Simulation of Neutral Flow around Plasma Actuator

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ABSTRACT

Numerical simulations were carried out of the effects of momentum and heat produced by a plasma actuator on neutral flow. Momentum and heat generated during plasma discharge were modeled as a body force and heat source using results of experiments and DSMC of particle. These force and heat model were inserted into a Navier-Stokes equation and the flow around the plasma actuator could be explored by solving fluid dynamics only. Fluid simulation showed that force produced in DSMC generated a jet flow in the vicinity of the plasma actuator and heat accounted for density change.

INTRODUCTION

Plasma actuator have demonstrated the capability to apply to boundary layer control of separated flow of airfoil with high angle of attack[1], low-pressure turbine blade[2], and vortex control of body with blunted trailing edge[3], etc. Experiments and simulations have shown that plasma actuator imparts momentum to the boundary layer flow and promote boundary layer attachment.[4,5] Figure 1 illustrates the configuration of plasma actuator, which is a rather simple and a device of the dielectric barrier discharge configuration with two electrodes, one buried and the other exposed to air. The electrodes are subjected to an alternating current of several thousands volts at a frequency in up to tens of kilohertz.

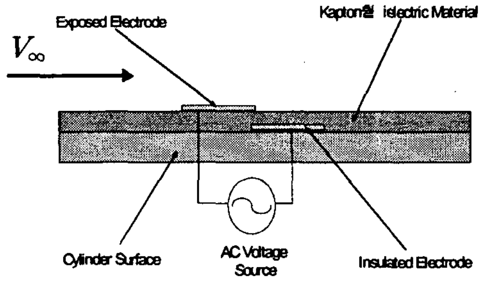

Figure 1. Configuration of plasma actuator

FORCE AND HEAT MODEL

Figure 2. shows a temporal distribution of force during one cylce of 5kHz alternating current applied to the plasma actuator. The initial discharge produces a negative force and the second discharge produces a positive force acting as thrust. The total integrated force was scaled to

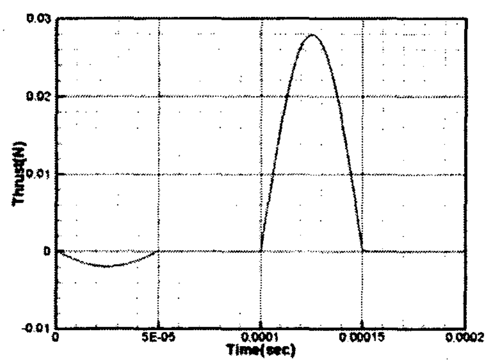

Figure 2. Temporal Distribution of Force produced by Plasma Actuator

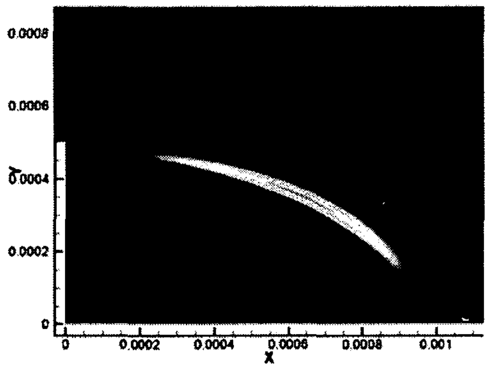

Figure 3. Spacial Distribution of Force produced by Plasma Actuator

produce an average force of about 1.5mN, which is representative of the experiments.

Spacial distribution of force was determined from the results of DSMC of air molecule during discharge[6]. Domain, where plasma exist and accelerate, is shown in figure 3 and force are concentrated in the center region.

NUMERICAL ANALYSIS

In order to analyze the neutral flow around the plasma actuator, this modeling approach for force and heat produced by plasma actuator is implemented in the FLUENT. Grid for the computation domain, 40 cm long and 20 cm high, is shown in Figure 4 and flow was assumed to be laminar.

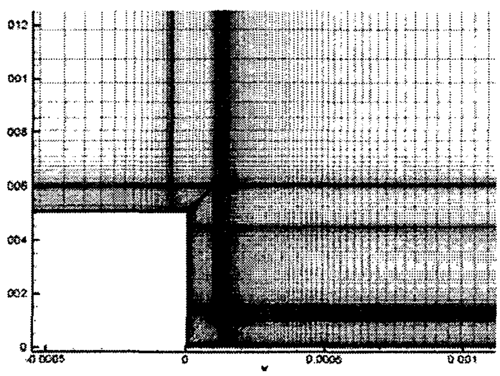

Figure 4. Grid near the edge of the exposed electrode

The force and heat was applied as a momentum and heat source to air which was not moving initially. A 2nd order time-accurate Newtonian sub-iteration scheme was applied to get unsteady feature of air flow. 200 time steps were put in one cycle of 5 kHz alternating current so the size of time step had to be $1\mu s$. Even with 2D simulation, parallel computing were needed because millions of iteration should be carried out to reach the converged status of unsteady solution.

Figure 5. shows velocity magnitude of time-averaged solution during one cycle at 45ms after plasma actuator initiation. Temperature distribution near the edge of the exposed electrode is shown in figure. 6, which shows temperature rise of about 20K.

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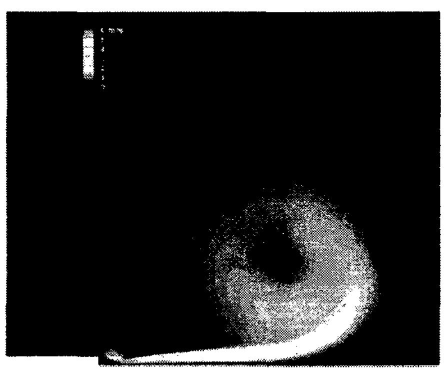

Figure 5. Velocity Magnitude Contours at 5kHz

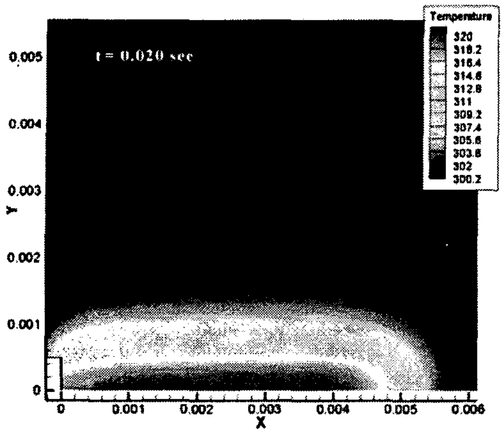

Figure 6. Temperature Distribution for 10W at 5kHz

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