BIFURCATIONS AND INSTABILITIES IN FLUID DYNAMICS (BIFD2013)

Fifth International Symposium

Faculty of Mechanical Engineering

Technion – Israel Institute Of Technology

Haifa Israel

8-11 July 2013

Support

Technion- Israel Institute of Technology

Department of Mechanical Engineering,

Technion-Israel Institute of Technology

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Acknowledgments

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Local Organizing Committee

The order of the abstracts included in this collection fits that of the appearance of the talks in the Conference program. This PDF is fully searchable.

BIFD-2013, Technion, Haifa, July 8-11, 2013

Sunday, July 7
18:00 – 20:30 Registration and reception
Coler-California Visitors Center

The Reception on Sunday July 7 will take place in the Coler-California Visitors Center (Building 430 on the Technion map posted on the conference website, see "practical information" and "venue" pages there) located on the David Rose Avenue (Ring Road).

All plenary sessions and the opening/closing sessions will take place in the Auditorium LD 250 in the Lady Davis (LD) Building of Mechanical Engineering (Building 371 on the Technion map). All separate sessions will be held in the Lady Davis Building on the 4th floor, rooms 442, 443, 450 and 451. Coffee breaks and lunches will take place in rooms 430 and 433 of the Lady Davis Building. The entrance to the Lady Davis building is <u>behind</u> the new D. Dan & Betty Kahn Mechanical Engineering Building to the <u>right</u> of the new building. From there it is possible to take an elevator to the 4th floor. Auditorium LD 250 is right by the entrance to the building.

The front desk of the Conference will be located on July 8 -11 in room LD 441 during the activities' time. During the reception on July 7 the front desk will be open in the Coler-California Visitors Center.

Monday, July 8

8:30 – 9:00	**Registration Lady Davis Building LD441**			
9:00 – 9:30	**Chair: A. Oron Opening session Lady Davis Building LD250**			
9:40 – 10:30	**Chair: P. Z. Bar-Yoseph Plenary lecture: Gustav Amberg, KTH Stockholm, Sweden Surface tension driven instabilities and bifurcations** **Lady Davis Building LD250**			
10:30 – 10:40	**Group photo**			
10:50 – 11:20	**Coffee break (LD 430, 433)**			
Sessions	**M1 Convection** (Chair: H. Kuhlmann) **LD 451**	**M2 Films and drops** (Chair: A. Oron) **LD 450**	**M3 Localized States in Fluids** (Chair: I. Mercader) **LD 442**	**M4 Shear flows** (Chair: D. Barkley) **LD 443**
11:20 – 11:40	L. Oteski, Y. Duguet, L. Pastur, P. le Quéré, *Bifurcations, synchronizations and chaos inside a two-dimensional differentially heated cavity*	J. M. Perez-Gracia, J. Porter, F. Varas, J. M. Vega, *Oblique cross-waves in horizontally vibrated containers*	M. Withalm, N.P. Hoffmann, *Weakly localized solutions in a three dimensional boundary layer*	
11:40 – 12:00	I. A. Babushkin, V. A. Demin, *Convection, thermocouple measurements and applications*	M. Bestehorn, A. Oron, *Thin film behavior under external vibrations*	I. Mercader, O. Batiste, A. Alonso, E. Knobloch, *Drifting convectons in binary mixtures*	M. F. de Medeiros, *The effect of phase and modulation on nonlinear TS wavepackets*
12:00 – 12:20	S. Stefanov, M. Vargas, *Thermal gas flow instability in micro scale enclosures*	O. Haimovich, A. Oron, *Nonlinear dynamics of large-amplitude drops on an axially oscillating cylindrical surface*	A. V. Taraut, B. L. Smorodin, M. Lucke, *Convection in binary liquid mixtures: collisions of localized structures*	M. Brøns, *The topology of boundary layer eruption*
12:20 – 12:40	A.G. Abramov, E.M. Smirnov, V.D. Goryachev, *Vortex structures in transitional free-convection boundary layer: numerical simulation results*	M. Binz, W. Rohlfs, R. Kneer, *Direct Numerical simulation of the Plateau- Rayleigh instability deve-loping on an oscillating cylinder covered by a thin liquid film*	F. Feudel, N. Seehafer, L.S. Tuckerman, *Multistability in radially forced rotating spherical shell convection*	K. Kostarev, A. Mizev, E. Mosheva, *Instability of mixing zone formed at the boundary between the counter flows of two miscible liquids*
12:40 – 13:00	J. Curbelo, A.M. Mancho, *Bifurcations and dynamics in a convection problem with temperature-dependent viscosity with O(2) symmetry*	A.A. Alabuzhev, S. Shklyaev, M. Khenner, *Averaged description of Marangoni convection in a vertically vibrating liquid layer*	S. Zammert, B. Eckhardt, *Localized periodic orbits in plane Poiseuille flow*	A. Alexeev, Z. G. Mills, T. Shah, *Flow instability in pressure-driven flow through wavy channels*

Monday, July 8

13:00 – 14:20	**Lunch (LD 430, 433)**			
Sessions	**M5 Convection** (Chair: L. Tuckerman) **LD 451**	**M6 Films and drops** (Chair: J. Vega) **LD 450**	**M7 Instabilities in biofluid flows** (Chair: P.Z. Bar-Yoseph) **LD 442**	**M8 MHD instabilities** (Chair: M. Mond) **LD 443**
14:20 – 14:40	A. Gelfgat, *Oscillatory instability of natural convection of air in a laterally heated cubic box*	A.B. Mikishev, A. Nepomnyashchy, *The influence of heating conditions on the instabilities in an evaporating liquid layer with insoluble surfactant*	P. Hofemeier, J. Sznitman, *The role of respiratory flow asynchrony on convective mixing in the pulmonary acinus*	N. Weber, V. Galindo, M. Seilmayer, F. Stefani, T. Weier, *Simulation of the Tayler instability in liquid metals*
14:40 – 15:00	J. F. Torres, D. Henry, A. Komiya, S. Maruyama, *Bifurcations in natural convection inside a tilted cubic cavity*	S. Shklyaev, and A. A. Nepomnyashchy, *Steady longwave Marangoni convection in a layer of a binary liquid heated from above*	M. Centeno, B. Thiria, R. Godoy-Diana, *Bio-inspired flapping wings: forewing-hindwing phase-lag effect*	T. Vogt, I. Grants, D. Räbiger, S. Eckert, G. Gerbeth, *Transient Taylor-Görtler vortex flow in a spinning liquid metal*
15:00 – 15:20	A. Teymurazov, A. Vasiliev, P. Frick, *Experimental and numerical study of turbulent convection in bounded vertical layers*	I. S. Fayzrakhmanova, S. Shklyaev, A. Nepomnyashchy, *Longwave convection in a binary liquid layer with modulated heat flux at the bottom*	V. Batishev, *The modelling of the helical blood flows in aorta*	A. Kapusta, B. Mikhailovich, *Magnetic field and turbulence impact on the flow stability in a rotating magnetic field*
15:20 – 15:40	O. N. Goncharova, E. V. Rezanova, *Modeling of the convective fluid flows in the two layer systems with evaporation at interface on the basis of the exact solutions*	M. Morozov, A. Oron, A. Nepomnyashchy, *Nonlinear dynamics of long-wave Marangoni convection in a 2D layer of binary liquid*	Y. T. Delorme, A.-E. M. Kerlo, K. Anupindi, J. Chen, S. H. Frankel, M. D. Rodefeld, *Dynamic mode decomposition of fontan hemodynamics in an idealized total cavopulmonary connection*	I. Belyaev, L. Genin, I. Melnikov, V. Sviridov, E. Sviridov, Yu. Ivochkin, N. Razuvanov, *Experimental investigation of liquid metal heat transfer specific applied to TOKAMAK reactor cooling*
15:40 – 16:00	D. Kuznetsova, I. Sibgatullin, *Bifurcations in penetrative convection in plane layer*	M. Higuera, J. Perales, J. Vega, *Long wave theory for experimental devices with compressed/ expanded surfactant monolayers*	E. Khain, M. Katakowski, N. Charteris, F. Jiang, M. Chopp *Migration of adhesive glioma cells: front propagation and fingering*	A. Kharicha, I. Teplyakov, Yu. Ivochkin, M. Wu, A. Ludwig, A. Guseva, *Free surface deformation in electrically driven flow*
16:00 – 16:20		L.E. Johns, R. Narayanan, *The nature of branching in miscible displacement*		Y. Tasaka, K. Igaki, T. Yanagisawa, S. Eckert, T. Vogt, *Regularization of flow reversals in a MHD Rayleigh-Bénard convection*

Monday, July 8

16:20 – 16:50	**Coffee break (LD 430, 433)**			
Sessions	**M9 Convection** (Chair: R. Narayanan) **LD 450**	**M10 Shear flows** (Chair: J. Cohen) **LD 442**	**M11 Instabilities in astrophysics** (Chair: M. Mond) **LD 443**	**M12 Fluid –structure interaction** (Chair: O. Gottlieb) **LD 451**
16:50 – 17:10	A. Alonso, I. Mercader, O. Batiste, *Pattern selection near the onset in cylindrical binary mixture convection*	C. Galletti, E. Brunazzi, R. Mauri, *Symmetry breaking and time-periodic flow structures in T-shaped micromixers*	***Keynote lecture:*** F. Rincon, *From pipe flow to astrophysical magnetic fields: subcritical dynamo transitions and self-sustaining nonlinear magnetohydrodynamic processes*	D. Crowdy, Global bifurcations for low-Reynolds-number swimming in confined geometries
17:10 – 17:30	H. Herrero, M.C. Navarro, *Top-down vortices developed in a cylindrical annulus cooled on the top*	J. R. Picardo, D. S. Pillai and S. Pushpavanam, *Stability of disfigured liquid jets: effect of interfacial geometry*		A. Boymelgreen, G.Yossifon and T. Miloh, *An electrokinetically driven Janus micromotor: stability and rotation*
17:30 – 17:50	V. Prusa, *On models for fluid-like materials that are mechanically incompressible and thermally compressible or expansible and their Oberbeck–Boussinesq type approximations*	L. Biancofiore, F. Gallairey, P. Laurez, E. Hachem, *Interaction between counter-propagating Rossby and capillarity waves in planar jets and wakes*	U. Griv, H.-H. Wang, *Numerical exploration of density waves formation in rapidly and differentially rotating spiral galaxies*	D.E. Raveh and E.H. Dowell, *Aeroelastic Limit cycle oscillations in transonic buffeting flows*
17:50 – 18:10	A. Sukhanovsky, A. Evgrafova, E. Popova, *Secondary flow dynamics in a temperature boundary layer in a cylindrical tank*	A. M. Mathai, S. Pushpavanam, *Patterns in the breakup of slender compound jets in the presence of gravity-inviscid and viscid studies*	M. Gellert, G. Rüdiger, *Magnetic pinch-type instability and alpha-effect in a liquid metal container*	A. Katz, R. van Hout, D. Greenblatt, *VIV of a tethered sphere in a steady flow: Near-wake flow and effect of active flow*
18:10 – 18:30		J.R. Picardo, S. Pushpavanam, *On the stability of two phase Poiseuille flow between coaxial cylinders*	U. Keshet, *Spiral flow instability in galaxy clusters*	A. Postnikov, E. Pavlovskaia, M. Wiercigroch, *Calibration of the wake oscillator model using CFD*

Tuesday, July 9

9:00 – 9:50	**Chair: Gustav Amberg Plenary lecture: Transient states in the transition to turbulence in channels (LD 250)** **Jose Eduardo Wesfreid, PMMH, ESPCI, Paris, France**			
10:00 – 10:30	**Coffee break (LD 430, 433)**			
Sessions	**T1 Instabilities in Astrophysics** (Chair: W. Kluźniak) **LD 443**	**T2 Films and drops** (Chair: M. Bestehorn) **LD 450**	**T3 Subcritical transitions in shear flows** (Chair: A. Bottaro) **LD 442**	**T4 Fluid –structure interaction** (Chair: H. Benaroya) **LD 451**
10:30 – 10:50	***Keynote lecture:*** R. Arlt, *Magnetic instabilities in stars*	K. Kanatani, *Effect of convection of the vapor on the Marangoni instability in evaporating liquid films*	Y. Duguet, A. Monokrousos, L. Brandt, D. S. Henningson, *Minimal transition thresholds in plane Couette flow*	Y. Green, G. Yossifon, *Dynamics of colloids and hydrodynamic vortices due to competition between various electrokinetic modes*
10:50 – 11:10		E. Benilov, C. Cummins, *Stability of a static liquid column pulled out of an infinite pool*	D. Barkley, M. Avila, B. Hof, *The speed of turbulent-laminar fronts in pipe flow*	Y. Liu, *Instability in axial-flow-induced vibrations of cylindrical clusters*
11:10 – 11:30	O.M. Umurhan, R. Yellin-Bergovoy, E. Heifetz, *Shear instabilities in self-gravitating models of accretion disks: a kernel gravity wave interpretation*	S. Veremieiev, P.H. Gaskell, *The stability of and eddy genesis within a heated film flowing under gravity on an inclined substrate exhibiting a sinusoidal variation*	M. Karp, J. Cohen, *On transition via transient growth in Couette flow*	A. Kleiman, O. Gottlieb, *The onset of flutter and self-excited oscillations of a viscoelastic slender body immersed in a uniform fluid flow*
11:30 – 11:50	P.L. Sulem, T. Passot, D. Laveder, *Viscous instabilities and intermittent dissipation of Alfvénic intermediate shocks and solitons: a possible contribution to coronal heating*	R. Borcia, M. Bestehorn, C. Egbers, *Partial coalescence of sessile liquid droplets*	O. Semeraro, F. Giannetti, L. Brandt, *Sensitivity analysis of the periodic orbits of plane Couette flow*	O. Shoshani, O. Gottlieb, *Nonlinear stability of a perturbed Orr-Sommerfeld solution for the wake of stationary and moving cylinders at low Reynolds numbers*
11:50 – 12:10	M. Gedalin, *Shock structure and ion gyration*	S. Duruk, A. Oron, *Rayleigh-Taylor instability of a liquid film on a solid corrugated surface subjected to tangential oscillation*	V. Bekezhanova, *On the instability of convective flow in cylinder and possible secondary regimes*	M. Heil, D. Pihler-Puzovic, R. Perillat, A. Juel, *The effect of fluid-structure interaction on the viscous fingering instability in an elastic-walled Hele-Shaw cell*
12:10 – 12:30	E. Liverts, Y. Shtemler, M. Mond, *Nonlinear interaction of the Alfvén-Coriolis waves with magneto-acoustic modes in thin rotating discs*	M. Nagel, F. Gallaire, *Investigation of droplet shedding in flow focusing geometries using the boundary element method*	J.A. Martín, C. Martel, *Downstream development of fully nonlinear intrinsic streaks in the at plate boundary layer*	Z. Aginsky, O. Gottlieb, *Nonlinear fluid-structure interaction of viscoelastic panels in an acoustically excited inviscid compressible fluid*

Tuesday, July 9

12:30 – 14:00	**Lunch (LD 430, 433)**			
Sessions	**T5 Technological applications and rotating flows** (Chair: A. Gelfgat) **LD 442**	**T6 Films and drops** (Chair: P. H. Gaskell) **LD 450**	**T7 Micro- and nano- systems** (Chair: S. Pushpavanam) **LD 443**	**T8 Fluid –structure interaction** (Chair: D. Crowdy) **LD 451**
14:00 – 14:20	A. Yeckel, P. Daggolu, J.J. Derby, *Instabilities during meniscus-defined crystal growth*	J. P. Pascal, N. Gonputh, S.J.D. D'Alessio, *Long-wave instability of flow with temperature dependent fluid properties down a heated incline*	A. Lytra, N. Pelekasis, *Static response and stability of coated microbubbles as a means of parameter estimation*	A. Manela, L. Huang, *Sound generated by a wing with a flap interacting with an eddy*
14:20 – 14:40	E. Miroshnichenko, V. Haslavsky, E. Kit, A. Gelfgat, *Scaling laws for instabilities in Czochralski crystal growth configuration at large Prandtl numbers*	N. Kofman, S. Mergui, C. Ruyer-Quil, *Three-dimensional instabilities of solitary waves in a falling liquid film*	K. Efthymiu, N. Pelekasis, *Acoustic interaction between a coated microbubble and a nearby surface – Steady pulsations vs. transient break-up*	E. Passov and Y. Or, *Dynamics of Purcell's three-link microswimmer with a passive elastic tail*
14:40 – 15:00	A. Saurabh, C.O. Paschereit, *Transverse acoustic forcing effects on an annular swirling jet*	E. Benilov, C. Cummins, *Drops climbing on vibrating, inclined substrate*	D. S. Pillai, S. Pushpavanam, *On the buckling instability of liquid threads in a divergent microchannel*	*Y. Or, Asymmetry and stability of shape kinematics in microswimmers' motion*
15:00 – 15:20	J. Bohacek, A. Kharicha, A. Ludwig M. Wu, *A shallow layer model to study the wave instabilities of a thin liquid layer inside a rotating cylinder*	W. Mao, A. Alexeev, A. Oron, *Fluid transport in thin liquid films using traveling thermal waves*	J. Schiffbauer, N. Leibowitz, U. Liel, S. Park, G. Yossifon, *Transient electrical response at the microchannel-nanochannel interface near the overlimiting transition*	V.L. Okulov, D. Kulikov, I. Naumov, R. Mikkelsen, J.N. Sørensen, *PIV-visualization of bubble structures in a tall cylinder driven by a rotating endwall*
15:20 – 15:40		I. Wertgeim, A. Mikishev, *Bifurcation analysis in low-frequency and high-frequency models of Marangoni convection with period-ically modulated localized heating*	J. Schiffbauer, N. Leibowitz, U.Liel, S. Park, G. Yossifon, *Geometric modulation of electrokinetic instability in micro-nanochannel interface devices*	E. Domany, O. Gendelman, *Targeted energy transfer in fluttering systems*

Tuesday, July 9

15:40 – 16:10		**Coffee break (LD 430, 433)**		
Sessions	**T9 Geophysical flows** (Chair: V. Zeitlin) **LD 451**	**T10 Instabilities in astrophysics** (Chair: P.L. Sulem) **LD 443**	**T11 Subcritical transitions in shear flows** (Chair: Y. Duguet) **LD 442**	**T12 Fluid –structure interaction** (Chair: M. Heil) **LD 450**
16:10 – 16:30	Y. Amitai, Y. Ashkenazy, H. Gildor, *Mediterranean deep water formation bi-stability*	***Keynote lecture:*** R.V.E. Lovelace, M.M. Romanova, *First global 3D simulations of waves in accretion discs and new results on Rossby waves in discs*	H. Vitoshkin, A. Gelfgat, *Transient growth of 3D perturbations in a stratified mixing layer flow*	H. Benaroya, S. Mottaghi, *Reduced-order modeling of vortex-induced oscillations*
16:30 – 16:50	H. Dijkstra, F. Wubs, *Bifurcation analysis of global ocean-climate models*		S. Cherubini, P. De Palma, *Minimal perturbations targeting the edge in a Couette flow*	P. Zhang, H. L. Cao, Y. Zhou, *Closed-loop control of a turbulent jet based on fluidic means*
16:50 – 17:10	A. Kharicha, M.Stefan-Kharicha, A. Ludwig, M. Wu, *A meandering sinking flow as possible explanation for the thermohaline staircases in oceans*	W. Kluźniak, *Period doubling, high frequency QPOs, and instabilities in black hole accretion disks*	H. Wedin, G. Zampogna, A. Bottaro, *Three-dimensional vortex structures in the Blasius boundary layer flow*	A. Gat, M. Gharib, *Elasto-capillary instability and coalescence of multiple parallel sheets*
17:10 – 17:30	Y. Ashkenazy and E. Tziperman, *Instabilities and eddies of a Snowball ocean*	M. Gedalin, E. Golbraich, M. Balikhin, T. Zhang, *Large amplitude nonlinear waves in Venus magnetosheath*	F. Guéniat, L. Pastury, Y. Fraigneau, F. Lusseyran, *Shear layer modes competition in open cavity flow: experimental and numerical exploration of 3D features through a 3D DMD analysis*	
17:45-18:35		Rafael Plotnik *Lecture on the history of Jerusalem* **LD 250**		

Wednesday, July 10: ***Day trip to Jerusalem and Caesarea***

Thursday, July 11

9:00 – 9:50	**Chair: Jose Eduardo Wesfreid Plenary lecture: Flow states in thermocapillary liquid bridges—a review of the experiments (LD 250)** **Dietrich Schwabe, University of Giessen, Germany**			
10:00 – 10:30	**Coffee break (LD 430, 433)**			
Sessions	**Th1 MHD instabilities** (Chair: S. Eckert) **LD 451**	**Th2 Geophysical flows** (Chair: N. Harnik) **LD 450**	**Th3 Computational methods** (Chair: F. Wubs) **LD 442**	**Th4 Miscellaneous topics** (Chair: M. Brøns) **LD 443**
10:30 – 10:50	Ya. Listratov, D.Ognerubov, O. Zikanov, V. Sviridov, *Temperature fluctuations as a result of mixed convection in a liquid metal flow with imposed transverse magnetic field*	I. D. Borcia, T. Seelig, A. Ghasemi, M. Klein, A. Will, C. Egbers, E. Schaller, U. Harlander, *Inertial wave modes excitation inside a container with cylindrical geometry*	N. Périnet, D. Juric, L. Tuckerman, *Exotic behavior of hexagonal Faraday waves*	I. Oprea, G. Dangelmayr, J. Gleeson, G. Acharya, *Steady state–Hopf mode interactions at the onset of nematic electroconvection*
10:50 – 11:10	A.F. Zibold, *Hydrodynamic structu-res generated by the rotating magnetic field in cylindrical vessel*	Y. Cohen, N. Paldor, *The linear instability of barotropic shallow-water eddies in gradient balance for various basic states*	S. Abelman, *Reduction and solution for unsteady flow of a sisko fluid for cylindrical geometry revisited*	A.I. Mizev, A.I. Trofimenko, A. Viviani, *Impact on the stability of divergent capillary flow*
11:10 – 11:30	P. Oborin, S. Khripchenko, E. Golbraikh, *The use of the traveling magnetic field generated by a modulated current for the liquid metal stirring*	B. Ribstein, R. Plougonven and V. Zeitlin, *Inertial vs barotropic and baroclinic instabilities of the Bickley jet: continuous stratification*	F. Guéniat, L. Pastury, F. Lusseyran, *GPU and SIMD acceleration for Identification of Lagrangian coherent structures. Application to an open cavity flow*	H.C. Kuhlmann, R. Mukin, *Flow topology of a hydrothermal wave*
11:30 – 11:50		Z. Kizner, Stability of point-vortex multipoles	A. Yochelis and M. Sheintuch, *Drifting solitary waves in a reaction-diffusion medium with differential advection*	

Thursday, July 11

Sessions	**Th5 Computational methods** (Chair: H. Dijkstra) **LD 443**	**Th6 Geophysical flows** (Chair: O.M. Umurhan) **LD 450**	**Th7 Miscellaneous topics** (Chair: A. Alexeev) **LD 442**	
12:00 – 12:20	S. Albensoder, H. Kuhlmann, *Primary instability of the lid-driven flow in a cube: a Chebyshev-collocation method with reduced edge singularity*	J. Schröttle, A. Dörnbrack, U. Schumann, *Meandering of a vortex line in shear flow*	S. Ramananarivo, B. Thiria, R. Godoy-Diana, *Dynamics of an elastic filament undulating at a free surface*	
12:20 – 12:40	J.Thies, F. Wubs, W. Song, *Evaluation of HYMLS, LOCA and ANASAZI for bifurcation analysis of flow in a 3D lid driven cube*	N. Harnik, D. Dritschel, E. Heifetz, *On jet sharpening and the equilibration of meridional-asymmetric barotropic instability*	I.A. Mackarov, *Numerical observation of large-scale instabilities in counter flows of viscoelastic fluid*	
12:40 – 13:00	F. Terragni, and J. M. Vega, *Efficient computation of bifurcation diagrams via adaptive ROMs*	T. Tamarin, J. Maddison, L.Zanna, D. Marshall, *Eddy mean flow interaction in idealized flows using a geometric framework to parameterize eddy fluxes*	T. Albrecht, T. Gundrum, F. Stefani, Experimental and numerical study of flow in a precessing cylinder	
13:00 – 13:20		O. Lachmy, N. Harnik, *Flow regimes of the upper tropospheric jet stream*		
13:25 – 13:40	**Introductory talk for BIFD – 2015 (LD 250)**			
13:40 – 14:00	**Closure session (LD 250)**			
14:00 – 15:30	**Lunch (LD 430, 433)**			

Surface tension driven instabilities and bifurcations

Gustav Amberg

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ABSTRACT

Capillarity and dynamic wetting phenomena are increasingly important in microfluidic applications, where very small liquid volumes need to be transported, mixed and analyzed. In many materials processes capillarity, also in the sense of surface tension at a liquid surface, is the driving force. In nature phenomena where wetting and capillarity are crucial abound, for example on the feet of insects on water, liquid repellent surfaces on plants, etc. From a computational point of view there are still important challenges in accurate representation of free interfaces, capillarity, and in particular wetting phenomena.

In this talk, flows where capillarity is a crucial component in determining a flow regime or a bifurcation will be investigated, primarily using numerical simulations. Examples to be discussed include: One capillary dominated bifurcation is the splitting of a droplet suspended in another flowing liquid. If surface tension is strong, the droplet will stay essentially spherical and follow the flow as a solid particle; if it is weak, a diverging flow will extend it until it develops a Rayleigh Plateau instability and separate in two. We have explored numerically the conditions for splitting a droplet at a channel bifurcation, which would be a common question in microfluidics, where droplet creation and handling is a key ability. Dynamic wetting phenomena often also become important. This is nontrivial to describe theoretically or computationally, and fundamental issues regarding the physical processes remain controversial. The modeling needed to obtain accurate prediction of dynamic wetting is touched upon. As an example of a situation when dynamic wetting will determine the overall qualitative features of a flow we study a small solid sphere hitting a liquid surface. Other cases of droplet impact will also be shown.

Bifurcations, synchronisations and chaos inside a two-dimensional differentially heated cavity

L. Oteski, Y. Duguet, L. Pastur, and P. Le Quéré*

We present a new numerical study of the bifurcations inside a two-dimensional differentially heated air-filled cavity with height-to-width aspect ratio two. Adiabatic boundary conditions are considered at the top and bottom wall and the flow obeys the Boussinesq approximation. This study focuses on the transition from steady to chaotic regime as the Rayleigh number Ra is increased. Several oscillatory bifurcations occur until the dynamics becomes multi-periodic and eventually chaotic. We highlight the occurrence of resorption windows, including frequency locking on either periodic (T^1) or toroidal (T^2) dynamics. Simulations were performed using a spectral code developed at LIMSI[1]. This work is funded by the EADS Foundation.

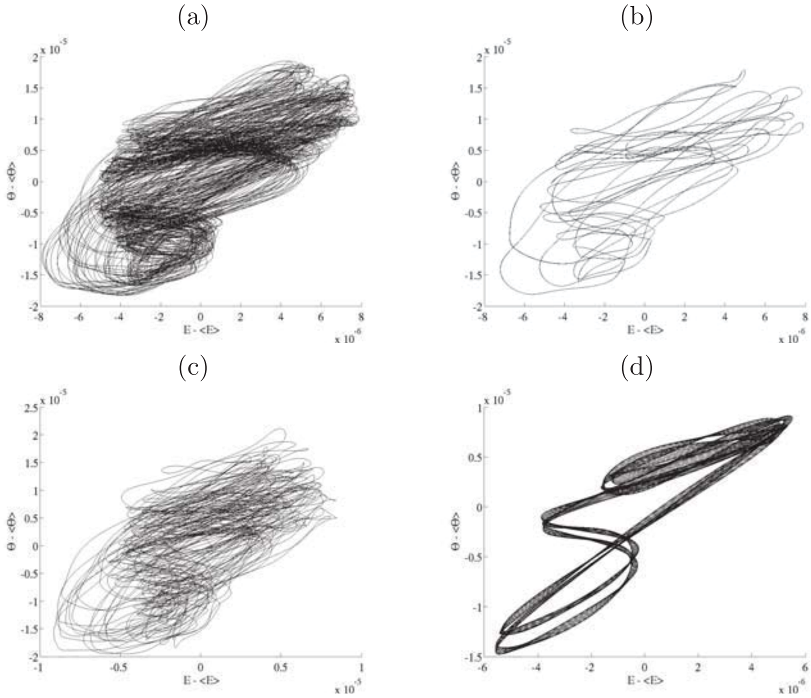

Figure 1: $(\Theta- < \Theta >, E- < E >)$ phase portraits for various values of Ra: (a) 2.6×10^8, (b) 2.631×10^8, (c) 2.7×10^8, (d) 2.907×10^8. Θ is the total thermal energy and E the total kinetic energy.

[1]S. Xin, P. Le Quéré, Numerical Heat Transfer, Part A, 50: 437466, 2006.

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CONVECTION, THERMOCOUPLE MEASUREMENTS AND APPLICATIONS

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Inertial oscillatory influence on a cavity filled with a fluid in the presence of temperature inhomogeneity may induce regular mean flows even when the static gravity is absent. Characteristics of inertial signals can be determined according to the reaction of hydrodynamic system on an external influence by means of thermocouple measurements. To realize the idea of the device for registration of inertial signals only one stable flow has to exist in a cavity for definite conditions excepting the origin of any transitional regimes. Hele-Shaw cell is the example of the same cavity with a simple geometry and effectively controlled flows. In practice convective sensor must be calibrated before operation.

Convective flows in vertical Hele-Shaw cell were investigated by experimental and theoretical methods when the cavity was heated from below and subjected to the influence of arbitrary oriented vibrations. Non-acoustic approximation was applied to calculate averaged convective flows and to analyze the scenarios of transition to chaotic regimes. The stability boundaries for mechanical quasi-equilibrium state, different stationary and time-dependent convective flows were calculated numerically and visualized experimentally. Theoretical investigation was carried out with the help of Galerkin – Kantorovich method using the procedure of the temperature and velocity fields expansions in series. In addition the method of finite differences was applied to verify previous technique. The methods of direct video visualization and thermocouple measurements were used in experiment. The results of theoretical research confirmed experimental data. Asymmetrical variations of non-stationary four vortices regime were found. The order parameter was suggested to describe the measure of flow asymmetry.

Also the influence of short oscillatory inertial signals on convective flows in Hele-Shaw cell was studied theoretically and experimentally. The cavity was heated from below with the help of dotted thermoelement to create in a cavity very sensitive thing convective jet. The temperature and velocity fields were calculated numerically in the case of arbitrary oriented inertial signals.

Numerical modeling has demonstrated the possibility to develop technique that can permit to reconstruct amplitude and direction of external oscillatory signals. The results of research have been used to design the model of sensor which is intended for registration of low-frequency microaccelerations. Working liquid is selected and optimal aspect ratio of the cell sides is found on the base of numerical modeling.

Thermal gas flow instability in micro scale enclosures

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The recent development of micro electro-mechanical systems (MEMS) has led many authors to study heat transfer and thermal effects in rarefied gases. Convective flows appear under rarefied conditions for some specific flow configurations. A classic example is the well-known Rayleigh-Benard convective flow. In this case, the convection is caused by buoyancy forces which occur only in a frame which either has a gravitational field or is accelerating due to a force other than gravity. There are gas flow conditions when the effect of the buoyancy force is week or absent. Particularly, this is true for gas flows in micro/nano-sized domains. Nevertheless under such conditions, convective flows driven only by thermal effects are possible in enclosures and channels with different geometry. Flows induced by temperature fields (for instance the flow created by a non-uniform temperature distribution at the wall) are known for a long time and they are observed especially under rarefied conditions of the gas. Nowadays, these flows are present in many microfluidic applications such as vacuum pumps without moving parts etc.

In this study the thermal driven flow in two and three dimensional enclosures with constant temperature gradient at the vertical walls is investigated for a set of Knudsen numbers and aspect ratios in the whole range of rarefaction using completely diffusive boundary conditions. This flow configuration may have applications in microtechnology for devices which are heated only from one side or also could be applied to satellites which rotate and face a specific source of radiation.

Our aim is to investigate the influence of the governing parameters (Knudsen number, max/min temperature ratio and domain aspect ratio) in order to find the region where the thermal driven flow appears and discover the different pattern formations in this flow. The traditional Direct Simulation Monte Carlo (DSMC) method, proposed by Bird [1] is used for the calculations. It is found that the flow pattern formation is very sensitive to the Knudsen number and the aspect ratio obtaining non-intuitive convective patterns in the opposite direction to that predicted by thermal creep theory.

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VORTEX STRUCTURES IN TRANSITIONAL FREE-CONVECTION BOUNDARY LAYER: NUMERICAL SIMULATION RESULTS

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The turbulent air free-convection boundary layer (BL) along a vertical hot flat plate is a classical example of thermally driven flow and was investigated intensively both experimentally and numerically. Much less attention was paid to transition phenomena in this type of flow despite in many cases the transition region can occupy a considerable part of the vertical surface with a developing boundary layer. Moreover, transitional Rayleigh numbers, based on the distance from the plate edge, differ considerably in various experiments, and the reasons of that remains to be questionable. From the general position, it points to the necessity of research work on the problem of receptivity of the developing free-convection boundary layer to external disturbances of various kinds and scales. As a part of this research work, studies aimed at discovering and classification of "eigen" non-linear modes of disturbances in the BL are of special importance.

Direct Numerical Simulation (DNS) on the base of the 3D unsteady Navier-Stokes equations, supplemented with the energy balance equation, is the most attractive and reliable approach for getting a detailed knowledge on convection. Two approaches were used in the present study: the spatial DNS approach (SDNS) which assumes full modeling of spatial-temporal development of free-convection boundary layer, and the time-developing DNS technique (TDNS) which allows reducing computational efforts significantly due to imposing periodicity conditions in the streamwise direction. The TDNS approach is based on substitution of flow development in space by its temporal evolution, i.e. time plays here a role of coordinate in the main flow direction.

The computations were performed under thermal conditions of one of the most acknowledged experimental investigations (Tsuji&Nagano, 1988) of the air boundary layer developing along a hot isothermal vertical plate. The Boussinesq approximation was applied for incorporation of the buoyancy effects. For TDNS, the computational domain had a form of a parallelepiped of size 0.48×0.24×0.24 m, covered by a grid of 6.4 million cells. In case of SDNS, the domain was a parallelepiped of 1.92×0.24×0.24 m in size, and a grid of 26 million cells was used.

The main aim of the present report is identification and analysis of vortex structures at transitional studies of the boundary layer developing under influence of initial disturbances introduced into the computational domain. Different visualization techniques oriented on creation of static scenes and animation are used to clarify flow features associated with formation and evolution of the vortex structures. A special attention is paid to 3D vortex structures that occur first at the non-linear stage of 2D laminar flow destruction and clearly manifest themselves up to the end stage of laminar-turbulent transition in the layer. These structures visualized in particular with isosurfaces of Q-criterion has a hairpin form, with the "hairpin" head oriented upstream, in contrast to the case of forced-convection boundary layer where hairpin vortices are directed downstream. Effects of the vortex strictures on unsteady local heat transfer are analyzed via superposition of maps created for temperature and heat flux with those for flow kinematics.

The study was supported by the Russian Foundation for Basic Research, grants 11-08-00590 and 11-07-00135.

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TITLE: Bifurcations and dynamics in a convection problem with temperature-dependent viscosity with O(2) symmetry.

We address the numerical study of convection at infinite Prandtl number in fluids in which viscosity strongly depends on temperature in the presence of O(2) symmetry. The study of convection in fluids with temperature-dependent viscosity is of interest because of its importance in engineering and geophysics. For instance in the study of Earth's upper mantle convection, typically viscosity decreases with temperature and viscosity contrasts of several order of magnitude have been considered both in experiments and in theory. In these contexts the dependence of viscosity with temperature is expressed by means of an Arrhenius or an exponential law.

In this presentation we focus on the study of a fluid in which the viscosity changes abruptly in a temperature interval around a temperature of transition. This defines a phase change over a mushy region that expresses for instance the melting of minerals or other components.

We explore the morphology of the plumes for several parameter values of the viscosity law and perform bifurcation studies at several aspect ratios. We report that at intermediate aspect ratio and high Rayleigh numbers traveling waves and chaotic regimes are present, which are greatly influenced by the presence of the symmetry.

Oblique cross-waves in horizontally vibrated containers

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Abstract

The behaviour of vibrated fluids is of great interest in a variety of fields and can be very complex. The simplest and most studied configuration is that of a container of fluid vibrated vertically because the basic (unexcited) state is quiescent in the reference frame of the moving container. Horizontally vibrated fluids are generally less straightforward to treat and have received less attention, especially in the limit in which the vibrating frequency is large compared to that of the fist capillarity-gravity sloshing mode. Horizontal vibrations directly force harmonic waves and, beyond a critical acceleration, can also excite subharmonic cross-waves, which can be analyzed by semi-analytic means in the small viscosity limit. In this limit, the vibrating end-walls produce a (harmonic) oscillatory bulk flow, which is slowly varying in space and extends over a distance comparable to the container depth. It is this oscillatory bulk flow that triggers the cross-waves (as the forcing amplitude exceeds a threshold value) by a mechanism analogous to that responsible for Faraday waves in vertically vibrated containers; the main difference is that the oscillatory pressure field is not uniform but dependent on distance from the end-walls. The resulting cross-waves are not perpendicular to the vibrating end-walls, as standard cross-waves produced by partially immersed wave makers typically are. A linear theory will be presented to calculate the threshold amplitude, which compares well with experimentally measured thresholds. As a result of this, we obtain a general linear amplitude equation that governs pattern selection in containers of arbitrary cross-section.

Thin Film Behavior Under External Vibrations

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We study the dynamics of a thin liquid film on a horizontal substrate. The film is parametrically excited by mechanical vertical and/or horizontal oscillations. Inertia effects are taken into account and the standard thin film formulation is extended by a second equation for the horizontal flow rate

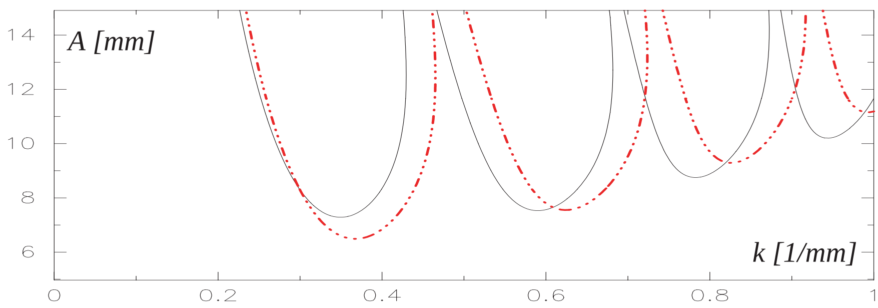
$$\vec{q}(\vec{x},t) = \int_0^{h(\vec{x},t)} \vec{v}(\vec{x},z,t)\,dz \ ,$$

where h is the film thickness, $\vec{v}$ the horizontal velocity components and $\vec{x}=(x,y)$. The set of coupled (2+1)-dimensional PDEs for h and $\vec{q}$ allows for resonances and instabilities of the flat film due to external vibrations. In dimensionless form, they read

$$\begin{aligned} R\left(\partial_t\vec{q} + \nabla\cdot\underline{Q}\right) &= -\frac{3}{h^2}\,\vec{q} + R\,\vec{b}(t)h + h\nabla\left[\Gamma\nabla^2 h - G(1+a(t))h\right] \qquad (1) \\ \partial_t h + \nabla\cdot\vec{q} &= 0 \end{aligned}$$

with Reynolds number R, gravity number G, vertical and horizontal accelerations $a(t), \vec{b}(t)$, surface tension Γ and $Q_{ij} = \frac{6}{5}q_i q_j/h$, all nondimensional.

Linear results based on a damped Mathieu equation as well as fully nonlinear results in the frame of longwave approximation found numerically will be presented. For certain regions in the amplitude-frequency plane we obtain standard Faraday patterns such as oscillating squares. Also hexagons and much more complex spatial and temporal pattern formation are observed.



Faraday instability (vertical oscillations) of a silicone oil with $\nu = 5\cdot10^{-6}\mathrm{m}^2/\mathrm{s}$, $\rho = 920\mathrm{kg}/\mathrm{m}^3$, $\gamma_0 = 0.02\mathrm{N}/\mathrm{m}$, film thickness 0.7 mm and driving frequency 63 Hz. The solid and dashed curves are found by direct numerical solution eqs. (1) and of the Navier-Stokes eqs, respectively. A is the amplitude of excitation, k the wavenumber of the disturbances. The regions of instability are located inside the tongues.

Nonlinear Dynamics of Large-Amplitude Drops on an Axially Oscillating Cylindrical Surface

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Investigation of the nonlinear dynamics of a thin axisymmetric liquid film on a horizontal circular cylinder subjected to harmonic axial oscillation was recently carried out in the isothermal [1], non-isothermal [2] and the double-frequency forcing [3] cases. It was found that it is possible to arrest the capillary long-time film rupture typical to the case of a static cylinder, if the substrate is forced with a sufficiently high amplitude and/or frequency.

In this research, we extend the study to the case where the given initial condition is of a large amplitude relatively to the initial mean film thickness, using methods of long-wave theory [4]. The initial conditions for the numerical investigation are obtained from the unforced case for different long waiting times bringing the film to the configurations *near* rupture. We have found that the critical forcing amplitude above which the emergence of non-ruptured regimes is warranted, increases with an increase in the value of the waiting time. However, for a certain range of the waiting times, the critical amplitude is almost constant and the topology of the emerging droplet may serve as the explanation to this phenomenon.

We have shown that in the regimes where the film rupture is prevented, the minimal film thickness oscillates around a non-zero value and the structure of the film interface represents an attractor reached from various initial conditions when the forcing and geometrical parameters are fixed.

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Direct Numerical Simulation of the Plateau-Rayleigh Instability Developing on an Oscillating Cylinder Covered by a Thin Liquid Film

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Liquid films on cylindrical bodies like wires or fibres disintegrate if their length exceeds a critical measure (Plateau-Rayleigh instability) and create droplets. This phenomenon may cause problems in production processes. In coating processes, for instance, a deformation of the liquid film before solidification has to be avoided. For example, an insulating lacquer layer on a wire should maintain a uniform, predefined thickness until solidification.

Stabilisation of the liquid layer can be achieved by imposing an axial oscillation on the solid core, if a suitable set of forcing parameters (amplitude and frequency) is provided. Haimovich and Oron stated an empiric equation for the minimum excitation amplitude that is necessary to prevent the film from rupture.[1] This correlation is based on the results of numeric simulations with a nonlinear evolution equation which has been derived from the general set of Navier-Stokes equations using methods of long wave theory.

Another approach, used in the present study, to this physical problem is to solve the complete set of axis-symmetric Navier-Stokes equations by way of direct numerical simulation. Although such an approach requires more computational power compared to simplified models, it allows checking critical assumptions such as for instance neglecting the outer gaseous phase in the long wave approach.

For those numerical simulations an open source multiphase solver (interFoam from the CFD Code OpenFOAM®) was modified to further investigate the stabilising effect of an oscillating cylinder. Adaptations to the solver were necessary because the original implementation lacks of a precise calculation of the instability-driving capillary forces. In order to enhance accuracy a height functions based method for the calculation of the interface curvature as well as an additional interface compression have been implemented.

To validate the modified solver, the traditional Plateau-Rayleigh instability of a liquid cylinder was studied. The time-evolution of initial disturbances of finite amplitude and wavelength has been investigated for a specific set of parameters (a case which has also been investigated in Haimovich and Oron[1]). Further, "quasi-steady", periodic solutions which emerge for cases when the oscillations prevent a rupture of the film surface will be shown in dependence of the critical parameters such as the wavelength (i.e. the length of the periodic domain), the diameter of the solid core as well as the amplitude and frequency of the oscillations.

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Averaged description of Marangoni convection in a vertically vibrating liquid layer

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We consider longwave Marangoni convection in a layer of liquid heated from below. Cases of high and low heat conductivity of the substrate are considered. Thus, in the former case the temperature of the solid wall is kept constant, whereas in the latter case the vertical temperature gradient is fixed at the substrate.

The system is subjected to the vertical harmonic vibration. Since microfluidic applications are of primary concern, we assume a layer sufficiently thin, so that the vibration period is comparable to a typical time of the momentum relaxation across the layer. We also assume that the amplitude of the vibration is large in comparison with the layer thickness. Under these conditions, the viscosity cannot be neglected in the description of the oscillatory motion, and the conventional averaging procedure fails. However, the averaged description is still possible because the difference of the vibration period and the typical time of the free surface evolution is large; the latter time is large for the longwave convection. Thus the approach developed in [1] should be applied; to that end all fields are decomposed into mean and oscillatory parts.

In the case of high heat conductivity we deal with the finite values of the Biot number, which characterizes the heat flux from the free surface. The conventional generalized Cahn-Hilliard equation [2 is reproduced with the additive vibration-induced force, which is exactly the same as in the isothermal case [1]. The vibration stabilizes the layer, but does not change the direction of branching. Therefore, the instability leads to a layer rupture.

In the case of low heat conductivity the Biot number is small. This case is more complicated because oscillations of the temperature are also generated due to advection. The resulting set of averaged equations generalizes the one that was obtained in [3]. In particular, within the linear stability problem the vibration only effectively increases the capillary number and therefore, it stabilizes the layer. In particular, the oscillatory mode for heating from below is reproduced. We also study the one-dimensional steady solutions of the amplitude equations.

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"Weakly" localized solutions in a three dimensional boundary layer

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Solutions with a localized character have been found in an Ekman boundary layer. They appear as saddle-node bifurcations and could so far not be linked to any periodic solution or the base flow. As it is not possible to expand the computational box at will and a periodic dependency still seems to exist, we refer to them as "weakly" localized solutions.

The Ekman boundary layer is a three dimensional boundary layer, which occurs in many technical or geophysical configurations under the influence of Coriolis forces. To study this layer, a classical Couette-System in a rotating frame of reference normal to the bounding plates is used. Searching for equilibrium solutions in the fully nonlinear Navier-Stokes-Equations[1], some localized solutions in the system have already been found[2,3], however, not for a distinctive Ekman boundary layer but for a joined layer at lower rotational rates.

Now, in the present work, the distinctive boundary layer was explicitly looked at and indeed, aside from the well-known Type I and Type II solutions[4], some strangely behaving, obviously localized solutions have been found. They appear mainly as counterrotating rolls in pairs or double pairs, with one roll inside the boundary layer and the counterrotating roll outside (see Figure 1). Following the solution path it was not possible to trace the solutions back to either the base flow or periodic solutions. In fact, by following them one ended up in a chaotic series of saddle-node bifurcations, somehow resembling the bifurcation characteristics found by Schmiegel for stationary solutions in the Couette-System[5]. After each turn there is not simply just a roll added or subtracted, like it is the case in the snaking phenomena, but the solutions seem to get more close to the periodic roll solutions and then again dissociate from those solutions.

So far the solutions have not been analyzed in a three dimensional or time dependent manner. Therefore it is not known yet whether the solutions are only streaks or fully developed rolls. Comparing them with solutions in the Couette-System one might conclude the former is true. However, it is not clear why the periodic dependency still persists. Likewise it would be valuable to know whether the solutions are temporarily stable or not.

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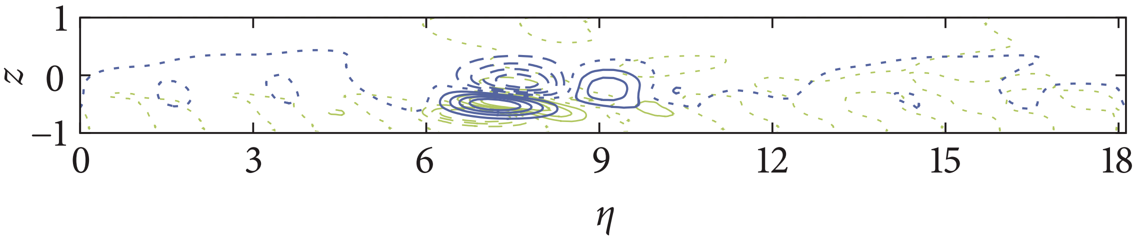

Figure 1: Example of a localized solution. Streamlines (blue) and normal velocities (green), positive (negative) quantities solid (dashed).

Drifting convectons in binary mixtures

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Binary fluid mixtures with a negative separation ratio heated from below exhibit steady spatially localized states called convectons for supercritical Rayleigh numbers. With no-slip, fixed temperature, no-mass flux boundary conditions at the top and bottom stationary odd and even parity convectons fall on a pair of intertwined branches [1, 2] that form the backbone of the snakes-and-ladders structure of the so-called pinning region. These branches are connected by branches of asymmetric localized states that drift. When the boundary condition on the top is changed to Newton's law of cooling the odd parity convectons start to drift and the branch of odd parity convectons breaks up and reconnects with the branches of asymmetric states [3]. We explore the dependence of these changes on the associated Biot number using numerical continuation, and compare and contrast the results with a related study of the Swift-Hohenberg equation by Houghton and Knobloch [4]. We use the results to identify stable drifting convectons and employ direct numerical simulations to study collisions between them. The collisions are highly inelastic, and result in convectons whose length exceeds the sum of the lengths of the colliding convectons.

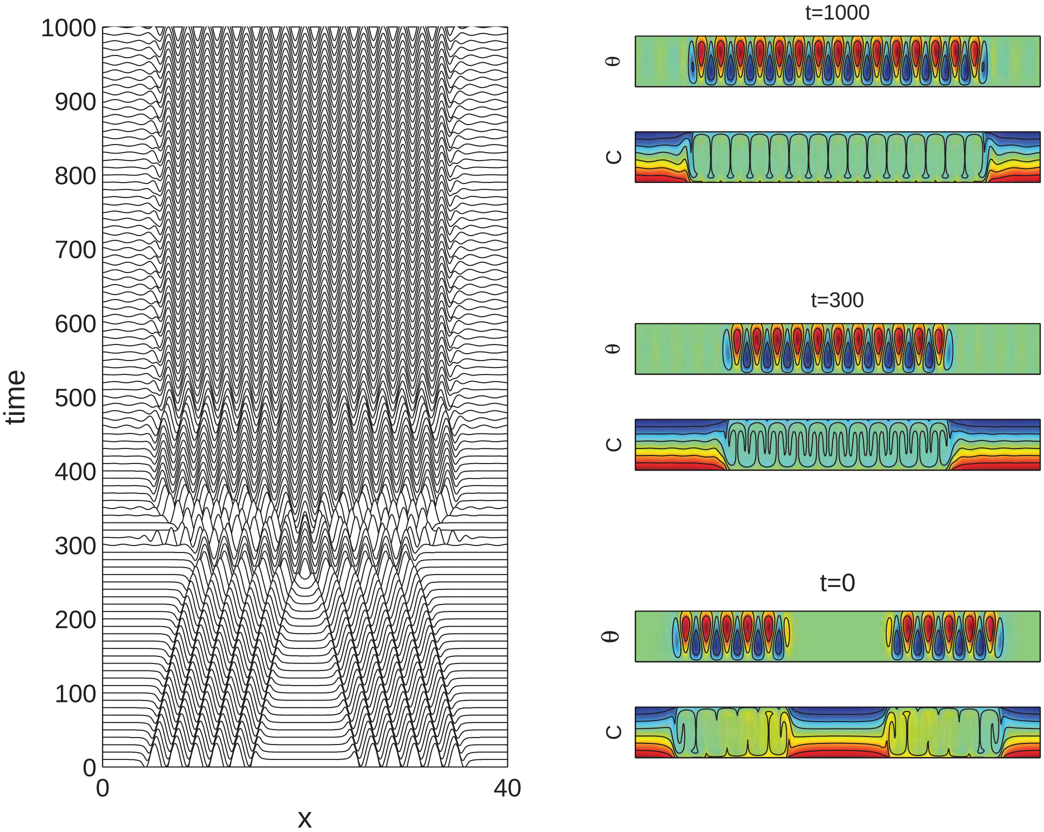

FIG. 1: A symmetrical collision between two identical drifting convectons. The collision radiates waves and results in an even parity stationary convecton whose width exceeds the combined width of the colliding convectons.

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Convection in binary fluid mixtures: collisions of localized structures

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Abstract

Collisions of a localized traveling wave (LTW) structure with a a localized stationary overturning convection (LSOC) structure are investigated. In ethanol-water mixtures with small negative separation ratios both exist bistably in the unstable quiescent surrounding for a range of supercritical heating rates.

The bifurcation properties and the spatiotemporal behavior of colliding localized convective structures in binary fluid mixtures are analyzed in a cross-section perpendicular to the roll axes. Three different scenarios are found with three spatiotemporally different convection properties in the post-collision phase depending on the Rayleigh number.

In scenarios I and II the LSOC absorbs the LTW. Then the LSOC expands into the surrounding quiescent fluid. In scenario I both of its fronts move with a constant, selected front velocity as new stationary overturning convection rolls are generated with constant rates at the moving fronts in the post-collision phase. In scenario II only the LSOC front that is hit by the LTW gets unpinned and moves into the conductive state while the opposing front remains pinned. Thus, the pinned and the moving front solutions of LSOC states are observed in the bistability range of these solutions: before the collision the fronts are pinned and after the collision perturbation one or both LSOC fronts moved.

Scenario III is realized at lower heating rates. There the incident LTW is almost unaffected by the collision. But the LSOC is transformed into a second LTW that has the same selected characteristics as the incident LTW. In the post-collision phase the newly created LTW drifts at short distance ahead of the incident one. Both form a couple that is linked together via fast propagating concentration waves – the trailing LTW emits them and the leading LTW absorbs them.

The mechanisms involved in these scenarios are analyzed and elucidated with the help of finite difference numerical simulations that are carried out subject to realistic boundary conditions.

Multistability in radially forced rotating spherical shell convection

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Convection patterns in a rotating fluid shell subjected to a temperature gradient between the spherical boundaries and a central gravitational field are explored numerically. By keeping the Ekman and Prandl number fixed and varying the Rayleigh number, the stable solution branches are traced systematically while special attention is paid to consecutive bifurcations on the route to chaos.

Convection sets in as rotating waves (RWs) in the form of a spiral pattern drifting in the eastward (prograde) direction with respect to the rotating frame of reference. Further RW branches belonging to higher-wavenumber instabilities of the conductive state are unstable at onset, but become stable for higher Rayleigh numbers, leading to multistability. Eventually, four stable RW branches are established. Although all of the RWs first appear with a prograde drift, their drift velocity decreases with Rayleigh number until they eventually drift in the opposite direction. In addition they show a common scaling of the drift with the Rayleigh number.

At increased Rayleigh number, all the RWs become unstable via Hopf bifurcations, leading to modulated rotating waves (MRWs) as is generic due to the axial symmetry of the problem. We characterize the resulting spatio-temporal symmetries of the MRWs according to the classification by Rand [1]. Before the onset of chaos, some of the MRWs undergo a third Hopf bifurcation, generating stable solutions with three clearly identifiable frequencies. For higher, but still moderate, Rayleigh numbers, multistability is manifested by the coexistence of MRWs, three-frequency solutions and distinctive chaotic attractors.

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Localized periodic orbits in plane Poiseuille flow

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The study of exact solutions of the Navier-Stokes equation has attracted lots of attention within the past two decades. Starting with the discovery of the first exact 3-dimensional solution for plane Couette flow by Nagata [1], many exact solutions were found for various systems. For instance, Gibson et al. [2] studied in detail exact solutions in plane Couette flow, while Faisst et al. [3] and Wedin et al. [4] discovered the first travelling waves for pipe flow. In particular, two types of exact solutions receive special attention. One type are the so called *edge states* [5, 6]. These states have a stable manifold of co-dimension one, which is able to divide the state space. Edge states play an important role in the transition process and the formation of the turbulent attractor [7]. The second important class of exact solutions are the localized ones. To use the tools of dynamical systems theory to explain the dynamics of localized structures such as puffs in pipe flow or turbulent spots in plane Couette or Poiseuille flow, localized exact solutions are necessary [8]. For the case of plane Couette flow Schneider et al. [9, 10] studied spanwise localized solutions and just recently Avlia et al. [11] reported a streamwise localized periodic orbit in pipe flow. Nevertheless, until now there is a lack of fully localized solutions for plane shear flows that could help to understand the formation of turbulent spots. The focus of our research is on plane Poiseuille flow. For this system we investigate the edge state for different domains sized and are able to contribute exact solutions for the two important classes.

For all our simulations the *channelflow*-code [12] is used. We applied the method of edge tracking to the plane Poiseuille system and were able to identify the edge state. In small domains ($L_x = L_z = 2\pi$, $L_y = 2$) the edge state is a simple travelling wave. The travelling wave appears in a saddle-node bifurcation at $Re \approx 459$ and can be continued to Reynolds-numbers far above the critical Reynolds-number. In figure 1a the average flowfield in the YZ-plane perpendicular to the direction of the flow is shown. It is evident that the wave fills the whole domain and is dominated by a strong low-speed streak. Furthermore, it is symmetric to the midplane. For Reynolds-numbers above 510 the wave has only one unstable direction and therefore it is an edge state.

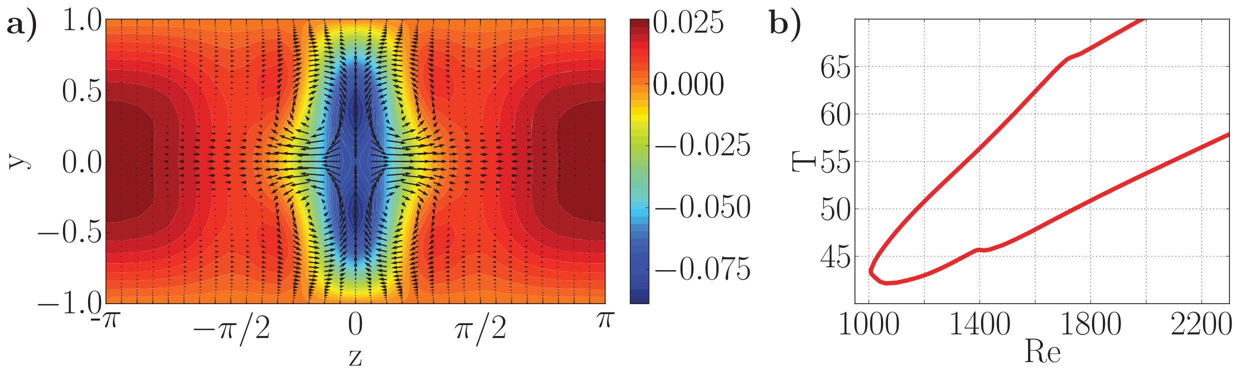

Figure 1: a) Average flowfield in the YZ-plane for the edge state travelling wave that was found in a domain of size $L_x = L_z = 2\pi$ at $Re = 1400$. b) Period of the streamwise localized periodic orbit depending on the Reynolds-number. The size of the domain is $L_x = 32\pi$, $L_z = 2\pi$.

Using appropriate initial guesses for a Newton-method it is possible to find localized versions of the travelling wave in longer boxes. In a domain with extends $L_x = 32\pi$ and $L_z = 2\pi$ a streamwise localized periodic orbit is found. The period of the orbit is of the order of 50 time units, but the state only varies slightly within a period. In figure 1b the period depending on the Reynolds-number is shown for the upper and the lower branch of the solution. As a visualization of the flowfield the streamwise velocity in the midplane at the time of minimal energy-norm is shown in figure 2b. It is obvious that the orbit has a strong low-speed streak which is surrounded by a larger high-speed streak. By a comparison with the flowfield in the midplane of the edge state travelling wave, which is shown in figure 2a, one recognizes some similarities between the two exact solutions. The similarity is even stronger if one compares the flowfield in the YZ-plane of the travelling wave to the flowfield in the core region (close to x=0 in figure 2b) of the periodic orbit. The periodic orbit appears in a saddle-node like bifurcation at $Re \approx 1000$ and can be continued to $Re > 3000$. In wide domains it is possible to obtain periodic orbits that are localized in streamwise and spanwise direction. We will present and discuss the properties of the streamwise localized and the fully localized orbits depending on the Reynolds-number. In particular, the stability and the strength of the localization depending on the Reynolds-number is discussed. For example, it turns out that the localization is strongest for low Reynolds-numbers and that the streamwise length of the localized states increases with the Reynolds-number.

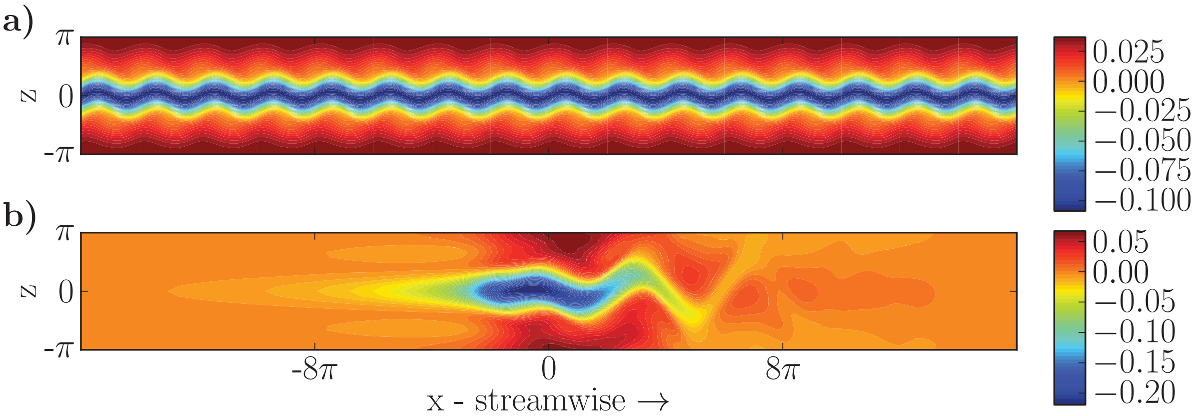

Figure 2: a) Instantaneous streamwise velocity in the midplane for the edge state in the small domain with $L_x = L_z = 2\pi$ (periodic continued). b) Instantaneous streamwise velocity in the midplane for periodic orbit. For both plots the Reynolds-number is 1050.

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Experimental study of open- and closed-loop control of a turbulent mixing layer

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Control of free shear layers is an essential issue when we are dealing with drag or noise reduction. Flow behind a landing gear bay or control surfaces, is characterized by a free shear layer (mixing layer) and its global dynamics. This paper will present the experimental investigation of a mixing layer response to open and closed loop control using fluidic jet actuators. By changing the actuation frequency we are able to significantly change the basic features of the mixing layer, such as the spreading rate. This study is a part of an effort to build a robust experimental facility capable of investigating closed loop control scenarios of a turbulent mixing layer through the use of reduced order models.

The mixing layer is composed of two independent streams generated by the wind tunnel, specifically built for the purpose of this experiment. The two streams meet at the end of a splitter plate, whose trailing edge contains 96 micro-jet nozzles along its span which are used as actuators. Our current experiment is set up for two very different conditions of the mixing layer flow; a low speed mixing layer with $U_1=4.6\ m/s$ and $U_2=1.2 m/s$ and a high speed mixing layer $U_1=9\ m/s$ and $U_2=3\ m/s$. The low speed mixing layer is generated by the detachment of laminar upper and lower boundary layers. Based on the initial sum of the momentum thicknesses of boundary layers, and the convective velocity of, we can estimate an initial Reynolds number of around $Re \approx 500$ for this mixing layer. The natural mixing layer stays laminar a good distance downstream of the origin before beginning its transition to turbulence. By changing the frequency of actuation we can affect the transition point or force an immediate transition to a completely turbulent mixing layer. The high speed mixing layer is generated by detached boundary layers which are already turbulent and the estimated Reynolds number is around $Re \approx 2000$. The primary instability is affected by different actuation frequencies and we can observe phenomenon such as frequency locking or damping of characteristic frequencies. The spreading rate is also affected.

A campaign is in progress with a goal of implementing the control system for closed-loop experiments. Currently, we are capable of sending 96 different output signals, which enables us to actuate with each of the micro jets separately and thus superpose different frequencies of actuation or actuate on the span wise modes. The sensor system comprises a rack of 24 hot wire probes. POD analysis of the velocity signals from the hot wires gives us efficient real-time feedback information necessary for the closure of the control loop.

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The effect of phase and modulation on nonlinear TS wavepackets

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Natural transition involves modulated waves. The work studies the evolution of waves with different levels of streamwise modulation emanating from an otherwise harmonic point source. The hot-wire measurements of the streamwise velocity only were carried at y = $0.6\delta^*$. The experiment reproduced most base flow conditions of Medeiros (JFM, 2004). The measurements covered the whole disturbance in the spanwise direction. Frequencyspanwise wavenumber spectra were also calculated. Previous works showed that subharmonic resonance is active in the nonlinear wavepackets (Cohen et. al, JFM, 1991) and that this activity is very sensitive to the phase of the waves relative to the modulation envelope (Medeiros and Gaster, JFM, 1999). The phase effect, as well as other nonlinear activities in the packet have not yet been explained, namely, the growth of waves with fundamental frequency, high spanwise wavenumber modes (Cohen, PoF, 1994) and the formation of streaks at several spanwise wavenumbers (Yeo et. al. JFM, 2010). The evolution of packets with several degrees of modulation, and phases 0 and π are shown in figure 1. It was here found that these activities were triggered by the spanwise modulation only. The first nonlinear stage was associated with directly forcing via mode-mode nonlinear interaction and produced longitudinal streaks. The spanwise wavenumber predicted by a weakly nonlinear model was in good agreement with experiments. The second nonlinear stage was K-type instability, which produced highly oblique fundamental modes and new streaks. The spanwise wavenumbers predicted by the secondary instability of the dominant two-dimensional wave was in agreement with the experimental results. It was also shown that similar spectral peaks were found for the streamwise modulated signals. Only the third nonlinear regime was subharmonic resonance and was restricted to streamwise modulated signals. The spanwise wavenumbers predicted by the triad resonance model (Craik, JFM, 1971) for the dominant two dimensional wave agreed with experiments. Several phases relative to the envelope were tested. For all streamwise modulated signals the phase had strong effect, but was restricted to the subharmonic regime. A weakly nonlinear model developed by (Craik, JFM, 2001) explains that, owing to streamwise modulation, a direct mode-mode interaction of the linear modes in the wavepacket can produce the seeds for the subharmonic instability. This interaction can be linked to the first nonlinear stage here described. The model yields strong phase dependence. However, it is shown (Medeiros and Gaster, JFM 1999) that the most dangerous phase varies with the wavepacket amplitude, a feature that Craiks model could not explain. Here this model was extended by allowing the production of subharmonic seeds by the direct nonlinear interaction of the K-type modes too. The model predicts that the most dangerous phase changes with the packet amplitude, in qualitative agreement with experiments.

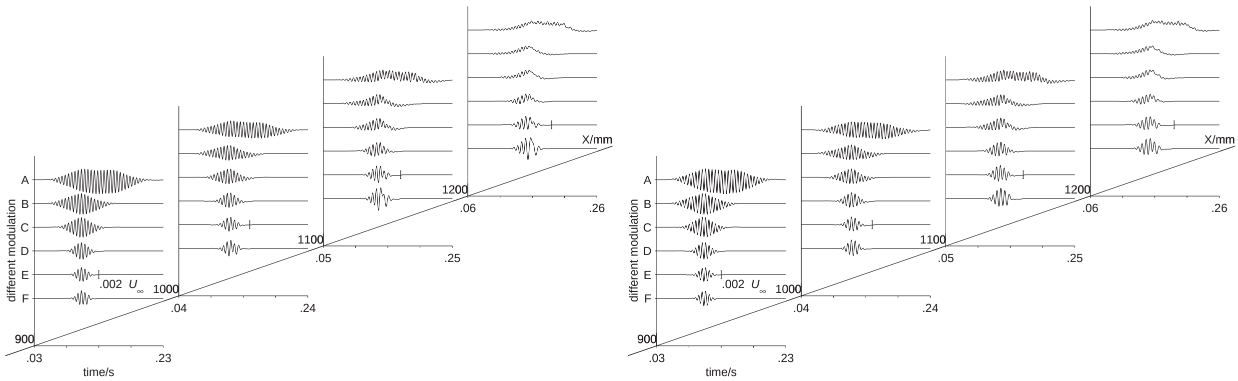

Figure 1: Centerline evolution of wavepackets with different modulation envelopes and with phase 0 and π.

The topology of boundary layer eruption

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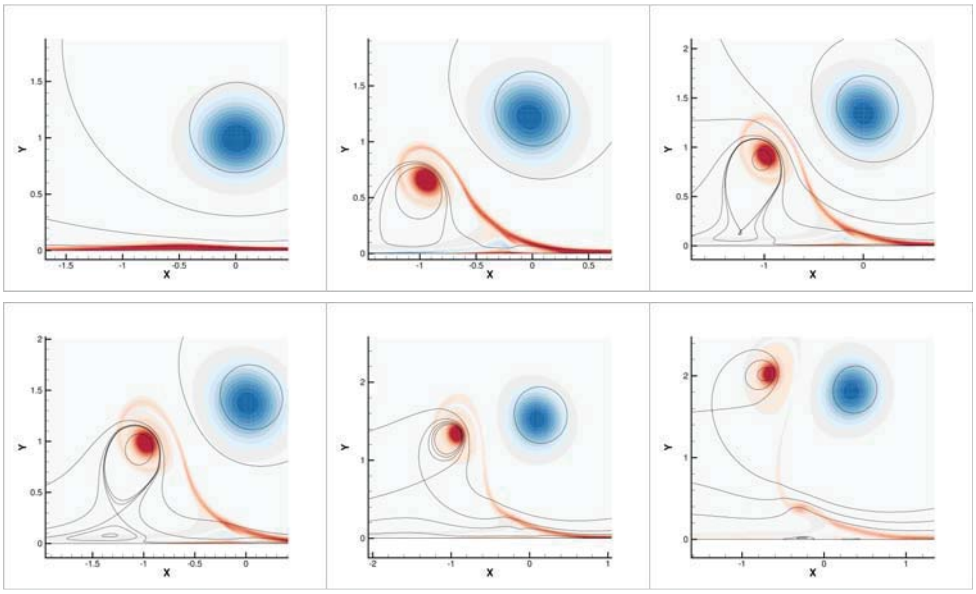
To understand the development of structures in a flow, a topological approach seems to be a very natural one. Topology focuses on qualitative rather than quantitative features, and creation, merging and destruction of structures such as vortices, are naturally interpreted as bifurcations in the topology.

For two-dimensional incompressible flows, two scalar fields present themselves for a topological analysis, the stream function ψ and the vorticity $\omega = -\Delta\psi$. For both quantities local extrema could define the center of a vortex. For ψ, isolines are instantaneous streamlines which are closed around an extremum (a critical point of center type), suggesting a rotating motion of the fluid. In general, however, different structures are identified by the two approaches since ω is Gallileian invariant while ψ is not.

In the present paper we discuss to which extent bifurcations in the stream function topology must be followed by bifurcations in the vorticity. Inspired by Kudela & Malecha (Fluid Dynamics Research 41(2009) 0555502) we consider a specific example, namely the eruption of vorticity from a no-slip wall induced by a concentrated patch of vorticity.



The figures show snapshots of the eruption process at $\mathrm{Re} = 10^4$ in the wall reference system. Vorticity is shown by color and the lines are the instantaneous streamlines. The wall vorticity is organized into a vortex which erupts and is driven away by the main vortex patch. This is accompanied by a sequence of bifurcations of the streamlines: First a recirculation zone attached to the wall is created. Inside this, a saddle and a center form, and in a global topological bifurcation the top center pinches off with the saddle and follows the secondary vortex closely.

In this paper we discuss under which circumstances there is a basic agreement with the structures defined on the basis of the stream function and the vorticity. We show that the bifurcation sequence shown here is to be expected in a codimension-2 bifurcation of the streamlines discussed by Hartnack (Acta Mechanica 136(1999), 55-75). We also discuss the similarities and differences between the two kinds of patterns in the reference frame following the main vortex.

INSTABILITY OF MIXING ZONE FORMED AT THE BOUNDARY BETWEEN THE COUNTER FLOWS OF TWO MISCIBLE LIQUIDS

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The paper presents the results of experimental research into gravitational over-flow of two miscible liquids in a thin channel. The tests were carried out in the 9.0×2.4 cm Hele –Shaw cell of thickness ranging from 0.1 to 0.4 cm. The boundaries of the cavity formed the cell of the Fizeau interferometer, which allowed visualization of the concentration distribution. Highly –purified water and aqueous solutions of alcohols, acids and salts were used as the working liquids. At the beginning of the experiment, a two-layer system with a thin (1-2 mm) transition zone was formed in a cell aligned vertically. Then, the cell was put horizontally on its wide face to observe the flow of the two layers over each other (Fig.1a). It has been found that the velocity of the front propagation depends on the density difference, the layer viscosities and cell thickness. These parameters were used to construct a dimensionless parameter, time dependence of which describes the system behavior by one curve.

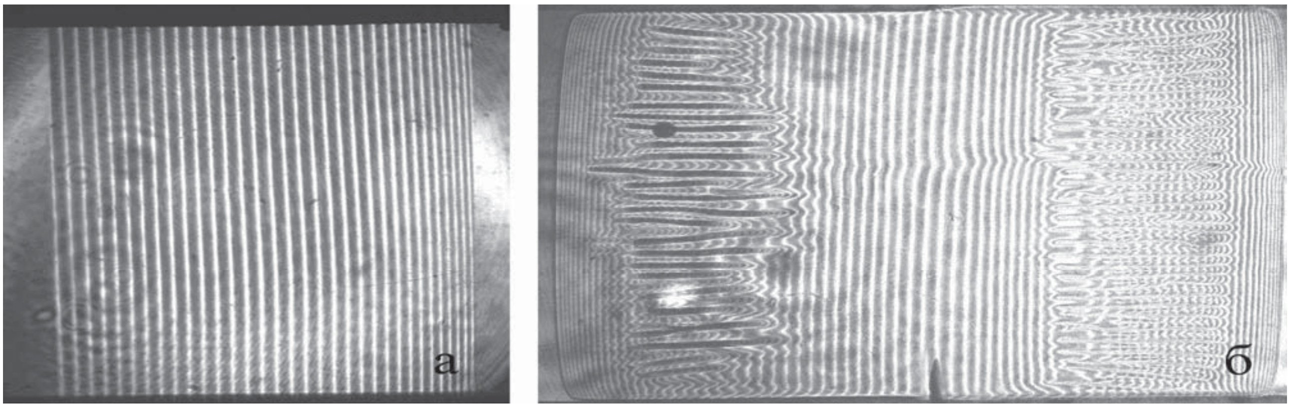

Fig. 1

It has also been found that a two-dimensional motion of two layers becomes unstable at some ratio of the problem parameters. This results in the formation of a secondary flow inside the mixing zone. The secondary flow has the form of convective rolls oriented along the flow (Fig1b). It has been shown that the time of its initiation (counted off from the starting time of the layer motion) and the wave number of the secondary structure essentially depend on the density difference and are independent of the layer viscosity and cell thickness. Moreover, the initiation time strongly depends on the initial thickness of the transition zone. Possible mechanisms responsible for the occurrence of instability observed during the experiments are discussed.

The study was supported by the RFBR (projects № 12-01-00656 and № 13-01-00508), and joint project of SB, UB and FEB of RAS (project № 12-C-1-1006).

Flow instability in pressure-driven flow through wavy channels

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Using computational modeling and numerical analysis we investigated the effects that wavy channel geometry has on the flow, heat transfer, and thermophoretic particle deposition in a parallel plate heat exchanger. In this channel, the upper and lower walls exhibit in-phase sinusoidal variations with equal amplitude, and period. First, we probed the effects of the geometry on the pressure-driven flow through the channel. Using theoretical analysis we determined the effects of the wave amplitude and period on the magnitude of the critical Reynolds number at which the flow changes from steady to oscillatory. The time periodic, oscillatory flow is the result of vortex shedding occurring at the peaks (lower wall) and crests (upper wall) of the channel. The results from our theoretical analysis we validated using our computational lattice Boltzmann method and show that it correctly reproduced the effects of the wavy walls on the flow in the channel. To probe the heat transport and particle deposition in wavy channels, we developed a hybrid computational model that integrates the lattice Boltzmann method for the fluid flow, a finite difference scheme for the temperature distribution, and a Brownian dynamics model for the mass transport. Using this hybrid model we expanded our investigations to study the effects that the unsteady flow channel flow had on the heat transport and thermophoretic deposition of particles onto the channel walls. Specifically we varied the amplitude and period of oscillations in the wall to determine the geometry that minimizes the deposition of particles. Additionally, we probed the effects of the unsteady flow on the local shear stresses occurring along the wall, which could aid in the removal of deposited particles. Results from our study could be useful for designing heat exchangers that are less prone to fouling.

Oscillatory instability of natural convection of air in a laterally heated cubic box

- BIFD 2013 -

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ABSTRACT

While oscillatory instability in two-dimencional cavities is well-studied, there are very few results on instabilities of convective flows in three-dimensional enclosures. The classical benchmark case here is convection of air (*Pr*=0.71) in a laterally heated cubic box having a pair of opposite vertical boundaries kept at constant and different temperatures. The horizontal and two other vertical boundaries can be considered either perfectly conducting or perfectly thermally insulated, thus leading to four different cases. The oscillatory instability in some of these cases were studied experimentally in [1] and numerically in [2-6], however converged and/or experimentally validated critical parameters were never reported. Our recent convergence studies [7] performed for convection in 2D cavities showed that one needs at least 100 grid points in the shortes spatial direction to obtain reliable stability results. Such convergence studies for the corresponding three-dimensional problems were never reported. Clearly, one cannot expect that the convergence of critical parameters of a 3D flow will be better than that of a 2D one.

In the present study we make the first attempt to follow convergence of the critical Grashof numbers and critical frequencies of the appearing osccillations for all the four mentioned configurations and grids having 100^3, 150^3 and 200^3 points. In the course of direct numerical simulations we also reveal multiple oscillatory three-dimensional supercritical states that never were reported before.

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Bifurcations in natural convection inside a tilted cubic cavity

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We have conducted a numerical study on the hydrodynamic instability of natural convection inside a tilted cubic cavity subject to temperature gradients. Previous studies have conducted a thorough three-dimensional instability study inside a cubical cavity heated from below [1,2]. However, in real applications, it is common that the cavity is inclined at certain degrees and, even when the cavity is intended to be placed horizontally, small angles of inclination exist. Therefore, addressing the instability in natural convection inside a tilted cubic cavity is of great importance. In order to achieve this, several studies have focused on tilted cavities [3,4]. Nevertheless, unlike the three-dimensional calculations conducted by Puigjaner et al. [1,2], these studies have been limited to a two-dimensional domain, ignoring the three-dimensional effects [3] or focusing on an infinite cavity [4]. In this study, three-dimensional numerical calculations are conducted for the first time to analyze the instability of a flow inside an inclined cavity. The method is validated by comparing our results with those reported in the literature for a horizontal cavity and a Prandtl number Pr = 0.71 [1]. The method is then applied for an inclined cubic cavity with Pr in the range $0.71 < Pr < 130$. The results show that the symmetries found in the horizontal case are broken, which induces changes in the stability properties of the solutions. We particularly focus on the case Pr = 5.9, for which detailed bifurcation diagrams have been determined at different inclination angles. Moreover, the precise variation of the main bifurcation points (expressed in terms of the critical Rayleigh number) with respect to the inclination angle has been calculated in order to provide a thorough description of the dynamics of the system. In that way, it was found that the rolls with a rotation opposite to the inclination and the semi-diagonal rolls with a component in the direction of the inclination remain stable until a critical angle of 4.68^{o} and 2.27^{o}, respectively. On the other hand, the steady-state rolls with a component in the direction of the inclination are stable for the calculated range.

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EXPERIMENTAL AND NUMERICAL STUDY OF TURBULENT CONVECTION IN BOUNDED VERTICAL LAYERS

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Turbulent Rayleigh-Benard convection in a bounded vertical layer of size $L \times d \times L$ with $d \leq L$ demonstrates a variety of dynamical regimes governing by the aspect ratio $\Gamma = d/L$ as well as by the Rayleigh and the Prandtl numbers [1, 2]. The behavior of large-scale circulation appearing against the background of Rayleigh-Benard turbulent convection in rectangular cavities of various rectangular geometries (from a thin layer to a cubic cell) has been experimentally investigated in [2]. In this work we continue the experimental study of the turbulent convection in rectangular boxes of different aspect ratio, focusing on the characteristics of small-scale turbulence, and we perform DNS, aiming to study the ability of two-dimensional (2D) and quasi-two-dimensional (Q2D) mathematical models for describing the most important characteristic of turbulent Rayleigh-Benard convection in a bounded vertical layer of size $L \times d \times L$. Both mathematical models are based on the Boussinesq equations for free convection of incompressible fluid. In the first case we considered plane 2D flow in the square domain (2D model). In the second case we considered flow in the thin vertical layer ($d << L$) using the linear friction model (Q2D model). This model uses modified 2D equations, which derived from Navier-Stokes equations in assumption of laminar transverse velocity profile. Equations were solved numerically by a high performance multiprocessor system using the finite volume method. The calculation grid was 512×512 nodes.

Furthermore, experimental investigation into the convective flow of water in a rectangular box heated from below with dimensions $250 \times d \times 250 \text{ mm}^3$ (d varied from 15 to 50 mm) was carried out. The experimental setup is a cubic cell with the side $L = 250$ mm whose horizontal walls are massive copper heat exchangers and vertical walls are made of 25 mm thick plexiglas. Two opposite walls of the cell are equipped with a system of vertical slots in which plexiglas partitions are mounted, which separate a rectangular region with the thickness d in the central part of the cube. The experiments were performed with $d = 15$, 24, and 50 mm. The cube was completely filled by distilled water and the motion of water in the central cross section of the inner cell was investigated using particle image velocimetry (PIV).

Direct numerical simulations (DNS) mainly performed for Rayleigh number $\mathrm{Ra} = 2.2 \cdot 10^9$ and Prandtl number $\mathrm{Pr} = 7$ (it corresponds to average water temperature $25°C$ and temperature difference between heat exchangers $\theta = 10°C$).

Detailed comparison between numerical and experimental results show that, even in the framework of a crude model of linear friction used in the Q2D model, consideration of friction on lateral boundaries allows us to get a realistic structure of the turbulent flow with the aspect ratio $\Gamma \leq 0.1$ (where aspect ratio $\Gamma = d/L$ characterizes layer thickness). In addition, the Q2D model correctly describes the dynamics of the large-scale flow and reproduces the experimental power spectral density of velocity fluctuations. Meanwhile 2D results reveal poor correlation with the real structure of fluid flow in the domain for any aspect ratio.

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Modeling of the convective fluid flows in the two layer systems with evaporation at interface on the basis of the exact solutions

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Study of the convective flows with interfaces presupposes consideration of the various effects in the fluid and gas media. Interaction of the thermal gravitational and thermocapillary convection and arising interface phenomena is studied analytically and numerically very intensively in the last years (Nepomnyaschy et al. 2012, Andreev et al. 2012). In the papers devoted to construction of the exact solutions, which describe the fluid flows with interfaces, modeling of the flows is carried out without consideration of a mass transfer at interface, as usual. The stationary convective flows in a horizontal two layer system with evaporation have been investigated analytically in (Shliomis and Yakushin 1972) on the basis of the Birikh type solution (Birikh 1966).

We study the dynamics and heat- and mass transfer processes in a two layer system of the fluids with a thermocapillary interface in the full problem statement. The lower layer is filled with a fluid that can evaporate at interface into the gas-vapor phase. The stationary flows are described by the Boussinesq approximation of the Navier-Stokes equations including the Dufour effect in the gas phase. The no-slip conditions and linear temperature distributions are prescribed on the fixed impermeable walls of the system. The kinematic and dynamic conditions, condition of heat transfer and mass balance equation are fulfilled at interface. The additional conditions of a given specific gas flow rate, of continuity of the velocity and temperature at interface and an expression for saturated vapor concentration are assumed to be fulfilled.

The two-dimensional solutions are characterized by a linear dependence of the temperature and of the vapor concentration in the upper gas phase on the longitudinal coordinate. Only the longitudinal components of velocity are not equal to zero and depend on the transverse coordinate. The results (velocity profiles, temperature distributions and vapor concentration) are presented under conditions of normal gravity and microgravity. They allow to compare the processes in the two layer systems for the different variants of the conditions for vapor concentration on the upper fixed boundary. In the first case we suppose that the vapor flux is equal to zero on the upper boundary. The second case is based on an assumption that the vapor in the gas layer is condensed and absorbed on this boundary. Although the closed flow requirement for the fluid is not set explicitly a parameter relation has been found when this condition is fulfilled.

The paper presents the flow pictures for the "fluid-gas" system like "benzin-air" and "ethanol-nitrogen".

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Bifurcations in penetrative convection in plane layer

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Here we present some results which are the contunuation of the study of penetrative convection due to nonmonotonic density variation [1]. Fluid with quadratic dependance of density on temperature (water at about 4 degree) is confined to a plane layer. Sequences of bifurcations and variety of steady and unsteady convective modes are described. We have included now two parameter vatriation: Rayleigh number and position of density maximum in the conductive state. More general boudary conditions are concidered which allow to address interaction with mean horizontal flow. For numetrical investigation pseuspectral technics are used.

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The influence of heating conditions on the instabilities in an evaporating liquid layer with insoluble surfactant

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The stability of a horizontally infinite layer of incompressible Newtonian liquid, heated from below, with insoluble surfactant on the deformable surface, is considered. On the upper free interface both cooling processes due to conduction and evaporation occur. The heat transfer process related to the conduction is governed by the regular Newton's law (heat flux is proportional to the difference between the temperature on the surface of the layer and the temperature of the ambient gas). The evaporation is described by a 2D one-sided model, the corresponding cooling is proportional to the mass flux through the interface and the latent vaporization heat. Both processes influence the instability regimes. We consider two different cases of the layer heating. The first one corresponds to the heated rigid bottom plane with fixed temperature, another one relates to the case when the heating is subjected to a transverse temperature gradient. In both heating conditions we suppose that the insoluble surfactant adsorbed at the surface hinders the evaporation.

Using the long-wave approximation and assumption of slow time evolution the system of nonlinear equations is obtained. This system describes the spatiotemporal behavior of the layer interface and the field of the surfactant concentration. The equations retain all relevant physical effects which take place in the system. The stability analysis of the base state solution in framework of the frozen approximation is performed. The cases of quasi-equilibrium evaporation (when the interfacial temperature equals the saturation one) and non-equilibrium evaporation are considered.

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Steady longwave Marangoni convection in a layer of a binary liquid heated from above

S. Shklyaev, A. A. Nepomnyashchy

The study of Marangoni convection in a layer atop a substrate of low heat conductivity was initiated by the seminal work by Pearson [1]. It was shown that the critical wavenumber was determined by the Biot number characterizing the heat losses from the free surface. In the limit of small Biot number, the critical wavenumber is proportional to the fourth root of the Biot number. For a layer of a binary mixture with the Soret effect there appears a competition of that "conventional" mode and a novel mode with the wavenumber proportional to the square root of the Biot number [2]. The latter mode is critical for heating from above and negative but not too small values of the Soret number.

This mode demonstrates an intriguing property: an additional dissipative mechanism, a heat transfer from the free surface, results in a layer destabilization. In fact, this feature can be easily explained. Indeed, for heating from above the solutocapillary effect plays a destabilizing role, whereas the thermocapillary one is stabilizing. The heat losses from the free surface diminish the stabilizing temperature gradient and therefore amplify the solutocapillary flow.

The present work aims at the nonlinear analysis for the novel mode. To that end we derive an amplitude equation which governs the nonlinear dynamics of finite-amplitude longwave perturbations. We find that the concentration perturbation is of order unity, whereas the temperature disturbance is small. The velocity of convective motion is small which is inherent to longwave convective flows. Although the derivation has much in common with the standard analysis for the Pearson's mode [3], the final amplitude equation is completely different. Instead of getting a local partial differential equation, we have shown that the nonlinear dynamics is governed by a solvability condition for a certain linear nonhomogeneous problem, i.e., by a nonlocal problem. The situation is similar to that found for a longwave oscillatory mode [4], but for the steady flow the analysis is considerably simpler.

Representing the perturbation of the solute concentration as a superposition of several rolls, we derive a set of Landau equations governing the amplitudes of these rolls. It is shown that Rolls are unstable on both square and hexagonal lattices. On the contrary, both Squares and Hexagons are stable on their own lattices and as well as on a superlattice. Thus, multistability occurs with the selected pattern depending on the initial conditions.

The work is partially supported by RFBR (grant N 13-01-00273).

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Longwave convection in a binary liquid layer with modulated heat flux at the bottom

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We consider a layer of a binary liquid placed on a substrate of low heat conductivity. The heat flux at the substrate is modulated with a low frequency. An oscillatory distribution of the solute concentration is generated due to the Soret effect in such a way that the mass flux at the boundaries vanishes. The upper boundary is nondeformable, and its surface tension is linear in both temperature and solute concentration. The linear stability of the quiescent state with respect to longwave and shortwave perturbations has been studied in [1]. In particular, for negative values of both the Soret and Marangoni numbers the longwave synchronous mode is shown to be critical. The present work is devoted to the nonlinear analysis of this mode.

To that end two time scales are introduced, which describe the oscillations (the fast time scale) and the averaged dynamics (the slow time scale). We derive an amplitude equation which governs the averaged nonlinear behavior of the system. This equation has the same form as that obtained by Shtilman and Sivashinsky for the Marangoni convection in a pure liquid [2]. Moreover, the coefficients coincide with those calculated for a steady convection in a binary mixture with a constant heat flux [3]. The only difference is in the linear term with the fourth-order spatial derivatives, where a modulation-induced correction appears. This term changes the critical wavenumber and, therefore, can change the pattern selection as well.

The calculations show that patterns on a square lattice branch via the inverse pitchfork bifurcation within the domain of parameters where this mode is critical. The same conclusion is valid in the absence of modulations, although this result has not been reported in [3]. On the hexagonal lattice up-hexagons emerge subcritically, the transition between up- and down- hexagons is possible only at extremely small Prandtl numbers.

Numerical simulations within a one-dimensional reduction of the amplitude equation demonstrate that in spite of the subcritical bifurcation the amplitude of convection remains finite; the system arrives at the stable steady convective regime. Multistability is found and studied thoroughly.

The work is partially supported by RFBR (grant RFBR-Ural, N 13-01-96010).

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Nonlinear dynamics of long-wave Marangoni convection in a 2D layer of binary liquid

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The dynamics of the Marangoni convection in liquid layers is rich and complex. However, its analysis can be greatly simplified in the case of long-wave convection: using the large disparity between the horizontal and vertical scales of the flow, it is possible to derive nonlinear evolution equations describing large-scale dynamics of the system [1]. This approach was recently used to develop a weakly nonlinear theory of the Marangoni convection in a heated binary-liquid layer with a deformable interface in the presence of the Soret effect [2–4]. In the present work, we employ numerical methods to study the nonlinear dynamics of this system away from the instability threshold. We adopt the evolution equations describing the oscillatory mode of instability derived in [3] and solve these equations numerically in the case of a 2D flow and periodic boundary conditions.

In our numerical investigation, we employ both the Newton-Kantorovich method and the method of lines to cross-check the obtained results. The results are then analyzed by means of Fourier transform and phase plane portraits. Our numerical solution compares favourably with the analytical results from [3].

Away from the instability thresholds, we find a rich variety of patterns and study transitions between them. In a sufficiently large computational domain, we observe multistability of waves chaotic in time and spatially replicated periodic and quasiperiodic solutions. For sufficiently high values of the Marangoni number, we also observe a breakdown of the model equations which can be attributed to the presence of unbalanced backward diffusion terms.

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Long wave theory for experimental devices with compressed/expanded surfactant monolayers

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Abstract

Surfactant monolayers are of interest in a variety of phenomena, including thin film dynamics and the formation and dynamics of foams. Measurement of surface properties has received a continuous attention and requires good theoretical models to extract the relevant physicochemical information from experimental data. A common experimental set up consists in a shallow liquid layer whose free surface is slowly compressed/expanded in periodic fashion by moving two slightly immersed solid barriers, which varies the free surface area and thus the surfactant concentration. The simplest theory ignores the fluid dynamics in the bulk fluid, assuming spatially uniform surfactant concentration, which requires quite small forcing frequencies and provides reversible dynamics in the compression/expansion cycles. Sometimes, it is not clear whether departure from reversibility is due to non-equilibrium effects or to the ignored fluid dynamics. Here we present a long wave theory that takes the fluid dynamics and the symmetries of the problem into account. In particular, the validity of the spatially-uniform-surfactant-concentration assumption is established and a nonlinear diffusion equation is derived. This allows for calculating spatially nonuniform monolayer dynamics and uncovering the physical mechanisms involved in the surfactant behavior. Also, this analysis can be considered a good means for extracting more relevant information from each experimental run.

The Nature of Branching in Miscible Displacment

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Miscible displacement in a bounded fluid layer introduces instabilities due to viscosity variation in the layer and due to viscosity difference across the surfaces separating the layer from surrounding fluid. We find that the problem in the layer itself is similar in many ways to the Bénard problem with the neutral curve exhibiting the characteristic dip leading to the possibility of many flow cells at the critical speed of displacement.

The viscosity difference across the surface modifies the dip, slightly at large surface tensions, completely at low surface tensions. The effect of the surface deflection is present whether or not the surface is stable and can be omitted only if the viscosity of the driving fluid is very high or the surface tension is very low.

The nature of the branching at the critical speed depends on the cross section of the fluid layer and on how much of the dip in the neutral curve remains.

The role of respiratory flow asynchrony on convective mixing in the pulmonary acinus

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The deep regions of the lungs, characterised by the presence of dense micron-scale alveolated airways, are known to give rise to quasi-steady low-Reynolds-number flows that are inherently complex. Indeed, respiratory microflows result from the underlying coupling that exists between recirculating alveolar flows (i.e., cavity flows) and cyclic breathing leading to wall boundary motions. Together these mechanisms yield irreversible convective mixing and dispersion despite creeping flow characteristics. The properties of chaotic mixing in the pulmonary acinus are critical in understanding, and eventually predicting, the fate of inhaled aerosols. In particular, fine submicron-sized particles are largely acknowledged to follow convective respiratory flows while relying little on intrinsic motion (e.g., sedimentation or diffusion). One perturbation mechanism that has received comparatively less attention in quantifying irreversible mixing lies in the temporal and spatial asynchrony exhibited in acinar wall motion; this latter phenomenon results from a small yet significant amount of geometric hysteresis observed during normal lung expansion (and contraction).

In the present work, we attempt to shed some light on the role of flow asynchrony in enhancing convective dispersion in the acinar regions of the lungs and assess its importance for aerosol transport. Numerical simulations (OpenFOAM) are conducted for generic models of alveolated airways under physiological breathing conditions where we investigate systematically the influence of spatial and temporal asynchrony in alveolar wall displacements on resulting aerosol trajectories. Here, we compare enhanced mixing phenomena under asynchronous breathing motions to synchronous breathing patterns. For such studies, we track Lagrangian passive tracers and extract statistics relating dispersion, including mean-square displacements (MSDs). In particular, to quantify the process more macroscopically across lung acini we evaluate effective diffusion coefficients and compare the role of irreversible convective dispersion against sedimentation and diffusion processes, using characteristic length and time scales. These efforts are helpful in evaluating the influence of asynchronous breathing perturbations in transporting inhaled fine aerosols in the acinus.

Bio-inspired flapping wings: forewing-hindwing phase-lag effect

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ABSTRACT

In cruising forward flapping flight at constant speed, the thrust generated by the up and down motion of the wings is balanced by the net drag on the flyer and the average wake of the self-propelled flyer is thus momentumless. Recent work in our group has made use of an experimental device in such a configuration, a self-propelled model mounted on a ”merry-go-round”, to investigate the effect of wing compliance on the propulsive efficiency of flapping flyers. We have shown that passive mechanisms associated to wing flexibility govern the flying performance of flapping wing flyers (Thiria & Godoy-Diana, *Phys. Rev. E* 2010; Ramananarivo et al. *PNAS* 2011). These determine for instance that the elastic nature of the wings can lead not only to a substantial reduction of the consumed power, but also to an increment of the propulsive force.

Here we use the same setup to address the problem of flyers with two pairs of wings, which introduces a new parameter: in addition to the flapping frequency and wing flexibility, the thrust production is now also determined by the phase lag between the forewings and the hindwings. We study thus a four-winged flapping flyer (see figure 1) with chord-wise flexible wings. For a given physical configuration of the flyer (i.e. fixed distance between the forewing and hind wing pairs and fixed wing flexibility), we explore the kinematic parameter space constituted by the flapping frequency and the forewing-hind wing phase lag. Net thrust force, cruising speed in a self-propelled configuration and consumed electric power measurements were performed for each point in the (f, φ) parameter space. These results are analyzed in parallel with two-dimensional velocity field measurements obtained by time-resolved particle image velocimetry around a forewing-hind wing pair.

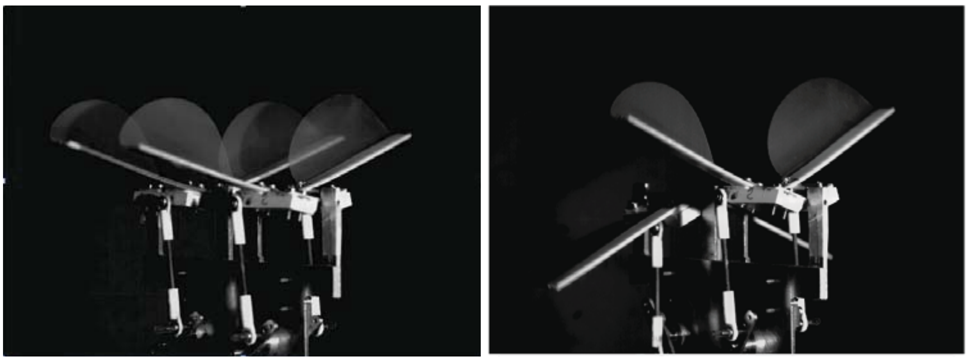

Figure 1: Left: Phase lag 0, Right: Phase lag π

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The Modelling of the Helical Blood Flows in Aorta

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The first observations of the swirling blood flows in the large vessels have been reported at the end of last century. The arising of the swirl may be caused by the helical structure of the walls of the left ventricle. It is well-known that the helical structure of the walls leads to the long helical waves. There is a possibility that the blood flow in the left ventricle becomes unstable, and this instability leads to the bifurcation of rotation.

In this communication we present a mathematical model for the helical flows in the ascending aorta. We assume that the helical waves are imposed by the swirl inflow from the left ventricle. We consider the aorta a circular cylinder confined within thin elastic shell. We construct the model with the use of the the Navier-Stokes equations and the dynamical equations of thin shell. We apply the model to the finding of long and short waves and quasisteady modes.

The long pulse waves in aorta are well-known and studied extensively since the end 19-th century. There is a steady blood flow as well. We consider the Poiseuille flow as a model this steady flow. We present the long wave asymptotic for helical waves. We show that such waves concentrate themselves in the boundary layers near the walls of the vessels and depend on the walls elacticity.

The experimental studies have discovered thin boundary layers on the walls of the aorta and left ventricle. We present short wave asymptotic for helical waves in aorta based on the boundary layer approximation. In contrast with the long waves, the helical ones fill all the cross-section of the vessel. The transport of the shortwaves strictly involves the steady flow. The asymptotic and numerical solutions shows that the short waves are partly concentrated in the critical layer. In addition, we find quasisteady modes which are independent of time within the principal approximation. Among them the first one does not change the direction of the rotation.

We show that the blood flow is able to transport the short helical waves along ascending aorta to relatively small distances of order a few santimeters. The dsitances depend on the speed of the steady flow. The helical waves decay by the end of the systole. During the systole, the flow may have qualitatively different swirls. In particular, a unidirectional rotation of blood is possible. As well, the rotation can change its direction during some time interval which is small relative to the systole duration and which can localize itself nearby each time moment of the during the systole. The obtained results are in a good agreement with the experiments. Finally, we note that the long wave dominate over the short one in the boundary layers near the walls.

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Dynamic Mode Decomposition of Fontan Hemodynamics in an Idealized Total Cavopulmonary Connection

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Univentricular congenital heart disease typically requires a series of three open-heart surgeries within the first few years of life to establish what is called the Fontan circulation, the basis of which is the Total Cavopulmonary Connection or TCPC. This blood vessel configuration involves a direct connection between the superior and inferior vena cavae with the left and right pulmonary arteries forming a T-junction. The TCPC flow field is nominally steady but involves two confined impinging jets with confined outlets and is highly unstable. Minimizing frictional pressure losses across the TCPC junction has formed the basis of several passive (geometric) and active (mechanical pump) proposed enhancements. A fundamental understanding of the dynamics of the instability and its relation to coherent vortical structures is the goal of this study. In particular, both quantitative and qualitative comparisons between measured PIV data and predicted LES results for the same idealized TCPC are presented with a focus on Dynamic Mode Decomposition (DMD) analysis. DMD is a modal decomposition technique that takes instantaneous data sets and produces modal growth rates and frequencies associated with the underlying flow. Comparisons between numerical predictions and experimental measurements are presented for both mean flow and main decomposed modes. The DMD results are used to better understand the underlying flow physics associated with the TCPC geometry.

Migration of adhesive glioma cells: front propagation and fingering

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Abstract

We investigate migration of glioma cells on a substrate as a front propagation phenomenon both theoretically (by using both discrete lattice modeling and a continuum approach) and experimentally. For small effective strength of cell-cell adhesion q, the continuum reaction-diffusion equation can be derived from the underlying stochastic lattice model. The dependence of the front velocity on the effective strength of cell-cell adhesion q is examined. When q exceeds a critical threshold, a fingering-like front propagation is observed. We suggest that this fingering occurs due to cluster formation in the invasive zone and subsequent coalescence of the main front with these clusters. We performed an additional experiment on cell migration. A detailed comparison with experimental observations showed that the theory correctly predicts the maximal migration distance but underestimates the migration of the main mass of cells.

BIFURCATIONS AND INSTABILITIES IN FLUID DYNAMICS
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SIMULATION OF THE TAYLER INSTABILITY IN LIQUID METALS

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INTRODUCTION

A well-known paradigm for the occurrence of current driven instabilities is the z-pinch, a cylindrical plasma column with an electrical current in the direction of the cylinder axis that produces an azimuthal magnetic field $B_\varphi(r)$. For the kink-type ($m = 1$) instability in an ideal, incompressible plasma the relevant criterion is $\partial(rB_\varphi^2(r))/\partial r > 0$. The term *Tayler instability* (TI) had originally been coined to describe a situation in which the azimuthal magnetic field becomes strong enough to act against the stabilizing effect of density stratification in a star. Such an instability could provide the second ingredient, in addition to differential rotation, for an alternative type of stellar dynamos, which is called now *Tayler-Spruit dynamo*.

Going over from plasmas to liquid metals, it is also necessary to consider the stabilizing effect of viscosity and resistivity. In this case, the relevant dimensionless parameter turns out to be the Hartmann number, $Ha = B_\varphi R(\sigma/\rho\nu)^{1/2}$, which must exceed a value of approximately 20 for the TI to set in. With typical viscosities and conductivities of liquid metals the corresponding critical current is in the order of 10^3 A. Using the eutectic alloy GaInSn, we had experimentally confirmed the onset of TI at a critical current of approximately 3 kA [1].

The TI is considered very important for liquid metal batteries, i.e. batteries with a fully liquid inventory, forming a stable density stratification of electrodes and electrolyte. Here, the TI might lead to a violent mixing of the liquid layers, short circuiting and destruction of the device, hence it sets a limit to the maximal current or size of such batteries [2].

NUMERICAL METHOD AND RESULTS

The mathematical description of the TI relies on the momentum and continuity equation and on Maxwell's equations. The classical approach, i.e. solving the Navier-Stokes and the induction equation, works usually only for values of the magnetic Prandtl number $Pm = \mu_0\sigma\nu$ of down to 10^{-2}, which is 3 or 4 orders of magnitudes larger then for real liquid metals. We circumvent this Pm-limitation by replacing the solution of the induction equation by the quasistatic approximation, i.e., we compute the electrostatic potential by a Poisson equation and then the current density and magnetic field by Biot-Savart's law.

With this integro-differential approach we carry out 3D simulations of the the TI in incompressible, viscous and resistive fluids at realistic Pm. The crucial value for determining the time step for our solver is not the ordinary Courant number, but a modified Courant number based on the Alfvén velocity. Several techniques are applied to make the expensive calculation of Biot-Savart's law faster: the Alfvén Courant number is varied, b is not re-calculated at every time step, and may also be determined on a coarser grid.

The measured growth rates in the liquid metal TI experiment [1] are nicely confirmed by our simulations, the obtained spatial wave length matches those calculated by linear stability theory [3]. Moreover, chiral symmetry breaking is observed, and the dependence of critical currents for onset of the TI on the aspect ratio is analyzed in detail.

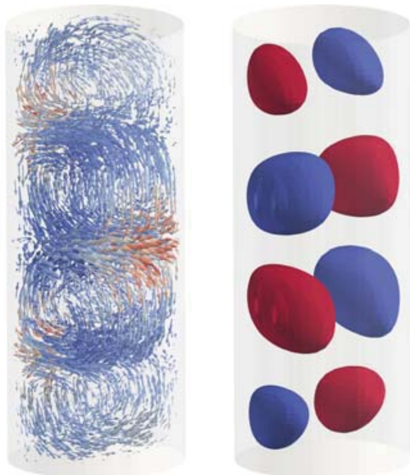

Figure 1: Computed velocity field and isosurface plot of the magnetic field perturbation b_z arising from the Tayler instability in a liquid metal.

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Transient Taylor-Görtler vortex flow in a spinning liquid metal

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This paper is concerned with a liquid metal flow driven by a rotating magnetic field inside a stationary cylinder. We focus on the secondary flow in the r-z-plane during the spin-up from rest. A cylinder of the GaInSn eutectic alloy with a height of 120 mm and a diameter of 60 mm is exposed to a low-frequency rotating magnetic field. The fluid velocities are measured non-intrusively using the ultrasound Doppler velocimetry (UDV). UDV delivers spatio-temporal information of the velocity field and is ideally suited for studying transitional flows. The measurements of the transient flow are compared with predictions from direct numerical simulations.

Instabilities in the form of Taylor–Görtler vortices have been observed just above the instability threshold ($Ta > 1.5*Ta^{cr}$). They evolve from local spots near midplane that quickly spread around the whole circumference of the cylinder to form closed rings. Subsequently, the central TG-vortex ring is advected by the secondary flow towards the top or bottom of the container. In some cases, the central vortex pair is observed to remain stable at half height of the vessel for a long time. The rotational symmetry may survive over a long time even if a first Taylor–Görtler vortex pair has been formed as closed rings along the cylinder perimeter. The transition to a three dimensional flow in the side layers results from the precession and splitting of the Taylor–Görtler vortex rings facilitated by advection in the side layer. The predictable behaviour of the Taylor–Görtler vortices disappears with increasing magnetic field strength. The numerical simulations agree very well with the flow measurements.

MAGNETIC FIELD AND TURBULENCE IMPACT ON THE FLOW STABILITY IN A ROTATING MAGNETIC FIELD

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Small velocity and pressure disturbances in a melt contained in a vessel of circular cross-section are sought in the form of waves travelling along *z*-axis. In a cylindrical coordinates r, φ, z, a system of dimensionless equations for small disturbances *u*, *v*, *w* has the form

$$(\sigma + N_\omega + \lambda^*)u - \frac{2V_0 v}{r} = -\frac{\partial q}{\partial r},$$
$$(\sigma + N_\omega + \lambda^*)v + D_* V_0 u = 0,$$
$$(\sigma + 2N_\omega + \lambda^*)w = iaq,$$
$$D_* u + \frac{\partial w}{\partial z} = 0,$$

where

$$V_0 = \frac{Ha^2}{\beta^2}\left[r - \frac{I_1(\beta r)}{I_1(\beta)}\right],\ \beta^2 = \lambda + Ha^2,\ \lambda = \frac{C_\varepsilon \operatorname{Re}_\omega^{-\varepsilon} V_0^{1-\varepsilon}}{\delta_z},\ C_\varepsilon = C_0 e^{a\varepsilon},\ \delta_z = Z_0 / R_0,$$
$$\operatorname{Re}_\omega = \frac{\omega R_0}{\nu},\ \varepsilon \cong 1; 0; -1,\ \sigma = \sigma_R + i\sigma_i,\ N = Ha^2 / \operatorname{Re}_\omega,\ D_* = \frac{d}{dr} + \frac{1}{r}.$$

The results of computations performed on the basis of this mathematical model have shown that within a certain range of the parameters values, both stationary instability (of the type of the Taylor vortices) and wave instability can arise.

EXPERIMENTAL INVESTIGATION OF LIQUID METAL HEAT TRANSFER SPECIFIC APPLIED TO TOKAMAK REACTOR COOLING

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It is assumed to use liquid metal (LM) as a coolant in advanced nuclear and fusion devices. In the latter case, the LM flow will be affected by strong magnetic field (MF)

The impact of MF on a flow with presence of high heat fluxes, that give rise to buoyancy forces, is ambiguous and can not be reduced only to the suppression of secondary flows and turbulence.

Complex experimental study of liquid metal flow and heat transfer in various configurations affected by longitudinal or transverse magnetic field under conditions close to tokamak reactor have been held.

The MPEI research team has been held modeling experiments of LM heat transfer in the tubes with respect to the tokamak cooling channels for many years. Present experimental researches are conducted on magneto hydrodynamic (MHD) complex by joint team of MPEI-JIHT RAS. MHD facility combines two mercury loops, where researches in the longitudinal and in the transverse magnetic field are available.

Measurements of the three-dimensional averaged and fluctuating temperature fields were carried out in regimes with homogeneous and inhomogeneous along the perimeter heating. Available complexes of the dimensionless parameters are $Ha^2/Re=1\div30$ $Gr/Re^2=0.2\div2.2$.

It is considered, that strong MF (uniform longitudinal or transverse) laminarize flow by suppressing the turbulence. However, in some cases (if any TGC presented) MF leads to the unexpected appearance of velocity and temperature fluctuations of abnormally high intensity.

This result depends on the orientation of the tube about the gravity force and MF induction vectors and also on heating configuration. Different configurations were investigated: tubes (vertical, horizontal, inclined) and vertical flat channel close to configuration of LLCB type ITER test blanket module.

For example, one of the scenes observed in down flow vertical tube is shown on fig.1. Temperature fluctuation amplitude in this regime is almost equal to the temperature difference between the wall and the LM flow, which can be a hundred degrees and more in real conditions of the tokamak.

Nature of these phenomena is completely different from turbulence. These fluctuations on the one hand, contribute to the increase of the heat transfer coefficients, and on the other represent a danger for the wall, causing it`s fatigue destruction by pulsating thermal stresses.

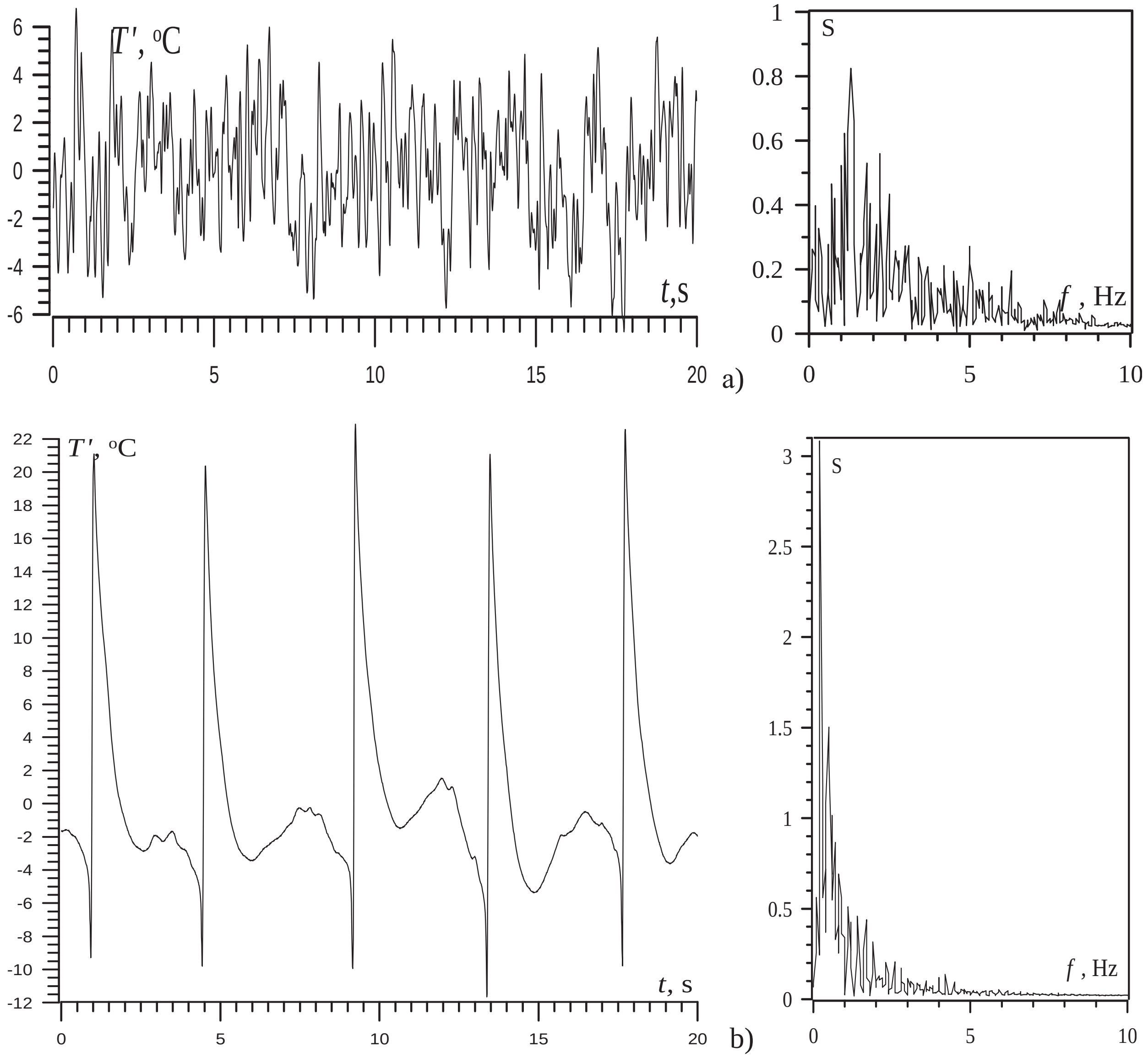

Fig. 1. Characteristic temperature fluctuations and its power spectrum in the vertical tube with inhomogeneous heating: z/d =37, q_1/q_2= 55/0 kW/m^2, Re =20000, transverse MF,

Waveforms are taken at intensity maximum, Ha=0; b) 330.

FREE SURFACE DEFORMATION IN ELECTRICALLY DRIVEN FLOW

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Electrically induced flows are present in many industrial processes such as Electroslag remelting, Vacuum arc remelting, electrolyzers, DC arc furnaces, smelting, aluminium reduction cells…etc. Study of the mechanism of generation and development of the flows generated within a current carrying fluid due to the interaction of an electric current with a self magnetic field is important in order to gain correct understanding of these engineering processes. In spite of the practical significance, some essential features of these flows have not yet been explored. The present paper presents an experimental and a numerical study of an electrically induced flow generated within a cylindrical container (188 mm diameter) filled with a In-Ga-Sn alloy (figure 1). The applied current is applied from cooper electrodes of various diameters (2-8mm) and varied from 100 to 700 Amps. Velocity measurements in the liquid metal were carried out using original fibre-optic probes. The deformation of the free surface just under the small electrode (figure 2) is reported in term of depth and width for various radius and applied current intensity. For sufficiently large currents the velocity measurements show very special pulsations. For higher current a critical current exists where the liquid metal surface looses the contact with electrode leading to the creation of an arc. To explore numerically what happens in such flows, 2D and 3D calculations of the MHD flow are performed. The numerical model is based on a potential formulation for the electromagnetic field. The evolution of the free surface flow is tracked with a VOF model. The electromagnetic parameters are fully coupled with the evolution of the free surface and the contact surface at the electrode.

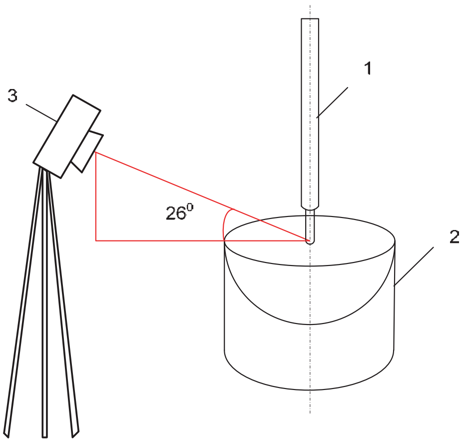

Figure 1: Scheme of experiment. 1 – electrode, 2 – container, 3 –photocamera

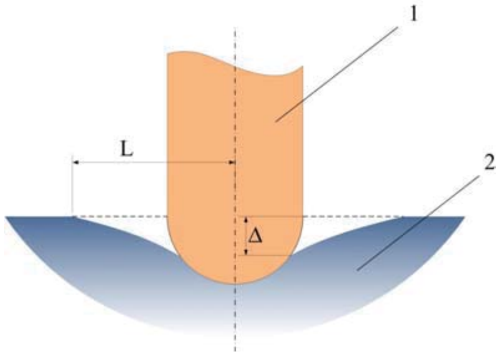

Figure 2: Scheme of surface deformation Δ – depth of cavern, L – width of cavern, 1 – small electrode, 2 – In-Ga-Sn.

Regularization of flow reversals in a MHD Rayleigh-Benard convection

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In this paper Rayleigh-Benard convection has been investigated under the influence of a DC magnetic field. Similar configurations can be found in geophysical or steel production. Our group reported recently that spontaneous flow reversals of quasi two-dimensional rolls randomly occur in Rayleigh-Benard convection of liquid metal exposed to a horizontal magnetic field (Yanagisawa, *et al.*, *PRE*, 2011). In fluid layers with relatively large aspect ratios (see Fig.1 (a)) the convection roll pattern becomes isotropic. However, the rolls are aligned with the magnetic field direction if the Lorentz force becomes comparable to the buoyancy or larger. In our experiment, where the fluid layer has a dimension of 200 * 200 * 40 mm (corresponding to an aspect ratio of 5), the convection pattern can show 3, 4 or 5 rolls regimes depending on the Rayleigh number *Ra* and the Chandrasekhar number *Q*. Flow reversals occur spontaneously between these steady states in the *Ra*-*Q* parameter space.

A new regime has been found in experiments conducted at Chandrasekhar numbers in a magnetic system at HZDR. In this regime the flow reversals occur regularly as shown in Fig. 1(a) which displays a spatio-temporal velocity map measured by ultrasonic velocity profiling in the GaInSn fluid layer. The coloration in the map indicates the sign and intensity of the horizontal velocity whereas the vertical axis stands for the distance from the side wall along a measuring line perpendicular to the magnetic field (ch2). Thus, the stripes represent the existence of 5 quasi two-dimensional rolls in the fluid layer at $Ra \sim 4.9 * 10^4$ and $Q \sim 3.8 * 10^3$, respectively. 15 reversals can be observed during the measurement time of more than 14000 sec (~ 4 hours). The non-dimensional characteristic time of the reversal normalized by circulation time of the roll is around 100, being similar to the characteristic time of the 'random' flow reversals reported by Yanagisawa, *et al*. Detailed observations reveal that movements of each cell toward the reversal start just after the last reversal occurs unlike the random flow reversals. Then these grow exponentially with time to the reversal.

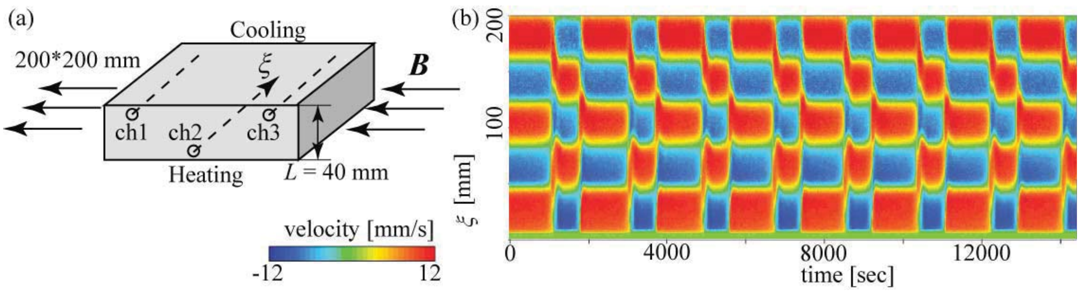

Fig. 1 (a) System configuration, (b) spatio-temporal velocity map of convection obtained at ch2

Additionally, we found that the rolls are not always parallel to the magnetic field, but, they are tilted with respect to the magnetic field lines. Fig. 2 shows the enlarged velocity maps obtained at different positions of UVP measurements (ch1, ch2 and ch3). Dashed lines are added to the drawings to support a comparison of the positions of roll boundaries, which differ from each other depending on the measurement channel. The reason for the inclination is not clear until now. Specific experimental conditions are under discussion like the non-uniformity of the magnetic field, a potential, small tilting of the fluid vessel with respect to the field lines, or the higher values of the Chandrasekhar number *Q*.

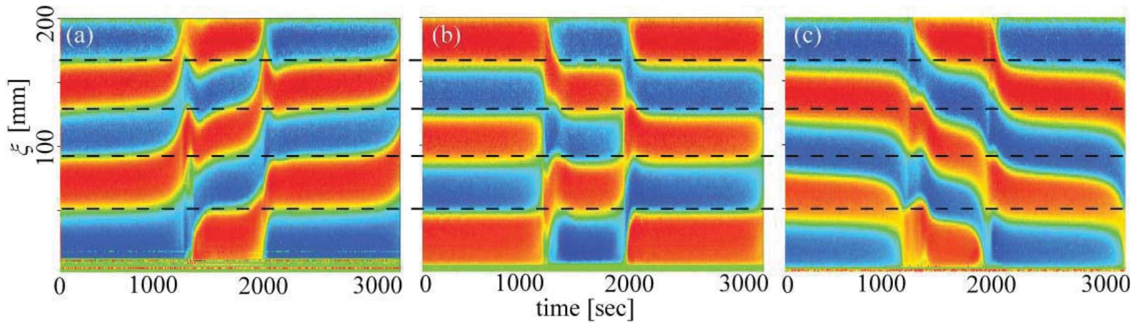

Fig. 2 Spatio-temporal velocity map of convection obtained at (a) ch1, (b) ch2 and (c) ch3

Pattern selection near the onset in cylindrical binary mixture convection

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ABSTRACT

Thermal convection in a binary fluid layer heated from below is a system that exhibits a great variety of pattern forming phenomena when driven away from equilibrium. In mixtures with a negative Soret coefficient ($S < 0$), the spatio-temporal properties of the arising flow patterns are known to be complex due to the subcritical oscillatory nature of the primary bifurcation. The two dimensional system has been widely studied, numerically as well as experimentally using annular cells. Near the onset, spatially extended patterns (travelling and standing waves, stationary rolls or spatio-temporal chaotic states) and confined solutions (localized travelling waves and stationary states) have been obtained. The localized stationary states are known to be favoured by the strongly subcritical nature of the steady bifurcation beyond the primary Hopf bifurcation.

In the present work, we investigate numerically three dimensional pattern selection in a vertical cylindrical cell heated from below for a water-ethanol mixture. We focus on the spatio temporal dynamics in the neigborhood of the initial oscillatory instability and extend the results presented in [1] by varying the aspect ratio of the container. For highly constrained geometries we obtain that, despite the oscillatory nature of the primary instability, pure thermal stationary modes are selected after long time-dependent transients. For intermediate aspect ratio cylinders, stable oscillatory states seem to coexist with the stationary thermal modes, indicating that concentration begins to play a role in the dynamics. In highly extended cylinders we obtain a diversity of confined patterns, many of which are consistent with experimental observations [2]. Remarkably, though, we have obtained persistent large amplitude highly localized patterns not reported in experiments.

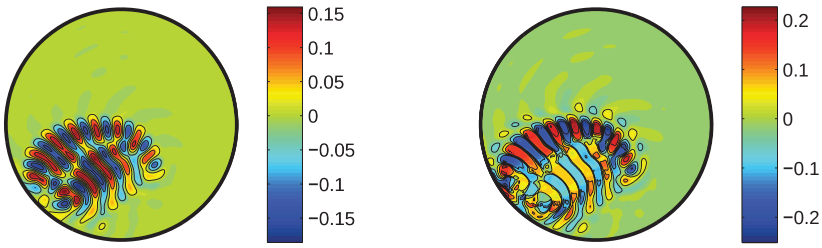

Figure 1: Contour plots of temperature (left) and concentration (right) at midheight for a persistent localized state obtained at R=1918 for a water-ethanol mixture in a $\Gamma = 11$ cell

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Top-down vortices developed in a cylindrical annulus cooled on the top

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ABSTRACT

The importance of thermoconvective processes in the formation of atmospheric phenomena such as dust devils, cyclones, hurricanes or tornadoes is well known [1-3]. Dust devils are widely recognized as an example of this: on a flat ground with strong heating, thermal convection can become intense; the hot air near the surface rises quickly through a small pocket of cooler, low pressure air above it forming intense updraft that can begin to rotate [1]. In Ref. [4], we show that a stable vortex, very similar to a dust devil, can be generated from a convective instability, in a cylindrical annulus non-homogeneous heated from below.

Tornadoes are another complex phenomenum involving a rich spectrum of fluid-dynamic processes, including rotation. There are different theories for genesis of tornadoes in supercell and non-supercell storms. In the case of tornado genesis in supercell storms, early views were based on a top-down concept in which the mesocyclone builds downwards by a pressure-deficit tube maintained by intense convection [5-6]. In this work we show that axisymmetric top-down vortices can be formed from a convective instability in a cilindrical annulus cooled on the top and with a lateral inflow/outflow permitted. A pressure drop is formed in the center on the top that favours the formation of the vortex. The trajectorie of particles from the top of the vortical structure is characterized by a spiral down motion around the inner cylinder (as observed in tornadoes). It is also observed an upwards motion for particles at the bottom.

The governing equations considered are the incompressible Boussinesq Navier-Stokes equations. For the numerical implementation, non-linearities are treated with Newton's method. For the discretization (for basic state and linear stability analysis) we use a spectral method by expanding the fields in Chebyshev polynomials and evaluating at the Gauss-Lobatto points [7-8].

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ON MODELS FOR FLUID-LIKE MATERIALS THAT ARE MECHANICALLY INCOMPRESSIBLE AND THERMALLY COMPRESSIBLE OR EXPANSIBLE AND THEIR OBERBECK–BOUSSINESQ TYPE APPROXIMATIONS

VÍT PRŮŠA

Oberbeck–Boussinesq system is a system of equations describing the buoyancy driven motion of a viscous (Newtonian) fluid and as such it plays an important role in many applications. Unlike other equations in continuum mechanics it is however only an approximation of some "exact" system of equations, and a natural question is whether an approximate system of Oberbeck–Boussinesq type—density changes are neglected everywhere except in the buoyancy term—can be used even in rather extreme conditions (high temperature gradients) or for non-Newtonian fluids. Following the ideas of Rajagopal and co-authors (Rajagopal *et al.* 1996, Math. Models Methods Appl. Sci. 6, 1157) and (Rajagopal & Srinivasa 2000, J. Non-Newton. Fluid Mech. 88, 207), we discuss the validity of Oberbeck–Boussinesq type approximation for viscous fluids and primarily for viscoelastic fluids.

On an intuitive level, one can guess that the validity of the Oberbeck–Boussinesq type approximation for viscoelastic fluids is indeed questionable. For example, the energy equation must somehow reflect the fact that the viscoelastic fluids can store the energy, and the interplay between the storage mechanisms and thermal effects must be thoroughly described. This issue is not reflected in the Oberbeck–Boussinesq type system, which leads to an inconsistency of the energy budget in the system. By deriving an "exact" system of equations for convection in viscoelastic fluids, and comparing it with the standard Oberbeck–Boussinesq type approximate system, we show that such inconsistency can be significant if one considers for example high temperature gradient driven convection in viscoelastic fluids.

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Secondary flow dynamics in a temperature boundary layer in a cylindrical tank.

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Secondary flows in the form of horizontal rolls are a common feature of a large variety of flows of different nature and scale. Roll vortices are often observed in the atmospheric boundary layer. Depending on their size and strength, rolls play a significant role in transporting momentum, heat and moisture through the atmospheric boundary layer. Horizontal rolls, generated in convective flow above a partially heated bottom in a rectangular box were studied in details in (Sukhanovsky et al. EPJ B, 2012). The main goal of this study is investigation of boundary layer dynamics in a more complicated case – in a cylindrical layer with discrete heat source. The structure of velocity fields is studied by PIV measurements. It is found that different types of horizontal rolls (transverse and radial) appear simultaneously. The formation of transverse rolls is periodic in time and dependence of characteristic frequencies on Grasshof number is obtained. Series of long time temperature measurements are analyzed by wavelet-analyses for several fixed locations over the heating area. Azimuthal dependence of characteristic frequencies of temperature fluctuations and is shown. Numerical simulations are carried out by the CFD package FLUENT. Numerical results are in a good agreement with results obtained in experiment. Analyses of heat transfer in the boundary layer showed that secondary flows lead to remarkable heat transfer enhancement.

The study is supported by Program of UD RAS, project No 12-T-1-1008 and RFBR projects (11-01-96031, 11-01-96000).

Symmetry breaking and time-periodic flow structures in T-shaped micromixers.

by

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We observe that the degree of mixing in a T-shaped micro-mixer with rectangular cross sections is strongly influenced by the flow conditions at the inlet. In particular, here we study numerically the symmetry breaking in a mixing channel having a 3:2 aspect ratio, due to having a fully developed velocity profile instead of a flat one at the micromixer confluence. We find that, when fully developed conditions are ensured, the engulfment occurs at relatively low Reynolds numbers, with typical S-shaped symmetric contour plots. On the other hand, when the fluid flow at the confluence is non-fully developed and presents a plug flow region at the center, engulfment occurs at much larger Reynolds numbers and, in addition, we observe a C-shaped engulfment pattern (with the tracer crossing the mixing channel mid-plane either near the center or at the walls), with much lower mixing efficiencies. In addition, a careful Direct Numerical Simulation of the mixing process indicates that, for fully developed inlet flows with $228 < Re < 408$ Reynolds numbers, the flow regime at the outlet is unsteady, with time-periodic structures. In our case, analyzing the fluid velocity time series, we find a Strouhal number, $St \simeq 0.25$, which is in excellent agreement with previous results. Such pulsating flows strongly enhance the degree of mixing, that can be as large as twice the one that is observed in the steady engulfment regime. Then, when we increase the Reynolds numbers beyond the pulsating range, the flow is no more unsteady, with a consequent reduction of the mixing efficiency. Finally note that, for our investigated geometry, no unsteady, periodic behavior was observed when the inlet flows are blunt and not fully developed.

Stability of Disfigured Liquid Jets: Effect of Interfacial Geometry

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The action of interfacial tension at the surface of a liquid jet is a key factor in deciding its stability characteristics. In the special case of a static, inviscid jet in an inviscid medium of relatively low density, the interfacial curvature (geometry of the jet) is in fact the only deciding factor. The critical wavelength of disturbances (below which all disturbances are stable) and the fastest growing wavelength are specific to the jet geometry and independent of fluid properties. Thus Rayleigh was able to determine the critical wavelength for a circular right cylindrical jet (Fig. 1a) from a purely geometric argument based on interfacial potential energy considerations (Rayleigh's Work Principle).[1]

In this work, we consider the stability of liquid jets which are deformed from the classic right cylindrical geometry with a circular cross section. Two cases are of interest- (i) a curved jet of circular cross section (Fig 1b) and (ii) a right elliptical cylinder wherein the cross section is an ellipse (Fig. 1c). These geometries are motivated by confined two phase microflows in which the liquid jet is forced to take up the configuration of the channel in which it flows. Examples are flow in a curved microchannel[2] and flow through a rectangular channel of high aspect ratio.

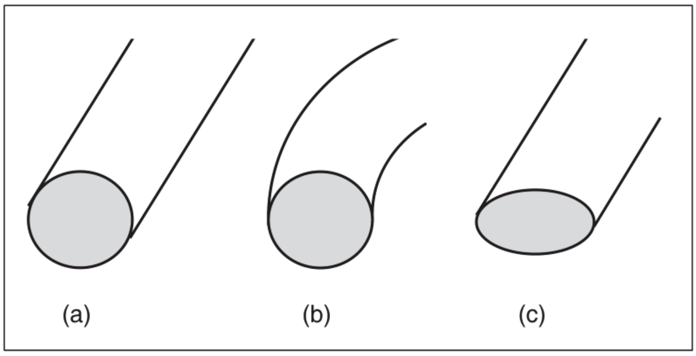

Figure 1. (a) The classic right cylindrical jet studied by Rayleigh (b) curved cylinder of circular cross section (c) elliptic right cylindrical jet.

We are primarily interested in the effect induced by the change in interfacial curvature of these 'disfigured' jets on their stability. To single out this feature, we consider static inviscid jets within inviscid fluids of relatively low density. We apply Rayleigh's Work Principle to obtain the critical wavelength of disturbance in both cases. An increase of this critical wavelength is found for the case of the curved jet (Fig. 1b). This implies that the curved axis of the jet has a stabilizing influence. The elliptic cylindrical jet (Fig. 1c), on the other hand, shows no change in critical wavelength. A linearized stability analysis of the inviscid Navier-Stokes equations is also carried out to corroborate these results and obtain information about the growth rates of various disturbance wavelengths (dispersion curve). The present analysis yields Rayleigh's classic results as a special case.

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Interaction between counterpropagating Rossby and capillarity waves in planar jets and wakes

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By means of a global linear analysis, Tammisola *et al.*[1] have observed a counterintuitive destabilizing effect of the surface tension in planar wakes. They have justified this destabilization by the presence of two different temporal unstable modes found when analyzing the local stability of an extracted velocity profile from the base flow.

In the present study, we approximate the velocity profile of a jet/wake flow through a piecewise broken-line. We then explain the presence of these two temporal unstable modes for such flows using the counterpropagating Rossby wave (CRW) perspective[2]. which associates to each vorticity discontinuity an individual Rossby wave. The introduction of a finite amount of surface tension at the interface creates two capillarity waves (CW) which move with the same velocity but in opposite directions. The interaction of this four waves originates in the two temporal unstable modes for both sinuous and varicose symmetries.

Analyses of the influence of the shear layer thickness δ_w and the confinement h on the behaviour of both CRWs and CWs and on their interaction are provided. Finally, comparisons with direct numerical simulations of jets/wakes including surface tension will complete the study. These direct numerical simulations have confirmed the destabilizing influence of a finite amount of surface tension, as seen in figure 1.

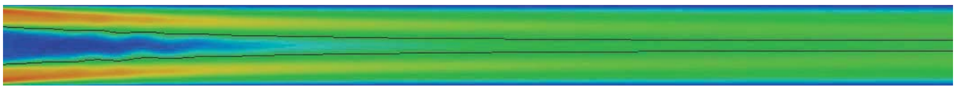

Figure 1: Contours of the streamwise velocity for a two-phase wake with a finite amount of surface tension. The wake is globally unstable. The corresponding single-phase wake, conversely, is globally stable.

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Patterns in the Breakup of Slender Compound Jets in the presence of gravity-Inviscid and Viscid Studies

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The capillary instabilities in compound jets have been studied using a slender jet approximation. Different modes of breakup have been reported in literature both experimentally and through simulations. The two basic types of break up observed are (a) breakup of the core fluid within annular fluid, resulting in a train of drops inside the annular sheath and (b) the disintegration of the annular sheet into drops over an intact core fluid (Uddin et al, 2011).

The slender jet approximation captures the breakup behavior of a viscous single jet (Eggers et al, 1993). We extend the slender jet analysis to a generic compound jet (viscous-viscous,viscous-inviscid, inviscid-viscous and inviscid- inviscid). The model is used to predict the break up profiles using a method of lines (MOL) algorithm in MATLAB. A nonlinear analysis shows that the presence of gravity is destabilizing. The dispersion curve (break up time vs wave number (k)) in the presence of gravity shows local maxima for shorter wave number. This shifts the fastest growing wavelength (the minima) to the right, clearly indicating that the fastest growing wavelength is shorter than that observed in the absence of gravity (Fig. 1)

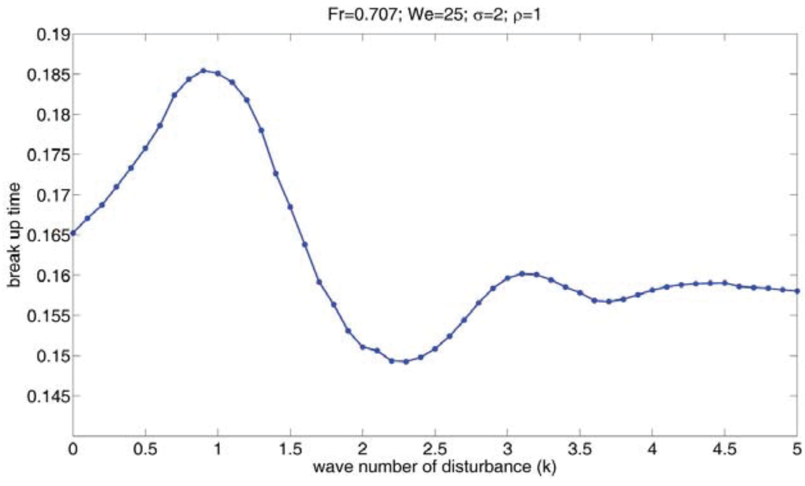
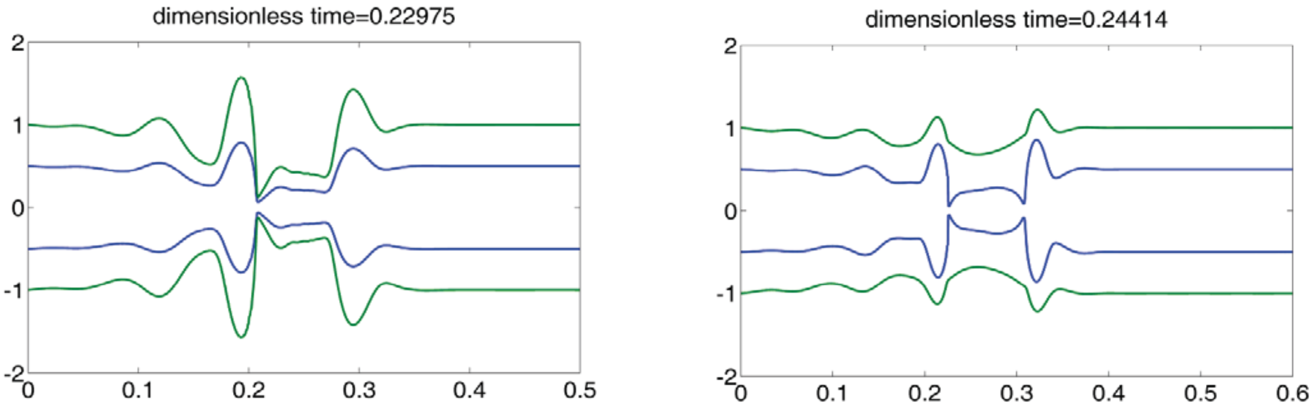


Figure 1 Dispersion curve for an inviscid-inviscid compound Jet in the presence of gravity

The major parameters emerging out of the non dimensional slender jet equations are the density ratio, Weber number, viscosity ratio, diameter ratio, Reynolds number and the surface tension ratios. The variation of break up profile across the parameter space is being investigated.

In the viscid-viscid case, the continuity of tangential velocities at the interface of the core and annular fluids forces the jet to always breakup at the same point resulting in a compound drop as shown in Fig (2a). For large variations in viscosity of the inner and the outer fluid, the continuity of tangential velocities can be dropped as shown in fig (2b), where the inner fluid breaks up while the annular fluid is intact.



(a) **(b)**

Figure 2 Breakup profile of (a) viscid-viscid compound jet on imposing the continuity of tangential velocity at the inner interface (b) inviscid-inviscid case where there is a slip at the fluid interface. Parameter values in both the cases are We=25, ρ=1, σ=1, Fr=0.707

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On the stability of two phase Poiseuille flow between coaxial cylinders

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In this work, the stability of a two phase Poiseuille flow between coaxial cylinders is addressed. The cylinders are of infinite extent in the axial direction. The two fluids are radially stratified with a pressure difference imposed in the azimuthal direction. In the base state, the fluids flow tangential to the walls of the cylinders in the azimuthal direction. The flow field is fully developed and due to the infinite geometry of the cylinders, the velocity is also invariant in the axial direction. Thus, the velocity field is a function of radial position alone. A linear stability analysis is carried out to determine the stability of this base flow.

This stability problem may be viewed as a two phase extension of the single phase problem in which the tangential flow becomes unstable via a *Taylor* instability.[1,2] This instability results in the formation of vortices similar to those observed in the well known Taylor-Couette problem. This instability arises due to the centrifugal force experienced by the fluid. In the present two phase problem, there are several other mechanisms which can lead to an unstable flow. There is the *Kelvin-Helmholtz* instability which can arise if the two fluids are of different density and flowing with different velocities.[2] In addition, *shear instabilities* caused by a viscosity difference between the two fluids can destabilize the flow. Both these mechanisms are commonly encountered in two phase parallel flows. If the fluid near the inner wall is denser, then a *Rayleigh-Taylor* instability can arise under the action of the centrifugal force field and cause the fluids to ultimately switch locations.[2] Due to the cylindrical curvature of the interface in its base state, one must also consider the possibility of a *Rayleigh-Plateau* instability- the mechanism by which liquid jets are broken up under the action of surface tension[3]. Thus there are five fundamentally different mechanisms to be considered.

As a first step towards understanding this multi-faceted problem, each instability mechanism is singled out and studied independently. For example, one can focus on the *Taylor* instability alone by requiring the interface to be stationary and cylindrical, retaining its base state configuration. Further, even if interface deformation is considered, the *Rayleigh-Plateau* instability can be eliminated from the problem by considering the limit of a thin gap between the cylinders (so that the interface is nearly flat). Such special cases correspond to various limiting values of the physical parameters. These cases provide a foundation from which we develop an understanding of the more general problem in which the various instability mechanisms act simultaneously and interact.

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From pipe flow to astrophysical magnetic fields: subcritical dynamo transitions and self-sustaining nonlinear magnetohydrodynamic processes

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Instability-driven dynamos are magnetic-field and turbulence-generating processes suspected to be at work in shear flows prone to local magnetohydrodynamic (MHD) instabilities, such as the magnetorotational instability (MRI) in Keplerian flow. These dynamos are very interesting candidates to explain the origins of large-scale magnetic activity and magnetohydrodynamic turbulence in a variety of differentially rotating astrophysical bodies such as stellar interiors or accretion disks [1–5], and could perhaps be observed in dynamo experiments in the near future. The conditions of emergence of these dynamos and the statistical properties of the MHD turbulence that results from their development are however still rather poorly understood.

In the first part of this talk, I will introduce several candidate instability-driven dynamos and explain what is understood (and not understood) about them. I will notably review past and recent work showing that the excitation of these dynamos requires three-dimensional, finite amplitude perturbations and is essentially non-kinematic, namely the excitation of magnetic field fluctuations is completely coupled to that of velocity fluctuations. I will then argue that these forms of dynamo action have much in common with hydrodynamic turbulence in linearly stable shear flows [6] and are in fact based on a self-sustaining MHD process [7] whose generic physical principles are analog to the hydrodynamic self-sustaining process in shear flows [8].

The second part of the talk will be devoted to the presentation of a large set of recent numerical results on the MRI dynamo ("zero net-flux MRI") problem in Keplerian flow [9, 10] aiming at uncovering the bifurcation mechanisms at work in this problem, in relation to recent work on the transition to turbulence of hydrodynamic shear flows. I will notably present evidence that the emergence of three-dimensional chaos and transient magnetohydrodynamic turbulence in the MRI dynamo problem in the incompressible shearing box numerical framework is primarily associated with global homoclinic and heteroclinic bifurcations resulting from collisions between the stable and unstable manifolds of three-dimensional,nonlinear MRI dynamo cycles born out of saddle-node bifurcations, suggesting that these cycles play a key role in the transition to MHD turbulence of the system.

I will finally discuss how these results may be used to assess the conditions of excitation of instability-driven dynamos in Nature and in laboratory experiments. Because they represent the most detailed characterization to date of homoclinic tangency crises in a three-dimensional fluid dynamical system, I will also argue that the results may prove useful to better understand the bifurcation mechanisms at work in various hydrodynamic shear flows, in combination with several studies of that particular problem [11–14].

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Numerical Exploration of Density Wave Formation in Rapidly and Differentially Rotating Spiral Galaxies

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ABSTRACT

Most rapidly and differentially rotating disklike galaxies display graceful spiral patterns. Yet, over almost 240 years after their discovery in M51 in 1773 by Charles Messier, we still do not fully understand how they originate. In the spirit of Lin and Shu, we strongly believe that these spirals consist of different material at different times. We regard the spiral structure in astrophysical disks as a Lin–Shu type density wave pattern, which does not remain stationary in a frame of reference rotating around the disk center at a proper speed, excited as a result of the Jeans instability of small-amplitude gravity perturbations. The classical Jeans gravitational instability is set in when the destabilizing effect of the self-gravity in the disk exceeds the combined restoring action of the pressure and Coriolis forces. The instability is one of the most frequent and most important instabilities in the stellar and in the planetary cosmogony and galactic kinematics and dynamics, and deals with the question of whether initial density fluctuations will be amplified or will die down. Jeans instability identifies *nonresonant* instabilities of fluctuations associated with almost aperiodically growing accumulations of mass. In this talk, the dynamical behavior of a rotating galactic disk is examined numerically by a high-order Godunov hydrodynamic code. As the zeroth-order approximation for a disk, composed of stars and gas clouds, we investigate the motion of a "fluid" element under the influence of a self-consisted perturbed gravity field, looking for time-dependent oscillations. Since the collisional effects are negligible, the motion equations are the Euler equations. These equations are completed with the continuity and Poisson equations, and the isotropic state equation. The code is implemented to simulate a two-dimensional flow driven by an internal Jeans gravitational instability in an infinitesimally thin disk composed of stars or gas clouds. A goal of this work is to explore the local and linear regimes of density wave formation, employed by Lin, Shu, and others in connection with the problem of spiral pattern of galaxies, by means of computer-generated models and to compare those numerical results with the generalized stability theory. The focus is on a statistical analysis of time-evolution of density wave structures seen in the simulations. The leading role of collective processes in the formation of both the circular and spiral density waves (or "heavy sound") is emphasized. Certain applications of the simulation to actual gas-rich spiral galaxies are also explored.

Magnetic pinch-type instability and alpha-effect in a liquid metal container

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The influence of magnetic fields on the evolution of hot stars became of new interest by including magnetic pinch-type instabilities, especially the so-called Tayler instability. This instability of a toroidal magnetic field (under the influence of differential rotation) have been studied in a simplified approach in the cylindrical geometry of hydromagnetic Taylor-Couette flows. A toroidal field due to a homogeneous current between conducting cylinders with different rotation rates is considered. We show numerical predictions for a non-rotating laboratory experiment and compare it to the real measurements. The experiment has been the first one to demonstrate the existence of TI in liquid metals. The resulting critical currents as well as the growth rates agree very well with numerical results. Differential rotation to generate the toroidal field dynamically can also be used to reach a Tayler-unstable configuration. The potential difference between top and bottom plate due to the electromotive force of the nonaxisymmetric modes of the TI can become large enough to measure the resulting alpha-effect in such a height-dependent differentially rotating setup. The proposed realization in liquid metals with a container of 10 cm diameter and height needs an initial axial field of 1000 Gauss and a rotation frequency of 40 Hz to measure a potential difference of 30 mV.

Spiral flow instability in galaxy clusters

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Most galaxy clusters have a cool core, which appears to be thermally unstable. Spiral flows are ubiquitously found in such cores, inducing spiral features in the thermal and chemical properties of the intracluster medium, and X-ray edges known as cold fronts (CFs). We show that the core consists of a cold, fast flow, which propagates below a hot, slow inflow, separated by a slowly trailing, quasi-spiral, tangential discontinuity surface. Such flows can eliminate the cooling problem, provided that mechanical feedback regulates the flow, for example through buoyant active galactic nucleus (AGN) bubbles.

Global bifurcations for low-Reynolds-number swimming in confined geometries

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In this talk we will present simple mathematical models giving insights into the dynamics of low-Reynolds-number microorganisms, or swimmers, in bounded two-dimensional geometries. We introduce a model treadmilling swimmer whose dynamics in the presence of no-slip walls can be conveniently studied by a variety of complex variable techniques. It will be demonstrated that the geometry of the confining walls can produce interesting local and global bifurcations in the swimmer dynamics.

Electrokinetic phenomena and hydrodynamics around a bubble in a microchannel

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We present recent experimental and numerical results regarding electrokinetic phenomena occurring around a dielectric (air) bubble trapped inside a microchannel filled with an electrolyte. The presence of air bubbles within microchannels has long been a challenge in the field of microfluidics as the capillary forces at this small scale may result in immobile bubbles which can block the channel, impeding flow and increasing the electrical resistance of the channel. More recently, the thin film between bubble and wall has actually been used to trap and stretch DNA and generate streaming current. We focus on the flow and electrokinetic phenomena occurring within the regions adjacent to this thin film of electrolyte. At the electrolyte-wall interface, a (positively charged) electric double layer (EDL) is spontaneously formed along the length of the channel to shield the negatively charged wall. Under the application of a DC electric field, the net charge in this EDL is driven towards the cathode, inducing electroosmotic flow which is characterized by a plug profile. The presence of the bubble disrupts the EO flow as the fluid is forced into a confined region within the thin film and may result in backflow vortices. The addition of fluorescent colloids for tracking the flow further enrich the physical phenomena observed with interesting colloidal electrokinetic interaction. This process is further complicated in the case where the size of the thin film is of the order of the electric double layer (~100nm) which may induce ion-permeselectivity and at large enough voltages even result in unstable concentration-polarization regions at the edges of the film.

Aeroelastic Limit Cycle Oscillations in Transonic Buffeting Flows

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Wind tunnel testing and computational investigationshave shown that various nonlinear aeroelastic phenomena, such as limit-cycle oscillation (LCO), may be associated with the shock-buffet phenomenon. Shock-buffet is the term used for the self-sustained, low frequency, large amplitude shock oscillations that are observed for certain combinations of Mach number and steady mean angle of attack at transonic flows, even in the absence of airfoil motion. The interaction of shock-buffet with the elastic structural motion may induce significant aeroelastic responses that are highly undesirable from point of view of structural integrity, and flight handling qualities.

Currently, advances in viscous Navier-Stokes CFD modeling and simulation methods enable the prediction of heavily separated and buffeting flows with good correlation to wind tunnel test experiments. Recent studies by the authors [1–3] presented Navier-Stokes simulations of airfoil responses to prescribed motions about flow conditions that exhibit shock-buffet. A lock-in phenomenon was discovered, in which the shock-buffet frequency synchronizes with the frequency of the prescribed airfoil motion. It was found that lock-in occurs when the shock-buffet frequency and the prescribed airfoil motion frequency are sufficiently close, and the amplitude of the prescribed airfoil motion is above a certain threshold. These findings are in agreement with early experimental data [4, 5] in which aerodynamic resonance responses to harmonic excitations at transonic flows were observed. In all the above noted studies of responses to prescribed structural motions some of the aerodynamic responses exhibited positive phase with respect to the prescribed motion, for some range of excitation frequencies, implying that the response of the *aeroelastic* system might be unstable at these flow conditions.

The current study focuses on characterization of the aeroelastic response of a spring suspended airfoil in transonic buffeting flows. Navier-stokes turbulent simulations of an aeroelastic system comprised of a NACA 0012 airfoil suspended on a single degree of freedom (DOF) pitch spring, as well as on a combination of two DOF pitch-and-heave springs, are performed to compute the aerodynamic forces and elastic displacements. The natural frequencies of the aeroelastic system are varied from below to above the shock buffet frequency to study their effects on the aeroelastic responses. The effects of the system's damping and the flow dynamic pressure are also studied.

The nature of the response appears to be dependent on the relationship between the buffet frequency and the natural frequency (or frequencies) of system. For single-DOF pitch systems of natural frequencies that are *lower* than the buffet frequency, the pitch response reaches a limit cycle of very small pitch angles, that does not affect the aerodynamic buffet. Systems of natural frequencies that are *higher* than the buffet frequency develop pitching oscillations of increasing amplitudes, at a combination of the buffet and the elastic natural frequencies. When the pitching angle is above some threshold lock-in occurs, after which the system pitching frequency is at the elastic natural frequency solely. Following lock-in the pitching amplitude keeps growing, reaching a limit-cycle oscillation of substantial amplitude. For two-DOF heave and pitch system, in which the heave and pitch natural frequencies bracket the buffet frequency, similar responses were simulated. Increasing pitch amplitudes lead to lock-in, followed by a limit-cycle response. This aeroelastic response mechanism, which is distinctly different than flutter, may be responsible for some aircraft transonic LCO occurrences.

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VIV of a tethered sphere in a steady flow: Near-wake flow and effect of active flow control on sphere dynamics

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Bluff bodies in a moving fluid often undergo vortex induced vibrations (VIV) as a result of asymmetric vortex shedding. Vibrations are usually harmful but in some instances they can be harnessed for energy generation. This investigation considered VIV of a tethered sphere mounted in a low-speed wind tunnel and subjected to active boundary layer control by means of acoustic perturbations using speakers. Sphere tracking and high-speed Particle Image Velocimetry (PIV) measurements were made. Without acoustic perturbations, sphere tracking revealed three different bifurcation regions, i.e. stationary, periodic and non-stationary motion in agreement with previous publications. PIV measurements of the near wake indicated interactions between near-wake vortices visualized by swirling strength and the separated shear layer. At a reduced velocity of 8.8, the shear layer was characterized by intermittent vortical structures whose frequencies corresponded to linear inviscid instability theory. Acoustic perturbations had a strong impact on the sphere dynamics. Perturbations applied at a frequency 64 times the sphere natural frequency completely nullified sphere oscillations in the periodic regime when the sound pressure level (SPL) exceeded 96dB. When this ratio was 22, oscillations in the non-stationary mode were amplified for all investigated SPL.

CALIBRATION OF THE WAKE OSCILLATOR MODEL USING CFD

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Slender marine structures such as risers, mooring cables and umbilicals are very sensitive to excitations caused by vortex shedding. These resonant vibrations know as Vortex-Induced Vibrations (VIVs) can be destructive to the structures and lead to increased fatigue damage and collapse. Semi-empirical tools are widely used by engineers to predict VIV, however, these tools are subject to many assumptions which limit their applicability. The fluid-structure interaction aspects are far from being completely understood and advanced modelling is required to investigate and predict the impact of VIV on the service life of marine structures.

We study VIVs of a slender marine structure using low dimensional models. Specifically, we perform computational fluid dynamics simulations of VIV of low-mass ratio rigid cylinder in order to calibrate existing reduced-order models based on nonlinear self-excited oscillators of Van der Pol type known as the wake oscillator models. We use the wake oscillator model that focuses on fluid-structure coupling through acceleration term [1].

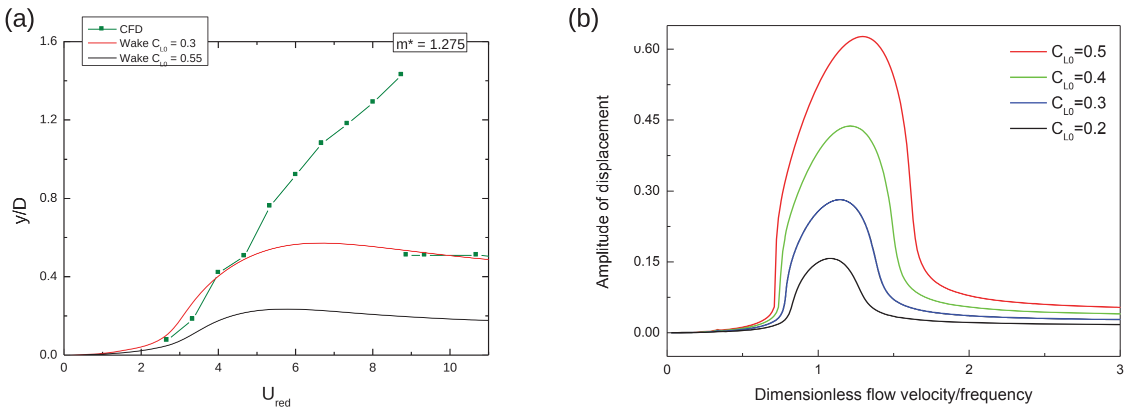

Figure 1. (a) Comparison of numerical solutions (C_{L0} = 0.3; C_{L0} = 0.55) with CFD simulations; (b) dependence of the vibration amplitude on the coefficient C_{L0} (single mode approximation)

In this work we present numerical solution of the wake oscillator model for a single mode approximation compared with results obtained with CFD (Fig. 1a) and discuss the choice of parameters for the wake oscillator model (Fig. 1b) coupled with a structure [2]. A series of CFD simulations is performed where the flow is analysed for a cylinder capable of moving in transversal and in-line directions. CFD results are verified against experimental data, where so-called "super-upper" branch of response is observed for a low-mass ratio cylinder which is free to vibrate in both directions.

The work is still in progress and the CFD model is being expanded towards multiple “strips” in order to observe higher modes of vibration of the structure.

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Transient states in the transition to turbulence in channels

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Transition to turbulence in wall bounded shear flows like Couette flow, Poiseuille pipe or channel flow and boundary layer flow occurs in the presence of localized coherent structures, known as turbulent spots. These objects are composed of an assemblage of small-scale longitudinal vortices, separated from laminar flow by sharp fronts. These spots show either a transient growth and decay or a process of self-sustainment, showing a complex spatio-temporal intermittent behaviour, including collective organisation and branching.

The dynamic of this subcritical transition to turbulence with finite amplitude perturbations is strongly related to the existence and interplay of these localized structures. Since the pioneering work of Sir O. Reynolds in 1883, there is still no satisfying explanation of this transition and it remains one of the most fundamental and practical problem still unsolved in fluid mechanics.

The purpose of this talk is to present experimental work, doing with G. Lemoult and J.L. Aider, in a rectangular channel with plane Poiseuille flow, in a range of Reynolds numbers Re in which transition occurs. The linear theory of stability predicts undisturbed stable Poiseuille flow in channel until Re_c= 5772 but experiments show transition at $Re \approx 1300$ in the presence of isolated turbulent spots.

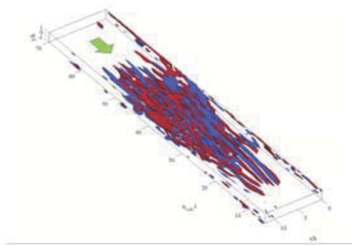

Figure 1: Spot structure: Cross sectionnal view for $Re = 2000$.

Many theoretical efforts have been made in order to understand the mechanisms sustaining the existence of turbulent spots. The non-normal linear models of stability explain relatively well, the fact that inner structures present maximum transient growth when they have components in the direction of the flow. But these linear models cannot predict the further process of destabilisation. A privileged frame for understanding this situation, is provided by non linear models of self sustained turbulence. Using Particle Image Velocimetry, we study the dynamics of the turbulent fluctuations of the velocity components and compare with predictions of non linear low dimensional models. We also show the separation of the flow in a small scale motion, mainly composed of destabilized streamwise streaks, and a large scale flow which surrounds the turbulent spot and can influence the morphology of these structures

Magnetic instabilities in stars

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Magnetic fields in stars are often attributed to a dynamo process. But there are several types of stars where a dynamo is apparently not operating. Observed magnetic features may be explained by the stability or instability of magnetic fields in theses cases. The results are actually interesting also for convective stars hosting a dynamo. We may only be able to understand all observed properties of stellar activity by the combined action of kinematic dynamos and MHD instabilities.

Shear instabilities in self-gravitating models of accretion disks: a kernel gravity wave interpretation

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The instance of shear driven gravitational instabilities in relation to planet formation in cold protoplanetary discs has received renewed interest. Recent results published in the literature show that Rossby wave instability (RWI) in the presence of gas self-gravity lead to counterintuitive predictions of the onset of instability as a function of system parameters including (but not limited to) instability in the presence of pressure depressions which are stable in the non self-gravitating limit. We examine the stability properties of self-gravitationally modified RWI in two shearing box accretion disk models (infinite cylinders and vertically averaged ``flat'' models) using the Kernel Gravity Wave formulation of shear instability analysis. We examine the responses of a pressure supported over/under density configurations separated by sharp boundaries. It is along these sharp boundaries that KGW's (i.e. buoyancy/entropy modified shear induced edgewaves) propagate. We extend previous results and detail how the onset instability can be due to either intra layer KGW instabilities or inter layer KGW phase locking mechanisms. Furthermore, we find that a given annular density depression/enhancement is unstable depending upon where in the disk this same density anomaly is located. We provide here the foundations for a unified interpretation of self-gravity modified shear instabilities. If time permits, nonlinear pseudospectral numerical simulations will be presented qualitatively examining how the transition to instability occurs under controlled parameter conditions.

Viscous instability and intermittent dissipation of Alfvenic intermediate shocks and solitons: a possible contribution to coronal heating

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Alfvén waves are ubiquitous in space and astrophysical plasmas, and are in particular supposed to contribute to the heating of media such as the solar loops that display intermittent properties both at the level of impulsive reorganization of the magnetic structures and of dissipative events associated with micro and nano flares. We study these phenomena in the framework of one-dimensional asymptotic models, the Cohen-Kulsrud-Burgers equation (in the purely MHD regime) and the derivative nonlinear Schrödinger equation supplemented with a diffusive term (when dispersion due to the Hall term is retained). It turns out that these models exhibit violent events (collapse), associated with reconnection and resulting from the viscous instability of intermediate shocks or of solitonic structures which form from the evolution of rotational discontinuities which are exact solutions of ideal MHD and of the Cohen-Kulsrud equation in its original non dissipative form (a consequence of the non strictly hyperbolic character of these equations, originating with their rotational symmetry about the ambient field). These equations provide paradigms of systems that, under certain conditions, have to undergo gradient or amplitude quasi-singularities to dissipate. These events, whose development require a longer time as the viscosity is reduced, are associated with the elimination of 2π phase jumps ("phase slip"), through the reconnection of the transverse magnetic field. They occur in situations where the magnetic field vector turns by an angle $|\Delta\theta| > \pi$ within the rotational discontinuity. Indeed, within this configuration, the solution cannot decay by a two-step process where the phase gradients is reduced before the outer field amplitude are dissipated. Reconnection can proceed smoothly in the case of a dark soliton which only needs to increase its depth for the amplitude to vanish, but is more violent in other configurations such as intermediate shocks or bright solitons where it involves a quasi singularity of gradient or of amplitude respectively. This viscosity-induced quasi-collapse strongly affects the turbulent regime which establishes when the system is randomly driven, providing a specific mechanism of energy transfer towards the small scales significantly different from the Kolmogorov cascade. It in particular leads to a strongly intermittent dissipation characterized by isolated bursts which are more intense and less frequent as the dissipation parameter is reduced. This small-scale generation process does not require backward propagating waves nor plasma inhomogeneities. Furthermore, the viscous decay of intermediate shocks which do not undergo instability produces a dissipation range at intermediate scales in the turbulent energy spectrum, thus invalidating the notion of inertial range and making turbulence properties non universal. A qualitatively similar dynamics is observed in simulations of one-dimensional MHD along the guide field, when taking into account the anisotropy of viscosity and magnetic diffusivity [G. Sanchez-Arriaga, G. Laveder, T. Passot, P.L. Sulem, Phys. Rev. E, **82**, 016406, (2010); D. Laveder, T. Passot, P.L. Sulem, G. Sanchez-Arriaga, Phys. Lett. A, **375**, 3997-4002 (2011); D. Laveder, T. Passot, P.L. Sulem, Phys. Plasmas, **19**, 092116, 2012; D. Laveder, T. Passot, P.L. Sulem, Dissipation bursts and lack of universality in Alfvenic turbulence, Phys. Lett. A, submitted].

Shock structure and ion gyration

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Recent observations of the Venusian bow shock and low-Mach number interplanetary shocks have shown that the structure of subcritical shocks is more complicated than it was earlier thought. It is shown, theoretically and with two-dimensional hybrid simulations, that the magnetic field profile is intimately related to the downstream gyration of the directly transmitted ions. The gyration results in a spatially quasi-periodically ion pressure and, therefore, spatially periodic magnetic pressure. The phenomenon is common for the shocks in a rather wide range of Mach numbers and upstream temperatures. With the increase of the Mach number the contribution of reflected ion increases and masks the periodicity due to the transmitted ions. Yet, even for a significant fraction of reflected ions the transmitted population dominates.

NONLINEAR INTERACTION OF ALFVÉN-CORIOLIS WAVES WITH MAGNETOACOUSTIC MODES IN THIN ROTATING DISCS

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The magnetorotational instability (MRI) of thin, vertically-isothermal Keplerian discs, under the influence of an axial magnetic field is investigated near the instability threshold. The weakly nonlinear interaction of in-plane polarized Alfvén-Coriolis (MRI) modes with stable vertically polarized magnetoacoustic waves is studied. Two (non-resonant as well as resonant) mechanisms of interactions are discussed. In the case of non-resonant interaction a nonlinear Duffing ordinary differential equation that characterizes the evolution of the amplitude of the MRI mode near the threshold of instability is obtained. As for the second (resonant) mechanism of waves interaction the conditions of possible resonances are defined and discussed. Both mechanisms act in such a way that the MRI is saturated due to the transfer of energy to the stable magnetosonic mode.

Effect of convection of the vapor on the Marangoni instability in evaporating liquid films

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ABSTRACT

The Marangoni effect appears on a pure liquid layer evaporating into an inert gas [1, 2]. The previous model of evaporating liquid films [1] disregards the effect of convection of the vapor by the flow of the gas induced by evaporation. However, in this study we first show that this effect cannot be neglected compared to that of diffusion of the vapor in the gas phase for the long-wavelength deformation of the liquid film. In order to investigate these effects on the Marangoni instability of evaporating liquid films, we model the dynamics of the liquid film taking into account the above effects. In the liquid phase we apply the long-wave approximation [3] to the governing equations. Assuming that the variation of the vapor concentration due to the deformation of the liquid-gas interface is localized in the vicinity of the interface, we consider only the dynamics of the vapor concentration at the interface. The diffusion term in the vertical direction of the mass transport equation in the gas phase is modeled using its expression at the flat-film state. The model consists of two partial differential equations for the two unknown variables, the film thickness and the interface concentration.

The basic state is the flat-film state with the liquid height decreasing, where the vertical advection and diffusion terms of the mass transport equation balance. The linear stability analysis of the basic state with our model yields a dispersion relation essentially different from that of the previous study [1]; long-wavelength disturbances always grow in the gravity-free case. When gravity is present, there exists a critical depth above which the film is stable. The effect of the vapor diffusion along the interface mitigates the Marangoni effect for short-wavelength disturbances. We also show that if the evaporation rate is sufficiently low the variation of the vertical advection term can be neglected and the dispersion relation becomes independent of the details of the model of that term.

In this presentation, we evaluate the critical thickness, the cutoff wavenumber and the maximum growth wavenumber for the ethanol-nitrogen system [2] as functions of the system parameters such as the wall temperature, the ambient vapor concentration and the depth of the concentration boundary layer in the gas phase. Simple analytical expressions for the above quantities are obtained if linearization is made with respect to the difference between the interface concentration and that in the limit of the vanishing film thickness. Both the values with and without the linearization will be compared.

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The stability of a static liquid column pulled out of an infinite pool

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We consider a solid cone whose vertex points down and dips in an infinite pool of liquid. If the cone is slowly lifted, a liquid column with its top attached to the cone is pulled out of the pool.

Previous work (Benilov & Oron 2010) showed that, paradoxically, small-height columns are unstable, whereas taller columns are stable – in both case, with respect to a particular type of axisymmetric disturbances. We extend this work to general non-symmetric disturbances.

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E. S. Benilov & A. Oron 2010, "The height of a static liquid column pulled out of an infinite pool", *Phys. Fluids* **22**, 102101.

Title: **The stability of and eddy genesis within a heated film flowing under gravity on an inclined substrate exhibiting a sinusoidal variation**

Authors: S Veremieiev and PH Gaskell

The topical problem [1, 2] of two-dimensional, gravity-driven, free-surface laminar film flow, for a Newtonian fluid, over a uniformly heated (at a constant surface temperature Θ_w), inclined, wavy substrate is explored for the case of films whose thickness is much smaller than the wavelength of the substrate. Of particular interest is the coupling between substrate topography and thermo-capillary/Marangoni, thermo-viscosity and thermal-expansion effects. It is assumed there is no evaporation from the free surface of the film, that the air above is stationary having a constant temperature Θ_a, while the heat transfer across it follows Newton's law of cooling. The specific heat and thermal conductivity of the liquid are taken as constant while the density, $\rho(\Theta)$, dynamic viscosity, $\mu(\Theta)$, and surface tension, $\sigma(\Theta)$, obey temperature dependencies of the form $\rho = \rho_0[1 - \beta'\Theta_r]$, $\mu = \mu_0[1 - \mu'\Theta_r]$, $\sigma = \sigma_0[1 - \gamma'\Theta_r]$, with $\Theta_r = (\Theta - \Theta_a)/(\Theta_w - \Theta_a)$; ρ_0, μ_0 and σ_0 are their values at the reference temperature Θ_a, while β', μ', γ' denote the associated thermal expansion, thermo-viscosity, thermo-capillary coefficients, respectively.

First, the stability of the flow is investigated with the number of parameters and dimensionless groupings involved giving rise to a wide range of interesting and novel results. The analysis performed to identify the critical Marangoni number, Ma_{crit} , for the onset of instability utilises Floquet-Bloch theory [1], which is applied to the linearised long-wave equations used to model the flow. The influence and importance of substrate waviness, capillary number, Ca, Biot number, Bi , substrate inclination angle, α, and especially thermo-viscosity and thermal-expansion on Ma_{crit} is investigated and corresponding neutral stability curves constructed.

Next, in regions were the flow is stable the underpinning flow structure, temperature field and the global heat transfer across the film are obtained via solution of the full Navier-Stokes, continuity and associated temperature equation, representing essentially the first reported solutions of their kind. These are obtained using a finite element discretisation of the governing equation set, based on Bubnov-Galerkin mixed interpolation with the free-surface parameterised via an Arbitrary Lagrangian-Eulerian (ALE) method of spines. It is shown that thermo-viscosity, thermal-expansion and Marangoni number all affect the internal flow structure (and heat transfer), in that when they are non-zero a skewed eddy is observed to be present. Comparisons are drawn with eddy genesis resulting from the subtle inter-play between inertia and varying surface geometry in the case of isothermal film flow [3].

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Partial coalescence of sessile liquid droplets

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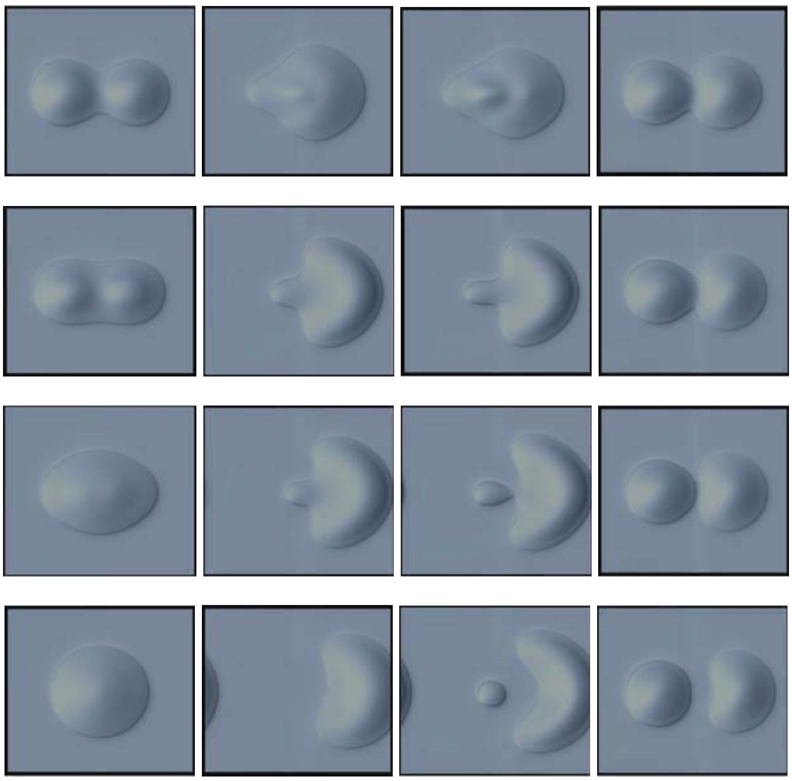
ABSTRACT

We examine numerically the interaction between two deformable drops consisting of two perfectly miscible liquids sitting on a solid substrate under a given contact angle. Driven by solutal Marangoni forces, several distinct coalescence regimes are achieved after the droplets collision (see Figure 1). Phase diagrams for different control parameters are emphasized, which give predictions about drop behavior along the solid substrates, control of various interfacial effects, manipulations of tiny droplets in micro- and eventually in nano-fluidic devices without power supply, design of droplets or cleaning surfaces.



(a) (b) (c) (d)

Figure 1: Time evolution for various coalescence regimes obtained for different surface tension gradients $\Delta\sigma = \sigma_2 - \sigma_1$ between the interacting drops: (a) total coalescence, $\Delta\sigma = 0$; (b) total coalescence, $\Delta\sigma = 4.2$ mN/m; (c) partial coalescence, $\Delta\sigma = 4.6$ mN/m; (d) drop separation, $\Delta\sigma = 6.5$ mN/m. The numerical computations are provided by the phase field theory with the liquid density $\rho = 1000\ kg/m^3$, the kinematic viscosity $\nu = 5 \cdot 10^{-6}\ m^2/s$, the drop radius $R = 4 \cdot 10^{-4}$ m, the contact angle $\theta = 15°$, and the surface tension of the left-hand-side droplet $\sigma_1 = 0.05$ N/m.

Rayleigh-Taylor Instability of a Liquid Film on a Solid Corrugated Surface Subjected to Tangential Oscillation

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Abstract

We consider a thin liquid film coating the underside of a solid corrugated surface subjected to harmonic oscillation in the direction tangential to the average location of the substrate in the gravity field in the high-frequency limit. We derive the nonlinear evolution equation describing the dynamics of the averaged film thickness in slow time. The method used in this work is based on long-wave theory and separation of relevant fields into fast and slow components.

We carry out linear stability analysis for a film of a constant thickness in the case of the substrate of a sinusoidal shape. It shows that axial forcing may either stabilize or destabilize the system with respect to the unforced one, depending on the choice of the parameters. The analysis is extended to the weakly nonlinear stage and reveals that the system bifurcates from its equilibrium supercritically independently of the forcing amplitude. Numerical investigation of the problem is carried out based on the evolution equation. Comparison with the static case shows that forcing can change the topology of the film interface, and affect the rupture time.

Investigation of droplet shedding in flow focusing geometries using the boundary element method.

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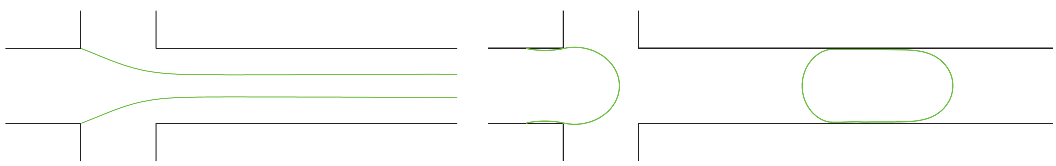
In microfluidics, one mostly encounters low Reynolds number flows, with the promise of linear governing equations. This linearity is however lost in many microfluidic Lab-on-a-Chip applications, where droplet emulsions serve as nano-liter sized transport containers, with the advantage to reduce contamination of species entrapped in the droplet with the channel, as well as cross contamination between droplets. These microfluidic two-phase flows are, even though at low Reynolds number, non-linear in essence because of the free droplet interface and the many-droplet interactions.

The flow focusing geometry is a key technique to create mono-dispersed droplets and the Rayleigh-Plateau instability is one of the main mechanisms that lead to a pinch-off of the fluid thread. In confined geometries, like flat microchannels the liquid thread can be stabilized and the pinch-off inhibited below a certain co-flow ratio at the cross junction. We investigate numerically the droplet formation and highlight the influence of the geometrical aspects ratios as well as viscosity ratio and flow rate ratio in the destabilization and controlled droplet formation.

For this purpose a microfluidic two-phase flows solver has been developed to account for for low Reynolds and Capillary number flows in flat microchannels. Exploiting the high aspect ratio we model the flow in a depth-average manner using the Brinkman equation.

The resulting 2D equation is equipped with boundary conditions that model for instance 3D effects like film formation and necking. This model equation is then solved by a boundary element technique (BEM), which is efficient for problems with moving interfaces. The solver has been validated against several static and dynamic solutions such as the Saffman-Taylor instability.

The figure below shows two configurations of different flow rates, left in the threading regime (a), right in the dripping regime (b). A numerical bifucation diagram, depending on the control parameters (co-flow ratio, viscosity ratio, capillary number etc.), is constructed and compared to the experimental literature.



(a) Threading

(b) Dripping

Figure 1: Simulation of threading and dripping in a microfluidic flow focusing geometry.

Minimal transition thresholds in plane Couette flow

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Subcritical transition to turbulence requires finite-amplitude perturbations. Using a nonlinear optimisation technique [1] in a periodic computational domain of plane Couette flow of size $4\pi \times 2 \times 2\pi$, we identify the perturbations transitioning with least initial kinetic energy. We propose a new scaling law $E_c = O(Re^{-2.7})$ for the energy threshold, steeper than all previously identified scalings in plane shear flows but matching well experimental estimates for pipe flow[2]. In all cases the associated perturbations are initially localised in space. The route to turbulence associated with the minimal perturbation is analysed in detail for $Re = 1500$. Several instabilities are found to occur in sequence: Orr mechanism, Oblique Wave interaction, lift-up, streak breakdown and spanwise spreading. The phenomenon of streak breakdown is revisited using leading finite-time Lyapunov exponents along the edge trajectory.

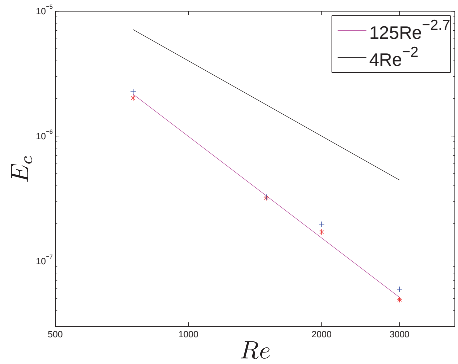

Figure 1: Critical energy as a fonction of Re for a plane Couette flow (pink line). Comparison with the $O(Re^{-2})$ Oblique Wave scenario[3] (black line).

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The speed of turbulent-laminar fronts in pipe flow

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ABSTRACT

Puffs and slugs in pipe flow are demarcated by turbulent-laminar interfaces, i.e. fronts, at their leading and trailing edges. In this work we are concerned with the speed of these fronts for Reynolds numbers from around the critical value, $Re_c = 2040 \pm 10$[1], to well into the slug regime [2, 3]. A simplified model of pipe flow [4, 5] provides a bifurcation-theoretic understanding of the transition from puffs to slugs. This bifurcation analysis explains why the speed of the upstream front (trailing edge) of a slug is smoothly connected with the speed of puffs at lower Reynolds numbers and it explains the continuous but non-smooth variation in speed of the downstream front (leading edge). The model predicts that there are two types of slugs – something that has gone unnoticed in the literature. Moreover, the model provides a comprehensive theoretical picture of how puff speeds are related to the speed of edge states, and in particular, why edge states move faster than the mean flow speed and why puff speed decreases with Reynolds number. An asymptotic analysis of the simplified model agrees remarkably well with real experiments and fully resolved DNS.

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ON TRANSITION VIA TRANSIENT GROWTH IN COUETTE FLOW

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Abstract A possible explanation for the transition phenomenon in Couette flow is the mechanism of transient growth. In this work we consider the instability of a two dimensional base-flow, consisting of Couette flow and pair of streamwise independent counter-rotating vortices (CVPs). We show analytically that the inclusion of nonlinear interactions between the base-flow and the CVPs is required in order to obtain eigenvalues that correspond to transition scenarios obtained using a direct numerical simulation (DNS). The relative dominance of the inflection points in the wall-normal and spanwise directions is studied using linear and nonlinear analysis.

INTRODUCTION

It is well known that Couette flow is stable with respect to infinitesimal wavy disturbances. An alternative possible explanation for the flow instability and the consequent transition to turbulence may lie in the linear mechanism of transient growth. Accordingly, a small disturbance can achieve a significant non-modal transient growth that can trigger nonlinear mechanisms before its eventual long-time decay owing to viscous effects. The maximal growth is obtained by a disturbance initially consisting of a pair of nearly streamwise independent counter rotating vortices (CVPs) which create streamwise streaks varying along the spanwise direction (with a spanwise wavenumber β) [1]. The streaks may become unstable with respect to infinitesimal disturbances and undergo secondary instability. In this study we have performed a two dimensional (wall normal and spanwise directions) linear and nonlinear stability analyses to the base-flow undergoing transient growth (namely, Couette flow with streamwise streaks) in order to obtain the optimal disturbance and to compare it with direct numerical simulation (DNS) of the transition scenario using the `Channelflow' code by Gibson [2].

METHOD & RESULTS

In order to follow the transition process, a two dimensional linear stability analysis is performed to a base flow of the form $\mathbf{U_0}$=(U_0(y, z), 0, 0) where y and z are the wall-normal and the spanwise directions, respectively (e.g. [3]). The analysis is conducted using the Floquet theory for the periodic base-flow in the spanwise direction, i.e. $U_0(y, z+2\pi\beta) = U_0(y, z)$. Initially, the base flow includes only the superposition of Couette and the modes associated with the initial CVP. It is found that the obtained eigenvalues are stable (having a negative growth rate (ω_i)), contrary to the DNS results which under the same initial conditions yielded transition. Therefore, the stability analysis is extended to include also the nonlinear interactions between the base-flow and the CVPs. It is shown analytically that such interactions produce unstable eigenvalues, which may explain the observed DNS transition scenario. In addition, using the linear and nonlinear analyses, the relative dominance of the inflection points in the wall-normal and spanwise directions is studied.

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Sensitivity analysis of the periodic orbits of plane Couette flow

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In the last decade, concepts from dynamical systems have been applied to gain insight into the transition to turbulence in canonical shear flows, such as pipe and plane Couette flow. For the latter case, nontrivial equilibrium solutions, travelling waves and periodic orbits has been computed, enabling the analysis of transition from a new perspective.[1,2]

In our contribution we focus on the periodic orbits in Couette flow. These unstable limit cycles are dominated by the self-sustained interaction between vortices and streaks[3] and are believed to be the core of turbulence dynamics. By applying the Floquet analysis, we calculate the flow Floquet multipliers and examine the most unstable Floquet modes and the related adjoint modes.[4] The analysis enables us to investigate the sensitivity of the unstable periodic orbits to structural perturations and baseflow modifications.[5,6] An extensive, preliminary, analysis of all the available periodic orbits has been carried out by focussing on the main features of the spectra and the resulting eigenmodes.

The eigenvalue sensitivity to localized structural perturbations over the orbit period is investigated by means of a sensitivity map, computed as function of time. It is found that the core of the instability coincides with the region where the streaks are bent, in agreement with previous numerical results. This feature characterises most of the analysed orbits.

Preliminary analysis of the sensitivity of the limit-cycle frequency to feedback forcing has shown the presence of high sensitivity regions localised where the velocity of the shear flow is higher. This analysis will be completed by considering the sensitivity of the limit-cycle amplitude to feedback forcing. The final goal of the investigation is to provide indications on how to alter the self-sustaining mechanisms of a turbulent flow.

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On the instability of convective flow in cylinder and possible secondary regimes

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Observations performed at Lake Baikal indicate the presence of deep mixing mechanism that transfers surface water to bottom regions. At the moment there is no general mathematical theory describing this phenomenon. For studying of the features heat and mass exchange the problem of convective flow of viscous heat-conducting liquid was investigated in the framework of the Oberbeck–Boussinesq model. Complex rheology and radiative heating take into account in the considered problem.

Exact solution describing the stationary flow in a cylinder with large radius is axisymmetric analogue of Hiemenz solution of Navier–Stokes equations in plane case:

$$\mathbf{u} = (u, v, w),\ u = u(z)r,\ v = 0,\ w = w(z),\ p = p(z) + ar^2/2,\ \theta = \theta(z),$$

where u, v, w are the radial, azimuthal and axial velocity components, respectively; p is the pressure, θ is the temperature, parameter a is to be defined.

The original problem is divided into consequently solved problems for u, w, p, θ. The basic one of them is the boundary problem for $u(z)$ function

$$\begin{gathered} u_{zz} + 2u_z \int\limits_0^z u(z)dz - u^2 + a = 0, \quad 0 < z < 1, \\ u(0) = u(1) = 0, \quad \int\limits_0^1 u(z)dz = 0, \end{gathered} \tag{1}$$

which can be reduced to the operator equation $u = Au$, where A is a strongly nonlinear operator satisfying the Schauder theorem in $C[0, 1]$. The iterative procedure for finding the a parameter and obtaining the radial velocity component was suggested. Three different values of the a parameter were found in the domain of the problem's physical parameters.

The linear stability of the three classes of solutions with regard to small perturbations was investigated numerically. The instability mechanism is changed and restructuring of neutral curves occurs depending on the a value. Critical thermal mode was sorted out, that leads to growing of thermal waves. Evolution of oscillatory mode depending on Prandtl number was investigated. Under small Prandtl numbers oscillatory modes decay. If Prandtl numbers are not small a new instability type will appears. This instability is connected with growing thermal disturbances.

Other instability mechanism was found out in the short waves domain. In this case the crisis attributes to growing hydrodynamical disturbances. Secondary regimes arising in the hydrodynamical mechanism of the instability loss was calculated.

This work was supported by Russian Foundation of Basic Research, Grant #11–01–00283 and Siberian Branch of Russian Academy of Sciences, Grant #38.

Downstream development of fully nonlinear intrinsic streaks in the flat plate boundary layer

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January 13, 2013

Abstract

Luchini [JFM, vol.327, 1996] analyzed the flow near the leading edge of a flat plate boundary layer with zero incidence using the linearized Navier-Stokes equations around the Blasius solution. He found that there is just one single streaky mode (periodic in the spanwise direction) that grows downstream from the leading edge. The presence of this growing mode in the linearized problem indicates that, in the fully nonlinear problem, there is a one parameter family of 3D steady streak solutions that emerge from the Luchini mode at the leading edge of the boundary layer. In this presentation, we will show the results of the numerical computation of the downstream nonlinear evolution of this family of intrinsic streaks (we call them intrinsic because they appear in the complete abscense of any free stream perturbations). These nonlinear streaks are computed using the Reduced Navier Stokes (RNS) formulation, which is a boundary layer like formulation that is obtained from the complete Navier–Stokes equations in the high Reynolds number limit, and provides the correct asymptotic description of three-dimensional streaks. Typical nonlinear streak computations present in the literature are performed using either direct numerical simulation (DNS), or the nonlinear parabolized stability equations (PSE). The RNS integration requires much lower computational effort than using DNS, and it does not have the consistency and convergence problems of the PSE. We will show and comment the characteristics of the resulting Reynolds-number independent, fully nonlinear streaks, which show a strong spanwise localization, and are very different from the previously computed linear streaks.

Dynamics of colloids and hydrodynamic vortices due to competition between various electrokinetic modes

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Abstract

By applying a stepwise overlimiting voltage to a nanoslot system in equilibrium it is possible to follow the time evolution of the electroconvective instability vortex array via the depletion dynamics or alternatively by following dielectrophoretically trapped particles at the stagnation points of each of the hydrodynamic vortex pairs (Figure 1). Particles are advected to the stagnation point by the hydrodynamics, while a short-ranged dielectrophoretic force traps them at the stagnation point. It is experimentally confirmed that the wave length selection process occurs at the diffusive time scale and that the wave length selection mechanism, started by the Rubinstein & Zaltzman [1,2] electroconvective instability is eventually determined by the system lateral geometry and dictated by Dukhin's [3] electroosmosis of the second kind (

Figure 2) [4,5]. The steady state case was numerically studied by solving the fully coupled electro-convective problem and solving the particle's planar (2D) equations of motions are solved after adding a dielectrophoretic force that accounts for quasi-3D effects. It is shown that this force can account for trapping at the nanoslot interface. This is extended also for the case of a single narrow nanochannel and to the case of an array of such narrow channels with varying interchannel spacing. In the former the controlling mechanism will be that of Dukhin's while in the latter interplay of these two mechanisms will exist depending on the interchannel spacing.

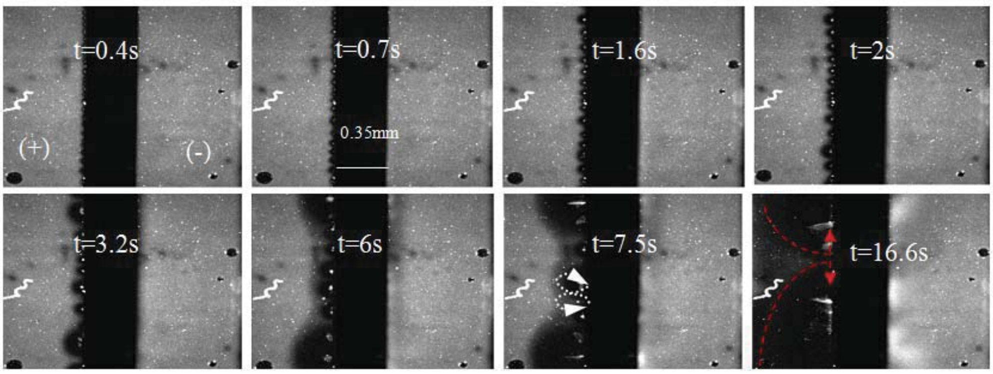

Figure 1: Time evolution of the electroconvective instability.

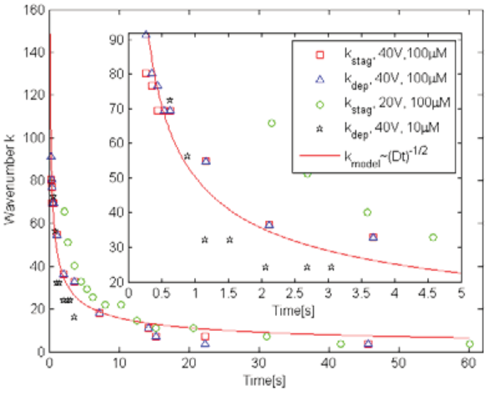

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Figure 2: Time evolution of the electroconvective instability's wavenumber.

INSTABILITY IN AXIAL-FLOW-INDUCED VIBRATIONS OF CYLINDRICAL CLUSTERS

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ABSTRACT

The induced vibration of cylinders in axial flow is one of the most basic and revealing problem in the general subject of axial-flow-induced vibration. It is particularly important for the study of safety of pressurized water reactor (PWR). Several researchers studied this problem theoretically and experimentally. This paper is aimed to numerically study the vibrations of two simple cylindrical clusters, one of which consisting of two cylinders and the other with four cylinders, and mainly to investigate the effect of the dimensionless flow velocity on the vibrations. An explicit partitioned scheme is applied to numerically solve the fluid-structure interaction (FSI) between the cylinders and the axial fluid flow. The fluid flow is assumed to be turbulent and simulated numerically based on the Navier-Stokes (N-S) equations with LES model and the dynamics of cylinders is modeled by Euler-Bernoulli beam theory. The damping effect on the initial strong vibrations is found, when the dimensionless flow velocity is small and the vibration eventually develops into weak oscillation as a result of the turbulent flow. The buckling instability could occur if the dimensionless flow velocity is large enough. Comparing the two results for the two models, it is suggested that increasing number of the cylinders promotes the buckling instability. The buckling shapes of all cylinders in the two models are dominated by the first mode beam shape.

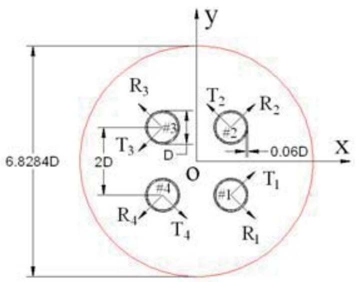

Fig. 1 **Schematic view of the four-cylinder model**

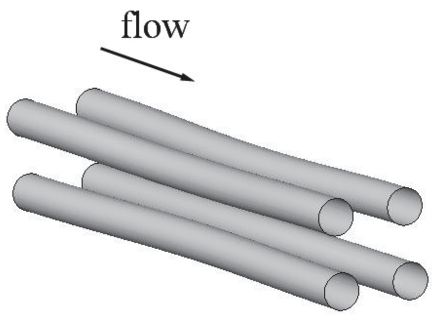

Fig.2 The buckling shapes of the cylinders

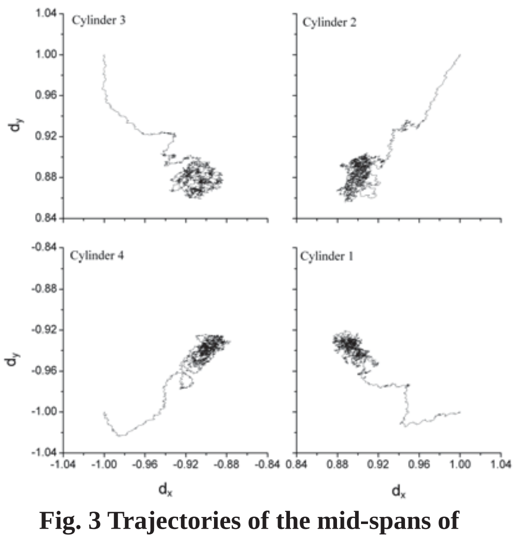

Fig. 3 Trajectories of the mid-spans of the cylinders

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The onset of flutter and self-excited oscillations of a viscoelastic slender body immersed in a uniform fluid flow

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The interest in complex nonlinear and non-stationary spatio-temporal dynamics of a flag immersed in a uniform flow dates back to the nineteenth century and is not fully resolved to this day. In this research we assume an inextensible viscoelastic nonlinear Euler-Bernoulli beam model truncated to cubic order combined with a slender body reactive force proposed by Lighthill in the context of fish locomotion. A stability analysis of a Galerkin based reduced order model is shown to accurately reproduce the onset of flutter measured experimentally. A weakly nonlinear multiple-scales asymptotic analysis of a truncated two mode system yields conditions for an unstable subcritical branch or the emergence of periodic supercritical self-excited dynamics. The latter is validated by numerical integration, and shows a good agreement with experimentally measured limit-cycle oscillations that extend beyond the limits of the slender body assumption.

Nonlinear stability of a perturbed Orr-Sommerfeld solution for the wake of stationary and moving cylinders at low Reynolds numbers

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We derive and investigate the nonlinear stability of a perturbed Orr-Sommerfeld solution for the wake of stationary and moving cylinders at low Reynolds numbers assuming quasi-parallel flow at a distance greater than ten diameters downstream. A weakly nonlinear asymptotic multiple-scales analysis yields a Stuart-Landau oscillator for the slow time evolution equation for the disturbance which in turn enables a consistent estimation of parameters based on physical measurements. For a streamwise location of twelve diameters behind the cylinder we find an excellent agreement between the asymptotically computed Strouhal number and measurements from several experimental studies. The spatial variation of the fundamental and second harmonics of the disturbance in this study also agree with experimental observations. Furthermore, the weakly nonlinear analysis does not change the location of the critical layer throughout the range of two-dimensional laminar vortex shedding ($47 < R < 190$) and hence verify the proposed asymptotic model-based estimation procedure for the reduced order analysis. Controlled periodic cylinder motion and self-excited vortex-induced vibration for an elastically mounted cylinder will be discussed.

The effect of fluid-structure interaction on the viscous fingering instability in an elastic-walled Hele-Shaw cell

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ABSTRACT

The development of viscous fingers in Hele-Shaw cells is a classical and widely studied fluid mechanical instability. When air is injected into a viscous fluid layer that fills the narrow gap between two rigid, parallel plates, the radially expanding air bubble that displaces the viscous fluid tends to be unstable to non-axisymmetric perturbations. These perturbations grow rapidly into large-amplitude fingers which undergo repeated tip-splitting, resulting in complex dendritic structures; see, e.g., [1].

In recent experimental work [2], we showed that the system's behaviour is changed dramatically when one of the two plates bounding the Hele-Shaw cell is replaced by an elastic membrane: Fluid-structure interaction considerably delays the onset of the instability and fundamentally alters the large-amplitude interfacial patterns that develop subsequently; with sufficiently flexible membranes, the fingering instability may be suppressed completely.

We present a theoretical model of the system, based on the coupled solution of the Reynolds lubrication equation (used to describe the flow of the viscous fluid) and the Föppl von-Karman equation (used to describe the deformation of the elastic membrane). Results of a linear stability analysis demonstrate how the stability of the axisymmetrically expanding air bubble to non-axisymmetric perturbations is affected by the presence of the elastic membrane. We then present results of direct numerical simulations, performed with `oomph-lib` [3], which allow us to follow the evolution of the instabilities into the large-amplitude regime. Finally, we use our results to identify the physical mechanisms by which fluid-structure interaction affects (or even suppresses) viscous fingering.

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Nonlinear Fluid-Structure Interaction of Viscoelastic Panels in an Acoustically Excited Inviscid Compressible Fluid

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Acoustic fluid-structure interaction is defined as structural response to excitation by sound and sound scattering due to structural fluctuations, respectively. In many cases the acoustic pressure fluctuations are small, and linear analysis is suitable. However, when structures such as aircraft panels, are exposed to significant acoustic excitation, such as in vicinity of engine outlets, linear assumptions are no longer valid and a nonlinear analysis is required. A combined asymptotic and numerical analysis of a clamped acoustically excited viscoelastic panel immersed in an inviscid compressible fluid is employed to reveal coexistence of stable and unstable, symmetric and asymmetric, periodic, quasiperiodic and spatio-temporal chaotic-like panel dynamics. The resulting bifurcation structure enables the tracking the spatio-temporal evolution of an intricate scattered pressure field due to complex and non-stationary symmetric and asymmetric panel surface pattern formation. The investigation reveals the need for a consistent nonlinear acoustic fluid-structure interaction analysis of a viscoelastic panel that is exposed to a high source pressure level and sheds light on the importance of nonlinear damping due to the panel viscoelasticity and acoustic radiation. Furthermore, the coexistence of multiple periodic and non-stationary solutions may be a crucial factor for design of high integrity structural systems required for aviation or space where light structures are exposed to intensive acoustic pressure fluctuations.

INSTABILITIES DURING MENISCUS-DEFINED CRYSTAL GROWTH

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Meniscus-defined melt crystal growth processes offer the possibility of growth of a crystal directly from a liquid surface, thus avoiding deleterious wall contact. Several processes have been developed, including detached Bridgman growth, edge-defined film fed growth, horizontal ribbon growth, and micro-pulling-down crystal growth. From a theoretical point of view, these are low to intermediate Bond number systems in which there often exists several meniscus shapes that can satisfy the local force balance. Consequently, these systems exhibit a variety of dynamical bifurcations, signaling existence of multiple steady solutions as well as time-periodic behavior. Bifurcations of the saddle node, pitchfork, transcritical, and Hopf types can occur depending on the growth configuration, particularly the manner in which the meniscus is confined at its ends. In addition, thermal effects often play an important role, either instigating or modulating the bifurcation. Commonly, solutions are found to exist only within a narrow range of operating parameters, posing problems to both physical operation and computer simulation of these systems.

We investigate these systems using hydrodynamic thermal-capillary models which rigorously solve for incompressible flow, heat transfer, and mass segregation within domains of liquid and solid that faithfully represent interfacial phenomena at the solidification growth front and the melt meniscus. Steady-state model equations are solved on deforming grids by the Galerkin finite element method. Locations of the growth front, triple-phase line, and meniscuses are all computed to satisfy appropriate physics at these interfaces. Solution stability is assessed by nonlinear transient analysis.

We present cases of instabilities for several crystal growth systems with technological relevance. Specific failure mechanisms are discussed, as well as generic behavior common to all meniscus-defined growth systems. The nature of the end condition imposed on the meniscus, namely whether it meets a smooth surface at the wetting angle, or is pinned at a sharp corner, has a profound influence on system behavior. Saddle node limit points are commonly observed in pinned systems. Symmetry-breaking pitchfork bifurcations are observed in systems of a planar geometry having two pinned menisci. Perhaps most unusual, however, is the appearance of a transcritical bifurcation in the detached vertical Bridgman system which marks a loss of solution stability above a critical wetting angle of melt on crucible. This bifurcation presents a limit on stability but none on existence, making it possible to employ an active control strategy based on controlling the pressure below the meniscus.

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Scaling laws for instabilities in Czochralski crystal growth configuration at large Prandtl numbers

- BIFD 2013 -

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ABSTRACT

The aim of the present research is to perform systematic study of three-dimensional steady-oscillatory Czochralski melt flow. Measurements are focused on the steady-oscillatory flow transition, which is defined by appearance of temperature oscillations measured mainly by optical methods. The performed research aimed to extend our understanding of destabilization of convection at various Prandtl and Grashof numbers in order to validate experimentally a series of numerical predictions indicating on a strong destabilization of CZ flow (Figure 1). The results show that that critical temperature difference (critical Grashof number) scale with the power of -0.815 of the Prandtl number. To achieve the goal we modified the existing so called small experimental facility. This facility now enables to vary in a wide range the diameters of dummy as well as the height of working liquid while taking care of the meniscus between the working fluid and the dummy. In a real crystal growth facility the ratio of these values lead to variety of aspect ratio due to transition of crystal from liquid to solid phase during actual growth of a crystal. This process affects the conditions of instability. The different silicon oils are used as experimental liquids for examination of influence of different aspect ratio values on instability onset at different Prandtl numbers. In Figure 2 the results are presented for silicon oil with viscosity 5 cSt showing that critical temperature difference dependence according to power of about -4.5 of the dummy diameter for all aspect ratios.

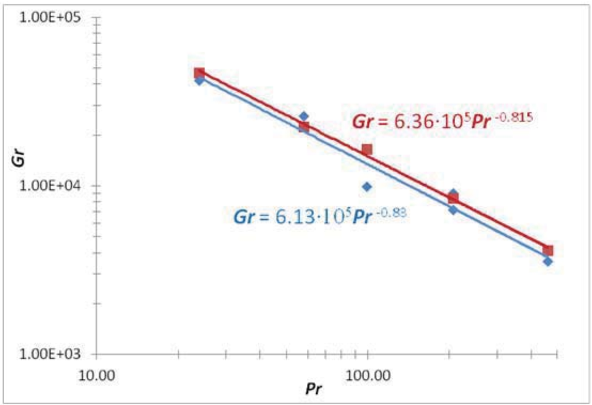

Figure 1. Critical Grashof number ***Gr*** depending on Prandtl number ***Pr*** and comparisson of correlations obtained by experimental observations (blue and diamonds) and computational results (red and squares).

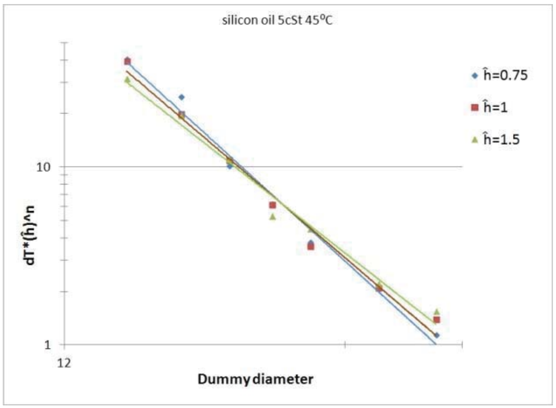

Figure 2. Normalized critical dT vs. dummy diameter for silicon oil 5cSt at varying heights ĥ. Parameter ĥ is normalized height of oil: $\hat{h}=h/r_c$, where r_c – radius of crucible.

Transverse Acoustic Forcing Effects on an Annular Swirling Jet

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A fuel-lean premixed flame stabilized on an annular swirling jet is the most common burner configuration incorporated in state of the art gas turbine combustors. Axial and azimuthal shear layers formed in such a flow configuration aid in flame stabilization at high inlet flow velocities. At high swirl numbers, the formation of reverse flow regions associated with vortex breakdown further facilitates flame stabilization. In order to achieve high power outputs, modern gas turbines employ an array of multiple annular swirling jet burners. The burners are arranged circumferentially and share a common combustion chamber. Such gas turbine combustors are referred to as annular combustors (ACs).

One of the major issues experienced in such a gas turbine system is the occurrence of thermoacoustic instability. Thermoacoustic instability is the spontaneous emergence of high amplitude pressure and heat release rate oscillations in a combustion system. In a premixed swirl flame system, heat release oscillations are associated with flame surface wrinkling and the pressure oscillations are associated with acoustic modes of either the manifold upstream of the burner or/and the combustor downstream. When heat release rate oscillations and acoustic oscillations get coupled via a feedback mechanism, self-sustained oscillations (thermoacoustic oscillations) are established. The basic criterion for the occurrence of such instabilities was first proposed by Lord Rayleigh in 1877. Centuries later, thermoacoustic instability has emerged as a concerning issue for the power and propulsion industries.

In ACs, during thermoacoustic instability, coupling of acoustic modes associated with the annular combustor and heat release rate oscillations from individual burners is established. As such, individual flames experience acoustic fluctuations that are transverse to the axis of the burner. Although flame dynamics in response to acoustic oscillations aligned with the burner axis has been studied extensively, significant understanding needs to be developed on swirl flame dynamics in response to transverse acoustic fluctuations to tackle the issue of thermoacoustic instability in ACs. This is the motivation of our investigations.

We are investigating a single swirl burner test-rig with transverse extensions. The transverse extensions provide the possibility of introducing transverse acoustic forcing on the swirl flow/flame. The first step is to analyze the effect of transverse acoustic forcing on the isothermal swirl flow at different swirl numbers. In particular, the effect on the vortex breakdown zone and the shear layers will form the focus of our investigations.

The methodology of this investigation will involve high speed Particle Image Velocimetry (PIV) of the swirl flow at different swirl numbers to identify the onset of vortex breakdown, followed by high speed PIV of the swirl flow in the stream-wise plane with transverse acoustic excitation for discrete frequencies and three different swirl intensities: low swirl (no vortex breakdown), intermediate swirl (following the onset of vortex breakdown) and a high swirl case.

Transverse acoustic forcing is expected to induce strong oscillations in the flow at low frequencies (60-400 Hz). The effect is expected to be more pronounced at acoustic forcing conditions such that a velocity antinode exists at the swirler axis. Such acoustic forcing will lead to asymmetric velocity fluctuations about the axis of the annular swirling jet. Asymmetric coherent structures in the flow (associated with the precessing vortex core) will be amplified. In contrast, acoustic forcing such that a pressure antinode exists over the swirler axis is expected to be favorable for bulk oscillations symmetric to the swirler axis.

This investigation will elucidate the role of transverse acoustic forcing on the vortex breakdown bubble and the associated precessing vortex core and their role in the interaction of the swirl flame with transverse acoustic forcing.

A SHALLOW LAYER MODEL TO STUDY THE WAVE INSTABILITIES OF A THIN LIQUID LAYER INSIDE A ROTATING CYLINDER

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Key words: Centrifugal casting, shallow water model, vibrations, waves, solidification, Coriolis force

During the horizontal spin casting of rolls, vibrations and mould deformations seems to have a significant effect on the final quality of the product. Sources for vibrations can be found in the poor roundness and a static imbalance of the chill itself.

Since the layer of liquid metal is usually much smaller than the radius of the cylinder, a shallow water model for the flow of liquid metal layer on the inside surface of a rotating cylinder was developed. The objective was to study wave patterns of the free surface, wave birth, propagation, and death. Besides, the aim was also to study a response of the system on different initial conditions i.e. the initial liquid height was either constant or perturbed using a sine-like function. The main assumptions of the model are: The angular frequency Ω of the cylinder is so high that the fluid is mainly rotating with the cylinder. For this reason, the model was defined in the rotating frame of reference. A parabolic velocity profile along the liquid height was taken into account with no slip boundary condition on the cylindrical wall. The model was further extended in order to account for vibrations and an axis bending. The set of shallow layer equations had to be derived for the cylindrical geometry, it concerns essentially the gravity, the centrifugal and the coriolis force. The expression of these forces becomes very complicated in the case of mould deformation. It was shown that despite extremely high centrifugal forces (~100 G) acting on a liquid layer the interaction between the inertia, the gravity, and the vibrations can lead to the formation of waves on the free surface. The higher the liquid height is, the more it is prone to instabilities. The magnitude of accelerations and flow velocities predicted by the present model leads to the idea that strong fragmentation of the solidified elements occur. The results are compared to experimentally observed wave pattern on a rotating cylinder made of plexiglass.

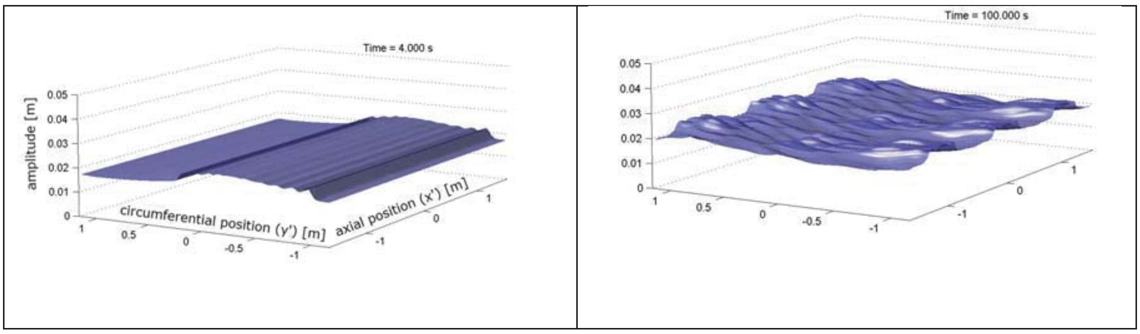

Figure 1: Simulated shape of free surface **(Ω=72 rad/s)** at times 4 s and 100 s

Instabilities and eddies of a Snowball ocean

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An ocean covered by (~1 km) thick ice, motivated by Snowball Earth conditions and driven by a very weak geothermal heat flux, is shown to be characterized by an energetic turbulent eddy field. There are two opposite-sign zonal jets on the two sides of the equator, and changing sign with depth. In addition, multiple barotropic eddy-driven jets appear off the equator. We discuss the instability processes underlying eddies and jets, and the eddy-mean flow interactions generating and sustaining them. We also estimate eddy-parameterized viscosity and diffusion coefficients based on the eddy resolving simulations.

Long-wave instability of flow with temperature dependent fluid properties down a heated incline

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Abstract

We present an analytical study which investigates the effect of temperature dependence in fluid properties on the interfacial instability of flow down a heated incline. Along with temperature variation in surface tension we consider variable mass density, viscosity, thermal conductivity and specific heat. A linear stability analysis is carried out which yields the critical conditions for the onset of instability in long-wave perturbations. Results are obtained for the particular case when there is variation only in surface tension, density and specific heat, and in the case with negligible and high rate of heat transfer across the free surface. For the general case, asymptotic expansions are implemented based on the assumed smallness of the variation with temperature in viscosity and thermal conductivity, or on weak heat transfer across the free surface.

Three-dimensional instabilities of solitary waves in a falling liquid film

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ABSTRACT

We consider a liquid film falling down an inclined plane for moderate Reynolds number. Applying temporal forcing at the inlet, two-dimensional fast solitary waves are observed at low frequency. If the forcing frequency is higher, the waves are nearly sinusoidal ; these slow waves are unstable and evolve downstream into fast solitary waves as a result of a secondary instability ([1], [2]). We study both numerically and experimentally the transition to 3D waves in order to better understand the generation of wave turbulence in liquid films.

Starting from low-dimensional models [1], 2D stationary solutions are computed by continuation. Then, three-dimensional linear stability analysis is done with a pseudo-spectral Fortran code which has already been used for studying the stability of slow waves [1]. We analyse the results by doing an energy budget in order to identify which terms are stabilizing or destabilizing [3]. Two distinct modes are identified : a capillary mode, which is oscillatory and grows only in the capillary waves region, and an inertial mode, which slowly deforms the whole wave and disappears when the inclination angle is lower than $12\,^\circ$.

These theoretical predictions are put to the test by mean of comparison to experimental results. The experiment consists in a water film flowing down an inclined glass plate whose dimensions are 150 cm (length) $\times$ 40 cm (width). The inclination angle can vary up to $\beta = 20\,^\circ$. The forcing at the inlet is applied through harmonic oscillation of a plate above the liquid surface in the range of frequencies : $2 \leq f \leq 20$ Hz. The Reynolds number is varied up to $R = 100$. A Schlieren method [4] is employed to visualize the wave patterns and measure the film height (Fig. 1). This method, based on the observation of a dot pattern through the liquid interface, provides 3D thickness maps over large domains (20 cm $\times$ 25 cm) with high temporal (> 100 Hz) and spatial (0.5 mm) resolutions and with a precision of about $20\,\mu m$. We make a cartography of the 3D structures observed in the plane $\beta - f$ and compare the topography and wavelengths of the two modes of instability to numerical data. Influence of the forcing frequency as well as the viscosity and surface tension of the liquid is discussed.

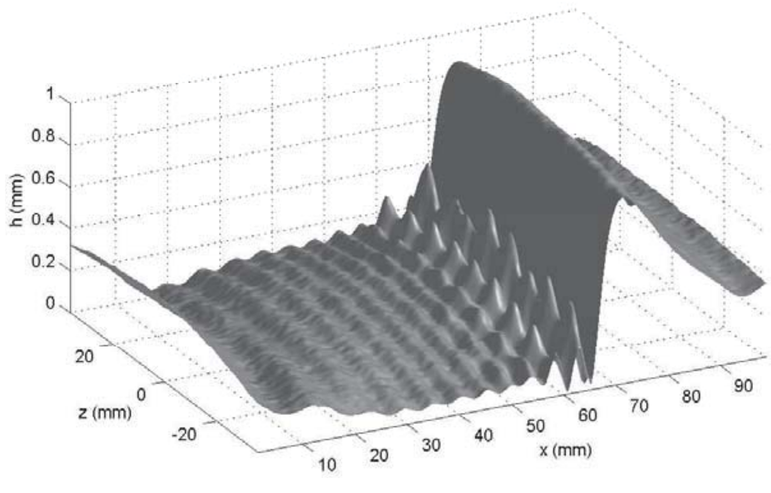

FIGURE 1 – Schlieren topography of a solitary wave on a water film undergoing a 3D capillary mode of instability. Experimental parameters are : $\beta = 8.3\,^\circ$, $R = 60.3$, $f = 3.5$ Hz

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Drops climbing uphill on vibrating inclined substrate

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We examine the evolution of a liquid drop on an inclined substrate oscillating vertically. The oscillations are assumed weak and slow. This makes the liquid's inertia and viscosity negligible, so the drop's shape is determined by a balance of surface tension, gravity, and vibration-induced inertial force – whereas its motion is determined by the motion of the contact line.

On the basis of these approximations, an asymptotic expression is derived for the mean velocity of the drop. It is shown that, if the amplitude of the substrate's oscillations exceeds a certain threshold value, the drop climbs uphill. This extends the previous study by Benilov (2011) where the drops were assumed thin. Relaxing this restriction enables one to compare the results with those of the experiments of Brunet et al. (2007).

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FLUID TRANSPORT IN THIN LIQUID FILMS USING TRAVELING THERMAL WAVES

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Fluid pumping in open microfluidic devices is essential in many engineering, biochemical, and medical applications. We use direct numerical simulations of the full continuity, Navier-Stokes and energy equations along with the analysis based on the long-wave theory to examine the dynamics of thin liquid films on planar substrates with spatially periodic non-uniform heating that propagates in the form of a thermal wave along the substrate. Using these two modeling techniques, we probe how the periodic thermal wave can be harnessed to induce and regulate directed fluid flows along the substrate. We find that the net flow rate can be regulated by the magnitude of the substrate heating non-uniformity and the relative period, amplitude, and velocity of the traveling thermal wave. In particular, there exists an optimal speed of the thermal wave maximizing the net liquid flow rate for a given wave periodicity. Its variation with respect to the parameter set of the problem is currently under scrutiny. Furthermore, we study the stability of thin films to identify the parameter range providing robust operation of open microfluidic systems involving thermocapillary effects.

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Bifurcation analysis in low-frequency and high-frequency models of Marangoni convection with periodically modulated localized heating

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In the work [1] two long-wave models are derived of Marangoni convection in a thin layer of fluid with a free surface, subjected to a localized periodically modulated heating, further addressed as LF and HF models, with the low-frequency and high-frequency modulation of localized heat flux respectively. The heat inhomogeneity is treated as compatible with long-wave approximation, slightly exceeding the critical value for the case of homogeneous heat flux inside the localized hot spot, and having subcritical value outside it. The problem for both models is reduced to the system of two-dimensional nonlinear equations for the amplitudes of the disturbances of temperature, vorticity (only for the LF model) and deviation of free surface from the flat undeformed state. In the present work further study of stability and bifurcations in this system is presented, in wide range of values of frequency modulation and of parameters of spatial inhomogeneity of localized heat flux. The flat and axisymmetrical versions of the horizontal inhomogeneity of thermal spot are examined. The LF model gives a localized in space basic solution, the time-periodic with period of modulation. Change of parameters of spatial inhomogeneity of heat flux leads to the instability of this solution and to development of local and global structures, also periodic in time with a period of modulation. In the numerical calculation using the LF model the resonance frequencies are obtained, corresponding to characteristic hydrodynamic times. At frequencies exceeding resonance, the analysis of time-averaged over period of modulation values of variables, and their comparison with those calculated using the HF model, are performed. This allowed determining the limits of applicability of the HF model, formulated in terms of amplitudes of temperature field and deformation of the surface, averaged over fast time of HF modulation period. Due to the fact, that the problem of linear stability of basic state in the LF model is nonself-adjoint, both the monotonous and nonmonotonous development of the disturbances, averaged over period of modulation are possible in this case. The parameter domain of non-monotonicity is determined, at change of by frequency and amplitude of modulation, for various parameters of spatial inhomogeneity of heat flux. For the HF model in [1] only monotonous instability modes are predicted, due to gradient character of system evolution at deviation from basic states. In the present work the possibility is analyzed to retrofit the HF model by account of influence of large-scale vorticity of the mean flow, which leads to nonself-adjointness of the linear stability problem for the basic state, and to its possible oscillatory instability.

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Static response and stability of coated microbubbles as a means of parameter estimation

- BIFD 2013 -

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ABSTRACT

The static response of a coated microbbuble subject to an external pressure distribution is investigated, in order to employ Atomic Force Microscopy (AFM)as a means for estimating the viscoelastic properties of contrast agents. Available AFM measurments reveal a linear regime in the force displacement curve followed by nonlinear response. These regimes are determined by the relative strength of stretching and bending energy of the coating. Current practice relies on the linear part of the response for estimating shell stiffness. Numerical/theoretical analysis of the axisymmetric response to a point load can be used to provide the area dilatation modulus and bending stiffness of the shell without prior knowledge of the shell thickness, by focusing on the behavior of the linear and nonlinear parts. When a flat cantilever is used the linear part of the response curve is extended. Compressibility of the internal gas becomes relevant at relatively large displacements in this context. The buckling instability of a uniformly loaded shell is also investigated in order to assess the effect of internal gas compressibility on the axisymmetric and three dimensional bifurcation structure. This is viewed as an alternative approach for parameter estimation and identification of folding instabilities exhibited by lipid monolayer shells.

Acoustic interaction between a coated microbubble and a nearby surface – Steady pulsations vs. transient break-up

- BIFD 2013 -

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ABSTRACT

Boundary element simulations are performed on coated microbubbles that pulsate subject to acoustic disturbances. Their coating is treated as a viscoelastic solid while the surrounding liquid is treated as an ideal fluid. When the microbubbles are immersed in an infinite medium they pulsate upon insonation performing radial or axisymmetric shape oscillations depending on the sound amplitude and frequency, as well as the shell material and initial size and stress state. Further increase of sound amplitude determines a threshold between steady pulsations and transient break-up that is of central importance in establishing the parameter window for implementing imaging modalities using such particles as contrast agents. The effect of a nearby surface in modifying the microbubble response is investigated, by treating the former as a rigid wall or elastic medium. In particular, the time evolution of the distance between the microbubble and the surface is monitored and its effect on the backscatter cross-section and microbubble cohesion is captured. A comparison is also performed against available in vitro acoustic and optical measurements.

On the buckling instability of liquid threads in a divergent microchannel

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Studies on buckling of viscous jets can be historically dated back to Taylor[1]. Though he presented no quantitative or qualitative analysis of the involved physics, he importantly attributed buckling to the presence of longitudinal compressive forces acting along the axis of the jet, analogous to the case of buckling of solid beams. Following the seminal contribution by Taylor, several experimental and theoretical works have focused on the buckling instability of viscous threads impinging on flat surfaces[2]. This phenomenon is also referred to as the "rope-coiling effect" of viscous fluids. Buckling has also been reported in jets flowing at very high Reynolds number. However, the origin of instability in this case is attributed to inertial forces and are not relevant to the current work.

In this work, we shed some light on a recent experimental work by Cubaud and Mason[3] which presents an interesting instance of buckling instability in a divergent microchannel. A straight flowing configuration of the viscous thread along the length of the channel appears to be unstable as they report that the thread folds and propagates sinusoidally through a divergent microchannel [Fig. 1].

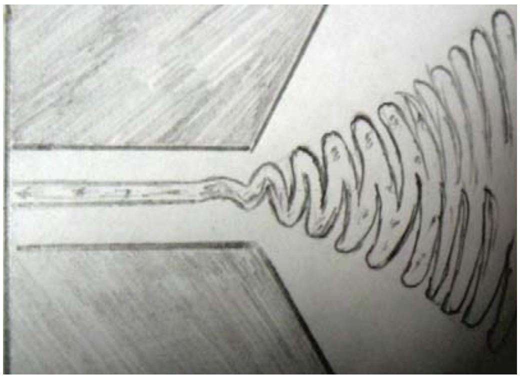

Fig. 1. A schematic sketch of buckling instability of a viscous thread in a divergent microchannel

We develop a minimalistic model to capture the essential dynamics of buckling for this case. In micro flows, inertial effects are insignificant owing to their characteristic low Reynolds numbers. Also, as the jet appears surprisingly stable to capillary instability, surface tension forces can be rendered unimportant. The situation, on the outset, resembles the "rope -coiling effect" seen in the case of viscous threads. However, unlike the "rope-coiling effect", wherein the impingement on the flat surface results in a compressive force along the jet, the buckling observed in a divergent microchannel is a result of the adverse pressure gradient in the channel arising as a result of its divergent geometry. We use the results of the model to bring forth the underlying physics governing the instability.

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Transient electrical response at the microchannel-nanochannel interface near the overlimiting transition

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Transient response of the interface between a permselective membrane and electrolyte has been studied both theoretically and experimentally in the context of several well-developed electrochemical measurement paradigms. Similar studies of the microchannel-nanochannel interface have been conducted in the Ohmic response regime, however little work has been done at currents near and above this transition. The transition from Ohmic to non-linear response occurs during the development of concentration polarization under increasing DC bias—a result of charge-selective transport through the nanochannel, due to overlapping electric double-layers induced by the presence of a fixed surface charge on the channel walls. The increasing contribution to device impedance of the depleted concentration region, eventual development of extended space charge at the micro-nanochannel interface, and subsequent onset of electrokinetic instability will affect the electrochemical impedance response of the device. Here we report experimental results concerning the use of electrochemical impedance spectroscopy (EIS,) along with other electrochemical measurements (chronoamperometry, linear sweep voltammetry,) used to characterize the response of the micro-nanochannel interface. In addition to providing a useful probe of transient behavior at the interface, such techniques have great potential in biomolecular sensing applications.

Geometric modulation of electrokinetic instability in micro-nanochannel interface devices.

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We present a survey of recent experimental and theoretical results concerning geometric effects on electrokinetic instability in micro-nanochannel devices. The instability occurs at the microchannel-nanochannel interface where overlap of electric double-layers inside the nanochannel—due to the presence of fixed surface charge groups—results in preferential transport of counter-ions over co-ions, e.g. charge selectivity. This charge-selective transport induces a concentration polarization effect; passage of DC current through the nanochannel promotes the growth of depleted and enriched electrolyte layers on opposite sides of the nanochannel. At sufficiently high currents, the depleted region develops an extended space charge layer adjacent to the micro-nanochannel interface. As the applied voltage exceeds a critical threshold, the loss of mechanical stability in this space-charge region leads to the formation of fast fluid vortices which undergo a complex wavelength-selection process, exhibiting distinct regimes. Both microchannel dimensions and interfacial geometry have been shown to affect the onset and subsequent development of the vortex flow field. Here we present results concerning suppression and control of the onset of instability as well as demonstrating competition between different vortex mechanisms. These effects modulate the interfacial mass transport and, hence, ionic current, through the interface and produce observable patterns. These results are of both fundamental and practical interest, with implications regarding energy cascading in the wavelength-selection process and colloid-hydrodynamic interactions. The practical applications of such effects range from bio-molecular concentration, separation, and detection to micro-purification and on-chip electro-dialysis.

SOUND GENERATED BY A WING WITH A FLAP INTERACTING WITH AN EDDY

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Abstract

Acoustic signature of a rigid wing, equipped with a movable downstream flap and interacting with a line vortex, is studied in a two-dimensional low-Mach number flow. The flap is attached to the airfoil via a torsion spring, and the coupled fluid-structure interaction problem is analysed using thin-airfoil methodology and application of the emended Brown and Michael equation. It is found that incident vortex passage above the airfoil excites flap motion at the system natural frequency, amplified above all other frequencies contained in the forcing vortex. Far-field radiation is analysed using Powell-Howe analogy, yielding the leading order dipole-type signature of the system. It is shown that direct flap motion has a negligible effect on total sound radiation. The characteristic acoustic signature of the system is dominated by vortex sound, consisting of relatively strong leading and trailing edge interactions of the airfoil with the incident vortex, together with late-time wake sound resulting from induced flap motion. In comparison with the counterpart rigid (non-flapped) configuration, it is found that the flap may act as sound amplifier or absorber, depending on the value of flap-fluid natural frequency. The study complements existing analyses examining sound radiation in static- and detached-flap configurations.

“Dynamics of Purcell's three-link microswimmer with a passive elastic tail”

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Abstract:

One of the few possible mechanisms for self-propulsion at low Reynolds number is undulations of an elastic tail, as proposed in the classical work of [Purcell, 1977]. This effect is studied here by investigating a variant of Purcell's three-link swimmer model where the front joint angle is periodically actuated while the rear joint is driven by a passive torsional spring. The dynamic equations of motion are formulated and explicit expressions are given by using resistive force theory for slender bodies in viscous fluid. Next, the leading-order solution is derived by using perturbation expansion and leading-order expressions are formulated for the displacement-per-stroke, mechanical work per travel distance, and average Lighthill’s efficiency. The dependence of the motion on the actuation amplitude and frequency is analyzed. Finally, optimization with respect to the actuation frequency and the swimmer's geometry is conducted.

“Asymmetry and stability of shape kinematics in microswimmers' motion”

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Many swimming microorganisms that are governed by low-Reynolds-Number hydrodynamics utilize flagellar undulations for self propulsion. Most of existing theoretical models assume that the shape kinematics is directly controlled, while in reality, shape changes are induced by applying actuation forces and torques, as in eukaryotes like sperm cells in which molecular motors actuate internal bending moments along the flagellum. Under control of the internal forces and torques, the swimmer’s shape is dynamically evolving and periodic gaits may become unstable. In this work the problem is addressed by revisiting Purcell's three-link swimmer model where the joint torques are controlled. The swimmer's dynamic equations of motion are formulated and the underlying geometric symmetries are analyzed. It is found that certain symmetry properties of the input induce a reversing symmetry on the dynamics of the joint angles, under which periodic solutions are marginally stable. Moreover, it is proven that one has to break the front-back symmetry of the swimmer's structure and/or actuation profile in order to induce time-periodic solution for the shape kinematics which is orbitally asymptotically stable under perturbations. In particular, a swimmer with large drag resistance at its front enjoys a strongly stable shape kinematics. The results may explain why most of the flagellated eukaryotes swim with their head forward.

Section 3: Bifurcation and instabilities in technological applications

PIV-visualization of bubble structures in a tall cylinder driven by a rotating endwall

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A fundamental problem of our investigations concerns a phenomenon of vortex breakdown which is characterized by an abrupt structural change in swirling flows without outside disturbances and energy consumption. That interesting scientific problem is very important because this phenomenon appears in many practical problems in aerodynamics, geophysics and engineering sciences.

For moderate aspect ratio (H < 3) of the cylindrical cavity (simplest model of bio and chemical reactors) the visualizations [1] and PIV - measurements [2] already performed and clearly indicated regimes with steady and unsteady bubbles. However for taller cylinders (H > 3) only regimes of multi-vortex breakdowns without bubble has been seen in our early experiments and simulations [3-4]. These flows in both equivalent interpretations as rotating waves or as helical multiplets [5] are distinguished from the more widely studied swirling flows in shorter cylinders, where regimes with steady bubbles onset at first and then it dominate for big area of Reynolds numbers [1-2]. Nevertheless, early simulation of the flow in taller cylinders [6] has indicated a flow regime with unstable bubble which could not confirm in next numerical study [7]. For this reason we repeated our experimental investigations of the tall cylinder to see more carefully these flow regimes by stereoscopic PIV and as result the flow regimes with unstable bubbles has been indicated undoubtedly (fig. 1)

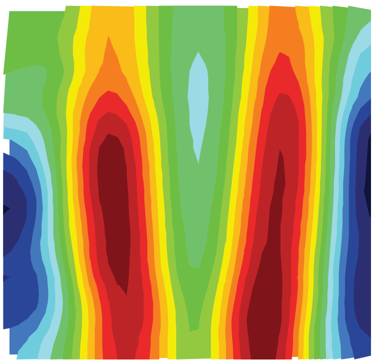

Fig. 1. An example of bubble: distribution of the axial velocity with reversal flow on the axis in a middle part of the diametrical cross-section of the cylinder at H = 4.0 and Re = 3800

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Targeted Energy Transfer in Fluttering Systems

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Models of self-excited oscillations, which involve autonomous systems with stable limit cycle (or more complicated attractors), arise in various sorts of engineering problems. LCOs (Limit Cycle Oscillations) are known to be one of the most dangerous problems in mechanical structures in general, and more specifically in fighter aircrafts at high subsonic and transonic speeds.

The purpose of this research is to develop a design for suppression of these undesired self-excited oscillations, based on the concept of nonlinear energy sink (NES). This idea is based on adding to the primary system a relatively small and spatially localized attachment, which leads to essential changes in the properties of the whole system.

For modeling purposes, we will use a primary system described as Van der Pol - Duffing oscillator, and attach to the NES device with cubic nonlinear stiffness and linear damping. Account of strong nonlinearity of the primary system (and inevitable frequency changes at various response amplitudes) is necessary in many models of flutter; this feature has not been considered before in the systems comprising the NES.

In order to investigate the model analytically we use averaging and singular perturbation analysis. These methods allow prediction of possible response regimes of the system. The results are verified by means of numeric simulations.

Similar idea is used for partial prediction of dynamic responses of the cylinder immersed in the moving liquid, with the NES attached in order to mitigate vortex – induced vibrations. Numeric simulation of the system is based on the Navier-Stokes equations, which can only be solved numerically; thus, we construct a reduced – order approximation of the cylinder motion and attach the NES. For part of the responses (not too close to the bifurcation points and for relatively small mass ratios) the reduced – order model successfully predicts the response regimes, both qualitatively and quantitatively.

Mediterranean Deep Water Formation Bi-Stability

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In the middle of the 90's, a hydrographic survey conducted in the Eastern Mediterranean (EM) discovered a transition in the EM deep water formation region. Dense water, which was known to form in the Adriatic Sea at a rate of ~0.3 Sv (1 Sv = 10^6 m^3/s), was observed outflowing from the Aegean Sea at a rate of ~1 Sv instead. This climatic transition, known as the Eastern Mediterranean Transient (EMT), lasted for 7 years and was associated with increased salinity preconditioning followed by 1991-1992 abnormal atmospheric cooling. Both high salinity and low temperature are major actors in winter convection. This recent change seems to have many impacts on water mass structures and properties as well as on the EM biogeochemistry.

It is clear now that the thermohaline circulation of the Aegean and Adriatic Seas can undergo rapid changes. Past-climate studies also suggest that EM thermohaline circulation can show multiple equilibria and may even be unstable. However, the question regarding the stability of these changes remains.

Our objective is to explore the possible multiple equilibria states, and their stability characteristics using an Oceanic General Circulation Model (OGCM). This is done using the Massachusetts Institute of Technology OGCM in a fairly realistic configuration of the Mediterranean Sea.

Bifurcation analysis of global ocean-climate models

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ABSTRACT

The Atlantic Ocean, in particular its Meridional Overturning Circulation (MOC), is sensitive to the patterns of atmospheric forcing, in particular to that of the freshwater flux. Relatively small changes in atmospheric conditions can therefore lead to a spectacular reduction (collapse) of the Atlantic MOC. As the time scale of a collapse is only a few decades, the associated changes in heat transport may have a large impact on European climate and society. Over the last decades, bifurcation analysis has been applied to a hierarchy of ocean models to detect the locations in parameter space where multiple equilibria of the MOC occur. Here, we present results of such a bifurcation analysis using a global ocean model coupled to an idealized atmosphere model. Focus will be on the methodology (linear system solvers, special purpose preconditioners, generalized eigenvalue problem solvers) and on the role of the ocean-atmosphere feedbacks on the stability of the MOC.

A MEANDERING SINKING FLOW AS POSSIBLE EXPLAINATION FOR THE THERMOHALINE STAIRCAISES IN OCEANS

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It is known that well-mixed layers separated by sharp diffusive interfaces are responsible for stair-like appearance of the temperature profiles in the central Arctic thermocline. Such profiles are referred to as thermohaline staircases. There exist numerous studies on formation of staircase-like structures. Its mathematical modelling, including fluid dynamics, and in oceanography is supported by many laboratory experiments with a large amount of experimental data. Many aspects of the origin of such structures, in spite of long history of its studies, are still unclear and are a subject for speculations. However all previous experimental and numerical work have only considered and showing the existence of successive superposed convective cells.

We presence here experiments (PIV) and simulations revealing the existence of a new regime: “meandering flow regime” (Figure 1). In this regime the liquid was found to flow along a snaky path from the top of the cavity (high concentration) to the bottom near the mushy zone. The velocity was mainly horizontal in the bulk, the flow was downward only at the vicinity of the lateral mushy zones. It is shown numerically that staircase layering of the concentration field is at the origin of this snaky flow regime.

To achieve these experiments special Particle Image Velocimetry (PIV) was used to measure the velocity field during a solidification process. It was applied to solidification of an NH4Cl salt in a die cast cell of 10*10*1 cm^3. During the cooling down different regimes were observed. Before solidification, the flow is controlled by only thermal buoyancy. As soon as the solidification starts, turbulence and chaos are generated in the liquid due to solutal convection. At the later stage of the process, the concentration and velocity field start to be stratified. The first and short lasting stratified stage consists in multiple convective cells. But quickly the long lasting meandering flow regime takes place. As a result or origin of the two dimensional meandering flow patterns, the concentration field is found to be organised in horizontal layers of uniform concentration. Those layers are separated by very thin boundary layers so that the concentration varies vertically in staircases. The authors propose the hypothesis that giant meandering sinking flow path are systematically associated with the presence of thermohaline staircases in oceans.

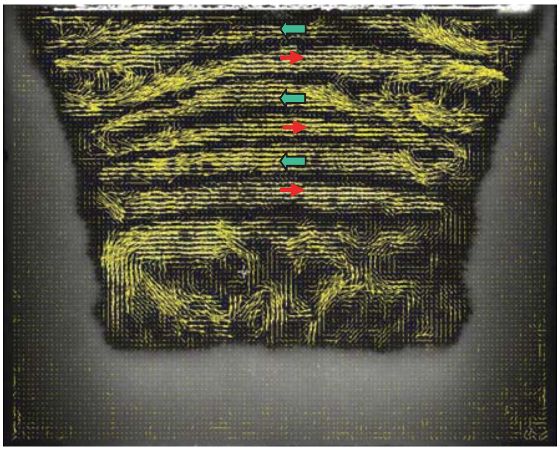

Figure 1: PIV measurement of the velocity field during the meandering flow regime. The liquid with higher concentration and temperature sinks slowly downward by taking a long snaky horizontal path.

GPU and SIMD Acceleration for Identification of Lagrangian Coherent Structures. Application to an Open Cavity Flow

- BIFD 2013 -

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ABSTRACT

In autonomous dynamical systems, it is well known that the stable and unstable manifolds drive the mixing properties of the flow. when they intersect transversally, folding and stretching follow, leading to chaos. Hyperbolic points and chaos properties are therefore linked, and defined by the way manifolds cross. The definition of such manifolds may be transposed to fluid flows as Lagrangian Coherent Structures (LCS).

In [1,2], LCS are defined as ridges of a scalar field, the Finite Time Lyapunov Exponent (FTLE) field. The field is defined, at each space point, as the largest eigenvalue of the Cauchy-Green strain tensor. When the horizon time is well-defined, in respect with the physical time scales, then the LCS are true material frontiers in the flow, *i.e.* there is no mass flux through these frontiers. Hence, for positive time horizon, LCS can be seen as the equivalent of unstable manifolds. Similarly, for a negative time horizon, resulting LCS are equivalent to stable manifolds. These structures give better understanding of the underlying physics of the flow since fluid particles will have different behaviours and fates depending in their position, relatively to the lagrangian frontier.

One of the drawbacks of tracking LCS is the computing time, as the trajectories of all particles have to be computed, at each time[3]. In this contribution, we expose some improvements on the algorithm allowing vectorization, SIMD and GPU Deported computations to the legacy way of computing such structures. The gain is typically about three orders of magnitude. We will present some results on 2D and 3D open cavity flows, both on LCS identification and how hyperbolic points may drive the oscillations in the shear layer.

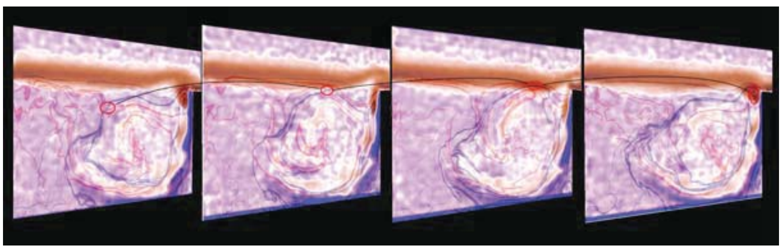

Figure 1: Tracking of an hyperbolic point: injection into the shear layer. Red and blue lines represent finite-time unstable and stable manifolds while the background field is the vorticity field.

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First Global 3D MHD Simulations of Waves in Accretion Discs and New Results on Rossby Waves in Discs

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We report results of the first global 3D MHD simulations of warp and density waves in accretion discs excited by a rotating star with a misaligned dipole magnetic field [1]. A wide range of cases are considered. We find for example that if the star's magnetosphere corotates approximately with the inner disc, then a strong one-arm bending wave (a warp) forms. The warp corotates with the star and has a maximum amplitude ($|\Delta z|/r \sim 0.35$) between the corotation radius and the radius of the vertical resonance. If the magnetosphere rotates more slowly than the inner disc, then a bending wave is excited at the disc-magnetosphere boundary, but it does not form large-scale warp. In this case the angular rotation of the disc ($\Omega(r)$) has a maximum as a function of r so that there is an inner region where $d\Omega/dr > 0$. In this region we observe radially trapped density waves in approximate agreement with the theoretical prediction of a Rossby wave instability [2]. This instability may provide an explanation of the quasi-periodic kilo-Hertz oscillations observed from disc-accreting neutron stars in low mass X-ray binary systems.

Recent theoretical and simulation studies Rossby wave instability (RWI) in protostellar accretion discs is motivated by the evidence that Rossby vortices act to concentrate dust grains and thereby can accelerate the formation of macroscopic planetesimals. The instability intially grows exponentially but then saturates. A simple theory for the saturation has recently been developed and verified by hydrodynamic simulations [3]. The influence of the disc's self-gravity on the RWI has recently been analyzed [4].

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Period doubling, high frequency QPOs, and instabilities in black hole accretion disks

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Black hole accretion disks may be undergoing a bifurcation leading to chaos. An analogy with pulsating stars will be pursued, where in numerical models a period doubling bifurcation is known that leads to a loss of stability of the periodic oscillation solution.

Accretion disks in black hole, neutron star and white dwarf systems are observed to exhibit a variety of puzzling quasi-periodic phenomena (QPOs), some with extraordinarily high frequencies up to ~ kHz. It is not yet clear whether these QPOs correspond to the disk oscillation modes predicted by the theory of disko-seismology. In Galactic black hole binaries a non-linear resonance between disk modes is strongly suggested by the observed ratios of the highest frequency QPOs, such as 5:2 or 3:2 (e.g., 450 Hz and 300 Hz in the source GRO J1655-40). Such frequency ratios have long been known in several types of oscillating stars, where a well understood period doubling has been observed (in RV Tauri and RR Lyrae type stars), and even predicted (in BL-Herculis type stars, Moskalik & Buchler 1990). I am going to compare and contrast the observed properties of stellar and disk oscillations (Rebusco et al. 2012). Certain accretion disk instabilities are also going to be discussed, as they may explain an established phenomenological relationship of high and low frequency QPOs in neutron stars and black holes.

Large amplitude nonlinear waves in Venus magnetosheath

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Abstract

Observations by the Venus Express magnetometer have shown the existence of large-amplitude variations of the magnetic field within the Venus magnetosheath. The spatial scale of the variations is determined by ion gyration and comparable to the ion gyroradius. We interpret these variations as a periodic nonlinear wave, standing between the Venusian bow shock and the pileup boundary (PLB). We derive the shape of one-dimensional nonlinear waves standing downstream of an oblique shock within two-fluid hydrodynamics. The magnetic field profile of these waves is in a good agreement with the observations, given the approximate nature of the assumption of one-dimensionality. We speculate that the standing waves appear due to the small distance between the two boundaries, the shock and the PLB.

Bifurcations from double-layered streamwise-independent vortex flow in rotating plane Couette flow

- BIFD2013 -

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ABSTRACT

It is well-known that the laminar plane Couette flow subject to a spanwise rotation loses stability at the critical Taylor number $Ta = \Omega(Re - \Omega) = 106.735$, where Re is the Reynolds number and Ω is the rotation rate, and that streamwise-independent vortex flows (TV_1) set in, followed by the bifurcation of wavy vortex flows (WVF) from TV_1 [1, 2, 3]. It is also known that the WVF with some streamwise and spanwise wavenumber pair (α, β) exists at $\Omega = 0$ (plane Couette flow) [4] as shown in Figure1 (a).
Our present analysis reveals that there exists another bifurcation route from the laminar state, being independent from the one described above. Namely, streamwise-independent vortex flows (TV_2) with a double-layered vortex structure bifurcate from the basic state at the *second* critical Taylor number $Ta = 1100.650$ and two new classes of three-dimensional flows, classified as *Ribbon* (or $\mathscr{A}_0$) and $\mathscr{A}_3$, bifurcate from TV_2 as shown in Figure 1(b). The bifurcation of $\mathscr{A}_0$ is subharmonic. The flow structure of $\mathscr{A}_0$ and $\mathscr{A}_3$ is characterized by mirror-symmetry about a plane normal to the parallel boundaries. Both of the solution classes inherit the double-layered vortex structure of TV_2. We even find that the

(a) (b)

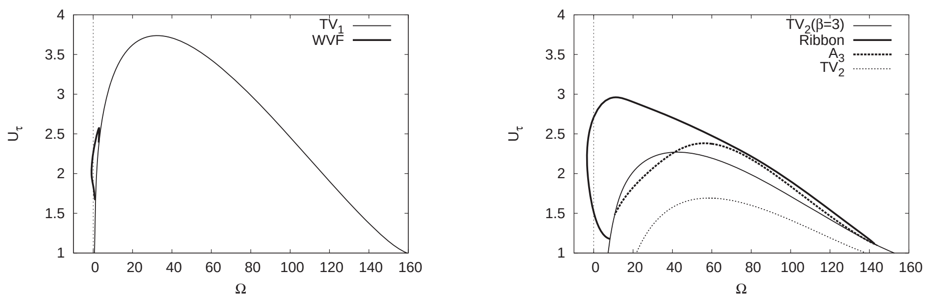

Figure 1: The conventional (a) and the new (b) bifurcation routes at $R = 160$. $\beta = 1.5$ except for $\mathscr{A}_3$ and one of TV_2's for which $\beta = 3.0$ in (b). $\alpha = 0.9$ for WVF in (a) and *Ribbon* in (b). $\alpha = 1.8$ for $\mathscr{A}_3$.

class $\mathscr{A}_0$ reaches $\Omega = 0$ for some (α, β) as indicated in Figure 1(b).

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Minimal perturbations targeting the edge in a Couette flow

- BIFD2013 -

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ABSTRACT

Recent studies have focused on the search of localized perturbations able to lead optimally shear flows to a chaotic state following a purely non-linear route (for instance, see Ref. [1], [2] and [3]). Such *non-linear optimal* perturbations are defined as finite-amplitude disturbances providing at a given time the largest growth of a given objective function, such as the energy [1-2] or the time-averaged dissipation [3]. In some of these studies, a bisection procedure was also used to compute the perturbation of minimal energy which reaches the edge of turbulence at a large time. However, no attempt has still been made to map the flow states which lye on the laminar-turbulent boundary and are attracted in a short time by the edge state. In this work we compute, for a Couette flow, the perturbations of minimal energy on the laminar-turbulent boundary which directly target the edge state found in [4]. We use a multiobjective Lagrangian optimization minimizing, at a given target time: i) the norm of the difference between the edge state and the final state reached by an initial perturbation superposed to the laminar flow; ii) the initial energy of such initial perturbation. For very short target times ($T = 20$ in the left frame of figure 1), we found a minimal perturbation characterized by oscillating streaks and symmetric pairs of vortices. For larger target times, the perturbation localizes in the streamwise and spanwise directions and the initial spanwise symmetry is broken. Inclined vortices along patches of streamwise disturbances, somehow recalling the shape of the non-linear optimal perturbation for a Couette flow are recovered.

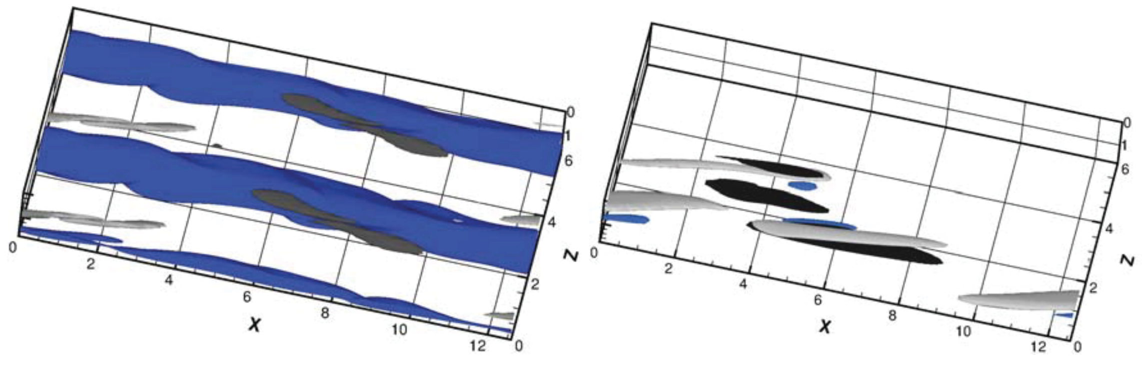

Figure 1: Streamwise vorticity (black/white) and perturbation (blue) for $T = 20$ (left), $T = 100$ (right).

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Three-dimensional vortex structures in the Blasius boundary layer flow

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Abstract

Understanding the turbulent transition in the Blasius boundary flow is a challenging problem of hydrodynamics. Osborne Reynolds laid the groundwork with his experimental study on transition to turbulence in pipe flow in 1883 [1]. Since then the issue of how turbulence develops and maintains itself is still not completely understood even though the past two decades have witnessed advancements on this topic. Turbulent boundary layers occur in a wide range of practical flows, therefore a better appreciation of this configuration is of great importance. Despite the fact that turbulent flows seem chaotic it actually has a degree of regularity which renders it feasible to do progress using bifurcation theory and searching for simple nonlinear equilibrium solutions to the Navier-Stokes equations, also called exact coherent structures (ECS). These nonlinear solutions are large scale structures [2-5]. They are believed to be unstable in general with usually only a few unstable directions and many stable ones [6-8]. Early experimental observations are the wavy unstable structures observed in turbulent boundary layers [9]. The last twenty years or so have seen promising results in this field, with aid from direct numerical simulations and laboratory experiments [10-13]. It is believed that the ECS are target states in phase space to which a time-dependent flow trajectory is attracted. When put together they can reproduce statistics of turbulence. To find solutions for the parallel boundary layer flow, of possible connection to near-wall turbulence, the idea of the self-sustaining process (SSP) was used [14]. The SSP involves an artificial body forcing of amplitude f_A, and is used to force nonlinear large scale structures bifurcating from a base flow different from, e.g., the Blasius profile [15]. In figure 1 (left) we see a bifurcation diagram for the Reynolds number *Re*=400 (based on the boundary layer scale $\delta=(\nu x/U_\infty)^{1/2}$, the free-stream speed U_∞ and the kinematic viscosity ν) showing how the solution in figure 1 (right) was obtained by bringing f_A to zero.

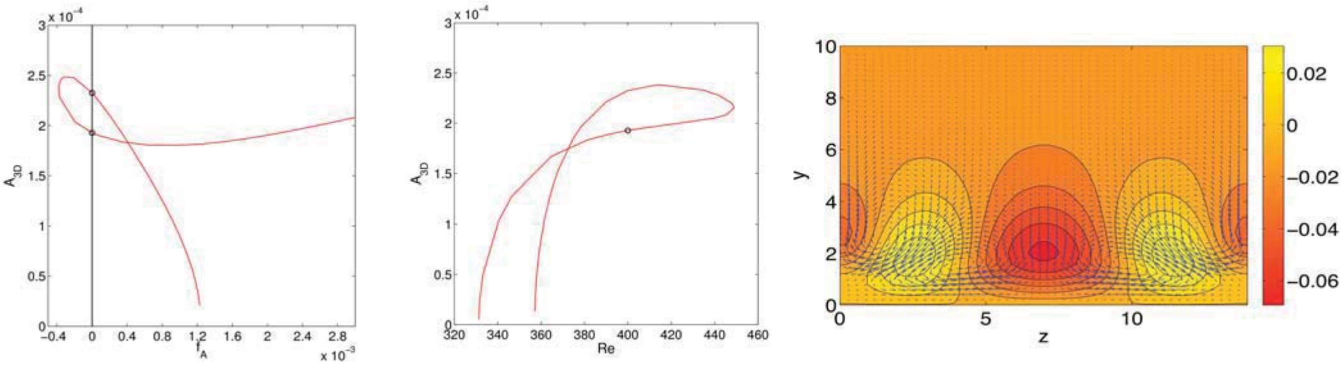

Figure 1. *Left:* Continuation in f_A from a finite value to the desired two points where f_A=0. The A_{3D} is a measure of the amplitude of the solution. *Middle:* The nonlinear solutions mapped out in the *Re* using the solution in the left plot at *Re*=400 as an initial guess (f_A=0). *Right:* The mean velocity field at *Re*=400, represented by the black point on the lower branch in the middle figure. The thickness of the Blasius boundary layer flow corresponds to *y*=5.

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Transient growth of 3D perturbations in a stratified mixing layer flow

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ABSTRACT

Three-dimensional non-modal disturbances growth in a stably stratified viscous mixing layer flow is studies. The research is performed in the framework of linearized equations using two indepndent approaches and then is verified by computational modeling of evolution of the optimal perturbations found via numerical solution of fully non-linear time-dependent Boussinesq equations.

We examined the effect of stratification on linearly stable three-dimensional disturbance, which attains the largest non-modal amplification in the non-isothermal case. The transient strong amplification could be reached at short times by a 3D optimal perturbation, whose amplitude grows larger than those computed in the 2D case, even in cases of very strong stable stratification. This non-modal growth is governed mainly by the Holmboe modes, and does not necessarily weaken with increase of the Richardson number.

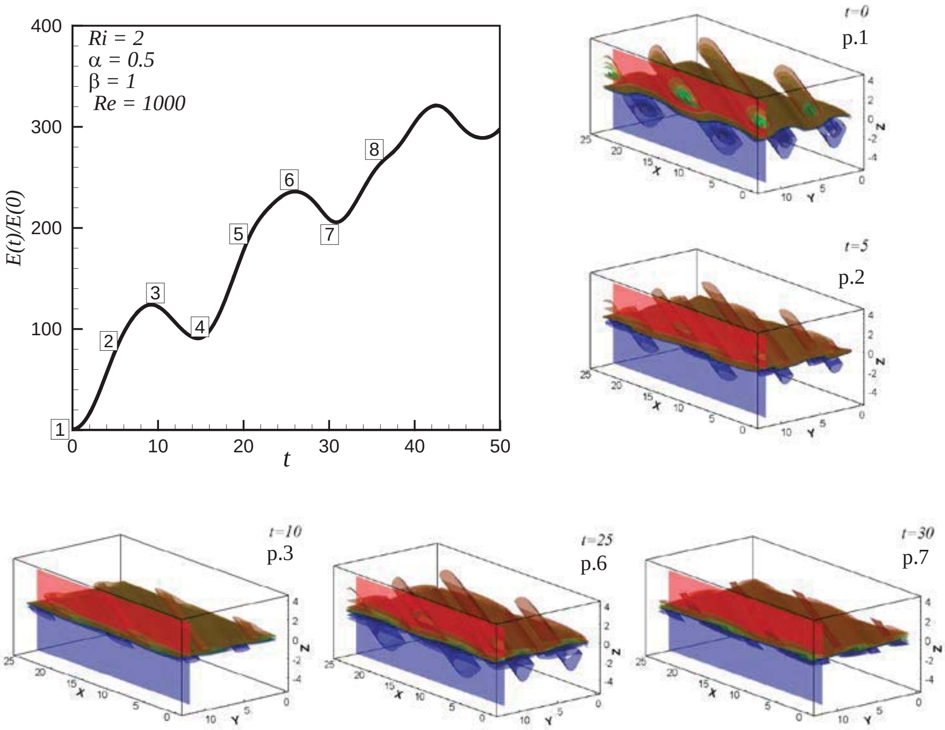

Figure 1. Time evolution of the 3D optimal temperature perturbation superposed with base flow profile for $\boldsymbol{Ri = 2}$, $\boldsymbol{Re = 1000}$, $\boldsymbol{\alpha = 0.5}$, $\boldsymbol{\beta = 1}$, yielding the maximal values at t=10. Blue color corresponds to cold fluid, red color corresponds to warm fluid; the growth function increases at $\boldsymbol{t = 0(p.1), 5(p.2), 20(p.5), 35(p.8)}$, attains maximal values at $\boldsymbol{t = 10\ (p.3), 25\ (p.6)}$, and decays at $\boldsymbol{t = 15\ (p.4), 30(p.7)}$.

Reduced-Order Modeling of Vortex-Induced Oscillations

H. Benaroya and S. Mottaghi

ABSTRACT

Fluid-structure interaction research has gathered a large community because of scientific curiosity and engineering applications. One sub-discipline, vortex-induced oscillations, has been similarly examined, theoretically, numerically and experimentally. Such oscillations occur for bluff as well as aerodynamic bodies. As a complex physical problem, simplifications have been attempted in order to make headway with understanding the exchange of energies between the fluid and the structure. Reduced-order analytical models have been attempted to capture the physics of the system while maintaining a solvable set of equations. Generally, these are two coupled differential equations, one for the oscillating shedding vortices and the other for the coupled structure. Our efforts have centered about the development of an analytical procedure for the derivation of such equations, in particular for bluff bodies, with a minimal set of assumptions. We will summarize these studies.

Closed-loop control of a turbulent jet based on fluidic means

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Active control of an air round jet using radial unsteady air microjets was developed and experimentally implemented. Two microjets were placed at diametrically opposite locations upstream of the nozzle exit (fig 1). The Reynolds number was 8000. The flow was measured using hot wire, flow visualization and particle imaging velocimetry techniques in two orthogonal diametrical planes. The open-loop control was first investigated. The jet centreline decay rate K exhibits a strong dependence on the mass flow ratio C_m of microjets to the primary jet and excitation frequency ratio f_{ex}/f_0 of microjets, where f_{ex} is the microjet excitation frequency and f_0 the preferred mode frequency of the uncontrolled jet. A closed-loop controller was then developed. As shown in figure 1c, three hotwires (fig 1b) were deployed in the injection plane. Feedback wire 1 was placed at x/D = 2 and z/D = 0.3, serving for detecting the vortex frequency $f_{x/D=2}$, and feedback wire 2 at x/D = 3 and z/D = 0 was used to capture the instantaneous centreline velocity $U_{x/D=3}$. Another wire was placed at x/D =5 and z/D = 0 for monitoring the variation in K. The controller acted on one hand to convert the $f_{x/D=2}$ value to the input voltage for the servo motor (fig 1a), which is directly linked to the frequency f_{ex} of unsteady microjets, and on the other hand to search $f_{x/D=2}$ corresponding to the minimum of $U_{x/D=3}$. The closed-loop-control could achieve automatically and rapidly the optimal f_{ex}/f_0 of microjets (fig 2), at C_m = 0.8%, and the maximum decay rate, obtained from the open-loop control. Investigation continues to understand thoroughly the physics and control mechanisms behind effective control.

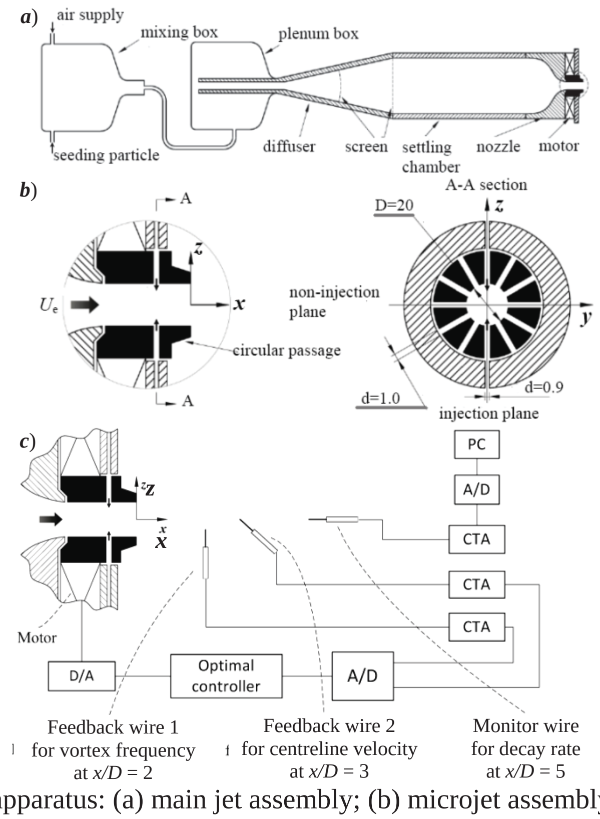

Figure 1 Schematic of jet control apparatus: (a) main jet assembly; (b) microjet assembly; (c) experimental arrangement for the closed-loop-controlled jet.

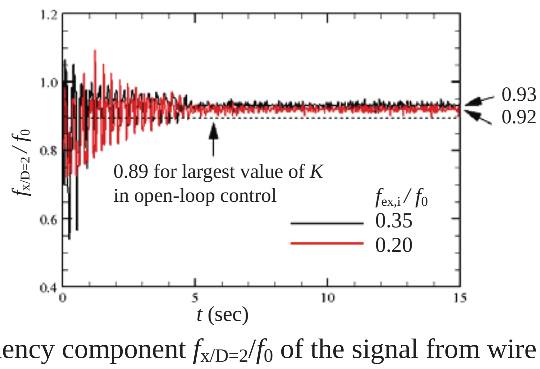

Figure 2 Time history of the frequency component $f_{x/D=2}/f_0$ of the signal from wire 1 in the closed-loop-controlled jet.

ACKNOWLEDGMENT: YZ wishes to acknowledge support given to him by the Research Grants Council of the Government of the HKSAR through Grant PolyU B-Q33J.

Elasto-Capillary Instability and Coalescence of Multiple Parallel Sheets

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We analyzed two-dimensional clamped parallel elastic sheets which are partially immersed in liquid as a model for elasto-capillary coalescence. The existing literature studied this problem via minimal energy analysis of capillary and elastic energies of the post-coalescence state, yielding the maximal stable post-coalescence bundle size. Utilizing modal stability analysis and asymptotic analysis, we studied the stability of the configuration before the coalescence occurred. Our analysis revealed previously unreported relations between viscous forces, body forces, and the instability yielding the coalescence, thus undermining a common assumption that coalescence will occur as long as it will not create a bundle larger than the maximal stable post-coalesced size. A mathematical description of the process creating the hierarchical coalescence structure was obtained and yielded that the mean number of sheets per coalesced region is limited to the subset 2^N where N is the set of natural numbers. Our theoretical results were illustrated by experiments and good agreement with the theoretical predictions was observed.

TEMPERATURE FLUCTUATIONS AS A RESULT OF MIXED CONVECTION IN A LIQUID METAL FLOW WITH IMPOSED TRANSVERSE MAGNETIC FIELD

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We report the results of direct numerical simulations of mixed convection in a liquid metal flow in a horizontal pipe with constant transverse magnetic field. The pipe walls are electrically insulated and subject to constant flux heating in the lower half. The simulations show agreement with experimental observations and provide insight into the dominant mechanisms of the flow. It is found that, in the case of strong magnetic fields at Hartmann numbers far exceeding the laminarization threshold, natural convection develops in the form of coherent quasitwo-dimensional rolls aligned with the magnetic field. Transport of these rolls by the mean flow causes anomalous high-amplitude, low-frequency fluctuations of temperature detected in earlier experiments.

HYDRODYNAMIC STRUCTURES GENERATED BY THE ROTATING MAGNETIC FIELD IN CYLINDRICAL VESSEL

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Donetsk, Ukraine

1. Infinitely long cylinder. The stability of the primary laminar flow of viscous incompressible conducting liquid, which is formed under the influence of the rotating magnetic field in infinitely long cylinder, is investigated in sufficient detail by numerical methods. For a wide range of process parameters the curves of neutral stability were obtained, separating the area of one-dimensional azimuthal flow from that of the three-dimensional laminar-vortical flow. It is established that at not small relative frequencies ϖ $\left(\varpi = \mu_0 \sigma \omega R_0^2 / p\right)$ the stability essentially depends on physical properties of a conducting liquid. While in the area of small ϖ stability is characterised by two independent criteria Re_ω and Ha_{ac} ($\mathrm{Re}_\omega = \omega R_0^2 / p\nu$, $Ha_{ac} = B_0 R_0 \sqrt{\sigma / 2\eta}$), in area of not small ϖ the number of the criteria characterising stability, increases to three – Re_ω, Ha_{ac} and Pr_m. Calculations produced one-vortical (in the radial direction) structure of Taylor's vortices. Secondary flows appear in the instability zone with the internal border with zero vorticity of primary flow. The increase in an order of rotary symmetry of rotating magnetic field p, as well as increase Ha_{ac} and ϖ, reduces the characteristic size of a vortex. The vortex centre is thus displaced to a vessel wall.

A. B. Kapusta made an assumption, that (without viscous dissipation) the flow would be steady if in the Rayleigh's instability area of the flow characterized the decrease in the square of circulation, the amount of energy spent to increase kinetic energy of the flow did not exceed the that dissipated as Joule's heat. This allowed for energy-balance estimates of stability in asymptotics both for small and large values of Hartmann number. Taking into account viscous dissipation and using numerical methods had allowed one to obtain an energy-based estimate of stability of such type of flows for a wide range of change in flow parameters. Rather simple calculations have allowed predicting potential behaviour of the curve of neutral stability in the case of the strict solution of the problem of stability.

2. The cylinder of final length. The problem about the three-dimensional stationary flow of the viscous incompressible conducing liquid generated by the rotating magnetic field in a cylindrical vessel of the limited length is solved with use of a method of iterations. Calculations have shown, that iteration ceases to converge, as soon as problem's parameters approach the values of the critical parameters corresponding to arising of hydrodynamic instability in a problem about stationary instability of MHD-rotation in infinitely long cylindrical vessel. Such relationship between convergence of iteration in a problem for a vessel of final length and transition to instability in case of infinitely long cylinder, most likely allows one estimating the stability of the flow in the cylinder of final length at natural final perturbations, based on the convergence of iteration,. Numerical experiment has allowed studying generated spatial structures of a flow and to tracking their evolution upon the change in flow parameters. At small values of Hartmann numbers (~ 1) defining influence on the structure is produced by relative height of a vessel. At small relative height at half of the vessel's length, one intensive end-wall vortex appears When the relative height increases the vortex is being pushed towards the end-wall and while in the central zone of the vessel some weak near-wall meridional vortices of an alternating direction of rotation appear, these vortices arising by detaching from the end-wall vortex, separating from it in pairs. With the increase in the relative height of the vessel the number of these small vortices increases while their relative sizes approach the corresponding sizes of Taylor vortices which appear in an infinitely long cylinder.

Patterned turbulence in transitional MHD flows in pipes and ducts

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Results of recent numerical simulations of transitional states of MHD duct and pipe flows at moderately high Reynolds and Hartmann numbers [1,2] are presented. The main novelty of the analysis is that we use very long (tens to hundreds of hydraulic diameters) computational domains. This allows us to detect principally new regimes with localized turbulent spots near the side walls and otherwise laminar flow (see fig. 1). Part of the simulations is conducted to reconstruct the classical experiments of Julius Hartmann and Freimut Lazarus [3]. The computed critical parameters for laminar-turbulent transition as well as the computed values of the friction coefficient are in excellent agreement with the experiment.

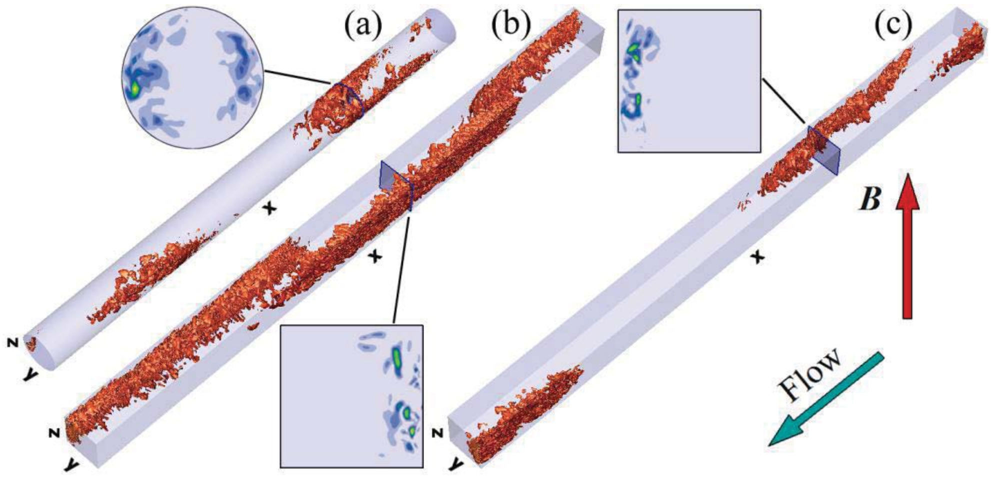

Fig. 1: Patterned turbulence regimes detected in computations with periodic inlet/exit conditions at Re=5000 [1]. Turbulent kinetic energy (TKE) in transverse velocity components is visualized for: (a) pipe at Ha=22, (b) duct at Ha=22, and (c) duct at Ha=25. The length of the computational domain is 80 radii in (a) and 32π of duct half-widths in (b) and (c). Iso-surfaces corresponding to 2% of the maximum are shown. Inserts present TKE distributions in selected cross-sections. The isolevels are the same in all inserts.

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The use of the traveling magnetic field generated by a modulated current for the liquid metal stirring

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The present investigation is carried out in the framework of the scientific–research directed towards a solution of the fundamental problems in the magnetohydrodynamics dealing with studying the processes of admixture homogenization in a molten metal under the conditions of stirring flow generated by the traveling magnetic field.

Mixing processes in liquid metals play a key role in metallurgy. In such processes as alloy preparation, ingot casting production, the stirring process is the main factor that influences the quality of finished alloys and products. It is a well-recognized fact that stirring provides a more homogeneous distribution of admixture. However, today the situation in metallurgy is such, that it doesn't know what fluid dynamics is necessary to achieve the best mixing.

At present, the stirring of aluminum alloys in the bath of furnace by the traveling magnetic field is a popular and wide-spread way of mixing metals. However, the existing stirrers have high power consumption and low efficiency. Besides, the question remains over the effectiveness of stirring produced by these devices. It is difficult and uneconomical to check the efficiency of stirring regimes under actual production conditions. The appearance of modern devices and the development of computing facilities made it possible to model turbulent processes in laboratory conditions. Mathematical modeling and computer simulations enable researchers to choose the right parameters from a wide range of available options.

This paper focuses on a study of the process of stirring carried out in a rectangular cavity and produced by the traveling magnetic field generated by the inductor located beneath the cavity. The transfer of a passive admixture in the volume of liquid metal, as well as the influence of various parameters and their complexes on the rate of flow and distribution of impurities in the metal, are considered.

The objective of the work is to examine both theoretically and experimentally the distribution of admixtures in the volume of liquid metal during its stirring. The results of mathematical calculations and numerical experiments are compared to determine the conditions for obtaining a homogeneous alloy and a set of parameters characterizing the stirring process.

To verify the results of numerical simulation, numerical computation and physical experiment are conducted using the laboratory model.

This research was supported by RFFI foundation (Grant 12-08-31526) and by the project of the International Research Group "Magnetohydrodynamic stirring of liquid metal and its influence on a solidified alloy structure".

Inertial wave modes excitation inside a container with cylindrical geometry

Ion Dan Borcia,[1,*] Torsten Seelig,[1] Abouzar Ghasemi V.,[2] Marten Klein,[2]
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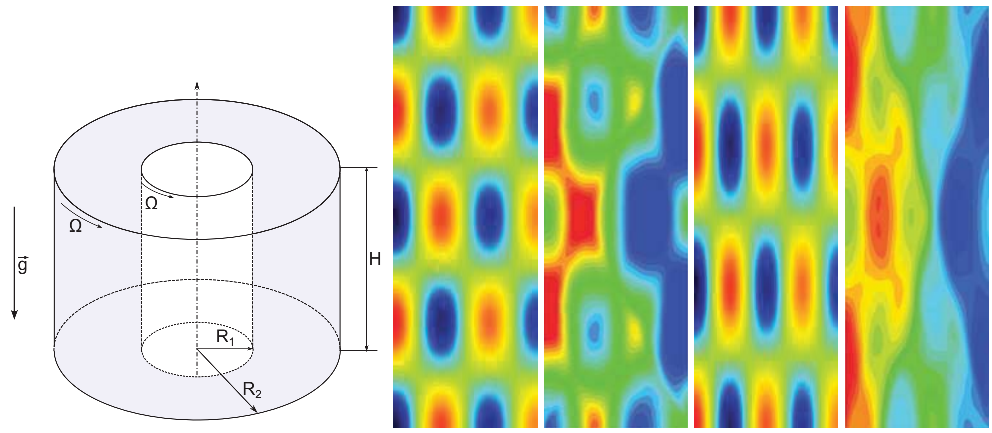
Inertial waves are excited in a liquid confined between two co-axial co-rotating cylinders (see Figure 1(a)) by different methods. Two of them are experimentally realized on the Dept. of Aerodynamics and Fluid Mechanics in Cottbus: the longitudinal libration of the inner cylinder or of the outer cylinder together with the bottom and the lid of the container. For the firstly mentioned excitation, no Ekman layer spin-up and spin-down is involved. In contrast, when the lids librate with the outer cylinder, such oscillating Ekman layers become important.

The inviscid inertial modes for this geometry were calculated in [1]. Generally, eigenmodes are independent of the excitation method or excitation amplitude. The question we address here is which of these modes can actually be observed when viscosity and the excitation are taken into account. We find that in correspondence with [2], only a subset of inertial modes calculated in [1], match the symmetries of the forcing and can be excited by the libration. The efficiency of the mode excitation is studied in more details numerically and experimentally for different excitation methods.



(a) (b) (c) (d) (e)

FIG. 1: (a) The sketch of the experiment; (b) the calculated symmetric (3,4) mode in vertical direction; (c) the numerical simulation of the excited (3,4) mode. The excitation is due to simultaneously bottom plate and lid libration. (d) and (e) – the same as (b) and (c) but for an antisymmetric (4,3) mode in vertical direction.

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The Linear Instability of Barotropic Shallow-Water Eddies in Gradient Balance for Various Basic States

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The basic states of oceanic eddies (the classical, quadratic gradient balance) are extended to cases of non-constant Rossby number (i.e. to a differential problem) and the stability of these basic states is examined. The basic state solutions are classified by using a canonical form in which each of the intersections of the depth gradient with a parabolic function for the Rossby number is a solution of the problem. The basic state of an eddy in which the depth gradient varies radially occupies a segment (range of values) along the parabola on either the regular or the anomalous brunches. The depth profile in these basic states can either be prescribed or computed given an additional condition such as constant Potential Vorticity, both cases are considered here. Solutions of the linear instability problem in a barotropic shallow water model are searched in order to characterize the stability of eddies (regular and anomalous) in which the Rossby number is a variable and compared with cases of constant Rossby number. The results are compared with the approach of the well known centrifugal instability (which is a wavenumber zero instability) which predicts overall stability of the regular brunch of the canonical parabola and overall instability of the anomalous one.

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Inertial vs barotropic and baroclinic instabilities of the Bickley jet: continuous stratification

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"Bifurcations and Instabilities in Fluid Mechanics", Haifa 2013

We present a detailed study of the inertial instability of a barotropic Bickley jet on the $f-$plane in the continuously stratified primitive equation model and a comparison of this ageostrophic instability with the classical barotropic and baroclinic ones. This is a continuation of the previous work [1], where similar analysis was performed in the framework of the two-layer rotating shallow water model. Full analytical and numerical investigation of the linear stability of the jet in the long-wave sector is performed. The sensitivity of the instabilities to changes in parameters, such as the Rossby and the Burger numbers is investigated. The major result is that the standard inertial instability, appearing at high enough Rossby numbers, turns to be an infinite wavelength limit of an asymmetric inertial instability, which has the highest growth rate, in accordance with [1]. This dominant instability is essentially baroclinic and its growth rate increases with increasing vertical wavenumber.

Nonlinear saturation of the inertial instability of the Bickley jet with a superimposed random small-amplitude perturbation is then studied, using the *Weather Research and Forecast* model. It is shown that at the first stage the inertial instability develops, being localized near the maximum of the anticyclonic shear and associated with the highest attainable value of the vertical wavenumber. Its saturation leads to the homogenization of the geostrophic momentum in the unstable region. At later stages, another quasi-barotropic instability develops. It is characterized by lower values of the vertical wavenumber. The secondary instability saturates by forming large-scale vortices downstream. As follows from the stability analysis, this instability corresponds to the most unstable mode of a marginally inertially stable jet obtained from the initial one by homogenization of the geostrophic momentum. It is shown that reorganization of the flow due to developing instabilities is an efficient source of inertia-gravity waves.

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Stability of point-vortex multipoles

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Relative equilibria of point vortices, the tripoles and pentapoles, are considered in the hierarchy of models: the rigid-lid barotropic, equivalent-barotropic and quasigeostrophic two-layer model. A tripole is assembled by three symmetrically arranged collinear vortices, while a pentapole, by five vortices of which one is located in the center of a square and the other four in the vertices of the square. In a multipole equilibrium, the vortices located on the sides (the satellite vortices) are equal in strength to each other and opposite in sign to the central vortex. In the two-layer model, two cases are distinguished, in which (i) all of the vortices are located in the same layer and (b) the central vortex and the satellite vortices reside in different layers (the so-called carousel multipoles).

Conventionally, a relative equilibrium of point vortices is regarded to be stable if, in response to small initial perturbations in the distances between the vortices, the variations in these distances remain small for all times. The dynamics of an ensemble of point vortices is described by a finite number of ordinary differential equations. This fact eases the use of the Hamiltonian approach in the stability analysis.

In all the models, the tripoles with zero net circulation are shown to be nonlinearly stable. The proof of the tripole stability is based on the fact that, among the possible three-vortex configurations characterized by the same value of the Hamiltonian, there exists only one tripole and, within this iso-Hamiltonian sheet, the squared linear momentum vanishes at this unique tripole only. This approach, being in essence universal for all models, works only with tripoles. For instance, a quadrupole cannot be treated in such a way, because there is a continuum of configurations of four vortices with zero net circulation on which the squared impulse vanishes.

An approach kindred with the outlined above is employed to show that pentapoles with zero net circulation are unstable in the rigid-lid barotropic and equivalent-barotropic models and, generally, in the two-layer model. At this stage, we consider only the perturbations that do not violate the central symmetry and the angular momentum of the pentapole, and ascertain whether on this iso-momentum sheet the Hamiltonian reaches its extremum in the pentapole. Carousel pentapoles comparable in their size with the Rossby radius (an intrinsic length scale in the two-layer quasigeostrophic model), and smaller, are exceptional in that they are stable to centrally-symmetric perturbations and, presumably, to arbitrary perturbations.

Exotic behavior of hexagonal Faraday waves

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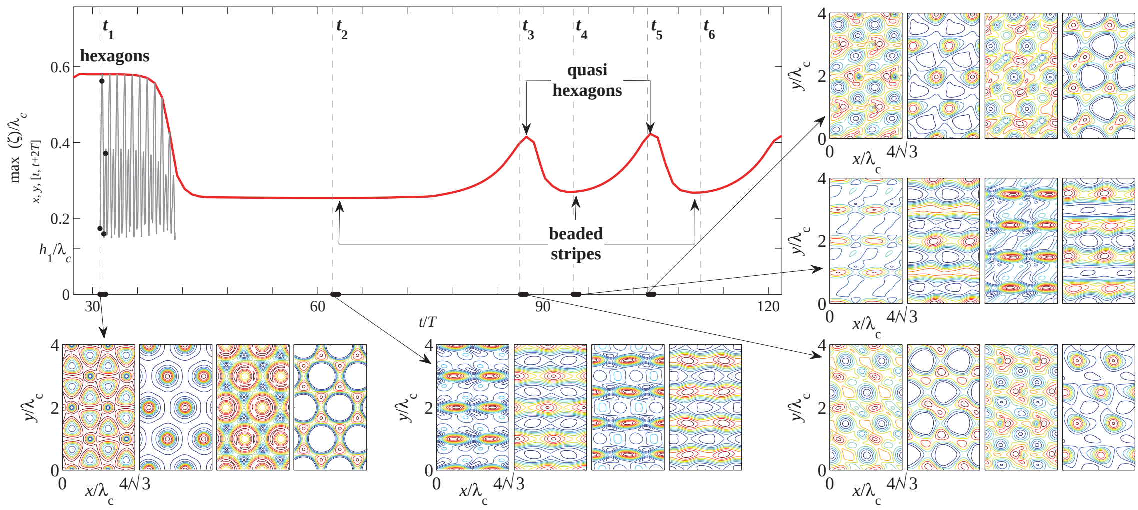

Evolution of maximum interface height and its envelope. Surrounding visualizations show hexagons, beaded stripes, and quasi-hexagons.

Faraday waves are standing wave patterns produced by the vertical oscillation of a fluid layer. Stripes, squares and hexagons are the most common patterns, but quasipatterns, superlattices, and solitons can also occur. We have recently carried out the first numerical simulation of three-dimensional Faraday waves. Our simulations lead to a hexagonal pattern, which is not permanent, but gives way to a pattern we have called "beaded stripes". This is succeeded by a regular alternation between two other sets of patterns which we call quasi-hexagons and asymmetric beaded stripes and which are related by spatio-temporal symmetries. We analyze this sequence of patterns via their Fourier coefficients.

REDUCTION AND SOLUTION FOR UNSTEADY FLOW OF A SISKO FLUID FOR CYLINDRICAL GEOMETRY REVISITED

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In this study a reduction and solution for unsteady flow of a Sisko fluid is investigated. The governing nonlinear equation for unidirectional flow of a Sisko fluid in a cylindrical tube due to translation of the tube wall is modeled in cylindrical polar coordinates. The exact steady-state solution for the nonlinear problem is obtained. The reduction of the nonlinear initial value problem is carried out by using a similarity approach. The partial differential equation is transformed into an ordinary differential equation, which is integrated numerically taking into account the influence of the index n and the material parameter b of the Sisko fluid. The initial approximation for the fluid velocity on the axis of the cylinder is obtained by matching inner and outer expansions for the fluid velocity. A comparison between velocity profiles of Newtonian and Sisko fluids is presented.

Shear layer modes competition in Open Cavity Flow: Experimental and Numerical Exploration of 3D features through a 3D DMD analysis.

- BIFD2013 -

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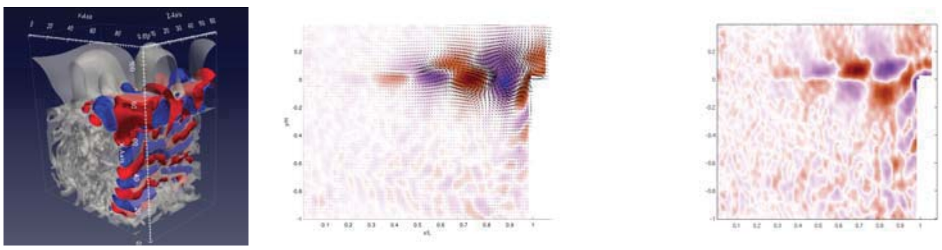
ABSTRACT

Open cavity flows are well known for enhancing characteristic self-sustaining oscillations [1]. It was shown, in numerical simulations of the flow, that a proper orthogonal decomposition (POD) is able to properly discriminate between coherent structures within the shear layer, from those inside the cavity [2]. Moreover, the time evolution of these coherent structures, in the shear layer, also exhibit the characteristic self-sustained oscillations of the flow. However, in [2], the flow oscillations did not exhibit any mode switching phenomenon, since only one mode was mainly amplified within the shear layer. In the case where two dominant modes are in competition, POD fails to extract each mode independently, since both are strongly coherent with respect to each other.

In contrast, Dynamical Mode Decomposition (DMD)[3,4] naturally extracts the shear layer coherent structures associated with each dominant mode. Shear layer modes are often assumed to be roughly 2D coherent structures, *ie* without significant variations in the spanwise direction. This is due to the fact that self-sustained oscillations in the shear layer result from a Kelvin-Helmholtz instability, which is intrisically two dimensional.

The study is based on time-resolved PIV in a streamwise plane and 3D numerical datasets. By considering the divergence of the 2D velocity field constitutive of the two shear layer dynamical modes, we show that shear layer modes clearly exhibit spanwise velocity gradients. The DMD analysis of the 3D numerical dataset (see figure 1) confirms the complex 3D behaviour of the shear layer oscillations.



(a) (b) (c)

Figure 1: The 3D organization of a shear layer mode.(a): 3D dynamical mode from DNS. (b): 2D dynamical mode from PIV measurement. (c): divergency field of the 2D dynamical mode.

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Drifting Solitary Waves in a Reaction-Diffusion Medium with Differential Advection

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Abstract:

A distinct propagation of solitary waves in the presence of autocatalysis, diffusion, and differential advection, is being studied. These pulses emerge at lower reaction rates of the autocatalytic activator, i.e., when the advective flow overcomes the fast excitation and induces a fluid type “drifting” behavior, making the phenomenon unique to reaction-diffusion-advection class systems. Using the spatial dynamics analysis, we present the bifurcation properties and the organization of such drifting pulses. The insights underly a general understanding of localized transport in simple reaction-diffusion-advection models and thus provide a background to potential chemical, pipe flow and biological applications.

Reference —

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Steady State–Hopf Mode Interactions at the Onset of Nematic Electroconvection

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A new mode interaction found in electroconvection experiments on the nematic liquid crystal mixture Phase V in planar geometry is discussed, and an amplitude system of equations modeling the instability is analyzed. The codimension two mode interaction point occurs at a critical value of the frequency of the driving AC voltage. For frequencies below threshold the primary pattern-forming instability at the onset voltage is an oblique stationary instability involving oblique rolls, and above it is an oscillatory instability giving rise to normal traveling rolls. The transition has been confirmed by measuring the roll angle and the dominant frequency of the time series. The globally coupled system of Ginzburg–Landau equations that qualitatively describe this mode interaction is constructed, and the resulting normal form, in which slow spatial variations of the mode amplitudes are ignored, is analyzed. This analysis shows that the Ginzburg–Landau system provides the adequate theoretical description for the experimentally observed phenomenon. The numerical study of the patterns predicted by the globally coupled Ginzburg–Landau equations is also presented.

IMPACT ON THE STABILITY OF DIVERGENT CAPILLARY FLOW

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The initiation of the surface or capillary flows in liquid systems with the interface is related to the existence of the surface tension gradient or to increase in the thickness of the near-surface layers by the inflow of volumetric flows under the action of viscous forces. In the theoretical and numerical investigations the structure of such flows is easily predicted and readily simulated. However, some experimental investigations have shown that the structures of the observed surface flows differ essentially from the structures predicted theoretically or derived on the basis of the problem symmetry considerations. Most likely, the reason of the observed disagreement is that the state of the free interface during experiments remains uncontrolled. The content of the adsorbed film of surfactant-active impurities changes the existing boundary conditions (surface tension, surface rheology). On the other hand, the redistribution of the surfactant molecules by a convective flow may lead to the inhomogeneous boundary conditions and accordingly, to loss of symmetry of the basic flow. The focus of this paper is to investigate the interaction of the convective flow with the adsorbed surfactant film for two cours: insoluble and soluble substances.

The paper presents the results of the experimental study of stability of the axisymmetric solutocapillary flow initiated at the surface of water by a localized source of a weak solution of ethanol. Solution injecting into the surface of ultra-pure water through a thin needle. The bevel of needle is located in the center of the cylindrical cell. Oleic acid was used to create adsorbed insoluble surfactant films. It was shown that axisymmetric divergent flow appears on the free water surface (Fig. 1 a), which remains stable for all values of the Marangoni number (determined by the concentration of ethanol and the solution flow), obtained in the experiment. Addition surfactant to the free surface leads to instability of the main flow and the development of the secondary flow with multivortex structure that is periodic in the azimuthal direction (Fig. 1 b, c).

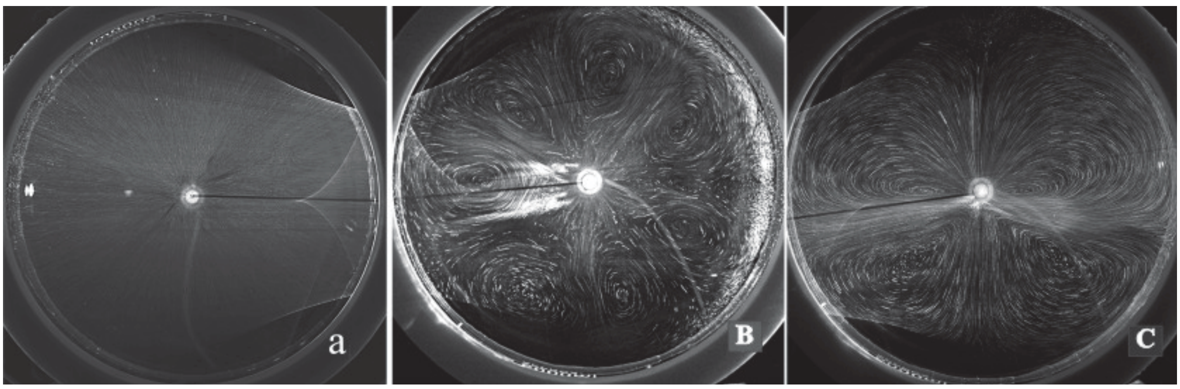

Fig. 1

It is shown that the azimuthal wave number is substantially dependent on the intensity of the concentration-capillary flow and the amount of adsorbed surfactant on the surface. Wave number increases with the increasing Marangoni number or decreasing of surface density of surfactant. It was shown that at a certain threshold value of the surface density, which depends on the Marangoni number, the surface of the fluid remains stationary, i.e. solutocapillary movement does not occur.

In the case of soluble surfactant admixture an aqueous solution of potassium salts of fatty acids: potassium propionate and potassium laurate. Prelimenary tenziometry methods display a number of physical and chemical parameters, including surface activity, the critical micelle concentration, the characteristic times of adsorption-desorption processes, Langmuir–Shishkovsky constant. It is shown that the numerical value of the found constants differ by two orders of magnitude. Review of the literature also indicates that the selected surfactants exhibit a different type of kinetics of mass transfer processes between the bulk and surface phases. Study on the Marangoni flow stability has shown that, as in the case of insoluble surfactant, axisymmetric flow becomes unstable to multivortex flow being periodic in the azimuthal direction. The main difference from the case of insoluble surfactant is unsteady flow structure. The number and location of vortices is always changing in the course of time while the average quantity of vortices is invariable. This difference is probably caused by the presence of adsorption-desorption processes, which lead to the changing of boundary conditions along the interface.

The work was supported by the program of joint project with, UB and FEB of RAS (№ 12-C-1-1006), Ministry of Education of the Perm region (№ C-26/210) and a project for young scientists and graduate students of UB RAS 13-1-NP-411.

Flow Topology of a Hydrothermal Wave

- BIFD 2013 -

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ABSTRACT

A cylindrical liquid bridge is probably the most popular system for investigations of thermocapillary flows. In this system a rapid accumulation of small suspended and density-matched particles into Particle Accumulations Structures (PAS) has been observed by Schwabe et al. [1] when the flow state is a hydrothermal wave. These waves typically arise for Pr > 1 and they travel azimuthally. Hofmann and Kuhlmann [2] related PAS to certain regions of regular streamlines of the hydrothermal wave which are embedded in a sea of chaotic streamlines in the frame of reference rotating with the wave. In order to better resolve the flow topology and to minimize the dissipation error for the computation of streamlines and of particle trajectories we have computed hydrothermal waves for Pr = 4 using OpenFOAM. The flow topology is studied in the rotating frame of reference in which the hydrothermal wave is steady. A very high resolution is required to resolve the KAM tori near the free surface. We confirm and refine the coarse-flow results of [2]. Kuhlmann and Muldoon [3] have provided evidence that Stokes drag and pressure gradients in the bulk of the flow are too weak to cause rapid PAS formation for nearly density-matched particles. We follow [2] and argue that PAS is caused by a dissipative mechanism for the particle motion near the free surface which can be approximated by a streamline hopping of the particles. The implications of the corresponding streamline mapping are discussed.

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Primary Instability of the Lid-Driven Flow in a Cube: A Chebyshev-Collocation Method with Reduced Edge Singularity

- BIFD 2013 -

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ABSTRACT

The incompressible flow in a cube is computed numerically. The motion is driven by a steady tangential motion of one sidewall parallel to the neighbouring edges. The numerical code is based on the Chebyshev-collocation method of the authors [1]. In this method the velocities and the pressure are approximated by polynomials of order N and N-2, respectively. For time integration the second-order Adams–Bashforth backward–Euler scheme is used. The singularity of the boundary condition along the two edges which are perpendicular to the direction of the wall motion is reduced by the help of the two-dimensional asymptotic solutions of Hancock et al. [2] and Gupta et al. [3]. Calculations have been carried out for grids with 36^3, 48^3, 72^3 and 96^3 grid point. The critical Reynolds number for the onset of oscillations is determined by extrapolation of the growth rates of the amplitude of the flow oscillations as a function of the Reynolds number. In contrast to Liberzon et al. [4] we used the subcritical growth rates rather than the supercritical ones. This way the bifurcation point of the subcritical Hopf bifucation can be determined accurately. The transient oscillatory subcritical flows have been computed up to the full relaxation to the steady flow, i.e. up to the termination condition for a steady flow [1].

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Evaluation of HYMLS, LOCA and ANASAZI for bifurcation analysis of flow in a 3D lid driven cube

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ABSTRACT

Bifurcation analysis of systems arising from partial differential equations needs efficient parallel code. We constructed such a code from the EPETRA-package available within Trilinos (see http://trilinos.sandia.gov/). The code consists of the following ingredients. Both the construction of the matrix and the right-hand side is performed in parallel using a domain decomposition approach. The solution process exploits the same data layout, which keeps data movement between processors low. We chose to use structured grids and finite volume discretizations. For the incompressible Navier-Stokes equation we use the staggered C-grid. Our implementation is matrix oriented instead of function oriented. Before computation we compute and store all stencils needed in the code. Even the nonlinear terms, which are in fact bilinear forms, can be expressed as a combination of stencils. The Jacobian matrix and the right-hand side are now constructed from products from stencils and vectors. For the continuation process we use LOCA which calls HYMLS to solve the systems. HYMLS is a linear system solver for solving steady state incompressible Navier Stokes equations in 2 and 3D [1,2,3]. We constructed recently a multilevel variant of it, which makes it possible to solve 3D problems of over 1 million unknowns quickly on a parallel computer. The solver is very robust and allowed a quick increase in the Reynolds number to get into the interesting region around Re=2000 of the benchmark problem described in [4]. In the neighbourhood of this number we compute the most critical eigenvalues using the ANASAZI-package, which contains a generalized version of the Arnoldi method. Also here we employ HYMLS to solve the linear systems resulting from a Cayley transform of the generalized eigenvalue problem. For our computations on an 128 cubed grid we needed at least 128 cores to get the work done in a few wall clock hours. In the talk we will give a more detailed explanation of the used algorithms, show the break up of the computation time over the various parts of the algorithm, and show results for the benchmark problem.

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Efficient computation of bifurcation diagrams via adaptive ROMs

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ABSTRACT

Construction of bifurcation diagrams involving complex, time dependent attractors may require huge, non-affordable computational resources in physical and engineering problems modeled by partial differential equations. On the other hand, if the system is dissipative, its large time dynamics are usually low dimensional.

In this scenario, *proper orthogonal decomposition* (POD) can provide a flexible strategy to efficiently compute bifurcations over a given parameter span. Indeed, we show that the POD modes are fairly independent of time and possible parameters in the problem [1, 2], a property that can be exploited to construct *reduced order models* (ROMs) adapting to the dynamics as the bifurcation parameter is increased.

The proposed method starts up at the lowest bound of the desired bifurcation parameter span, where a POD basis is calculated from some snapshots obtained by a short, generic run of a time dependent numerical solver. The governing equations are then Galerkin projected onto the POD modes and continuation is performed (using a Poincaré map) along the bifurcation diagram associated with the resulting Galerkin system. The strategy is able to detect when the POD manifold needs to be updated, thus ensuring a good approximation and avoiding truncation instabilities. Updating is done by appropriately mixing the old modes with some additional modes resulting from new, numerically computed snapshots, and leads to a new Galerkin system to be used for larger values of the bifurcation parameter.

The constructed adaptive method is tested on the complex Ginzburg-Landau equation, considering bifurcation diagrams that exhibit a variety of bifurcations involving periodic, quasi-periodic, and chaotic attractors, and turns out to be flexible, robust, and fast.

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MEANDERING OF A VORTEX LINE IN SHEAR FLOW

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ABSTRACT

Background

Vortex lines form as coherent structures behind wind mills. When the vortex line oscillates, one can observe vortex meandering. This phenomenon is studied at a relatively small scale in laboratory experiments [4, 5, 10], and with lidar measurements in large scale field experiments [1, 2]. The vortex meandering mechanism is explained in different ways: as a 2D instability in the wake flow [4], advective transport of the wake by coherent structures in the turbulent atmosphere [3, 8, 10], or an oscillation due to a 3D vortex shedding process in the wake of the turbine [5].

The meandering of a wind mill wake has direct consequences on the location of velocity deficits in wind farms, fatigue loads on blades, and the enhancement of small scale turbulent energy in the atmospheric boundary layer (ABL). The wind mill wake experiences shear over complex terrain or forests. In this presentation we explore the meandering under strong shear conditions and investigate the following processes: Is the meandering due to advection of the wake by coherent structures in the turbulent ABL as proposed by [3, 10]? Or, is it an intrinsic property of a vortex line instability, as e.g. Kelvin waves [7]?

Method

Frist, an idealized setup with a vortex line in shear flow (Fig. 1a) is investigated by means of linear stability analysis. From the linearized vorticity equation, we derive an equation for the displacement vector $\underline{\ell}'$ of the vortex line: $\partial_t \underline{\ell}' + \mathscr{A}_u \underline{\ell}' = \underline{\underline{\Omega}} + \mathscr{D}$, where $\mathscr{A}_u$ is the advection operator, $\underline{\underline{\Omega}}$ is an operator for the interaction between the vortex line displacement $\underline{\ell}'$ and the outer shear Ω, and $\mathscr{D}$ symbolizes the diffusion.

To capture the full non-linearity of the phenomenon, we run large-eddy simulations of the vortex line in shear flow with EULAG [6, 8, 9]. This multiscale geophysical flow solver can simulate fluid flow from the laboratory scale, up to phenomena in the ABL, or higher up in the earth's atmosphere. It offers the possibility to study the effect of flow over complex terrain or forest canopy flow on the vortex line.

Results

The analysis shows that strong shear is crucial to trigger an oscillating motion of the vortex line. The intensity of the shear $\|\Omega\|$ is inversely proportional to the time scale τ of the meandering motion. The ratio $\frac{U}{L\|\Omega\|}$ with flow velocity U determines wether advective transport $\mathscr{A}_u$ or the meandering $\underline{\underline{\Omega}}$ dominates the dynamics. L is a length scale for the shear layer depth.

For the case, where advection dominates, an instability evolves in the simulations and a snapshot of the horizontal velocity field is shown in Fig. 1b. The growth rate β of this instability can be determined from linear theory. It depends on advection velocity and shear layer depth: $\beta \sim U/L^2$

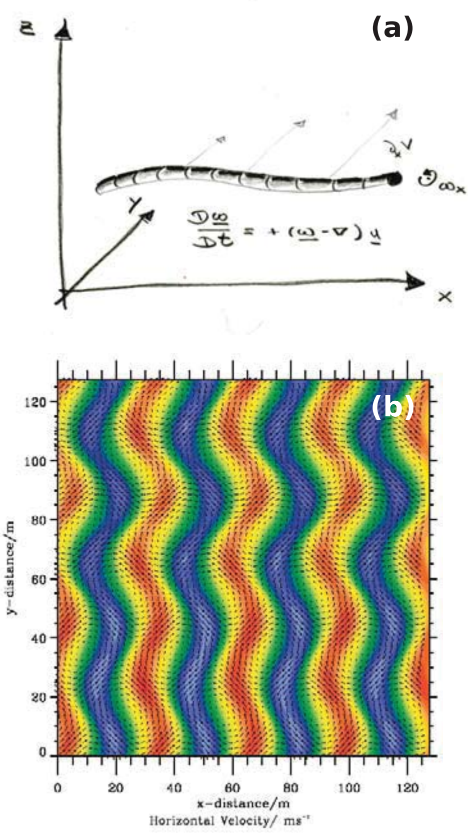

Figure 1: **(a)** Vortex line with vorticity ω_x in shear flow $\Omega_z = \partial_x V$ **(b)** simulated horizontal velocity field V after 340 s – portrays a shear instability in two dimensions

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On jet sharpening and the equilibration of meridional-asymmetric barotropic instability

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Barotropic wave dynamics and barotropic instability are fundamental to the development and variability of atmospheric and oceanic jets. While the linear problem has been extensively studied, many basic aspects of the nonlinear problem are still poorly understood.
We examine the nonlinear dynamics of one of the simplest barotropic jet configurations which incorporates many fundamental aspects of real flows, including linear instability and its equilibration, nonlinear interactions, scale cascades, vortex dynamics, and jet sharpening. We make use of the simplicity of the problem to conduct an extensive parameter sweep, and develop a theory relating the properties of the equilibrated flow to the initial flow state, making use of marginal stability together with conservation of circulation, impulse and wave activity.

Eddy mean flow interaction in idealized flows using a geometric framework to parameterize eddy fluxes

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ABSTRACT

Eddy properties are analyzed using geometric characteristics of the eddy stress tensor, the anisotropic part of the velocity correlation tensor. In this framework, one can define a 'variance ellipse' that describes the mean eddy shape and tilt, allowing for an insightful investigation of the eddy-mean flow feedback [1], [2].
We first study simple idealized flows such as piecewise linear jet profiles, and perform high-resolution simulations with eddy-permitting diagnostics. For these simple flows, analytic solutions can be found and the dynamics are easily interpreted, forming building blocks for the understanding of more complex flows. We find a direct relation between the eddy tilt given by the geometric description and that given by the phase difference of a normal mode solution, which gives a straightforward interpretation in terms of classical stability theory [3].
We next revisit the problem of a barotropic jet on a beta plane, where the new framework sheds light on important mechanisms such as jet stabilization and jet sharpening. The initially unstable jet gives rise to eddies which are tilted 'against the shear'; hence perturbations can grow and extract energy from the mean flow. However, since the jet becomes gradually weaker, at a given moment it can no longer satisfy the Rayleigh condition for instability [4]. Once the jet stabilizes, eddies abruptly become tilted 'with the shear' therefore all perturbations decay as they return their energy to the mean flow, resulting in jet strengthening. The geometric parameters allow us to identify and describe the transition in the eddy-mean flow interaction, where down-gradient eddy fluxes suddenly become up-gradient and the behaviour of the system changes.
Finally, we also use the Ray Tracing theory to investigate the eddy propagation within the jet. An analytic solution for the eddy orientation can be found assuming a plane wave solution, for which an interesting relation between the group velocity, the EP flux, and the eddy tilt exists. The ray tracing results capture the essence of the eddy propagation observed, showing how energy is radiated into the jet core in the unstable regime and outward in the stable regime.

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<u>**Flow regimes of the upper tropospheric jet stream**</u>

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The properties of the tropospheric jet stream depend on the specific season, year and geographical area. There may be a double or single jet, the jet may be located in the subtropics or midlatitudes, it may have a strong or weak vertical shear and its variability pattern may be dominated by pulsing or meridional displacement. The properties of the jet are determined by the nonlinear interactions between the jet itself, the mean meridional circulation (MMC) and the eddies (defined as perturbations from the zonal mean). Since the momentum budget of the zonal mean flow in the atmosphere is close to balance, each observed state of the jet can be viewed as a different flow regime, in which the balance between the jet, the MMC and the eddies is different.

An idealized two-layer model, based on the quasi-geostrophic (QG) assumptions on a sphere with a few modifications, is able to reproduce the observed regimes of tropospheric jet stream. The main difference between this model and the more common version of spherical QG models is the inclusion of a term representing the advection of zonal mean momentum by the a-geostrophic MMC, which allows for the mechanism creating the subtropical jet.

As the parameters of the model are gradually varied two main regime transitions appear – a transition between a double and single midlatitude jet and a transition between a midlatitude and subtropical jet. In each regime the dominant eddies are different in terms of amplitude, wavenumber, phase speed, location and phase tilt. The most unstable linear modes of the time averaged mean flow are found to have similarity to the dominant modes in the nonlinear model. This implies that while the eddies determine the properties of the mean flow through the momentum and heat fluxes, their structure is also determined by the mean flow itself through baroclinic instability.

Dynamics of an elastic filament undulating at a free surface

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Many living organisms use body undulations to propulse themselves through fluids: they achieve net forward motion by propagating wave of curvature down their deformable body. In inertial regimes, the anguilliform swimming mechanism has first been addressed in pioneer study by Lighthill [J. Fluid Mech., vol 9, 305-317, 1960]. In his so called *reactive* model, Lighthill considered the inertial momentum redistribution caused by the undulations within the fluid and he showed that the thrust force generated through this process could be estimated from the kinematic of the tail of the swimmer alone. A vast amount of theoretical and numerical works has followed, providing the basis for a broad spectrum of applications, especially in robotic and engineering.

We present here a swimmer able to propulse itself at the surface of a water tank. The set up consists in a flexible filament forced to oscillate by imposing an harmonic motion to one of its extremities (using magnetic interactions). We fully characterize its dynamics, with the objective to bring a better understanding of fluid-solid interactions in undulatory propulsion. The characteristics of the propagating wave are crucial in determining the swimming performance. Modeling the filament as a forced beam under fluid loading, we pinpoint the different elements that can account for the observed kinematic. In particular, we show that in our Reynolds number regime, a quadratic fluid dissipation term is needed to propagate passively a wave in a finite elastic beam. The order of magnitude of this term is estimated by comparing the theoretical predictions of the model against the experimental data. When injecting the prescribed body deformations into Lighthill's model, we show that this *reactive* theory gives good predictions of the performance of the swimmer (its forward speed).

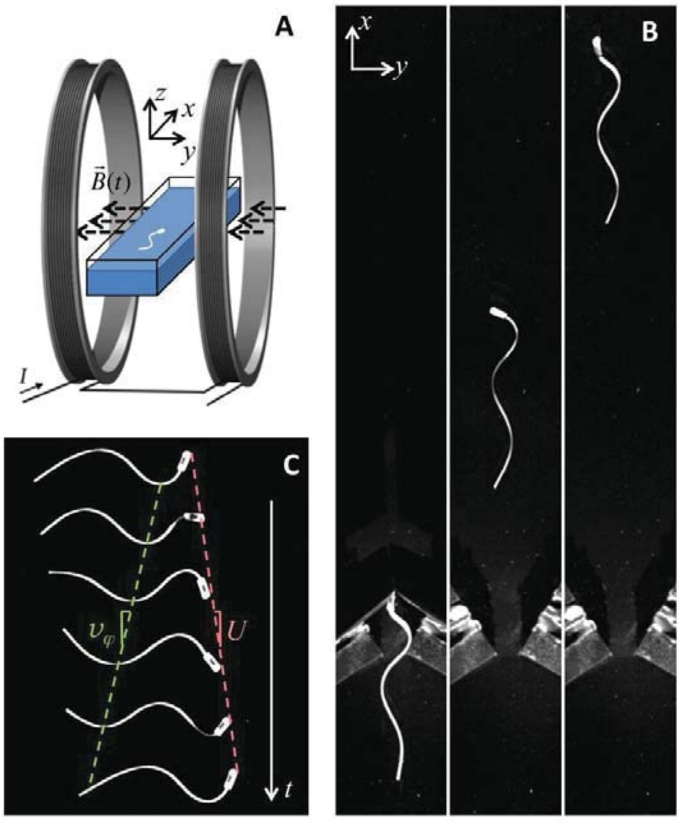

Figure: (A) Experimental setup: Swimmer at the free surface of a water tank consisting of a flexible cylindrical tail made of acrylic polymer. A magnet embedded in the head of the filament is forced to oscillate using the time-varying magnetic field produced by a Helmholtz pair. (B) Top-view snapshots of the self-propelling swimmer. (C) Successive pictures of a filament over a period of undulation showing the forward swimming velocity U and the speed of the traveling wave v_φ.

Numerical observation of large-scale instabilities in counter flows of viscoelastic fluid

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One of the flows structural instability phenomena, the asymmetries near flow stagnation points, is considered. Such asymmetries were earlier observed in some experimental and theoretical investigations of viscoelastic fluids contraflows in cross slots. The report presents analytically obtained symmetric and asymmetric asymptotic solutions for the flow in the vicinity of the stagnation critical point.

The symmetric part of the solution is proved by its comparison with an earlier obtained numerical symmetric solution. The existence of two asymptotic modes demonstrates that the contraflows involve bifurcation near the stagnation critical point. Possible types are identified of this critical point: a centre, a saddle, and a centre-saddle transitional type. Finally, the probability of bifurcations in Newtonian fluid stagnation flows is shown.

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Experimental and numerical study of flow in a precessing cylinder

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Precession has long been discussed as a complementary energy source for homogeneous dynamo action. To that end, DRESDYN, a large scale, precession driven dynamo experiment, is currently in advanced planning stage at Helmholtz-Zentrum Dresden-Rossendorf. DRESDYN will consist of a variable axis, precessing cylinder of approximately 2m diameter filled with liquid sodium.

Ultrasonic flow measurements using a 1:6 scale water experiment are currently performed, focussing on laminar-turbulent transition characteristics. A sudden jump in the motor's mesured electrical power suggests transition to occur at a precession rate of $\Gamma = 0.06$. We also conduct Direct Numerical Simulations, although, for the time being, limited to a Reynolds number $\mathrm{Re} = O(6000)$, which is ten times smaller than in the water experiment.

At the conference, we will introduce the planned setup of DRESDYN and show first experimental and numerical results for the 1:6 water model.

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