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MONACO_2025: Modelling natural convection: A Challenge for the Full Digital 2025 Ambition

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MONACO_2025

MOdelling NATural CONvection:
A Challenge for the Full Digital 2025 Ambition

ANR Project ANR-17-CE06-0005-01
(01/03/2018–28/2/2023)

Coordinator:
Rémi Manceau (LMAP, CNRS-University of Pau-Inria)



17th ERCOFTAC SIG15 / MONACO_2025 workshop
Turbulent natural convection flows in differentially heated cavities
19-20 January 2023, Pau, France

✓ **Road vehicles: underhood thermal management**

- ▷ CFD = routine tool for cruise regime (forced convection)
- ▷ Transient phases (stops): dominated by natural convection ⇒ CFD defective
- ▷ Dimensioning: costly wind-tunnel experiments using full size models
- ▷ Ambition fixed in 2015: full digital in 2025

✓ **Nuclear engineering**

- ▷ Importance of natural convection: thermal shocks, stratification, boiling, *etc.*
- ▷ Improvement of safety and extension of the lifespan of the power plants
- ▷ Design of future generations of power plants, including SMR

**Very different industrial contexts / very close scientific issues
⇒ Numerical simulation of turbulent flows in natural convection
regime**

✓ **Themes of the challenge *Clean, secure and efficient energy:***

- ▷ Design of technologies with low environmental impact
- ▷ Prevention of risks linked to energy technologies

LMAP

(Applied mathematics department)

University of Pau/CNRS/E2S

UPPA

Inria project-team CAGIRE

- ✓ Coordinator: Rémi Manceau
- ✓ Turbulence modelling

Institute Pprime

CNRS/ENSMA/University of

Poitiers

- ✓ Project leader: Didier Saury
- ✓ Experiments

PSA Group (now Stellantis)

R&D Vélizy

- ✓ Project leader: Vincent Herbert
- ✓ Simulation and experiments in industrial configurations

EDF

R&D Chatou

- ✓ Project leader: Sofiane Benhamadouche
- ✓ Modelling and code development (Code_Saturne)

Objectives

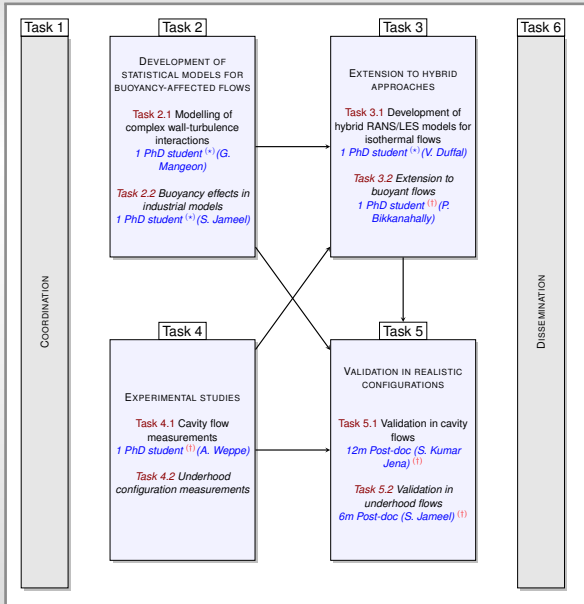
✓ Scientific objectives

- ▷ Progress in modelling of turbulence/buoyancy interactions
- ▷ Hybrid RANS/LES modelling: cost compatible with industrial needs
- ▷ Statistical approach (RANS) (low cost) where possible
- ▷ Fine-grained description of turbulence (LES) only where necessary
- ▷ New experimental database in cavity = unique database open to the community

✓ Technical objectives

- ▷ Propose a numerical methodology for dimensioning, operational reliability and safety
- ▷ Address regimes dominated by natural convection, which were not addressed numerically
- ▷ Decision-making tools in order to reach the appropriate methodology for the high-performance design of low-emission vehicle and power plants with a high level of safety

Work program



- ✓ 1 PhD thesis supported by PSA
- ✓ 2 PhD theses supported by EDF
- ✓ 2 PhD theses and 18 months of post-doc supported by the ANR

Summary of the results

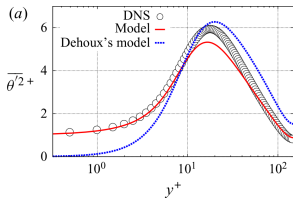


Figure: Temperature variance at the wall: conjugate heat transfer

- ✓ Dynamic second-moment closure (EB-RSM)
- ✓ Thermal second-moment closure (EB-DFM)
- ⇒ Extension to all possible boundary conditions

- ✓ Eddy-viscosity models (automotive industry)
- ✓ Issue of the sensitivity to buoyancy
- ⇒ Extension of the model (Boussinesq) to buoyancy

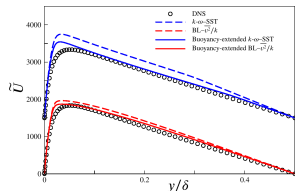


Figure: Velocity in a differentially heated infinite cavity

Summary of the results

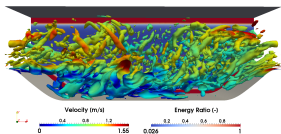


Figure: Q contours in a periodic hill flow

- ✓ Development of the HTLES hybrid RANS/LES model in Code_Saturne
- ✓ Improvement of the model (theory → practice)
- ✓ Convincing results for wall-bounded dynamics
- ✓ Encouraging for mechanical and thermal fatigue

- ✓ Extension of the HTLES approach to natural convection
- ✓ Problems at the RANS → LES transition
- ⇒ New model (elliptic shielding)

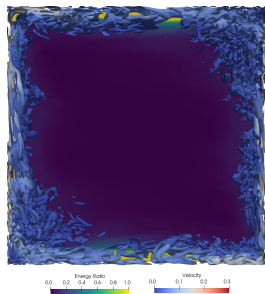


Figure: Q contours in a differentially-heated cavity

Summary of the results

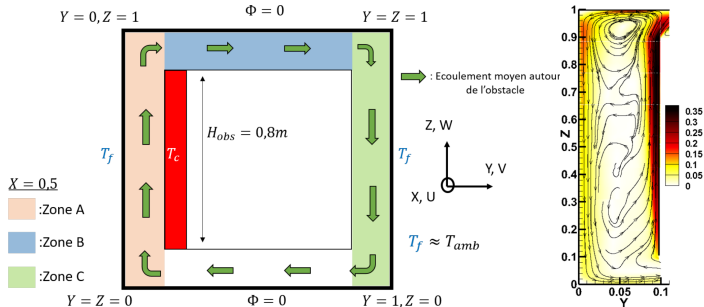


Figure: Cavity with a partially heated inner obstacle at $Ra = 1.4 \times 10^9$

- ✓ Experimental configuration representative of the underhood of a vehicle
- ✓ PIV (mean and rms velocities) and thermocouples (temperature)
- ✓ Stationary and transient cases
- ✓ Identification of a complex physics (laminar/turbulent transition, high and low frequencies, complex recirculation patterns, flapping of the jet)
- ✓ Ongoing validation of models from RANS to LES

Publications (so far)

✓ 4 PhD theses:

- Duffal, V. (2020). “Développement d’un modèle hybride RANS-LES pour l’étude des efforts instationnaires en paroi”. PhD thesis. Université de Pau et des Pays de l’Adour.
- Weppe, A. (2022). “Étude expérimentale d’écoulements turbulents à effets de flottabilité dominants en milieu confiné comportant un obstacle partiellement chauffé”. PhD thesis. École Nationale Supérieure de Mécanique et d’Aérotechnique.
- Mangeon, Gaëtan (Feb. 2020). “Second-moment closure of the turbulent heat fluxes for all type of thermal boundary conditions at the wall”. Theses. Université de Pau et des Pays de l’Adour.
- Jameel, Syed Mohd Saad (Dec. 2020). “Turbulence modelling of mixed and natural convection regimes in the context of the underhood-space of automobiles.”. Theses. Université de Pau et des Pays de l’Adour.

✓ 4+1 articles:

- Weppe, A., F. Moreau, and D. Saury (Sept. 2022). “Experimental investigation of a turbulent natural convection flow in a cubic cavity with an inner obstacle partially heated”. In: *International Journal of Heat and Mass Transfer* 194, p. 123052.
- Mangeon, Gaëtan, Sofiane Benhamadouche, Jean-François Wald, and Remi Manceau (Dec. 2020). “Extension to various thermal boundary conditions of the elliptic blending model for the turbulent heat flux and the temperature variance”. In: *Journal of Fluid Mechanics* 905.A1, pp. 1–34.
- Manceau, Remi (2019a). “Hybrid temporal LES: Development and applications”. In: *ERCOFTAC Bulletin*. Progress in RANS-based Scale-Resolving Flow Simulation Methods 120, pp. 38–42.
- Weppe, Alexandre, Florian Moreau, and Didier Saury (Nov. 2021a). “Experimental study of a natural convection flow in a cubic enclosure with a partially heated inner block”. In: *Journal of Physics: Conference Series* 2116.1, p. 012033.

Duffal, Vladimir, Benoît de Laage de Meux, and Remi Manceau (2022). “Development and Validation of a new formulation of Hybrid Temporal Large Eddy Simulation”. In: *Flow, Turbulence and Combustion* 108, p. 42.

✓ 13 conferences:

Duffal, Vladimir, Benoît de Laage de Meux, and Remi Manceau (July 2019a). “Development and validation of a hybrid RANS/LES approach based on temporal filtering”. In: *ASME - JSME - KSME Joint Fluids Engineering Conference 2019*. Proc. ASME - JSME - KSME Joint Fluids Engineering Conference 2019, Jul 2019, San Francisco, CA, United States. San Francisco, CA, United States.

Bikkanahally, Puneeth, Remi Manceau, and Franck Mastrippolito (Jan. 2021). “Development of a hybrid RANS-LES model based on temporal filtering for natural convection flows”. In: *WCCM - 14th World Congress in Computational Mechanics, ECCOMAS Congress 2020*. Virtual, France.

Manceau, Remi (May 2018). “Modélisation des transferts thermiques turbulents (conférence plénière)”. In: *26e congrès français de thermique*. Pau, France.

Jena, Sofen Kumar, Puneeth Bikkanahally, and Remi Manceau (Dec. 2022). “Numerical simulation of a turbulent natural convection flow in a cubic cavity with centrally placed partially heated inner obstacle”. In: *3rd high-fidelity industrial LES/DNS symp. (HiFiLeD)*. Brussels, Belgium.

Manceau, Remi (Oct. 2019b). “Modelling of turbulent natural convection (keynote lecture)”. In: *16th ERCOFTAC SIG15 Workshop on Modelling of wall bounded turbulent natural convection*. Jozef Stefan Institute (IJS). Ljubljana, Slovenia.

Bikkanahally, Puneeth and Remi Manceau (Oct. 2020). “Modeling turbulent flows in the natural convection regime using hybrid RANS-LES approaches”. In: *jspyrene2020 : Journée Scientifique autour du cluster Pyrene et autres moyens de calcul 2020*. Pau, France.

- Manceau, Remi and Puneeth Bikkanahally (Sept. 2021). “Hybrid Temporal LES: from theory to applications”. In: *HiFiLeD - 2nd High Fidelity Industrial LES/DNS Symposium*. Toulouse / Virtual, France.
- Duffal, Vladimir, Benoît de Laage de Meux, and Remi Manceau (Sept. 2021). “A new formulation of hybrid temporal large-eddy simulation”. In: *ETMM 2021 - 13th International ERCOFTAC symposium on engineering, turbulence, modelling and measurements*. Rhodes / Virtua, Greece.
- Jameel, Syed Mohd Saad, Remi Manceau, and Vincent Herbert (Sept. 2019a). “A buoyancy extension for eddy-viscosity models for the natural convection regime”. In: *17th European Turbulence Conference (ETC-2019)*. Torino, Italy.
- (July 2019b). “Sensitization of eddy-viscosity models to buoyancy effects for predicting natural convection flows”. In: *HEFAT 2019 - 14th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics*. Proc. HEFAT 2019 - 14th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics. Wicklow, Ireland.
- Mangeon, Gaëtan, S. Benhamadouche, Jean-François Wald, and Remi Manceau (Sept. 2018a). “Modelling of the dissipation rate of the temperature variance”. In: *ETMM12 - 12th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements*. Montpellier, France.
- Mangeon, Gaëtan, Sofiane Benhamadouche, Jean-François Wald, and Remi Manceau (July 2018c). “Unifying the near-wall treatment of the turbulent heat fluxes for all kinds of temperature boundary conditions with the Elliptic Blending approach”. In: *THMT-18 - 9th International Symposium on Turbulence, Heat and Mass Transfer*. Rio De Janeiro, Brazil.
- Weppe, Alexandre, Florian Moreau, and Didier Saury (Sept. 2021b). “Experimental study of Natural convection flow in a cubic enclosure with a partially heated inner block”. In: *EUROTHERM2020 - 8th European Thermal Sciences Conference*. Lisbonne, Portugal.

✓ 5 posters:

- Mangeon, Gaëtan, Sofiane Benhamadouche, Remi Manceau, and Jean-François Wald (May 2019). *Conjugate heat transfer: A big challenge for RANS modeling*. Code_Saturne user meeting. Poster.
- Jameel, Syed Mohd Saad, Remi Manceau, and Vincent Herbert (Dec. 2017). *Turbulence modelling of mixed and natural convection flow in underhood space of automobiles*. Journée doctorants PSA. Poster.
- Mangeon, Gaëtan, Sofiane Benhamadouche, Remi Manceau, and Jean-François Wald (May 2018b). *Modeling of the dissipation rate of the temperature variance*. Code_Saturne user meeting. Poster.
- Duffal, Vladimir, Remi Manceau, and Benoît de Laage de Meux (May 2019b). *Hybrid RANS/LES modelling of unsteady turbulent loads in hydraulic pumps. A hybrid approach based on temporal filtering*. Code_Saturne user meeting. Poster.
- Duffal, Vladimir, Benoît de Laage de Meux, and Remi Manceau (May 2018). *Hybrid RANS/LES modelling of unsteady turbulent loads in hydraulic pumps*. Code_Saturne user meeting. Poster.

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