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Estimation and Validation of Cooling Effect by DBD Plasma Actuator

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Extended Abstract

A plasma actuator is an active flow control device that utilizes atmospheric pressure dielectric barrier discharge (DBD). It consists of two asymmetric electrodes separated by a dielectric layer: one electrode is exposed to the atmosphere, while the other is covered by the dielectric material. When a high-voltage alternating current is applied between the electrodes, discharge occurs and induces an airflow along the surface. Due to its simple structure with no mechanical moving parts and no pressure loss caused by installation, the plasma actuator is considered a promising technology for applications in forced convection cooling[1]. However, there are two major challenges in applying plasma actuators to thermal management. The first is that the actuator generates heat due to the discharge [2], and it is necessary to identify the design parameters contributing to this heat generation. The second challenge is the insufficient understanding of the actuator's heat transfer coefficient. As mentioned above, the plasma actuator heats the airflow, so to determine the heat transfer rate, the airflow temperature needs to be measured. However, accurate temperature measurements near the high-voltage electrode are difficult due to noise from the electric field. Therefore, in this study, we estimate both the airflow temperature and the heat transfer coefficient simultaneously and evaluate the validity of the estimation.

This study aims to quantitatively determine the heat transfer coefficient of the flow induced by the plasma actuator and the amount of heat added to the airflow. To this end, the transient response method was employed to measure the heat transfer coefficient. This method estimates the heat transfer coefficient from a theoretical expression by observing the temporal variation in wall temperature exposed to a high-temperature flow. The theoretical expression used is the analytical solution for one-dimensional heat conduction inside the actuator. Since the airflow temperature is unknown, but by combining it with Fourier's law, the unknown quantity is treated as the wall heat flux. The wall heat flux was calculated using a two-dimensional heat conduction simulation with the measured wall temperature as a boundary condition. An infrared camera was used to measure the wall temperature, and measurements were conducted under various conditions, including dielectric thickness, applied voltage, and external flow velocity. Furthermore, velocity and temperature fields were measured using Particle Image Velocimetry (PIV) and Background Oriented Schlieren (BOS) techniques to validate the estimation results.

As a result, the estimated distribution of the heat transfer coefficient resembled the velocity field, and the estimated airflow temperature distribution qualitatively agreed with the BOS measurements. However, the temperature field obtained via BOS was lower than the wall temperature, suggesting that pressure field variations cannot be neglected. Additionally, the estimated heat transfer coefficient distribution contained noise, highlighting the challenge of noise reduction when incorporating experimental data as boundary conditions in the heat conduction simulations. In this presentation, we address these issues and report improved estimation results for the heat transfer coefficient.

References

[1] S. Uehara and H. Takana, "Surface cooling by dielectric barrier discharge plasma actuator in confinement channel," *J. Electrostat.*, vol. 104, p. 103417, Mar. 2020.
[2] R. Tirumala, N. Benard, E. Moreau, M. Fenot, G. Lalizel, and E. Dorignac, "Temperature characterization of dielectric barrier discharge actuators: influence of electrical and geometric parameters," *J. Phys. D Appl. Phys.*, vol. 47, no. 25, p. 255203, May 2014.