Electrical properties of a sliding discharge in supersonic air flow

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Abstract— **Recent studies have shown atmospheric plasma discharge to be an effective means of air flow control. In supersonic airflow it seems that the effects of the plasma are mainly of thermal origin. Nevertheless some experiments have shown some anomalous flows around the body and anomalous shock waves structures in cold plasma. In order to explain these experiments some teams works on the hypothesis of the existence of non thermal effect in non equilibrium weakly ionized gases. The nature of the observed effects was not clear and from the very beginning there were a lot of controversial speculations around the problem. Flow control of supersonic air flow by means of surface plasma discharge is a new topic of our laboratory. In this paper we show how we obtain a stable plasma discharge in a supersonic air flow with help of a third electrode and a combination of DC and AC high voltage potential. Experimental results will be presented. We will show the influence of different parameters like the frequency, DC potential, AC potential on the discharge current.**

I. Introduction

Recent studies have shown atmospheric plasma discharge to be an effective means of air flow control. In subsonic air flow DC discharge or Dielectric Barrier Discharge are used to produce "ionic wind". This momentum is used to modify characteristics of the air flow. The first experiments of boundary layer control were made for low velocities (up to 25 m/s) [1-6] but now efficiency is showed for flow velocities up to 75 m/s [7]. In supersonic airflows, the main problem is associated with generation of shock waves resulting in high mechanical and thermal loads on elements of an aircraft construction, sharp growth of drag force, and reduction of ramjet efficiency. In supersonic airflow the discharge induces gas heating. This energy addition to the flow results in an increase in the local sound speed that leads to expected modifications of the flow. The reviews of plasma applications in high speed aerodynamics are presented in [8-9]. Nevertheless some experiments have shown some anomalous flows around the body and anomalous shock waves structures in cold plasma For some authors [10-12], it seems that plasma generation is not equal to conventional heating because the plasma structure is self sustained with the flow structure and the plasma influence on the flow leads to non evident consequences. One example among these supposed non thermal effects is the non-symmetrical effect of AC et and DC discharges on the drag reduction when the polarity is changed [12]. This non thermal mechanism should be responsible for this anomalous effect.

The first step is to study the discharge in a supersonic air flow. In a precedent work [13], we have shown that the plasma discharge created by means of DC potential difference applied between two thin electrodes placed on the surface of a flat plate, was very unstable in a supersonic air flow. Indeed the discharge goes into an arc regime as soon as the air flow velocity increases. In this paper we show how we obtain a stable plasma discharge in a supersonic air flow (M=1.7) with help of a third electrode and a combination of DC and AC high voltage potential. This kind of discharge are used for laser application, but to the authors' knowledge, no work has been published in this field of research. We will show the influence of different parameters like the frequency, DC potential, AC potential on the discharge current.

II. Experimental setup

The experiments were undertaken in the test section of a $70\ \text{mm} \times 120\ \text{mm}$ supersonic induction wind tunnel. This wind tunel is equipeds with adaptative nozzle that enable to achieve different Mach numbers. While the run time of this tunnel in its various modes depends on the flow conditions required, a typical time is 30 seconds. The upstream flow used during experiments is Mach 1.7 airflow with static pressure of about P =200 mbar. Because of an attached shock wave on the leading edge, the air flow velocity located at the top of the discharge is 238 m/s, his Mach number is 0.77, his temperature is 264 K and the static pressure is about 680 mbar (68000 Pa). At this location the fluid density is 0.98 kg/m^3.

The model under investigation is a Plexiglas flat plate with a sharp leading edge (15°). A shematic representation of this model is presented in figure1. It is 150 mm long, 65 mm wide PMMA plate. Two 20 mm width aluminium strips are glued on it. The first electrode is placed at 60 mm of the leading edge. They are 0.3 mm thick and the space between them is 30 mm. The third electrode is embedded inside the model. She is placed between the two electrode placed at surface.

During experiments two hight voltage power supply are used. The first one is negative DEL® DC power supply (-40 kV, 3.75 mA). This power supply indicate the applied

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voltage and the time averaged current with a resolution of 0.1 kV and 10 µA, respectively. The second one is a HV power amplifier TREK® 20/20C (± 20 kV, ± 20 mA, 20 kHz) driven by a signal generator. An internal current sensor makes it possible to visualise current. This sensor have a precision of about 10 µA and bandwidth of 10 kHz.

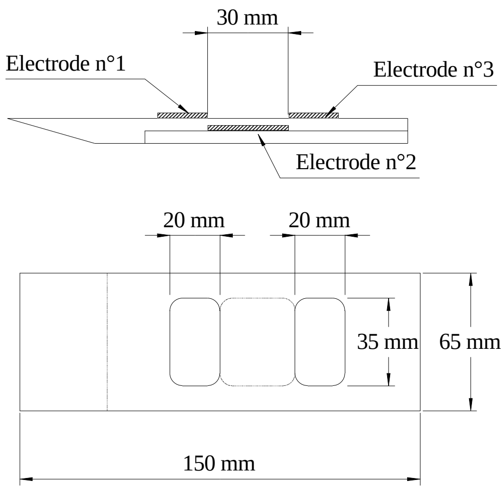

Figure1 : Schematic represetation of electrodes configuration

We use two slidinng discharge created by two configuration (figure 2). The first one is created by appliying positive AC voltage on the electrode n°1 and a negative DC voltage on electrode n°2 and n°3. This is the configuration n°1. In the second configuration, the positive AC voltage is applied on the electrode n°3, the negative DC voltage is applied on electrode n°2 and n°1. This is the configuration n°2. The difference between these two configurations is the position of the positive AC electrode which in the first case is placed upstream and in the other case downstream.

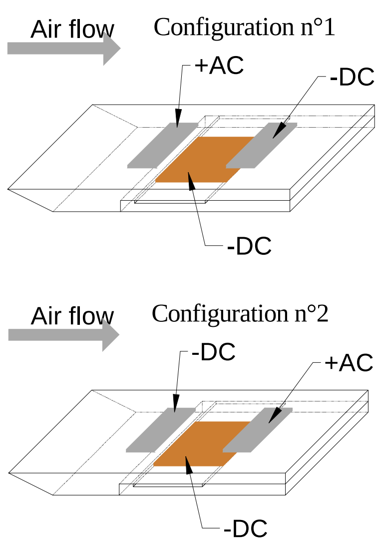

Figure 2: Schematic represention of the two configuration used.

III. Result and Discussion

The figure 3 shows discharge current in function of time in the presence of the flow and without flow. Theses measurements were made with the internal sensor of the H.V. amplifier. Without flow one observes a capacitive current due to the presence of the H.V. cables and the electrode arrangement. There is no discharge and no current peak. With the same electric conditions, a current peak appears when the flow is running. Only these peaks are representative of the discharge current. They appear on the one hand because of the pressure decrease and on the other hand because of the presence of the air flow. An increase in the current results in an increase in the amplitude of the peaks and an increase in the number of peak during an alternation.

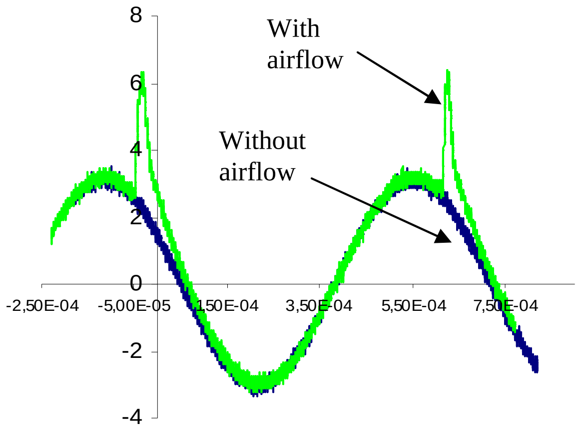

Figure 3: Current (mA) versus time with configuration n°1, f = 1500 Hz, vAC =0/+8, vDC = -4 kV, with and without air flow

We can see on the figure 4 the difference of current measured with air flow and without airflow. That makes it possible to isolate only the part of current due to the presence of the discharge. If we compute the average during one period of this difference, one finds the value of the current given by the second HV power supply. One notes an error ranging between 6 and 20% following the representativeness of the selected period. This shows us that the average value of current delivered by the HV DC power supplied is representative of the amplitude of these peaks as their number. Thereafter we will use this mean values.

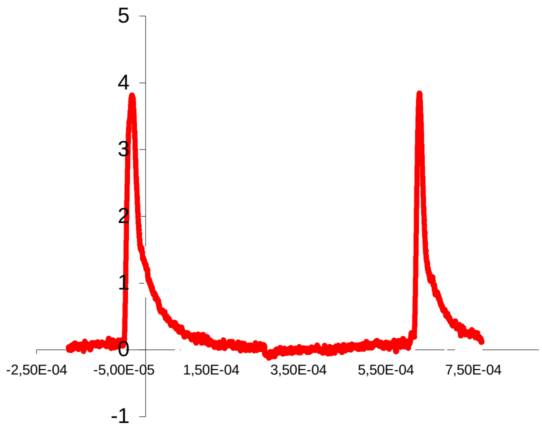

Figure 4: Current diffence versus time betwen the case with and without airflow. Configuration n°1, f=1500 Hz, v AC =0/+8, vDC=-4 kV, with and without air flow

Figure 5 shows the mean discharge current value in function of fréquency of positive AC voltage with airflow. The configuration used is the configuration n°1, negative DC voltage is equal to -4 kV, maximum voltage of AC voltage is 8 kV. It is observed that the mean discharge current increases linearly with the frequency. More the frequency amplifies more the average current increases.

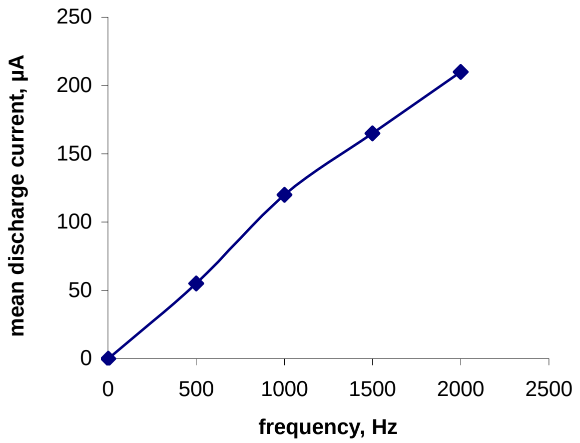

Figure 5: Mean current versus frenquency. Configuration n°1, vAC =0/+8, vDC=-4 kV, M = 1.8

Figure 6 shows the mean discharge current value in function of positive AC voltage with airflow. The configuration used is the configuration n°1, negative DC voltage is -4 kV, frequency is 1500 Hz. We can observe that more the HV amplitude increases, the minimun being maintained to 0 kV, more the mean discharge current value increases. We could not increase the AC high voltage, if one exceeds 12 kV the discharge changes mode and becomes an arc.

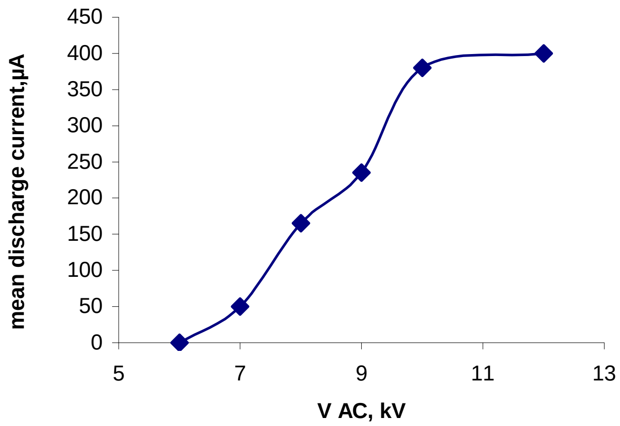

Figure 6: Mean current versus positive AC voltage. Configuration n°1, f=1500 Hz , vDC=-4 kV, M = 1.8

Figure 7 shows the mean discharge current value in function of negative DC voltage with airflow for configuration n°1 and configuration n°2. Maximum voltage of AC positive voltage is 8 kV, frequency is 1500 Hz.

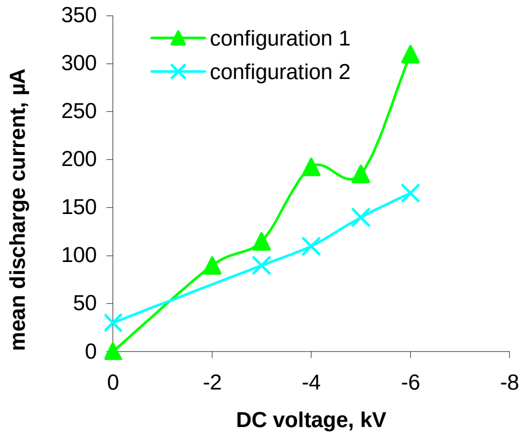

Figure 7: mean discharge current versus negative DC voltage with airflow for configuration n°1 and configuration n°2. vAC = 8 kV, f=1500 Hz.

In configuration 1 the AC positive voltage is applied upstream. We observe that more the negative DC voltage increases more the mean discharge current increases. It is the same observation in case of configuration n°2, when the AC positive voltage is applied downstream. But in this case mean current values are weaker. This shows that position 2 (when the anode is placed downstream) is more unfavorable, may be because the migration of positive charges from the downstream electrode to the upstream electrode is slowed down by the presence of the flow. This comportement in the case of continuous discharge in the presence of subsonic flow was already observed [14]

IV. CONCLUSION

We have shown that it is possible to obtain a stable surface discharge in presence of supersonic air flow (M=1.8). This discharge can be effectively used because she allows us to obtain large surface plasma and because she does not pass to the arc.

We have shown that more the voltage différence betweeen anode and cathode increases, more the mean discharge current value increases. We have oberved that the discharge current increases when the frequency increases.

In the next work we have to observe aerodynamics effects of this kind of discharge.

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