Bigand, Audrey and Espinosa, Christine and Rabat, Hervé and Bauchire, Jean-Marc Lightning strike protection explosion and overpressure profile. (2018) In: 15th International High-Tech Plasma Processes Conference (HTPP), 2 July 2018 - 6 July 2018 (Toulouse, France).

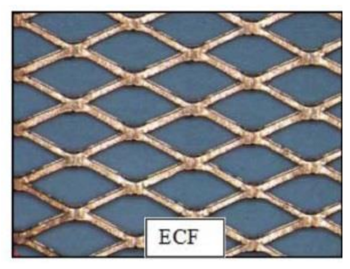
LIGHTNING STRIKE PROTECTION EXPLOSION AND OVERPRESSURE PROFILE

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

[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

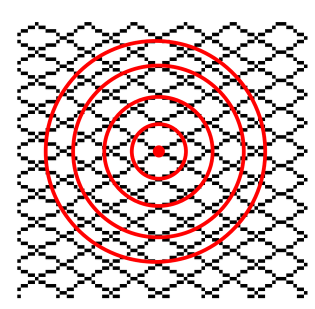
INTRODUCTION

- Lightning is a natural and unpredictable phenomenon due to charge generation in clouds producing intense electrical field leading to flashes of extremely high current 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.
- One of the main contributor is the overpressure generated by the quick vaporization of the metallic lightning strike protection that covers the composite aircraft surface in order to divert lightning current. This lightning protection is usually an Expanded Copper Foil (ECF) of 195gsm or 73gsm.



Expanded Copper Foil close-up view

- This protection can be approximated to a web of wires of Ø125µm for ECF195 & Ø75µm for ECF73. Each wire is considered as a source of overpressure dependent on current density which is assessed as follow: $J_n=I_n/S$ with $I_n = {}^{I}/_{4+8n}$, S: section of the wire and n: Iteration of a circular injection.

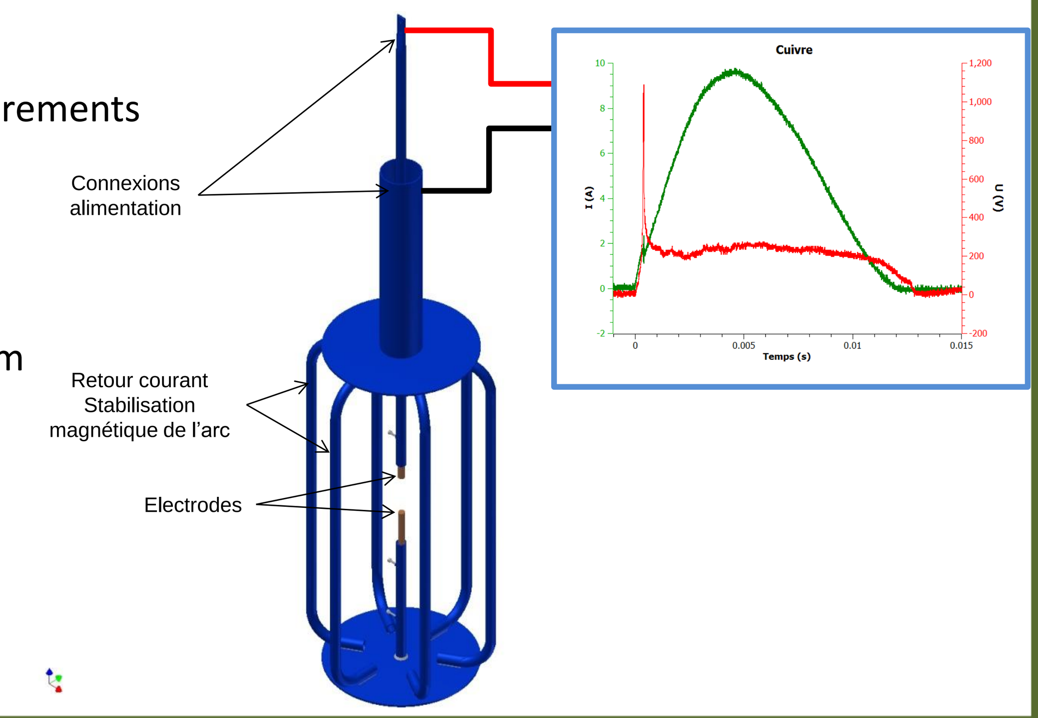


Circular current distribution approximation for current density assessment in wire depending on distance from injection

- The aim of this study is to validate the representation a each copper wire through the comparison of electro-thermal simulation of its vaporization with experimental tests measurements.

EXPERIMENTAL SETUP

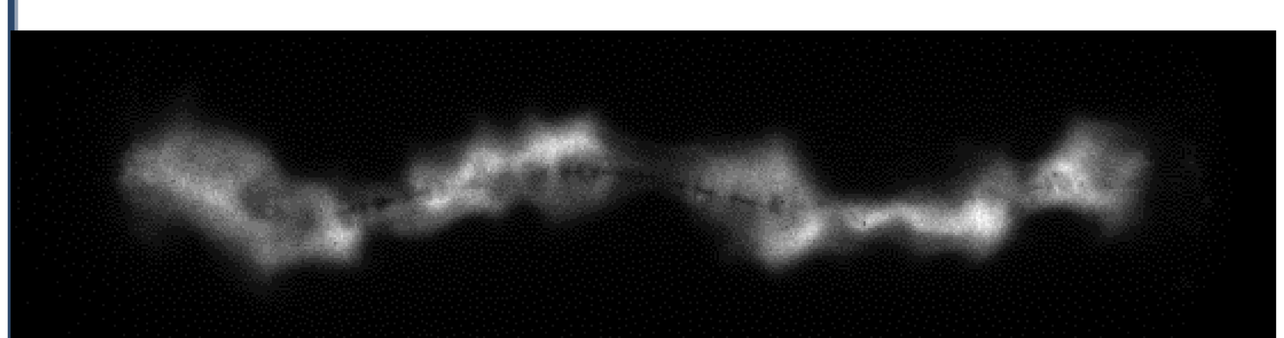
- In order to study the vaporisation profile, a copper wire of 40mm is bonded between 2 electrodes with a coaxial return to ensure homogeneity.
- In order to validate the principle of vaporisation profile, a slow current waveform with a peak current at 5ms has been considered before studying lightning waveforms with peak current reached in few µs.
- To support the study, several measurements have been performed:
    - Current
    - Voltage
    - Picture at vaporisation
    - Pressure sensor at 50mm from the wire



VAPORISATION DETECTION TEST

PRINCIPLE :

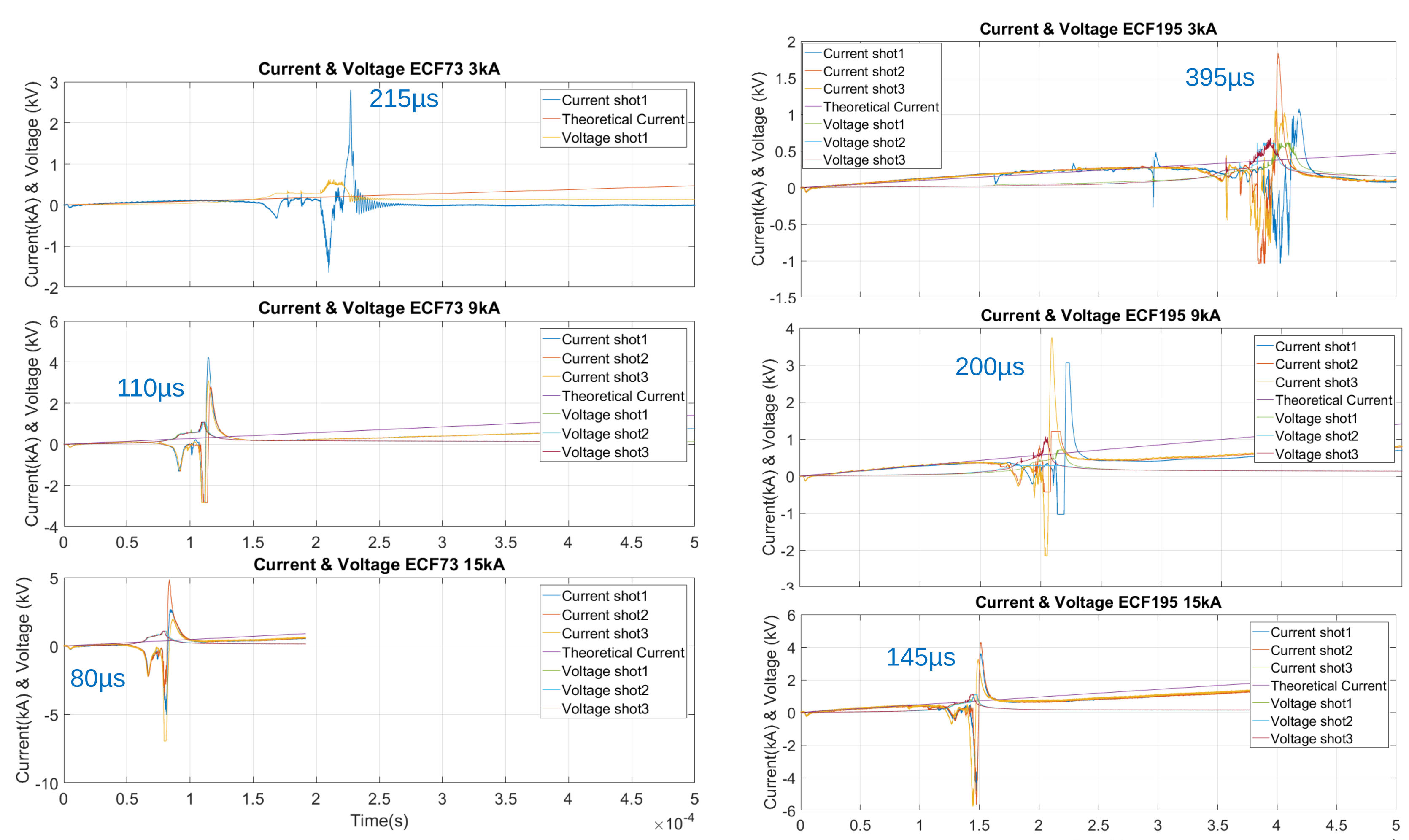
- Up to vaporisation, current measured in the wire will be equal to the injected current.
- As soon as the arc is generated a voltage peak and a current disruption can be detected which help in the study of the vaporisation.
- Because of the strong solicitation, instabilities are visible in the copper wire and could impact vaporisation.



ICCD snapshot at vaporisation time

- Due to Joule heating, the copper wire will abruptly vaporise and this phenomenon will appear more and more quickly with the current increase and the section decrease.

RESULTS :



ECF73 ECF195

VAPORISATION PREDICTION 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.
- A copper wire has been simulated as a cylinder with equivalent dimension and the temperature profile has been recorded with a current injection equivalent to the lab injection: A x sin(2πft) with A= 3, 9 and 15kA, f=50Hz.
- Dependency of properties on temperature is important to consider in order to simulate joule heating impact on such phenomenon with important temperature evolution.

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

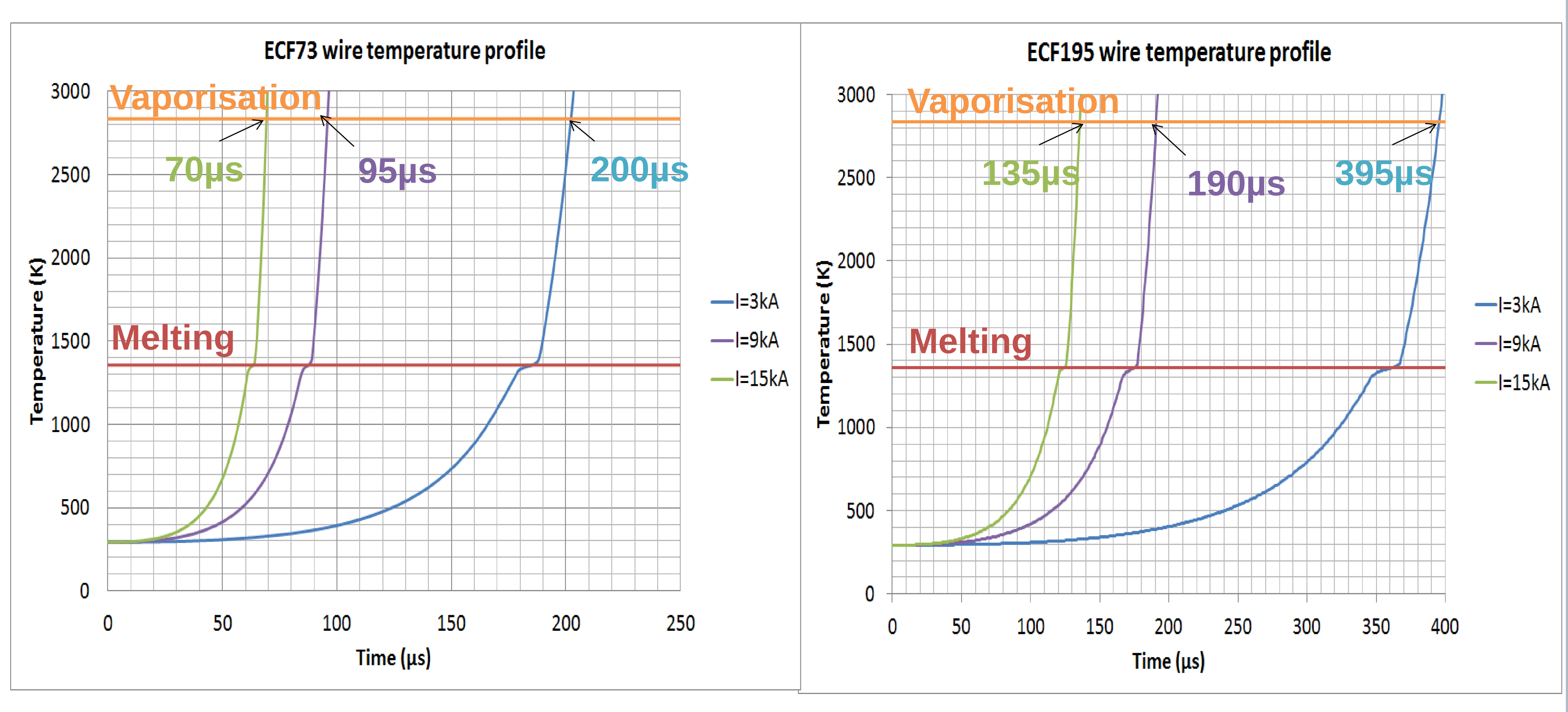
s: Solid
l: Liquid

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

Properties dependency on Temperature

RESULTS :

- Temperature profiles with ECF195 and ECF73 equivalent wires predict well vaporization appearance on different copper sections and with different current amplitudes.
- Few differences can be observed but it could be solved by the addition of another phase change from liquid to vapor.



CONCLUSION

•This specific experiment allowed to study the vaporization appearance in copper wires which are part of the composition of an expanded copper foil. Electrothermal model developed in COMSOL predict well Joule heating impact on temperature of the wire up to vaporization.
• It remains to add a pressure model for the wire when plasma is generated and to confront with shock wave measured by the pressure sensor, considering several distances, lightning current profiles and amplitude based on the distance law defined in the introduction, and based on wire configurations.
• This will be performed during a second test campaign.
•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.