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# Analytical Model: Characteristics of Nanosecond Pulsed Plasma Synthetic Jet Actuator in Multiple-Pulsed Mode

Zheng Li, Zhiwei Shi* and Hai Du

*College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*

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**Abstract.** Multi-field coupling simulation method based on the physical principles is used to simulate the discharge characteristics of nanosecond pulsed plasma synthetic jet actuator. Considering the effect of the energy transferring for air, the flow characteristics of nanosecond pulsed plasma synthetic jet actuator are simulated. The elastic heating sources and ion joule heating sources are the two main sources of energy. Through the collisions, the energy of ions is transferred to the neutral gas quickly. The flow characteristics of a series of blast waves and the synthetic jet which erupt from the plasma synthetic jet (PSJ) actuator are simulated. The blast wave not only promotes outward, but also accelerates the gas mixing the inhaled gas from the outside cavity with the residual gas inside the cavity. The performances of PSJ actuator fluctuate in the first three incentive cycles and become stable after that.

**AMS subject classifications**: 93A30, 76L05, 76N25, 76X05, 82D10

**Key words**: PSJ actuator, discharge, single-pulsed, multiple-pulsed, blast wave, jet.

## 1 Introduction

Active flow control (AFC) actuators have shown promise in manipulating flow to alter given flow fields in a positive manner. The interaction of micro-actuators with the external cross flow over the surface can influence the boundary layer to improve the flow environment on the surface or around the flight vehicles. These performances have many benefits, for example, improving aircraft maneuverability, reducing drag, improving lift, controlling unsteady flow and even replacing the control surfaces. Most of AFC actuators have been well characterized and used in low speed applications ($<100$m/s), for instance, synthetic jets [1], dielectric barrier discharge (DBD) plasma actuators [2], micro electromagnetic system (MEMS), circulation control and shape memory alloys [3]. However, only a few of AFC actuators can be used in high-speed (transonic, supersonic) flow

*Corresponding author.
*Email:* szwam@nuaa.edu.cn (Z. W. Shi)

 

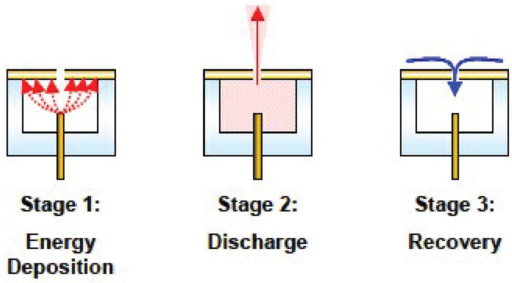


Figure 1: Periods of PSJ actuator [13].

environments, including steady microjets [4,5], resonance enhanced microjets (REM) [6], and localized arc filament plasma actuators (LAFPA) [7–12].

Although aforementioned actuators, which are used to control high-speed flows, have shown some promising characteristics, they still have some deficiencies. A novel ACF actuator, PSJ actuator, is developed by the Johns Hopkins University Applied Physics Laboratory (JHU/APL) [13–16]. The schematic of the PSJ actuator is seen in Fig. 1. It can truly realize the potential of unsteady actuation and make flow control become practical.

PSJ actuator creates a high energy arc inside the cavity instantly, which results in a high pressure and high temperature zone almost instantaneously. Then the excited gas exits the cavity through a small orifice with supersonic speeds which can penetrate supersonic boundary layers. Later the outside air flow into the cavity and the PSJ actuator prepares for next discharge. Since the jet frequency is the same with the discharge, PSJ actuator has a wide operation scope that is about kHz range. So it can perform at frequencies that are inherent in the base flows in order to take advantage of the flow instabilities/time-scales [17].

Both of computational analyses and experimental demonstrations indicate that the PSJ actuator has a strong jet ($>$100m/s) with a high frequency ($>$1kHz). So it has been widely used for controlling supersonic boundary layers, inducing a shock wave, and inducing aerodynamic noise and so on. K. R. Grossman et al. indicate that smaller orifice diameter and cavity volume, and larger deposition energy can improve single-shot PSJ actuator's performance [18]. B. Z. Cybyk et al. have developed an analytical model of the PSJ actuator using the energy equation to refine the model until the calculated results of the analytical model are in close agreement with the experimental data. They measured jet flow field by Particle Imaging Velocimetry (PIV) and vortex field by Digital Speckled Tomography (DST) in quiescent air [15,16,19]. S. J. Haack et al. measured the pressure fluctuation inside the PSJ actuator by using Kulite dynamic pressure sensor and got the peak pressure about 18atm. They also got an analytical solution to evaluate the performance of actuator indicating that 35% efficiency factor of PSJ actuator has a good agreement with the experiment [20].

Although previous simulations for PSJ actuator have revealed some characteristics, they are almost for a single-pulsed jet and millisecond pulse discharge [14,20–23]. PSJ ac-