Euromech Colloquium 443 & Lorentz-Center Workshop
High Rayleigh number convection

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Place: Leiden, Lorentz-Center
Organization: Detlef Lohse, Twente
Co-organization: Friedrich Busse, Bayreuth

One of the classical problems in fluid dynamics is Rayleigh-Bénard convection: A fluid heated from below and cooled from above.

About ten years ago, this problem had been considered to be basically solved. However, various experiments in the last decade have drastically changed our point of view on thermal convection. These experiments included high Rayleigh number measurements, large and small Prandtl number measurements, measurements on the Reynolds number, and measurements with rough boundary conditions.

The goal of the Euromech colloquium 443 and of the Workshop at the Lorentz-Center was to allow for an exchange of ideas on the recent developments in this field.

There were altogether about 50 participants and about 35 presentations, among them seven key-note lectures, namely Guenther Ahlers (Santa Barbara), Bernard Castaing (ENS Lyon), Siegfried Grossmann, (Marburg), Julian Hunt (London), K.R. Sreenivasan (Triest), Penger Tong (Hongkong), and Roberto Verzicco (Bari); see also the list of participants and the full programme. Most importantly, there was a lot of time for informal discussions between the participants who all were allocated in offices equipped with computers and white-boards.

Reoccuring issues addressed in the talks and discussed were:

- *Flow visualization:*
  The famous Chicago experiments on thermal convection in helium supplied one-point measurements. Meanwhile, the field is much further. In Leiden PIV measurements of the full velocity field were presented, either giving the full view of the cell, or focusing on the boundary layer. Considerable progress was also achieved with the Schlieren technique, which allows for a visualization of thermal structures in the boundary layers. The flow visualizations revealed that the flow geometry can be more complicated than a single convection role: Vortices can form in the corners, the convection role can oscillate sidewards, or for aspect ratio 1/2 it can even split in two roles. Besides the PIV experiments, also the numerical simulations now allow for very impressive flow visualizations, and wonderful movies were shown in Leiden, allowing for development of intuition on the flow.

- *$Nu(Ra, Pr)$ and $Re(Ra, Pr)$:*
  It became clear that the dependence of Nusselt and Reynolds on Rayleigh and Prandtl is more complicated than a simple power law. A new unifying theory of thermal convection, based on a decomposition of the kinetic and thermal energy dissipations, seems to be able to describe these more complicated dependences.

- *The aspect ratio dependence of the flow:*
  Hitherto experiments have mainly focused on aspect ratio 1 or 1/2. However,

there are strong indications that the flow pattern and in some regimes also the heat transfer strongly depends on the aspect ratio. Meanwhile, there are first theoretical predictions, and it became clear that future experiments will have to focus on a detailed exploration of the aspect ratio dependence.

- *Temperature boundary conditions at the top and at the bottom plate:*
  Numerical simulations including the top and bottom plate were presented. Those simulations revealed that at plume detachment the bottom plate can locally cool down or the upper plate can locally heat up, resulting in non-constant temperature at the top and at the bottom. Depending on the material constants, this effect will set in sooner or later, but ultimately, i.e., for large enough Ra, it is unavoidable, and will lead to a lower heat flux as compared to the ideal case with constant temperature at top and bottom. Future experiments will have to take this effect into consideration. For very large Ra constant temperature condition may be unrealistic, and one may have to live with constant flux boundary conditions. Another task is to develop correction schemes for the non-constant boundary conditions, and to check whether they are working by doing experiments with fluids and plates with different heat conductivities.

- *Character of the kinetic boundary layer:*
  Though older theories assume a turbulent boundary layer with a scaling of $\lambda_u \sim L/Re$ for its thickness, it became clear at the workshop that the Reynolds- and thus Rayleigh number dependence is much weaker. At the sidewall it is consistent with the Prandtl-Blasius scaling $\lambda_u \sim L/\sqrt{Re}$, and at the top and bottom wall it is even weaker. Nonetheless, the flow in the kinetic boundary layer is of course clearly time dependent.

- *Role of plumes:*
  During the workshop the role of the thermal plumes for the organization of the flow was again and again stressed. In spite of their importance, at least for small Prandtl number they do not seem to contribute much to the direct heat transfer. Future work will have to supply algorithms to distinguish between plumes and background in a systematic way.

- *Heat flux at $Ra > 10^{11}$:*
  The discrepancy between the Oregon data and the Grenoble data for the Nusselt number beyond $Ra > 10^{11}$ could not be resolved. One suggestion was that the flow field and flow geometry inside the cell is different for these two experiments, but it is unclear why this should be.

From above list it becomes clear that many questions are still far from being solved. The community agreed on meeting again in spring 2005, that time in Triest.

We have heard from many participants that they really liked the Meeting very much; several called it “the best Meeting they had ever participated in”. In the last months I have seen various preprints which have emerged out of the Meeting, and the field really got a boost from these two weeks. We thank the Lorentz-Center and Euromech for making the Meeting possible, and for all the financial and organizational support.