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News

Fundamental Research

Sustainable mobility Electrified Mobility Batteries

The development of electric vehicles has been accompanied by technological advances resulting in more compact and higher-speed motors (rpm), which create significant heat fluxes within reduced volumes. This leads to the emergence of critical zones in terms of material integrity. Direct cooling by oil jets applied to localized regions appears to be a promising solution to this issue, but remains challenging to simulate numerically. Indeed, the resulting flows are characterized by high Prandtl numbers (Pr)[1] and, consequently, a very thin thermal boundary layer[2], particularly in the jet impingement zone, where cooling is most effective. As a

result, in Computational Fluid Dynamics (CFD[3]), explicitly resolving this boundary layer in large-scale geometries requires very fine meshes and often prohibitive computation costs.

For this reason, in order to avoid explicit resolution of the thermal boundary layer, **a near-wall thermal model**, specifically designed for high-Prandtl number fluids and laminar flows, was developed as part of Adrien Ingles' PhD thesis [1,2]. The model, implemented in the Converge CFD code, is based on **Lévêque's analytical solution** [3] and makes it possible to estimate the wall heat flux from the local temperature, without requiring the solution of additional equations. This approach is illustrated in Figure 1 for a liquid jet impinging on a flat surface, where the Prandtl number can reach values as high as 1,000.

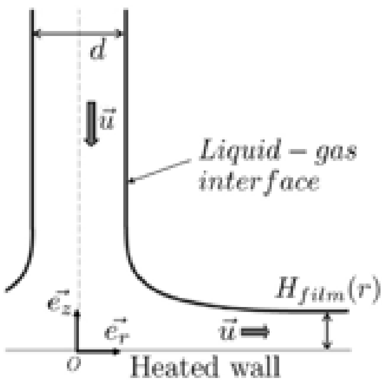

Figure 1: Cross-section of a cold liquid jet of a diameter d impinging on a heated flat surface at a velocity u ? and forming a film of height Hfilm (r)

Figure 2 shows the radial distribution of **the Nusselt number ??**, characterizing local heat transfer between the wall and the fluid. It compares a case in which the thermal boundary layer is fully resolved using a very fine mesh (reference solution denoted by A_r)) to simulations performed on a coarse mesh, with and without the developed model (A_c^m and A_c respectively). On the under resolved mesh (less than one cell across the thermal boundary layer), the absence of the model leads to a significant under estimation of ??, with an error as high as 40% in the impingement zone, where the thermal layer is thinnest (A_c case). Applying the model (A_c^mcase) significantly reduces this underestimation; the radial profile of ?? obtained with the coarse mesh and our model closely approximates the reference solution (A_r case).

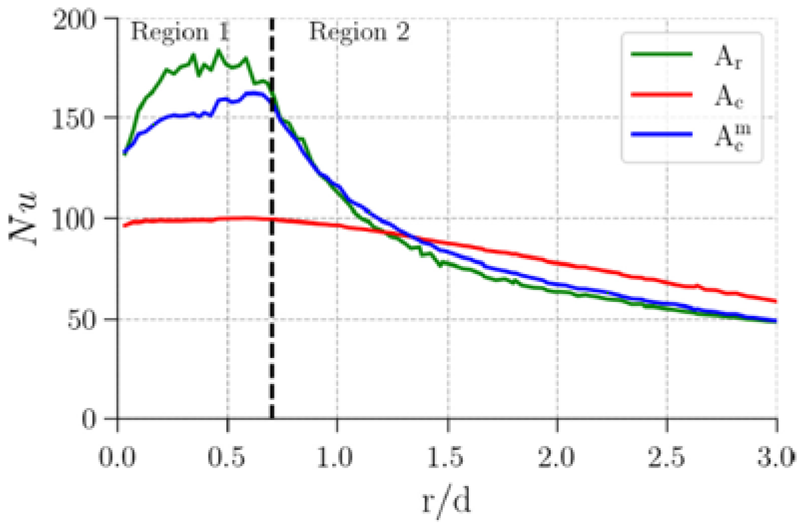

Figure 2: Nusselt profiles obtained for the fine mesh (Ar), the coarse mesh without a model (Ac) and the coarse mesh with a model (Acm) for Pr =158 : r?d=0 corresponds to the center of the jet

Moreover, using the model significantly reduces the computational cost compared to a fully resolved case: for the configuration tested at Pr=158, the reduction in computational time is around 68%, and can reach 93% for Pr ? 1000. Thus, the proposed method offers **an excellent compromise between accuracy and computational cost**, making it particularly well-suited for parametric studies and the preliminary design of oil-jet cooling systems for electric motors.

In conclusion, the newly developed model provides **an effective solution for estimating wall heat transfer in high-Pr laminar liquid jets**, while avoiding the extreme mesh refinement required to fully resolve the thermal boundary layer. Ongoing work aims to extend its validity to more complex flow configurations that no longer satisfy Lévêque’s hypotheses.

[1] A dimensionless number (ratio of thermal diffusivity to kinematic viscosity) that compares the rates of thermal and hydrodynamic phenomena in a fluid

[2] A region of fluid in contact with a solid surface where the temperature varies significantly due to heat transfer

[3] Computational Fluid Dynamics

References:

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[3] Lévêque A. Les lois de la transmission de chaleur par convection [The laws of heat transfer by

convection] Ann des Mines 13 (1928)

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