COMPUTER LABORATORY FOR NATURAL CONVECTION FUNDAMENTALS

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Summary Computer laboratory uses direct numerical simulation and linear stability analysis to learn and to research modern fundamental natural convection properties. High performance calculations, concurrent visualization, convenient intuitive interface, predefined cases set and intensive benchmarking make this PC-based software the certified and efficient tool for educational purposes.

The modern theoretical natural convection consider mainly the same paradigms as a few centuries ago, but due to the essential progress in numerical methods and especially in high performance computing in last few decades, now we have opportunity to analyse many fluid flows problems on a personal desktop computers. Unlike complicated applied problems, many theoretical problems in natural convection are studied in a simplest 2D/3D regions, and therefore to be used in an educational process. A computer (virtual) laboratory for natural convection focuses on fundamental properties of thermogravitational and thermocapillary convection. The fundamental properties include the following:

- linear and non-linear behaviour;
- non-uniqueness and multiple solutions;
- stationary and Hopf supercritical bifurcations;
- subcritical bifurcation;
- supercritical spatiotemporal structures.

Besides of direct numerical simulation a linear stability analysis for axisymmetric thermocapillary flows in a liquid bridge, an annular pool and Czochralski cristal growth geometries is used.
The computer laboratory role as an efficient tool for education, studying and research in heat and mass transfer problems is provided by the following:

- real-time and high computing performance with application of FFT and AMG algorithms for implicit schemes;
- convenient intuitive user interface and a use of non-dimensional predefined cases;
- full concurrent real-time visualization;
- intensive benchmarking.

Software works in Windows XP/Vista/7 with support of Intel MultiCore/OpenMP technique. A supercomputer performance provided version based on GPU/Cuda technology is under development.

The examples below demonstrate the computer laboratory ability to be the certified and efficient tool for educational purposes. The evolution of thermal fields for Rayleigh-Benard problem for high Rayleigh number is present at fig. 1. Plot "a" corresponds to initial development of instability, "b" shows non-linear development with secondary longitudinal instability in the growing layer, "c" and "d" show fully developed flow with increasing structure scale.

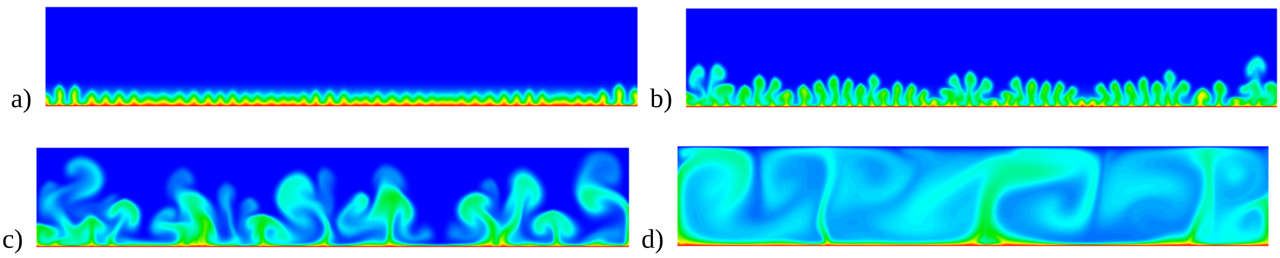

Fig. 1. Evolution of thermal fields for Rayleigh-Benard problem.

Fig. 2 shows fluid flow structures of heated from the side low-Prandtl melt (Pr=0,015) in a horizontal enclosure. Plot "a" with unique roll correspond to the Grashof number (Gr) $5\cdot10^4$, for "b" with the four rolls at Gr=$8\cdot10^4$, there are again the three rolls for "c" at Gr=10^5; plots "d" and "e" show multiple solutions with three and four rolls at Gr=$2\cdot10^5$, as well as "f" and "g" have four and five rolls at Gr=$3\cdot10^5$. Fig. 3 shows an appearance of layer structures in a stable stratified fluid with side heating: the left picture is a temperature and the right picture is salinity. Fig. 4 shows initial unstable rolls for the bottom heating (a), secondary oscillatory instability (b), developed oscillatory structure for thermogravitational convection (c), and a spot-like oscillatory structure for thermocapillary convection. The Marangoni (thermocapillary) convection is intensively studied now due to its role in thin free surface-liquid layers and in microgravity. A liquid bridge is a half-zone model of Bridgman crystal growth technique. The linear stability analysis is used because of high-Prandtl number of silicone oil, used in experiments (up to 200). The eigen functions for thermal

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distrurbances for MEIS-2 (Japan, 2009) spacial experiment with a silicone oil liquid bridge are presented for two aspect ratios.

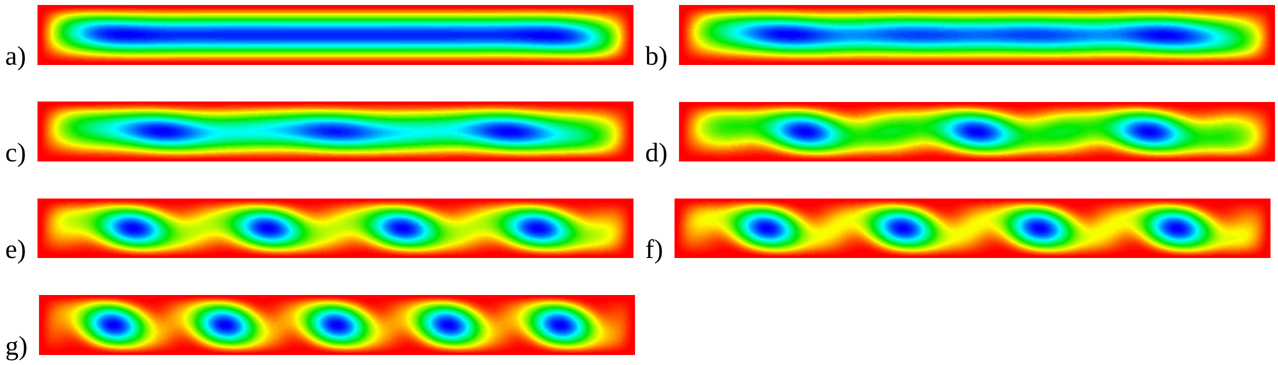

Fig. 2. Flow structure (stream function) for low Prandtl number fluid in a horizontal enclosure heated from the side at different Grashof numbers.

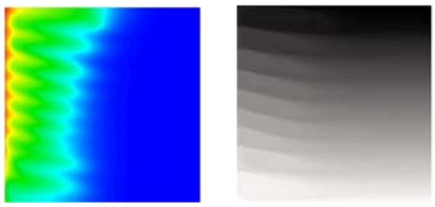

Fig. 3. Appearance of “layer structures” for a side heating of a stable stratified liquid.

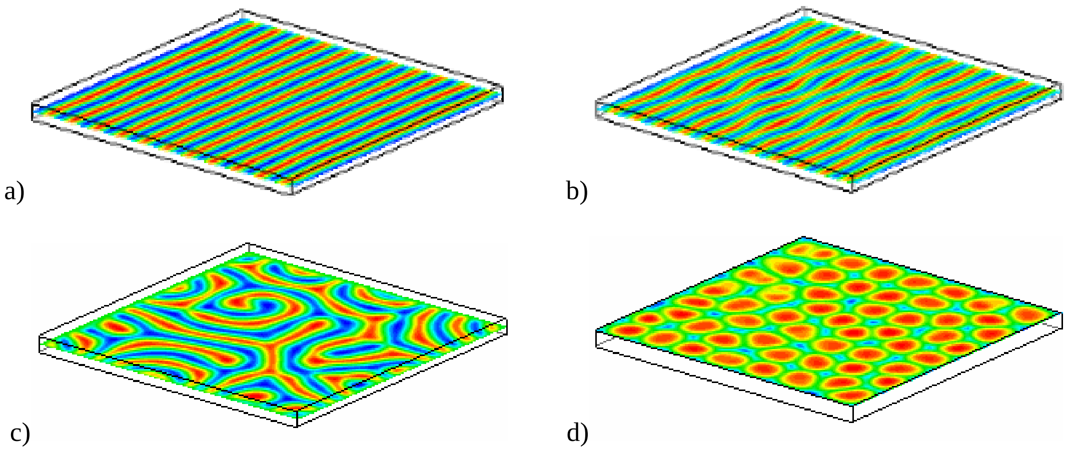

Fig. 4. Thermogravitational and thermocapillary convection for heating from the below in a 3-D horizontal enclosure.

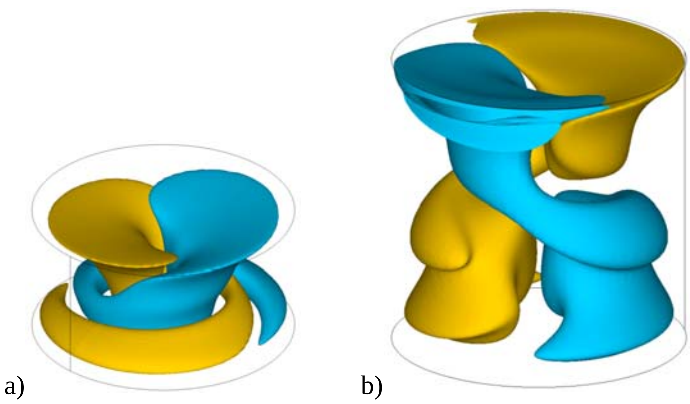

Fig. 5. Eigen functions for thermal disturbances in a liquid bridges with two aspect ratios.