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Steady control of laminar separation over airfoils with plasma sheet actuators

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Abstract

This work analyzes the effects produced by an EHD actuator on the flow around an airfoil at low *Re* numbers ($Re \approx 10^4$). The analysis is undertaken from flow visualizations and measurements of the surface pressure distributions. The experiments indicate that, for low *Re* number, the effects of the actuation depend on the power added to the flow and on the relative distance between the actuator and the separation line.

Keywords: Airfoil; Flow control; Laminar separation; EHD; Plasma

1. Introduction

The performance of airfoils operating at low *Re* number, has been providing increasing interest as a result of the desire to improve the performance of general aviation aircraft at low-speed, high-aspect-radio sailplanes wings, as well as to improve the design of remotely piloted vehicles, jet engine fan blades, and propellers at high altitude. The inboard sections of helicopter rotors, wind turbine rotors, and free-flying model aircraft also represent applications where low Reynolds number performance is important.

Different significant problems may contribute to diminish the aerodynamic performance of the airfoils with cord Reynolds number lower than about 200.000. Flow control in this area has focused on the mitigation of these problems, using different strategies like flapping or flexible wings [1] or boundary layer control (e.g., blowing, suction, etc.) [2–4].

The use of electrohydrodynamic (EHD) actuators was proposed some years ago. These actuators produce ionization of the flowing air and add localized momentum to the flow through a collision process of the migrating charged particles with the neutral species of the gas. EHD phenomena are based on the fact that currents involved are so low that the intensities of the magnetic forces are negligible compared to the electric ones. The main advantages of the EHD actuators are that they have no moving part, a very short response time (delays in the establishment of a discharge are theoretically of the order of nanoseconds) and a relatively good efficiency in transforming electrical to mechanical energy [5].

EHD actuators may be divided into three large groups: corona-based devices [6,7], dielectric barrier discharge devices [8,9] and plasma sheet devices [5,10,11].

Plasma sheet devices use generally two air-exposed electrodes flush mounted on the surface of a dielectric body separated by a few centimeters. The electrodes may be excited with a continuous (DC) or with a periodic potential difference. The device produces a homogeneous luminescence that occupies the interelectrode space along the span. In this region, the surface is covered by a thin film of ionized air. In some cases, a third electrode may be added to the system to ameliorate the stability of the discharge [12].

The objective in this work is to study the improvement of the aerodynamic performance of an airfoil operating at low Reynolds number ($Re < 50.000$) by means of a plasma sheet device working with a DC potential difference.

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2. Experimental setup

2.1. Wind tunnel and airfoil

Flow visualization was utilized in an open low-speed wind tunnel (velocity ranges 0–5 m/s-rectangular cross-section of $0.45 \times 0.45\,\mathrm{m}^2$) with a turbulence level of the air flow below 3%.

The airfoil shape was a NACA 0015 cross-section fabricated from polymethyl metacrylate (PMMA) with a cord dimension $c = 200\,\mathrm{mm}$ and a spanwise dimension $b = 450\,\mathrm{mm}$. The airfoil was fabricated in two separate parts (male and female) matched to obtain a hollow body. The airfoil was suspended on both ends using pieces of electrical insulating material (nylon).

2.2. Flow visualization

The flow visualization at low-speed air velocities ($\approx 1\,\mathrm{m/s}$) were utilized using a paraffin oil smoke generator. This device allowed the creation of a single smoke filament that had an approximate diameter of $\phi_\mathrm{f} = 2.5\,\mathrm{mm}$. A laser sheet intercepted the smoke filament assisting the visualization. The laser sheet had an approximate thickness of 0.5 mm and was generated by a 5 mW diode laser mounted on the ceiling of the probe section. The flow visualization was recorded with a digital video camera.

2.3. Pressure measurements

The pressure along the airfoil surface (P_i) was measured by means of 30 pressure ports that were drilled at the half of the span location of the airfoil. The tapped hole diameter was 1.5 mm and electrical insulating tubes of Tygon ($\phi_\mathrm{int} = 0.5\,\mathrm{mm}$) were inserted in the holes, passed through the hollow of the airfoil and brought out through one end support of the model.

The static pressure of the free stream (P_0) was sensed using a tab mounted on the ceiling of the test section upstream the model. An electronic micromanometer was used to determine the differential pressure (P_i–P_0), in the pressure range between 0 and 0.1 WC inches (0–24.9 Pa) with accuracy of 1.0%. The electrical signals of the transductor at each tab were recorded using a data acquisition system.

For the present study the pressure coefficient C_p is defined as

$$C_\mathrm{p} = \frac{P_i - P_0}{0.5\rho U_0^2} \tag{1}$$

where P_i is the surface pressure at station i, ρ the gas density, and U_0 the freestream velocity.

In regions where the flow was separated, the surface pressure at the different ports was unsteady and the value of the pressure considered there was a time-averaged value obtained by the direct measurement of the fluctuating surface pressure integrated over the time T of the experiment [11].

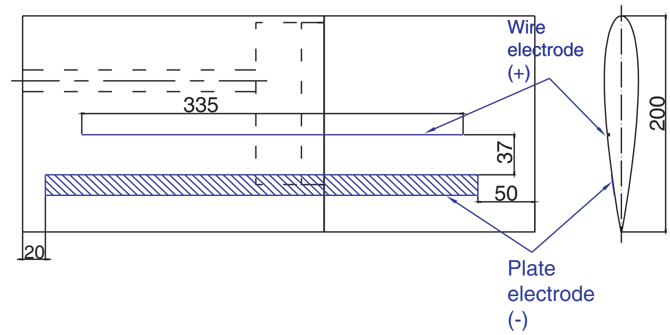

Fig. 1. Electrodes location on the airfoil surface (distances are in mm).

2.4. The coefficients of lift and of drag pressure

The coefficient of lift, $C_\mathrm{l}(\alpha)$, and drag pressure, $C_\mathrm{Dp}(\alpha)$, were calculated by integrating the distribution of the value of the coefficient C_p around the airfoil.

The $C_\mathrm{l}(\alpha)$ and $C_\mathrm{Dp}(\alpha)$ have been, in consequence, time-averaged values that hid the dynamic behavior of the lift and drag forces. However, they could give a fruitful data and result in a useful tool to compare the aerodynamic performance of the airfoil in the presence or in absence of the discharge.

2.5. Velocity measurement

Velocity measurements of the flow (U_0) were taken with a micromanometer (accuracy 0.04 Pa) and a Pitot probe located 0.15 m upstream the airfoil leading edge.

2.6. EHD excitation

Two different DC H.V. sources of opposite polarity (+20 kV, −20 kV, 1.5 mA) were used to apply the voltage differences between the two electrodes. The electrodes were located flush mounted on the suction surface of the airfoil.

A copper wire of 0.9 mm diameter was fitted in a slot of the airfoil surface at $x/c = 0.55$. The plate electrode consisted of a strip of 3.5 mm width of thin aluminum foil (50 μm thick) located at $x/c = 0.79$ (Fig. 1).

The wire electrode was connected to the source with a positive polarity while the plate electrode was attached to the negative polarity.

3. Experimental results

The range of velocities and angles of attack tested in our sets of experiments includes those associated with the occurrence of different phenomena [13]:

- flows with laminar boundary layer almost fully attached to the surface of the model,