Bifurcations of a creeping air–water flow in a conical container
This numerical study describes the eddy emergence and transformations in a slow steady axisymmetric air–water flow, driven by a rotating top disk in a vertical conical container. As water height $H$ and cone half-angle $\alpha$ vary, numerous flow metamorphoses occur. They are investigated for $H/\alpha$, and $\alpha$. For small $H/\alpha$, the air flow is multi-cellular with clockwise meridional circulation near the disk. The air flow becomes one cellular as $H/\alpha$ exceeds a threshold depending on $\alpha$. For all $\alpha$, the water flow has an unbounded number of eddies whose size and strength diminish as the cone apex is approached. As the water level becomes close to the disk, the outmost water eddy with clockwise meridional circulation expands, reaches the interface, and induces a thin layer with anticlockwise circulation in the air. Then this layer expands and occupies the entire air domain. The physical reasons for the flow transformations are provided. The results are of fundamental interest and can be relevant for aerial bioreactors.
Patterns of a slow air-water flow in a semispherical container
This numerical study analyzes the development of eddies in a slow steady axisymmetric air-water flow in a sealed semispherical container, driven by a rotating top disk. As the water height, $H_w$, increases, new flow cells emerge in both water and air. First, an eddy emerges near the axis-bottom intersection. Then this eddy expands and reaches the interface, inducing a new cell in the air flow. This cell appears as a thin near-axis layer which then expands and occupies the entire air domain. As the disk rotation intensifies at $H_w = 0.8$, the new air cell shrinks to the axis and disappears. The bulk water circulation becomes separated from the interface by a thin layer of water counter-circulation. These changes in the flow topology occur due to (a) competing effects of the air meridional flow and swirl, which drive meridional motions of opposite directions in water, and (b) feedback of water flow on the air flow. In contrast to flows in cylindrical and conical containers, there is no interaction with Moffatt corner vortices here.

General information
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Topological Fluid Dynamics For Free and Viscous Surfaces

In an incompressible fluid flow, streamline patterns and their bifurcations are investigated close to wall for two-dimensional system and close to free and viscous surfaces in three-dimensional system. Expanding the velocity field in a Taylor series, we conduct a local analysis at the given expansion point. Applying the boundary conditions, some relations are obtained among the coefficients of the expansions. Series of coordinate transformations, which preserves the boundary conditions, are used to reduce the number of coefficients. Finally, using the normal form and unfolding theory, the velocity field is analysed structurally and bifurcation diagrams are obtained.

First, two-dimensional viscous flow close to wall for non-simple degenerate critical point is considered depending on three-parameter space. Second, three-dimensional axisymmetric, viscous and steady flow is analysed close to free and viscous
surfaces into three situations: Local analysis close to center axis; away from the axis and close to a stationary wall. Next, in the absence of axisymmetric condition, three-dimensional viscous flow is considered close to a free surface.

As an application of the bifurcation diagrams for three-dimensional axisymmetric viscous flow, three different shaped container driven by a rotating top disk is considered. Using a spectral collocation method, a code is constructed to obtain the meridional and swirl velocities. In a result of this code, all structural changes on the streamline patterns are observed and the occurring bifurcations are determined. These bifurcations are compared with the bifurcations obtained from topologically.

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**Codimension three bifurcation of streamline patterns close to a no-slip wall: A topological description of boundary layer eruption**
A vortex close to a no-slip wall gives rise to the creation of new vorticity at the wall. This vorticity may organize itself into vortices that erupt from the separated boundary layer. We study how the eruption process in terms of the streamline topology is initiated and varies in dependence of the Reynolds number Re. We show that vortex structures are created in the boundary layer for Re around 600, but that these disappear again without eruption unless Re > 1000. The eruption process is topologically unaltered for Re up to 5000. Using bifurcation theory, we obtain a topological phase space for the eruption process, which can account for all observed changes in the Reynolds number range we consider. The bifurcation diagram complements previously analyzes such that the classification of topological bifurcations of flows close to no-slip walls with up to three parameters is now complete.

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Organisations: Department of Applied Mathematics and Computer Science, Mathematics, Roskilde University, Monash University
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Vortex breakdown in a truncated conical bioreactor

This numerical study explains the eddy formation and disappearance in a slow steady axisymmetric air–water flow in a vertical truncated conical container, driven by the rotating top disk. Numerous topological metamorphoses occur as the water height, $H_w$, and the bottom-sidewall angle, $\alpha$, vary. It is found that the sidewall convergence (divergence) from the top to the bottom stimulates (suppresses) the development of vortex breakdown (VB) in both water and air. At $\alpha = 60^\circ$, the flow topology changes eighteen times as $H_w$ varies. The changes are due to (a) competing effects of AMF (the air meridional flow) and swirl, which drive meridional motions of opposite directions in water, and (b) feedback of water flow on AMF. For small $H_w$, the AMF effect dominates. As $H_w$ increases, the swirl effect dominates and causes VB. The water flow feedback produces and modifies air eddies. The results are of fundamental interest and can be relevant for aerial bioreactors.

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**Topological fluid dynamics: Symmetry breaking and fluid interfaces**

Technical University of Denmark  
Period: 01/09/2012 → 19/11/2015  
Number of participants: 5  
Phd Student:  
Balci, Adnan (Intern)  
Main Supervisor:  
Brøns, Morten (Intern)  
Examiner:  
Henriksen, Christian (Intern)  
Blackmore, Denis (Ekstern)  
Hartnack, Johan Nicolai (Intern)

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Project: PhD