Lightning Strike on aircraft:
Simulation With the electric module of *Code_Saturne*®

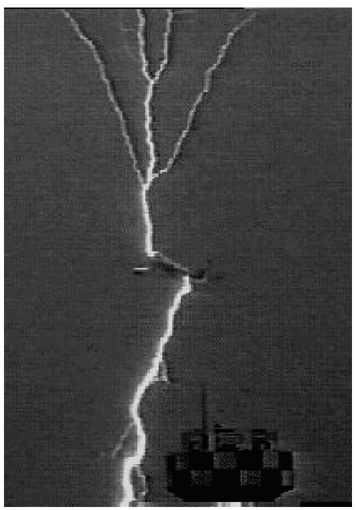
Collaboration ONERA-EDF-CEAT-CORIA

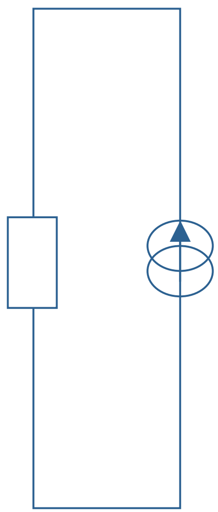
Laurent Chemartin

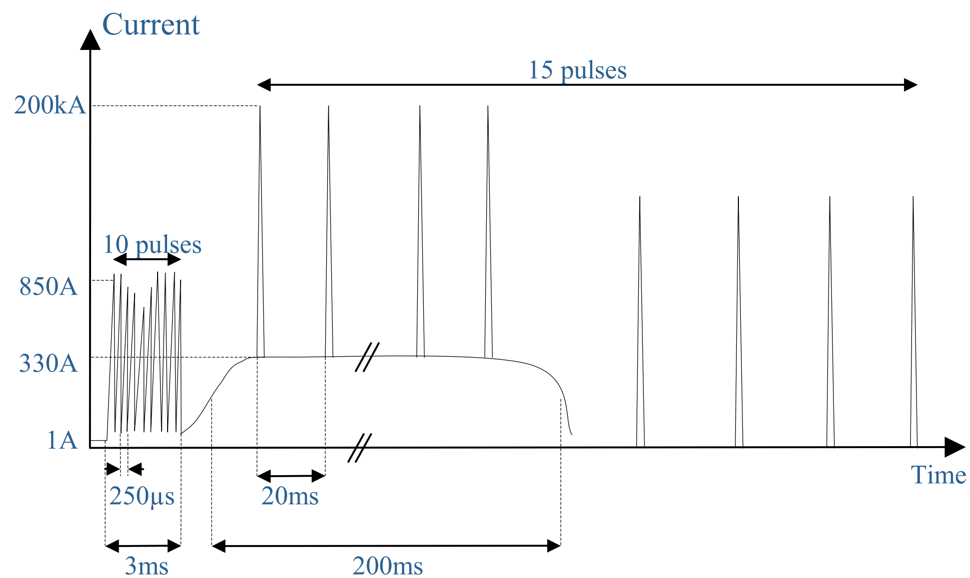
I. Introduction: Lightning Striketo an Aircraft

Lightning strike to an aircraft

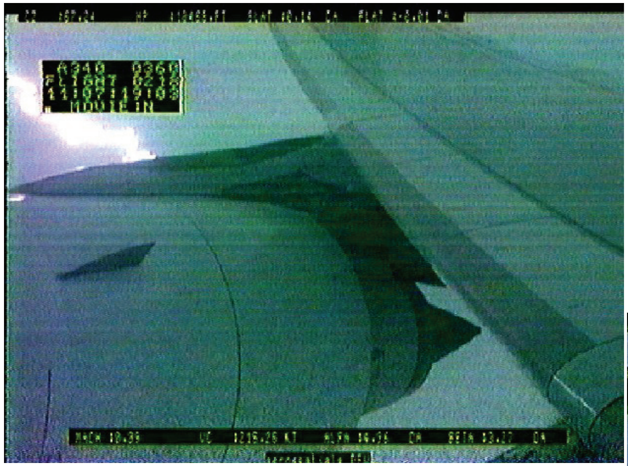
- Struck by lightning once a year
- Ignited most of the time (90 %) by the aircraft itselft
- Occurs most of the time, during landing and taking off stage

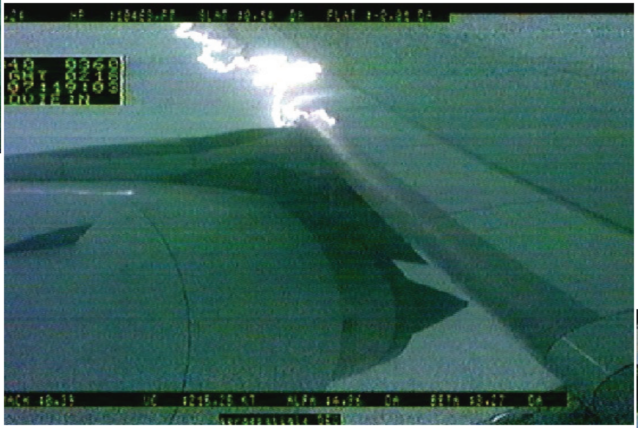






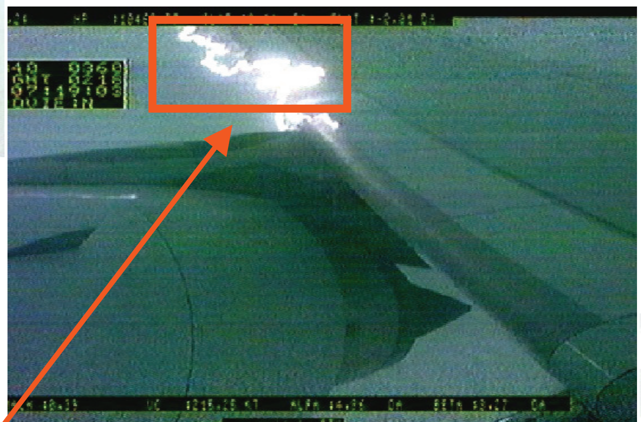
I. Introduction: Lightning Strike to an Aircraft

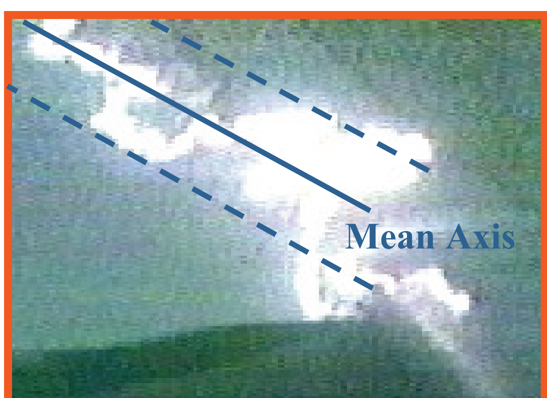




Images Airbus France

I. Introduction: Lightning Strike to an Aircraft



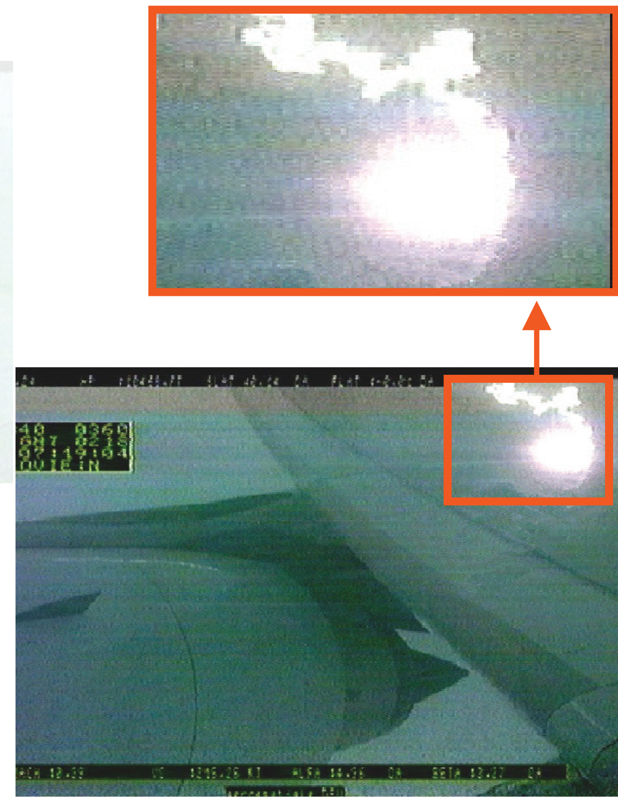


Lightning Channel Properties

Images Airbus France

I. Introduction: Lightning Strike to an Aircraft

Interaction with the material



Images Airbus France

I. Introduction: Electric module of *Code_Saturne®*

Electric Arc modelling: Resistive Magneto Hydrodynamic

- Heating Source: Joule Heating: J.E

(E and J calculated by an equation on the electric potential φ) $\nabla \cdot \sigma \nabla \varphi = 0$

- Momentum Source Term: Laplace Force J×B

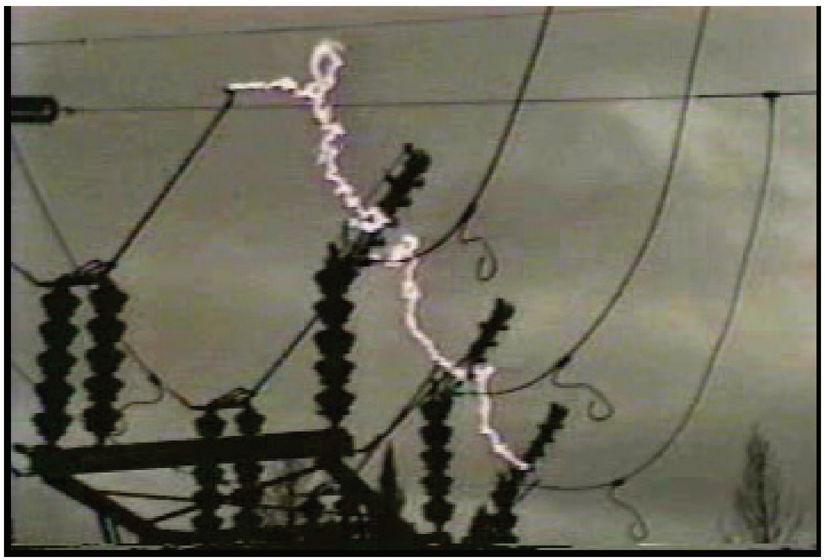
(B calculated by an equation on the magnetic vector potential A) $\nabla \cdot \nabla A_i = \mu_0 J_i$

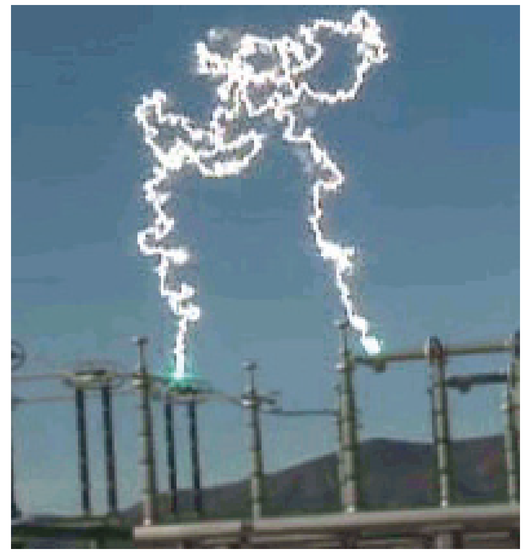
Main assumptions

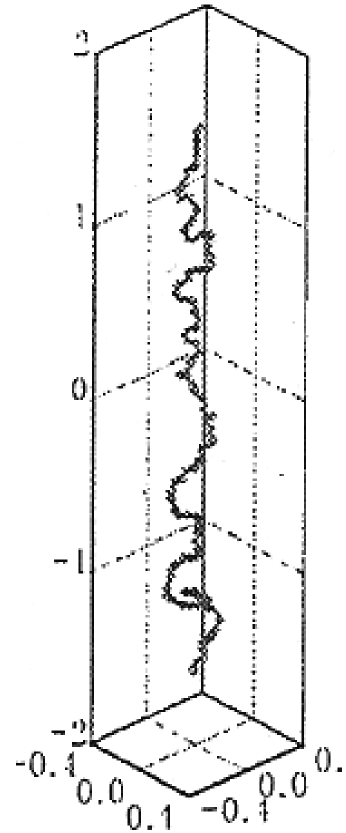
- Local Thermal Equilibrium (LTE):
- Incompressible flow (*Ma < 0,1*)
- Simplified Ohm's Law (no Induction, no Hall effect)
- Static Electric and Magnetic field
- Radiative Transfert: Net emission Coefficient

II. Lightning Channel : problematic

Long arc column: no electrode influences







Tanaka et al., "Three Dimensional behaviour analysis of D.C. free arc column by image processing technique", GD 2000, Glasgow

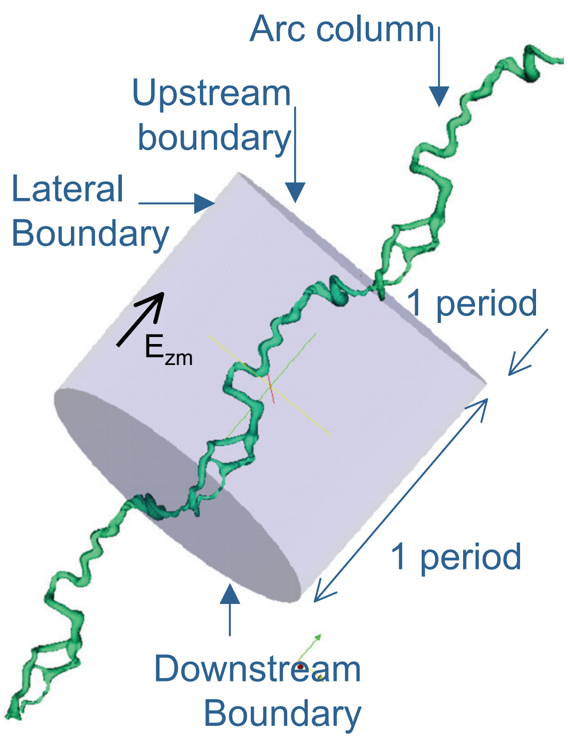
⇒ How to avoid the electrode influence and reduce the computation cost ?

« tip tip » configuration of 50 cm (1 million cells) => 8h/ms/proc

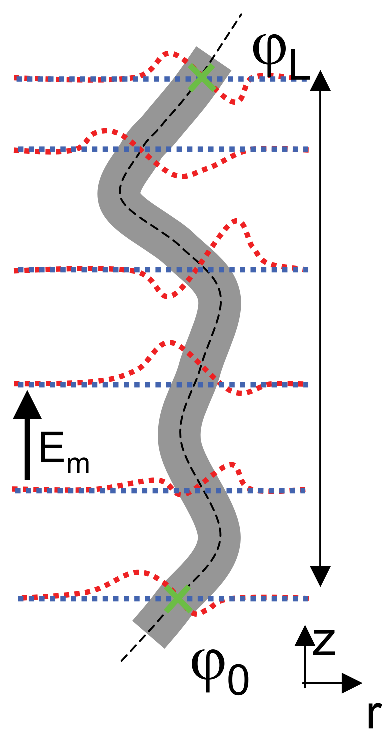
3,2 m arc during 300ms !!!

II. Lightning Channel : modelling

Periodic arc column distribution (50cm, 250A, 23ms)



Formulation with “fluctuating potential” $\widetilde{\varphi}$



Current production: $\varphi_L > \varphi_0$
Periodic distribution: $\varphi_L = \varphi_0$ } ???

⇩

Quasi uniform electric field,
Quasi linear electric potential:

$$\varphi = \Phi + \widetilde{\varphi} \quad with \quad \Phi = E_m z$$

$$\vec{E} = \vec{\nabla}\widetilde{\varphi} + E_m \vec{u}_z$$

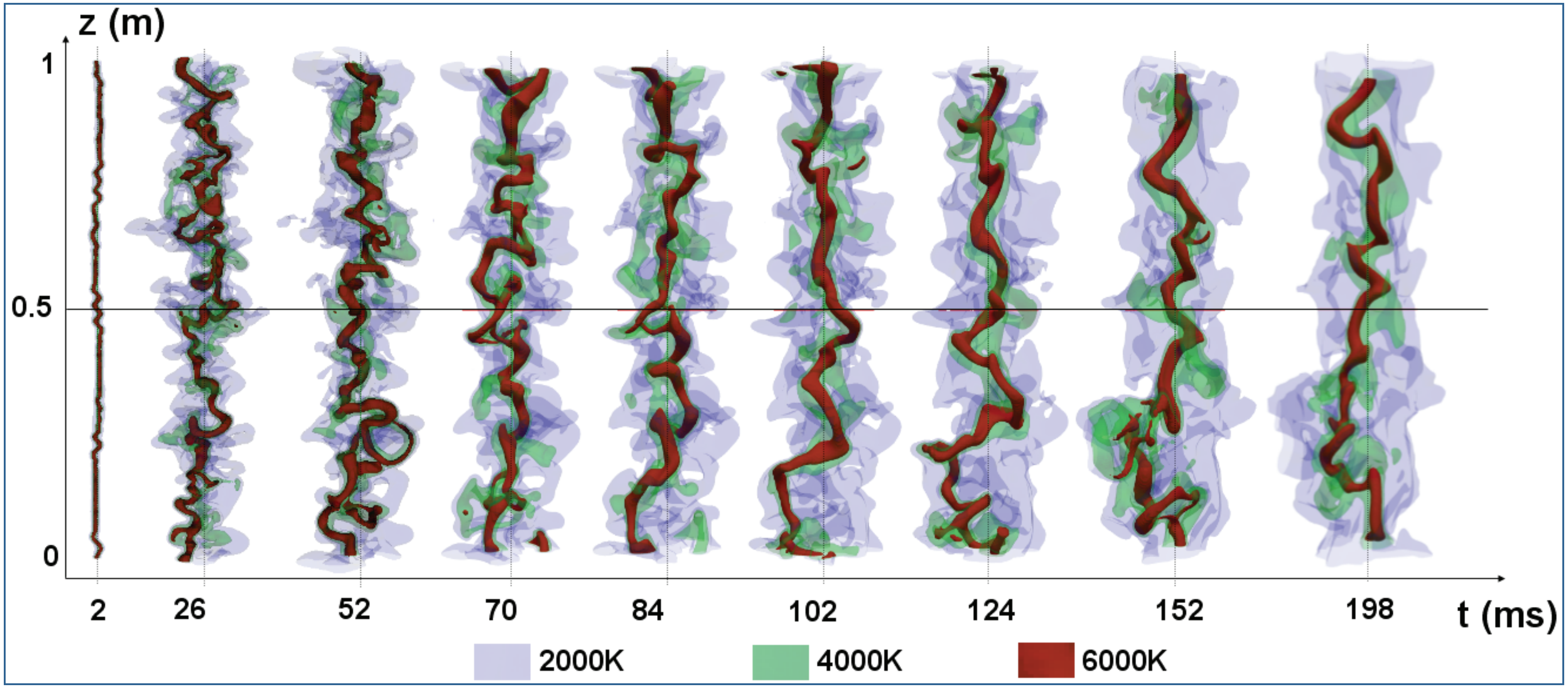
⇩

The current conservation equation writes:

$$\vec{\nabla} \cdot \sigma \vec{\nabla} \widetilde{\varphi} = -E_m \partial_z \sigma$$

II. Lightning Channel : results

Evolution of the isotherm surfaces

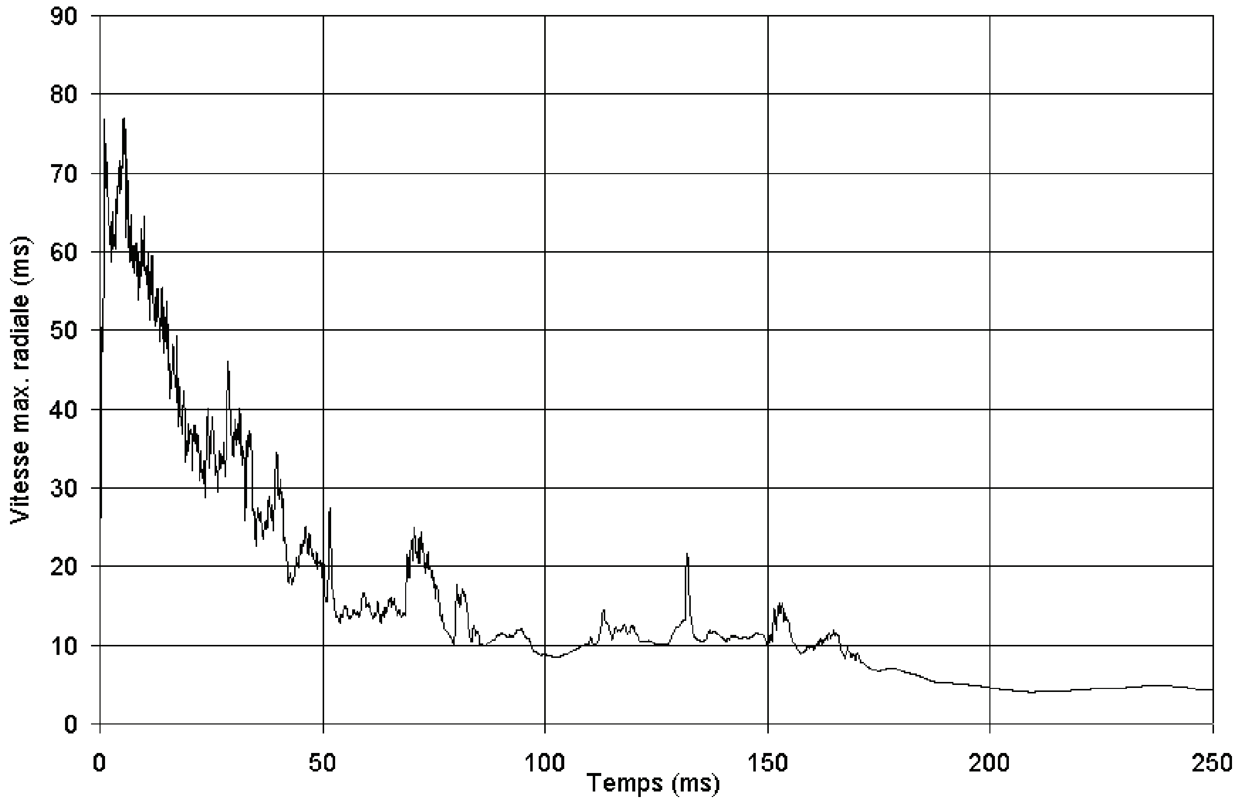


Latham, 1986 : 7000K with current of 100A

Latham DJ, "Anode column behavior of long vertical air arcs at atmospheric pressure", IEEE Transaction on Plasma Science, PS-14, 220-227, 1986

II. Lightning Channel : results

Evolution of the displacement velocity (m/s)

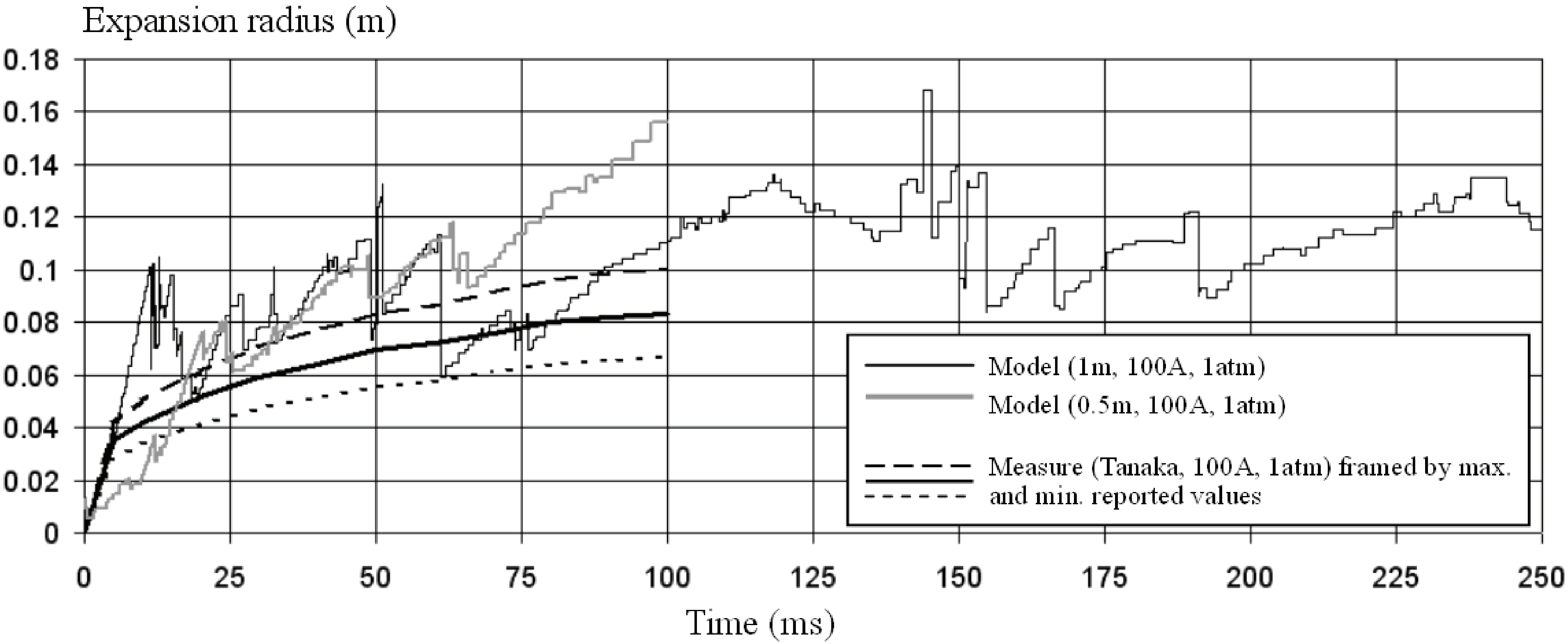


Sunabe and Inaba, 1989 : 10 m/s with 100A

Sunabe K, Inaba T, “Electric and Moving Characteristics of DC kilo-Ampere High Current Arcs in Atmospheric Air”, IEEJ, vol.109-A, No.3, pp.95-102, 1989.

II. Lightning Channel : results

⇒ RESULTS : data for macroscopic lightning ONERA model



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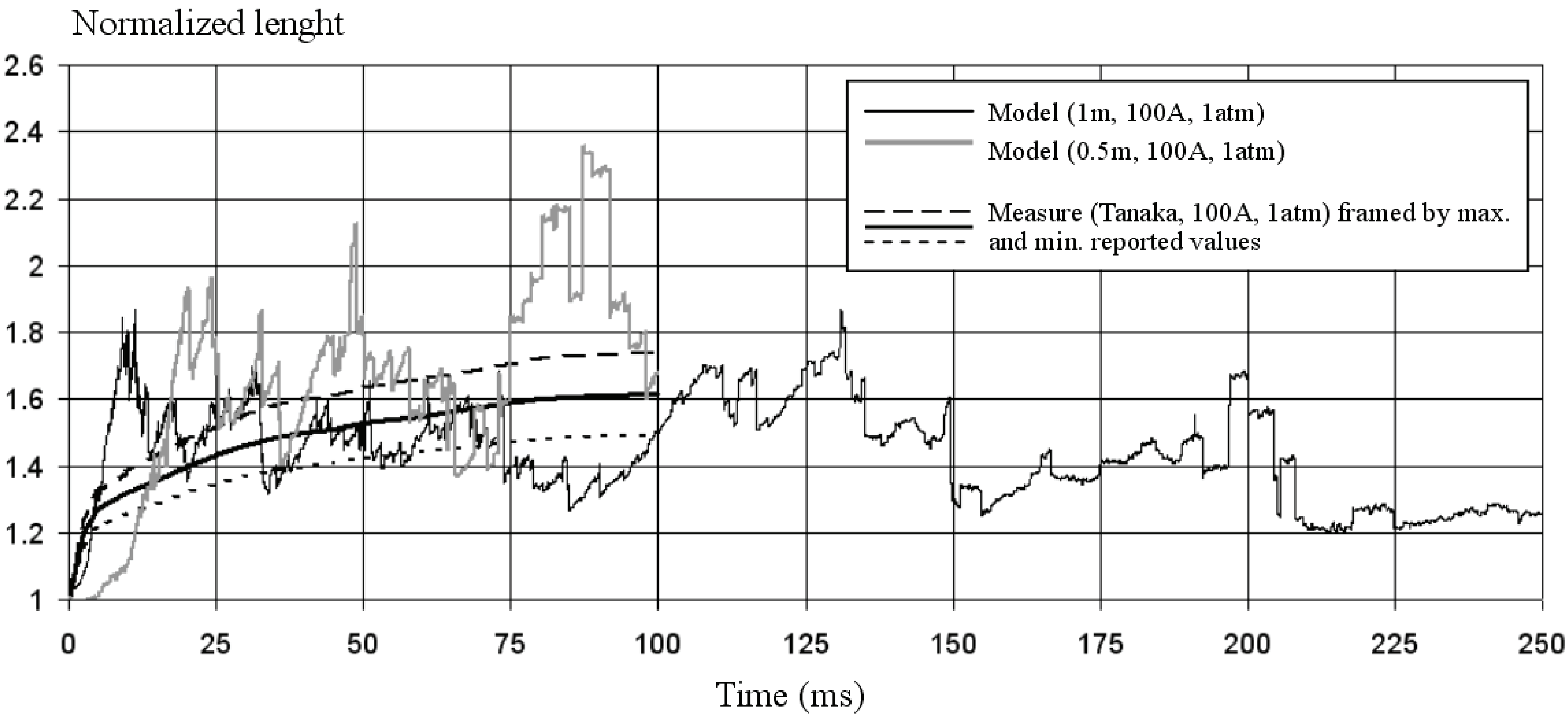

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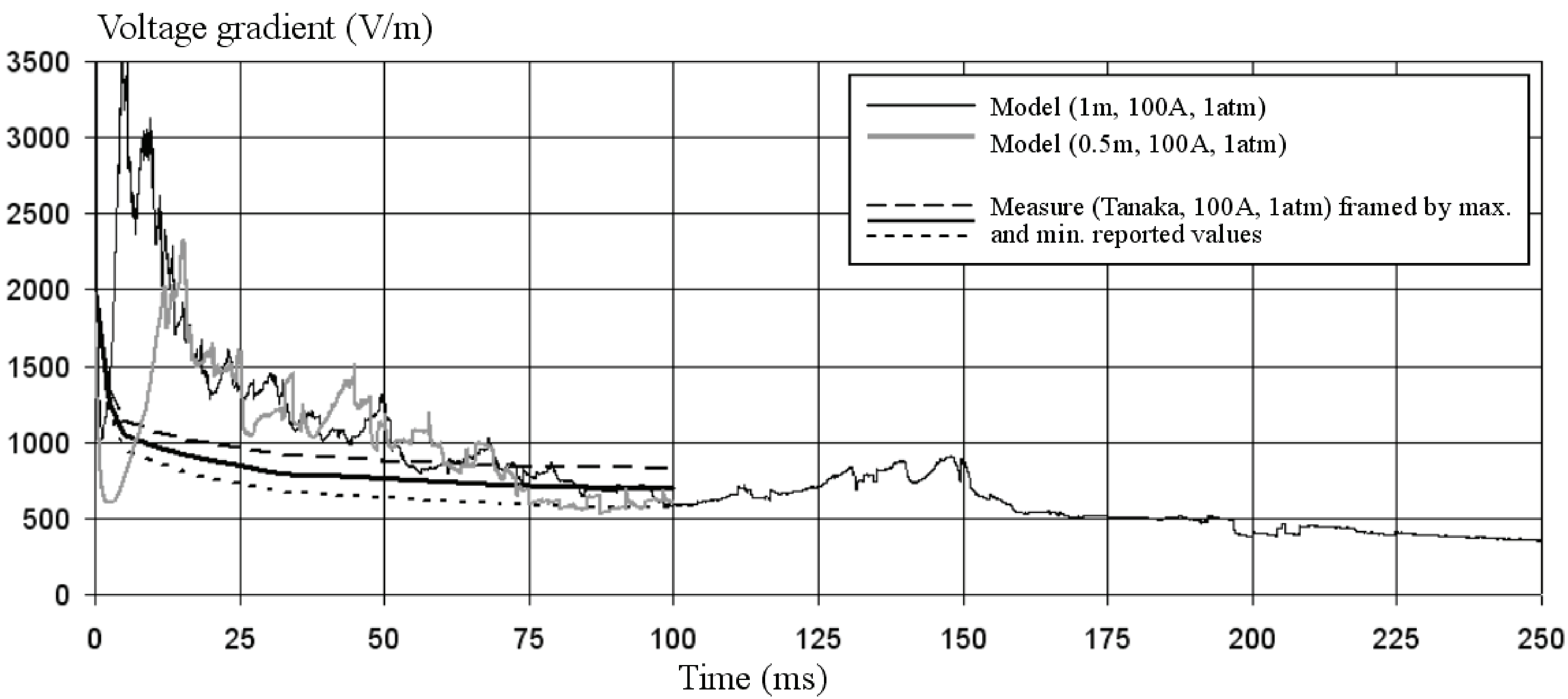
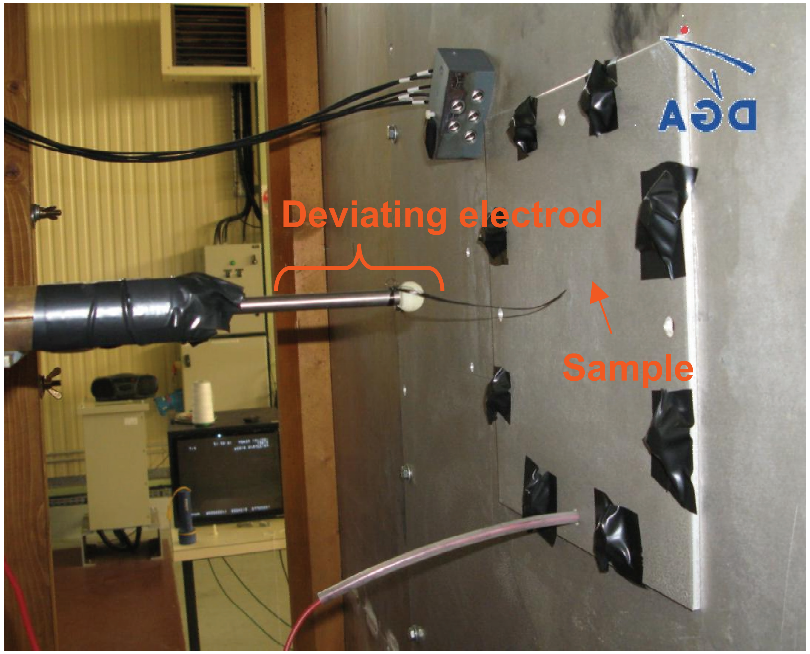
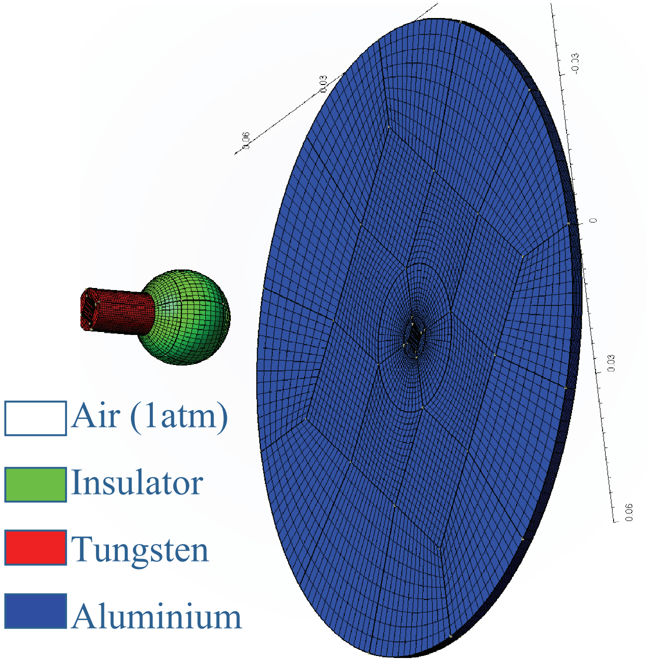


III. Lightning interaction with material : direct effects

Direct effects: damage at the attachment point





III. Lightning interaction with material : modelling

Simulation of electric arc including the electrodes

-Hydrodynamics in the electrodes !

« penalty method»

$$T_S = \frac{\rho}{\tau}\left(u - u_0\right) \quad with \quad \tau << \Delta t$$

- Electric conductivity σ discontinuity:

« Harmonic mean »

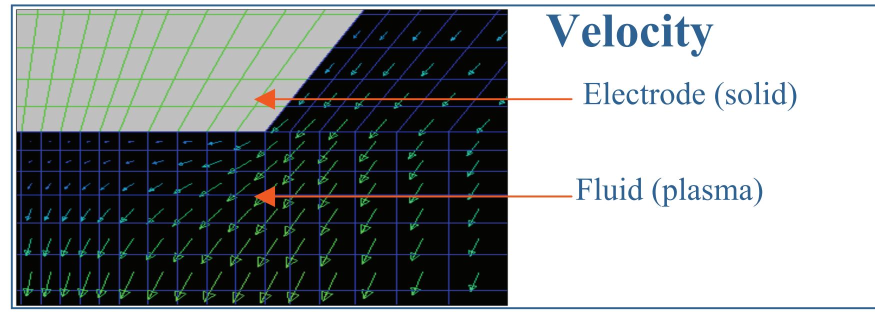
$$\sigma_{Interface} = 2\frac{\sigma_{Fluid}\sigma_{Solid}}{\sigma_{Fluid} + \sigma_{Solid}}$$

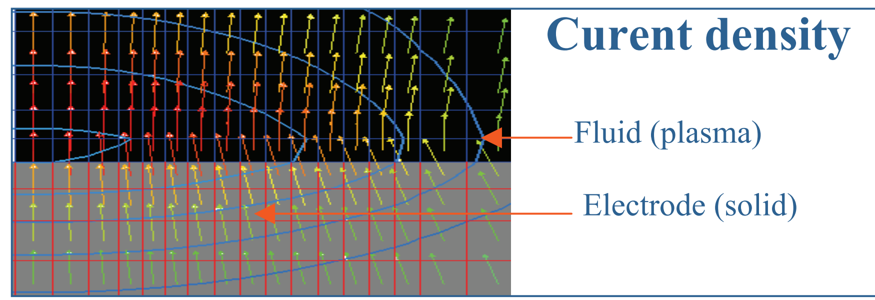
- Vaporization of the electrode

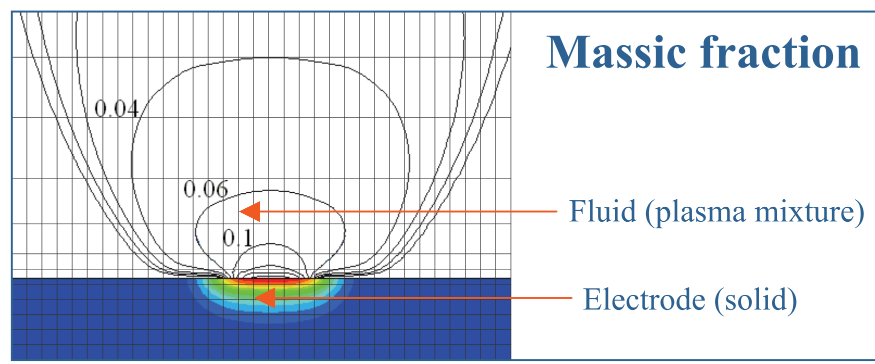
Metallic massic fraction X at the interface

« penalty method »

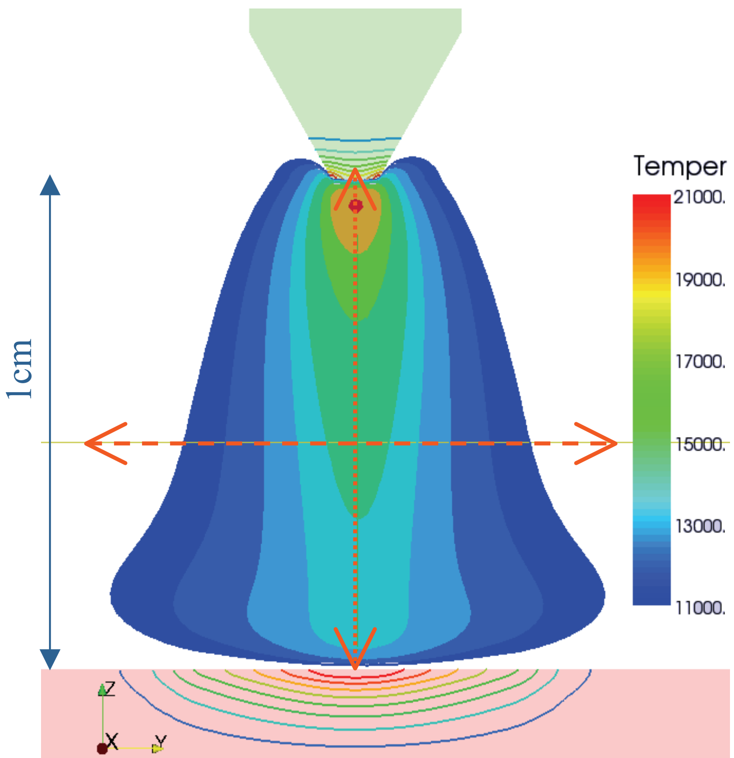
$$T_S = \frac{\rho}{\tau}\left(X - X_{Model}\right) \quad with \quad \tau << \Delta t$$

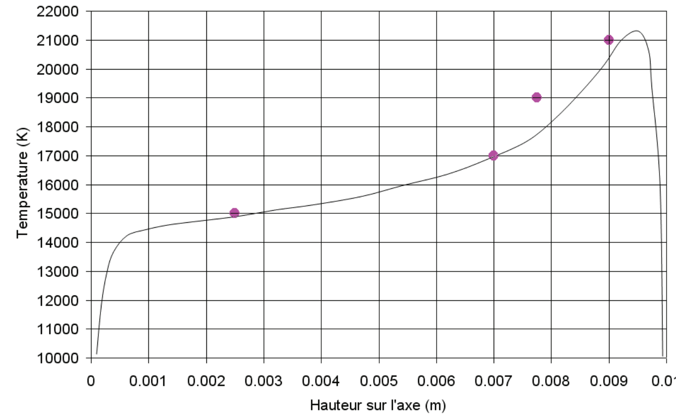


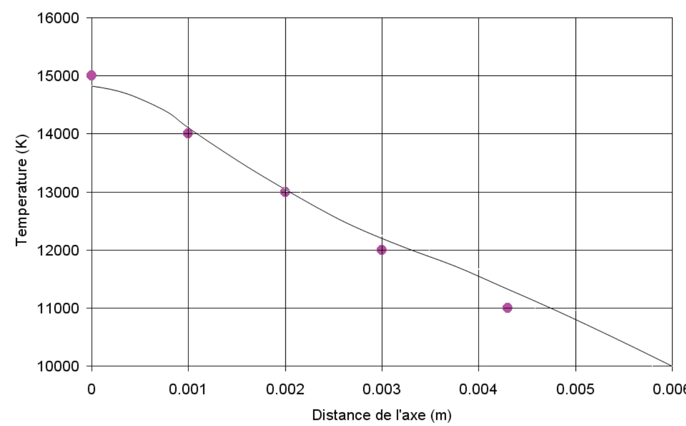




Comparison with measurment: steady state argon arc (1cm, 200A)





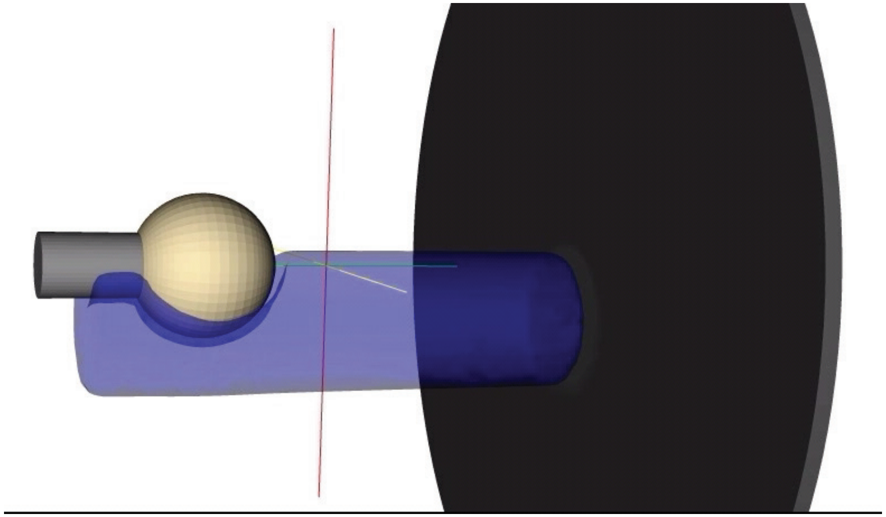


Hsu K.C., Etemadi K., Pfender E., "Study of the free-burning high intensity argon arc", J. Appl. Phys. Vol. 54 n3 (p 1293), (1983).

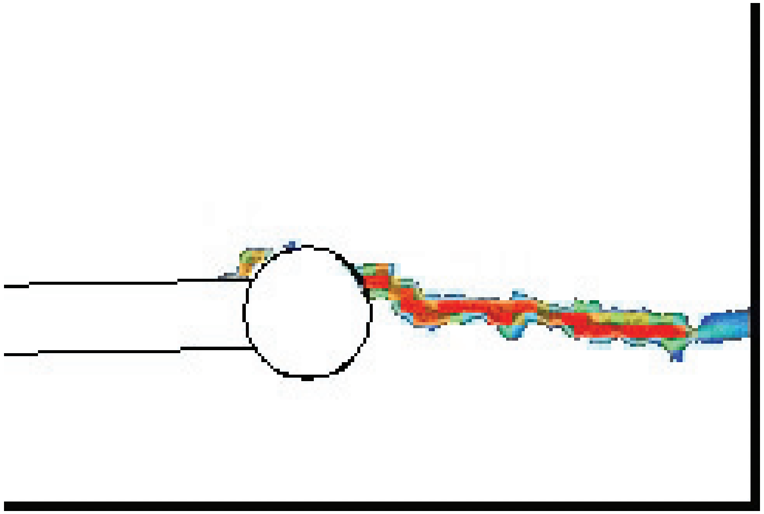
III. Lightning interaction with material : results

Comparison of the behavior

SIMULATION
Code_Saturne®
(24 ms, 5cm)

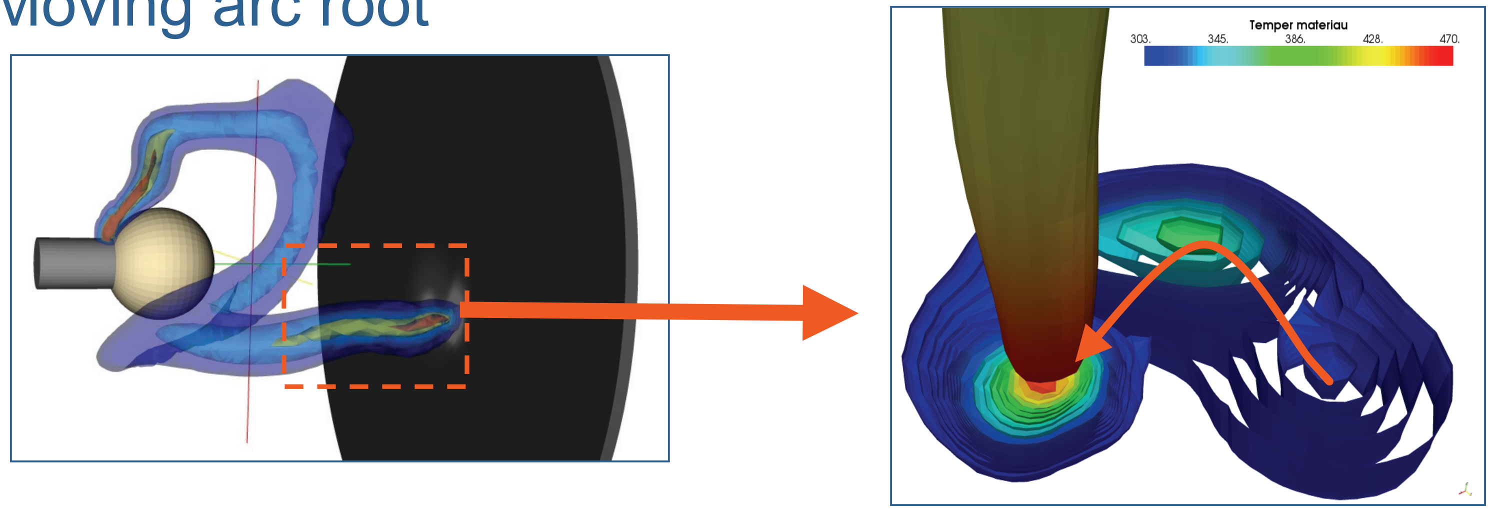


EXPERIMENT
CEAT
(24 ms, 5cm)

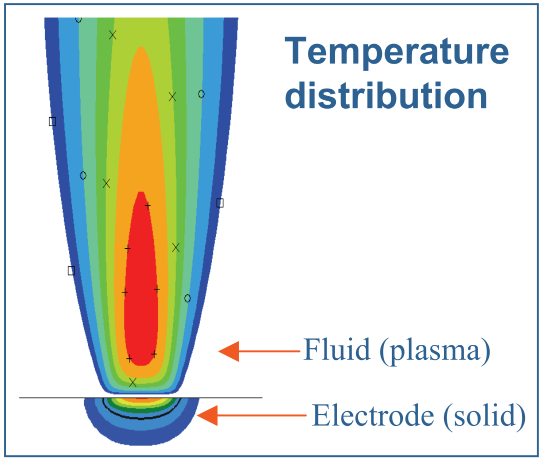


III. Lightning interaction with material : modelling

Moving arc root



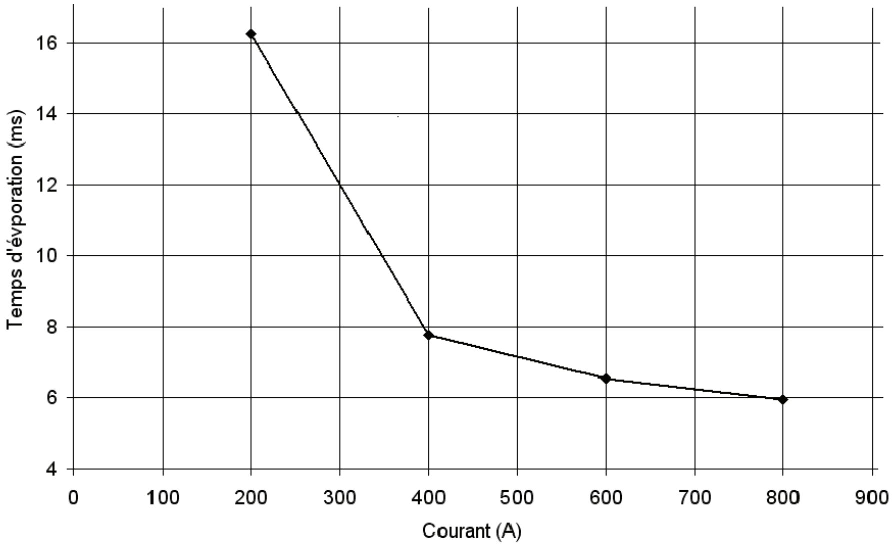
Steady state modeling of the arc root



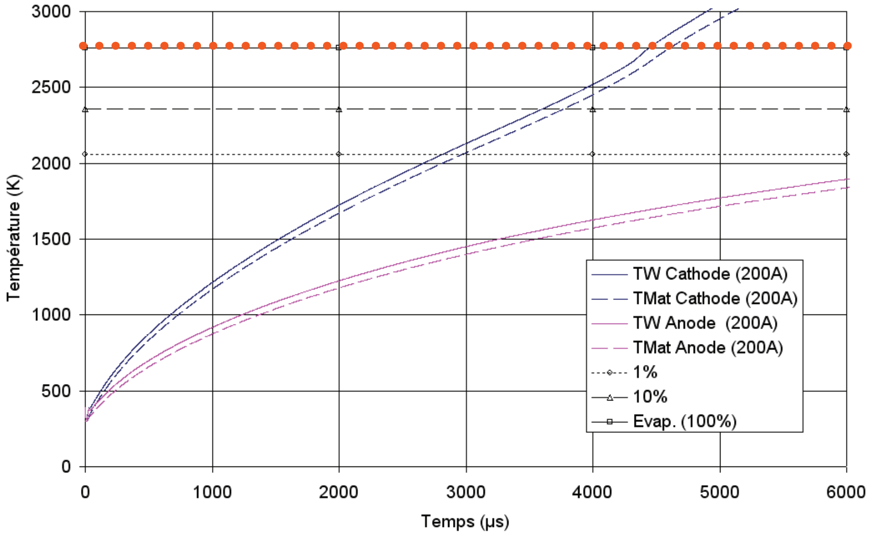
III. Lightning interaction with material : results

Steady state modeling of the arc root

Electrode vaporization time (ms) as a function of the current (A)



Evolution of the temperature (K) in a cathode (blue) and in an anode (pink) as a function of the time (µs)



Conclusion

Lightning channel modelling

- With a periodic distribution (fluctuating potential)
- Good agreement with litterature
- Used for macroscopic modelling of lightning

Lightning interaction modelling

- 1 computation domain including both solid (electrodes) and fluid
- Good agreement with the behavior on an unsteady case (experiment/simulation)
- Results for steady state arc :
  - **Vaporisation of an anodic sample: 16ms with 200A, 5ms with 800A**
  - **Vaporisation of a cathodic sample: 4,5ms with 200A**

Thank you for your attention