applied sciences

MDPI

Editorial

Special Issue "Active Flow Control Technologies for Energy and Propulsive Systems"

Maria Grazia De Giorgi * **and Antonio Ficarella**

Department of Engineering for Innovation, University of Salento, Via Per Arnesano, I-73100 Lecce, Italy; antonio.ficarella@unisalento.it

* Correspondence: mariagrazia.degiorgi@unisalento.it; Tel.: +39-0832-299-420

Received: 23 December 2019; Accepted: 24 December 2019; Published: 27 December 2019

check for updates

1. Introduction

Active flow control (AFC) is a fast-growing, multi-disciplinary science and technology for energy and propulsive systems. It is aimed to achieve transition delay, drag reduction, lift enhancement, turbulence management, separation postponement, noise suppression, combustion enhancement, etc. The potential benefits of flow control may include improved performance, affordability, fuel consumption economy, and environmental compliance.

In the aerospace field, the flow control has a significant impact on the aerodynamic design, as well as on the propulsion systems (such as jet engines and rockets) of future aerospace vehicles. Regarding engine components, flow control in turbomachinery is needed to increase efficiency of thrust and power generation while reducing environmental footprint.

Several applications of active flow control to the low-pressure turbine section of a gas turbine are reviewed and evaluated in previous studies [1–4]. Some characteristics of low-pressure turbine flow conditions such as freestream turbulence, secondary flows, and unsteady wakes lead to questions for flow control that must be considered during the design of these components.

Furthermore, efficient combustor designs and stable compressor flows using flow control are also needed. In recent years, attention has also been focused on the control and suppression of combustion instabilities by actively and continuously perturbing certain combustion parameters in order to interrupt the growth and persistence of resonant oscillations [5–8].

Remarkable developments in control theory have considerably expanded the selection of available tools which may be applied to regulate physical systems. These techniques show great benefits for several applications in fluid mechanics, including the delay of flow transition, and thus of turbulence.

Active flow control research is characterized by a highly multi-disciplinary approach including theoretical, computational and experimental fluid dynamics, aerodynamics, physics, chemistry, and propulsion. Although many flow control technologies have been identified and researched at the basic level for many decades, few have ever reached maturity and full-scale deployment in a commercial product.

2. Flow Control Applications

In light of the above, this Special Issue collected some of the latest research on relevant topics, and more importantly, addresses present challenging issues in the implementation of active flow control techniques as plasma actuators for the control of flow separation in compressors.

The performance of modern, highly loaded compressors are limited by the corner separations. Plasma actuation is a typical active flow control methodology, which has been proven to be capable of controlling the corner separations in low-speed compressor cascades [1].

In reference [9], the mechanism of high-speed compressor cascade corner separation control with plasma actuations was investigated.

Numerical simulations have been performed in order to investigate the control effects of the suction surface as well as the endwall plasma actuations in suppressing flow separation in a high-speed compressor cascade flow. The main flow structures related to the corner separation and the corresponding flow losses are firstly predicted in the absence of active flow control. Then the reduction of the corner separation flow structures through the implementation of suction surface and endwall plasma actuations are investigated. It was shown that plasma actuators improve the high-speed compressor cascade static pressure rise coefficient, while reducing the corresponding total pressure loss and blockage coefficients. In particular, the suction surface plasma actuators are suitable to suppress both corner separation vortex and airfoil separation, and they are more efficient than the endwall plasma actuators in terms of reduction of the total pressure losses However, the endwall plasma actuation is more efficient in the reduction of the flow blockage and improvement of the static pressure rise.

In reference [10], plasma actuators have been applied for the optimization of steady and unsteady airloads on a compressor cascade. Plasma actuators have been located both on the pressure and on the suction side of the blade trailing edge, in this way suction side plasma actuation reproduces the effects of mechanical wing spoilers, whereas pressure side plasma actuation acts as a mechanical Gurney flap.

Traveling wave mode simulations demonstrate that reductions in the peaks of the blade pitching moment can be obtained on the whole spectrum of interblade phase angles through a proper triggering of pressure/suction side actuation. Hence virtual control surfaces can provide effective load alleviation on the cascade, with potential remarkable reduction of fatigue phenomena.

The control of unsteady load is confirmed also in other recent studies [11], that demonstrate the feasibility of using multiple dielectric barrier discharge (multi-DBD) plasma actuators (PAs) as a novel approach for load alleviation and stability control of airfoils in unsteady flow.

As flow separation is a critical phenomenon for aircraft, flow separation control over airfoils is an important application, the effectiveness of asymmetrical and symmetrical plasma actuators for enhancing the aerodynamic performances of an airfoil is of great interest.

In reference [12], a DBD plasma actuator, attached near the leading edge of an airfoil and operating in burst mode, is shown to be very effective for controlling flow separation at a Reynolds number of 6.3×10^4, when applied to the flows at an angle of attack higher than the stall. In the paper, guidelines for the effective use of DBD plasma actuators are proposed. A DBD plasma actuator is also applied to the flows under cruise conditions. A simple airfoil with an attached DBD actuator presents a higher lift-to-drag ratio than a well-designed airfoil.

The high voltage waveform has a great effect on the control authority of the DBD plasma actuator. In reference [13], nanosecond pulsed dielectric barrier discharge (DBD) actuators have been installed on a NACA 0015 airfoil and the operation of the actuator at the dominant experimentally measured flow frequencies at stall conditions was shown to give good control authority.

In recent years, fluidic actuators as synthetic jet actuators have been investigated as suitable devices for a wide range of flow control applications.

Synthetic jet actuators are zero net mass flux devices, which modify lift and drag forces by altering the boundary layer and wake for a body in crossflow. Boundary layer modification is reached through a propagating train of vortices, which are created by an oscillating diaphragm within a cavity inside the body.

In reference [14], synthetic jet actuators and plasma DBD actuators have been compared in terms of active separation control performance on a highly loaded subsonic compressor stator cascade.

The plasma actuator is slightly more efficient for the reduction of flow separation in the region just downstream of the blade actuators. However, at the same mechanical power delivered by the actuator to the fluid, the synthetic jet actuator SJAs are more advantageous than the continuous jet actuator CJAs and slightly outperform plasma actuator application from the pressure loss reduction and pressure rise viewpoints. The fluidic jets have low power requirements, whereas the power consumption would be prohibitive for the PA configuration that shows low fluid mechanic efficiency.

Another area of interest, other than flow around streamlined airfoils or turbine blade, is flow control around bluff bodies such as large pylons, e.g., onshore wind turbines, tidal turbine mounts or the risers used for offshore platforms, deep-water wind turbines or bridge sections. Synthetic jet actuators could modify the wake produced by a structure and hence reduce the magnitude and/or frequency that a structure oscillates at, with a beneficial effect on reducing the risk of failure.

In reference [15], a numerical study was performed to investigate the effect of varying synthetic jet actuation frequency on drag and lift coefficients, pressure coefficient and the turbulence intensity in the wake of a circular cylinder in cross-flow.

A significant modification of the drag coefficient for a circular cylinder in cross-flow at Reynolds equal to 3900 is achieved by varying the actuation frequency of the synthetic jet.

The passive flow control has also been of great interest in many studies. Vortex generator, distributed roughness, streamlining, and uniform blowing and suction are among various devices that are employing for the passive flow control technique.

Vortex generators (VGs) are increasingly used, especially in the field of wind turbines, as flow control devices to improve rotor blade aerodynamic performance.

Nevertheless, VGs may produce excess residual drag in some applications. The so-called sub-boundary layer VGs can lead to a significant flow-separation control with lower drag than the conventional VGs. In reference [16], an investigation has been performed about how well the simulations can reproduce the physics of the flow of the primary vortex generated by rectangular sub-boundary layer VGs mounted on a flat plate with a negligible pressure gradient with an angle of attack of the vane to the oncoming flow of 18°.

The computational results show good agreement with the experimental data provided by the Advanced Aerodynamic Tools of Large Rotors (AVATAR) European project for the development and validation of aerodynamic models. Finally, the results indicate that the highest VG seems to be more suitable for separation control applications.

Finally, control of the flow could be also useful for heat transfer enhancement in heat exchangers. Thermal augmentation techniques can be divided into active and passive. The passive techniques with the tube inserts are most frequently used because they do not require the direct application of external power. Twisted tape is the most commonly used solution. The thermal augmentation of twisted tape is given by its ability to induce swirl flow and increase the turbulence intensity close to the tube wall, which can promote mixed flow from the near-wall and central regions.

In reference [17], the effects of ball turbulators (BTs) on the heat transfer and fluid friction characteristics in a circular tube are investigated through numerical simulation. The performance evaluation criterion (PEC) data underline that the use of a smaller ball diameter ratio and a smaller spacer length are preferred. The results also reveal that BTs with a larger diameter ratio and a smaller spacer length yield the highest heat transfer rate as well as the largest pressure loss. It was also shown the BTs outperform plain tubes in terms of fluid flow velocity near the tube wall.

In the field of active control, the development of control algorithms is a key issue. In reference [18] a new wind farm control algorithm that adjusts the power output of the most upstream wind turbine turbines to maximize the total power output and load decrease was implemented.

Author Contributions: All the authors contributed to writing—review and editing the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pescini, E.; Marra, F.; De Giorgi, M.G.; Francioso, L.; Ficarella, A. Investigation of the boundary layer characteristics for assessing the DBD plasma actuator control of the separated flow at low Reynolds numbers. *Exp. Fluid Sci.* **2017**, *81*, 482–498. [CrossRef]
2. Cui, J.; Nagabhushana Rao, V.; Tucker, P.G. Numerical investigation of secondary flows in a high-lift low pressure turbine. *Int. J. Heat Fluid Flow* **2017**, *63*, 149–157. [CrossRef]
3. Martínez, D.S.; Pescini, E.; De Giorgi, M.G.; Ficarella, A. Plasma-based flow control for low-pressure turbines at low-Reynolds-number. *Aircr. Eng. Aerosp. Technol.* **2017**, *89*, 671–682. [CrossRef]
4. Bons, J.P.; Sondergaard, R.; Rivir, R.B. The fluid dynamics of LPT blade separation control using pulsed jets. *J. Turbomach.* **2002**, *124*, 77–85. [CrossRef]
5. De Giorgi, M.G.; Ficarella, A.; Sciolti, A.; Pescini, E.; Campilongo, S.; Di Lecce, G. Improvement of lean flame stability of inverse methane/air diffusion flame by using coaxial dielectric plasma discharge actuators. *Energy* **2017**, *126*, 689–706. [CrossRef]
6. De Giorgi, M.G.; Sciolti, A.; Campilongo, S.; Ficarella, A. Flame structure and chemiluminescence emissions of inverse diffusion flames under sinusoidally driven plasma discharges. *Energies* **2017**, *10*, 334. [CrossRef]
7. Bao, A.; Utkin, Y.G.; Keshav, S.; Lou, G.; Adamovich, I.V. Ignition of ethylene-air and methane-air flows by low-temperature repetitively pulsed nanosecond discharge plasma. *IEEE Trans. Plasma Sci.* **2007**, *35*, 1628–1638. [CrossRef]
8. Starikovskaia, S.M. Plasma assisted ignition and combustion. *J. Phys. D* **2006**, *39*, R265. [CrossRef]
9. Zhang, H.; Yu, X.; Liu, B.; Wu, Y.; Li, Y. Control of corner separation with plasma actuation in a high-speed compressor cascade. *Appl. Sci.* **2017**, *7*, 465. [CrossRef]
10. Motta, V.; Malzacher, L.; Peitsch, D. Numerical Assessment of Virtual Control Surfaces for Load Alleviation on Compressor Blades. *Appl. Sci.* **2018**, *8*, 125. [CrossRef]
11. De Giorgi, M.G.; Motta, V.; Suma, A. Influence of actuation parameters of multi-DBD plasma actuators on the static and dynamic behaviour of an airfoil in unsteady flow. *Aerosp. Sci. Technol.* **2019**, *96*, 105587. [CrossRef]
12. Fujii, K. Three Flow Features behind the Flow Control Authority of DBD Plasma Actuator: Result of High-Fidelity Simulations and the Related Experiments. *Appl. Sci.* **2018**, *8*, 546. [CrossRef]
13. Skourides, C.; Nyfantis, D.; Leyland, P.; Bosse, H.; Ott, P. Mechanisms of Control Authority by Nanosecond Pulsed Dielectric Barrier Discharge Actuators on Flow Separation. *Appl. Sci.* **2019**, *9*, 2989. [CrossRef]
14. Traficante, S.; De Giorgi, M.G.; Ficarella, A. Flow separation control on a compressor-stator cascade using plasma actuators and synthetic and continuous jets. *J. Aerosp. Eng.* **2016**, *29*, 04015056. [CrossRef]
15. McDonald, P.; Persoons, T. Numerical Characterisation of Active Drag and Lift Control for a Circular Cylinder in Cross-Flow. *Appl. Sci.* **2017**, *7*, 1166. [CrossRef]
16. Fernandez-Gamiz, U.; Errasti, I.; Gutierrez-Amo, R.; Boyano, A.; Barambones, O. Computational Modelling of Rectangular Sub-Boundary Layer Vortex Generators. *Appl. Sci.* **2018**, *8*, 138. [CrossRef]
17. Yuan, W.; Fang, G.; Zhang, X.; Tang, Y.; Wan, Z.; Zhang, S. Heat Transfer and Friction Characteristics of Turbulent Flow through a Circular Tube with Ball Turbulators. *Appl. Sci.* **2018**, *8*, 776. [CrossRef]
18. Kim, H.; Kim, K.; Paek, I. Model based open-loop wind farm control using active power for power increase and load reduction. *Appl. Sci.* **2017**, *7*, 1068. [CrossRef]