# A THERMAL STUDY OF POWER CABLES COOLING IN TUNNELS

**F. Boukrouche[1] (PhD),**
**C.Moreau[1], S.Harmand[2], F. Beaubert[2], J.Pellé[2], O.Moreau[3]**

[1]EDF R&D, Moret-sur-Loing, France,
[2]LAMIH-UMR CNRS 8201, University of Lille Nord-de-France, France
[3]EDF – CIST, Paris, France

E-mail: fahd.boukrouche@edf.fr

COMSOL CONFERENCE 2016 BOSTON



# SOMMAIRE



COMSOL CONFERENCE 2016 BOSTON




Université de Valenciennes et du Hainaut-Cambrésis

LAMIH UMR CNRS 8201

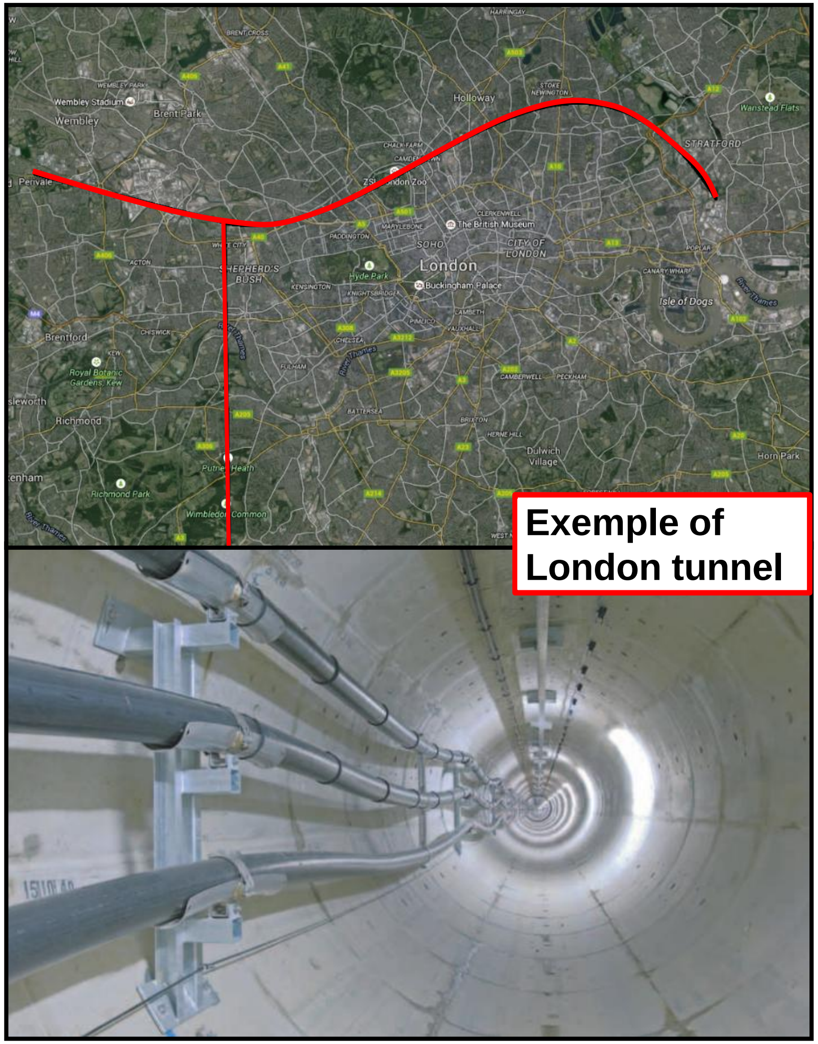
# I – POWER TRANSMISSION NETWORK

- From energy production centers to the distribution networks, several solutions are available :

**Overhead lines :**

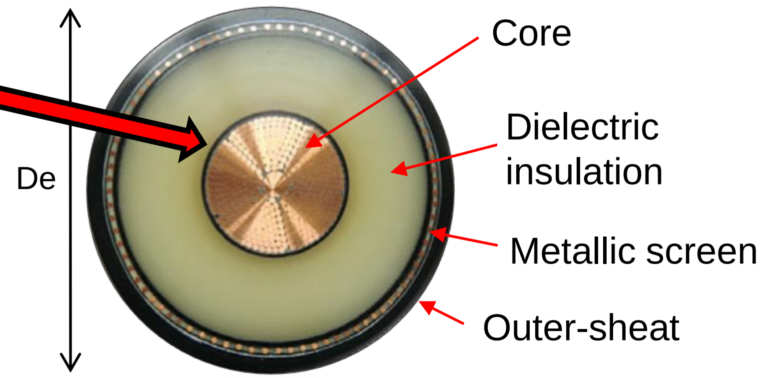
**Buried lines :**

**Tunnels :**

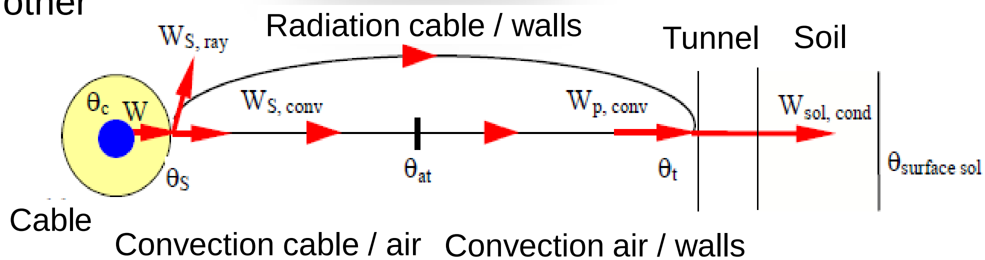


# I – THERMAL LIMITING FACTOR

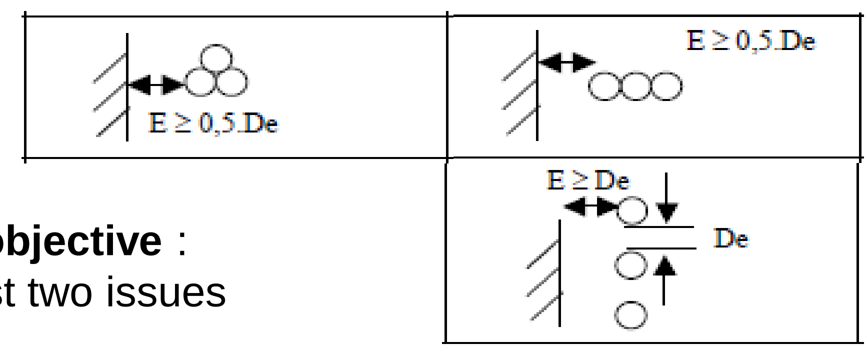
- **Principal limiting factor : the dielectric insulation temperature.**




- **The Joule heating from the transiting current is dissipated through.**
  - Conduction in the cables layers.
  - Convection with the surrounding air.
  - Radiation with other surfaces (tunnel walls, other cables, etc.).



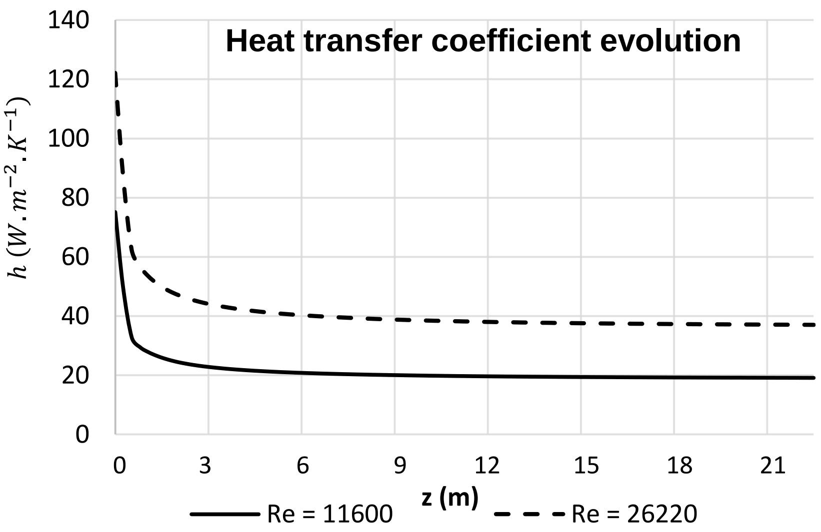

- **Existing rating methods suffer some limitations such as :**
  - All cables are considered identicals.
  - Empirical derating coefficients for groups.
  - Cooling laws not proposed for fully developed turbulent flow.




**Ph.D. main objective** :
Remove the last two issues

# I – SIMULATION CHALLENGES

- **Tunnels are kilometers long…**
  - ➔ Long geometries involved
- **High aspect ratio between the tunnel and the cables**
  - ➔ High number of elements for a good mesh quality.
- **Need of a Low Reynolds approach for high precision in the computed heat transfer.**
  - ➔ Even higher number of elements…
- **Turbulent flow regime needs a (very) long entrance length.**
  - ➔ More elements…



COMSOL CONFERENCE
2016 BOSTON

I. INTRODUCTION

## II. EXPERIMENTAL & SIMULATION SETUP

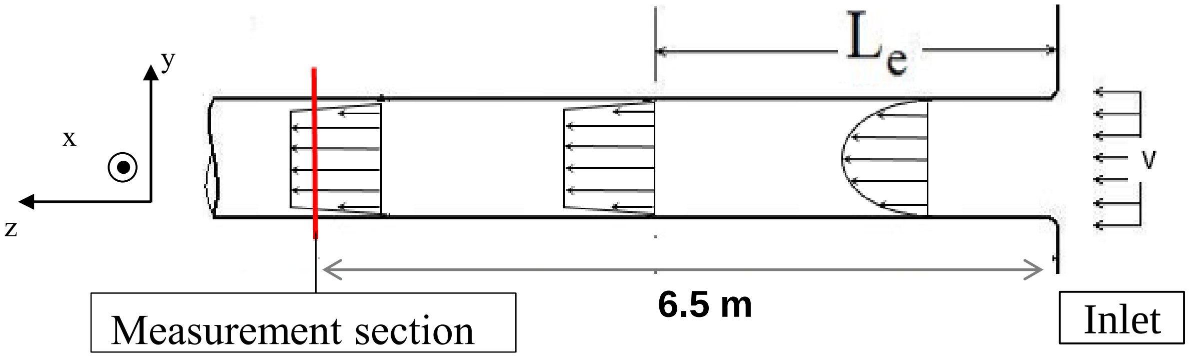
- I. Ventilated cable tunnel Mock-up
- II. COMSOL use for data treatment
- III. 3D numerical simulations

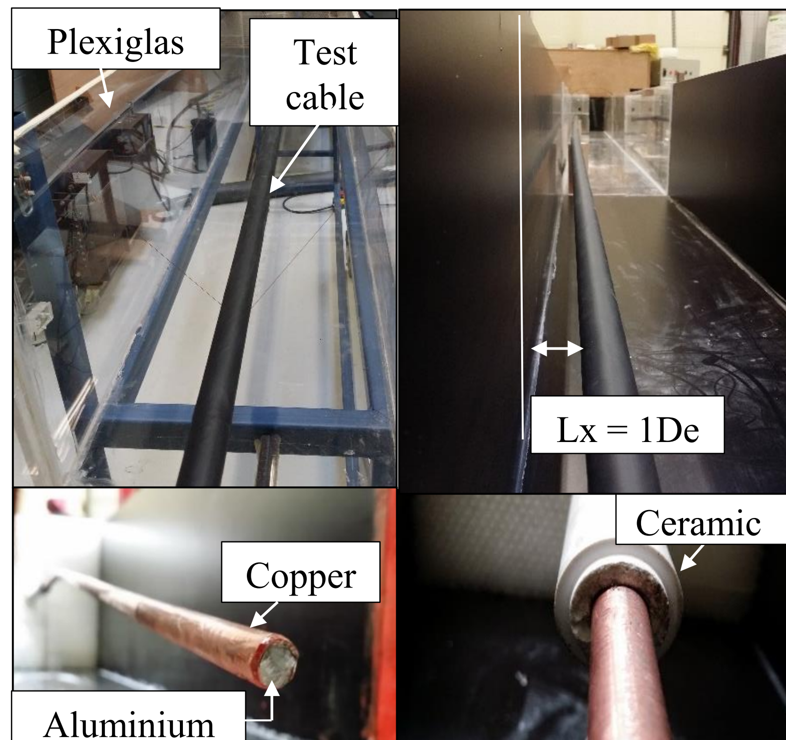
III. CABLE COOLING : RESULTS & DISCUSSION

IV. IMPACT ON THE MAXIMUM PERMISSIBLE CURRENT

V. CONCLUSIONS

# II –VENTILATED TUNNEL MOCK-UP



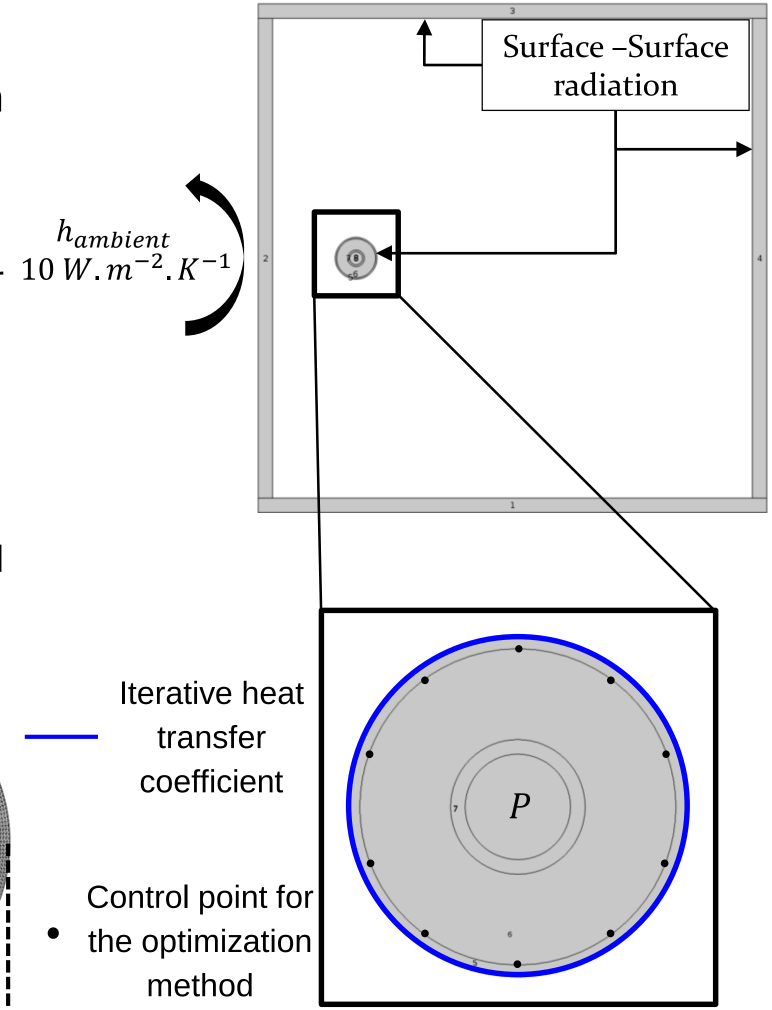



# II – COMSOL USE FOR DATA TREATMENT

- **The experimental data are treated with a coupled MATLAB-COMSOL inverse method.**

- **The local Nusselt numbers $Nu_i$ are obtained with an optimization script using two parts:**

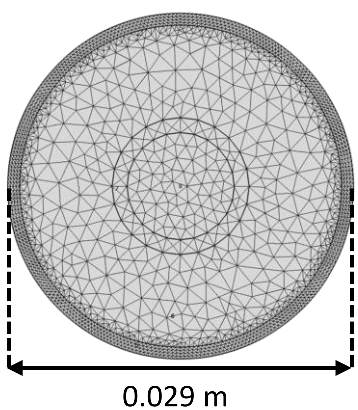
- **The COMSOL heat transfer module** for the heat transfer resolution.
  - 2D geometry.
  - Heat conduction in the cables & tunnel walls.
  - Surface-to-surface radiation (hemicube formulation).
  - Heat transfer coefficient at the cable surface controlled by the optimization process in the MATLAB interface.




- **The mesh is a very fine one**

  **➔ Underconstrained model.**

  Use of an interpolation fonction for the heat transfer coefficient



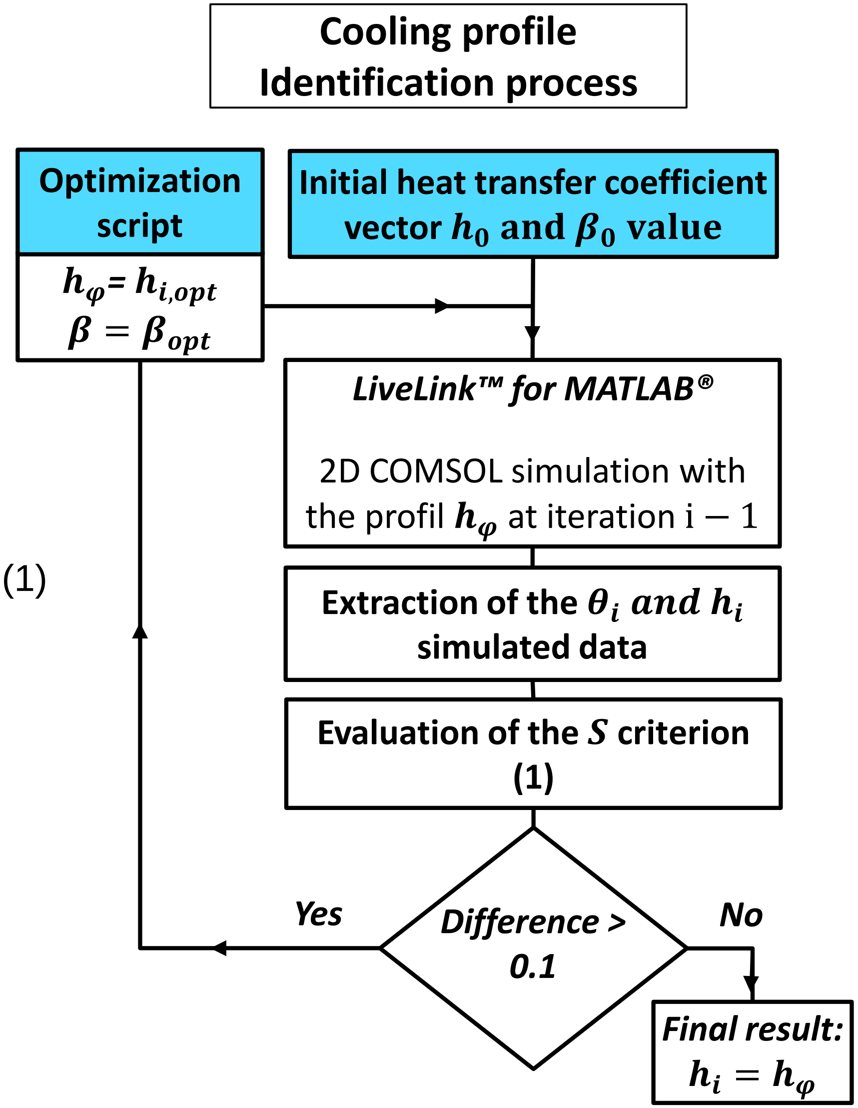
# II – COMSOL USE FOR DATA TREATMENT

- **The local Nusselt numbers $Nu_i$ are obtained with an optimization script using :**
  - **A MATLAB optimization process** based on the minimization of the S criterion (1).
    - A second order regularization is chosen.
    - The regulation coefficient $\beta$ is optimized for each iterations.

$$S = \sum_{i=1}^{10} (\theta_{comsol} - \theta_{mes})^2 + \beta \sum_{j} \left(h_{j+1} - 2h_j + h_{j-1}\right)^2 \quad (1)$$

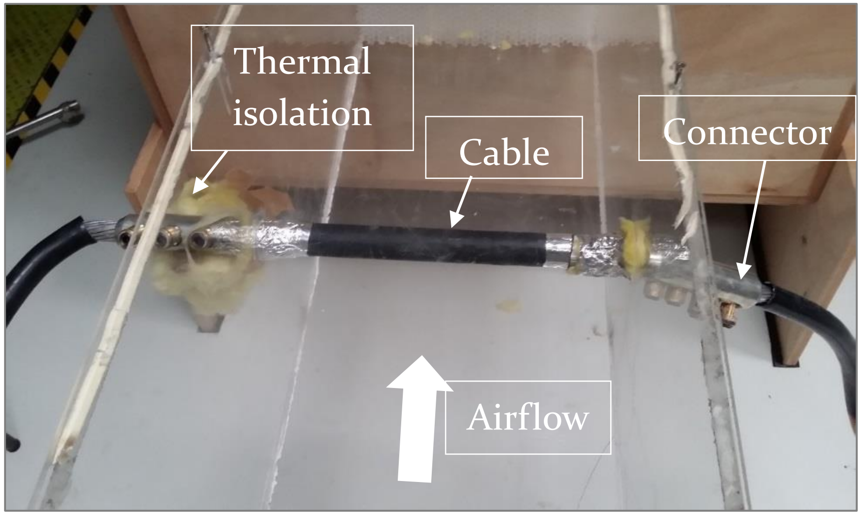
- The mean Nusselt number is obtained by integration on the cable surface.

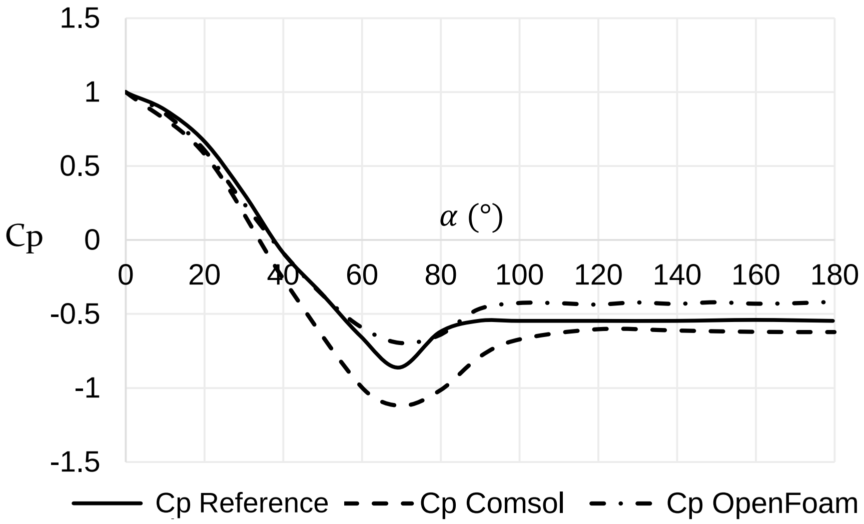
$$\overline{Nu_{D_e}} = \frac{D_e}{2\pi\lambda(\overline{\theta}_s - \theta_{ambient})} \int_0^{2\pi} \mathrm{P_{conv}}(\varphi)\, d\varphi \quad (2)$$

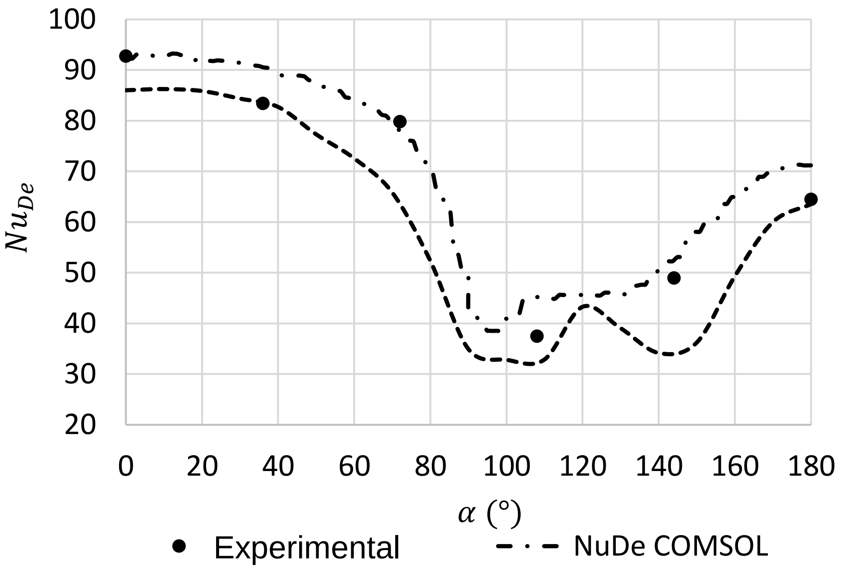


# II – COMSOL USE FOR DATA TREATMENT

- **The validation case led to a benchmark with the opensource code OpenFOAM and experimental published results.**
  - Similar results obtained.
  - OpenFOAM finite volume formulation preferred to COMSOL for the 3D multi-million mesh elements (cluster availability).

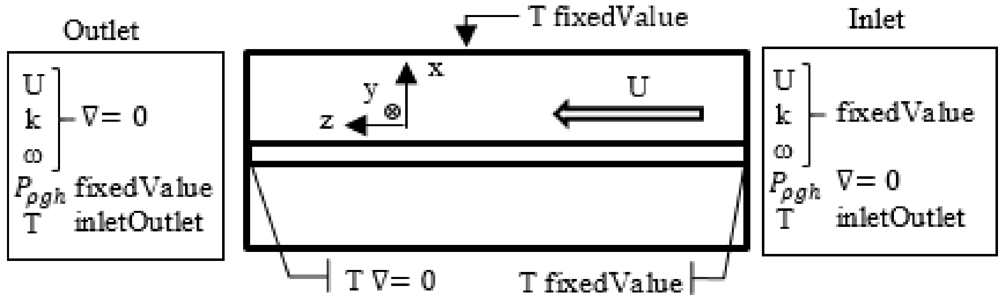


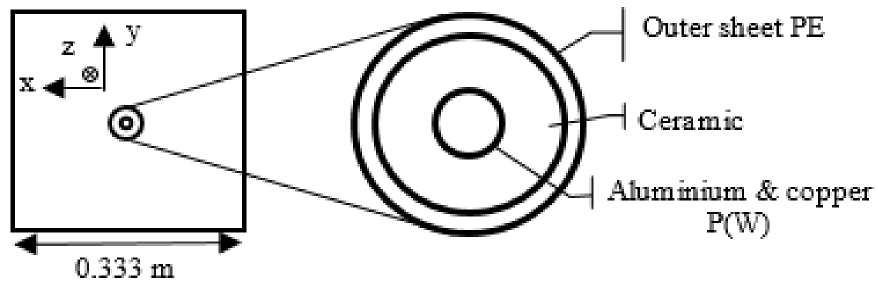



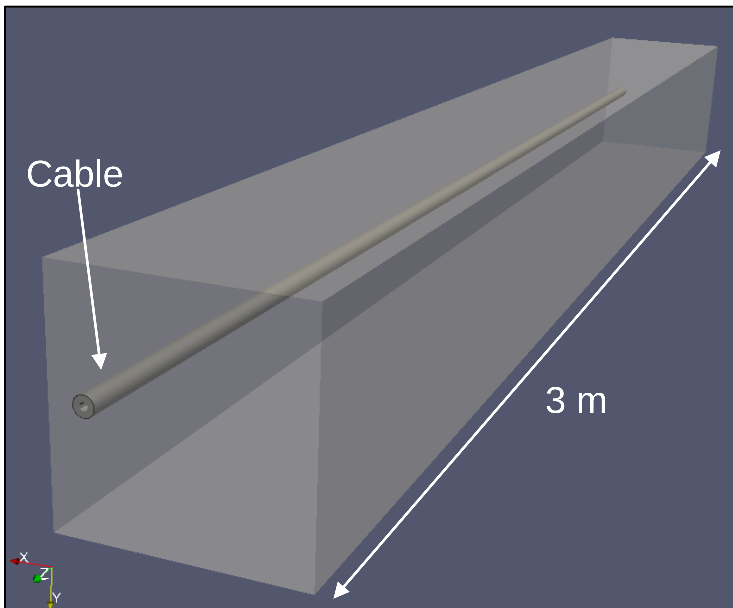



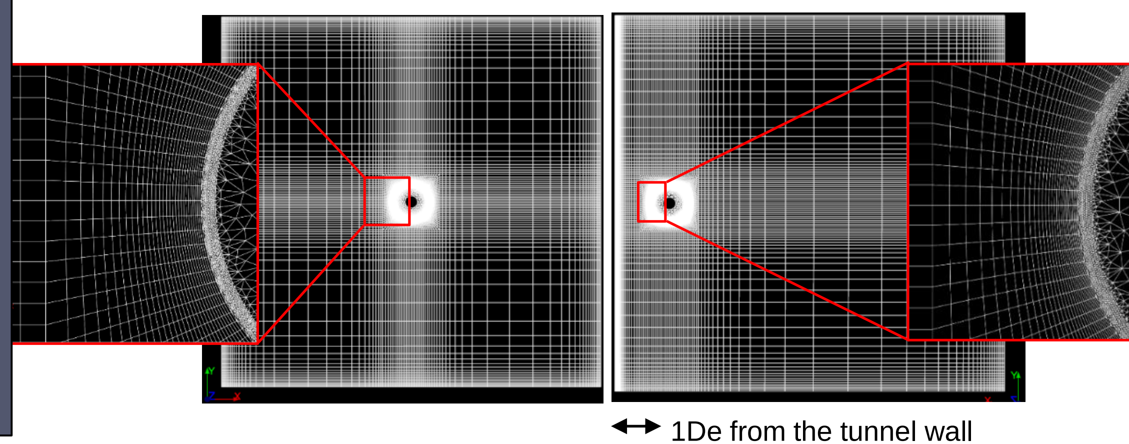
# II – 3D NUMERICAL SIMULATIONS

- Simulation RANS using the open source code OpenFOAM.
- Coupled solver and low Reynolds mesh with a turbulence model k-omega SST.
- Y+ << 1



COMSOL CONFERENCE 2016 BOSTON

I. INTRODUCTION

II. EXPERIMENTAL & SIMULATION SETUP

## III. CABLE COOLING : RESULTS & DISCUSSION

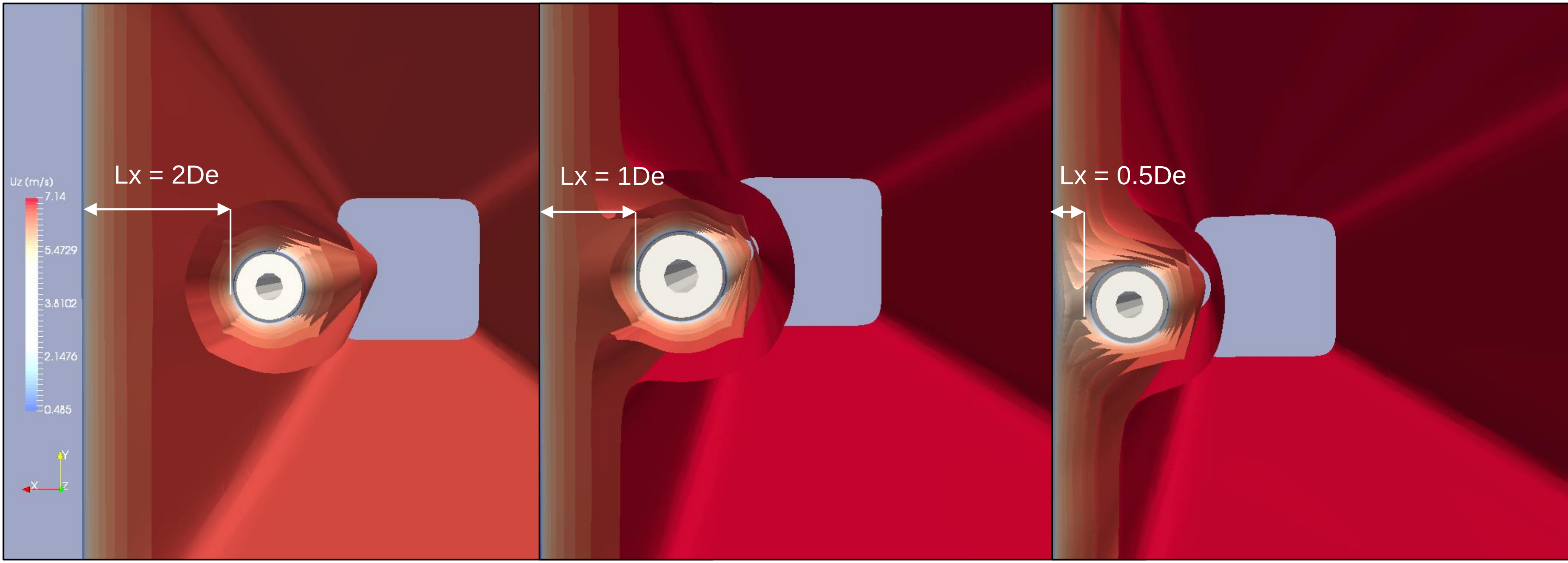
- I. Airflow analysis & cable cooling profile
- II. Mean Nusselt numbers
- III. New cooling laws

IV. IMPACT ON THE MAXIMUM PERMISSIBLE CURRENT

V. CONCLUSIONS

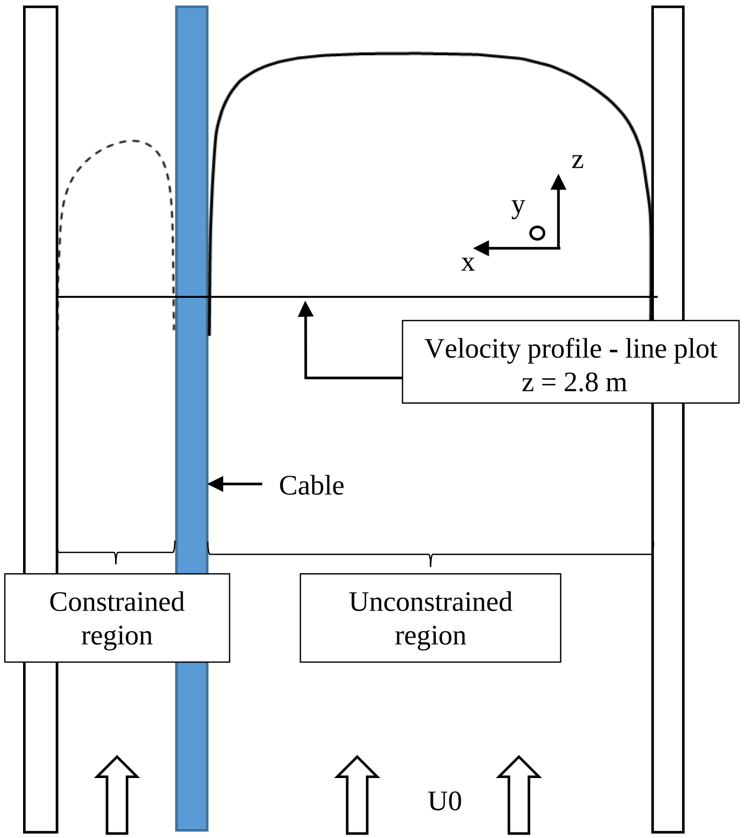
# III – AIRFLOW ANALYSIS & CABLE COOLING PROFILE

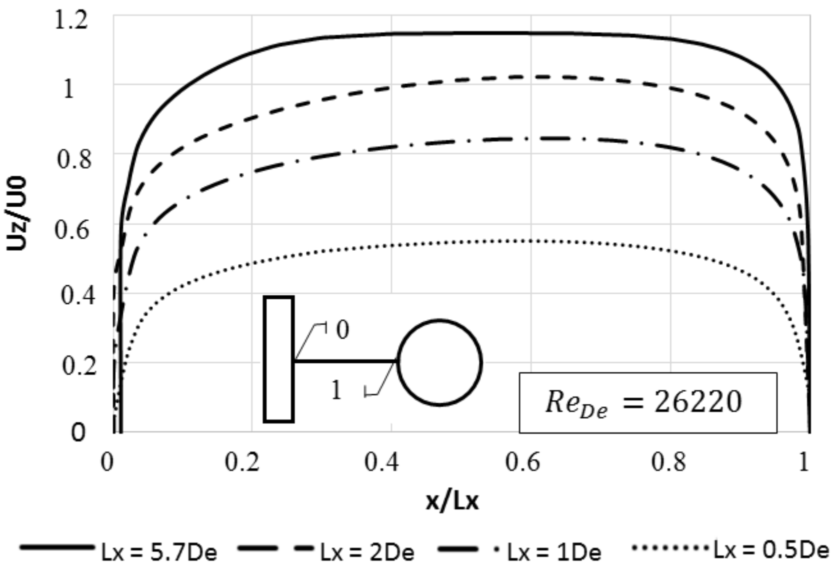
- As the cable wall spacing decreases, the air flow structure deforms itself.
  - A velocity drop is observed in the gap between cable and wall.

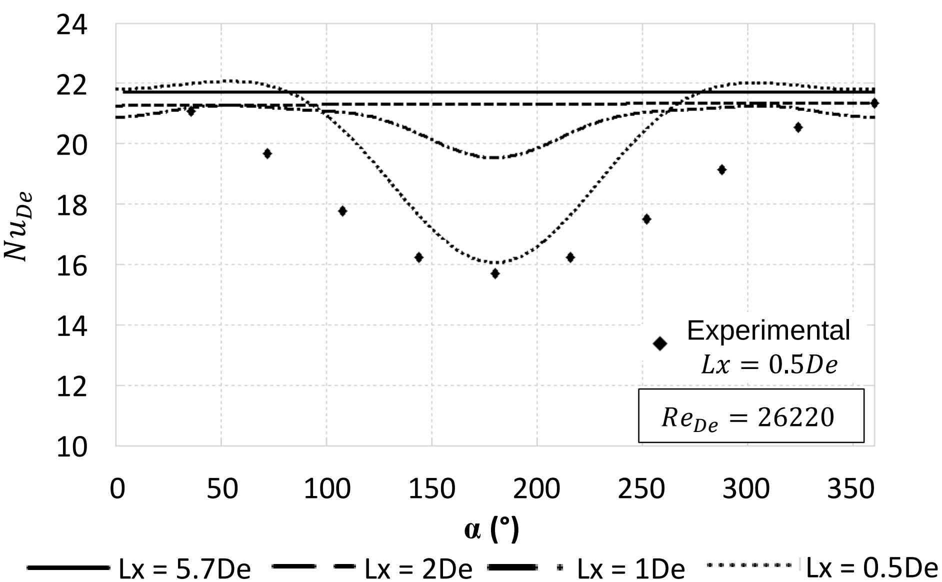


# III – AIRFLOW ANALYSIS & CABLE COOLING PROFILE

- The observed velocity drop can be down to 50% of the entrance velocity.
- A threshold wall spacing value of Lx = 2De can be defined.



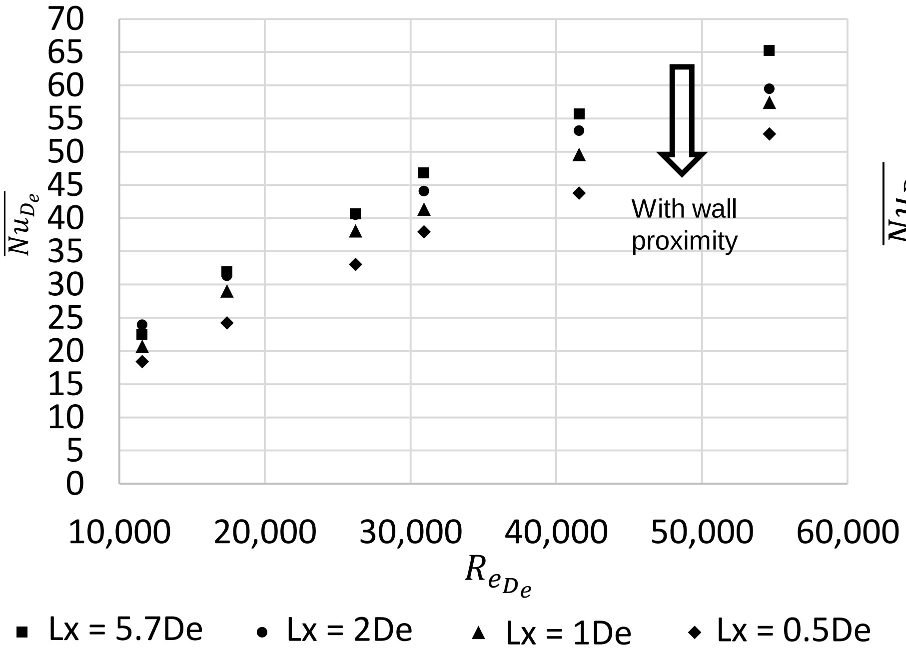



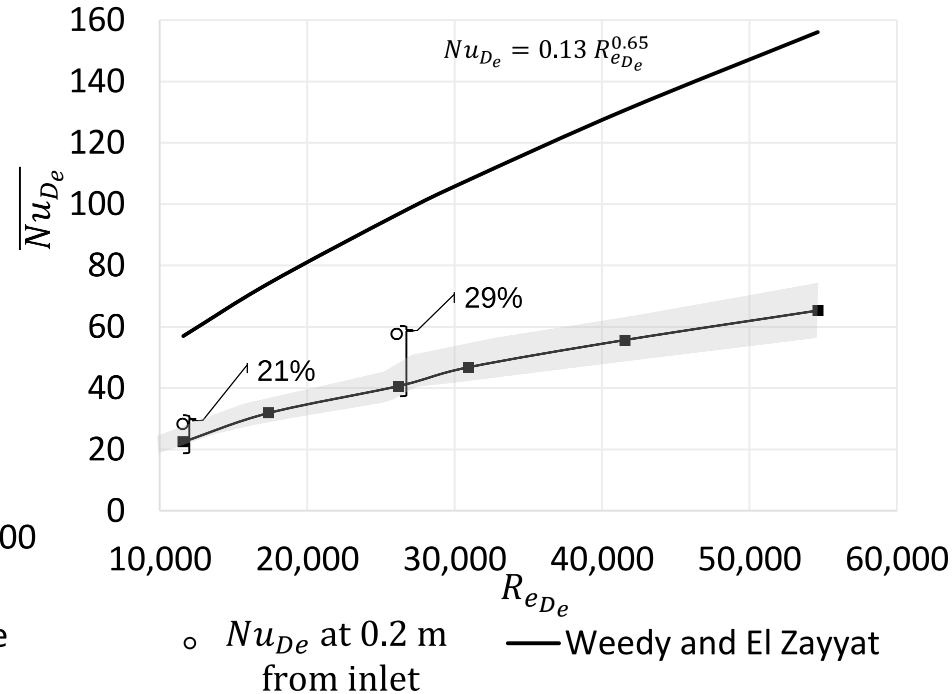
# III – MEAN NUSSELT NUMBERS

- The depreciation of mean Nusselt number is clearly obtained, with a 20% drop for very close proximity with a wall (Lx = 0.5De).
- Heat transfer 2 times less important as regards to the current cooling law [1].

- **Possible reasons :**
  - Turbulence entrance length not reached in [1].
  - Studies without support elements (brackets).

[1] B,M Weedy, H,M El Zaayat, Heat Transfer From Cables In Tunnels And Shafts, IEEE-PES 1972



COMSOL CONFERENCE 2016 BOSTON

I. INTRODUCTION

II. EXPERIMENTAL & SIMULATION SETUP

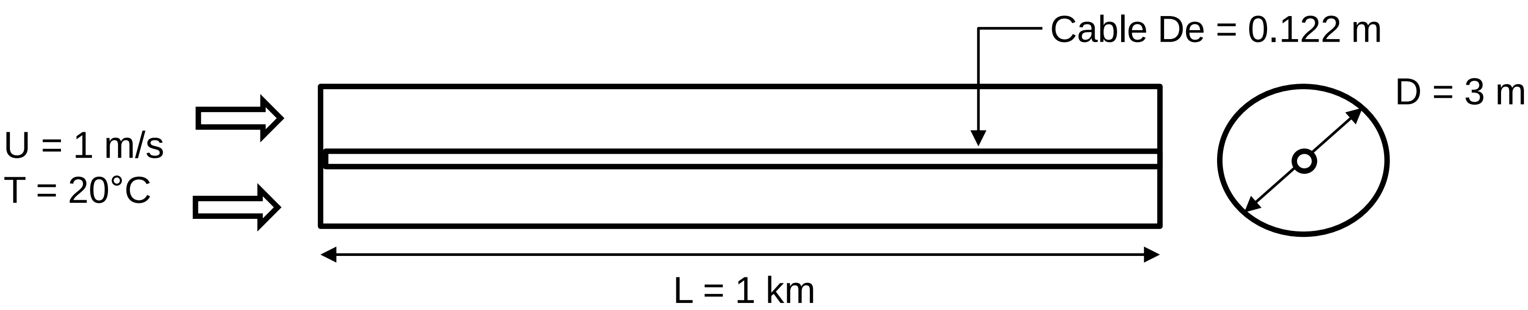
III. CABLE COOLING : RESULTS & DISCUSSION

## IV. IMPACT ON THE MAXIMUM PERMISSIBLE CURRENT

V. CONCLUSIONS

# IV – IMPACT ON THE MAXIMUM PERMISSIBLE CURRENT

- Using the design tool for underground power cables with the new laws, the impact on the maximum transmissible current in the power link can be tested.
- Idealized case (no brackets, no corkscrewing effects, etc.)




Max. operating temperature: 90°C in the core

| | **Weedy and El Zayyat** | $Nu_{De}(Lx/De)$ | **Weedy and El Zayyat I = 2354 A** |
|---|---|---|---|
| T core (°C) | 89,96 | 89,97 | 79,16 |
| T air (°C) | 30,41 | 28,86 | 28,8 |
| h wall (W/m².K) | 2,91 | 2,91 | 2,91 |
| h cable (W/m².K) | 9,35 | 3,96 | 9,37 |
| **I max (A)** | **2526** | **2354** | **2354** |

- 12%

- 7%

COMSOL CONFERENCE 2016 BOSTON

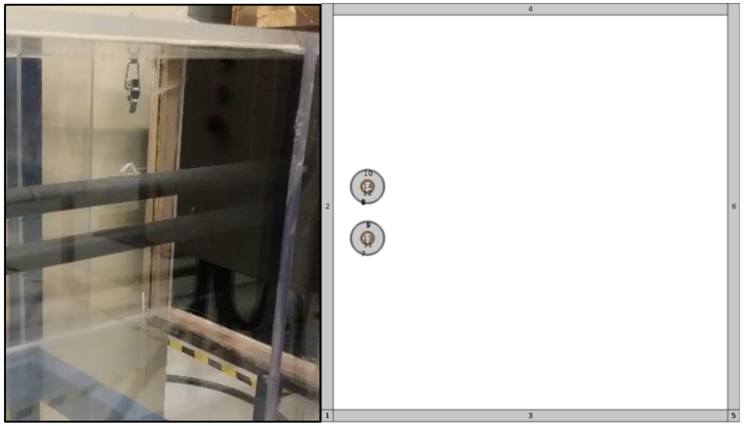


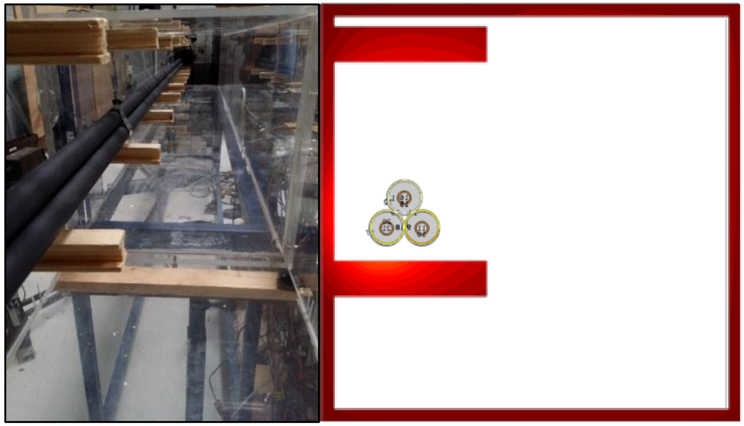
# V - CONCLUSION

- **Experimental & numerical studies have highlighted the impacts of the proximity to a tunnel wall and the flow development.**
  - The depreciation of the heat transfer can be of 20% for close installations to a wall.

- **On-going work.**
  - Cable groups effects on the heat transfer (two cables and trefoil configurations).
  - Effects of the support elements .

- **Wish list**
  - Get rid of the OpenFOAM platform for the 3D ➔ have COMSOL simulate everything.
  - A mean to simulate details local heat transfer for very long geometries with limited mesh elements (ideas ?).
  - Or else, a full COMSOL cluster license…





COMSOL CONFERENCE 2016 BOSTON

# THANK YOU

# ANY QUESTIONS

Université de Valenciennes et du Hainaut-Cambrésis

LAMIH UMR CNRS 8201