Numerical and Experimental Study of Transitions and Slightly Supercritical Regimes in Confined Three-Dimensional Recirculating Flows

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This study compares numerically resolved instabilities of three-dimensional recirculating flows in a cube with the corresponding experimental results. Two model flows, a lid-driven flow in a cube and convection in a laterally heated cubic cavity are considered.

The numerical results were obtained by a fully pressure-velocity coupled three-dimensional time-dependent finite volumes approach. The time stepping is performed with a Parallelized Analytically Solution Accelerated Collective Line Gauss-Seidel (Par-ASA-CLGS) smoother [1] used as a sub-iteration of a block implicit multigrid algorithm [2]. No boundary conditions for pressure are necessary. The parallelized algorithm is characterized by a superior performance and was successfully verified by running on up to 2048 cores yielding a theoretical threshold of an overall speed up proportional to $N/log(N)$, where N is a number of involved cores.

It was found that for a differentially heated cavity with perfectly conducting top and bottom and insulated lateral walls the steady–unsteady transition is followed by a supercritical symmetry breaking Hopf bifurcation. Values of the critical Ra number $2.98\times10^6<Ra<3.07\times10^6$ and the dimensionless oscillating frequency $\omega\approx 1.39$ are in a good agreement with experimental results of [3]. It was also found that the instability onset for three-dimensional lid driven cavity sets in at Re_{cr}=1914 via a subcritical symmetry-breaking Hopf bifurcation and is characterized by the value of $\omega\approx 0.58$ [4]. The results are in a good agreement with the PIV experiments (not yet published). Besides a good agreement in critical values these experiments also exhibit distribution of the oscillations amplitude similar to one predicted numerically.

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