Flow Control by Plasma in PLASMAERO project

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Aerodays 2011
Madrid – 30th March – 1st April 2011
Outlook

• Why plasmas for aerodynamics?
  – Needs
  – Plasma technology

• PLASMAERO project presentation & objectives.

• Project progress, 1st results
  (one year activities).

• Perspectives.
Project Rationale

Needs for aircraft improvement:
- Performance increase *(Flow optimization, weight and consumption improvement, design simplification, flight operation improvement etc.)*
- Reduction of impact on environment *(ACARE 2020 and after)*
Project Rationale

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- Reduction of impact on environment (ACARE 2020 and/or after)

One way:

**Flow optimisation and control**

*Permanent adaptation to global and local aerodynamic conditions*
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One way:

**Flow optimisation and control**

*Permanent adaptation to global and local aerodynamic conditions*

How can flows be optimised?
- geometry adaptation
- devices (passive, active)

Need of breakthrough and Emerging Technology
Plasmas devices for Aerodynamics. Why?

- considered as active devices (add energy, independent)
- various flow control
- easy installations & use, very short response time
- electric energy use (no compressed air flow)
Plasmas devices for Aerodynamics.

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Plasmas in the Universe:
- Temperature of electrons
- Density number of charged particles

→ Chosen Plasmas here
Plasmas devices for Aerodynamics.

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- various flow control
- easy installations & use, very short response time
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→ **PLASMAERO chosen technologies:**
  - Surface plasmas (DBD, ns-DBD)
    → cold plasma (weakly ionised, no thermal equilibrium)
  - Spark plasmas (PSJ)
    → thermal plasma (ionised in discharge, thermal equilibrium)

DBD: Dielectric Barrier Discharge

PSJ: Plasma Synthetic Jet
How DBD devices work?

→ Roth 90's years

- Ionic wind close to the wall

→ Alternating power supply

- Sinusoidal high voltage
- Upper face Plasmas (positive part) (some micro-discharges)
- Lower face plasma

V: 1 – 30 kV
I: 10 to 20mA, elec. power. ~ 500W/m²
f : 500 à 20000 Hz
How DBD devices work?

→ Roth 90's years

- Flow
- Electrodes
- Plasma
- Dielectric material
- Mass

Sinusoidal high voltage

→ alternating power supply

Upper face Plasmas (positive part)
(some micro-discharges)

Lower face plasma

→ Production of mass flow: ionic wind

V: 1 – 30 kV
I: 10 to 20mA, elec. power. ~ 500W/m
f : 500 à 20000 Hz


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How ns-DBD devices work?

- No use of ionic wind
- Voltage increase in a very short rise time \( \Rightarrow \) ns
- Development of high current streamers

Pressure wave generated by the discharge (rise time<100 ns)

Energy per unit length: \(~1\text{mJ/cm}\)


Phase averaged schlieren images
(10 kV, 400 Hz, no flow)
How DBD-ns devices work?

- No use of ionic wind
- Voltage increase in a very short rise time \( \rightarrow \) ns
- Development of high current streamers

Pressure wave generated by the discharge (rise time<100 ns)

Energy per unit length: \( \sim 1 \text{mJ/cm} \)


Phase averaged schlieren images
(10 kV, 400 Hz, no flow)

\( \rightarrow \) Large part of deposit energy converted in gas heating


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How PSJ devices work?

1) Energy deposition (discharge): T, P increase
2) Jet blowing
3) Recovery (natural)

Power supply
High Voltage + RC circuit
Voltage: 3 to 5000 Volts
Current: 1 to 100 mA (mean)

Cavity energy deposit = 5mJ
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Prototypes – φ8mm
Project Identity Card & Consortium
www.plasmaero.ue

**Name:** Useful **Plasmas for Aerodynamic Control:** PLASMAERO
**Start date:** 1st October 2009, 3 years long, **European framework:** FP7
**Thème:** Transport (including Aeronautics)
**Activity 1.1.6:** Pioneering the Air Transport of the Future

**AREA:** 7.1.6.1: Breakthrough and Emerging Technologies, AAT.2008.6.1. Lift
**Small-scale project, Level 1, Overall budget:** 4 988k€, **Overall EU contribution:** 3 815k€

**Consortium composed of:**
- 7 countries
- 11 companies or universities

**Project Officer:** Dietrich Knoerzer
Main Project Objectives

- Demonstrate how discharge plasma actuators can be used to control aircraft aerodynamic flow. *(Actuators design, Plasmas physics and Flow physics)*
- Provide exhaustive recommendations on future work to be performed to achieve the implementation of this technology.

- Understand, model and classify the most relevant physical characteristics of plasma actuators capable of influencing flow

- Demonstrate through WT experimentations and CFD the ability of plasma devices to significantly improve or control the aerodynamics

- Demonstrate the integration of these actuators in a reduced size flight platform and their use in real atmospheric conditions
Work Breakdown Structure

WP0 Consortium Management
(D. Caruana - ONERA)

WP1 Plasma devices investigation, development & improvement
(C. Hollenstein – EPFL
E. Moreau – CNRS)

Task 1.1 Surface discharges actuators
(E. Moreau – CNRS)

Task 1.2 Spark discharges actuators
(D. Caruana - ONERA)

WP2 Physics Modelling and computation
(JP Bœuf – CNRS
F. Rogier - ONERA)

Task 2.1 Plasma modelling and computation
(P. Leyland - EPFL)

Task 2.2 Aerodynamic / plasma coupling
(F. Rogier - ONERA)

Task 2.3 Computational Fluid Dynamic Simulation
(J. Kok - NLR)

WP3 Wind tunnel investigations for flow control
(C. Gleyzes – A. Séraudie - ONERA)

Task 3.1 Separation
(KS Choi - UNOTT)

Task 3.2 Wing tip vortex
(P. Molton - ONERA)

Task 3.3 Laminar flow & transition
(A. Séraudie - ONERA)

Task 3.4 High lift noise
(X. Zhang - SOTON)

Task 3.5 Shock/Boundary layer interaction
(C. Hollenstein – EPFL)

WP4 Validation & integration
(C. Tropea - TUD)

Task 4.1 Take-off and landing flow configuration
(P. Barricau - ONERA)

Task 4.2 Cruise flow configuration
(R. Donelli - CIRA)

Task 4.3 Subsonic Flight Platform
(C. Tropea - TUD)

WP5 Dissemination, Exploitation & training
(D. Caruana - ONERA)
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• Perspectives.
Plasma devices – Improvement & Characterisation

- DBD « ionic wind » → classic, sliding, pulsed, VG, multi, saw-like, floating

**LEA, IMP**

Plasma devices – Characteristics & Physics

- DBD « ionic wind » → classic, sliding, pulsed, VG, multi, saw-like, floating

LEA, IMP

IW=10m/s

- ns-DBD

EPFL, LEA, TUD, EPEE

Phase averaged schlieren images (10 kV, 400 Hz, no flow)


→ generation of compression wave
P~10000 Pa, sonic velocity propagation
Plasma devices – Characteristics & Physics

- DBD « ionic wind » → classic, sliding, pulsed, VG, multi, saw-like, floating

**LEA, IMP**

- ns-DBD

**EPFL, LEA, TUD, EPEE**

- PSJ

**ONERA, LAPLACE**

Generation of compression wave
P~10000 Pa, sonic velocity propagation

V up to 300m/s (T=400K)
f up to 2500 Hertz

P. Hardy, P. Barricau, D. Caruana, C. Gleyzes, A. Belinger, J.-P. Cambronne. Plasma - AIAA-2010-5103
→ strategy: bring flow momentum to B. L.

- Fluidic injection by micro-jet = vortex generator (DBD, PSJ)

**DBD** – IW=1,5m/s – U0 → 17m/s

**PSJ** – V=230m/s – U0=40m/s

U. Nottingham – Flow visualisation
– dif. Yaw angles – U0=1,5m/s

ONERA – PIV measurements – α=45°,
β=60° – U0=40m/s – VJSP=230m/s
Aerodynamic applications - Separation

- NACA0015 – Fixed transition – Re=0.8M - T.E. separation (Onera)

→ 1st results with PSJ – V=230m/s – U0=20m/s

B.L. profile close to T.E.

ONERA – PIV measurements – \( \alpha=30^\circ, \beta=60^\circ \) – \( U0=20m/s \) – \( VJSP=200m/s \)
Aerodynamic applications - Separation

- Fluidic injection by layer (#DBD) – 1st results

- NACA0015 – T.E. separation (LEA)  
  IW=6m/s, V0=20m/s

- NACA0012 – L.E. separation (EPEE)  
  IW=5m/s, V0=40m/s

Leroy & all - The 20th International Symposium on Plasma Chemistry  
USA – July 24-29, 2011
Aerodynamic applications – Wing tip Vortex

→ strategy: transversal velocity control

- PSJ

3D Onera-D model

→ displacement of the vortex core & decrease of longitudinal vorticity
U0=20m/s (Onera)

- DBD

# configurations

→ decrease of longitudinal vorticity
U0=10m/s (Onera, Epee)
Aerodynamic applications – Laminarity

→ strategy: stabilisation of the B.L. by velocity profile modification (IW)

2D Onera-D model

ONERA

Hot wire probe

DBD actuator X/C = 10%

Transition location on ONERA D upper side
Alpha = 2.5° U0 = 7 m/s Plasma f = 2 KHz

Transition location on ONERA D upper side
Alpha = 2.5° U0 = 12 m/s Plasma f = 2 KHz

U0 = 7 m/s

‘natural’ transition onset

U0 = 12 m/s

Aerodynamic applications – Slat Noise

A. wake of cusp

B. region where the free shear layer converges with the stream coming from the stagnation point on the main element

C. wake off the trailing edge

D. gap flow, and an intensive source

Southampton U.

DBD actuator located in zone A

\[ \alpha = 6^\circ, \ V_0 = 25 \text{ m/s} \]

Plasmas on

SPL (dB)

frequency
Plasmas devices and physics (#DBD, DBDns and JSP)
- simple utilization, active & small, electrical
- very short response time
- characterizations and diagnostics, modeling

PLASMAERO project and 1st tests results
- encouraging, actually in progress
  - Devices improvement
  - Flow control applications (separation, tip vortex, laminarity, slat noise)
→ PLASMAERO perspectives (→ 18 months)
  → Control strategy, plasmas physics and flow interaction physics definition (tests and CFD) → How it works?
  → 3D flow configurations for separations and laminarity
  → DBDns in transonic flow conditions (larger scale)
  → Subsonic flight platform (4m span, 20-30m/s)
• Thank you for your attention

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