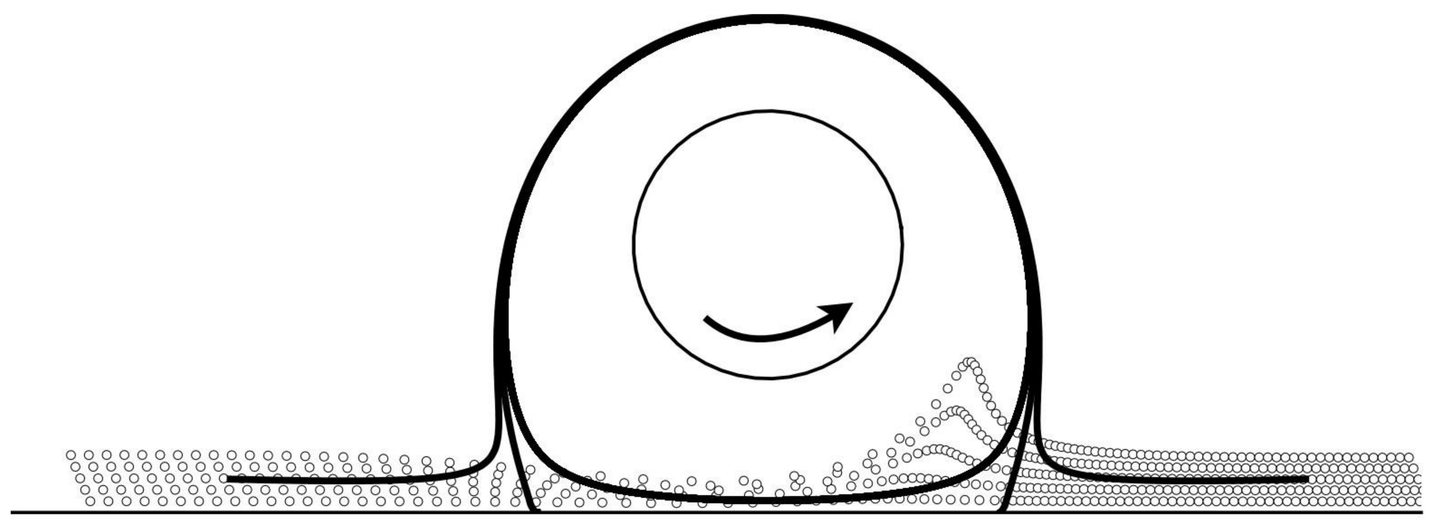
Lagrangian Separation in Turbulent Flows

Fatemeh Malmir, Jérôme Vétel

L^A^DyF– Dept. of Mechanical Engineering – Polytechnique Montréal, Montréal, Québec, H3C 3A7, Canada

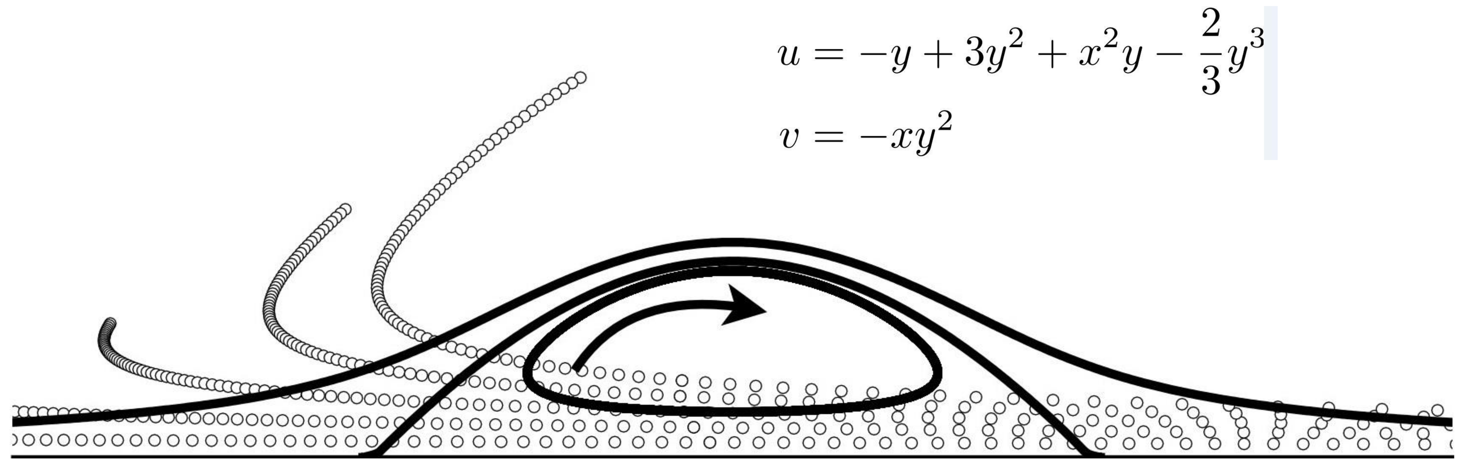
1 Introduction

Flow separation is an undesirable phenomenon that may occur in external flows, like around airfoils and buildings, and in internal flows such as combustors and diffusers. It increases the surface drag and, as a result, decreases efficiency. Therefore, the prediction of such phenomenon is crucial for air, land and marine transport, and for energy production.
The pioneering work of Prandtl [1] states that the separation point is determined where the shear stress on the wall becomes zero. However, his theory does not predict the separation point correctly for three-dimensional flows or unsteady ones. Even in 2D steady flows, the perception of separation, based on this theory, is not so well established.



Streamlines in the steady flow generated by a cylinder rotating close to a horizontal wall [2]. Visualizations of the advection of fluid particles, initially parallel to the wall, reveal that a material spike forms and develops upstream of the point where the wall shear-stress vanishes, which defines the separation point according to the Prandtl criterion.

$$u = -y + 3y^2 + x^2y - \frac{2}{3}y^3$$
$$v = -xy^2$$



In the model of a separation bubble, no Lagrangian separation occurs while the shear stress vanishes at the wall.

So, the separation could be defined differently from traditional approaches. Due to recent studies [3], 2D separation can be described as a material phenomenon where a layer of fluid is ejected from a boundary, i.e. by adopting a Lagrangian point of view. **This work, therefore, focuses on analyzing 3D separation based on Lagrangian approaches.**

2 Objectives

- To explore and analyze the Lagrangian separation in 3D flows.
- To obtain a general theory to build a criterion that does not depend on an observer change.
- To tackle turbulent flows, which represent most of the natural and industrial flows.

3 Methodology

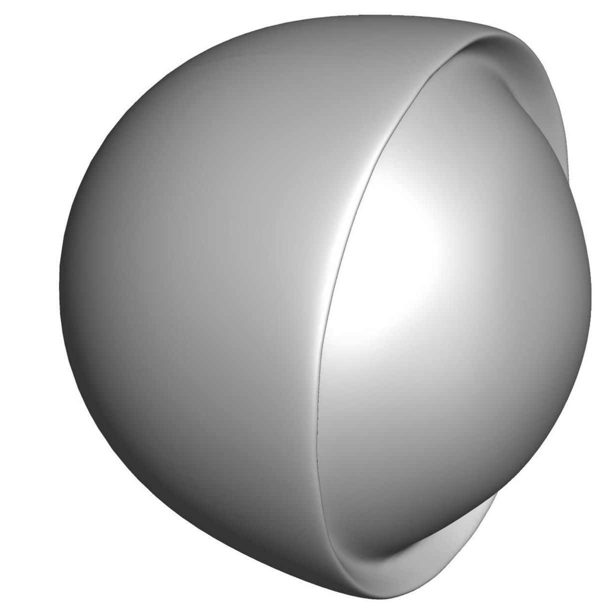
We currently use the Direct Numerical Simulation (DNS) open source code Incompact3d, which is a powerful high-order flow solver for academic research [4,5], written in Fortran 90. The modeling of a solid body inside the computational domain is performed with a special immersed boundary method that allows to reproduce any complex geometry.

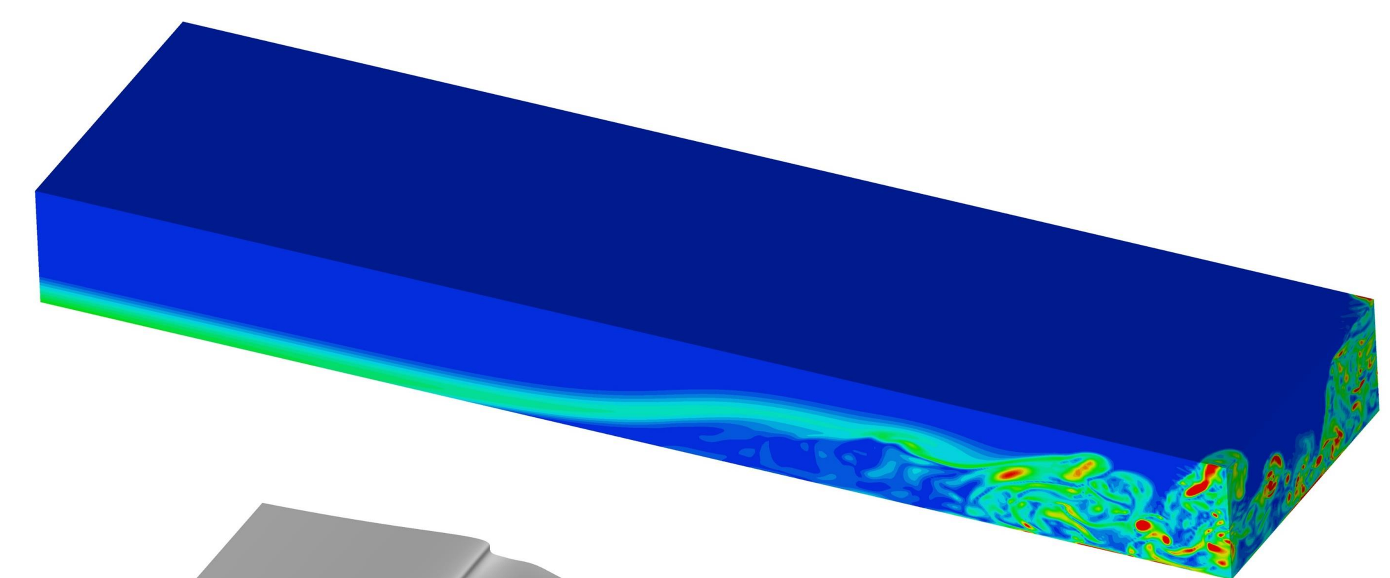
References

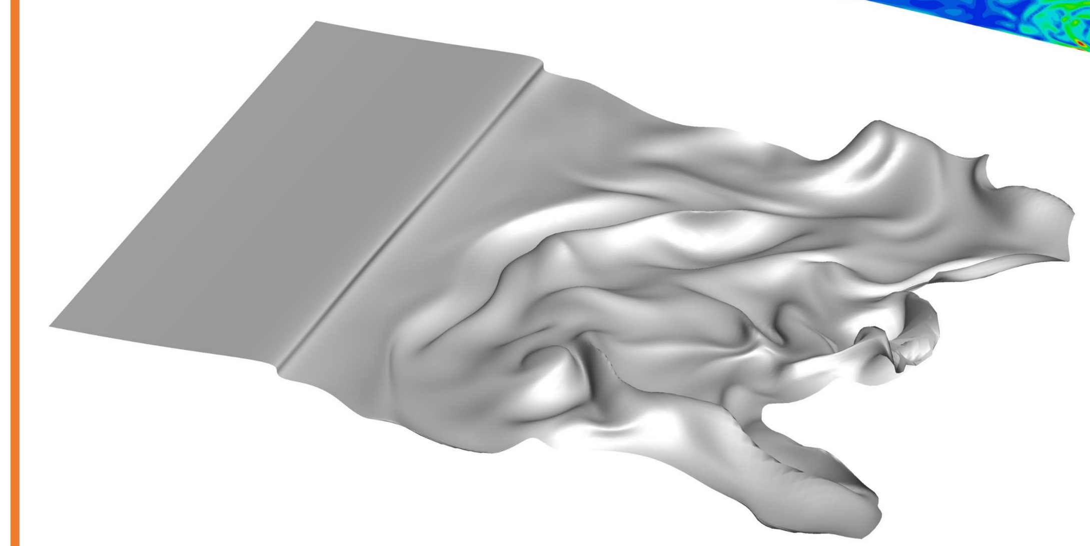
[1] L. Prandtl, "Uber Flussigkeitsbewegung bei sehr kleiner Reibung," Verh. III, *Intern. Math. Kongr*, 1904.
[2] P. Miron and J. Vetel, "Towards the detection of moving separation in unsteady flows," *J. Fluid Mech*, 2015.
[3] M. Serrah, J. Vetel and G. Haller, "Exact theory of material spike formation in flow separation,"*J. Fluid Mech*, 2018.
[4] S. Laizet and E. Lamballais, "High-order compact schemes for incompressible flows: a simple and efficient method with quasi-spectral accuracy," *J. Comp. Phys*., 2009.
[5] S. Laizet and N. Li, "Incompact3d: A powerful tool to tackle turbulence problems with up to O(10^5) computational cores", *Int. J. Numer. Methods Fluids*, 2011.

4 Results

A spherical material surface, initially centered on a solid sphere, deforms in time in a uniform flow.

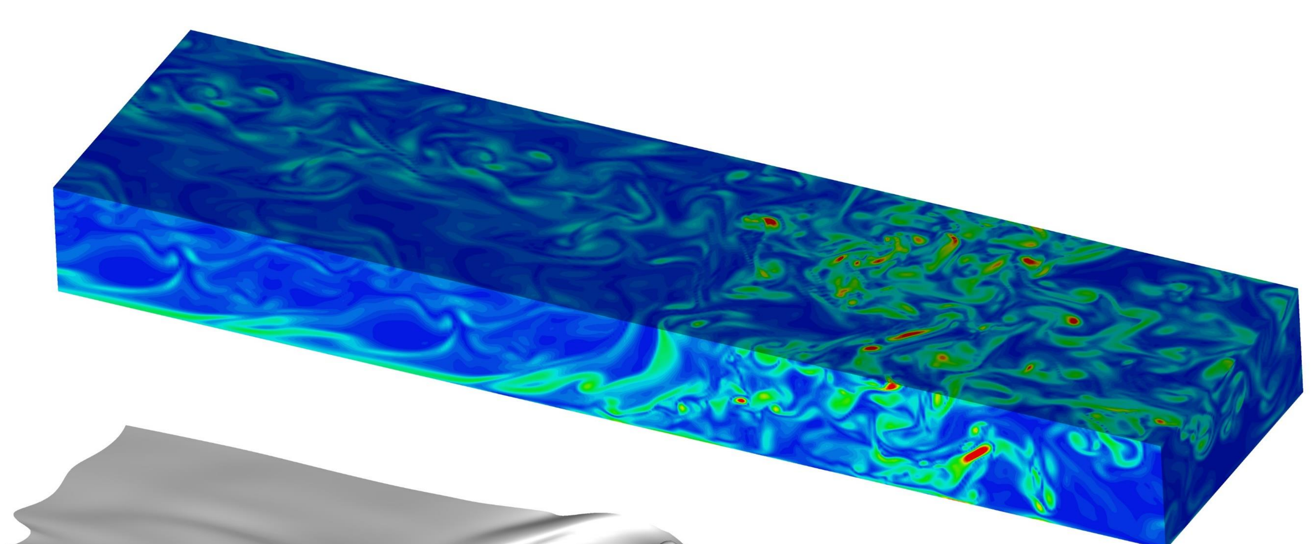


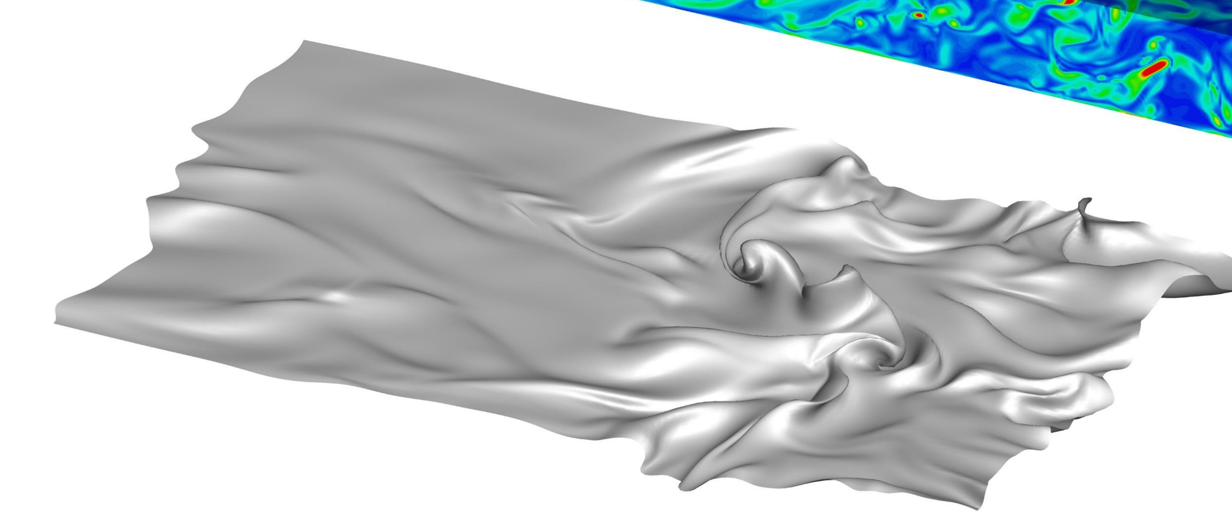




A laminar separation bubble has been computed, which means that even if turbulence develops in the wake of the instability triggered by separation, the initial separation process remains laminar.

The grey surface illustrates how a material surface, initially parallel to the bottom no-slip wall, deforms after a short time





A turbulent separation bubble has been computed, where inflow turbulent conditions were generated with a recycling technique. Contrary to the laminar case, multiple vortex induced separation phenomena are the predominant precursors of the whole separation process.

5 Conclusion and Future Works

For the first step, advection of material surfaces in the laminar and turbulent separation bubble have been simulated.
If such a complex flow physics can be captured by a general theory, this means that the problem of unsteady separation in turbulent flows could be solved, which will have a very strong impact on engineering problems such as in aerodynamics.
We will develop mathematical and numerical tools for this approach and will use the DNS code for an exhaustive validation on several complex flows.