Effect of Bio-inspired surface roughness on a wind turbine section

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Abstract

Flow control can be achieved through modification of surface characteristics. Here we present a bio-inspired passive surface capable of reducing flow separation. We test the micro-surface on an S835 airfoil at a momentum-based Reynolds number $Re_\theta = 1200$. Our results show a significant reduction in the recirculation zone. Additionally, the thickness of the boundary layer is reduced. The surface roughness falls within the hydraulically smooth regime ($k^+ \approx 1$). POD analysis, however, shows large scale modifications to the flow.

Keywords: *flow separation, micro-scale surface, flow control*

Introduction

Vertical axis wind turbines (VAWT) experience high angles of attack as their blades sweep their full rotation. This makes them prone to flow separation. This phenomenon also plays a critical role in the efficiency of bluff bodies—such as cars and trucks—and streamlined bodies at high angles of attack. By delaying flow separation and minimizing the size of the separation bubble, we can increase the efficiency in VAWT, reduce fuel consumption in transport vehicles, and reduce the size of the wake in naval vehicles. Several different methods have been used to reduce flow separation, including synthetic jet and plasma actuators [1]. Unfortunately, such active mechanisms require auxiliary systems, making their implementation costly. Passive mechanisms offer an alternative which does not require such auxiliary systems. Here we test the capability of a micro-scale surface to mitigate flow separation.

Experimental Setup

Laboratory experiments were performed in a refractive index-matching flume. This facility minimizes reflections close to the wall, therefore, allowing flow measurement within the viscous sub-layer, as close as $y^+ \approx 3$ for the current study. The incoming Reynolds numbers based on the momentum thickness was $Re_\theta = 1200$ and the dimensionless roughness parameter $k^+ \approx 1$, producing a flow in the hydraulically smooth regime. The adverse pressure gradient was induced by a divergent section mounted on the bottom wall of the flume (Figure 1a). This section was coated with bio-inspired micro-pillars, which are inspired by the setae found in the feet of the gecko and the denticles found in shark skin. Their shape is cylindrical with a divergent tip (Figure 1b). The pillars have a height of 85 μm with tip and base diameters of 70 μm

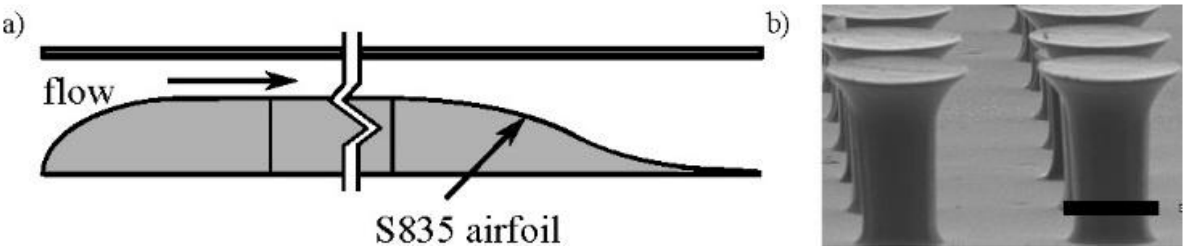

Figure 1. a) Schematic of the experimental setup. b) Microscopy image of the divergent tip micro-pillars; scale bar = 100 μm. The flume was adapted with contracting and expanding sections. In the expanding section, the flow experiences a strong adverse pressure gradient, triggering separation. The micro-pillar coating was present in the expanding section.

and 40 µm, respectively. They are fabricated from clear polyurethane directly on an acrylic substrate using a soft silicone mold. Details about the fabrication procedure are given in [2].

Results

The coating induced a reduction of 60% in the size of the reverse flow region when compared to its smooth counterpart, as well as a downstream shift in the separation point. These findings differ from previous experiments carried out on canonical roughness, i.e. sand grain roughness [3]. Surprisingly, the bio-inspired surface produced global changes in the flow evolution, including delaying the separation point, despite it is in the hydraulically smooth regime. The mechanism by which the micro-pillars reduced separation is linked to their uniform arrangement, which, in purely cylindrical pillars, produces areas of high and low pressure that generate blowing and suction resembling the action of synthetic jet actuators. This produces a higher vertical velocity towards the wall and higher streamwise velocity in the viscous region up to the lower region of the overlap layer. An important feature of this surface is that it works under wetted conditions, making it effective for applications in underwater bodies.

Inspection of the two-point correlation indicates little differences between the smooth and coated setups. However, the correlation in the coated case shows a tilt that is consistent with the flow parallel to the expanding wall; this effect is only seen near the wall. The POD modes are classified as high- and low-energy. The distinction between these two is set when the energy recovered from the addition of modes 1–n reaches 60% of the total. Modes (n + 1)–N are then classified as the low-energy modes. The coated case sees a considerably faster energy recovery, as it takes approximately 170 modes (equivalent to less than 10% of the total number of modes) to reach the 60% threshold, whereas it takes almost 230 modes in the smooth case to reach such level. This is a clear indication that the energy in the coated case is more concentrated in the first few modes. It is surprising that for the Reynolds shear stress for smooth or coated surfaces, the large scale motion account for 90% of the original experimental data. As demonstrated in the mean velocity profiles in which the wake region corresponds to most of the flow it is clear that large scale motions in separated flow are the dominant scales.

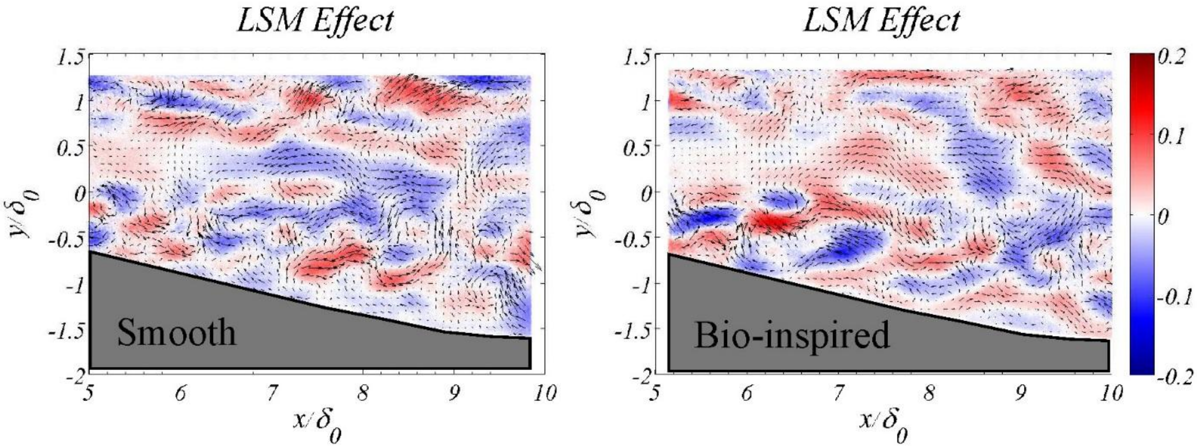

Figure 2. Effect of large-scale motions on smooth and coated surfaces under adverse pressure gradient.

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