

IMPLEMENTATION OF A DIVERGENCE-FREE TURBULENT SPOT METHOD FOR SYNTHESIS OF TURBULENT VELOCITY FIELDS INTO OPENFOAM

HANNES KRÖGER¹, NIKOLAI KORNEV²

¹*LEMOS (Chair of Modelling and Simulation, University of Rostock), hannes.kroeger@uni-rostock.de*

²*LEMOS, nikolai.kornev@uni-rostock.de*

Keywords: LES, DNS, inflow generator, turbulence synthesis, synthetic eddy method

Acknowledgments

For numerical simulation of turbulent flows, the large-eddy simulation technique has become a viable option due to constantly increasing computer power. Compared to the commonly employed RANS simulations, it has the advantage of a higher accuracy but also gives more detailed informations on the unsteady characteristics of the flow.

For the successful application of LES to complex flows, suitable boundary conditions are necessary. In engineering flow problems, turbulent inflow situations are encountered frequently. Contrary to RANS, in the context of LES or DNS at least a part of the turbulent structures is resolved and needs to be prescribed at the inlet. When costly precursor simulations shall be avoided or cannot be employed, a method for artificial generation of turbulent fluctuations is required.

Turbulent Spot Method

The current work is based on the method of turbulent spots for synthesis of turbulent fluctuations. The initial version of the method has been developed in 2003 for inhomogeneous non-solenoidal turbulent fields [1]. The idea was taken from the classical concept of the turbulence as a set of turbulent structures. In our method the structures are represented by a collection of spots of primary velocity \vec{u} defined on a compact support, which are then superimposed into a secondary velocity field \vec{v} . The biggest theoretical achievements of the works [2, 3, 4] were the exact relations between distribution of the primary velocity inside of the spots and the integral length, autocorrelation functions or spectra of generated velocity field.

Later on, the method was extended to obey the divergence free condition [5] by deriving the inner velocity distribution from a vector potential \vec{A} . Unfortunately, these “vortons” are ideal for isotropic turbulence and difficult to apply for anisotropic flows close to the wall where one component of Reynolds stress (R_{xx}) is much larger than the other ones.

This problem also became apparent in the work of Poletto et al. [6] who presented a formulation of the inner velocity distribution with free parameters which controls the Reynolds stresses of the generated velocity field. This method can reproduce only a very limited range of anisotropy. Especially, the strong levels of anisotropy that occur at $y^+ < 300$ cannot be reproduced this way.

Extension to Arbitrary Anisotropy with Retention of the Divergence-Free Condition

Until now, the final or secondary velocity field \vec{v} used for inflow conditions was obtained by application of the Lund transformation [7]. Unfortunately, the Lund transformation destroys the whole second order statistics of the primary velocity field, i.e. the secondary velocity field has the statistical properties of the second order (lengths, one-dimensional spectra) which are different from these of the primary velocity field. This fact is often ignored in existing methods of artificial turbulence generation. It should be noted that this problem does not exist if all components of \vec{u} have the same lengths and spectra. In this case the components \vec{v} have the same second order statistics. The Lund transformation also destroys the continuity of the fluctuations, if the produced Reynolds stress is not symmetric and isotropic- However, these are strong limitations since this situation is seldomly present in real turbulence.

In the current work, an approach for producing divergence-free fluctuations with arbitrary anisotropy is presented. It extends the work presented in [5] by a transformation of the vector potential. This transformation makes the corresponding velocity field unsymmetric and introduces anisotropy. It has free parameters for tuning the shape of the velocity distribution and is simple enough to yield closed expressions for the Reynolds stresses and length scales. Thus the need for a lund transformation is effectively eliminated. A sample of such a velocity field is shown in figure 1a.

The method is implemented in OpenFOAM and is applied to a number of test cases (turbulent channel flow, turbulent boundary layer, etc.). The results are compared with other available inflow data generation techniques, e.g. the method of Adamjan and Kraichnan [8].

In figure 1, results for a channel flow at $Re_\tau = 395$ are shown. Usually, channel flow simulation are performed using cyclic boundary conditions in axial direction. In this case, the velocity field has been prescribed by means of a dirichlet boundary conditions at the upstream boundary. The fluctuations have been produced by different methods for inflow data generation. The left chart shows the friction velocity. The inlet is at the left end of the chart. Ideally, all curves should be horizontal lines but there is always a more or less pronounced deviation from this shape. The distance from the inlet to the point of convergence into the asymptotic value is the adaption length and a measure of the quality of the inflow fluctuations. It is recognizable that there is a strong dependency of the adaption length not only on the method but also on the prescribed length scale distribution (the Reynolds stresses were always the same). The best results could be obtained with the anisotropic vorton formulation introduced above.

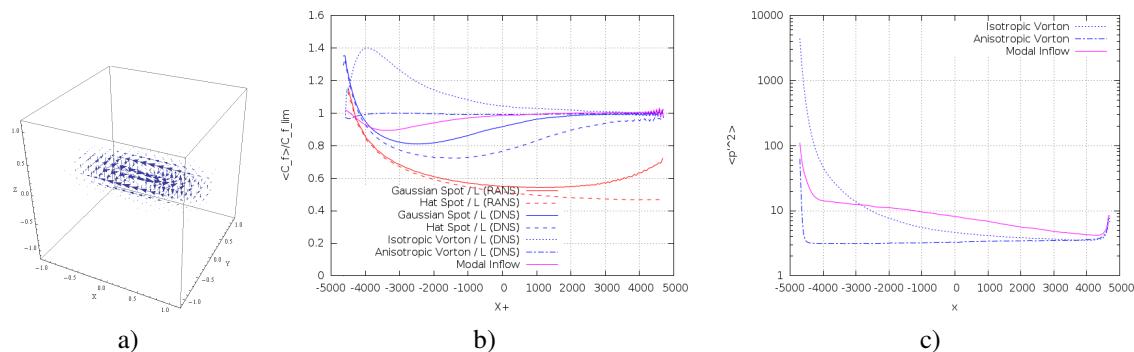


Figure 1: a) unsymmetric velocity field of a three-dimensional divergence-free vorton. b) results of channel flow simulations with different methods for inflow generation (Model inflow = Method of Adamjan and Kraichnan [8]), distribution of friction coefficient in longitudinal direction, c) magnitude of pressure fluctuations.

Another aspect of artificial turbulence generation are parasitic pressure fluctuations. These are created by the incompressible pressure correction procedure in the flow solver when the fluctuations are not divergence-free. The right chart in figure 1 shows a comparison of the magnitude of this fluctuations for the different methods. Again, the anisotropic vortons perform best, since they fulfill the divergence-free constraint always.

References

- [1] N. Kornev and E. Hassel, “A new method for generation of artificial turbulent inflow data with prescribed statistic properties for LES and DNS simulations,” *Schiffbau Forschung*, vol. 42, no. 4, pp. 35–44, 2003.
- [2] N. Kornev, H. Kröger, and E. Hassel, “Synthesis of homogeneous anisotropic turbulent fields with prescribed second-order statistics by the random spots method,” *Communications in Numerical Methods in Engineering*, vol. 24, no. 10, pp. 875–877, 2008.
- [3] N. Kornev and E. Hassel, “Method of random spots for generation of synthetic inhomogeneous turbulent fields with prescribed autocorrelation functions,” *Communications in Numerical Methods in Engineering*, vol. 23, no. 1, pp. 35–43, 2007.
- [4] N. Kornev, H. Kröger, J. Turnow, and E. Hassel, “Synthesis of artificial turbulent fields with prescribed second-order statistics using the random-spot method,” *Proceedings of Applied Mathematics and Mechanics*, vol. 7, pp. 2 100 047–2 100 048, 2007.
- [5] N. Kornev and E. Hassel, “Synthesis of homogeneous anisotropic divergence-free turbulent fields with prescribed second-order statistics by vortex dipoles,” *Physics of Fluids*, vol. 19, no. 5, 2007.
- [6] R. Poletto, A. Revell, T. Craft, and N. Jarrin, “Divergence free synthetic eddy method for embedded LES inflow boundary conditions,” in *Seventh International Symposium On Turbulence and Shear Flow Phenomena*, no. TSFP-7, Ottawa, 2011.
- [7] T. Lund, X. Wu, and K. Squires, “Generation of Turbulent Inflow Data for Spatially-Developing Boundary Layer Simulations,” *Journal of Computational Physics*, vol. 140, pp. 233–258, 1998.
- [8] D. Adamjan, “Method of synthetic turbulence generation on the inlet boundaries for the simulations of turbulent flows in vortex resolving approaches,” Ph.D. dissertation, St. Petersburg State Polytechnical University, 2011, (in russian).