Mapping approach for 3D mixing simulations

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Introduction

The mapping approach, based on a discretized description of marked fluid distribution (*coarse grain density* [1]) was previously used for efficient analysis of mixing in 2D time periodic and 3D space periodic flows. The goal of the current work is to extend this approach and test its applicability to 3D time periodic flows.

Application of 3D mapping technique

Stokes flow in a cubic cavity, caused by consecutive motions of two opposite walls, as shown in Figure 1, was used as a test example (an approximate velocity field was used).

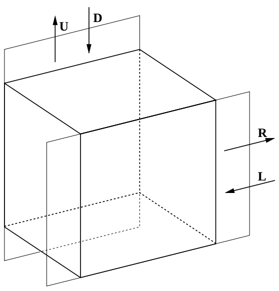

Fig. 1 *Scheme of the flow domain*

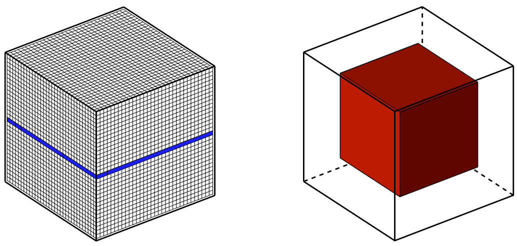

Fig. 2 *Discretization of the flow domain (left) and initial distribution of marked fluid (right).*

The mapping matrix was built for sliding of the front wall to the left over the cavity length. Other mappings are obtained using flow symmetry. The flow domain was subdivided into $32 \times 32 \times 32$ cells, except thin surface layer (1%) which was formally considered as single extra cell. Boundaries of cells were tracked in the flow using adaptive front tracking and intersections of deformed cells with the original ones computed, providing mapping matrix entries. A parallel algorithm was used to reduce computation time. From the more than 10^9 entries of the mapping matrix only $191,375$ (0.018%) are non-zero (sparse storage is used). This matrix has to be computed only *once*. After that, using customary sparse matrix routines, a single mapping takes only a fraction of second of CPU time.

Results

The technique is applied here to compare two different mixing protocols: 2-step **RU** (see Fig.1 for notations) with unidirectional wall movements and 4-step **RULD** with reversed movements. Wall displacement in every step was equal twice the cavity length.

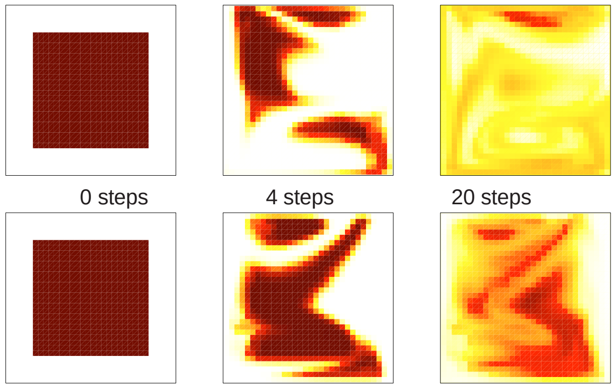

Fig. 3 *Results of mixing in 2-step (upper row) and 4-step (bottom row) protocols. The horizontal mid-plane, marked in Fig. 2 is shown.*

Results, presented in Fig. 3, show that 4-step protocol with the same energy input achieves a less uniform mixture (while in 2D cavity flows reverse motions usually increase mixing efficiency). Intensity of segregation for the whole domain after 20 steps is 0.26, compared with 0.06 for 2-step protocol. This shows that protocols with reverse flow may not always be more efficient in the 3D case. More definite analysis will require higher resolution.

Conclusions

The first tests confirmed that the mapping approach can be also used for studying mixing in 3D time-periodic flows, including comparison of different mixing protocols. Even a relatively low resolution allows to capture basic mixing patterns.

Future work

The flow under study will be investigated using higher resolution (reducing effect of numerical diffusion) and accurate velocity field. Next, the technique can be applied on more general flows.

References:

[1] TUCKER, III, C.L.: in Mixing in Polymer Processing, ed. Rauwendaal, C., Marcel Dekker Inc., N.Y., 1991.