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Mixing in cavities with transient lid velocity

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Introduction

The transient mixing flow induced by a time periodic motion of upper wall is studied (see also [1])

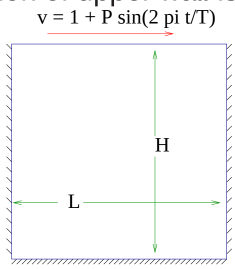

Fig. 1 *Geometry of the cavity*

The Reynolds number is equal to 50 and $P = 0,\ 0.5$ or 1.5. The objective is to analyze this flow for chaotic (exponential) mixing behaviour, originating from continuously stretching and folding [2].

Contourplots of the streamfunction of this flow at different time levels are presented in figure 4.

Chaos in Mixing

An initial strip (figure 2) is tracked and intermediate results are presented in figure 3. The period boundary condition results in a true periodic flow after approximately 12 periods. This is shown by comparing sequential velocity fields *at each time step* for a number of periods and results for the maximum norm difference are shown in figure 3.

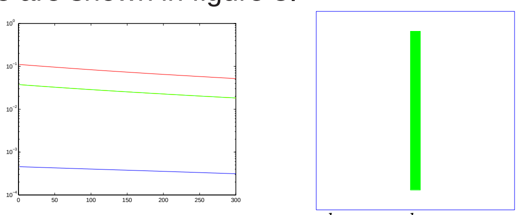

Fig. 2 *Red max. norm between velocity 2^{nd} and 3^{rd} period. Green 4^{rd} and 5^{th}, Blue 11^{th} and 12^{th}. On the right the initial strip is displayed.*

Deformation of the initial strip (see figure 2) for three different frequencies is displayed below.

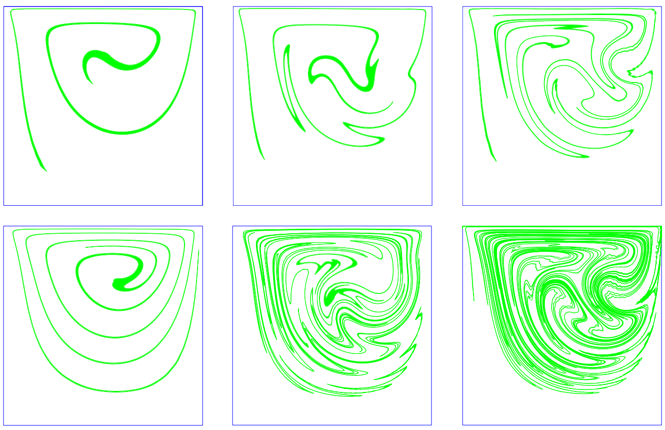

Fig. 3 *Displacement of a strip for $P = 0$ (left), $P = 0.5$ (middle) and $P = 1$ (right) displayed at $t = 8$ (upper) and $t = 18$ (lower) figure.*

A MPEG-MOVIE showing the deformation can be viewed at *http://www.wfw.wtb.tue.nl/mixing*.

The area conservation of the strip is within 0.01% and the scaled circumference is presented in the following table :

Frequency P	0	0.5	1.5
Circumference strip at t=8	5.2	7.4	17.1
Circumference strip at t=18	8.9	61	624.

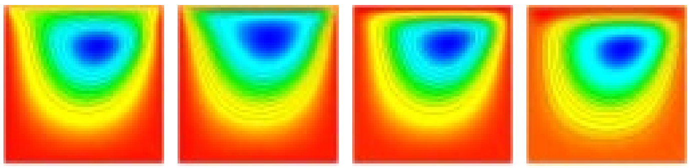

Fig. 4 *Streamlines for t/T $= 0.2,\ 0.4,\ 0.6$ and 0.8; Strouhal number is equal to 4.2 and $P = 1.5$.*

Locating Periodic Points

Periodic points are important for mixing behaviour and a method is developed to locate (if present) these points in arbitrary 2D and 3D flows. This method is based upon particle tracking of a grid of points. Displacement and stretching analysis is used to find points with low displacement and high stretching (hyperbolic points) or points in low stretching regions (islands) [2].

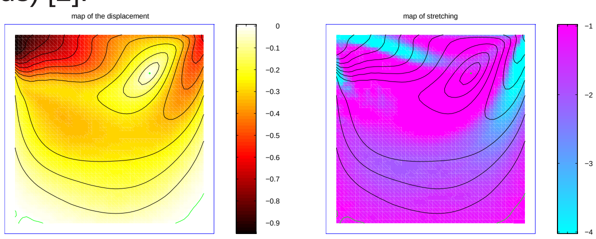

Fig. 5 *Left : Difference in initial and tracked grid after one period of motion; Right : Stretching of initial grid after one period of motion. The frequency parameter $P = 0.5$ and $St = 4.2$.*

In figure 5 the displacement map clearly shows a region of low displacement. A comparison with the stretching results shows that the low displacement zone is located in a low stretching area. The periodic point found is a first order elliptic point.

Conclusions

An unsteady component of the lid velocity which is superimposed on the steady flow, results in a large increase of stretching and folding of fluid volumes in the flow. This can lead to chaotic behaviour in the flow.

References:

[1] Nishimura, T. and Kunitsuga, K. , Fluid mixing and mass transfer in two-dimensional cavities with time periodic lid velocity, Int. J. Heat and Fluid Flow 18: 497-506, 1997

[2] Ottino, J. M., The kinematics of mixing: stretching, chaos and transport, Cambridge University Press, 1989