract

This project investigates a biomimetic redesign of a rotary cutting blade inspired by humpback whale flippers. The concept leverages leading-edge tubercles to improve flow organization, reduce separation, and mitigate material recirculation. A wavy leading-edge blade was modeled in *SolidWorks* and evaluated through flow-trajectory simulations to qualitatively compare particle evacuation and pressure distribution trends against a baseline geometry. The proposed design suggests improved debris transport toward the blade tips, more uniform loading, and potential reductions in localized wear and torque fluctuations.

1 Motivation

Rotary cutting systems operate in highly unsteady conditions where airflow, debris, and flexible vegetation interact with the blade during impact-driven cutting. Conventional geometries can promote recirculation regions where material remains near the blade surface, often requiring multiple passes for homogeneous cutting. Improving flow control around the blade can increase evacuation efficiency and reduce energy losses due to unfavorable separation.

2 Biomimetic Principle

Humpback whale flippers feature tubercles along the leading edge that generate streamwise vortices and help maintain attached flow at higher angles of attack. Translating this principle to a rotary blade motivates a wavy leading-edge profile designed to guide airflow and entrained particles in a more controlled manner, potentially reducing separation-related losses and improving post-impact debris transport.

Figure 1. Biological inspiration: humpback whale flipper leading-edge tubercles.

3 Methods

Baseline assessment. A reference blade geometry was analyzed to identify regions associated with flow separation and particle accumulation.

CAD modeling. A biomimetic blade with a wavy leading edge was designed in *SolidWorks*, preserving the main envelope constraints (overall length/clearances) while introducing controlled curvature along the leading edge.

Flow-trajectory evaluation. Flow trajectories (and representative particle paths) were simulated to compare (i) channeling of material toward blade tips, (ii) recirculation/accumulation over the upper surface, and (iii) pressure distribution tendencies along the blade.

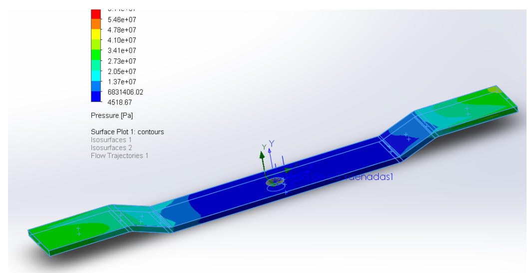

Figure 2. Biomimetic blade CAD model with wavy leading edge (SolidWorks).

4 Key Findings

The biomimetic geometry exhibits a more organized flow pattern around the blade, with trajectories suggesting enhanced transport toward the extremities and reduced recirculation over the upper surface. The pressure distribution appears more evenly spread, which may reduce localized stress concentrations and wear. Because rotary cutters rely primarily on impact (rather than a sharpened edge), improved flow organization and evacuation can translate into fewer repeated impacts on the same material, potentially lowering torque fluctuations and stabilizing operation.

- **Improved evacuation:** reduced tendency for debris to remain on the upper surface.
- **Flow control:** better channeling from the underside toward the blade tips.
- **Load distribution:** more uniform pressure trends, suggesting lower localized wear.

- **System implications:** potential reduction in torque peaks and dynamic loading.

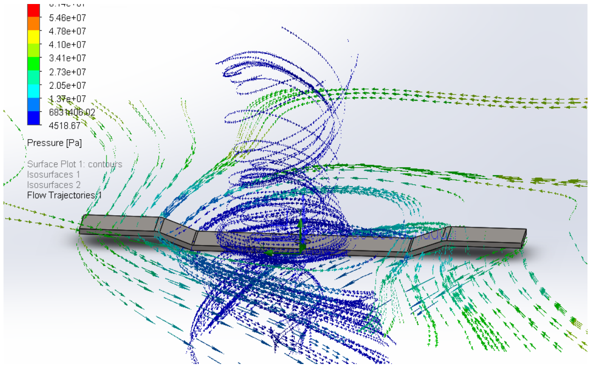

Figure 3. Baseline flow/particle trajectories (reference design).

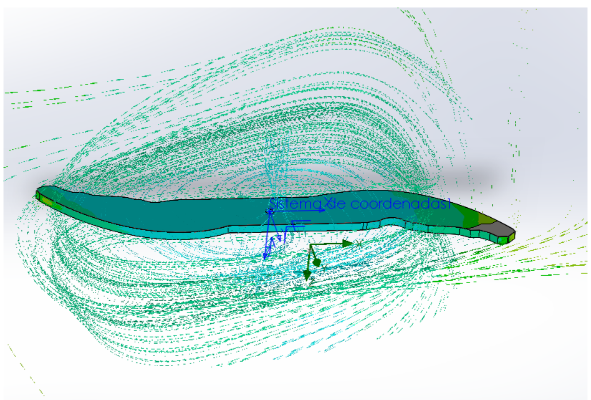

Figure 4. Flow/particle trajectories with biomimetic leading edge (proposed design).

Figure 5. Surface/pressure distribution visualization (optional).

5 Next Steps

- Quantify aerodynamic metrics (force/torque proxy, separation indicators) across operating conditions.
- Sweep tubercle amplitude and wavelength to identify optimal leading-edge profiles.
- Validate robustness with representative RPM and vegetation-density proxies.

References

[1] F. E. Fish and J. M. Battle, "Hydrodynamic design of the humpback whale flipper," *Journal of Morphology*, 225(1), 51–60, 1995.

[2] D. S. Miklosovic, M. M. Murray, L. E. Howle, and F. E. Fish, "Leading-edge tubercles delay stall on humpback whale flippers," *Physics of Fluids*, 16(5), L39–L42, 2004.