Team 12: The Emergence of Complex Phenomena in Turbulent Flows: an F1 Ground Effect Study

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Short description

This project investigates the emergent phenomenon of turbulence in the context of Formula 1 ground-effect aerodynamics. We utilize the Lattice Boltzmann Method (LBM), along with the Smagorinsky Large Eddy Simulation (LES) model to resolve turbulence, to simulate the interaction between airflow and a moving ground plane, specifically focusing on how small-scale variations in ride height and airflow viscosity lead to transitions in flow stability and generated downwards force.

Research questions and hypotheses

- At what point and under what conditions does a phase transition to chaotic occur? What order of phase transition is it?
    - As the Reynolds number increases via reduced viscosity or increased velocity, the flow field will undergo a subcritical bifurcation from laminar to turbulent flow.
- How sensitive is turbulent flow to initial conditions such as viscosity, ride height, pitch angle etc.
    - There exists a “tipping point” (dependent on ride height and viscosity) that results in a sudden transition to chaotic flow.
- How do microscopic particle interactions relate to macroscopic, turbulent behaviour?
    - Macroscopic turbulent structures are emergent properties of the microscopic particle collisions, attractions and repulsions.
- How does the inclusion of “ground/track” in the virtual wind tunnel affect the transition to turbulent flow?
    - The inclusion of ground/track will still result in a transition to turbulent flow but with a different transition type and characteristics.

Method and concept

- Lattice Boltzmann Method (LBM)
    - Setup a 2D virtual wind tunnel with a “Slip” or "No-Slip" bottom boundary representing exclusion or inclusion of the track/ground.
    - Setup a geometric proxy representing an F1 front wing.
    - Systematically vary the Reynold’s number and ride height to observe resulting phase transitions.
    - Qualitatively and quantitatively identify a transition to chaos (i.e Lyapunov exponent).

- Compare results of simulation to predicted theoretical results (Kolmogorov and Kraichnan)
- Move on to varying the proxy shape approaching the car's features.

- When possible, compare analytical solutions to computational results.
- Ensure all data generated such as results of runs, figures etc. are stored (Git) for later reference.
- All modelling will be conducted in Python using the LBMpy library, with Snellius being utilized should computational requirements become too great.

References

- Krüger, T., et al. (2017). *The Lattice Boltzmann Method: Principles and Practice*. Springer.
- Pomeau, Y. (2015). "The transition to turbulence: A personal view." Comptes Rendus Mécanique.
- Rosenstein, M.T.; Collins, J.J.; De Luca, C.J. (1992). *A practical method for calculating largest Lyapunov exponents from small data sets.* Physica D: Non-linear Phenomena
- Zhu, X., et al. (2019). *Transition to chaos in a cross-corrugated channel at low Reynolds numbers.* Physics of Fluids
- Hennig, F., et al (2023) *Advanced Automatic Code Generation for Multiple Relaxation-Time Lattice Boltzmann Methods*. SIAM Journal on Scientific Computing
- Bauer, M., et al (2021) *lbmpy: Automatic code generation for efficient parallel lattice Boltzmann methods*. Journal of Computational Science
- Smagorinsky, J. (1963) *General Circulation Experiments with the Primitive Equation I the Basic Experiment*. Monthly Weather Review
- Ruelle, D.; Takens, F. (1971). *On the nature of turbulence*. Communications in mathematical physics.

Time planning

Monday (19/01) - Brainstorm potential ideas, develop proof of concept/feasibility, work on project plan, create Git.
Tuesday (20/01) - Review, finalise and submit project plan.Utilise multiple conversational AI agents to iteratively generate a suggested work Division of work. Work on models. Setup data management system. Setup GenAI usage documentation. Develop Test-Driven-Development Framework.
Friday (23/01) - Complete modelling.
Weekend (24/01-25/01) - Review and suggest improvements on modelling. Check work with TAs/lecturer.
Monday (26/01) - Begin work on presentation, generate figures/animations etc. and address any issues raised.
Wednesday (28/01) - Finalise work on presentation, last chance to ask for assistance.
Thursday (29/01) - Practice presentation.

Friday (30/01) - Present.