Topological Analysis of High Velocity Turbulent Flow

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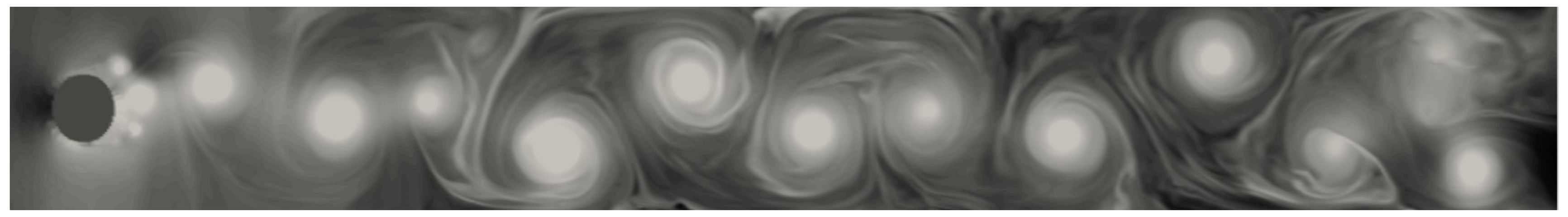
HIGH VELOCITY VON KARMAN STREET

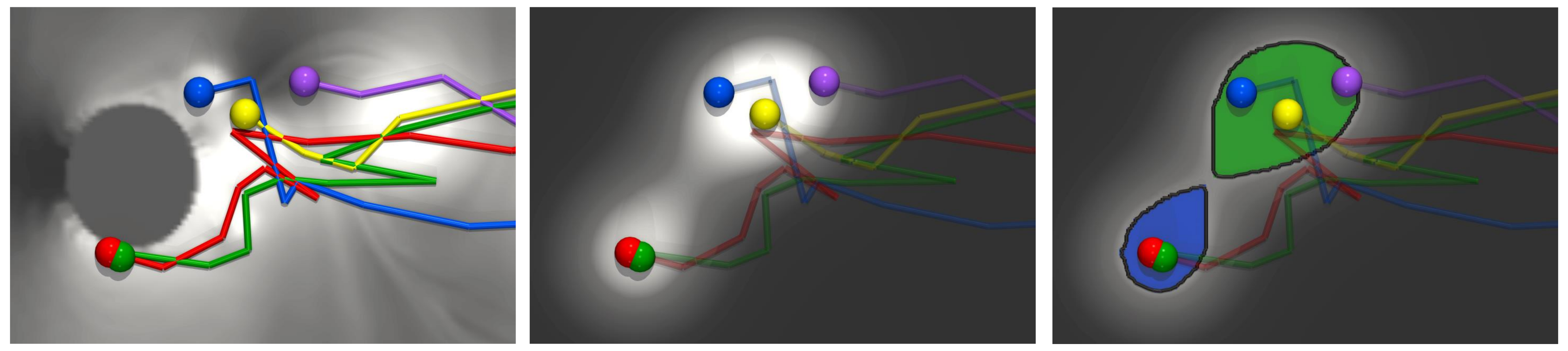


- Simulation of compressible turbulent flow
- Direct solver of the Navier-Stokes equations [16], Roe Riemann solver [15], 5th order WENO scheme [9], 3rd order Runge-Kutta algorithm [7]
- Von Karman street , Mach: 0.475 and Reynolds number: 100,000
- Physical time: 8.5 milliseconds
- 15,625 steps with 625 snapshots at a frequency of 75 kHz
- Cartesian grid of 5000x400, 14 GB of data
- Topological Data Analysis [6,12] of simulation data using the *Topological ToolKit* [13]
- TDA computation time: 215 seconds (Xeon CPU, 2.6 GHz, 2x6 cores).

Goal: understand the pattern and the behavior of the swirling vortices in a high velocity compressible turbulent flow around a fast moving object

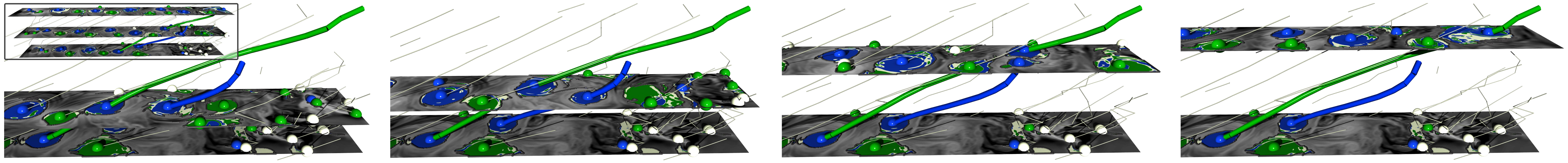
WAVEMAKER IDENTIFICATION

- Identification of the vortex starting points [2,4]
- Merge tree based segmentation of a density estimation of the trajectory start points
- Green clockwise vortices: suction region above the cylinder
- Blue counter-clockwise vortices: high pressure region below the cylinder
- Vortex shedding frequency extracted by TDA confirmed by the theoretical expectations [1]: 1,500 Hz



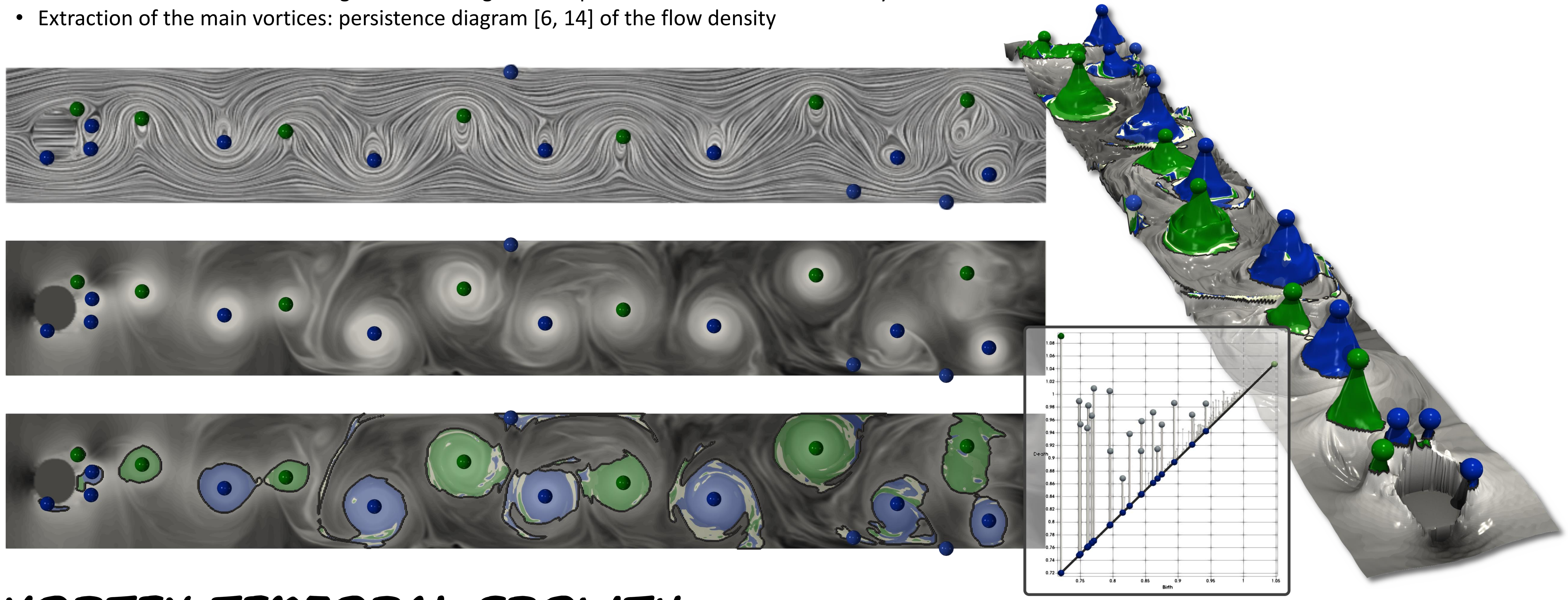
VORTEX SPIRAL MERGING

- Vortex lateral motion characterization: variation in Y coordinate
- Identification of the two trajectories which maximize their lateral movement
- Detection of a coupled spiral movement and subsequent merging



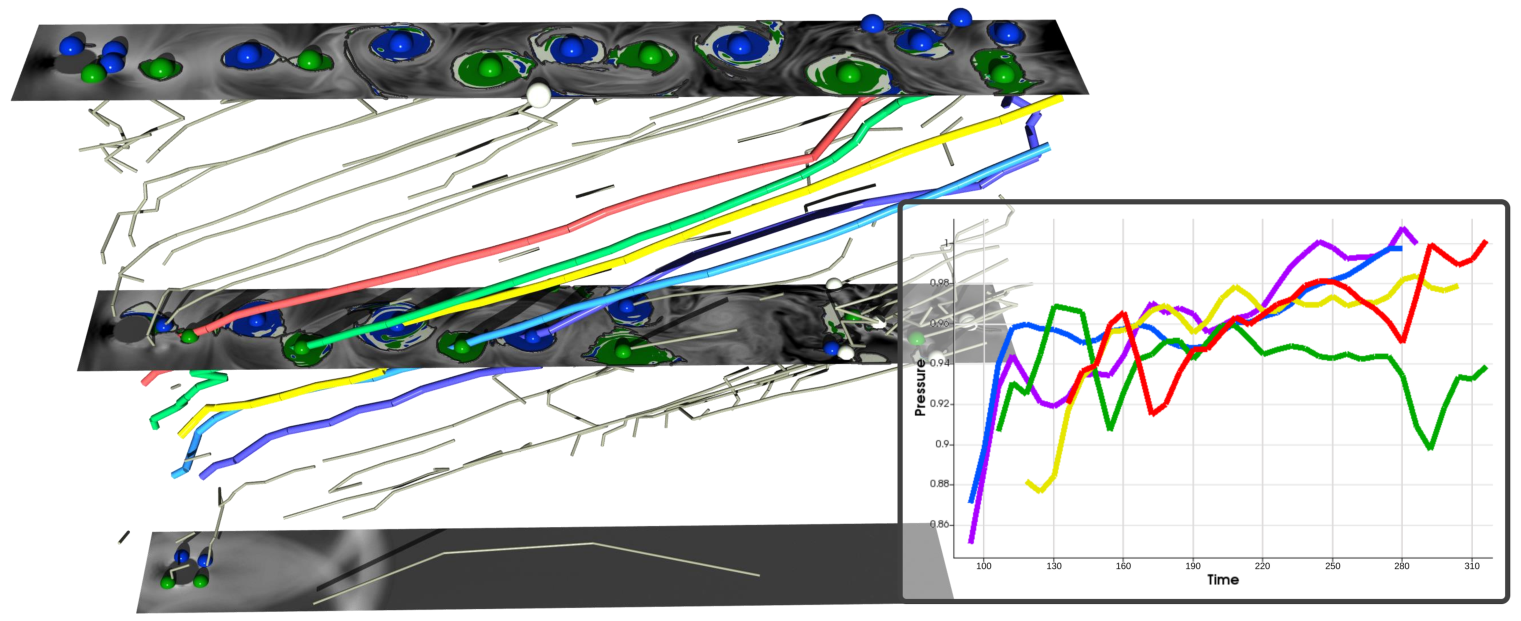
VORTEX EXTRACTION

- Segmentation of the vortices and their regions of influence: merge tree based segmentation on local minima of the flow density
- Rotation direction of a vortex: sign of the orthogonal component of the curl of the velocity
- Extraction of the main vortices: persistence diagram [6, 14] of the flow density



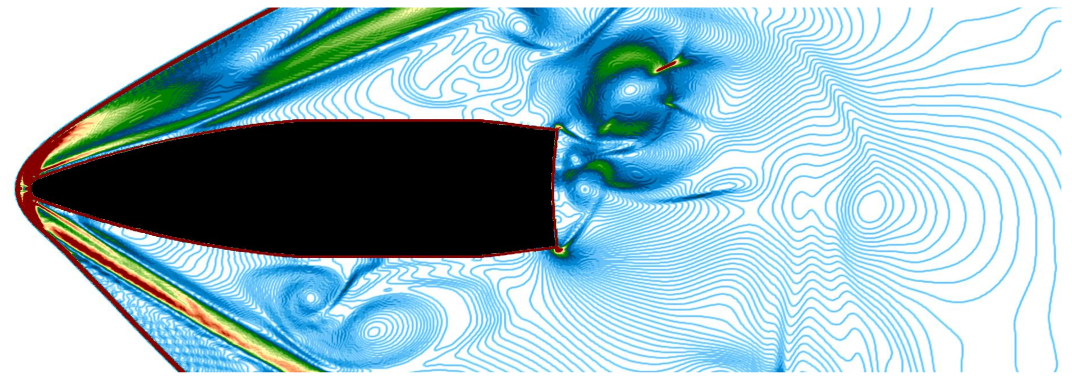
VORTEX TEMPORAL GROWTH

- Evolution of the flow density at the center of the vortices
- Minima of the density tracked through time: optimal assignment based on the Wasserstein [11] metric between consecutive time steps



WHAT'S NEXT

TDA provides an appealing analysis support for the investigation of more complex high velocity compressible turbulent flows.



REFERENCES

[1] R. D. Blevins. Flow-induced vibration. New York, Van Nostrand Reinhold Co., 1977. 377 p., 1977.
[2] T. Bridel Bertomeu. Investigation of unsteady phenomena in rotor/ stator cavities using Large Eddy Simulation. PhD thesis, 2016.
[3] B. Cabral and L. C. Leedom. Imaging vector fields using line integral convolution. Technical report, LLNL, 1993.
[4] S. Chandrasekhar. Hydrodynamic and hydromagnetic stability. Courier Corporation, 2013.
[5] C. Chi, B. J. Lee, and H. G. Im. An improved ghost-cell immersed boundary method for compressible flow simulations. International Journal for Numerical Methods in Fluids, 83(2):132–148, 2017.
[6] H. Edelsbrunner and J. Harer. Computational Topology: An Introduction. AMS, 2009.
[7] S. Gottlieb, D. I. Ketcheson, and C.-W. Shu. High order strong stability preserving time discretizations. J. of Sci. Comp., 2009.
[8] C. Gueunet, P. Fortin, J. Jomier, and J. Tierny. Task-based Augmented Contour Trees with Fibonacci heaps. IEEE TPDS, 2019.
[9] G.-S. Jiang and C.-W. Shu. Efficient implementation of weighted eno schemes. J. of computational physics, 126(1):202–228, 1996.
[10] R. Mittal and G. Iaccarino. Immersed boundary methods. Annu. Rev. Fluid Mech., 37:239–261, 2005.
[11] M. Soler, M. Plainchault, B. Conche, and J. Tierny. Lifted wasserstein matcher for fast and robust topology tracking. In IEEE LDAV, 2018.
[12] J. Tierny. Topological Data Analysis for Scientific Visualization. Springer, 2018.
[13] J. Tierny, G. Favelier, J. A. Levine, C. Gueunet, and M. Michaux. The Topology ToolKit. IEEE TVCG, 2017. https://topology-tool-kit.github.io/
[14] J. Tierny and V. Pascucci. Generalized topological simplification of scalar fields on surfaces. IEEE TVCG, 2012.
[15] E. F. Toro. Riemann solvers and numerical methods for fluid dynamics: a practical introduction. Springer Science & Business Media, 2013.
[16] F. M. White and I. Corfield. Viscous fluid flow, vol. 3. McGraw-Hill New York, 2006.