Surface Dielectric Barrier Discharge Plasma Actuators for Anti-icing: A Novel Icing-control Approach Using Coupled Aerodynamic and Thermal Effects

Xuanshi Meng[1,*] and **Jinsheng Cai**[1]

[1]Department of Fluid Mechanics, Northwestern Polytechnical University, Xi'an, China
[*]corresponding author: mxsbear@nwpu.edu.cn

Abstract Prevention of ice accretion on the aerodynamic components has been a topic of great concern in the aerospace community. The breakthrough of the significant technology in the area of aerodynamics, materials, and power raised many challenges on the current anti/de-icing methods. Plasma flow control has received growing research attention as an active flow control technique. One such development is the use of surface dielectric barrier discharge (SDBD) plasma actuators driven by an alternating current (AC) source for active flow control. A novel approach for anti-icing using the AC-SDBD plasma actuators is proposed. Research on the icing control using the AC-SDBD plasma actuator is reviewed in this paper based on plasma actuator characterization and the icing control tests in the icing wind tunnel over the cylinder and airfoil models.
Keywords: surface dielectric barrier discharge plasma, icing control, flow control, thermal effect

1 Introduction

Icing accumulation on aircraft can degrade the aerodynamic performance significantly, by reducing the lift while increasing drag. Prevention of ice accretion on the aerodynamic components has been a topic of great concern in the aerospace community. The breakthrough of the significant technology in the area of aerodynamics, materials, and power raised many challenges on the current anti/de-icing methods. The novel methods and techniques for more efficient anti/de-icing performance are considered desirable.

With breakthroughs of the significant technology in the area of aerodynamics, materials, and power, there are many challenges on the current anti/de-icing methods, and these are mainly reflected in the following aspects:

1) New composite technologies. The next generation of aircraft will use a large number of composite materials or all composite materials. The composite is temperature sensitive. Generally, using hot air (current anti-icing method) to prevent ice, a layer of the metal plate is often applied to the surface of the composite material for protection. However, the plasma discharge is self-sustaining;

2) All-electric engine technologies. Conventional hot air anti-icing requires the introduction of hot air from the engine. Once the engine is an all-electric engine, the hot gas system is no longer suitable;

3) New aerodynamic technologies. The laminar flow drag reduction technology used in the next generation of aircraft requires that there should be no steps and slots on the surface of the aircraft. Traditional mechanical deicing or hot air deicing is designed with steps or seams, which is not suitable for laminar flow design.

Current anti-icing methods would be not suitable for the next-generation aviation systems based on the new aviation technologies. An innovative approach to control the icing on these new aircraft, which depends on the plasma actuators, is proposed by plasma flow control team from Northwestern Polytechnical University in China.

Plasma flow control has received growing research attention in recent years. One such development is the use of surface dielectric barrier discharge (SDBD) plasma actuators driven by an alternating current (AC) source for active flow control. The AC-SDBD plasma actuator is composed of two electrodes separated by a dielectric material arranged in an asymmetric fashion. Application of a sufficiently high-voltage AC signal between the electrodes weakly ionizes the air over the dielectric covering the encapsulated electrode. The ionized air, in the presence of the electric field, results in a body force vector that acts on the ambient air, therefore induce a velocity field. Such induced air flow can be modulated to achieve active aerodynamic control.

On application of high voltage to the plasma actuators, most of the power is converted into heat and the rest is converted into an induced flow or ionic wind over the actuator, so the plasma actuator has both wind aerodynamic and heat effects.

Noticing the aerodynamic and thermal effects of the AC-SDBD plasma actuator, a novel approach for anti-icing using the AC-SDBD plasma actuators is proposed by Cai and Meng, et al., of Northwestern Polytechnical University. The concept is to achieve the flow control and icing control using the same set of equipment, i.e., the plasma actuator. The actuator is used for icing control in icing conditions and for flow control in non-icing environments. Plasma icing control technology almost satisfies all the icing control requirement of the next generation aircraft:

1) In the flight environment, the temperature does not exceed the limit temperature of the composite material, so it has a good protection effect on the composite materials;

2) The plasma actuator is purely electrically driven, so it fully meets the needs of electric aircraft;

3) The surface of the plasma actuator can be made very smooth to meet the needs of laminar flow control. Moreover, when the plasma actuator is used for flow control, it can be used as a boundary layer control technique itself.

The team of Northwestern Polytechnical University began to study the effect of plasma on icing in 2012 after a very simple but historic experiment: an ice cube taken out of the refrigerator was placed in the discharge area of the plasma exciter, which proved that under high pressure, the ice would not cause the plasma actuator to short-circuit, but it can change the path of the discharge and, most importantly, the ice cubes melt quickly.

The team reported on the work plan at the 2nd NPU-DLR Workshop on Aerodynamics meeting in Braunschweig, Germany in May of 2014. In August of 2014, the team demonstrated through a cylindrical model in the ice wind tunnel that the plasma actuators are effective and efficient in preventing ice and deicing in an icing environment[1, 2]. Zhou et al.[4] performed the study over an airfoil model using SDBD plasma actuator for icing mitigation. The results demonstrated that the actuators can be used as a promising anti-icing tool for realistic aircraft configurations. Tian et al.[3] showed an effective icing control using a pulsed dielectric barrier discharge plasma actuation with a free stream velocity of 90 m/s, which exhibits high possibility of the real application of SDBD plasma actuation in preventing aircraft icing in flight. Liu et al.[5] studied the duty-cycled technique effects on the plasma icing control and showed that power can be significantly reduced using duty cycle technique.

To reveal the physical mechanism of coupled aerodynamic and thermal effects on anti-icing and then provide a criterion for plasma actuator optimization, Meng et al. [6] designed three different types of actuators to generate the induced air flow in different directions to the incoming flow. The results show that the optimal design needs to generate as much heat locally, while mixing well with the incoming airflow. Such results have inspired us to engage in a new study: the coupling effect of plasma aerodynamic effects and thermal effects.

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