Impulsive Start of 3-D Shear Driven Cavity Flows

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Cavity Flows

In this study we have started an investigation of the flow physics of the vortical structures created by the cavity at a laminar Reynolds number. Deep cavities of the nature described here have been used in the past as resonance systems, and they are commonly referred to as *Helmholtz* resonators. More generally, flows over cavities occur in a wide range of engineering processes. They are a model for re-circulating flows, heat and mass transfer - and related physics.

We considered the impulsive stat of a shear driven cavity flow over a channel partly closed by slits. Compared to the classical lid-driven cavity flow (steady-state, lid-driven, without mass transfer, with well posed boundary conditions) the set-up shown in Figure 1 features formidable complexity - at the expense of minimal increased geometrical details. These flows are also characterized by unsteady three-dimensional effects, with oscillations that are self-sustained. For the general cavity flow to be established, it is necessary that periodic changes of in- and out-flux take place.

Computational Model

The three-dimensional cavity is shown in Figure 1. The spanwise aspect-ratio was 3.0. The lid opening considered was h/L = 1/4, and the Reynolds number, based on the free stream U and streamwise length L was Re = 3,000. The cavity was immersed in a channel flow, simulated over a length of 5 cavities downstream, and 1.5 cavity lengths upstream. The upper surface of the channel was fixed at two cavity lengths above the lid. The Reynolds number affecting the flow inside the lid is based on the reference length L. The flat plate boundary layer at the entrance of the cavity is also important.

The flow was started from rest and simulated in a fully unsteady mode. Only half a model was simulated. Preliminary research showed that the flow is symmetric with respect to the centre plane over a time of several seconds, though this statement may not hold over a long simulation time. Some researchers have pointed the importance of the boundary conditions, and seemed to conclude that correlation of between experimental and computational data may diverge over a long simulation time.

The flow solver is based on the discretised Reynolds-averaged Navier-Stokes equations. It is parallelized with MPI for execution on vector computers using a non overlapping decoupling technique.

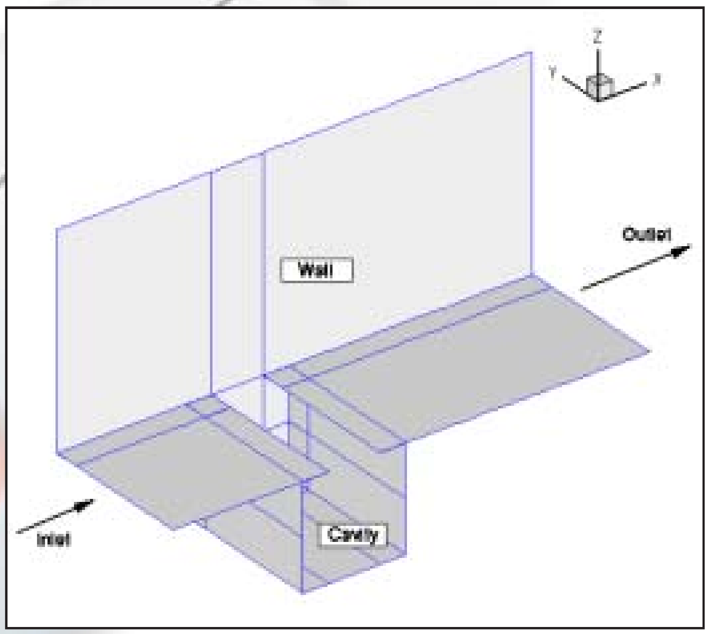

Figure 1: computational model (half-cavity).

Flow Solver Performance

The flow solver was tested on the classical lid-driven cavity flow started from rest. The solution reached an asymptotic value, and the residual history showed that the solver converged to machine accuracy on all the variables, 10^{-16} in about 2,000 iterations.

The results of the runs shown below were obtained on SGI Origin Green computer with 256 nodes. Up to 20 processors were used in our simulations. This computer allocated batches of 4 processors per run, therefore each run had to request a multiple of this number, which is not always optimal; the optimal condition is estimated

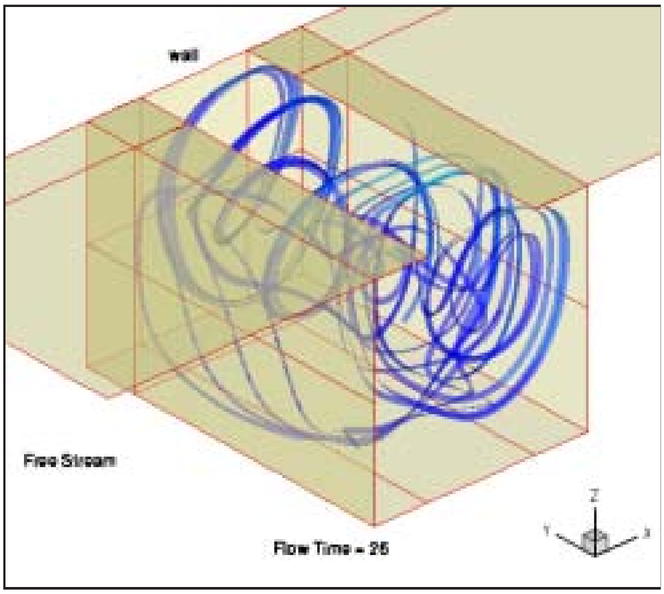

Figure 2: streamtraces at flow time = 26.

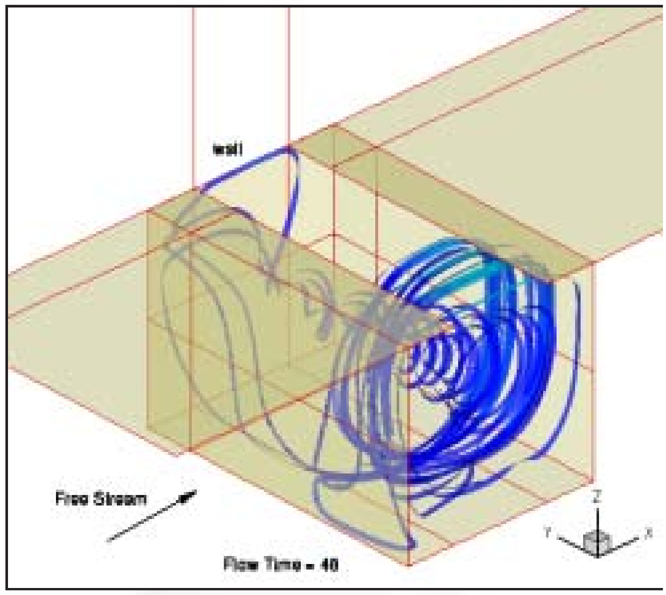

Figure 3: streamtraces at flow time = 48.

to occur when each mesh block is allocated to a single processor, or a multiple of the number of blocks. In spite of this difficulty, the solver was fast. Figure 4 shows the performances resulting from multi-processor runs. Each point was calculated from an average of time 650 iterations.

The computational grid was made of 18 cubic blocks (on the half-model) n^3, where n = 40 was the number of cells in each direction. The number of cells in the cavity was 768,000, out of a total 1,152,000. The simulations shown were carried out up to a normalised flow time equal to 90.

Results

The flow in the cavity is not confined to a two-dimensional pattern. Currents of fluid transfer mass from the end-walls to the centre and back again, see Figures 2 and 3. The end-walls are known to be responsible for this particular feature. The fluid in the primary vortex core tends to spiral towards the cavity's centre, following the pressure gradient.

The fluid is set in motion inside the cavity thanks to the shear layer at the open lid. Since the flow is started from rest, a considerable amount of time is needed to reach conditions such that the entire cavity is affected.

A number of other complex features exist: Taylor-Goertler vortices, hairpin vortices, other secondary vortices of short life-span. We have found that the flow is periodic with a very long wave. Research is undergoing to investigate all these fluid dynamic effects.

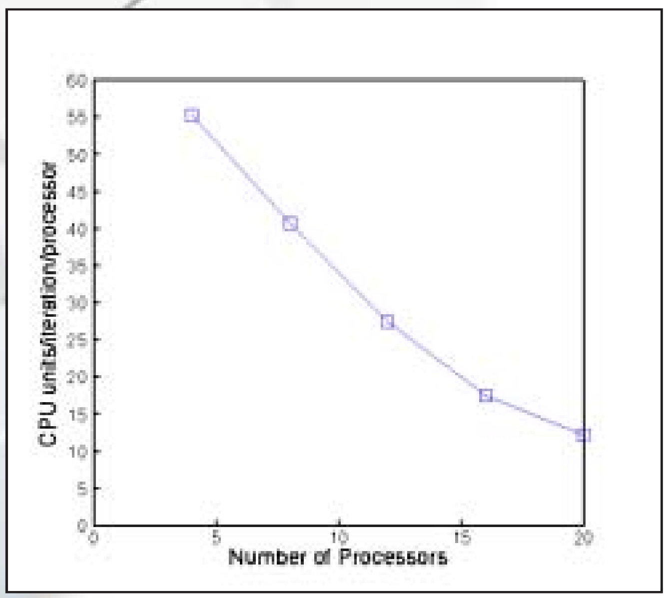

Figure 4: speed up rate on SGI Green.

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