Investigation of Bow Shock Dispersion on a Blunt Body by Counterflow Pulsed-Plasma Jets

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ABSTRACT

Ongoing worldwide interest for interplanetary travel has resurrected research on Apollo-like capsule modules. One of the most significant technical challenges of space exploration is controlled entry and re-entry of blunt bodies where considerable kinetic energy is dissipated as the spacecraft decelerates and enters planetary atmospheres. Traditionally, one such solution to avoid high heat load on stagnation points of the vehicle, was to design the nose as a blunt body. Although this modification reduces the surface heat transfer rate, a trade-off begins with the drag force experienced by the vehicle. Such a compromise has sparked an investigation at the University of New South Wales aerodynamics laboratory in various drag reduction techniques, in particular, counter-flow control methods. Among these methods of drag reduction technologies, injection of a pulsed-plasma counter-flow jet from the stagnation point to alter the flow field ahead of the nose is a promising method to significantly disperse or weaken the shockwaves on high speed vehicles.

To date, the plasma actuators that have been developed have relied on single dielectric barrier discharge (DBD) using electro-hydrodynamic (EHD) forces, magneto-hydrodynamic (MHD) forces and electro-thermal heating as flow control mechanisms. The main shortcoming of DBD actuators is the relatively small actuation effect as characterized by the induced velocity, where velocities greater than 10m/s are not possible. Alternatively, there has been strong interest in the application of pulsed plasma jets for reduction of heat flux and wave drag of vehicles in supersonic and hypersonic flows. More recent work has revealed that plasma jet actuators into high speed flows produce various shock reduction and other beneficial effects.

A pulsed-plasma jet operates by creating an electrical discharge across two electrodes within a cavity. The electric discharge results in an immediate build-up of heat and pressure which in turn transforms the gas in the cavity into plasma. This high pressure plasma is then released through a small orifice; forming the plasma jet. It has been understood that the exit velocity of the plasma is directly related to the pressure within the cavity. This pressure has been attributed to the intensity of energy placed onto the gas through electro thermal heating. Following the ejection of the plasma, a rarefaction wave draws gas back into the cavity whereby the process is repeated. Due to

the fact that no gas supply is required for this process, the pulsed-plasma jet is considered a synthetic jet with zero net mass flux across the orifice.

The plasma jet tested, initially inspired by the ‘spark jets’ developed by Cybyk et al, is similar to the jet designed by V. Narayanaswamy et al in their research with flat-surface shock wave boundary layer interaction (SWBL). The main advantage of this jet is that it can generate high exit velocities in the range of 250-350 m/s with low power consumption levels.

A cylindrical cavity of 2.3mm diameter was made from Renshape (*k*=2.5) made to fit flush into an Apollo capsule model. Copper electrodes (2.3mm) are inserted from opposing sides to enclose the cavity. The gap between the electrodes was fixed at 5mm resulting in a cavity volume of 83.1mm^3. A small hole of 1.7mm diameter was drilled in the middle of the cavity. This pulsed-plasma jet was placed flush in a 0.785% scale model Apollo capsule. Discharges were formed across the electrodes using a high voltage DC power supply. Pulsing was achieved with a high frequency MOSFET switch to sustain kilohertz frequencies. Experimental work was conducted in an intermittent blow-down type supersonic wind tunnel. The wind tunnel incorporates a closed test section 13.97cm x 10.16cm wide, operating at an air speed of Mach 3. The wind tunnel is operated from a compressed air supply provided by two 150 hp compressors.

Two mirror parallel path Schlieren system is used to visualize flow actuation by the discharge with and without supersonic counter-flow. The Schlieren method was a Z-type technique which depends on air density changes, which are very pronounced across shockwaves. The Schlieren images were captured using a high speed digital camera with a framing rate of 1000 frames per second.

The objective of this paper is to characterize the performance of the pulsed plasma jet to establish its suitability as a supersonic counter-flow actuator on the Apollo module. To this end, we assess the momentum of the pulsed plasma jet by studying its penetration into the Mach 3 counter-flow. We then characterize the properties of the pulsed plasma jet actuator. The characterization included current/voltage measurements, high speed Schlieren imaging and pressure tapping points as well as optical emission spectroscopy for temperature and heat flux data. The preliminary experiments show promising results of bow shock dispersion and its subsequent impact on the spacecraft aerodynamic performance (*L*/*D*) and heat transfer in atmospheric re-entry. The obtained results, therefore, suggest that counter-flow jets are a viable candidate technology concept that can be employed to give significant reductions in wave drag, heat flux, and other attendant aerodynamic benefits.