Next-Generation Plasma Actuators for Turbulent Drag Reduction

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Introduction

Dielectric barrier discharge (DBD) plasma actuators are low power electrical devices which can harness induced jet flows to reduce skin friction drag at the surface of aerodynamic vehicles [1]. Drag reduction provides both economical and environmental benefits through significant fuel savings and lowered CO_2 emissions.

Aim: Develop next-generation DBD plasma actuators which can tame the turbulence flowing over aerodynamic vehicles.

Design

The annular actuator has one mode of operation – all on or off. Each electrode on the linear actuator can be independently operated; this gives rise to both wall-normal and spanwise modes of operation.

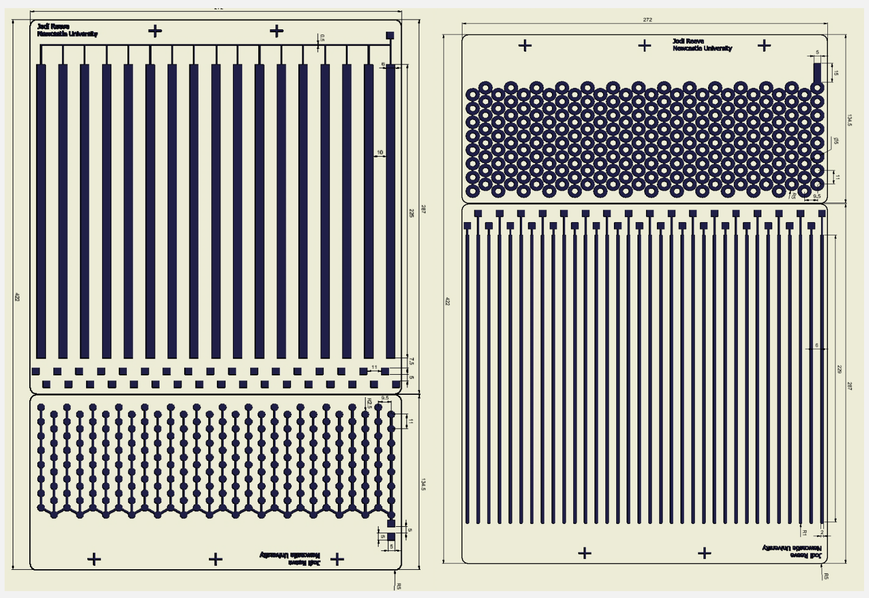

Figure 1 – Engineering drawings of top and bottom actuator designs.

The actuators were manufactured by copper cladding and etching cirlex sheets. Plasma was formed when a high voltage was applied across the upper electrodes.

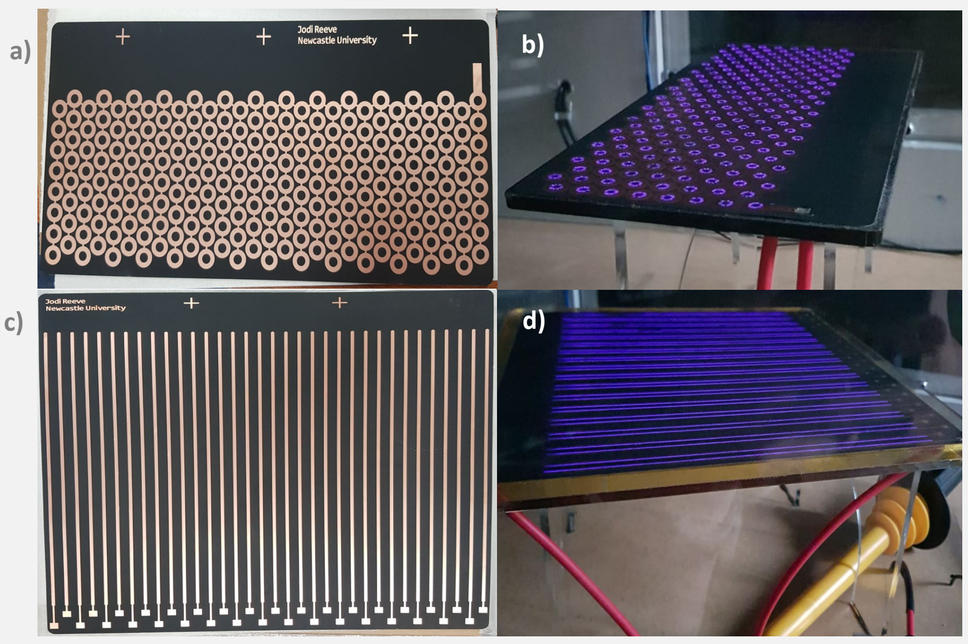

Figure 2a – Copper cladded annular actuator. 2b – Annular actuator plasma formation. 2c – Copper cladded linear actuator. 2d – Linear actuator plasma formation.

Results and Discussion

Instantaneous power was derived from the product of the voltage and current waveforms. The average power was then determined using the trapezium rule.

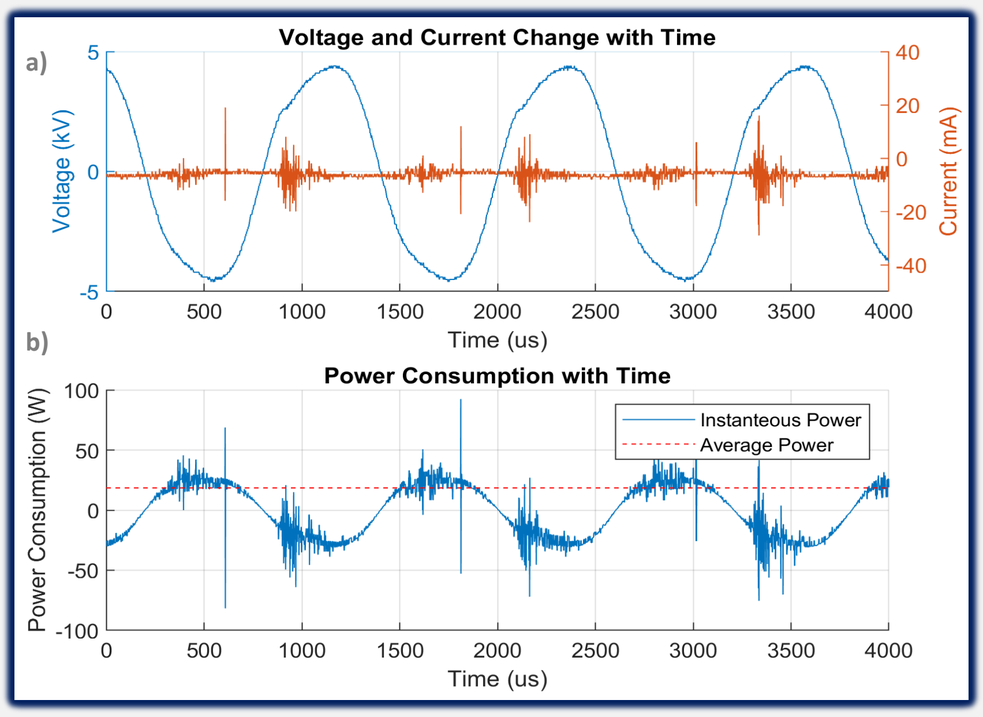

Figure 3a – Time waveforms of voltage and current signals at 8.3 kHz and 7.2 kVpp. 3b – Instantaneous power-time waveform.

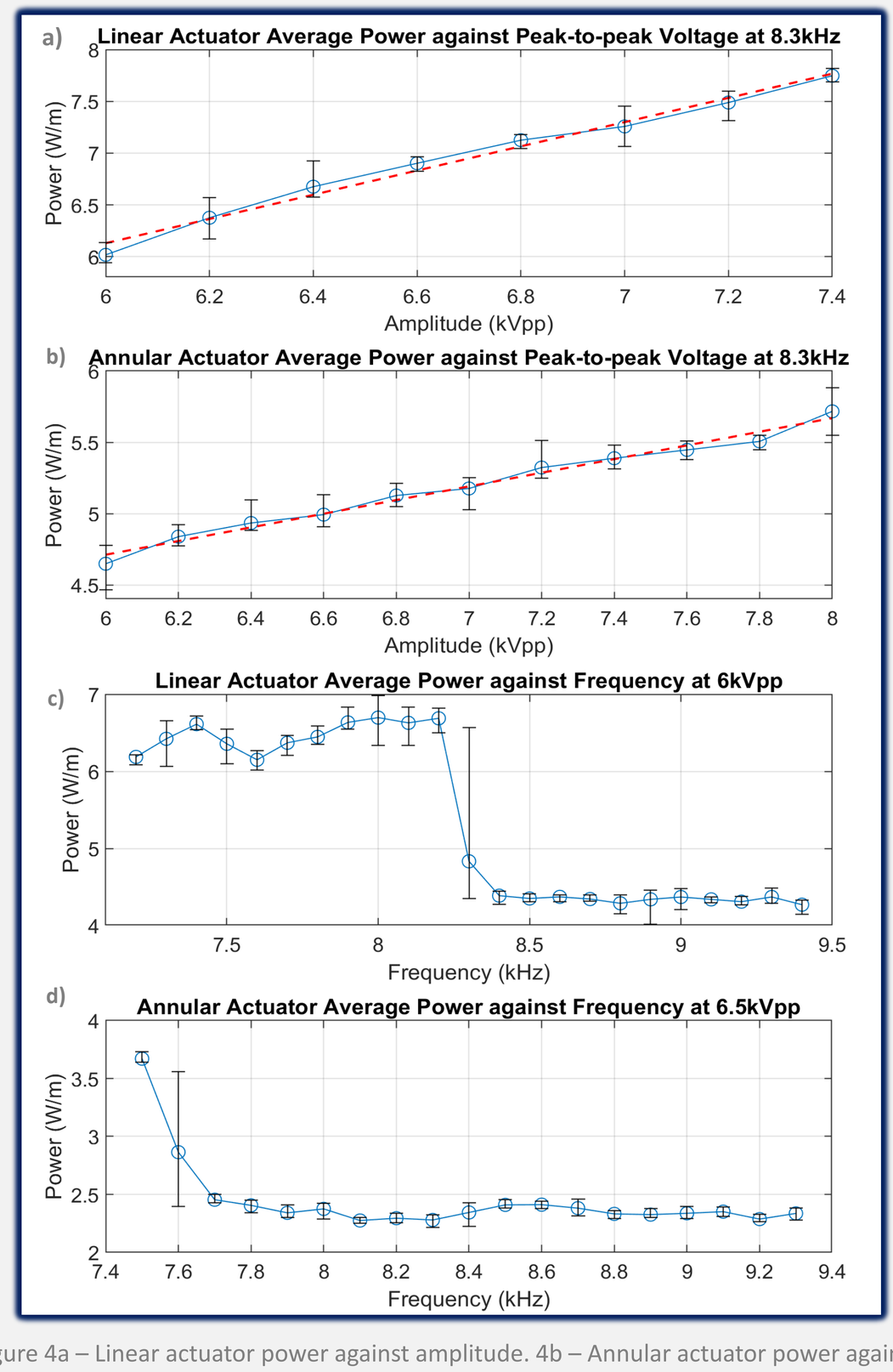

Figure 4a – Linear actuator power against amplitude. 4b – Annular actuator power against amplitude. 4c – Linear actuator power against frequency. 4d – Annular actuator power against frequency.

A positive relationship exists between power and amplitude and results are comparable to the work of Eid et al [2] and Benard [3]. The annular actuator consumes less power than the linear. Both actuators experience a significant power drop at specific frequencies. For the linear actuator, frequencies above 8.4kHz will yield a lower power consumption (at 6kVpp). The annular actuator exhibits the same drop in power at frequencies exceeding 7.7kHz (at 6.5 kVpp).

Conclusions

Plasma actuators were successfully developed, and power consumption results are comparable with literature. The annular design proved to be more efficient than the linear design as it requires less power to form plasma uniformly.

Future Work

- Velocity measurements should be taken in both quiescent air and in a wind tunnel.
- Mechanical devices exploiting a microblowing technique could be developed, such as those modelled in Figures 5a and 5b.

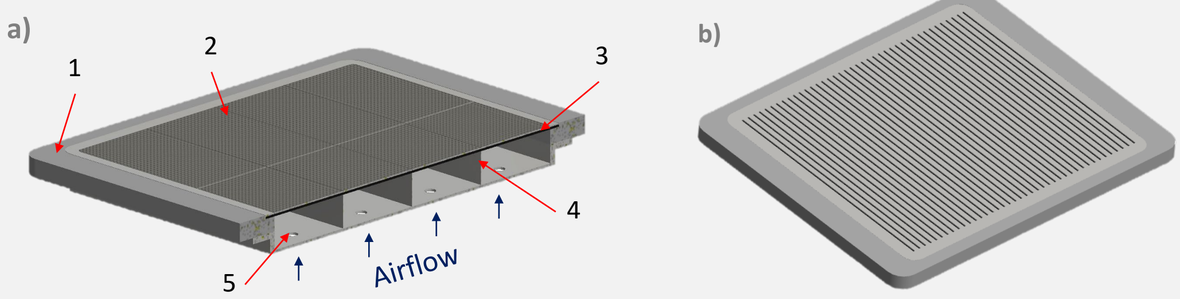

Figure 5a – Perforated microblowing concept model for wall normal blowing (1 – Flat plate, 2 – perforated insert plate, 3 – filter, 4 – chamber dividers, 5 – airflow ports, controlled by variable valves). 5b – Slotted flatplate for spanwise blowing.

References:
[1] Whalley, R. and Choi, K. (2012). The starting vortex in quiescent air induced by dielectric-barrier-discharge plasma. Journal of Fluid Mechanics, 703, 192-203.
[2] Eid, A. et al (2015). Experimental Study of Dielectric-Barrier-Discharge Reactor for Plasma Assisted-Combustion. International Journal of Plasma Environmental Science and Technology, 9(2).
[3] Benard, N. and Moreau, E. (2014). Electrical and mechanical characteristics of surface AC dielectric barrier discharge plasma actuators applied to airflow control. Experiments in Fluids, 55(11).