

## Electrohydrodynamic Methods for Fluid Flow Control

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### Introduction

- "Electrohydrodynamics" encompasses the study of electrically charged fluids. Recent studies have been focusing on methods/devices that can manipulate fluid flows as a result of their electrohydrodynamic (EHD) properties.
- In future these devices could replace the current heavy and drag inducing control surfaces and actuators on modern aircraft, reducing drag and thus lowering fuel consumption.
- Active flow control has already been proven to be effective on small scale projects e.g. DEMON UAV aircraft which performed world first "flapless" flight using blown jets. The same result could be achieved using electrohydrodynamic methods.
- Future research here will focus on the further understanding of electrohydrodynamic devices focusing on those discussed below. The eventual aim being to apply these to supersonic and hypersonic flows with the focus on applications that would improve efficiency of new supersonic transport for example. These experiments will be carried out in the newly opened compressible wind tunnel facilities at the University of Glasgow.

### Nanosecond Dielectric Barrier Discharge (NS-DBD) Plasma Actuators

- A basic DBD actuator geometry is shown in (figure 1). For high speed flows the actuator functions using an input signal in the kV's region with a nanosecond pulsed frequency.
- This input signal allows the actuator to rapidly heat the air through joule heating [1].
- This rapid temperature increase creates a blast wave followed by expansion waves, the means by which this actuator controls the flow.
- This technology is applicable to both subsonic and supersonic flows.
- Possible applications include but are not restricted to: modification of shock wave location [2], increasing bow shock stand-off distance [3] and boundary layer control [4].
- Future work is interested in the effects of using different electrode geometries on the discharge (examples shown in figure 2) and the operational efficiency of the actuators.

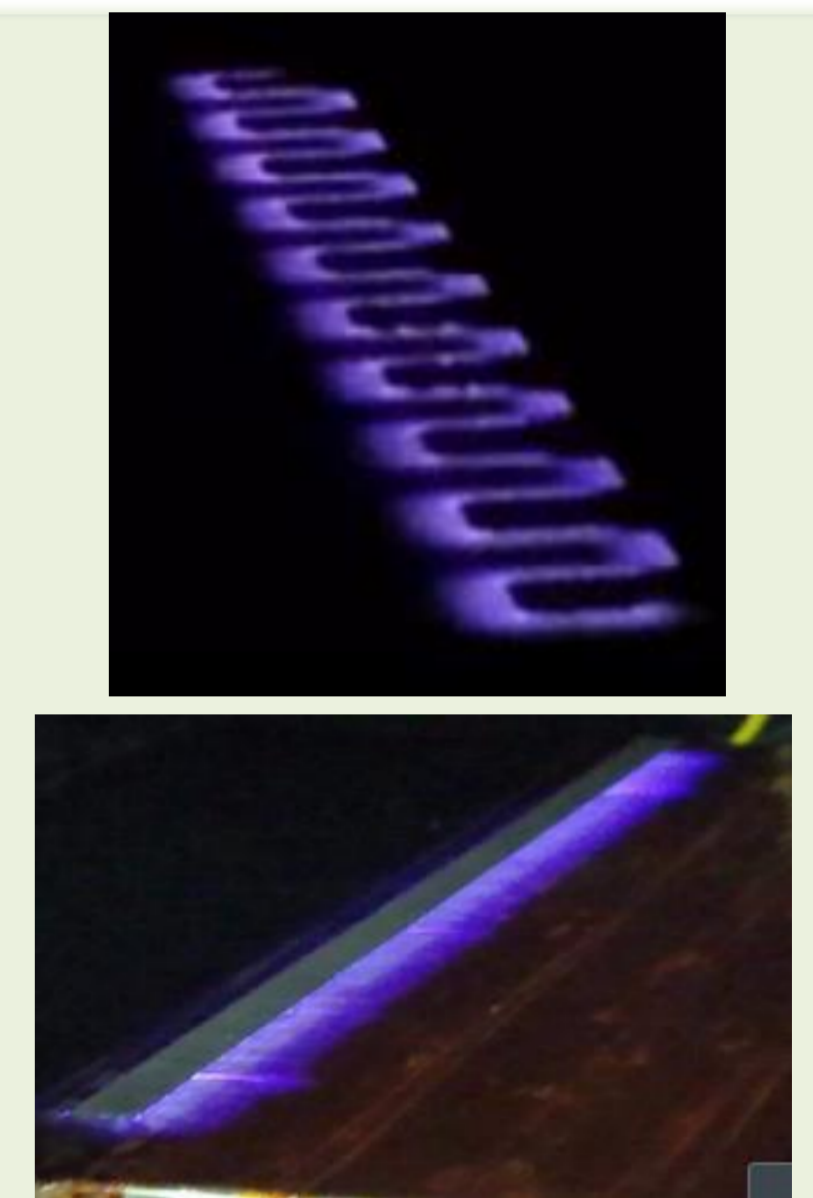
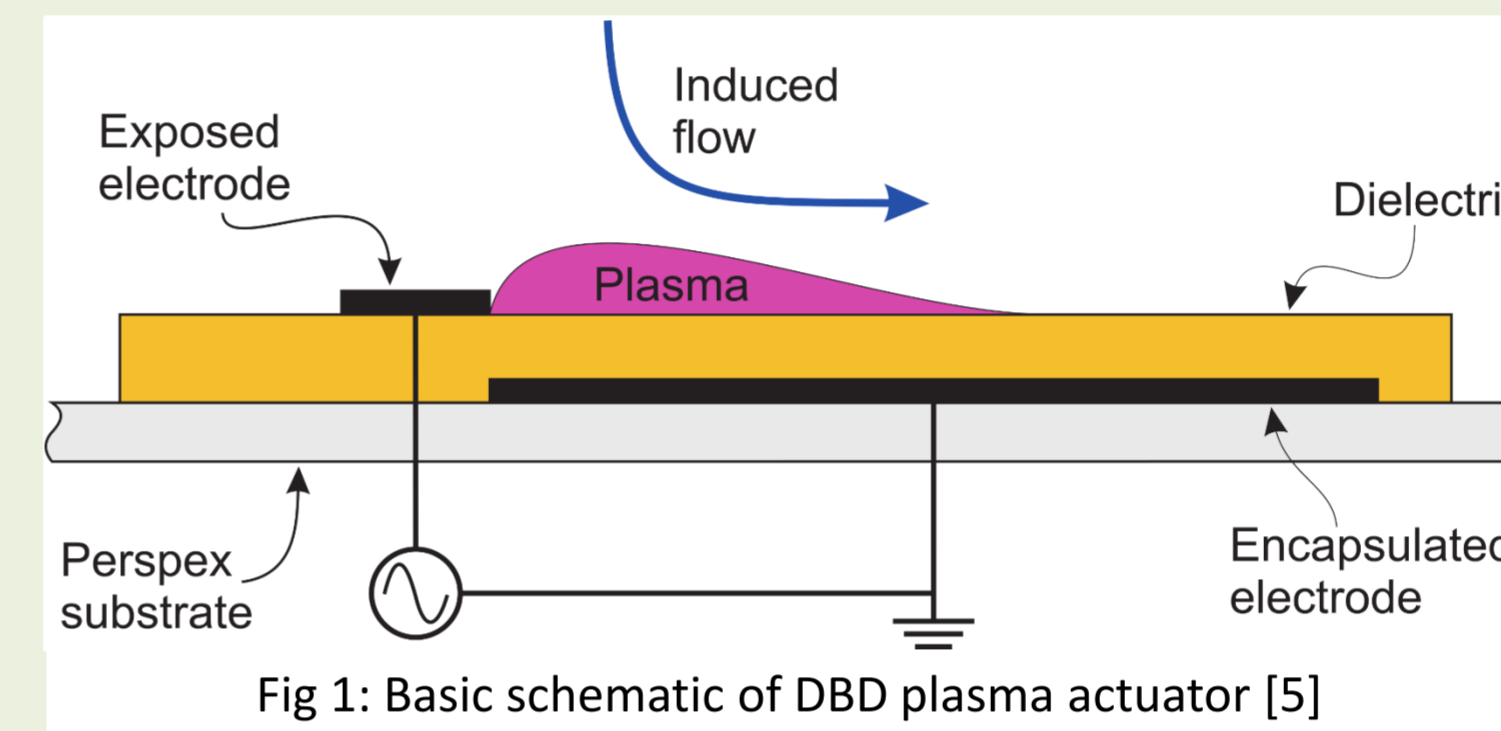


Fig 2: Examples of Serpentine (top) and linear DBD plasma actuator (bottom), generated plasma is the purple region [5]

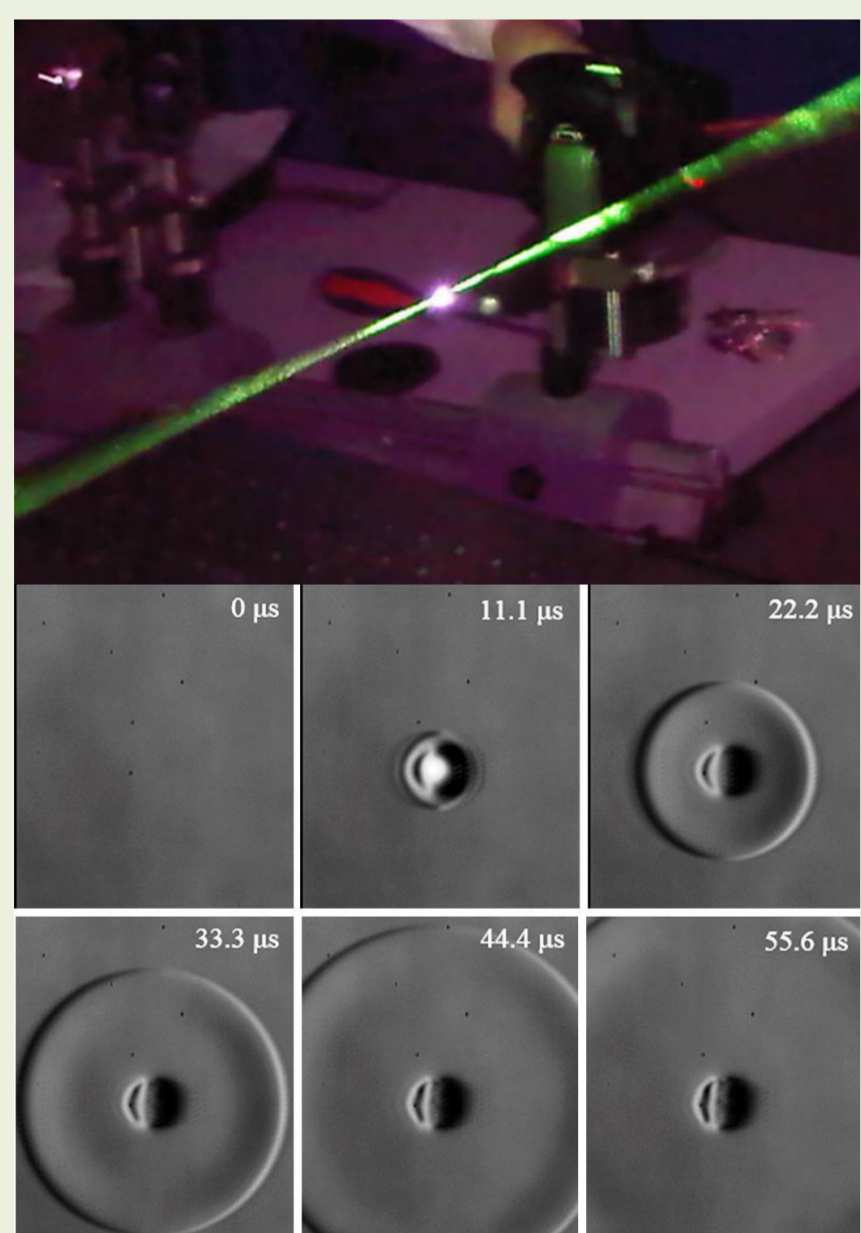


Fig 3: Top - Laser generated spark (bright white region) Bottom - Schlieren of resulting blast wave from a bird's eye perspective[5]

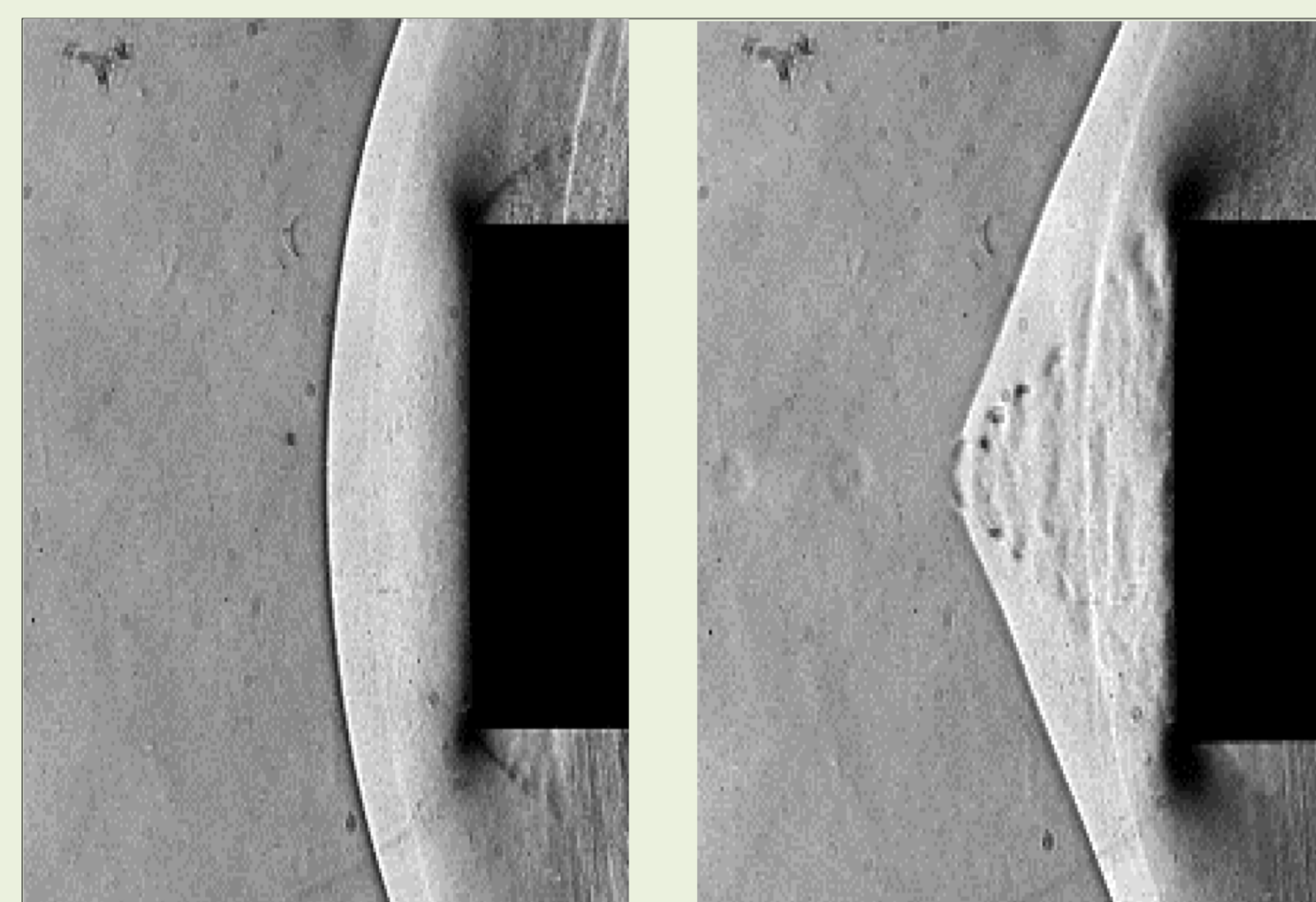


Fig 4: Schlieren images of the interaction between a bow shock and blast waves created by laser energy deposition (baseline case left and laser energy deposition case right)[5]

### Laser Energy Deposition

- The method in which the device can control supersonic/hypersonic flow is similar to the nanosecond pulse DBD actuator. The intense, focused laser radiation causes joule heating of the air and creates a blast wave. An example of the laser spark and resulting blast wave can be seen in figure 3. The main advantage here in comparison to DBD actuators is the ability to provide flow control from a distance. Therefore laser energy deposition can be considered to be nonintrusive whereas DBD actuators intrusive to varying degrees dependant on the design.
- Studies have been carried out to investigate the use of pulsed laser energy deposition for bow shock drag reduction (see figure 4 for example of laser energy deposition effect on bow shock waves) [6] and also on the prevention/delay of flow separation [8].

### Sustainable Aeronautics Applications

- It has been shown that plasma actuators can be used to minimise separation over aerofoil sections at subsonic speeds in various applications for examples wind turbine blades [7] (see figure 5a and 5b) and turbine blades[8].
- Studies have also been carried out proving fundamentally that wave drag can be reduced using pulsed energy deposition (both NS-DBD plasma actuation and laser energy deposition).
- Figure 6 below show the forcing of a bow shock upstream due to pulsed energy deposition which results in a drag decrease experienced by the body.

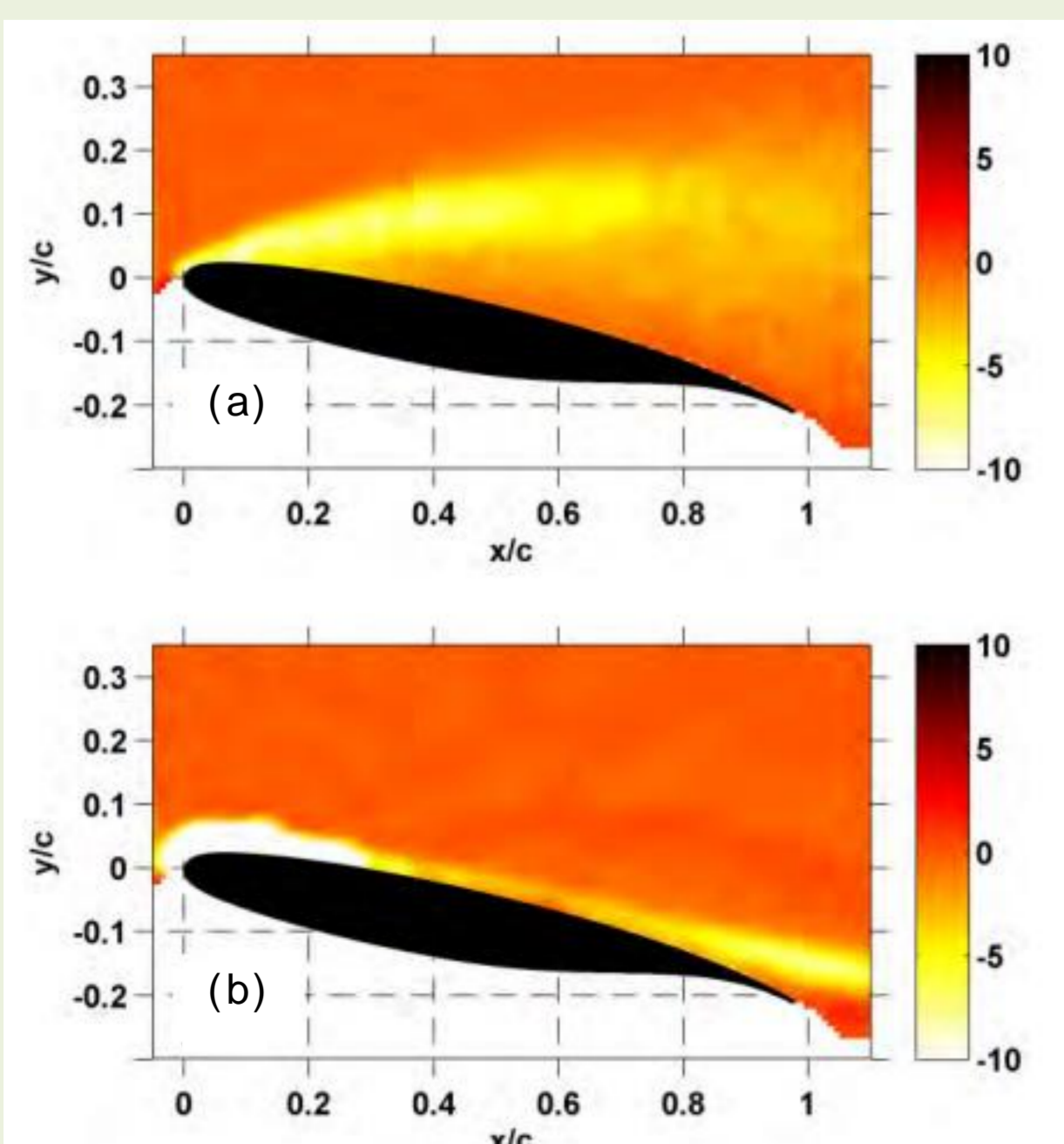


Fig 5: Ensemble-averaged vorticity for a) plasma actuator off and b) plasma actuator on illustrating the improved separation characteristics [9]

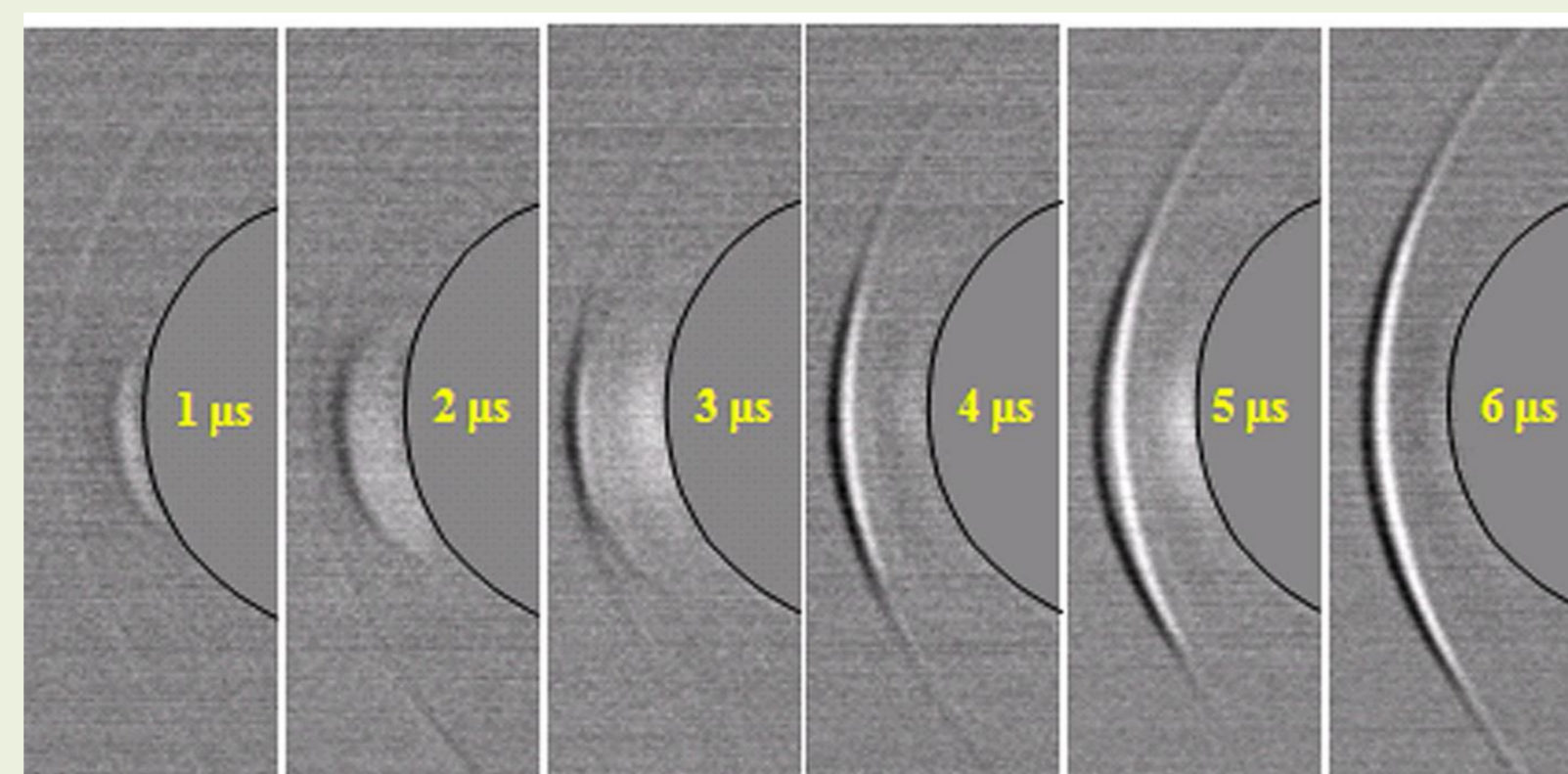


Fig 6: Series of images created from the difference between the baseline flow and the flow some time after actuation of NS-DBD showing the movement of the bow shock upstream in the latter images [3]

### Future Research at University of Glasgow

- Shock boundary layer interaction control using EHD techniques with applications to supersonic engine intakes.
- Application of plasma actuators to improve wind turbine performance.
- Control of open cavity flows using NS-DBD plasma actuators
- Fundamental investigation into effect of actuator characteristics on operational efficiency
- These studies will use a variety of flow diagnostic techniques available such as: Schlieren (fig. 7), pressure sensitive paints (fig. 8) and particle image velocimetry (fig. 9).

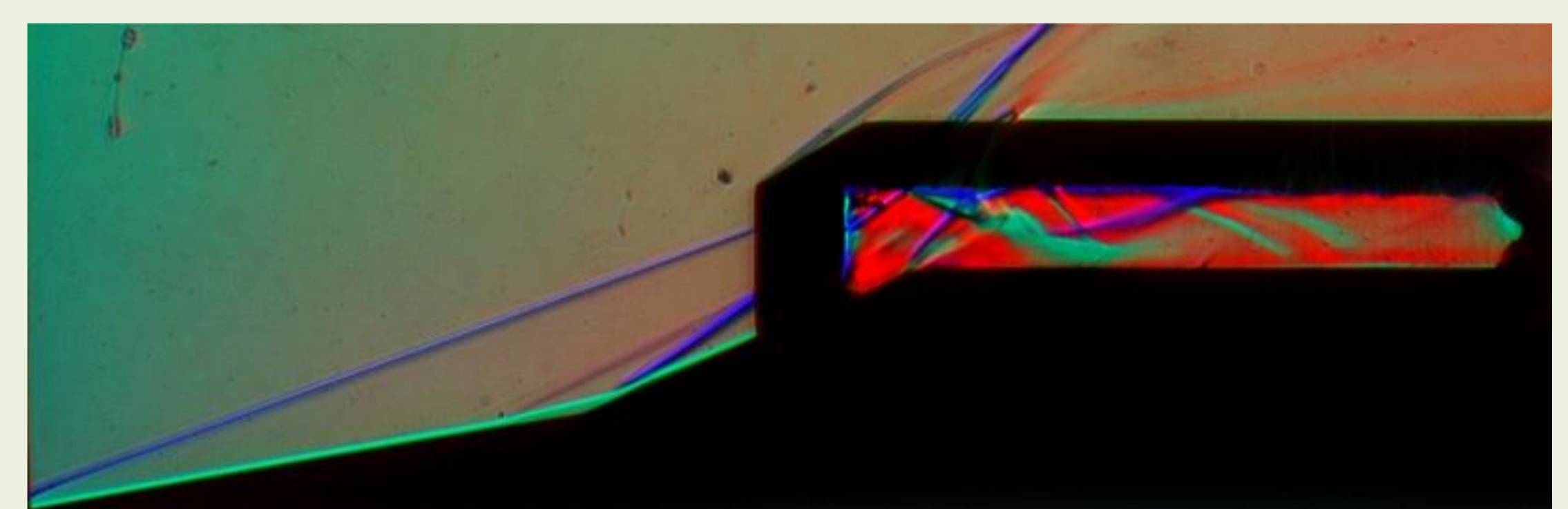


Figure 7: Colour Schlieren of Hypersonic Flow through a scramjet geometry [6]

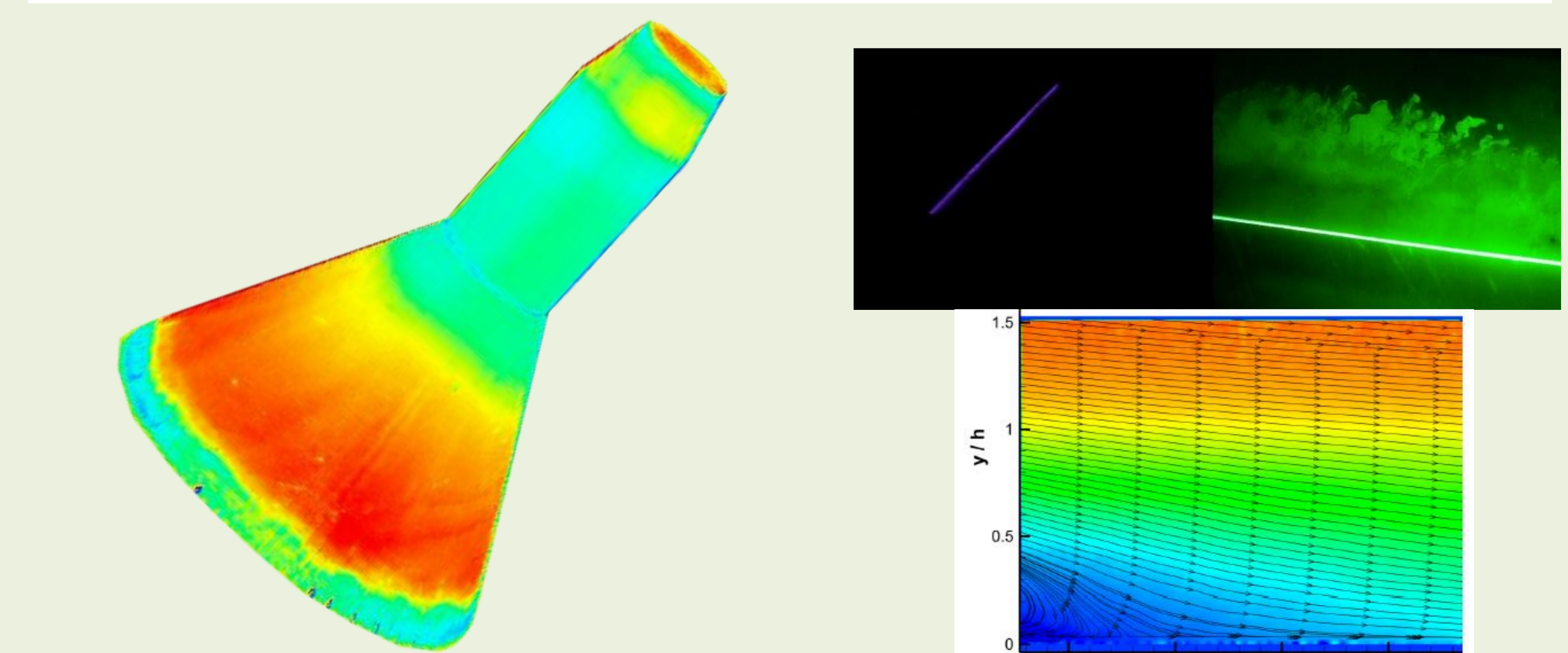


Figure 8: AA-PSP, Truncated flare in hypersonic flow [5]

Figure 9: PIV of plasma controlled flow over a backwards facing step [5]

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