Bigand, Audrey and Bauchire, Jean-Marc and Espinosa, Christine Lightning arc interaction with complex structure. (2018) In: 15th International High-Tech Plasma Processes Conference (HTPP), 2 July 2018 - 6 July 2018 (Toulouse, France).

LIGHTNING ARC INTERACTION WITH COMPLEX STRUCTURE

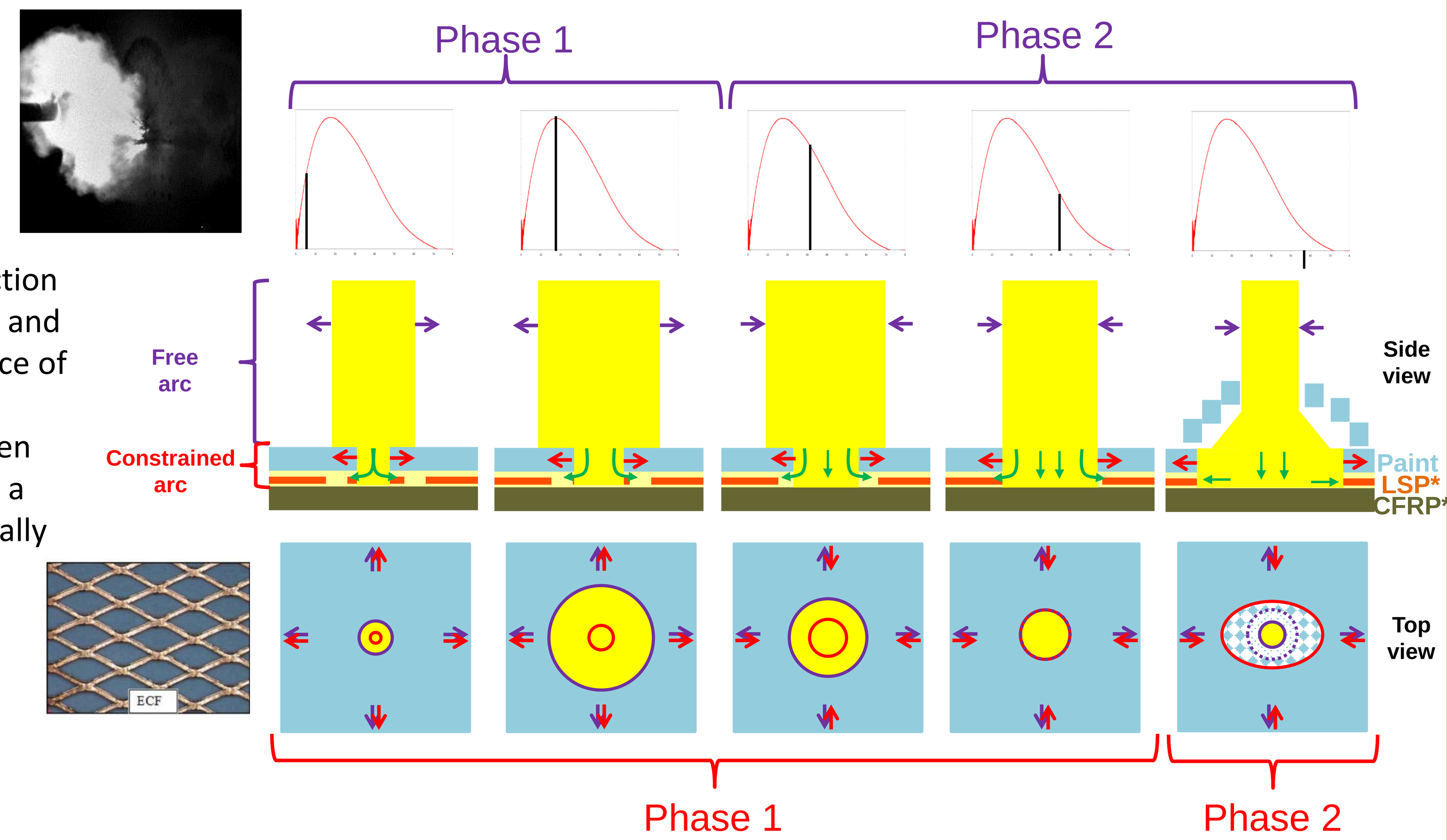
A.BIGAND[1,2], J.M. BAUCHIRE[2], C. ESPINOSA[1]

[1] Institut Clément Ader, UMR 5312, CNRS-University of Toulouse, 3, rue Caroline Aigle, F-31400 Toulouse CEDEX 04

[2] GREMI, UMR 7344, CNRS-University of Orleans, 14 rue d'Issoudun, BP 6744, 45067 Orleans Cedex 2

INTRODUCTION

- Lightning is a natural and unpredictable phenomenon due to charge generation in clouds producing intense electrical field leading to flashes of extremely high current and high voltage pulses of few µs. In this context, aircrafts are subjected to the risk of being struck during flight and the lightning damage mechanism for carbon laminate aeronautical structure is a complex multi-physical phenomenon.
- In order to understand this phenomenon, it is of first importance to understand and predict the interaction of the lightning arc with the aircraft structure as it will change the energy deposition into the structure and the associated vaporization profile. This sudden vaporization is equivalent to an explosion on the surface of the composite.
- Arc interaction is already complex to study with a bare metallic structure but it is far more complex when considering aircraft configuration. The structure is a substrate of low conductivity: (CFRP), protected by a metallic mesh (LSP) used to divert lightning from CFRP and thus vaporize with lightning current, and finally paint which constrained the arc root expansion.
- Lightning arc can be decomposed in 2 areas: Free arc and Constrained arc with 2 phases:
  - *Free arc:*
    - Phase 1: Peak current increasing phase -> Arc expansion
    - Phase 2: Peak current decreasing phase -> Arc contraction
  - *Constrained arc:*
    - Phase 1: Arc root expansion constrained by paint with $\varnothing_{\text{Constrained arc}} \leq \varnothing_{\text{free arc}}$
    - Phase 2: Arc root expansion dependent on LSP conductivity (anisotropic) with $\varnothing_{\text{Constrained arc}} > \varnothing_{\text{free arc}}$

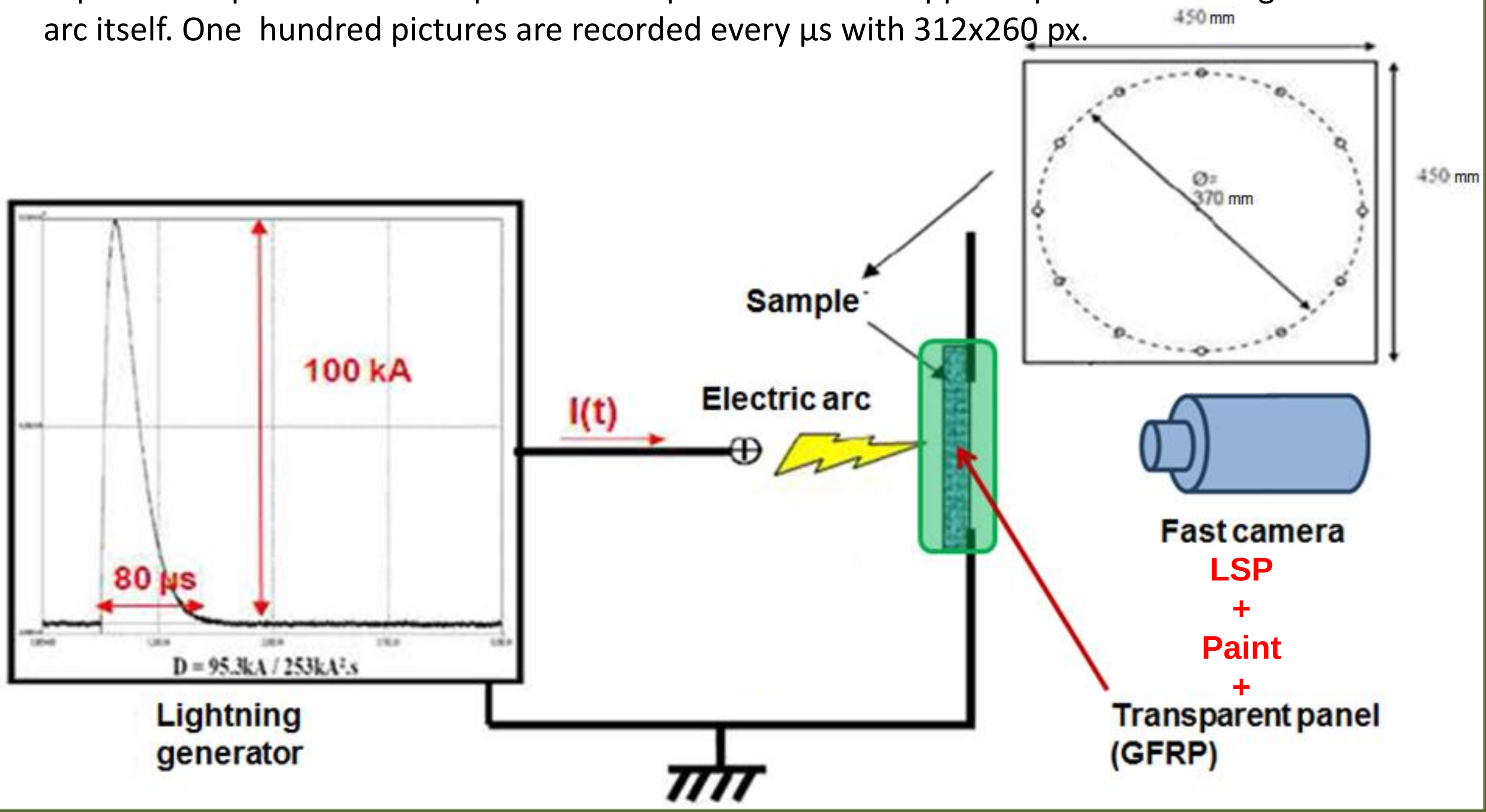


* CFRP = Carbon Fibre Reinforced Plastic, LSP = Lightning Strike Protection (usually ECF = Expanded Copper Foil)

- It is aimed here to evaluate this assertion through the comparison of experimental measurements of the vaporization radii for different painting configurations with numerical predictions.

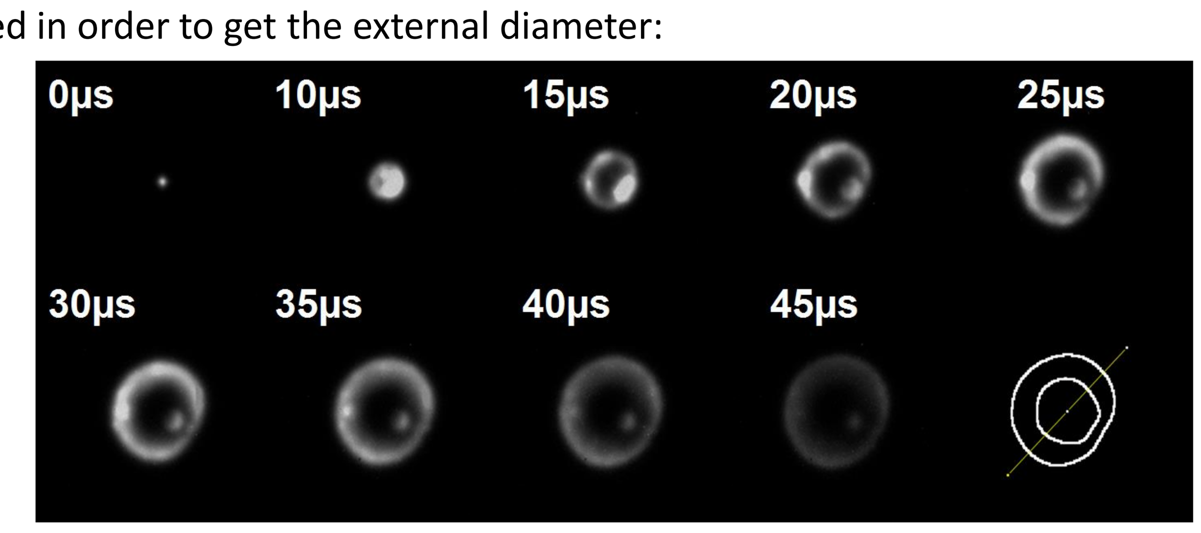
EXPERIMENTAL SETUP

- In order to study the LSP vaporization profile which will provide information on the constrained arc, a specific experimental set up has been built.
- An electrical arc simulated lightning strike peak current has been injected on several configurations of lightning strike protection and paint. This lightning current is a pulse of 100kA reached in 18µs which lasts 80µs.
- Transparent panels made of GFRP (Glass Fiber Reinforced Plastic) with different surface configurations combining different LSP (ECF195, ECF73 or SCF88) and paint thicknesses (200, 400, 800µm) have been manufactured.
- A high speed camera (Photron IS1M) is placed on the back of the sample and can record the vaporization profile since the panel is transparent and the copper vaporization is brighter than the arc itself. One hundred pictures are recorded every µs with 312x260 px.



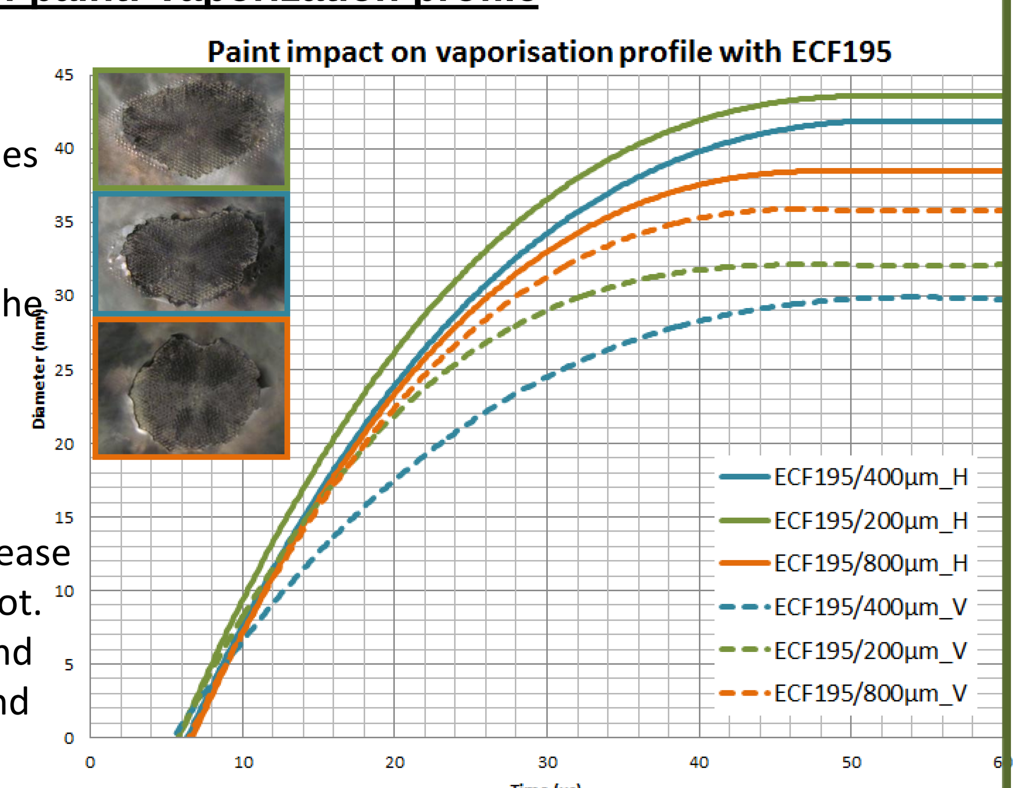
TEST RESULTS ON VAPORISATION PROFILES

- Vaporization profile pictures are similar to a white ring in expansion. On those pictures, a filter has been applied in order to get the external diameter:



SCF+400µm of paint: Vaporization profile

- ECF195 with different paint thicknesses has been studied: 200, 400 & 800µm.
- Due to its anisotropy, vaporization profiles are different in the Horizontal (—) and Vertical (---) directions.
- Paint thickness increase tends to make the profile more and more symmetrical, as seen on profile with 800µm of paint.
- Profile with 200µm of paint is close to a profile without paint
- Paint thickness increase leads to an increase of phase 1 which constrained the arc root.
- No paint is equivalent to phase 2 only and thick paint tends to suppress phase 2 and increase phase 1.



VAPORISATION PROFILE MODEL

PRINCIPLE :

- Vaporization profile can be predicted by running an electro-thermal simulation.
- In COMSOL Multiphysics ®, Joule heating has been considered in copper with phase change.
- In order to consider anisotropy of ECF and avoid real modelling of the geometry anisotropy has been introduced in the conductivity.

Heat equation including Joule heating

$$mC_p dT = Pdt$$

m: mass
P: Power
T: Temperature
t: Time

$$T < T_{melt}:\ \rho C_{ps}(T)\frac{dT}{dt} = \frac{j^2(t)}{\sigma_s(T)}$$

$$T = T_{melt}:\ \rho \Delta H_{melt}\frac{dx}{dt} = \frac{j^2(t)}{\sigma_{sl}}$$

$$T_{melt} < T < T_{vap}:\ \rho C_{pl}(T)\frac{dT}{dt} = \frac{j^2(t)}{\sigma_l(T)}$$

Cp: Specific heat
ρ: Density
j: Electrical current density
σ: Electrical conductivity
ΔH: Enthalpy of melting

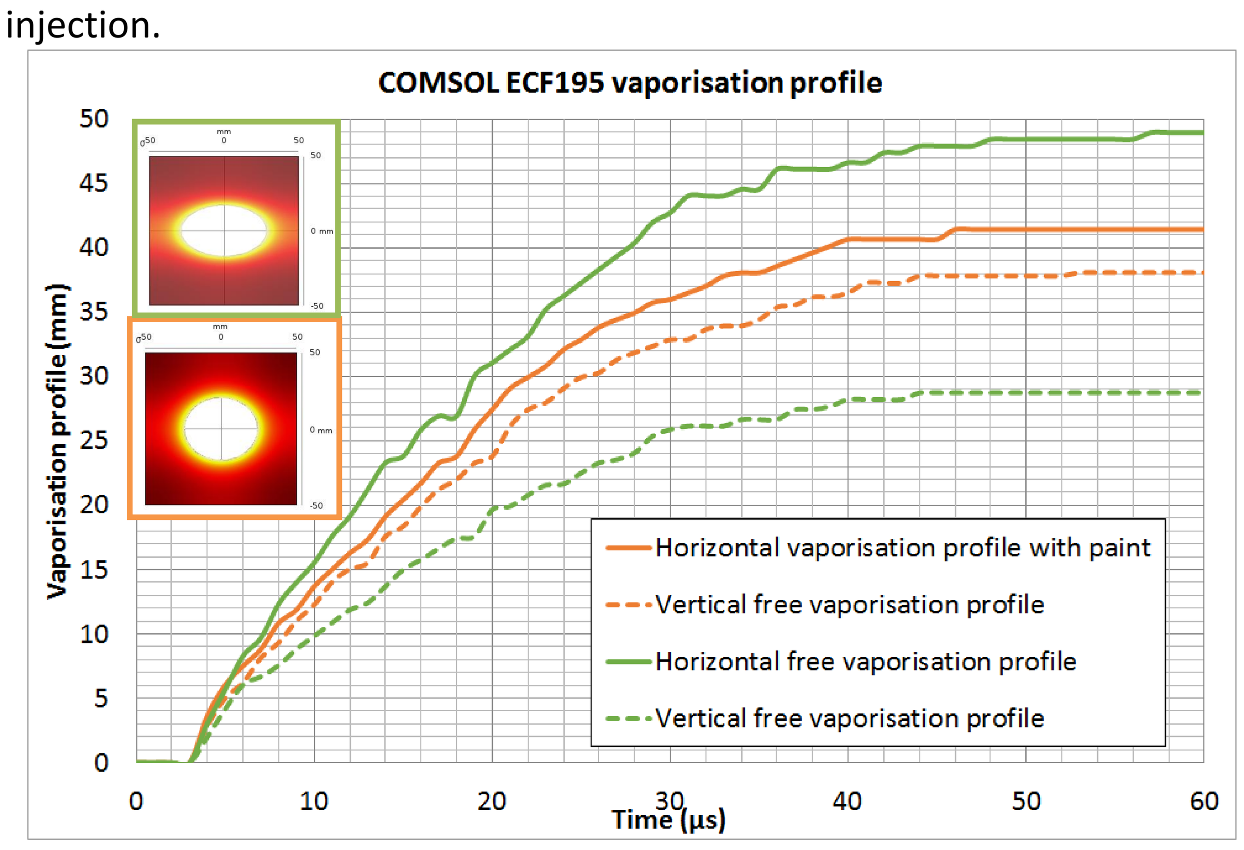
s: Solid
l: Liquid

T_{melt} = 1357K
T_{vap} = 2835K

Properties dependency on Temperature

RESULTS :

- With a change in the injection in order to represent arc confinement with paint, it is possible to reproduce symmetrization.
- The difference with test could be linked to phase change introduction and the hypotheses taken for the current injection.



CONCLUSION

- This specific experiment allowed to study the arc root evolution impacted by the vaporization of the metallic Lightning Strike Protection and the confinement of the paint. High speed camera is of first importance to study this quick multiphysic phenomenon and it highlighted an evolution in 2 phases.
- It remains to finalize free arc COMSOL Multiphysic s® model with dynamic analysis and to confront the maximum free arc diameter with the vaporization profile in order to confirm this 2 phases evolution, and thus to consider other experiences in different configurations (LSP, dielectric…).
- Paint thickness mechanical properties evolution will be determined in order to predict its impact on arc root constriction and transition from phase 1 to phase 2.
- This activity is part of a PhD which aims to predict the damage into composite structure due to lightning strike, supervised by ICA & GREMI and supported by a French R&T project: EDIFISS with Airbus.