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Ionic wind propulsion - effects of speed and confinement

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What is ionic wind ?

Ionic wind occurs when an electric field is applied to a gas seeded with ions of the same polarity. The ions are accelerated by the electric field, and through collisions with neutral molecules, the whole gas is accelerated. This phenomenon can easily be observed in the lab by applying a high voltage between a pair of asymmetrical electrodes, thus triggering a corona discharge on the electrode of smallest radius, called the emitter. This emits ions into the gas, which then drift to the larger electrode, called the collector.

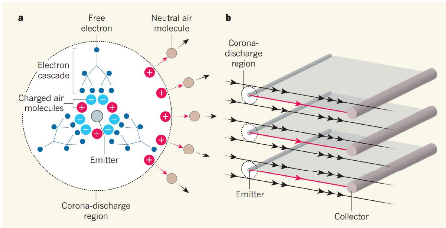


Fig. 1: Plouraboué, Nature 2018 [4] (a) : Injection de charges positives par la décharge couronne. (b) : Accélération du gaz entre l'émetteur et le collecteur.

Ionic wind for atmospheric propulsion

Fig. 2: Xu, Nature 2018 [2] Prototype of a model aeroplane powered by an ionic wind thruster.

Electrohydrodynamic (EHD) thrusters boast interesting characteristics : no moving parts, low noise, no carbon emissions, distributed propulsion. However, this technology remains challenging to implement due to its low thrust density compared to conventional propulsion technologies. Xu et al's [2] prototype shown in Figure 2 had a thrust density estimated at $3\,\mathrm{N\,m^{-2}}$, compared to around $1000\,\mathrm{N\,m^{-2}}$ for a commercial airliner. Attempts to boost this low thrust density include research on the effect of air velocity, ion sources, ion mobility, and multi-stage thrusters.

Effect of speed

Thrust F_{EHD} produced by an emitter-collector pair scales with current I :

$$F_{EHD} = \frac{ID}{\mu} \qquad (1)$$

With μ the ion mobility and D the emitter-collector distance. Neglecting freestream velocity, Townsend's law gives:

$$I \propto \frac{\mu}{D^2 ln(D)} V(V - V_0) \qquad (2)$$

With V the applied voltage and V_0 the corona inception voltage, which shows that increasing the emitter-collector distance for a given voltage reduces the thrust.

Taking into account the freestream velocity, the current flowing through a corona discharge has been shown by Chapman [1] to scale as :

$$I = \mu C_1 V(V - V_0) + C_2 u_\infty (V - V0) \qquad (3)$$

With u_∞ the freestream velocity. This scaling was verified in an emitter-collector configuration by Grosse et al. [3].

Neglecting the electrodes' drag, thrust then scales as :

$$F_{EHD} = \frac{ID}{\mu\left(1 + \frac{u_\infty}{\mu E}\right)} \qquad (4)$$

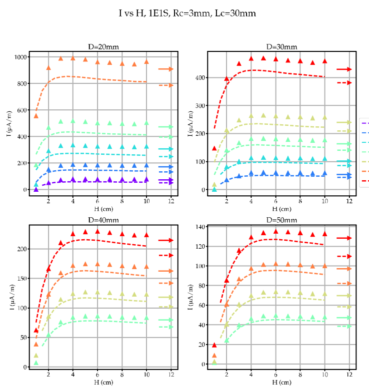
An experimental study is currently being set up at ISAE to study the influence of a high speed freestream velocity on an EHD thruster.

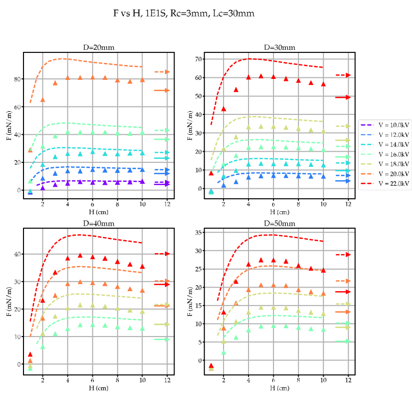
Effect of confinement

Studying the EHD thrusters inside a high speed wind tunnel was complicated by the electrostatic interactions between the electrodes and the dielectric walls of the test section. In order to understand these interactions, a smaller experimental apparatus was assembled to specifically study the consequences of a dielectric confinement.

This led to the unexpected observation that current and thrust do not depend monotonically on the confinement length H, equal to the emitter-dielectric distance.

The influence of confinement on current and thrust for various voltages and emitter-collector distances is shown in the following measurements, obtained at IMFT with a dropshape collector. The dotted lines are numerical simulations and the arrows show "unconfined" experiments.





References

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