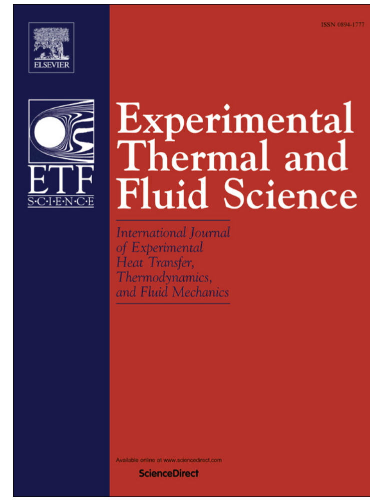

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E. Pescini, F. Marra, M.G. De Giorgi, L. Francioso, A. Ficarella

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Experimental Thermal and Fluid Science

INVESTIGATION OF THE BOUNDARY LAYER CHARACTERISTICS FOR ASSESSING THE DBD PLASMA ACTUATOR CONTROL OF THE SEPARATED FLOW AT LOW REYNOLDS NUMBERS

E.Pescini[a], F. Marra[a], M.G. De Giorgi[a*], L. Francioso[b], A. Ficarella[a]

[a] University of Salento, Dep. Engineering for Innovation, Via per Monteroni, 73100, Lecce, Italy
[b] CNR-IMM Institute for Microelectronics and Microsystems, Via per Monteroni, 73100 Lecce, Italy

ABSTRACT

The present study intends to investigate the boundary layer characteristics to assess the potentiality of the single dielectric barrier discharge plasma actuators (SDBDPAs) to reattach the separated flow at low Reynolds numbers. The effect of the actuator geometrical parameters and of the Reynolds number on the device control authority was experimentally investigated. For this aim, a curved wall plate, which profile shape was designed to reproduce the suction surface of a low-pressure turbine (LPT) blade, was installed in the test section of a closed loop wind tunnel and a groove was made over it, at the front of the adverse pressure gradient region, for allocating a SDBDPA. Three actuators, characterized by different streamwise width, were manufactured by photolithography technique and they were tested. The velocity flow field, in both presence and absence of external flow, was investigated by particle image velocimetry (PIV) measurements. When the actuator was turned on, a sinusoidal voltage excitation with amplitude of 8 kV and frequency of 2 kHz was applied and the dissipated power ($\overline{P}_{el}$) was retrieved by electrical characterization.

The effect of the active flow control was firstly estimated by analyzing the plasma induced velocity fields in absence of external flow. Subsequently the wind tunnel inlet free stream velocity ($v_{x,\infty}^{in}$) was set to 1.54 m/s. The velocity, turbulence intensity (*Tu*) and vorticity (ω_z) fields together with the boundary layer shape factor (H_{12}) and momentum coefficient (c_μ) were evaluated in both presence and absence of actuation. All the aforementioned analyses together with the estimation of the device electrical-to-fluidic energy conversion efficiency (η_{fm}) allowed identifying the best actuator geometry. Then, that configuration was chosen to investigate the effects of the wind tunnel velocity on the device control authority. The tested $v_{x,\infty}^{in}$ values ranged from 1.54 m/s up to 3.16 m/s. In absence of actuation, a large reverse flow and high turbulence intensity was observed in the separation region. Considering the actuated cases, it was found that at $\overline{P}_{el} \approx 7$ W, the SDBDPA operation always implied a reduction of the separated region, of the flow angle and of the turbulence intensity. Moreover, the plasma induced jet had a larger impact on the flow at lower velocities and a low flow control effect was noticed at the highest $v_{x,\infty}^{in}$ values. The H_{12} factor evaluation confirmed the flow regimes at the different tested velocities (i.e. c_μ values). The whole data set allowed to evaluate the actuator success for separation control and to identify a threshold value of the c_μ coefficient delimiting the still detached flow from the reattached one.

KEYWORDS: Active flow control; Plasma actuator; Photolitography; Low pressure turbine; Boundary layer characteristics; Momentum coefficient

1 INTRODUCTION

The turbines for aircraft propulsion systems are usually designed for peak performance at high Reynolds number conditions, such as taking off and landing [1]. During high altitude cruise, due to the low air density, the Reynolds number *Re* (based on axial-chord and inlet velocity) through a LPT stage of small gas turbine engines, typically used or planned for use in many high-altitude air vehicles as in unmanned air vehicles (UAVs), can be as low as 10000 to 25000 [2][3]. This Reynolds number value is considerably smaller than that of the conventional gas turbines [4][5], and thus the LPTs may work at off-design conditions with very poor performance.

At these such low *Re* numbers, the boundary layer in the stator is largely laminar and tends to separate easily from the suction surface of the blade, with associated aerodynamic losses increase and overall engine performance drop [6][7]. Sharma [8] indicated a nearly 300% rise in the loss coefficient at *Re* numbers below 95000 compared to that at higher *Re* numbers [1].

*Corresponding author: mariagrazia.degiorgi@unisalento.it