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Flow separation delay on trucks A-pillars by means of Dielectric Barrier Discharge actuation

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Abstract: The present investigation focuses on the flow around a half cylinder (i.e. an immersed cylinder) approached by a turbulent boundary layer, with the aim of separation control via Dielectric Barrier Discharge (DBD) plasma actuators. The geometry is chosen as a generic model of the flow around the front corners (A-pillars) of a truck cabin and the work is performed with the long-term vision to be able to reduce drag on trucks.

Keywords: Aerodynamics, road vehicles, separation control, half-cylinder wake, experiments.

1 Problem Statement

The aerodynamic drag counts for more than 20% of the total energy loss of heavy duty vehicles and 70% of this drag is induced by the tractor when considering a 0 degree yaw angle. One of the contribution comes from the flow separation from the truck surface while passing the A-pillars (front corners) of the tractor. Since the 60's, solutions to decrease the drag of the tractor, like rounded corners, have been extensively investigated and developed. It has been shown that rounded corners with a radius of about 300 mm are optimal to delay this separation [1]. However this value is only appropriate for a 0 degree yaw angle. Active control methods with potential feedback control loop would probably improve the separation delay when considering that trucks on the road are subjected to varying yaw angles.

This project focuses on the study of Dielectric Barrier Discharge (DBD) plasma actuators with the objective of using the induced electric wind to investigate if turbulent boundary layer separation occurring on the A-pillars can be controlled with such devices. For this purpose, the half-cylinder geometry has been chosen as a generic model of the rounded corner.

DBD plasma actuators are made of two electrodes asymmetrically placed on each side of a dielectric material. They present, among others, the advantage of not having any moving parts making them more robust than other types of actuators. By applying a high alternating voltage between the electrodes a plasma region is formed on the surface of the dielectric. This plasma is a consequence of accelerated electrons which ionize the surrounding medium: repulsion of ions during the ionization process induce momentum similar to a wall jet called the electric wind [2].

2 Experiments and Results

The first goal of the project was to design and construct in-house made DBD plasma actuators and electrical circuits for their control. The electric wind induced by the actuator placed at the top of a cylinder enclosed in a box, to prevent external flows, has been studied. The effect of parameters such as driving voltage, frequency, dielectric thickness and material are investigated in terms of their influence on the efficiency of the actuator by means of velocity measurements using Laser Doppler Velocimetry (LDV). Mean velocity profiles show that the plasma actuators are able to produce wall jets with velocities of several meters per

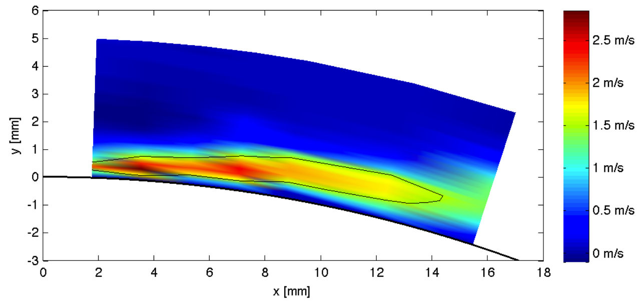

Figure 1: Mean flow or electric wind induced by the DBD plasma actuator using a driving voltage of 8 kV$_{p-p}$ at a driving frequency of 6 kHz. The thick black line represents the cylinder surface. The edge of the actuator top electrode is at x = 0 mm, y = 0 mm. The thin black line is the 1.5 m/s contour line.

second (see Figure 1). Increasing the driving voltage or frequency increases the jet velocity and its maximum moves closer to the wall. Because the actuator adopts to the shape of the model, the electric wind is found to follow the surface of the cylinder, which is an advantage for future separation control. Close to the actuator the airflow is periodic due to the alternating driving current. The phase-resolved study shows that the induced velocities increase both during the backward and the forward stroke of the high-voltage cycle indicating that the force produced by the actuator is directed towards the same direction during the whole cycle [3].

The separation control experiments are conducted in the open-circuit wind tunnel of the Fluid Physics laboratory, at KTH Mechanics. The tripped turbulent boundary layer develops over a plate upstream the half cylinder and separates while passing over the bluff body (see Figure 2 for a schematic of the setup). The baseline case, without control, is studied using hot-wire anemometry and pressure measurements to identify the separation point. The velocities and characteristic length of the separation bubble are investigated using pressure measurements and flow visualization techniques when using control. Parameters, such as the relative position of the actuator to the separation point, Reynolds number dependence and power consumption of the actuators are studied in order to identify key factors influencing the separation control. The final aim of this experiment is to be able to measure the drag reduction due to the use of the DBD plasma actuators and compare it to their power consumption.

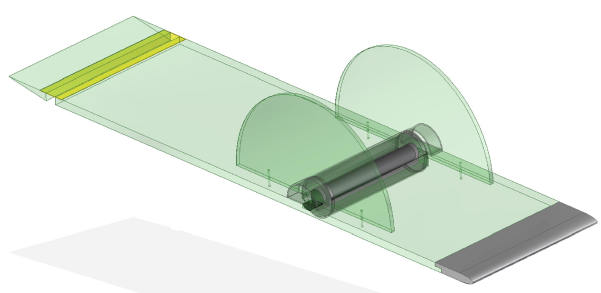

Figure 2: Sketch of the setup used in the open-circuit wind-tunnel for the separation control experiments.

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