Mr. Dorian Colas, École Centrale de Paris
Winner of the 2009 Young Aerospace Engineer of the Year – Scientific Award

Novel Electrode Configuration for Ionic Wind Generation in Air at Atmospheric Pressure

The electrohydrodynamic (EHD) effect known as the 'ionic wind' corresponds to the transfer of momentum from ions produced and accelerated by a plasma discharge to neutral molecules in the flow. The net effect is to produce a bulk movement of the flow without resorting to any moving machinery such as fans or turbines. The ionic wind is a promising atmospheric plasma technology with many potential aeronautical applications for controlling flow, reducing drag and delaying the transition to turbulence. In recent years, this effect has been successfully demonstrated for boundary layer separation control on wing profiles at low Reynolds numbers. However, the velocities produced by EHD have been limited to a maximum of 6m.s-1 using a specific type of plasma discharge known as the Dielectric Barrier Discharge.

In the current project, we have focused on another type of discharge, the DC Corona, which had been the topic of fundamental studies in our laboratory during a recent Ph.D. thesis whose objective was to demonstrate and validate the physical phenomenon of EHD through comparisons of modelling and experiments. In that Ph.D. thesis, a maximum optimized velocity of 3 m/s had been obtained.

The current project has been carried out over the past ten months this year by a team of three second year engineering students of École Centrale Paris. Our objective was to find a method to increase the flow velocity and to better understand the chemical kinetics through numerical simulations. The team was part of the non-equilibrium plasma research group of the EM2C Laboratory of École Centrale Paris. The team was supervised by a professor of ECP, a CNRS Research Engineer and a Post Doctoral fellow.

The challenge of carrying out both experimental work and modelling made the schedule tight for a single student year. The objectives were however achieved through careful planning, with the experimental optimization carried out during the first semester and the numerical model during the second semester.

On the experimental side, we have succeeded in increasing the flow velocity by almost a factor of three, up to 8-9 m/s through an innovative design that optimizes the production and acceleration of the flow using a geometry in which the field lines are better aligned with the axis of the bulk flow. The currently achieved velocities are thus higher than those obtained with even the best Dielectric Barrier Discharge systems. We submitted a paper entitled ''Novel electrode configuration for Ionic Wind Generation in Air at Atmospheric Pressure'', which was accepted for presentation at the EUCASS 2009 conference in Versailles on July 3-9.

The principle of wind generation by a corona discharge between two wires can be explained as follows. Around each wire, the electric field decreases inversely proportional to the distance to the wire. For small wire diameters, the electric field near the wire surface is sufficiently high to ionize the air. The positive ions drift toward the cathode while the negative ions stay close to the anode. In their movement, the positive ions transfer momentum to neutral molecules through collisions. In the vicinity of the cathode, electrons attach to oxygen, forming O_2- which drifts toward the anode, transferring momentum to the neutrals. Two opposite charge currents appear. The net flow is called the ionic wind. However, if the diameter of the cathode is much larger than the diameter of the anode, much fewer charges are produced at the cathode than at the anode. The ionic wind is therefore mainly from the anode to the cathode, and thus the maximum ionic wind can be obtained.

In the corona discharge experimental setup, the electric field induced by the applied potentials is responsible for both ionization and acceleration and thus the problem is coupled. In addition, the maximum velocity reached is limited by the apparition of a spark due to a space charge density when a critical electric field is reached. When the spark appears, charges concentrate in a narrow conductive channel and the ionic wind stops. Another limitation is related to the adsorption of charged particles on the electrodes: once adsorbed, these particles cannot participate in momentum transfer to the bulk flow.

On the experimental side, we addressed two issues in ionic wind generation.

First, we de-coupled the mechanism of ion generation from that of ion acceleration. Since the formation of a spark does not depend on the velocity of the ions, but rather on their density reaching a critical level, it is desirable to increase the electric field magnitude without increasing the ionization level. Second, we minimized ion adsorption on electrode surfaces. Toward these ends, we have focused on improving the topography of the electric field to 1) create separate ionization and acceleration zones in space, and 2) guide the trajectory of charged particles away from adsorbing surfaces.

On the numerical side, we have implemented the ionic wind simulations in the finite element software Comsol Multiphysics to perform 2-D simulations of the electrostatic field under various electrode configurations. We found that a configuration comprised of five electrodes accomplishes the aforementioned design goals. The DC corona discharge is generated in the space between a wire and two cylinders. The ions produced by the corona then drift past the cylinders and into a channel between two plates, where they undergo acceleration. The electric field in this channel has been optimized to avoid ion trajectories ending on the plates, so as to minimize adsorption.

This electrode configuration has been tested experimentally to generate ionic wind in air at atmospheric pressure and at ambient temperature. The wire and cylinder diameters are respectively 0.2 mm and 6 mm, and the plate cross-sectional dimensions are 8 mm × 20 mm. The adjustable parameters are the applied voltage amplitude and polarity on each electrode, the current, as well as the gap distance. The wire node is raised to a high DC potential of up to +20kV. The cylinders and the plates are connected to ground and to a negative potential of up to -20kV, respectively. We measured as a function of the various parameters the current-voltage characteristics and flow velocity profiles using two techniques, a hot-wire anemometer and a glass Pitot tube, both placed at a distance of 32mm behind the plate electrodes. The velocities measured with the two techniques are in excellent agreement and indicate a maximum flow velocity of 8-9 m/s.

In the last part of the project, currently ongoing, we are focusing on improving the modelling work by incorporating a better description of the chemical kinetics that determine the nature of the charged particles. Up to date, all models of DBD or corona discharge have been limited to the consideration of fictitious charged particles, namely one type of positive ion and one type of negative ion. In the reality, several ions can be formed, each having different thermophysical properties and momentum transfer efficiencies. Determining the dominant ion or ions would not only improve the numerical results, but in addition would allow us to concentrate on optimal methods to increase the production of that ion. One important difficulty comes from the discrepancies in literature values for the transport coefficients and reaction rates involving the candidate ions. Thus an extensive bibliographic study has been completed to determine a reliable and consistent set of coefficients and rates.

At present, a complete model involving 10 ionic species and 42 reactions has been created, taking into account the influence of the electric field on the reaction rates. For each species in the flow, accurate transport coefficients have been selected. The complete model is currently being implemented under Comsol Multiphysics and the results are expected to be obtained by the end of the project in July 2009. The expected outcome is the first model including realistic ion production chemistry. From this model, a reduced chemistry model will be inferred that can be applied to two- or three-dimensional simulations of the ionic wind under any geometry.

Why is this Project original?

First, the project has been conducted with DC corona discharges, unlike most of the work on ionic wind generation which focuses on the use of Dielectric barrier Discharges. The results justify this approach since we were able to obtain the highest flow velocities ever produced.

Second, this project has been based on a unique approach combining modelling and simulations of the physical phenomenon in order to de-couple acceleration and ionization.

Third, the numerical simulations including accurate chemical kinetics represent the first attempt to determine the main ionic species in the flow. This model may lead to new ways to increase the ionic wind even further.

How feasible is this project?

Although this work was conducted under the tight constraints of a 300-h academic laboratory project, we have accomplished the goals of our project ahead of schedule thanks to a rigorous project management approach with precise deadlines and check points. The last task of the project was added mi-way through the project as a way to obtain additional information on the chemical kinetics, and thus infer new methods to further increase the ionic wind by increasing the production of dominant ions through optimization of the applied electric field profile. This latter task is well under way and should be completed on time by the end of the project in July.

For further details on the Young Aerospace Engineer of the Year Awards, see www.aerospacetesting.com/yey