Filamentary EHD actuation on the surface of bodies contoured by compressible flows

M. Cabaleiro, G. DiPrimio, G. Artana
Department of Mechanical Engineering, University of Buenos Aires
Paseo Colon 850, Ciudad de Buenos Aires, 1063, Argentina

Abstract – *In these article we focus our attention on the ability of a filamentary discharge to affect the shock waves patterns generated by a streamlined diamond model in a high-speed airflow. Our results indicate that no significant changes could be detected at moderate supersonic regimes (Ma ≈1.8) or at transonic ones (Ma ≈0.8)*

1 Introduction

In last years there has been a growing interest in using weakly ionised gases (plasmas) in high speed aerodynamics. The EHD technologies have been considered as good candidates to enhance wave and viscous drag reduction, reduction of heat fluxes, sonic boom mitigation, boundary layer and turbulent transition control. [1]

Shock wave control has application in different areas as in supersonic and hypersonic vehicles, gas turbines, reactors and so far.

An electric discharge in a gas flow would result in a gas heating of different importance depending on the characteristics of the plasma so created. This heating can certainly have an effect on the flow but also other non-thermal effects of plasma interaction with electric fields, like the "ionic wind", can be used for high speed flow control.

Based on the thermal effects, some authors proposed that the jump in pressure of a shock wave could be weakened by a local alteration of the physical properties of the gas flowing in this region. One of the discharge configuration tested has been the filamentary discharge with important inputs of energy. Different test have been undertaken with wing profile, plates, steps and ducts using single electrodes mounted on the surface [2-4]. With exception of ducts the effects on the shock waves of filamentary discharges have not been very clearly established.. Some works [5] suggest that at high speed flows the non-thermal effects could be of greater importance if they occur at close vicinity of the surface. The single electrode filamentary discharge in generally can not achieve this as it gives rise to the plume like configuration with a complex dynamic behaviour.

The objective of this work is to analyse the ability of a filamentary discharge taking place close to the surface of a body to alter shock waves in a flow configuration of aerodynamic optimised bodies where a clear interpretation of the results can be easily achieved.

2 Experimental setup

2.a *Wind Tunnel*

A supersonic wind tunnel of the induction type with a test section of 101.6 mm x 25.4 mm has been used in our experiments. The Laval nozzle of this tunnel is composed by a fixed lower part and different geometries may be installed in the upper part to achieve different Mach numbers (maximum Ma=1.8). A set of 25 holes made in the lower part enables to determine the pressure at different streamwise stations of the nozzle.

The model is fixed through protrusions that are inserted in holes of the visualization windows. These windows may rotate to orientate the model at the desired angle.

The tunnel may be used as a closed loop or as an open loop by removing one of its elbows. In this last case the conditions of pressure and temperature at the entrance of the Laval nozzle are fixed by the atmospheric conditions.

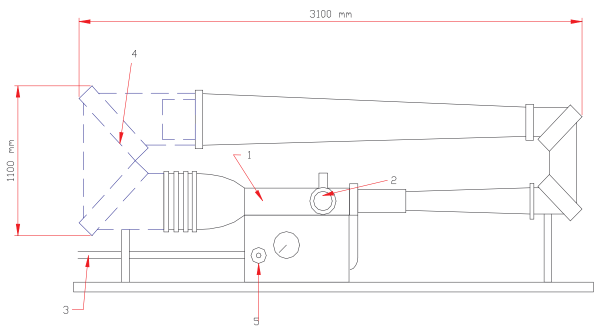

Figure 1 : Schematic of supersonic wind tunnel
1-Laval nozzle, 2-Test section, 3-Air supply, 4-Removable elbow, 5-Valve of regulation

2.b *Models*

The models tested consisted on diamond shape (semiangle 6°) bodies. They were constructed on PMMA and dispose of surface flush mounted electrodes made on aluminium foils.

The interelectrode spacement was 7.4 mm. Small holes on the surface enabled to determine the surface pressure at two different stations for the diamond model.

The wire connection and tubing exit the test section through the protusions of the models used for fixation.

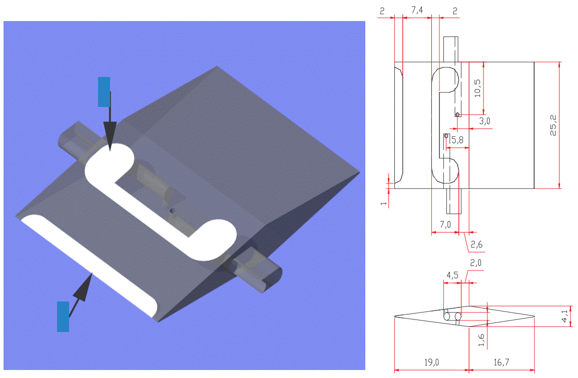

Figure 2: Diamond shape model (sizes in mm). Arrows signal the electrodes

2.c Schlieren system

A Schlieren system has been used to visualize the density fields of the compressible flow. It is composed of concave mirrors, a quasi-point light source, a single border knife and a digital video camera. The optical configuration is schematized in the figure 3.

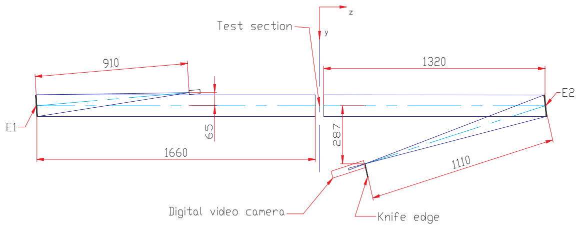

Figure 3 Schematic of Schlieren system: Concave mirrors, Knife, Test section, Digital video camera

2.d Pressure Measurement system

Pressure measurements on the models and on the Laval nozzles has been undertaken with absolute and differential piezoresistive sensors that enable measurements in the range of 0-100 kPa and 0-50 kPa. A circuit of amplification of the signal has been used and results has been recorded with a data acquisition system.

2.e Electric measurement system

Electrodes are excited with H.V. D.C. sources (0,±30kV). Current measurements are made with an optoisolator circuit (accuracy 1μA- passband filtering 0-1kHz) schematized in figure 4. This system is based on a previous report [6] and enables to convert the current signal in a voltage signal. This signal is then amplified and recorded through a data acquisition system.

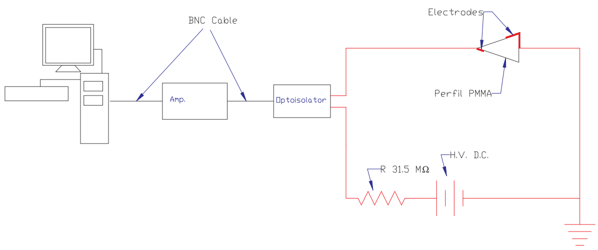

Figure 4 Schematic of the current measurement system.

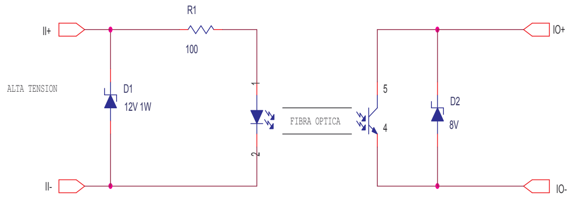

Figure 5 Schematic of the optoisolator system

3 Experimental Results

The models have been tested at different electrodes polarities and at different airstream velocities. For the diamond models two different positions of the model have been tested. In Position 1 the electrode in the apex faces is in the leading edge meanwhile for position 2 the model is rotated and the electrode in the apex is downstream. We name polarity 1 the case when the upstream electrode is at HV and the downstream one is earthed meanwhile polarity 2 is the opposite situation.

All the tests have been undertaken with an angle of attack of 0°.

The steady regime in the wind tunnel persisted a maximum of 25 seconds, depending on the Laval nozzle considered. The time elapsed between two different experiments was about 10 minutes.

3.a Discharge regimes

The experimental procedure consisted on fixing the electrode potentials and then establishing the air flow.

Different discharge behavior could be observed as a consequence of charged particles convection.

In general when steady conditions of the flow were established we could identify a multiple moving or a fixed filaments discharge configuration.

In figures 6 we show images of these both kind of configurations.

Figure 6a *Moving Filamentary discharge* (this discharge configuration occurred for position 1/polarity 2 or position2/polarity1)

Figure6b *Fixed filamentary discharge* (this discharge configuration occurred for position 1/polarity 1 or position2/polarity2)

A typical current curve during the test may be observed in figure 7.

In these graph the airflow starts at about 5 s, is followed by the steady regime (from about 7s to 17s) and from about 17s to 32 s the vessel is emptied but not at constant velocity. From this graph we observe that in the whole experiment when the airflow occurs the current signal show peaks but in the lapse where the steady regime is achieved an increase in current values takes place.

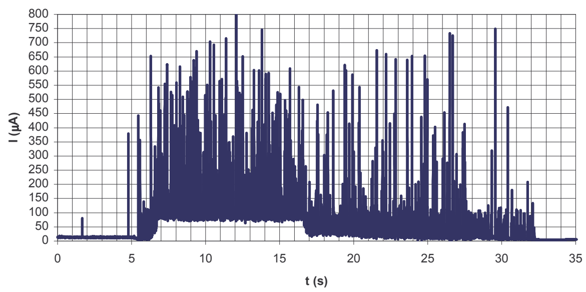

Figure 7: Current vs time Nozzle1, position2 polarity1, V=10.3kV

The voltage-current curves for the different cases are shown in figures 8. The value of current represented is the time averaged value observed in the steady regimes.

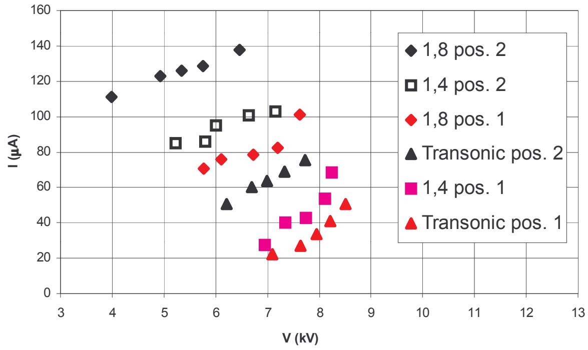

Figura 8a. Diamond model- Polarity 1 – Different Laval nozzles (Ma≈ 1.8, Ma≈ 1.4 and transonic)

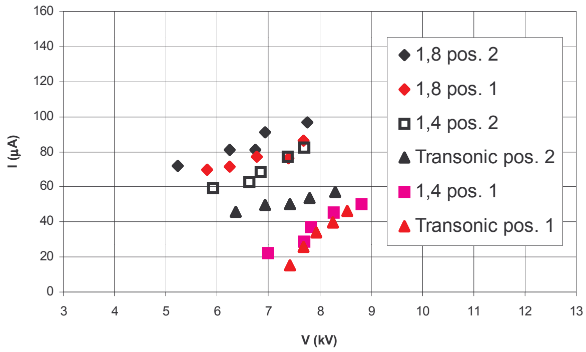

Figura 8b. Diamond model-Polarity 2- Different Laval nozzles (Ma≈ 1.8, Ma≈ 1.4 and transonic)

The analysis of these figures reveals that the higher the velocities the higher the currents achieved. However, the higher the velocities the higher the difficulties to achieve stable (arc free) discharges. Also we can observe that polarity 1 configuration enables to achieve higher values of currents than the polarity 2 meanwhile the moving filamentary regime (position 1/polarity 2 or polarity 2/ position1) enables to achieve higher values than the fixed filamentary regime (position 1/polarity 1 or polarity 2/ position2)

3.b Flow measurements

Next we show the flow configurations obtained with two different Laval nozzles.

Some typical pressure evolution at different ports and shock wave configurations may be observed in figures 9a-10a-and 9b-10b respectively.

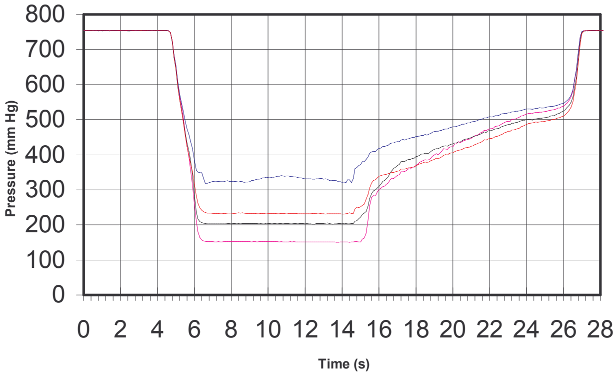

Figura 9a. **Pressure evolution. at different ports. Laval Nozzle 1. Ma_1 = 1.7. Position1.** (upper curve exit pressure, lower curve exit pressure, middle curves port model)

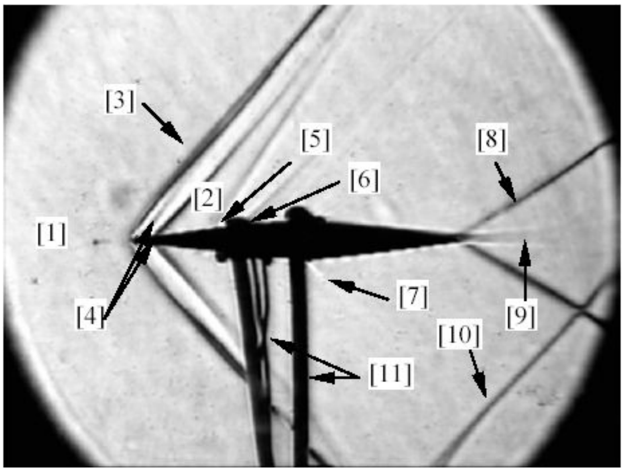

Figura 9b; Laval Nozzle 1. t = 10 s. Position 1. 1-Supersonic region (Ma_1 = 1.7); 2-Interelectrode region; 3-Oblique leading edge shock waves; 4-Expansion fan and shock wave at the leading electrode; 5 and 6 Shock wave and expansion fan at the trailing electrode; 6- 7-Expansion fan at the apex of the model 8-Trailing edge oblique shock wave; 9-Wake; 10-Reflection wave on the wall of the wind tunnel; 11-Tubings and cables.

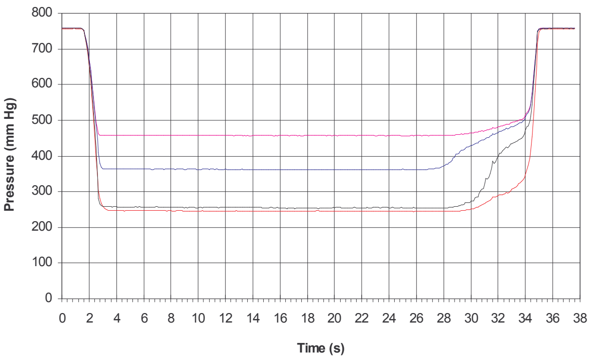

Figura 10a. Pressure evolution. at different ports.. Ma_1 = 0.88; t = 17 s , position 1 (upper curve exit pressure, lower curve exit pressure, middle curves port model)

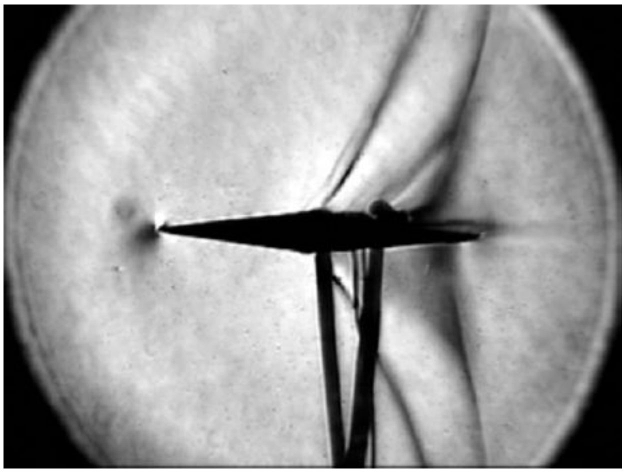

Figure 10b. Laval Nozzle 3 Ma_1 = 0.88; t = 17 seg. position 1. (The flow is subsonic and accelerates around the model to supersonic).

These figures correspond to the cases with actuation off. The results obtained for the case with actuation on show no significant differences with those of actuation off and are not shown.

We have undertaken other tests (not shown in this paper) concerning a diedric model (semiangle of 4.5° and a length of 20 mm) immersed in similar supersonic and transonic flow and it has also been observed negligible effects of a filamentary actuation on the shock wave characteristics.

It is of interst to signal that the flow conditions here analyzed does not give rise to separated shock waves as could occur in the case of non aerodynamic optimized bodies. It has been suggested [3] that in this situation changes attainable by plasma actuation could be more dramatic than the ones here studied. We have undertaken some preliminaries efforts using diedric bodies that give rise to this situation, but the first results observed does not indicate a dramatic effect on the shock wave patterns.

4 Conclusion

Concerning pressure measurements as no pressure changes have been detected as a consequence of filamentary actuation no significant changes neither on the pressure or Ma number occur. The results with Schlieren images corroborate this.

It could be argued that the filamentary discharge acts locally and that the Schlieren images give only an integral result. However the local changes should lead to changes in the thickness of the shock wave or a splitting of it. But this could not be clearly observed.

As a result filamentary discharges of low intensities like the one considered here seem not adequate to achieve shock wave control when this one is not separated and at moderate Ma number.

5 Acknowledgments

This research has been done with grants UBACYT I024 and PICT 12-09482 of the Argentine government

6 References

[1] V. Semenov, V. Bondarenko,V. Gildenburg, V. Gubchenko, A. Smirnov, "Weak1y ionized plasmas in aerospace applications", Plasma Phys. Control. Fusion, 44, (2002), B293-B305.

[2] S. Leonov, V. Bityurin, "Hypersonic/supersonic flow control by e1ectro-Discharge plasma actuation", AIAA paper 2002-5209.

[3] S. Leonov, V. Bityurin, A. Klimov, Y. Kolesnichenko, "Influence of structural electric discharges on parameters of streamlined bodies in airflow", AIAA papel 2001-3057.

[4] S. C Leonov, V. Bityurin, Y. Kolesnichenko, "Dynamic of a Single-Electrode HF Filament in Supersonic Airflow", AIAA paper 2001-0493.

[5] Macheret S., Shneider M., Miles R.,"Magnetohydrodynamic and electrohydrodynamic control of hypersonic flows of weakly ionized plasmas", AIAA paper 2002-2249

[6] Fothergill, J.C. & Houlgreave, J.A.: "A simple optical method for measuring currents at high voltages with an example of use on a coronating electrode in air", IEE Conference on Dielectric Materials, Measurements and Applications, Bath, 24 -27 September 1996.