The Actuator Line Model in Lattice Boltzmann Frameworks

Wake Characteristics and Turbulence Modelling

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June 18, 2019

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MOTIVATION

Motivation

The Lattice Boltzmann Method is fast

Motivation

Application in wind energy remains limited

11378	172	11
”Lattice Boltzmann”	”Lattice Boltzmann” & ”LES”	”Lattice Boltzmann” & ”Wind turbine”

Number of publications according to Web of Science (June 13, 2019)

SCOPE OF THIS STUDY

Scope of this Study

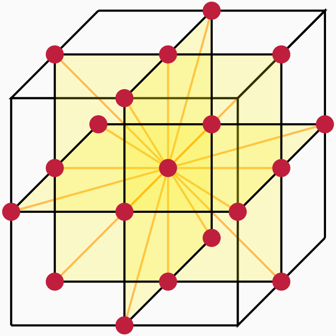
- Continuation of our recent Actuator Line Model (ALM) validation and analysis [1]
- Wake characteristics of a single turbine in uniform inflow
- Code-to-code comparison to standard finite volume Navier-Stokes (NS)

THE LATTICE BOLTZMANN METHOD

- The fundamental variable of the LBM, the particle distribution function (PDF): $f(\mathbf{x}, \boldsymbol{\xi}, t)$
- Governing equation: The kinetic Boltzmann equation

⇒ The Lattice Boltzmann equation:

$$f_\alpha(\mathbf{x} + \mathbf{e}_\alpha \Delta t, t + \Delta t) - f_\alpha(\mathbf{x}, t) = \Omega_\alpha \tag{1}$$



TikZ code by Christian Janssen.

D3Q19 lattice.

The LBM

- Raw velocity moments of f yield macroscopic quantities

$$\rho = \sum_{\alpha=1}^{m} f_\alpha \quad , \quad \rho\mathbf{u} = \sum_{\alpha=1}^{m} \mathbf{e}_\alpha f_\alpha \tag{2}$$

- A second-order approximation of the incompressible NSE

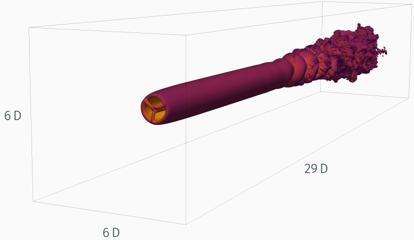
The Cumulant Collision Model

- Ω_α: Relaxation of f in cumulant space
- Superior stability and accuracy at high Re
- AllOne (**AO**): 2^{nd}-order in advection and diffusion [2]
- Parametrized cumulant (**PC**): 2^{nd}-order in advection, 4^{th}-order in diffusion [3]

CASE SET-UP

Case set-up

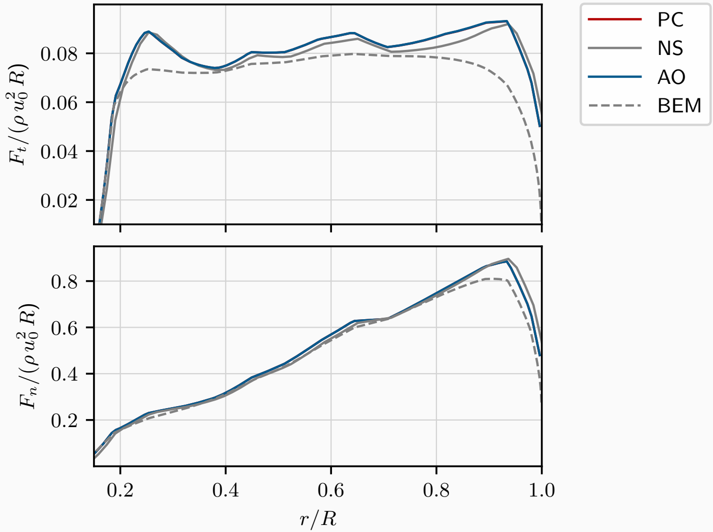
- ALM simulation of the NREL 5MW turbine in uniform laminar inflow
- $\lambda = 7.55$, $u_0 = 8\,\mathrm{m/s}$
- Isotropic Gaussian smearing approach with $\epsilon = 2.5\Delta x$
- Smagorinsky model, $C_s = 0.1$
- The LB-solver ELBE [4]
- NS-FV reference: EllipSys3D [5, 6, 7]



$\Delta x = 1/32\,D$

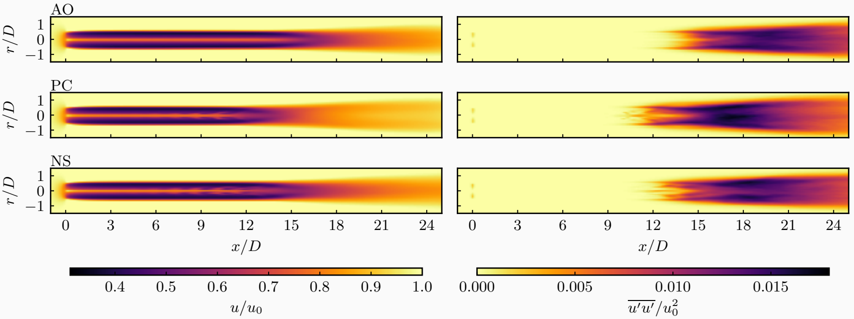
RESULTS

Blade Loads

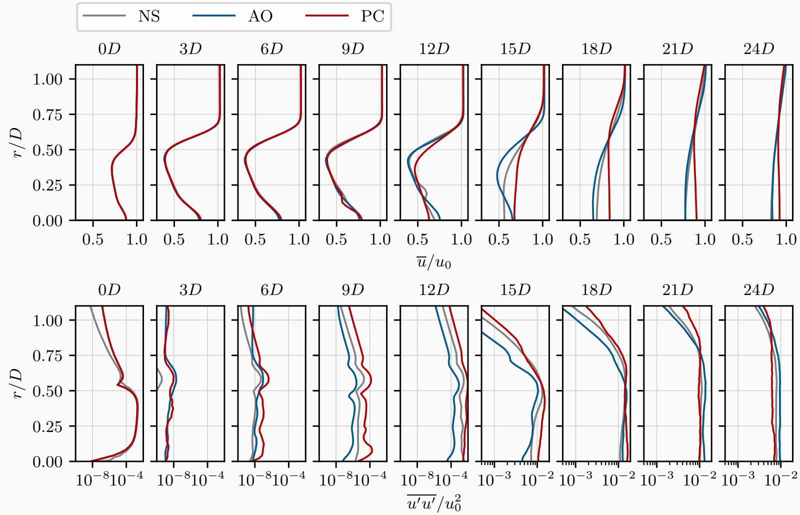


$F_t/(\rho u_0^2 R)$
0.02
0.04
0.06
0.08
$F_n/(\rho u_0^2 R)$
0.2
0.4
0.6
0.8
0.2
0.4
0.6
0.8
1.0
r/R
PC
NS
AO
BEM

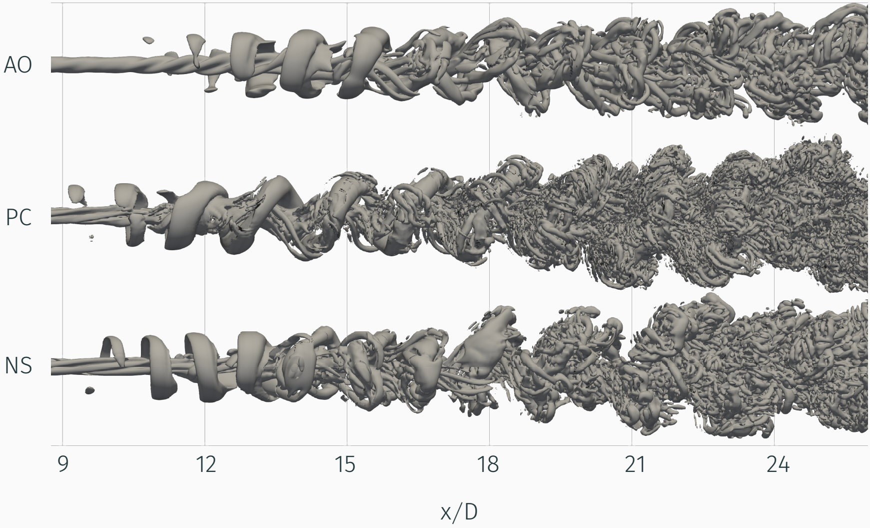
First- and Second-order Statistics



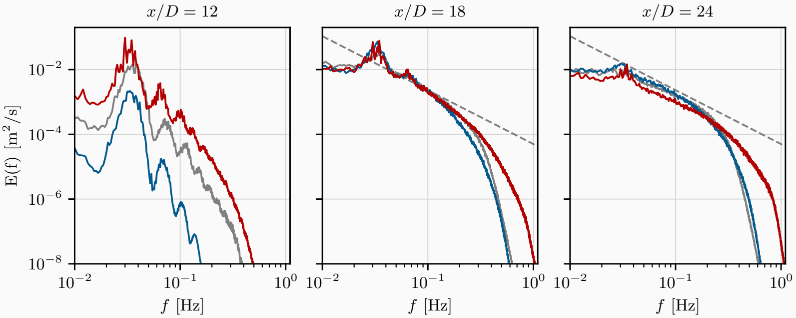
First- and Second-order Statistics

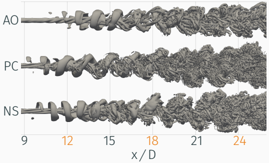


Turbulence Characteristics



Power spectra





Computational Performance

Performance measures of ALM simulations in EllipSys3D and ELBE with. Wall time and process time given per flow-through time (456s).

	NS-FV	Cumulant LBM
Processing unit	1080 CPU cores (Intel Xeon Gold 6130)	1 GPU (Nvidia RTX 2080 Ti)
Grid nodes	$35 \cdot 10^6$	
CFL number	0.132	0.057
Mach number	-	0.1
Wall time	2h 44m	0h 09m
Process time [CPUh,GPUh]	3019.79	0.14
Real time / Comp. time	0.05	0.90

CONCLUSION

Conclusion

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- The LB-ALM validation was successfully extended to the near- and far-wake
- The cumulant LBM is a suitable bulk scheme for typical high Re flows using relatively low spatial resolutions
- Notable differences between AllOne and parametrised cumulant
- Significant performance gains: close to real-time computing on the desktop

Outlook

- More soon in **Wind Energy Science**
- Mach-number dependency, more in-depth analysis of turbulence characteristics …
- Long-term: Wind farm simulations with the LBM

Thank you! Questions?

[1] Asmuth H, Olivares-Espinosa H, Nilsson K and Ivanell S 2019 Journal of Physics: Conference Series

[2] Geier M, Schönherr M, Pasquali A and Krafczyk M 2015 Comput. Math. Appl. **70** 507–547

[3] Geier M, Pasquali A and Schönherr M 2017 J. Comput. Phys. **348** 862–888

[4] Janßen C F, Mierke D, Überrück M, Gralher S and Rung T 2015 Computation **3** 354

[5] Michelsen J A 1994 Basis3D—a platform for development of multiblock PDE solvers Tech. Rep. Report AFM 92-05 Technical University of Denmark, DTU

[6] Michelsen J A 1994 Block structured multigrid solution of 2D and 3D elliptic PDE's Tech. Rep. Report AFM 94-06 Technical University of Denmark, DTU

[7] Sørensen N N 1995 General purpose flow solver applied to flow over hills Ph.D. thesis Risø National Laboratory, Roskilde, Denmark

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