3D Model of Flow Behaviour Near Dermal Denticles From Shark Skin

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Abstract

Sharks are known to be exceptionally energy efficient swimmers. Many studies have linked this to microscopic structures on the skin of the shark [1, 2]. If a successful biomimetic shark skin surface-coating can be constructed, the potential for fuel consumption reduction in the transport industries is substantial. The first step along this way is better understanding of the fluid flow phenomena near the surface of the shark skin.
This project uses the COMSOL Multiphysics® CFD Module to examine the fluid flow around models of the dermal denticles on the skin of the Smallspotted Catshark (Figure 1). The model is based on Scanning Electron Microscopy (SEM) images of shark skin samples provided by previous studies (Figure 2). In this early stage model, priority was given to the crown structures across the tops of the denticles as these are believed to hold the key to the reduction in skin friction. The k-epsilon turbulence model is employed. For the inlet condition, a fully developed, turbulent profile with a mean speed of 6 m/s is used. This is expected to simulate the swimming speed of the shark.
Meshing this model poses many interesting challenges; one of which being the sheer number of mesh elements required to mesh the denticles themselves. To achieve meshing, a user-defined, slightly coarser than desired, mesh was employed. Using the desired, built-in, physics controlled, normal mesh proved infeasible for this model.
The results show that the model is able to predict the fluid flow and obtain good agreement with experimental studies of the same flow phenomenon. Figure 3 shows the vorticity in the flow direction and the cross-stream velocity components. The vorticity indicates the presence of counter-rotating vortices in the flow. Continuing the work of this project would include looking at possibilities to simulate using the low-Reynolds k-epsilon model to get a more correct picture of the interesting boundary layer properties of this fluid flow.
Supervisors: Kirstine Berg-Sørensen & Mirko Salewski, DTU Physics.

Reference

[1] B. Dean et al, Shark-skin surfaces for fluid-drag reduction in turbulent flow: a review, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 368.1929, pp. 4775-4806 (2010)
[2] S. J. Lee et al, Flow field analysis of a turbulent boundary layer over a driblet surface, Experiments in in Fluids Journal, 30.2, pp. 153-166 (2001)
[3] T. E. B. Smithshusyen et al, Micro particle image velocimetry analyse af flowdynamik over hajskin, Student project at DTU Physics (2015) (unpublished)

Figures used in the abstract

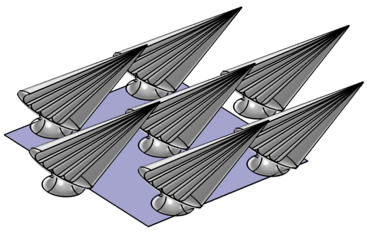

Figure 1: Seven identical models of a denticle are placed in approximately 1 sq. mm; to model the natural surface density of the structures.

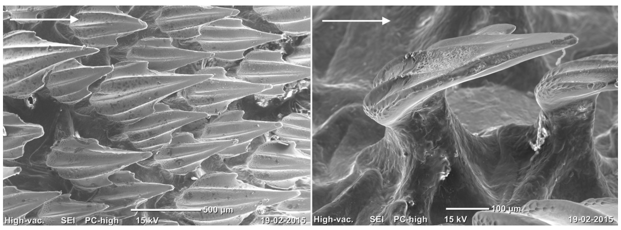

Figure 2: Scanning Electron Microscopy images of samples of shark skin formed the basis for the CAD model in COMSOL. Reprinted from [3].

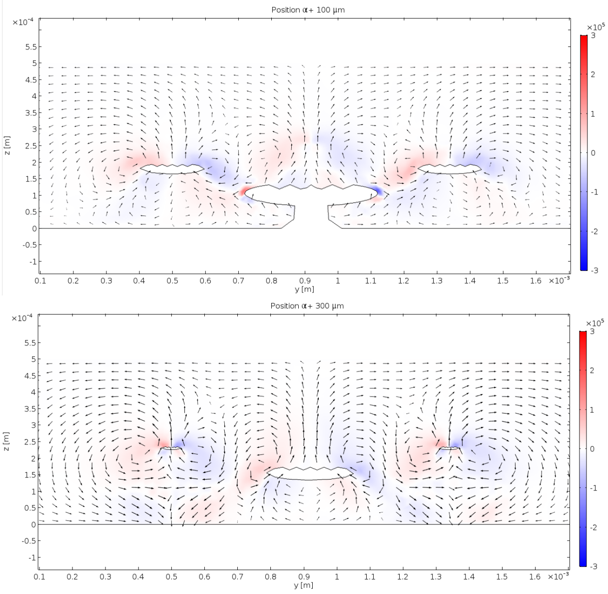

Figure 3: Front view of the flow field and vorticity [/s] in a plane perpendicular to the main flow direction.