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Stability of falling films on flexible substrates

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The linear stability of a liquid film falling down an inclined flexible plane under the influence of gravity is investigated, using a combination of analytical and numerical techniques. Using an extension of two different models for the flexible substrate already used in the literature, a modified Orr-Sommerfeld problem is formulated and, via asymptotic expansions in the wavenumber, the consequences for long waves are studied. At leading order the flexibility was found to have a destabilising effect, reducing the critical Reynolds number inversely proportional to the stiffness of the substrate and destabilising Stokes flow. To purse this further, a Stokes flow approximation was considered, which confirmed the long wave results, but also displayed a short wave instability setting in before the long wave instability. Increasing the surface tension was found to have little effect on these instabilities and so they were characterised as wall modes. Wider exploration revealed mode switching in the dispersion relation, with the wall and surface mode swapping characteristics for higher wavenumbers. The zero Reynolds number results demonstrate that the long wave limit is not sufficient to determine instabilities so the numerical solution for arbitrary wavenumbers was sought using a Chebyshev tau decomposition. The solution was verified using the long wave and zero Reynolds number analytical solutions, and these short wave wall instabilities were shown to persist for larger Reynolds numbers. Destabilisation of all Reynolds numbers is easily achieved by increasing the flexibility, however increasing the stiffness reverts smoothly back to the rigid wall limit.

Convective and Absolute Instability of Viscoelastic Liquid Jets In the Presence of Gravity

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The convective and absolute linear instability analysis of viscoelastic liquid jets in the presence of gravity has been examined for axisymmetrical disturbances. We use the upper-convected Maxwell (UCM) model to provide a mathematical description of the dynamics of a viscoelastic liquid jet. An asymptotic approach is used to obtain the steady state solutions. The dispersion relationship for viscoelastic liquid jets, which encompasses two dimensional flow, is derived using linear instability analysis. This dispersion relationship is solved numerically using the Newton-Raphson method. We show the effect of changing Froude number, Reynolds number, Weber number and the Deborah number on the steady-state solutions as well as on convective and absolute instability. In this work, we used a mapping technique developed by Kupfer, Bers, and Ram to find the cusp point in the complex frequency plane and its corresponding saddle point (the pinch point) in the complex wave number plane for absolute instability. The convective/absolute instability boundary (CAIB) is identified for various parameter regimes.

ID: **300**

Session: Waves and turbulence

Evolution of random wave fields and the role of the statistical closure

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Weakly nonlinear random wave fields are usually studied within the kinetic theory, based on the smallness of nonlinearity and a number of assumptions about the quasi-Gaussianity (in particular, the rather subtle assumption of the absence of coherent structures). Although the theory has been able to faithfully predict major features of wave field evolution in different physical contexts, the question of how well it captures the actual behaviour of physical systems remains open.

Here, we study the evolution of random wave fields with and without the statistical closure, using water waves as a representative example. The study is focused on the evolution of wave spectra, as well as higher statistical moments. Direct numerical simulations are performed using the algorithm based on the Zakharov equation (DNS-ZE), which does not depend on any statistical assumptions and plays the role of the primitive equation in the theory of wave turbulence. In the short term, the DNS-ZE simulations are validated against the available measurements and numerical simulations. Results are compared with the simulations performed using the standard and generalised kinetic equations (KE). Both DNS-ZE and KE demonstrate very close long-term evolution of integral characteristics of spectra. There are, however, significant discrepancies in spectral shapes and rates of spectral change.

We show that these differences lead to sizeable differences for the bound harmonics non-Gaussianity. The dynamic non-Gaussianity obtained via the statistical closure is qualitatively consistent with the DNS values, but is considerably underestimated in absolute value. As a further clarification of the role of the statistical closure, simulations are performed with the 'mirror' Zakharov equation with the opposite sign of nonlinearity, which leads to the same kinetic equation. The change of sign does not affect the spectral evolution, but leads to substantial differences in the evolution of the dynamic higher moments.

A CONTRAVARIANT FORM OF MODEL EQUATIONS FOR A WAVE FLOW OF A FALLING LIQUID FILM

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Wavy flow of thin viscous liquid layers are used in various technical applications. There are direct methods to model this type of flows; however, their boundaries of applicability are still under consideration. This is why the rigorous geometrical approach is very popular today. It usually comes to rewriting the equations in new variables, transforming the flow area into the strip of constant thickness. An easy way to implement this idea is to change the variables without transforming vectors and tensors included in main hydrodynamic equations [1]. A different approach proposed in [2] implies a full coordinate transformation of the Navier--Stokes equations written in invariant tensor form. This realisation is very complicated because of two reasons: the above mentioned transformation is essentially four-dimensional and non-orthogonal. Authors of [2] avoid these difficulties by using a relativistic hydrodynamic equations in the classical limit. However, their derivation was rather cumbersome and limited by two-dimensional case with additional long-wave assumption. To generalize the equations one may consider the metric tensor depending on time as a parameter (a 1-parametric family of maps representing the real wavy volume). The fixed Cartesian points are moving in this representation, and one may introduce a frame velocity field describing this motion. This field locally generates a Lie group, substituting which into the Lie derivative form of the Navier-Stokes equations will give the contravariant form of the equations [3]. In the present work, this form is used to derive the model equations for the film flow.

The work was supported by Russian Science Foundation (project 16-19-10449).

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Session: Active fluids

Spatial-temporal control of bacterial suspensions

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Suspensions of motile bacteria or synthetic microswimmers, termed active matter, manifest a remarkable propensity for self-organization and formation of large-scale coherent structures. Most active matter research deals with almost homogeneous in space systems and little is known about the dynamics of active matter under strong confinement. I will talk on experimental and theoretical studies on the expansion of highly concentrated bacterial droplets into an ambient bacteria-free fluid. The droplet is formed beneath a rapidly rotating solid macroscopic particle inserted in the suspension [1]. We observed vigorous inability of the droplet reminiscent of a supernova explosion [2]. The phenomenon is explained in terms of continuum first-principle theory based on the swim pressure concept. Furthermore, we investigated self-organization of a concentrated suspension of motile bacteria Bacillus subtilis constrained by two-dimensional (2D) periodic arrays of microscopic vertical pillars [3]. We show that bacteria self-organize into a lattice of hydrodynamically bound vortices with a long-range antiferromagnetic order controlled by the pillars' spacing. Our findings provide insights into the dynamics of active matter under extreme conditions and significantly expand the scope of experimental and analytic tools for the control and manipulation of active systems.

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Computing transition probabilities in stochastic ocean-climate models

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Transitions in an ocean-climate model may occur due to the existence of multiple steady states for the same parameter values. Because of unresolved small-scale variability, however, transitions may be observed even before a tipping point is reached. This unresolved variability is often represented as noise in a stochastic model. Methods for computing probabilities of such transitions in stochastic models have so far only been used on lower dimensional problems due to the high computational cost. We present a novel projected time stepping approach which greatly reduces the cost of these methods for high dimensional problems. We use this approach in combination with the Trajectory-Adaptive Multilevel Sampling [2] method to compute probabilities of transitions in an idealized model of the Meridional Overturning Circulation [1].

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Boundary-layer streaming in viscoelastic fluids

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Oscillations of immersed bodies are known to generate a steady streaming flow, originating from Reynolds stress within the viscous non-stationary boundary layer in the vicinity of the object. This phenomenon is very similar to acoustic streaming generated by sound or ultrasound waves within a fluid. Streaming flows have recently found a renewal of interest due the mixing requirement in microfluidics. A typical situation is that of a cylinder oscillating perpendicular to its axis, generating two pairs of counterrotating vortices due to the transfer of vorticity from the inner boundary layer. Outer vortices can be observed far from the object as a result of convection of vorticity. Here, we consider the situation of a viscoelastic fluid: by using PIV, we carry out an experimental study of the flow structure and magnitude over a range of amplitude and frequency.

A systematic comparison with a purely Newtonian fluid has been carried out and results showed several qualitative differences. First, when elasticity is significant enough, we observe that the inner boundary layer vortices are much larger than for a Newtonian fluid of the same viscosity. This is generally associated to the disappearance of outer vortices. We propose that elongational viscosity is a potential mechanism for this enlargement of vortices.

Second, for high enough forcing, the streaming flow loses the usual symmetry of the four-vortices. The pairs of vortices can become uneven, i.e. they are not image-mirror of each other with respect to the axis of vibration and to the axis perpendicular to the vibration. Finally, a more complex structure can appear where each initial vortex can split into two smaller ones, showing a steady eight-vortices structure. To the best of our knowledge, these phenomena were unobserved so far.

Thermal Instability in a Vertical Porous Channel with Permeable Boundaries

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Several stability analyses regarding the Rayleigh-Bénard flow systems are relative to small-amplitude perturbations. Many of them are focussed on the concept of convective instability, by regarding the dynamics of normal Fourier modes and their growth in time. Growing modes happen when the value of the Rayleigh number exceeds its critical threshold. However, the perturbations emerging in Nature are not necessarily Fourier modes, but they can be modelled as wave packets. Even if a given wave packet is a superposition including unstable Fourier modes, it may well display a stable behaviour at large times, meaning that its amplitude is ultimately damped in time. On the other hand, for sufficiently large values of the Rayleigh number (generally supercritical) every wave packet ultimately displays a growth in time. As is well-known, this concept is the basis for the definition of the absolute instability.

This study provides an analysis of the convective and the absolute instability in a vertical porous channel with permeable and isothermal sidewalls kept at different temperatures. The governing parameters are the Péclet number for the vertical flow and the Rayleigh number, proportional to the boundary temperature difference. The analysis is carried out through a numerical solution of the stability eigenvalue problem. This analysis yields both the neutral stability condition defining the onset of convective instability, and the threshold condition for the wave packet instability, viz. the absolute instability.

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Transient growth in stratified two-phase flows

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Linear stability of stratified two-phase flow is commonly studied via the modal analysis, which is based on the investigation of the eigenvalue problem**.** Conditions for which the modal analysis predicts exponential growth of the interface displacement can be associated with transition from stratified-smooth flow to other flow patterns (e.g., stratified-wavy, plug/slug flow). The present study is aimed at exploring whetherthe non-modal transient growth of perturbations may trigger flow pattern transition under subcritical conditions, for which the flow is linearly stable. The transient growth is characterized by the energy growth function and the optimal perturbation patterns that allow for the maximal transfer of energy from the basic flow to perturbations. The energy norm accounts for the gravitational potential energy and interfacial capillary energy, along with the kinetic energy. The latter is the only component of the energy considered for single-phase flows. The energy norm definition adopted in this work enables studying the effects of gravity and surface tension on the transient growth in horizontal and inclined two-phase flows. It is found that contrarily to the fastest exponential growth, which is exhibited by essentially 2D perturbations (Squire's theorem), the maximal transient growth is attained mostly by 3D perturbations. Significant transient energy growth is found to occur even in linearly stable flow configurations, which, similarly to single-phase flows, may trigger non-linear destabilizing mechanisms within one of the phases. However, it is shown that the transient energy growth in linearly stable cases can be accompanied by noticeable interface deformations, which may lead to transition from smooth-stratified flow to another flow pattern. Current research efforts are focused on studying the further (non-linear) evolution of the optimally perturbed flow on the route to the flow pattern transition via non-linear transient numerical simulations.

Finite-size coherent particle structures in thermocapillary liquid bridges

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The accumulation of small rigid spherical particles in high-Prandtl-number (Pr=68) thermocapillary liquid bridges is studied numerically. Initially randomly distributed particles are found to cluster in particle accumulation structures (PAS) which belongs to the class of finite-size coherent structures (FSCS). The accumulation process is investigated in the framework of a one-way coupling approach, modeling FSCS as a single-particle phenomenon. High-resolution flow simulations are carried out to resolve the thin flow boundary layers. Since the accumulation arises in three-dimensional azimuthally traveling hydrothermal waves, which are steady in the co-rotating frame of reference, only a single snapshot of the fully-developed hydrothermal wave is sufficient to compute the particle motion. We find the accumulation is due to a finite-particle-size effect when the particles move close to the impermeable flow boundaries. The extra drag force experienced by a particle near the boundaries creates a dissipation in the dynamical system describing the particle motion. The dissipation near the flow boundaries causes particles to be attracted to regions in or near Kolmogorov-Arnold-Moser (KAM) tori of the unperturbed fluid flow (without particles). Several simulations are carried out covering different height-to-radius aspect ratios for the liquid bridge, various thermocapillary Reynolds numbers and particle properties to study the structures and evolution time scales of the accumulation patterns. When PAS arises as a periodic orbit in the rotating frame of reference particle-particle interactions should be taken into account during the late stage of evolution, since the particle volume fraction becomes large locally. In this case, the single-particle model is extended to take into account collective effects.

Recent news about bacterial swarming

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Bacterial swarming is a biophysical phenomenon describing collective motion of thousands of self-propelled cells. During swarming, the cells interact and form long-lived jets and vortices, thought to be governed by short-range steric forces and long-range hydrodynamic effects. How exactly, and whether they indeed take decisions is not really clear, but the exact evolutionary advantage of swarming in bacteria is definitely unknown.

In the talk I will describe the experiments we perform in details, and will present some of the recent results we have obtained in the last five years. For instance, I will show results for (1) Levy Walk statistics of individual bacteria migrating among their siblings in the crowded swarm, (2) puzzling swimming of cells against their own collective flow, and (3) the influence of cell aspect ratio, and rotational diffusion on swarming.

Convectons and chaos in doubly diffusive convection

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Doubly diffusive convection in a closed vertically extended 3D container driven by horizontal temperature and concentration gradients is studied under the assumption that the buoyancy ratio N=-1 so that thermal and solutal variations within the fluid yield forces of equal strengths but opposite directions. This configuration admits a conduction state where the fluid is stationary and the temperature and concentration fields are linear in space. The primary instability from the conduction state is subcritical and generates two families of spatially localized rolls known as convectons. These steady states are organized in a pair of intertwined solution branches within a well-defined range of Rayleigh numbers in a behavior known as homoclinic snaking. Secondary instabilities along the primary branches of convectons are found to yield twisted convectons whose branches describe secondary snaking. The twist instability destabilizes the primary convectons and are responsible for the absence of stable steady states, localized or otherwise, in the subcritical regime. As a result, for Rayleigh numbers beyond the threshold for primary instability, the system exhibits an abrupt transition to large amplitude spatio-temporal chaos.

Self-interaction of Alfven waves in isentropically unstable/stable plasma

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Alfven waves are perturbations of transversal plasma velocity and magnetic field. These waves are considered as a possible energy carrier from the convection zone to the corona due to the fact that they can propagate for large distances without significant damping. Speaking about solar wind acceleration and solar plasma heating it is necessary to note that not only the interaction of Alfven waves with other MHD waves, but also the interaction of Alfven waves with itself ("self-interaction") can be important. Such self-interaction is described by the vector Cohen-Kulsrud equation, which predicts a steepening of large amplitude Alfven waves. This steepening can lead to the formation of current sheets and, consequently, the loss of energy by the wave.

At the same time, non-adiabatic heating and radiative cooling processes are present in the solar plasma. Taking them into account can significantly change the dynamics of the waves in the models under consideration. In particular, this heating/cooling misbalance can reveal itself through the isentropic instability / stability. This type of instability relating to the wave-type instabilities has a direct impact on the modes of the acoustic type, and, in particular, on the magnetoacoustic waves. So in an isentropically unstable medium magnetoacoustic waves become unstable and can amplify to large amplitudes, while Alfvén waves remain stable. Moreover, in an isentropic medium, the appearance of autowave solitary pulses and the bi-exponential amplification of Alfvén waves as a result of parametric interaction with unstable magnetoacoustic waves are possible.

Consideration of the propagation of linearly polarized Alfven waves in a heat-releasing plasma leads to an integro-differential equation describing the self-interacion of Alfven waves in this type of plasma. In the approximation of a quasi-harmonic signal, this equation is reduced to the scalar Cohen-Kulsrud equation supplemented by a cubic source term. This equation can be solved analytically. From the solution of this equation, it follows that the large-amplitude Alfven waves in the heat-releasing plasma can steepen with a speed different from the speed in the plasma without heating/cooling misbalance. The second consequence is that Alfven waves can amplify or decrease due to the presence of a cubic source term in the equation. In particular, under conditions of isentropic instability, Alfven waves steepen faster and increase in amplitude compared to the plasma without heating/cooling misbalance. In the case of isentropic stability, on the contrary, a slower steepening and a decrease in the wave amplitude occur. It is shown that the results of the study of the obtained non-linear equation are consistent with the results of numerical simulation of the propagation of linearly polarized Alfven waves in a heat-releasing plasma based on a one-dimensional system of MHD equations.

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Influence of shear stress fluctuations on dynamics of waves on a liquid film sheared by a turbulent gas flow

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In many industrial applications thin liquid films are sheared by a turbulent gas flow. Diesel and gasoline fuels, for example, are known to form wall films in the cylinder after injection. Deposits, which have a negative influence on the combustion process, can form from those films especially in the vicinity of three-phase contact lines, which appear as a result of the film rupture. This is why it is important to understand the stability and dynamics of film which can lead to the film rupture.

In this work, we investigate numerically the dynamics of a thin liquid film, which is sheared by a turbulent gas flow. It is known that even constant shear stress has an influence on film dynamics. In this work we examine the effect of turbulent fluctuations on the film development. The simulation is carried out in two steps. In the first step a direct numerical simulation (DNS) of a single-phase channel gas flow is performed. The shear stress at the lower wall, which varies with position and time is stored. In the second step a one-sided long-wave simulation of the liquid film is conducted using the previously gathered shear stress data as a boundary condition at the liquid-gas interface. The resulting film evolution is investigated for different Reynolds numbers, and the influence of the fluctuating turbulent shear stress on the film evolution is analyzed.

The results show that the amplitude, the characteristic size and the time scale of the turbulent fluctuations significantly affect the film dynamics. This influence has been explained with a help of simplified analytical model. Furthermore, we show that the film interface velocity in relation to propagation velocity of turbulent structures plays an important role. The maximum amplification of the film disturbances occurs for the cases where the propagation velocity of the turbulent structures is equal to the surface velocity of the liquid film.

Spatio-temporal symmetry breaking originates vertical propulsion in a free flapping wing

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The oscillations of a streamlined body surrounded by fluid allow it to move due to resulting average thrust and lift forces. Flying animals and fishes, for example, flap their wings or undulate their bodies to accelerate the surrounding fluid achieving propulsion. This mechanism of self-propulsion, which results from the coupling between the fluid and the deformation of the body, is nowadays considered for industrial applications such as submarine and micro-aerial vehicles.

As observed in nature, only individuals on finite Reynolds number scales, where inertial effects become important, adopt this propulsion strategy. To understand the emergence of flapping wings propulsion, we have numerically studied the flow originated by a two-dimensional symmetric rigid wing sinusoidally heaving as a function of heaving frequency and amplitude. Through this numerical analysis, we identify a frontier where symmetry breaking occurs leading to a net effort actuating on the solid that ultimately leads to propulsion. Two symmetry breaking are identified, one purely spatial that results in a net horizontal force, and one spatio-temporal resulting in a net vertical force over a period.

In literature, horizontal propulsion following spatial symmetry breaking is usually investigated. In this work we extend this analysis to vertical propulsion. A model is proposed to partially impose the vertical velocity allowing to study the appearance of vertical propulsion as an attracting state following the spatio-temporal symmetry breaking of the flow. We analyze the emergence of this attracting state through Floquet stability analysis of spatio-temporal symmetric (non-propulsive) solutions. To carry out this analysis, a symmetry preservation method based on Time-Spectral Methods (TSM) was developed. We finally conclude through the stability analysis of symmetric flows that the appearance of propulsive solutions is connected to the destabilization of a Floquet mode.

The tea-pot effect in two- and three-dimensional jets with a large Froude number

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We examine viscous jets with a large Froude number, which makes the radius of curvature of the jet's trajectory much larger than the jet's own radius. It is demonstrated that there is a significant difference in dynamics between sheared and non-sheared curved jets, with the former ones being much more complex (which is probably why they have never been examined before).

Using a set of asymptotic equations derived on the basis of the assumption $Fr \gg 1$, we obtain a condition when the so-called tea-pot effect occurs, i.e., when the liquid drips down at jet's exit.

The mystery of long-lived oceanic vortices: The solution of the problem

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Observations show that radii of oceanic eddies often exceed the Rossby radius of deformation, whereas theoretical studies suggest that such vortices should be unstable. The present paper resolves this paradox by presenting a wide class of large geostrophic vortices with a sign-definite gradient of potential vorticity (which makes them stable), in an ocean where the density gradient is mostly confined to a thin near-surface layer (which is indeed the case in the real ocean). The condition of a thin "active" layer is what makes the present work different from the previous theoretical studies and is of utmost importance. It turns out that without it, the joint requirement that a vortex be large and have a sign-definite potential vorticity gradient trivializes the problem by eliminating all vortices except nearly barotropic ones.

Dynamically Consistent Parameterization of Mesoscale Eddies

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This work aims at developing new approach for parameterizing mesoscale eddy effects for use in non-eddy-resolving ocean circulation models. These effects are often modelled as some diffusion process or a stochastic forcing, and the proposed approach is implicitly related to the latter category. The idea is to approximate transient eddy flux divergence in a simple way, to find its actual dynamical footprints by solving a simplified but dynamically relevant problem, and to relate the ensemble of footprints to the large-scale flow properties.

Stability and Pattern Formation in a Thin Volatile Liquid Film of a Binary Mixture

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Linear instability and subsequent nonlinear pattern formation in a thin film of a binary mixture is studied applying longwave approximation [1]. The two components of the mixture have different surface tension and different evaporation rates.
Recent experiments [2] showed that if the component with the higher surface tension evaporates faster than the other one with lower surface tension, the flat film becomes unstable due to surface undulations caused by the solutal Marangoni effect.
In this contribution, the basic equations are formulated and a frozen time stability analysis around the state of the homogeneous mixture is performed. Critical wave lengths and growth rates are computed. The obtained results are compared with the experiments and confirmed by a direct numerical simulation of the longwave thin film equations in three spatial dimensions.

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Spreading dynamics of reactive surfactants driven by Marangoni convection

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Self-propulsion of Marangoni surfers, such as camphor boats, is accompanied by a flow in the aqueous phase that contributes to the interactions between particles or with the boundaries of the system. Both the individual and collective dynamics that emerge are extremely rich and have not been fully elucidated yet. Still, several experiments have been performed recently in order to provide quantitative information regarding the physico-chemical parameters of the camphor-water system. The interpretation of experimental data is delicate, however, since it requires a fine understanding of the relation to the models' parameters.

In this talk, I will discuss the spreading dynamics of some insoluble surface-active species along an aqueous interface. The model includes both diffusion, Marangoni convection and first-order reaction kinetics. An exact solution of the nonlinear transport equations is derived in the regime of large Schmidt number, where viscous effects dominate the flow. I then demonstrate that the variance of the surfactant distribution increases linearly with time, thus providing an unambiguous definition for the enhanced diffusion coefficient observed in the experiments. The model thus presents new insight regarding the coupling between interfacial transport and Marangoni self-convection.

Travelling-waves, solitary pulses and bound-states on electrified falling films

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The flow of an electrified liquid film down an inclined plane wall is examined. Of particular interest are coherent structures on the liquid surface in the form of travelling waves and single-hump solitary pulses and bound states. In a long-wave model a newly-developed continuation method is used to study the bifurcation structure of the solution space, including travelling-wave states and single and double pulse waves, as well as Hopf bifurcations to time-periodic travelling waves. Solitary pulse solutions for Stokes flow are computed for the first time using a boundary integral method. Gravity has a destablising effect for obtuse inclination angles and in this case solitary pulses can be found even for non-electrified flow. For acute inclination angles spatially non-uniform solutions exist only beyond a critical electric field strength, and pulse solutions occur only for sufficiently high supercritical electric field strength. Steadily propagating two-pulse and multi-pulse bound states are predicted by a long-wave interaction theory, and the existence of two-pulse states for Stokes flow is confirmed numerically. Fianlly, long-wave simulations are used to demonstrate that the electric field can trigger a switch from absolute instability to convective instability, thereby regularising the dynamics.

Surface waves created by libration in a circular channel

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We excite surface waves in a circular channel placed on a rotating table. The tank can rotate with constant velocity and/or can librate.
The experiment works in two parameter regimes: high libration amplitudes and small frequencies are used for the generation of traveling surface waves, while smaller amplitudes and higher frequencies are necessary for studying the patterns generated by horizontally excited Faraday waves. For the parametric excitation regime, lower viscosity liquids (pure water) is used. For an efficient excitation, a wall should be placed in the channel. The horizontal Faraday instability in high viscosities liquids (glycerin-water solutions) can be excited by the mean of the shearing. The wall is not any more necessary. In this way periodic lateral boundary conditions are assured. The experimental and simulation results will be compared.

Drop Behavior Influenced by the Correlation Length on Noisy Surfaces

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We investigate numerically the role of the correlation length on drop behavior on noisy surfaces. To this aim a phase field tool has been used. Theoretical results are confirmed by experiments of distilled water drops sitting on stainless steel and silicon surfaces textured by laser-induced periodic self-organized structures (LIPSS): An increase of the noise amplitude results in an amplification of the original behavior (*i.e.* hydrophobic is getting more hydrophobic, hydrophilic is getting more hydrophilic). Furthermore, computer simulations in two and three spatial dimensions allow for predictions on drop behavior on noisy sloped substrates under gravitational force, a problem of large interest in controlled motion in micro- and nano-fluidics.

Optimal perturbations and transition of a boundary layer flow under the influence of a spanwise magnetic field

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The stability of magnetohydrodynamics flows is an important topic in many physical systems and industrial applications. Among these applications, fusion electric power plants are actively being developed with the aim of providing a widely available, safe and cleaner energy source. Currently, the most successful design is the Tokamak in which a magnetically confined plasma is exploited in a toroidal vessel. One of the most important components of a modern fusion reactor is a robust heat exhaust system. In various designs, such a system will operate with liquid metal flows as plasma facing components (PFC) in place of traditional solid walls. As a result, the liquid metal PFC will allow rapid heat evacuation and will not be subject to permanent structural damage. In terms of geometry, the liquid metal flows on flat or concave surfaces and the confinement magnetic field can be oriented in a spanwise direction with respect to the flow. It is therefore important in this context to analyse the stability of the liquid metal flow and whether the transport occurs in laminar, transient or turbulent regimes.

In the hydrodynamic case (without magnetic field), there are two main scenarios of laminar-turbulent transition in a boundary layer over a flat plate. In the first scenario, the transition is preceded by an excitation of Tollmien-Schlichting waves (TS-waves). These waves propagate in the streamwise direction and their amplification can be described, above a critical value of the Reynolds number, by the theory of linear stability. The second transition mechanism orginates from free-stream turbulence that gives rise to streamwise streaks. These streamwise streaks are associated with Klebanoff modes (K-modes) and are seen experimentally as longitudinal structures inside the boundary layer. In contrast to TS-waves that grow exponentially, the amplitude of the K-modes increases algebraically. The K-modes have larger amplitude and smaller frequency in comparison with the TS-waves. The spanwise length of the streaks is a few boundary layer thickness. In the wall-normal direction, the streaks are observed in the whole boundary layer **[1]**. Andersson *et al.* have shown that the characteristic length and time scales, as well as the downstream amplifications, can be predicted through the optimal growth analysis of the linearized equations **[2]**.

Here we analyse the stability of the MHD boundary layer flow and its transition to turbulence. We follow the methodology used in **[3]** in the case of the channel flow with spanwise magnetic field and also consider the quasi-static limit of the MHD equations to study the problem.

From the viewpoint of stability, the analysis is performed using the non-modal approach **[4]**. Indeed, for many sheared bounded flows, the linear operator arising from the linearization of the evolution equations is not normal. As a result of this non-normality, the eigenvectors of the linear operator are not orthogonal and a combination of some of them could temporally grow in time, leading to transient growth. Consequently, traditional linear stability methods which are based on normal mode decomposition fail to capture the transient growth of the so-called optimal perturbations. When the amplification of such perturbations is large enough, the flow may transition at lower Reynolds numbers through a modification of the base flow or the non-linear interactions of the optimal modes. These Reynolds numbers could eventually be smaller than the critical Reynolds number at which the most unstable normal modes start to grow. Moreover, the optimal perturbations and the fastest growing normal modes are affected by the presence of a spanwise magnetic field in a very different way. In the purely hydrodynamic case, the most unstable modes are oriented in the spanwise direction, while the optimal perturbations are streamwise rolls. When a spanwise magnetic field is applied, the most unstable modes remain the same **[5]**, which is not the case of the optimal perturbations: for a channel flow, they become increasingly oblique as the intensity of the magnetic field increases and become purely spanwise rolls when the magnetic field is strong enough **[3]**. The same behaviour is observed in our case.

In order to compute optimal perturbations and their maximum amplification, we adopt two different approaches. The first one is based on the procedure described in **[6]** in which a generalized eigenvalue problem is constructed and whose largest eigenvalues and eigenvectors respectively represent maximum amplification and optimal perturbations. This procedure is well suited when we make the hypothesis that the boundary layer base flow is homogeneous in the streamwise direction and does not depend on time. However, for comparison, we also consider the case of a time evolving boundary layer. In that case the analysis is more intricate and requires an analysis of the operator that propagates a disturbance from initial time to final time, the propagator, and its singular value decomposition to take the mentioned time-dependence into account **[4]**.

In both cases, we perform a parametric study varying the intensity of the magnetic field (using the Hartmann number Ha as the parameter) and the value of the Reynolds number. For each values of these parameters, we compute the optimal perturbations and the optimal wavenumbers. As in **[3]**, this allows to exhibit scaling laws for the maximum global amplification as a function of Ha and also the orientations of the optimal modes with respect to the applied magnetic field. In the second part of our talk, we will present some non-linear simulations of the boundary layer MHD flows considered to highlight their transition to turbulence, in particular when the Reynolds number is subcritical. For that purpose, the flow is initialized with a superposition of the relevant base states and the optimal perturbations described above. When the amplification of energy is the strongest, three-dimensional noise with low amplitude is added. As in the case of the channel flow, we analyse the different transition scenarios depending on the type of optimal perturbations which can be spanwise, streamwise or oblique depending on the intensity of the magnetic field.

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Elastic deformation instability in soft microfluidic configurations induced by non-uniform electro-osmotic flow

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Non-uniform electro-osmotic flow (EOF) in microfluidic configurations gives rise to internal pressure gradients. In soft devices, these internal pressures result in elastic deformation, thus yielding viscous-elastic interaction. In this theoretical work, we report for the first time a deformation instability of an elastic sheet separated from a rigid surface by a thin liquid film and subjected to non-uniform EOF. We first provide insight into the physical behavior of the system by considering a simplified 1D model, inspired by electrostatic MEMS actuators, in which the elastic sheet is modeled as a rigid plate connected to a linear spring. Our theoretical analysis, validated by numerical simulations, reveals that the instability is controlled by a non-dimensional parameter representing the ratio of electro-osmotic to elastic forces, and also indicates the existence of hysteresis for the onset of instability. Expanding our analysis for the case of an elastic sheet that is free to deform under bending and tension, we demonstrate that the elastic sheet exhibits different modes of instability depending on the electro-osmotic pattern. Furthermore, this instability can result in a non-symmetric deformation pattern, even for symmetric actuation. The mechanism illustrated in this work, together with the provided analysis, may pave the way for implementation of instability-based soft-actuators.

Control of mixing induced by convective mechanisms in the continuous-flow microreactors and microfluidic devices

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Continuous-flow microreactors and, more generally, microfluidic devices are an important development in chemical engineering technology, since pharmaceutical production commonly needs small amount of product yield and flexibility in reconfiguring the synthesis system. Microreactors of this type have a special vessel, in which the convective vortices are organized to mix the reagents to increase the product output. We propose a new type of micromixer based on the intensive relaxation oscillations induced by a fundamental effect discovered recently. The mechanism of these oscillations was found to be a coupling of the solutal Marangoni effect, buoyancy and diffusion. This gravity-dependent phenomenon can be observed in the vicinity of an air–liquid (or liquid–liquid) interface with inhomogeneous concentration of a surface-active solute. The periodicity of the oscillations is a result of the repeated regeneration of the Marangoni driving force. This feature is used in our design of a micromixer with a single air bubble inside the reaction zone. We show that the micromixer does not consume external energy and adapts to the medium state due to feedback. It switches on automatically each time when a concentration inhomogeneity in the reaction zone occurs, and stops mixing when the solution becomes sufficiently uniform.

We also investigate both experimentally and numerically the possibility to use the gravity-dependent convection mechanisms (double-diffusive instability, Rayleigh-Taylor convection) to organize more intensive mixing in long thin channels of microfluidic devices oriented perpendicular to gravity. Results are compared with mixing due to diffusion being standard approach in microfluidics. Since the convective mechanisms for the development of instability impose certain restrictions on the characteristic size of the system, the issue of scaling the effect for microfluidic devices with a characteristic channel size of 1 micron is discussed.

Session: Parametric excitation and control of instabilities

Faraday Instability at Liquid-Fluid Interfaces

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Resonance driven instability or Faraday instability occurs when vertically stacked fluid bilayers are subject to periodic forcing in a direction that is normal to their common interface. The forcing can arise from several means, for example, by mechanical motion, by acoustic means, or even via electrostatic fields. The instability at the interface, which is manifested by ordered patterns, has its origins in the resonance between the imposed frequency and the system's natural frequency. Our talk will focus on a comparison between theory and experiments showing remarkable agreement between the two. We also show how and why electrostatic forced resonance is an excellent candidate to determine interfacial tension between fluids such as liquid semi-conductors and encapsulants.

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Clogging of microswimmers at a constriction.

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We study the clogging of a suspension of photosensitive microswimmers [*Chlamydomonas Reinhardtii* (CR)] moving to a constriction in a microfluidic device. Swimming cells are fleeing light and accumulate at a gate which is twice larger than a CR. We study the statistics of times of egresses. Our results fall in the general framework of clogging obtained for panicking pedestrians at a gate or granular materials at the exit of a silo [1]: the survival function obeys a power law decrease with times. However, an unusual phenomenon occurs after the gate. Indeed, we observe the creation of an extruded bulb at the exit which is due to the hydrodynamic interactions between cells which are densely packed and strongly oriented at the exit. Then the strongly correlated CR in the bulb disperse after a few seconds. Our experimental observations are quantitatively supported by lattice Boltzmann simulations where each microswimmer transports a force dipole and where hydrodynamic interactions between CR as well as CR and walls are taken into account. Our results show that our system belongs to a universal clogging statistics but shows some unusual aspects that are not observed on other active or passive systems during a clogging process.

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Linear and nonlinear regimes of an inertial wave attractor

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Fluids submitted to a global rotation enable the propagation of a specific class of internal waves, called inertial waves, as a result of the restoring action of the Coriolis force. In closed domains, with walls not systematically vertical or horizontal, inertial waves at a given frequency converge, in certain geometry dependant ranges of frequencies, towards a limit cycle called wave attractor. These attractors appear as a consequence of the peculiar reflection laws of inertial waves whose dispersion relation sets their propagation angle with respect to the horizontal to a constant value dependant of the wave frequency.

We present an experimental analysis of the linear and non-linear regimes of an attractor of inertial waves in a trapezoidal cavity under rotation. We show that the attractor is subjected to a triadic resonance instability which tranfers the attractor energy towards subharmonic waves. This instability of the attractor leads to a reduction of its velocity amplitude and to an increase of its wavelength in agreement with recent observations from numerical simulations in rotating fluids and experiments in stratified fluids. Varying the rotation rate and the forcing amplitude and wavelength, we identify the scaling laws followed by the attractor amplitude and wavelength in the linear and non-linear regimes. We show that the non-linear scaling laws can be well described by replacing the fluid viscosity in the linear attractor model by a turbulent viscosity accounting for the effective energy dissipation that the instability creates for the attractor. The identification of these scaling laws could help extrapolating attractor theory to geo/astrophysically relevant situations in which strong non-linear effects are expected.

Transonic liquid bells: static shapes and spontaneous oscillations

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The shape of a liquid bell resulting from the overflow of a viscous liquid out of a circular dish is investigated experimentally and theoretically. The main property of this bell is its ability to sustain the presence of a ''transonic point,'' where the liquid velocity equals the speed of antisymmetric—or sinuous—surface waves. Their shape and properties are thus rather different from usual ''hypersonic'' water bells. We first show that the bell shape can be calculated very accurately, starting from the sonic point. We then demonstrate the extreme sensitivity of the shape of these bells to the difference of pressure across the interface, making them a perfect barometer. Finally, we discuss the oscillations of the bell which occur close to the bursting limit.

Non-stationary contact lines: the search for mobility laws

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The spreading and dewetting of liquids on substrates is generally ruled by a subtle balance between surface tension forces and viscous shear, which is the main source of dissipation. The classical situation is that of a drop sliding on an incline plane, or a liquid plug moving along a capillary tube. The inner flow and free-surface shape generally reach a steady state, leading to a selection of dynamical contact-angles given by the Cox-Voinov's law :

θ_d^3-θ_s^3 = 9 Ca log (L_M/l_m)

where Ca stands for the capillary number. This relationship reflects the viscous bending effect, occurring when the capillary number Ca is large enough (typically >10^{-5}). The dynamical angle θ_d is considered either at the front or the rear of the drop, depending on the sign of U. The static angle θ_s is within the range of hysteresis [θ_r,θ_a], and it was shown that θ_s should be equal respectively to θ_r or θ_a for receding or advancing contact-lines. Finally, L_M and l_m are respectively macroscopic and microscopic (molecular) length scales. To what extent the Cox-Voinov equation remains valid if fluid inertia is not negligible anymore ? The importance of inertia can be quantified by the ratio between the thickness of a viscous boundary layer and the liquid height δ/h. It can be smaller than one for instance in situations where contact-lines are driven by an external oscillating force of high enough frequency.

We addressed this question by carrying out experiments: (1) on sessile drops actuated with Surface Acoustic Waves (SAWs) with frequency 20 MHz, where the actuation is modulated at a frequency f between 10 and 200 Hz, close to the first inertio-capillary eigen modes of the drops, enabling an optimal response of the drop free-surface and oscillations of the drop contact-lines, and (2) with a liquid bridge sandwiched between a upper static plate and a lower oscillating one at f between 0.1 and 20 Hz.

Global wake instability of real minivan cars

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The fundamental work of Grandemange et al. (Physics of Fluids 25, 095103 2013) showed the existence of symmetry breaking modes in the wake of parallelepiped bodies reminiscent of a steady bifurcation in the laminar regime. It consists in a permanent and instantaneous strong asymmetry of the wake, similarly to that of a sphere facing a uniform flow at large Reynolds numbers. One may wonder if the instability is also present for a real industrial geometry of ground vehicles which, if this is the case, should be considered for any optimal aerodynamic improvements. The scale 1 wind tunnel of Renault SA and Peugeot SA has been used to test different cars in real flow conditions to identify the wake instability. The Peugeot Partner, Citroën Berlingo and Renault Kangoo have been chosen because of their blunt trailing edge similar to the academic bodies studied in Grandemange et. al (2013). The cars have been manipulated in pitch, yaw, clearance and air intake flow deviation with rotating wheels and road effect at 140km/h. Velocity field of the wake, pressure distribution at the base and aerodynamic forces are measured. The results indicate that the wake is permanently subjected to the instability which manifests itself through two wake states only. These modes can be selected depending on the manipulation. Discontinuous transitions in pitch and yaw corresponding to the switch between the modes are evidenced. Bi-stable dynamics are observed at each discontinuity. Eventually, the potential of direct passive control of the instability is demonstrated by improving from 4.6% to 8.3% the drag reduction obtained by closing the front air-intake of the car.

An exact Solution for the Thermocapillary Motion of a Newtonian Droplet in a Viscoelastic Fluid

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The steady-state thermocapillary motion of a Newtonian droplet translating in an otherwise quiescent Oldroyd-B fluid has been investigated analytically in the framework of a perturbation technique and in the limit of small Deborah numbers. The analysis has been carried out assuming the absence of convective transport effects and decoupling the solution of the energy equation from the velocity field. Specific non-Newtonian correction formulae for the droplet migration velocity have been obtained in the limit of small Capillary numbers, i.e., assuming a spherical drop, as well as in the presence of small boundary deformations (small but finite Capillary numbers). Equations describing the droplet shape have also been obtained. The results show that, in the absence of deformation, the migration speed decreases monotonically with the Deborah number irrespective of the other parameters. In particular, when the viscosity and thermal conductivity of the drop are much smaller than the corresponding values for the continuous phase, the effect of elasticity becomes increasingly more important and the migration velocity is significantly decreased. When shape deformations are allowed, the velocity, evaluated as a function of the Deborah number, either initially increases with respect to the Newtonian value, or takes a behavior qualitatively similar to that observed for the spherical particle depending on the specific value of the viscosity ratio.

Plateau-Rayleigh Instability in Stratified Liquid-liquid Pipe Flow

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Two-phase flow is present in a wide range of natural and industrial processes. Significant amount of work has been devoted to the understanding of gas-liquid flow systems, but the same cannot be said about liquid-liquid flow. The interest in liquid-liquid flow has increased mainly due to the petroleum industry, where oil and water are often transported together in directional wells or pipelines for long distances. The hydrodynamic stability of this kind of parallel two-phase flow has been subject of research over the last decades. Nevertheless, most of the available information is on flow of low viscosity fluids in pipes. When it comes to flow of viscous fluids, as heavy oil, the information is scanty. Due to the high viscosity ratio and interfacial-tension effects the stratified flow may present a wavy interface and no droplet detachment. Spatial development of interfacial instability has been recently observed, which caused the stratified flow to break into drops or slugs at several pipe diameters downstream the pipe inlet. The observations suggested that the phenomenon could be related to the destabilizing effect of interfacial tension or Plateau-Rayleigh instability that takes place when the viscosity ratio is high, the density difference is small and the pipe wall is preferentially wetted by the denser liquid. The hydrodynamic stability of a wavy-stratified liquid-liquid flow was investigated by applying the linear stability theory and a spatial analysis. The chosen mathematical model was the transient 1-D two-fluid model. The good agreement between model predictions and experimental data is encouraging. In addition, the application of a non-linear stability analysis through numerical methods, Method of Characteristics (MOC) and Pressure Implicit with Splitting of Operators (PISO), did not show consistent results, demonstrating that further research is in order.

Thermal instability of an Ellis fluid saturating a porous medium

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Thermally driven instability analysis in fluid saturated porous media is a research topic that has been deeply investigated in the last century. The studies present in the literature are mainly focused on the stability analysis of Newtonian type of fluids. The stability analysis of non-Newtonian fluids saturating porous media is a recent years topic. Some work has been done in [1] and [2]. These authors extended the classical Prats problem by considering a power-law fluid.The problem investigated in this work is the Prats problem where a non-Newtonian Ellis fluid is considered. Contrary to the power-law model, Ellis rheological model yields a finite value of the apparent viscosity for low values of shear stress. The momentum balance equations employed to perform the stability analysis is the extended Darcy's law for Ellis fluids. The fluid is assumed to be incompressible and the energy balance equation employed is a convection-diffusion equation without heat sources/sinks. The solid phase and the fluid phase are in local thermal equilibrium such that a one-temperature model is employed. The stationary basic throughflow is perturbed by plane wave disturbances of small amplitude. A linear stability analysis is thus carried out using the normal mode method. The eigenvalue problem obtained is solved numerically by means of the Runge-Kutta method coupled with the shooting method. The neutral stability curves are obtained along with the critical values of the stability parameters that identify the threshold for the onset of thermal instability.

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Session: Computational methods

scikit-finite-diff, a new tool for PDE solving

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Scikit-FDiff (formerly known as Triflow) is a new tool, written in pure Python, that focus on reducing the time between the developpement of the mathematical model and the numerical solving. It allows an easy and automatic finite difference discretization, thanks to a symbolic processing that can deal with systems of multi-dimensional partial differential equation with complex boundary conditions. Using finite differences and the method of lines, it allows the transformation of the original PDE into an ODE, provinding a fast computation of the temporal evolution vector and the Jacobian matrix. The later is pre-computed in a symbolic way and sparsed by nature. It can be evaluated with as few computational ressources as possible, allowing the use of implicit and explicit solvers at a reasoneable cost. Classic ODE solvers have been implemented (or made available from dedicated python libraries), including backward and forward Euler scheme, Crank-Nickolson, explicit Runge-Kutta. More complexe ones, like improved Rosebrock-Wanner schemes up to the 6th order, are also available. The time-step is managed by a built-in error computation, which ensures the accuracy of the solution. The main goal of the software is to minimize the time spent writting numerical solvers to focus on model developpement and data analysis. Scikit-Fdiff is then able to solve toy cases in a few line of code as well as complex models. Extra tools are available, such as data saving during the simulation, real-time plotting and post-processing. It has been validated with the shallow-water equation on dam-breaks and the steady-lake case. It has also been applied to heated falling-films, dropplet spread and simple moisture flow in porous medium.

Applications of Multi-Material ALE to Instability problems

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The Arbitrary Lagrangian-Eulerian Formulation has been the research hotspot since the work of Hirt etc., which emerged to alleviate the drawbacks of traditional Eulerian and Lagrangian formulations. The algorithm described by Hirt etc. couldn't rezone across material interfaces, which was called simple ALE. A powerful extension to SALE is to incorporate VOF(volume of fluid) or MOF(moment of fluid) capability into the mixed cells containing multiple materials, which was called multi-material ALE. Staggered Lagrangian schemes have been extensively used in the simulations of elastic-plastic multi-material problems since the numerical simulation emerged, but Lagrangian schemes couldn't tackle the problems with changing-topology interfaces. So, Multi-material ALE method, which is effective to the large-deformation problems with changing-topology interfaces, has been the trend of computational mechanics in recent years. Aiming to meet the need of numerical simulations of mutli-material large-deformation problems, we developed the staggered multiple-material ALE code. We use MOF interface reconstruction method, the equivalent strain closure model for mixed cells and conservative flux-based multi-material remapping method to develop the staggered multi-material ALE code. Numerical results of Rayleigh Taylor instability problem, Richtmyer-Meshkov instability problem and interaction problem of a shock wave with Helium bubble, proved that our multi-material ALE code was valid in instability problems with large-deformation interfaces.

Liquid drop impact: role of gas-kinetic effects and thin-film instabilities

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When liquid drops collide with a very smooth solid surface (drop impact), the intervening gas film can be a few tens of nanometres thick and thus thinner than the mean free path of air molecules at atmospheric pressure, so gas-kinetic effects (GKE; also known as rarefied gas effects) are expected to be significant. We develop a computational model of drop impact taking GKE into account using an interface-tracking finite-element approach for the drop coupled to gas film dynamics treated in lubrication approximation, with van der Waals (vdW) interactions included via a disjoining pressure term in the boundary conditions for the drop. The lubrication approximation for the film takes full account of GKE and is valid for arbitrarily thin films, much thinner than the mean free path.

The results of our simulations are in good agreement with experiments of Kolinski *et al.* [EPL 108, 24001 (2014)], reproducing the impact speed threshold between bouncing and contact leading to wetting with better than 5% accuracy, while if GKE are neglected, contact still does not occur at speeds 50% higher. The model is used to make new predictions on the effect of changing the ambient pressure, which is entirely due to GKE; we find that below a certain pressure bouncing does not occur at any impact speed. Contact with the surface, when it happens, is due to the instability of the film driven by vdW interactions and never occurs if these interactions are not included in the model. We modify the theory of thin-film instabilities by including GKE, calculate the critical film thickness at which contact is initiated and show how it is influenced by GKE, in good agreement with simulations. We find three modes of contact depending on its location and suggest how the transitions between these modes can be detected experimentally without measuring the film profile. The approach has also been applied to drop-drop collisions and is promising for studying other phenomena involving thin gas films.

Weakly nonlinear instability of a viscoelastic liquid jet

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The temporal capillary instability of a viscoelastic liquid jet is studied by using weakly nonlinear stability analysis.

The jet is supposed axisymmetric, of infinite length and evolving in an isotherm dynamically inert ambient medium. The liquid is considered incompressible and is represented by the Oldroyd-B rheological model. The free surface is assumed to be initially characterized by a single-mode deformation with a small amplitude compared to the radius of the undeformed jet.

The analysis is performed up to second order using the small-amplitude perturbation method and a polynomial approximation of the terms containing products of modified Bessel functions of the first kind with different arguments as done in the recently studied Newtonian case (Renoult et al. 2018 J. Fluid Mech. 856:169-201). The temporal evolution of the surface shape, the velocity field, and the pressure field are then derived. These flow quantities depend on five dimensionless numbers: the dimensionless wavenumber, the dimensionless initial deformation amplitude, an Ohnesorge number and two Deborah numbers generated following the two time scales of the Oldroyd-B model: the stress relaxation and deformation retardation times. We denote that the Newtonian case can be attained by taking these two numbers equal.

The spatio-temporal evolution of the jet will be shown for a large range of the five control parameters of the liquid mentioned above, and compared to the Newtonian case.

Symmetry breaking of rigid or flexible splitter plate in a cylinder wake

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The wake of cylinder with a clapped flexible or rigid splitter plate at its rear is studied. In the experimental work, a flexible filament is attached to the rear of a two dimensional cylinder. The experimental apparatus is a vertical flowing soap film. This gravity driven flow has been shown to be a good approximation of 2D flow. In order to observe the flow patterns created in the soap film, interferometric technique is used. Flow and filament dynamics are recorded with a high speed camera. A silk filament is attached at the rear of the 3 mm diameter cylinder and its length L adimensionned by the cylinder diameter D varies between 0 to 6. The Reynolds number based on the cylinder diameter is typically 420 in this study. In the numerical study, the 2D splitter plat is rigid and the cylinder/splitter plate combination can be made freely rotatable about the axis of the cylinder. The same range of plate/cylinder ratio and Reynolds number than in the experiment is studied. In both experimental and numerical studies, we observe similar behavior with 3 wake regimes depending of the length of the splitter plate over the diameter of the cylinder. The deviation of the plate and the oscillation frequency is discussed. It is proposed to build a model that aims to describe the symmetry breaking phenomenon experimentally and numerically observed. The model proved itself to be particularly relevant for the static analysis of the phenomenon, and predicts the stationary instability affecting the average position of the filament with precision. Unlike existing models, it provides a good prediction of the short plate deviation by notably taking in account splitter plate friction.

Linear stability and transient behaviour of viscoelastic fluids in boundary layers

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The behaviour of many real fluids is well described by Navier-Stokes theory, which is based on the assumption of a Newtonian constitutive equation. Specifically, the extra-stress tensor can be expressed as a linear, isotropic function of the velocity gradients. Common fluids, such as water and air can be assumed to be Newtonian. However, rheologically complex fluids such as polymer solutions, blood and shampoo are not adequately described by a Newtonian constitutive equation, which does not take into account any relaxation and retardation phenomena and cannot describe phenomena due to non-zero normal stress differences. Viscoelastic fluids are examples of non-Newtonian fluids, they exhibit both viscous and elastic properties when undergoing deformation. One of the first class of material models proposed to model non-Newtonian effects consists of fluids of differential type. We consider a subclass of differential type fluids known as Rivlin-Ericksen fluids of second order and second grade, which can represent non-zero normal stress differences. The aim of my research is to understand the stability behaviour of such fluids in boundary layers. At first, a two-dimensional configuration of a flow over a semi-infinite wedge is considered. A linear stability analysis shows that elasticity in this model has a stabilising effect or a destabilising effect, depending on the sign of the parameters. A second analysis shows that, when a three dimensional configuration is considered, elasticity can induce an instability that results in generation of streamwise vortices for the second grade model. Furthermore, results on transient behaviour show that elasticity generally increases the energy of the perturbations over short time periods for the second grade model, but it decreases for the second order model. We confirm the stability results by running direct numerical simulations.

Session: Liquid films, drops, and bubbles

The flow of a power-law fluid down a heated incline

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We report on our investigation of the instability of a thin fluid layer flowing along a heated inclined plane. We formulate a theoretical model having a power-law constitutive relation which captures the temperature variation in the rheology of the fluid. A linear stability analysis was carried out whereby Orr-Sommerfeld type equations were derived to predict the evolution of infinitesimal perturbations imposed on the equilibrium flow. An asymptotic solution based on expansions in the wavenumber was also performed to determine the critical conditions for the onset of long-wave instability. In addition, nonlinear effects were taken into account by implementing a first-order integral-boundary-layer (IBL) model. Various results will be presented and discussed. Good agreement between theory, numerical simulations and previous studies [1 - 4] was found.

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Asymptotic Analysis Of Thin Film Blow-up Profiles

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In this talk we consider self-similar blow-up profiles of a general thin film equation that includes a fourth order stabilising term and a second order destabilising term. The behaviour of this equation depends crucially on the exponents m and n in the coefficient functions of the respective terms; it is known that finite time blow up can only occur if $n \geq m+2$, and on the line $m=n+2$ only if $m<3/2$. Using matched asymptotics, we construct solutions for the profiles in the singular limit that n goes to m+2 from above, assuming $m>3/2$. The profiles exhibit a well-defined structure consisting of a peak near the origin, and a thin algebraically decaying tail, connected by a inner region equivalent (to leading order) to a generalisation of the Landau-Levich `drag-out' problem from lubrication flow. Four terms must be generated in the outer problem to find the leading order coefficient in the relationship between the distance from the critical line and the parameters that describe the solution; however, this can be done analytically up to a constant in the inner problem that must (usually) be determined numerically. The asymptotic solutions compare well to numerically computed profiles found using continuation.

Session: Active fluids

Novel active particles powered by Quincke rotation in a bulk fluid

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Dielectric particles suspended in a weakly conducting fluid are known to spontaneously start rotating under the action of a sufficiently strong uniform DC electric field due to the Quincke rotation instability. This rotation can be converted into translation when the particles are placed near a surface providing useful model systems for active matter. Using a combination of numerical simulations and theoretical models, we demonstrate that it is possible to convert the spontaneous Quincke rotation into spontaneous translation even in the absence of surfaces by relying on geometrical asymmetry instead. The resulting novel type of active particle (i) is capable of autonomous self propulsion, i.e. the direction of propulsion is not set and controlled by an external field, (ii) does not require the presence of a surface and (iii) is amenable to theoretical analysis using first principles. Suspensions of randomly-shaped particles under Quincke rotation would thus be expected to perform collective motion by exploring the full three-dimensional space as the swimming direction is unspecified, thereby, opening doors to a potentially new type of active matter.

Character traits of convective flows of multicomponent liquids in thin cavities

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It is known that the specific hydrodynamic phenomena take place during the motion of a liquid through micro-channels. These effects can be observed only at the microscale level. However the boundary between microfluidic effects and macroscopic hydrodynamic phenomena is fuzzy. It is really difficult to foresee the actual behaviour of the hydrodynamic system in the case of gradual change of a cavity proportions when any size diminishes in one of the directions. The basic problem is to define the main physical factors that derive the processes of heat and mass transfer in given conditions. Experiments under consideration show that the hydrodynamic paradoxes in thin cavities and channels become apparent in the case of the motion of multicomponent liquids. There can be a multicomponent molecular solution in non-uniformly heated thin connected channels, a binary metal melt in a capillary with non-wettable boundaries, a ferrocolloid in convective loop. Sometimes the fluidic media demonstrate unexpected behaviour in the specific process of mixing of initially homogeneous liquids as a result of viscous interaction with hard boundaries. It has to be emphasized that anomalous behaviour takes place in thin cavities and channels which have macroscopic dimensions. Common trait of the processes under discussion is in the predominant interaction of the liquid with the wide boundaries of a cavity that exerts decisive influence on heat and mass transfer formation. All describable hydrodynamic phenomena were found experimentally and many of them had no explanation for a long time. Now these processes in multicomponent liquid media have been investigated theoretically in details and have quantitative description. It is possible to unite the results of these theoretical and experimental researches and generalize the understanding of these phenomena.

Least-order mean-field models for two generic instabilities commonly encountered in fluid mechanics: illustration on the fluidic pinball

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In this work, we are interested in designing least-order mean-field models compatible with the Navier-Stokes equations for an incompressible flow undergoing two successive supercritical Hopf and pitchfork bifurcations. These are generic bifurcations commonly observed in fluid mechanics: Hopf bifurcations are for instance met in wake flows where von Karman streets of vortices develop beyond a critical value of the Reynolds number, while supercritical pitchfork bifurcations occur in the Rayleigh-Bénard convection at threshold, or in the Taylor-Couette instability, to cite two famous configurations, among many others.

Our approach is illustrated on the fluidic pinball, a two-dimensional wake flow around a cluster of three equidistantly spaced cylinders. In this system, on the route to chaos, the dynamics is shown to undergo supercritical bifurcations of Hopf, pitchfork and Neimark-Sacker type, giving rise to a quasi-periodic dynamics, before eventually turning into a chaotic regime at larger Reynolds numbers.

Our approach is based on mean-field considerations exploiting the symmetry of the steady base flow and the asymmetry of the fluctuation. Symmetry considerations generalize the mean-field theory, as e.g. no assumption of slow growth-rate is required. Elementary degrees of freedom of the flow could be identified, on the top of which the model could be designed. Most of the main features of the manifold on which the dynamics takes place could be recovered in a sparse, easily interpretable 5-dimensional dynamical system. As a result, trajectories of the original system are remarkably well reproduced by the model, from the transient dynamics up to the permanent asymptotic regime. This 5-dimensional reduced-order model is also the least-order Galerkin model compatible with the quadratic non-linearities of the Navier-Stokes equations.

The generalized mean-field Galerkin methodology introduced in this study is believed to apply to other transition scenarios.

Analysis of the engulfment of foreign particles during crystal growth of solar silicon

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The engulfment of silicon carbide (SiC) particles of 1-100 microns in diameter is a vexing issue during the growth of multi-crystalline silicon (mc-Si). These particles are problematic for subsequent processing of solar cells, leading to lower cell efficiency via the formation of dislocations and shunts, wafer breakage, sawing defects, and even saw wire breakage. The engulfment of such foreign particles during crystal growth is described by a balance between hydrodynamic drag around the particle and van der Waals repulsive forces between the particle and the melt-solid interface. When drag forces overcome repulsive forces, the particle is engulfed, otherwise it is steadily pushed ahead of the advancing interface.

We demonstrate, via finite element computations, that a critical velocity exists at which a particle of a certain size is engulfed. Nonlinear interactions involving fluid flow, heat transfer, premelting effects, and Gibbs-Thomson phenomena give rise to a unique critical velocity via a limit point in steady-state solutions. We also discuss a significant and previously unascertained interaction between particle-induced interface deflection (originating from the thermal conductivity of the SiC particle being larger than that of the surrounding silicon liquid) and curvature-induced changes in melting temperature arising from the Gibbs-Thomson effect. For a particular range of particle sizes, the Gibbs-Thomson effect flattens the deflected solidification interface, thereby reducing drag on the particle and increasing its critical velocity for engulfment. We show via numerical calculations and analytical reasoning that these effects give rise to a new scaling of the critical velocity to particle size as $v_c \sim R^{-5/3}$, whereas prior, classical models have predicted either $v_c \sim R^{-1}$ or $v_c \sim R^{-4/3}$. This new scaling is needed to quantitatively describe the experimental observations for this system.

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Control of thermocapillary flow in a cavity based on adjoint heat flux

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The thermocapillary flow in an open rectangular cavity is an ideal test case for the onset of two-dimensional flow oscillations and their control by imposing a suitable heat flux through the liquid--gas interface.

We propose to stabilize the flow for driving forces exceeding the linear stability limit (critical Reynolds number) by imposing a steady heat flux through the interface. The heat flux which stabilizes the flow can be obtained using results from linear stability and sensitivity analyses. To that end, the sensitivity of the most dangerous eigenvalue with respect to an imposed heat flux is calculated by solving four subproblems: (a) the eigenvalue problem, (b) its adjoint problem, (c) the sensitivity problem to changes of the basic flow, and (d) the sensitivity problem to the heat flux through the interface.

Once these problems are solved, zones of maximum sensitivity on the free surface are identified. The technique enables, e.g., to design a heat flux which minimizes a cost function with the aim to achieve a desired growth rate of a linear stability mode. Depending on the target growth rate one can either trigger or suppress the flow instability depending on the particular application.

Finite amplitude stability of internal steady flows of the Giesekus viscoelastic rate-type fluid

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We investigate the finite amplitude stability of internal steady flows of viscoelastic fluids described by the Giesekus model. The flow stability is investigated using a Lyapunov functional that is constructed on the basis of thermodynamical arguments. Using the functional, we derive bounds on the Reynolds and Weissenberg number that guarantee the unconditional asymptotic stability of the corresponding flow. Further, the functional allows one to explicitly analyse the role of elasticity in the onset of instability, which is a problem related to the elastic turbulence. The application of the theoretical results is documented in the finite amplitude stability analysis of Taylor–Couette flow of the Giesekus fluid.

Enhanced Czochralski crystal growth with submerged rotating baffle

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Czochralski (CZ) is the preferred method for the growth of single crystals of materials having low vapor pressure, such as silicon or sapphire. The demand for large size single crystals has increased in the recent years. Despite apparent simplicity, CZ process is difficult to analyze and optimize because the melt flow is complex. Forced convection driven by crystal and crucible rotation is supplemented by natural convection which, in large melts is turbulent and unstable, leading to the fluctuations of the growth rate, concave crystallization front and finally low crystal quality. The interface convexity can be reduced by using thermal shields around crystal i.e. influencing temperature gradient in crystal as well as by increasing the crystal rotation rate. Unfortunately, during scale up the economic and quality requirements cannot be reached solely by optimization of the process parameters. Applications of static magnetic fields, ultrasound and axial low-frequency vibrations for controlling the complex melt fluid dynamics were proposed in the literature. However, their application is limited to the electrically conducting melts and to the temperatures below 1000°C. Furthermore, it is difficult to predict their effect on the growing crystal.

In this work, 3D simulations were carried out to study the effects of the rotating baffle submerged in the melt beneath the crystal. Following the successful application of the rotating baffle in VGF growth [1], our goal is to dump the unsteady convection in the CZ melts. Different combinations of crystal and baffle rotation rates including iso- and counterrotation were considered. Feasibility of replacing crucible rotation by baffle rotation was addressed. 3D simulations were focused on the large scale silicon and sapphire melts.

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Upward-bending swirling jets

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We consider jets with two velocity components present: the (usual) axial component and the swirl one, with the latter being just as strong as the former. Assuming that the Froude number is large (so the radius of the jet's curvature due to gravity is much larger than its thickness), we derive a set of asymptotic equations describing the trajectory and structure of a steady jet. It is demonstrated that, given that the swirl velocity is sufficiently strong, the jet can – quite paradoxically – bend upwards, i.e., against gravity.

ID: **235**

Session: Geophysical flows

Instability of sheared density interfaces

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Of the canonical stratified shear flow instabilities (Kelvin–Helmholtz, Holmboe-wave and Taylor–Caulfield), the Taylor–Caulfield instability (TCI) has received relatively little attention, and forms the focus of the presentation. A diagnostic of the linear instability dynamics is developed that exploits the net pseudomomentum to distinguish TCI from the other two instabilities for any given flow profile. Next, the nonlinear dynamics of TCI is shown across its range of unstable horizontal wavenumbers and bulk Richardson numbers. At small bulk Richardson numbers, a cascade of billow structures of sequentially smaller size may form. For large bulk Richardson numbers, the primary nonlinear travelling waves formed by the linear instability break down via a small-scale, Kelvin–Helmholtz-like roll-up mechanism with an associated large amount of mixing. In all cases, secondary parasitic nonlinear Holmboe waves appear at late times for high Prandtl number. Finally, a nonlinear diagnostic is proposed to distinguish between the saturated states of the three canonical instabilities based on their distinctive density–streamfunction and generalised vorticity–streamfunction relations.

Stress Measurement around a Rising Bubble in a Viscoelastic Fluid through Birefringence

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The motion of gas bubbles in non-Newtonian liquids is important for many industrial processes including bubble columns, fermentation, and plastic foam processing. It is known that when a gas bubble rises in a viscoelastic liquid, for some critical bubble volume the shape of the bubble changes dramatically. A cusp-like structure occurs behind the bubble. Along with the shape change, there is also a change in its rising speed and also the stress around the bubble. A negative wake occurs at its trailing edge. Experimental studies to determine the stress around a bubble in a viscoelastic liquid are limited. In this work, the light around a bubble rising in a viscoelastic birefringent liquid will be photographed and employing the stress-optics law, the stress field around the bubble will be determined for various parameters.

Three-Phase Flow in a Microchannel subject to an Electric Field

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When three immiscible, leaky dielectric, incompressible Newtonian fluids are subjected to a pressure-driven base flow in a microchannel, two flat interfaces are formed between them. These interfaces can be destabilized in the presence of an externally applied electric field. In this work, a DC electric field is applied perpendicular to the flow direction. When the interfaces are destabilized, they can either flap each other or reach one of the walls according to the given physical and electric parameters. First, a linear stability analysis is performed, and then the nonlinear evolutions of the two interfaces are studied using the lubrication theory. For immiscible liquids, a surface coupled model is used where there is no electrical body force and the model assumes jumps in the electrical properties of the fluids at the interface. The important parameters that are analyzed are the electric number representing the applied voltage, the capillary number, the base flow, the thicknesses and the viscosities of the liquids. The results showed that the droplets of each fluid can be formed by manipulating the parameters. The amplitude and the wavelength of the interfaces; hence, the size and the frequency of the droplets can be controlled via the above mentioned parameters. However, for all parameters studied the droplet of which phase would be obtained is controlled via only the thickness ratios of the liquids.

ID: **187**

Session: Shear flows, boundary layers, and related problems

New nonlinear stability results for Couette and Poiseuille flows

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An overview of linear instability and nonlinear stability results for laminar flows in fluid-dynamics is given. We prove that, by choosing an appropriately weighted L_2-energy equivalent to the classical energy, plane *Couette and Poiseuille flows are nonlinearly stable with respect to streamwise perturbations for any Reynolds number Re.* In this case the coefficient of time-decay of the energy is $pi^2/(2 Re)$. We also prove that plane Couette and Poiseuille flows are nonlinearly stable if the Reynolds number is less then {Re}_{Orr}}/{sin varphi} *when the perturbation is a tilted perturbation in the direction x', i.e. a perturbation which forms an angle $varphi$ in (0, pi/2] with the direction of the motion and does not depend on x'.* {Re}_{Orr} is the Orr (1907) critical Reynolds number for spanwise perturbations which, for the Couette flow is 177.22 and for the Poiseuille flow is 175.31.In particular these results improve those obtained by Joseph (1966), who found for streamwise perturbations a critical nonlinear value of 82.6 in the Couette case, and those obtained by Joseph and Carmi (1969), who found the value 99.1 for plane Poiseuille flow for streamwise perturbations. *The results we obtain here are in a good agreement with the experiments (see Prigent et al. 2003) and the numerical simulations (see Barckley and Tuckerman 2007).Our results give a contribution to the solution of the Sommerfeld (or Couette) paradox.*

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New stability results for hydromagnetic plane Couette flows

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The instability of steady laminar flow of an electrically conducting fluid between two infinite parallel plates under a transverse magnetic field has been analyzed by Kakutani (1964), Takashima (1998) for plane Couette flow.

Alexakis et al. (2003) studied shear flows with an applied cross-stream magnetic field using dissipative incompressible magnetohydrodynamics. This study incorporates exact solutions, the energy stability method, and exact bounds on the total energy dissipation rate.

Recently Falsaperla et al. (2018) proved that the plane Couette and Poiseuille flows are nonlinearly stable with respect to streamwise perturbations for any Reynolds number. They also proved that the plane Couette and Poiseuille flows are nonlinearly stable if the Reynolds number is less then Re_{Orr} / sin φ when the perturbation is a tilted perturbation, i.e. 2D perturbations with wave vector which forms an angle φ in (0, π/2] with the direction of the motion.

The aim of this work is to generalize the results of Falsaperla et al. (2018) to the hydromagnetic plane Couette flow. We prove that the critical nonlinear Reynolds number is Re_{Orr-M} / sin φ for tilted perturbations. Re_{Orr-M} is the critical Reynolds number in the hydrodynamoc case in a suitable energy norm, and it is obtained for spanwise perturbatiions. We also compare our results with Alexakis et al. (2003), Takashima (1998) and experiments.

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Marangoni instability in ultrathin two-layer films under the joint action of gravity modulation and van der Waals instability

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We consider a thin two-layer film of immiscible liquids on a solid horizontal substrate. The development of instabilities under the joint action of the van der Waals forces, Marangoni stresses and gravity modulation in a two-layer film on a heated, or cooled, substrate is considered. Using a long-wave approximation we wrote coupled evolution equations for the interface profiles with taking into consideration both the van der Waals interactions and time-dependent gravity. The problem is solved by means of nonlinear simulations. We performed the numerical simulations by a pseudospectral method with time integration in Fourier space. The appearance of the threshold oscillations predicted by the linear stability theory is confirmed by nonlinear simulations. Results of nonlinear simulations without gravity modulation [1] are also confirmed by our testing computations.

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Surface bound liquid flow regimes

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Liquids which partially wet solid surfaces show distinct areas featuring flows in films, rivulets or single drops. Depending on the volume flux applied, transition between these flow types occur through breakup of closed liquid films into rivulets or through shedding of droplets at meandering rivulets. Gaining the possibility to well predict the so forming pattern of wet and dry parts on the surface helps to improve rain water guidance on cars.

The main factors of influence for the named phenomena are the volume flux on the surface, gravity and the superimposed aerodynamic force of the external airflow around the vehicle. Although the influential parameters can be easily defined, the conditions for transition between flow patterns are still not completely understood.

In this study a series of wetting experiments on a generic surface is carried out in a windtunnel. The phenomena are observed using both, a highspeed video system and a common photographic camera. An automated image interpretation is then used for measurements of the main geometric parameters of the pattern such as the occurrence and location of film breakup, the distance of rivulets that form or information about meandering of rivulets. The so gained dataset reveals quantitatively how the patterns change under a variation of airspeed and the applied volume flux, yielding the possibility to analyze the hydromechanics of surface wetting. Different aspects of the observed patters are assessed this way which has led to a mathematical modelling of different phenomena.

Models of both, the film thickness as well as films stability and breakup have been elaborated and show good agreement between analytically computed data and those measured in the analyzed wetting experiments.

On the origin and structure of circular hydraulic jumps

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We examine circular hydraulic jumps arising when a cylindrical jet impinges on a circular disk. We interpret the jump as a transition region between two solutions of a depth-averaged model (DAM) for a flow based on a parabolic velocity profile. The numerical solution of the exact shallow-water equations show that the jump's location virtually coincides with a singularity of the solution of the DAM, and is associated with the beginning of a recirculation region near the bottom. The nondimensional location of the jump and the Froude number at the crest following the jump turn out to be independent of the problem's parameters and are in agreement with the experimental results by Duchesne et al. (Europhys. Lett. 107, 54002 (2014)). We also investigate the role of surface tension and the disk size, and simulate the case where the jet impinges on the disk from below.

Session: Liquid films, drops, and bubbles

Thermal rupture of a free liquid sheet

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The breakup of liquid sheets plays a crucial role in the generation of industrial sprays or natural processes such as sea spray. The industrial production sprays proceeds typically via the formation of sheets, which break up to form ribbons. Ribbons are susceptible to the Rayleigh-Plateau instability, and quickly break up into drops. In nature, sheets are often formed by bubbles rising to the surface of a pool. Once broken, the sheet decays into a mist of droplets, and collapse of the void left by the bubble produces a jet. It is therefore of crucial importance to understand the mechanisms leading to the breakup of sheets. In contrast to jets and liquid threads, there is no obvious linear mechanism for sheet breakup, unless there is strong shear, and the mechanism is that of the Kelvin-Helmholtz instability. As a result, authors have invoked the presence of attractive van-der-Waals forces to explain spontaneous rupture. However, the mean sheet thickness near the point of breakup is often found to be several microns, while van-der-Waals forces only have a range of nanometers, and cannot play a significant role except perhaps for the very last stages of breakup. Instead, we will discuss whether gradients of temperature could promote breakup, because they produce Marangoni forces, which lead to flow. This cannot be a linear mechanism, since for reasons of thermodynamic stability Marangoni flow will always act to reduce gradients; molecular diffusion will also alleviate (temperature) gradients. Finally, the extensional flow expected near a potential pinch point will stretch the fluid particles, once more tending to reduce gradients. It is therefore surprising that temperature gradients can promote breakup, and if this is the case, the mechanism must be inherently non-linear.

Main reference: G. Kitavtsev, M. A. Fontelos, J. Eggers, Thermal rupture of free liquid sheets, Journal of Fluid Mechanics 840 (2018), 555-578

Amplification of Marangoni-induced ratchet flow by Rayleigh-Taylor instability

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We study the nonlinear dynamics of a two-layer liquid-gas horizontal system sandwiched between a flat thin solid substrate from below and a periodically corrugated solid surface from above in the Rayleigh-Taylor (RT) unstable configuration in the gravity field, i.e. when the liquid film is adjacent to the upper substrate and is superimposed on the gas film. The system is subjected to a temperature gradient due to heating at the substrate from the top. Since the solid-liquid interface is corrugated, a naturally induced equilibrium temperature distribution yields a nonuniform temperature along the gas-liquid interface, and thus, thermocapillarity becomes important along with gravity and capillarity.

We derive a nonlinear evolution equation governing the longwave film dynamics. First, we show that in the absence of heating, the presence of a corrugated upper surface can suppress the RT instability and lead to the emergence of a deflected steady state of the film interface. In this case, we derive an analytical solution for the steady position of the interface and find that it is determined by the Bond number and the upper surface geometry. Next, we determine steady states of the heated system, and derive a closed expression for the flowrate through the system.

Numerical study of the nonlinear evolution equation in the case where the liquid is more thermally conductive than the adjacent solid substrate shows that steady states of the liquid-gas interface exist for Marangoni numbers M below a certain value M0, and the averaged flowrate of these ratchet flows increases with an increase in the Marangoni number. When the Marangoni number exceeds M0, steady interfacial states cease to exist and the film interface oscillates with the amplitude of the flow-rate oscillations increasing with the Marangoni number. The RT unstable setting of the system yields an increase in the flowrate of a sustained ratchet flow with respect to that for a stabilizing gravity.

Effect of heat loss on hydrothermal wave instability in half-zone liquid bridges of high Prandtl number fluid

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We investigate the effect of heat transfer through a free surface on the primary instability of thermocapillary-driven convection in a geometry of so-called half-zone liquid bridge of high Prandtl number fluid. The target liquid bridge is a straight whose aspect ratio (= H/R) is mainly kept at 2.0, where H and R are the height and the radius of the bridge, respectively. We focus on the flow fields induced by the instability; it is found that the bifurcation diagram exhibits a significant difference between the cases of the Prandtl number Pr = 16 and 28. The effect of gravity level is also examined in order to discuss qualitatively the induced flow fields after the transition obtained in the ground-based experiments as well as in on-orbit experiments so-called 'Dynamic Surf' in the Japan Experimet Module 'Kibo' aboard the International Space Station (ISS).

Influence of interface width on pattern selection in two layers system of miscible liquids under horizontal vibrations

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Interfacial instabilities occurring between two fluids are of fundamental interest in fluid dynamics, biological systems and engineering applications such as liquid storage, solvent extraction, oil recovery and mixing. An understanding of this phenomenon is justified both from the fundamental point of view and also for its potential applications. Horizontal vibrations applied to stratified layers of miscible liquids may generate spatially periodic waving of the interface, stationary in the reference frame of the vibrated cell, referred to as a "frozen wave". Here we develop a connection between instabilities in a two-liquid miscible system and in a liquid mixture with a linear distribution of density. In both cases, the liquids are placed in a closed cell and subjected to horizontal oscillations at different frequencies and amplitudes in a microgravity environment. The study includes parabolic flight experiments and numerical simulations. We examine the transformation of the interfacial pattern when the diffusive interface widens from a thin transient zone occupying 4% of the cell height to a situation when it occupies the entire cell height. In the case of sharp concentration (density) difference between miscible liquids, under reduced gravity conditions, instability leads to the formation of rectangular columns of liquids of alternating densities with an amplitude nearly equal to the height of the cell. The increase of the interface width promotes the selection of a smaller wave number associated with columns. The experimental observations are confirmed by the numerical simulations.

From sub- to super-critical transition in helical pipe flow

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Helical pipe is widely used as an effective mixing tool. The Dean vortices necessarily appear in the helical pipe flow driven by an applied pressure drop regardless flow intensity. Flow in a helical pipe is characterized by the Reynolds number, defined similarly to the circular pipe flow, and two additional dimensionless geometrical parameters describing curvature and torsion of the pipe.

In the present study we focus on instabilities of steady flows in helical pipes. Pipes with arbitrary curvature and torsion are considered. The problem is formulated in Germano coordinates, which allows for consideration of three-dimensional instabilities of quasi two-dimensional flow. Two equivalent but different forms of the momentum equations are used, so that results obtained using both formulations cross verify each other. The calculations are performed by the finite difference method. Grid independence of the results is established and Richardson extrapolation is applied. The calculated steady flows agree well with experimental measurements and previous numerical results. The stability results exhibit a considerable scatter, and should be validated additionally.

It should be mentioned that the classical Poiseuille flow in a circular pipe is linearly stable, so that its critical Reynolds number tends to infinity. Surprisingly, all experimental and numerical studies show that it becomes finite already at very small helical pipe curvatures. Furthermore, with the increase of the curvature, the experimentally measured critical Reynolds number become close to those obtained via the linear stability analysis. This allows us to assume that with gradual increase of the curvature one can observe a replacement of by-pass transition, characteristic for the circular pipe flow, by a classical linear instability leading to a flow periodic along the pipe centerline.

Stability of flow in a wavy channel at moderate amplitudes of corrugation

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Flow in a wavy channel is studied. The analysis is carried up to Reynolds numbers resulting in formation of secondary flows. Large scale wall corrugations results in the appearance of two instability modes. The first one is the traveling wave mode which, in the smooth channel limit, connects to the classical Tollmien-Schlichting wave. This mode is responsible for the transition from stationary to oscillatory and eventually aperiodic flow. The second mode has the form of streamwise vortices and is attributed to the centrifugal forces due to groove-imposed changes of the flow. This mode connects in the smooth channel limit to a stationary Squire mode and is critical in channels with a certain class of grooves.

The main focus of this work is mapping the dynamics of flows in wavy channels created through application of large scale wall corrugation. The geometry of grooves covers full range of wavelengths of practical importance varying from short to long wavelength corrugations. The analysis relies on DNS based on the spectral finite-element method in the (x, y)-plane combined with the Fourier decomposition in the spanwise direction.

The analysis first focuses on 2D dynamics up to formation of secondary states. Then 3D dynamics is analyzed. Determination of conditions leading to the onset of streamwise vortices is of particular interest. The process of vortex creation can be interfered by travelling waves. It is thus important to establish conditions where such vortices are likely to dominate the system dynamics. At small amplitudes it is the travelling wave that dominates having a smaller critical Reynolds number. For both instabilities an initial monotonic decrease in critical values of Re is observed as S increases, with centrifugal instability quickly becoming dominant - appear at lower Re. Further increase of S eventually reverses variations of Re for centrifugal mode as growing separation prohibits the flow from producing enough of the centrifugal effect.

Mechanism of reactive convective-dissolution in the geological storage of carbon dioxide

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Studies on dissolution-drive convection have drawn recent interest in the context of large scale geological storage of carbon dioxide in porous aquifers where carbon dioxide dissolves in brine underneath and forms a diffusive boundary layer. Dissolution boosts the local density difference between the solute-saturated brine at the interface and the underlying pure brine resulting in natural convection accelerating transport of carbon dioxide into the aquifer. Recent research has shown that chemical reaction can dramatically alter the characteristics of the layer quantitatively, and in some situations to such an extent that the qualitative behaviour completely changes.

We theoretically and numerically investigate effects of a non-precipitation reaction on the stability and long term dynamic behaviour of the layer. We semi analytically[1,2] solve linear stability equations along with nonlinear numerical simulations of the reaction-diffusion-convection problem to discuss the mechanism behind the instability and the nonlinear dymanic behaviour of the layer. We quantify the dynamic characteristics of the layer varying two dimensionless parameters : the ratio of the Damköhler number and the square of the solutal Rayleigh number, and the coefficient of density change of the reaction product species compared to that of the diffusing solute. We show that unexpectedly, even when the density contribution of the soluble product is smaller than that of the dissolved solute, the reaction can destabilize the layer and accelerate the onset of convection.

We discuss implications of our findings in the geological storage of carbon dioxide.

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Inclined convection in a porous Brinkman layer: linear instability and nonlinear stability

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We investigate the stability of the basic stationary solution of a model for thermal convection in an inclined porous layer when the fluid motion obeys to the Darcy-Brinkman law. Inertial effects are also taken into consideration, and different physical boundary conditions are imposed. The model is an extension of the work by Rees and Bassom, where the Darcy's law is adopted. In this model the basic motion is a combination of hyperbolic and polynomial functions. We will present a numerical investigation of the linear instability of such basic motion for three-dimensional perturbations; we will give estimates of nonlinear stability thresholds solving a maximum problem for an energy Lyapunov functional. For longitudinal perturbations we will prove the coincidence of linear and nonlinear critical Rayleigh numbers. These types of fluid flows have applications to geophysics, engineering and many other areas (Straughan, Nield and Bejan and references therein).

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Temperature dependent boundary layer flows

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In this talk, we will consider two and three-dimensional boundary layer flows. The stability of both the flat plate and rotating disk boundary layers will be discussed in the context of fluids that exhibit a variational viscosity. In particular, we will present linear stability results for fluids with viscosity that varies as a function of temperature. Numerical results (neutral curves, growth rates, and energy analyses) will be supported by asymptotic predictions at large Reynolds numbers. The influence of an enforced axial flow will also be discussed in the context of Chemical Vapour Deposition (CVD).

Droplet dynamics on heterogeneous surfaces with mass transfer

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We consider the effects of mass transfer on the dynamics of thin, partially wetting droplets moving on a heterogeneous surface due to slip. This study is based on a combined numerical and analytical approach, through which a simplified, reduced model for the evolution of the contact line is deduced in the limit of vanishingly small slip lengths and slow mass transfer rates. A hybrid numerical scheme combining the boundary integral method and the relative merits of the reduced model is also proposed, which offers improved agreement with the predictions of the full model and requires considerably lower computing resources.

observability-based method for the construction of surrogates of chemical reactions

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This presention will show a method for reducing chemical kinetics mechanisms. It allows to derive, from a large and numerically stiff trusted mechanism, a smaller less stiff approximation. This is attractive for large-scale simulation of reactive flows.

The first step of the modeling procedure is identifying the manifold driving the slow dynamics of the chemical reaction. This identification is achieved by noting the analogy between progress variables and the observability theory.

Formally,the description of the reduced variables (respectively, the progress variables and the observable on the system), in both theories, is the same. An approximate slow invariant manifold (ASIM) is then computed. Dynamics on the manifold is identified using an impulsive method near the known equilibrium point. An analytical, **algebraic** surrogate of the chemistry is derived. The reduced mechanism can hence be quickly evaluated.

It is illustrated both on a dynamical system, and with to methane-air combustion. Kinetics mechanisms from the GRI 3.0 for methane combustion, with up to 53 species and 325 reactions will be considered for the illustration. Results for one-dimensional flames confirm that accuracy below 0.1% can be maintained with the time scales, which are carried with 16 species.

Propagation of residual liquid through upward inclined sections of hilly terrain natural-gas pipelines

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Offshore gas fields are challenged by liquid (e.g., condensates, water) accumulation at lower sections of the hilly-terrain profile the pipelines follow. Due to the harmful consequences, accumulation prevention by a complete purge-out of the liquid via the gas flow is desired. This is a subject of modeling efforts and experimental studies conducted by our group, where liquid withdrawal from a low horizontal section and its propagation along an inclined upcomer have been investigated. To this aim, data obtained in an open-loop air-water experimental system is combined with numerical simulations (with OpenFOAM). The latter enable exploring the effect of the gas high pressure encountered in field operations.

Our study revealed that the critical gas flowrate for flushing out the liquid from the pipeline is determined by the two-phase flow phenomena along the upcomer. At steep inclinations, the liquid propagation is mainly via drops entrainment by the gas stream. However, at shallow inclinations, the main mechanism is of a thin liquid film crawling on the bottom of the upcomer. Since the upward inclined sections of gas pipelines are typical of shallow inclinations, the latter mechanism is of particular interest. Moreover, as those sections may extend over long distances, the critical gas flowrate and the associated flow phenomena are independent on the amount of accumulated liquid and the flow history associated with its removal from the low section. The velocity of the film propagation along the upcomer is dependent on the phenomena, which take place at the front and tail of the film. These are affected by the combined effects of surface tension, contact angle, inertia and shear forces. A mechanistic model that considers those effects is established. Both the model and numerical simulations show a satisfactory agreement in the prediction of the gas pressure effects on the critical gas velocity and the film tail and front velocities at supercritical velocities.

Shape bifurcations of droplets evaporating on heterogeneous surfaces

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Understanding the evolution of liquid drops resting on solid surfaces as they evaporate is important for a broad range of industrial applications. Depending on the properties of the solid, different modes of evaporation are observed, including a constant-contact-angle mode for perfectly smooth and flat substrates, and the constant-contact-area and stick-slip modes on rough surfaces. More recently, it has been experimentally shown that slippery (pinning-free) solid surfaces of non-planar topography promote a different mode of evaporation in which the droplet follows a reproducible sequence of well-defined configurations as its volume decreases. Such configurations are paced by dynamic snap events that are triggered by shape bifurcations of the equilibrium droplet profile. From a theoretical viewpoint, this problem has been studied in two dimensions by assuming the contact angle is a function of the position, and by assuming the surface itself has a low amplitude wave-like surface rather than being perfectly flat.

This talk shall introduce the problem in three dimensions. We consider flat solid surfaces with smooth chemical variations, and by using bifurcation theory we are able to predict at which volumes the droplet experiences snap events, which are described in terms of a change of the location of the droplet on the solid plane, as well as its overall shape. Our results provide new insights into how droplets evaporate on smooth surfaces and how this process can be controlled.

Active depinning of bacterial droplets: The collective surfing of Bacillus subtilis

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How systems are endowed with migration capacity is a fascinating question with implications ranging from the design of novel active systems to the control of microbial populations. Bacteria, which can be found in a variety of environments, have developed among the richest set of locomotion mechanisms both at the microscopic and collective levels.

Recently we discovered a mode of collective bacterial motility in humid environment through the depinning of bacterial droplets. Although capillary forces are notoriously enormous at the bacterial scale, even capable of pinning water droplets of millimetric size on inclined surfaces, bacteria are capable of unpinning contact lines, by harnessing a variety of mechanisms which I will discuss, hence inducing a collective slipping of the colony across the surface. Contrary to flagella-dependent migration modes like swarming, we show that this much faster "colony surfing" still occurs in mutant strains of *Bacillus subtilis* lacking flagella. The active unpinning seen in our experiments relies on a variety of microscopic mechanisms, which could each play an important role in the migration of microorganisms in humid environment.

Shapes and stability of levitated spinning liquid drops

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The liquid drop forms the basis of models of physics on an extraordinary range of length scales, from the astronomical scale down to the scale of the atomic nucleus. I will discuss our experimental studies of the shapes and stability of cm-scale spinning liquid droplets, using diamagnetic levitation [1-4]. We use a strong, 18 tesla magnetic field produced by a superconducting coil to suspend cm-sized droplets by diamagnetic levitation. Using this technique, the force of gravity is balanced at the molecular level, allowing drops of water and alcohol (and other diamagnetic materials) to be suspended in a weightless environment. The equilibrium shape of the drops changes as we spin them up: they deform from spherical to oblate, then reach a bifurcation, wherupon they deform into peanut-shapes, eventually losing stability with increasing angular velocity and breaking apart. I will discuss our recent observations of highly charged and rapidly spinning droplets, and the effect of the charge on the equilibrium shapes, stability and fission modes [1]. I will also show results of experiments in which we observed a highly unusual three-lobed equilibrium shape.

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Linear three dimensional stability of convective flow in a horizontal duct subjected to a longitudinal temperature gradient

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Steady convective flow in a horizontal duct subjected to a longitudinal temperature gradient are investigated numerically for its linear three dimensional stability. The two-dimensional basic steady-state is first obtained by the Taylor-Hood finite element method through Newton iteration process. The triangulation of finite element mesh is based on a transformed Chebyshev Gauss-Lobatto collocation nodes, which is also used for the spatial discretization of the linear stability equations with a high-order finite-difference scheme. The resulting generalized eigenvalue problem in a matrix form is then solved by the implicitly restarted Arnoldi method with the shift-and-invert algorithm. The basic state loses its stability due to the stationary hydrodynamic mode without any pressure gradient along the duct. Furthermore, the through-flow can be produced by a given pressure gradient and can have an important impact on the stability neutral curve of the steady convective flow. Also the absolute and convective instability curves are given in the parameter region.

Effect of heat transfer through walls on the asymmetric premixed flame instability in planar symmetric sudden expansion channels

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The effect of heat transfer through the walls on the asymmetric instability of the premixed flames anchored at the sudden expansion in two dimensional channels has been studied. The premixed flames break symmetry with respect to the channel mid-plane above a certain Reynolds number (Re) termed as critical Re ($Re_{C,R}$), if the transverse ignition location distance is above a critical value. The corresponding reacting flow is asymmetric. The heat transfer through the top, bottom and side walls is found to have an effect on the value of the critical Re above which the flame becomes asymmetric. The competing effects of the flame speed and local flow speed determine the final flame and flow configurations (either symmetric or asymmetric), after ignition of the premixed mixture. The value of the $Re_{C,R}$ decreases with increase in the heat transfer through walls from the region containing the flame to the outer ambient. The peak temperature attained in the channel decreases with the increase in the heat losses through the walls. The flame speed correspondingly reduces as part of the heat generated due to combustion is conducted through the walls to the ambient. The numerical simulations with the adiabatic walls predict the value of $Re_{C,R}$ = 135, for the onset of asymmetric premixed flame instability for ignition near sudden expansion. However, with prescription of heat transfer coefficient = 10 W/(m^2K) at the walls, taking into account the natural convection and radiation to the ambient, the flame is found to become asymmetric even at Re = 120. The experimental flame visualization studies show that the critical Re value decreases if the walls are non-adiabatic. Similar trends are observed numerically and experimentally for the cases with and without the heat transfer through the walls. The study confirms that heat transfer through the walls plays an important role in determining the transition from symmetric to asymmetric flame holding in symmetric sudden expansion channels.

Session: Multiphase and non-Newtonian flows

Surfactant effects on droplet formation in microfluidic systems

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Multiphase flows in microscale channels allow manipulation of the flow patterns and offer high heat and mass transfer rates. Surfactants are commonly used in a wide variety of applications from emulsification to DNA extraction and inkjetprinting, and their effects on droplet formation is of great importance. In this study, the formation of aqueous droplets in an organic continuous phase was studied experimentally using a flow-focusing microchannel in the presence of a range of surfactants. A two-colour PiV system was used to identify changes in the interface during the drop formation and to obtain velocity fields in both phases. A low viscosity silicone oil (0.0046 Pa s) was used as the continuous phase and a mixture of 48% w/w water and 52% w/w glycerol was the dispersed phase. Two cationic surfactants, C12TAB (50 mM) and C16TAB (5 mM) were added in the aqueous phase, at concentrations above the CMC values. An ionic surfactant, SDS (1 mM) was also used to compare the effects on the drop formation. Four regimes of drop formation were identified, namely squeezing, dripping, jetting and threading, whose boundaries changed when the surfactants were present. For all solutions studied, three distinct drop formation stages were identified, expansion, necking and pinch-off. Smaller drops were observed at higher concentrations of surfactant, as expected. The dynamics of surfactant adsorption can play a vital role in the drop formation process and were studied. The effect of dynamic interfacial tension at the characteristic time scale of drop formation becomes more significant at for surfactants with low CMC values, which suggests increased surfactant activity. Using this information, the differences between surfactant systems during the transitions between drop formation stages could be explained.

Zonally Elongated Transient Flows in the Ocean: Phenomenology, Transport and Dynamics

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Satellite observations and numerical simulations reveal a series of zonally elongated transient flow patterns populating most of the World Ocean. The dynamical origins of these transient patterns remain unclear, although they have been hypothesized to be similar to stationary zonal jets in the atmospheres of giant gas planets. This study explores zonally-elongated large-scale transients (ZELTs) in a quasi-geostrophic, stratified flow on a beta plane, and focuses on their spatial structure, transport properties, sensitivity to environmental parameters, dynamics and energetics.

Both spectral analysis and Empirical Orthogonal Functions (EOF) decomposition consistently demonstrate the presence of ZELTs for a wide range of environmental parameters relevant to oceanic flows. The velocity streamfunction in this ZELT-dominated regime is characterized by a well-pronounced anisotropic spectral peak and by zonally-elongated leading EOFs of mesoscale variability. In addition to being the leading modes of mesoscale variability, ZELTs also explain why the material transport by mesoscale currents is significantly larger in the zonal than in the meridional direction.

To elucidate the dynamical origins of ZELTs, we perform a series of sensitivity experiments with specific components of the energy and enstrophy transfer turned off. The results demonstrate that nonlinear interactions between transient eddies are of vital importance for ZELT emergence and maintenance, and that these modes are non-linear phenomena, owing its existence to anisotropic upscale energy cascade. The major contribution to this energy transfer comes from the baroclinic-baroclinic and mixed-mode eddy interactions, while barotropic-barotropic interactions are of less or no importance for ZELTs dynamics. These results are further interpreted by analyzing projection of the corresponding terms in the vorticity and energy balance on EOFs associated with ZELTs.

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Session: Computational methods

Analogy between Creeping Flows in Cavities and Thermodynamic Phase Transitions

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We discuss the analogy between the stream line function of creeping flows in rectangular cavities and the thermodynamic potential at critical points and at phase transitions. Assuming no-slip boundary conditions, the corners of the rectangular cavity are fixed points. We analyze two such points: 1. Corner where one wall is moving and the other is stationary; 2. Corner where both walls are stationary. The first one is analogous to a to a thermodynamic first-order transition point while the second one is analogous to a thermodynamic critical point. Moffatt eddies, which impede mixing [P. S. Fodor, M. Kaufman, Proceedings of PPS-30, AIP Conf. Proc. 1664 (2015)], are present in the neighborhood of the second stationary point. The results discussed here are based on numerical solutions of the Navier- Stokes equations combined with analytical work valid in the vicinity of the fixed points.

Electrohydrodynamic instability in a microchannel between a Newtonian and a power-law fluid

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When two immiscible liquids flow in a microchannel, the challenge is to generate droplets of one liquid into the other one. When an electric field is applied normal to the flat interface, the interface deflects due to the discontinuities of the electrical properties at the interface, which is called electrohydrodynamic instability. Applying an electric field is an effective method which enables to generate uniform droplets in microchannels. However, the electric field may be either stabilizing or destabilizing depending on the electrical properties of the fluids. In this work, the focus will be on the linear stability analysis between a Newtonian and a power-law fluid in a microchannel in the presence of an electric field applied either normal or parallel to the interface. The fluids are assumed to be immiscible, incompressible and leaky dielectric. The surface coupled model is employed, which claims that electrical terms appear only at the interface. The eigenvalue problem is solved numerically by Chebyshev Spectral Method. The effects of the dimensionless groups, namely the electric number, the base flow strength, the thickness ratio, the viscosity ratio on the linear stability is conducted. The electric number and the thickness ratio are related to the applied voltage and the flow rate ratios of the liquids, respectively and they can be easily manipulated in the experiments. The results for both shear thickening and thinning liquids are compared with the results of the Newtonian liquids through dispersion and neutral stability curves. The velocity eigenvectors are examined to understand the difference of the Newtonian-Newtonian and the Newtonian-power-law systems.

The influence of invariant solutions on the transient behaviour of an air bubble in a perturbed Hele-Shaw cell

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We consider the propagation of a finite air bubble through a viscous fluid-filled Hele-Shaw channel of non-rectangular cross-section. Recent experimental work at the Manchester Centre for Nonlinear Dynamics (MCND) has revealed that the transient dynamics of a single bubble becomes increasingly complicated as the extraction rate of the fluid is increased; characterised by the formation of an increasing number of bubble tips. Depending on the size of the bubble, the bubble may eventually break-up into two or more bubbles or exhibit an oscillatory mode of propagation. To understand these dynamics we model the system using a 2D depth-averaged set of equations, and solve these equations using a finite element discretisation to reveal a rich bifurcation structure. For intermediate flow rates, there is a finite region of bi-stability: a stable asymmetric bubble solution is always present; a second solution propagates at lower speeds and transitions between a symmetric and asymmetric bubble. Two Hopf bifurcations exist on this second branch that indicate the presence of limit cycles. To quantify these limit cycles, we perform a numerical weakly nonlinear stability analysis (that can be readily applied to other systems) which provides a semi-analytic approximation to the location, size and stability of the invariant fixed points and limit cycles. Fully nonlinear simulations are consistent with this analysis and evidence is presented that the unstable periodic orbits are edge states of the system, states which mark the `boundary' between stable behaviour and the bubble breaking up. Finally these theoretical results are compared to recent experiments at the MCND.

Analysis of Thin Leaky-Dielectric Layers Subject to an Electric Field

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Applying an electric field to a fluid system can have a significant influence on its behaviour. For example, electrohydrodynamic (EHD) instabilities can lead to the breakup of fluids into droplets or the formation of patterned structures. In particular, these instabilities have applications to an abundance of industrial situations such as inkjet printing and the production of micro-electronic devices. The recent review by Papageorgiou [1] gives an overview of the recent work on electrohydrodynamic instabilities. In the present work, we investigate the two-dimensional problem of an electric field applied across a bilayer of a leaky-dielectric liquid and gas contained between two solid walls. This work builds on that of Wray et al. [2] who considered the enhancement and suppression of EHD instabilities, investigating the axisymmetric problem of a fluid layer on the outside of a solid cylinder. Using a long-wave approximation, we explore the linear stability of the system. An investigation of the nonlinear regime highlights three characteristic behaviours of the system, namely, asymptotic thinning, the return of the interface to its flat state, and singular touchdown. In the unstable singular touchdown case, the interface approaches the lower wall in a cusp-like manner and the interfacial charge blows up in finite time. Numerically calculated plots of appropriate parameter planes are obtained. Of particular interest are the critical conditions for the transitions between these characteristic states, which we investigate both analytically and numerically. In addition, we explore the self-similar dynamics of the liquid-gas interface near touchdown.

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Session: Parametric excitation and control of instabilities

Double-diffusive instabilities in evolving systems at isolated boundaries

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When a large body of salt-stratified fluid is heated from below at a horizontal surface, it may give rise to a gravitationally unstable layer at the boundary or the fluid may remain stably stratified. In both cases the heat continues to diffuse into the fluid altering the temperature profile. Linear instabilities may grow that are either oscillatory or steady, and which may subsequently change their nature as the thermal layer evolves. This shows the importance of the time-evolution of the background state.
When a salinity gradient is heated from a vertical wall, evolving temperature layer gives to horizontal salinity gradients and vertical shear. These have all been observed experimentally to have an influence on the instabilities that form (see, for example, [1]). The time-dependent nature of the background gradients has previously restricted stability analysis to some cases where a quasi-static assumption could be made. However, in many experiments this assumption is not valid.
The approach taken is to find the optimal evolution of an energy-like measure of the amplitude of the instabilities. This involves a matrix optimization problem. The choice of measure is not pre-determined, but selected to minimize this optimal growth. This approach was developed in [2] for the purely thermal case of heating from boundaries, and applied more recently to the double-diffusive case with a horizontal boundary in [3]. We will look at the case of heating a salinity gradient from a vertical boundary where experiments have shown a variety of behaviours.

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COATING FLOW NEAR EXIT

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The planar flow of a steady wall jet as encountered in slot and blade coating is examined theoretically for moderate inertia and surface tension. The method of matched asymptotic expansion is used to explore the rich dynamics near the stress singularity. A thin-film approach is also proposed to capture the flow further downstream where the flow becomes of the boundary-layer type. We exploit the similarity character of the flow to circumvent the presence of the singularity. The jet is found to always contract near the channel exit, but presents a mild expansion further downstream for a thick coating film. We predict that separation occurs upstream of the exit for slot coating, essentially for any coating thickness near the moving substrate, and for a thin film near the die. For capillary number of order one, the jet profile is not affected by surface tension but the normal stress along the free surface exhibits a maximum that strengthens with surface tension. In contrast to existing numerical findings, we predict the existence of upstream influence as indicated by the nonlinear pressure dependence on upstream distance and the pressure undershoot (overshoot) in blade (slot) coating at the exit.

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Khayat, R.E., 2017. Initial development of a free-surface wall jet at moderate Reynolds number. *J. Fluid Mech.* **826**, 235–269.

Moving contact lines in thin-film flow models

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Some new aspects of a very widely studied problem will be described, particularly with the goal of analysing subtle features of the asymptotic analysis.

(Joint work with Jim Oliver, University of Oxford.)

Instabilities of annular flows on a beta cone

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Considering quasigeostrophic two-dimensional flows around a cylindrical island with radial offshore bottom slope, we study their normal-mode linear stability analytically, and the related vortex production, numerically. By analogy with the conventional beta plane, we term our model a beta cone (Rabinovich, Kizner & Flierl 2018, J. Fluid Mech. **856**, 202–227). The basic flow is assumed to have zero total circulation and to be composed of two concentric, uniform potential-vorticity (PV) rings attached to the island. On the beta cone, unlike the flat-bottom case, a perturbation imposed on the contours bounding the PV rings will necessarily induce a PV perturbation in the exterior region. This makes the eigenvalue equation transcendental. When the bottom is flat, the flow direction is immaterial, and mode 1 is always stable (Kizner, Makarov, Kamp & van Heijst 2013, J. Fluid Mech. 2013, **730**, 419–441). The conical beta effect, even a weak one, causes the instability of mode 1 in clockwise flows (Rabinovich et al. 2018), whereas in counterclockwise flows, mode 1 is stable. Higher modes can be unstable in flows of both directions. As the slope steepness (beta) is increased sufficiently, in clockwise flows, mode 2 becomes stable in the entire parameter space, while in counterclockwise flows this mode still can be unstable, but the region of its instability shrinks. The bifurcation of mode 1 from stability to instability is discussed in terms of the Rossby waves at the contours of discontinuity of the basic PV and outside of the uniform-PV rings. The instability at a small beta leads to the emission of *m* dipoles, where *m* is the number of the most unstable mode. At a high beta, the topographic Rossby waves developing in the exterior region may smooth away the instability crests and troughs at the outer edge of the main flow, thus preventing vortex production, but allowing the formation of a new quasi-stationary pattern, a doubly connected PV structure possessing *m*-fold symmetry.

ID: **276**

Session: Crystal growth

Effect of weak and strong flow on the morphological instabilities of rapidly solidified binary alloys

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In the production methods of additive manufacturing, or three-dimensional printing, deposited material melts under a rapidly moving heat source and subsequently solidifies under the ambient thermal field. Despite significant progress undergone in the last three decades, the process is still subject to a range of undesirable effects. One of these involves the onset of thermocapillary-induced flow within the laser melt pool, affecting the morphological stability of the solidified alloys. We examine the stability of the interface of a rapidly solidifying binary alloy under weak and strong boundary-layer flow by performing an asymptotic analysis for a singular perturbation problem that arises as a result of departures from the equilibrium phase diagram. Under no flow, the problem involves cellular and pulsatile instabilities, stabilised by surface tension and attachment kinetics. We find that travelling waves appear as a result of flow and we map out the effect of flow on two absolute stability boundaries as well as on the cells and solute bands that have been observed in experiments under no flow.

EFFECT OF LIBRATIONS ON THERMAL CONVECTION IN ROTATING ANNULUS

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Vibrations are an effective tool for controlling thermal convection and heat transfer. Qualitative changes in the mechanism of vibrational convection occur in case of pendulum vibrations. Another factor that has a strong influence on vibrational thermal convection is rotation. This makes it relevant to study thermal convection in a cavity that performs nonuniform rotation. This task is also of interest in connection with geophysical and technical applications.

Thermal convection of a liquid in a rotating sector of a cylindrical layer with boundaries of different temperatures in case of high-frequency modulation of the rotation rate is studied experimentally and theoretically. It is shown that the azimuthal oscillations of the rotating layer lead to the manifestation of various independent mechanisms of vibrational convection. In particular, at slow rotation and large amplitudes of librations two mechanisms, linear and quadratic in temperature inhomogeneity, manifest themselves. In this case taking into account the centrifugal force, convection is determined by two vibration dimensionless parameters, as well as the Rayleigh centrifugal number and the dimensionless rotation velocity. Studies show that the modulation of the rotational rate do not only reduces the threshold of centrifugal convection excitation in a layer heated from the outside, but also leads to the initiation of thermal convection in a fluid layer heated from the inside, i.e. stably stratified in a centrifugal force field.

In the work, the thresholds of excitation of an averaged thermal convection, the structure of convective flows and heat transfer through the layer are studied experimentally and theoretically depending on the heating conditions, the rotation rate and the parameters of rotational vibrations of the cavity. The research results are presented in the space of dimensionless control parameters.

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On stability of the Thomson's vortex N-gon in the geostrophic model of the point vortices in two-layer fluid

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A two-layer quasigeostrophic model is considered. The stability analysis of the stationary rotation of a system of N identical point vortices lying uniformly on a circle of radius R in one of layers is presented. The vortices have identical intensity and length scale is $\gamma^{-1}>0$. The problem has three parameters: N, γR and β, where β is the ratio of the fluid layers thicknesses. The stability of the stationary rotation is interpreted as orbital stability. The instability of the stationary rotation is instability of system reduced equilibrium.

The quadratic part of the Hamiltonian and eigenvalues of the linearization matrix are studied. The parameters space (N,γR,β) is divided on three parts: ***A*** is the domain of stability in an exact nonlinear setting, ***B*** is the linear stability domain, where the stability problem requires the nonlinear analysis, and ***C*** is the instability domain. The case ***A*** takes place for N=2,3,4 for all possible values of parameters γR and β. In the case of N=5 we have two domains: ***A*** and ***B***. In the case N=6 part B is curve, which divides the space of parameters (γR,β) into the domains: ***A*** and ***C***. In the case of N=7 there are all three domains: ***A***, ***B***, and ***C***. The instability domain ***C*** takes place always if $N=2n\geq 8$. In the case of $N=2n+1\geq 9$ there are two domains: ***B*** and ***C***.

The main results are published in the papers "Kurakin L.G., Ostrovskaya I.V. On stability of the Thomson's vortex *N*-gon in the geostrophic model of the point Bessel vortices. Regul. Chaotic Dyn. 2017. 22(7), 865-879" and "L. Kurakin, I. Lysenko, I. Ostrovskaya, M. Sokolovskiy. On stability of the Thomson's vortex N-gon in the geostrophic model of the point vortices in two-layer fluid. Journal of Nonlinear Science. 2018. DOI 10.1007/s00332-018-9526-2".
The work of the first three authors was supported by the Ministry of Education and Science of the Russian Federation, Southern Federal University (Project No. 1.5169.2017/8.9).

ID: **333**

Session: Flows driven by buoyancy and/or Marangoni effect

Particle accumulation structures in high-Pr cylindrical and non-cylindrical liquid bridges

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Three-dimensional numerical simulations have been performed to investigate the onset of oscillatory Marangoni convection in liquid bridges made of a high-Prandtl number fluid (Shin-Etsu 5 cSt silicone oil) using the OpenFoam computational platform and high-resolution structured grids. Different aspect (length to diameter) ratios and volume ratios have been considered corresponding to tall and shallow fluid zones with straight, concave or convex surfaces (microgravity conditions). Particles dispersed in the fluid have been tracked in the framework of a Lagrangian approach relying on the solution of the so-called Maxey-Riley equation. Both one-way and two-way fluid-particle coupling has been implemented. A set of data is presented with the express intent of supporting the optimization of a dedicated series of experiments planned for execution onboard the International Space Station (JEREMI Project).

ID: **219**

Session: Active fluids

Elastohydrodynamic instability of swimming bacteria

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Peritrichously-flagellated bacteria, such as Escherichia coli, self-propel in fluids by using specialised motors to rotate multiple helical filaments. The rotation of each motor is transmitted to a short flexible segment called the hook which in turn transmits it to a flagellar filament, enabling swimming of the whole cell. Since multiple motors are spatially distributed on the body of the organism, one would expect the propulsive forces from the filaments to approximately cancel each other, leading to negligible swimming. We use a combination of computations and theory to show that the swimming of peritrichous bacteria is enabled by an elastohydrodynamic bending instability occurring for hooks more flexible than a critical threshold. The theoretical approach includes both a simple two-dimensional rod model and a full linear stability analysis of the N-flagella problem in three dimensions. Using past measurements of hook bending stiffness, we demonstrate how real bacteria are safely on the side of the instability that promotes systematic swimming.

On the dynamics of an acoustically-driven cavity flow.

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We consider the topology and the dynamics of flows generated by acoustic streaming along an ultrasonic beam undergoing reflections on walls. A potential application of this type of flow could be non-intrusive stirring of high temperature liquids, for instance in a photovoltaic silicon directional solidification furnace with only poor accessibility to the melt. The fundamental understanding of the flow in terms of scaling laws, stability properties and transition to chaos is a first step towards a thorough mastery of acoustic stirring. We will focus on a configuration in which the acoustically-driven jet forces a recirculating flow through 3 successive reflections on the walls of a square cavity.

Our experimental velocity measurements in water have shown an original flow topology and a complex dynamical evolution from steadiness to chaos with increasing acoustic forcing intensity [1]. Unfortunately a thorough characterization of the dynamics would necessitate prohibitively long experiments. We thus propose to characterize this transition on numerical computations of this same configuration by using non-linear dynamics tools. The flow dynamics indeed shows two successive transitions to chaos, separated by a sudden simplification of the dynamics.

We characterize successive bifurcations through the analysis of both the leading frequencies and nonlinear time series. We observe that the state preceding the dynamic simplification that initiates the second phase is chaotic. This chaotic state in fact results from a dynamic instability of the system between two non-chaotic states respectively observed at slightly lower and slightly higher acoustic forcing. The sudden intermediate simplification of the dynamics is linked to the breaking of the vertical symmetry [2].

[1] Cambonie *et al.*, Phys. Rev. Fluids 2 (2017) 123901.
[2] Launay *et al.*, arXiv:1806.09214, submitted to Phys. Rev. Fluids (2018)

Stability and receptivity of the leading edge boundary layer flow on a swept Joukowski airfoil

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Transition to turbulence on swept wings is related to the growth of crossflow waves in the leading-edge boundary layer, but the question of how these waves are generated remains open. Indeed, the transition thresholds found in experiments are consistently lower than the predicted instability thresholds from theoretical studies. Most stability analyses thus far have been based on local flow models, and two different instability mechanisms have been unveiled. The attachment-line itself is prone to a viscous instability, while the inflectional cross-flow profile further downstream along the chord may be subject to an inviscid instability. A long suspected connexion between the two mechanisms has recently been evidenced on the linear modes that develop on realistic airfoils, but the stability of the whole leading-edge flow has only been partially addressed.
In this work, we perform a numerical investigation of the stability and receptivity of the incompressible laminar flow at the leading-edge of a Joukowski airfoil. We present critical stability curves that show that the stability thresholds expected from local flow model predictions are overestimated, thus indicating a non-negligible influence of the airfoil shape on the stability properties of the flow. Assessment of the direct and adjoint modes at the critical threshold provides insight regarding the roles played respectively by the attachment-line and crossflow mechanisms in the destabilization of the whole leading-edge flow. Finally, an analysis of the gain and singular modes of the resolvant operator provides valuable information regarding the mechanisms most effective in the amplification of external perturbations in the subcritical regime.

Oscillations of electrically charged viscoelastic liquid droplets

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We studied the small-amplitude oscillations of electrically charged, slightly viscoelastic liquid droplets in vacuum. In the model the liquid was assumed to be a leaky dielectric described by the Taylor-Melcher theory, and its viscoelasticity was formulated by the Oldroyd-B constitutive equation. An explicit characteristic equation was derived and the complex frequency was solved numerically as a function of the relevant dimensionless parameters including the wave number, the Ohnesorge number, the relative stress relaxation time, the relative strain retardation time, the electrical Bond number, the relative electrical permittivity, and the relative electrical relaxation time. The effect of surface charge and the electrical properties of the liquid on the oscillation characteristics of the droplet was examined for the cases of large/small viscosity/elasticity. Special attention was paid to the quadrupole mode n=2. It was found that in the case of large or small elasticity, increasing surface charge may lead to a decrease in the critical Ohnesorge number at which a supercritical bifurcation occurs and narrow down the internal of Ohnesorge number for oscillations. Moreover, elasticity may induce oscillations of the droplet at large viscosities. The electric field may give rise to new aperiodic branches first appearing at large viscosities or elasticities. The effect of the relative electrical permittivity and the relative electrical relaxation time is complicated. Most significantly, when the electrical relaxation time is of the order of the capillary time or a little smaller, new supercritical and subcritical bifurcations with new intervals that favor the appearance of oscillations occur at moderate or relatively large viscosities or elasticities.

Elastowetting: statics, non-linearity and dynamics

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We have investigated experimentally and theoretically the behaviour of contact lines on soft gels. In summary:

- for very thin layers of gels on a rigid basis, we have established a completely new law relating the dynamic contact angle to contact line velocity that is in very good agreement with experiment.

- for layers of finte depth, but with very strong deformations, we have shown that the ridge formed at the contact line behaves in a completely unexpected non-linear way, developing an equivalent of Peach-Kohler forces that completely modifes Neuman equilibrium of surface tensions. This new approach reconciles conflicting observations performed recently by several teams without invoking any Shuttleworth effect.

Experiments and modeling are also under way in the very complex case of elasto-poro-wetting, i.e. in presence of solvent motions in the substrate. Preliminary results will be also presented.

Refs:

-Geometrical control of dissipation during the spreading of liquids on soft solids, M. Zhao, J. Dervaux, T. Narita, F. Lequeux, L. Limat and M. Roché, PNAS 115, 1748 (2018)

- Corners in soft solids behave as defects in crystals, R. Masurel, M. Roché, L. Limat, I. Ionescu, J. Dervaux, submitted to Phys. Rev. Lett., arXiv: 1806.07701 (2018)

- Growth and relaxation of a ridge on a soft poroelastic substrate, M. Zhao, F. Lequeux, T. Narita, M. Roché, L. Limat, J. Dervaux, Soft Matter, 14, 61 (2018)

Dynamics of contact lines versus solidification on a cold surface

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We have investigated by models and experiments how a contact line advances on a cold surface, while solidifcation of the liquid occurs at the plate surface. This problem is of great importance for several applications (aeronautics, 3D printing...) and is still a fudamental challenge for theory. In a first part we will develop simplified models extending to this situation the well known appraochs of de Gennes and Voïnov. Comparison with available experiments of drops put suddenly in contact with a cold plate is satisfactory when one assumes a few degrees of hysteresis, that we also try to justify from a thermodynamic point of view. In a second step, we present a new experiment in which a liquid bridge advances at a mean constant speed on a cold susbtrate. Depending on the imposed velocity, one observes a regular stationary advance of the liquid, or at low speeds, a transtion to a stick-slip behaviour. Qualitatively, the observation is similar to the model, but quantitatively the observed laws are completely different. We interpret this experiment in terms of a competition between a dendritic front growth, that propagates in competition with the contact line advance.

Ref: R. Herbaut, P. Brunet, L. Royon and L. Limat, "Liquid spreading on cold surfaces: solidification-induced stick-slip dynamics", to appear in Phys. Rev. Fluids (2019)

Dynamic feedback control of edge states in plane Poiseuille flow

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The transition to turbulence in many wall-bounded parallel shear flows, such as pipe or plane Poiseuille flow, is connected to the presence of a lower-dimensional manifold in state space, the edge of chaos, which distinguishes between initial conditions resulting in laminar or turbulent flow. States on the edge manifold have thus at least one unstable direction, and the dynamics will not remain confined to it. However, feedback stabilisation methods can be used to remove the effect of the unstable direction, as demonstrated for pipe flow by Willis et al. (J. Fluid Mech., **831**, pp. 579-591 (2017)). Here, we focus on similar strategies in plane Poiseuille flow. We investigate the effect of a dynamic pressure-based feedback control on the stable and unstable directions in order to stabilise states on the edge.

Thermal-Convective Instability of a Liquid Film with Phase-Changed Interface in enclosed cavity

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Convective flow with a phase-change interface has recently gained a lot of attention due to the great importance in scientific and industrial applications, such as crystal growth, two-phase capillary pumped loops and thermal management devices. In present study, we propose a new model of two-phase thermocapillary-buoyancy convection with phase change occurring in an enclosed cavity subjected horizontal temperature gradient, rather than the previous one-sided model without phase change.

The incompressible, Newtonian liquid (volatile 0.65 cSt silicone oil) and gas (component of air and vapor, where air dominates) are contained in a two-dimensional rectangular cavity where the liquid layer aspect ratio $\Gamma = L/H_l$ is 20. A temperature difference $DT = T_h - T_c$ is imposed parallel to the free surface between the lateral walls. The onset of multicellular convection and two modes of instability is studied numerically. Four different flow regimes of thermocapillary and buoyancy convection are found and the instability transition map with and without phase change are analyzed and compared. Numerical results show the stabilizing effect of phase-changed vapor and liquid interface. A new feature of instability and flow regimes transition of the flow coupled with phase-change effect on the interface will be presented in this presentation. The critical Ma_L for onset of steady multicellular flow and the instability is also compared with the experimental results. We have found the phase change plays a role in decreasing the interfacial temperature gradient, consequently, thermocapillary force is weaken. In other words, phase change tends to stabilize the thermocapillary-buoyancy flows.

Acknowledgements

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Consensus vs polarization: Collective behavior of active particles with selective interactions

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We study the orientational ordering in systems of self-propelled particles with selective interactions. To introduce the selectivity we augment the standard Vicsek model with a bounded-confidence collision rule: a given particle only aligns to neighbors who have directions quite similar to its own. Neighbors whose directions deviate more than a fixed restriction angle α are ignored. The collective dynamics of this system is studied by agent-based simulations and kinetic mean-field theory in the hydrodynamic limit [1]. We show that upon decreasing the restriction angle and the noise amplitude the system develops an orientationally ordered polar state. The transition between the ordered and disordred states can be either continuous or discontinuous, which controlled by the formation of density bands. At very small interaction angles, the polar ordered phase becomes unstable with respect to the bipolar phase. We derive analytical expressions for the dependence of the threshold noise on the restriction angle. We calculate the critical noise, at which the disordered state bifurcates to the bipolar state, and find that it is always smaller than the threshold noise for the transition from disorder to polar order. We generalize our results to systems that show fragmentation into more than two groups and obtain scaling laws for the transition lines. Finally, we discuss the similarity of this interaction model to bounded confidence models in social simulation and demonstrate an application of it to modelling opinion dynamics [2].

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ID: **201**

Session: Electrohydrodynamics

Numerical simulation of the spreading process of a liquid metal on the top surface of a cylindrical pore

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We investigate the replenishment process of a liquid metal in a cylindrical pore and its spreading along the top pore walls. The liquid metal is assumed to have good wetting properties and fully cover the walls. The dynamic transition between different static arrangements is examined as the pressure drop between the reservoir and the surrounding medium varies. The Navier-Stokes and continuity equations are employed, while typical kinematic and dynamic conditions are imposed on the free surface. In addition, since the height of the liquid film that covers the walls varies from several microns to sub-micron size, the capillary and intermolecular forces are incorporated into the normal force balance. Different types of interaction potential functions are examined for the disjoining pressure, i.e. attraction/repulsion or repulsion only with slope dependence. The system of differential equations is discretized with the FEM. The simulations recover the static solution that corresponds to the final shape of the free surface for a wide range of external overpressures. Previous study on the static arrangement of the free surface reveals that a static equilibrium cannot be reached for relatively high overpressures when a short range attractive - long repulsive interaction potential is considered, or for any positive reservoir overpressure for purely repulsive interaction potential. The present analysis investigates the possibility for steady state solutions to emerge at high overpressures, where the viscous stresses balance the intermolecular forces. In this context, the dynamic contact angle, the contact length and film thickness are calculated and the stability of multiple static solutions is investigated. As a next step, appropriate coupling with the magnetic field and an oncoming electric current and heat load is expected to provide reliable predictions of the replenishment time of the liquid metal and an assessment of the film stability in the presence of Lorentz forces.

Liquid-gas interface dynamics of long bubbles travelling in non-circular microchannels

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The displacement of liquid by a long air bubble in a microfluidic channel is a generic two-phase flow model that underpins applications as diverse as thin-film coating, enhanced oil recovery, microevaporators, biomechanics of the lungs, flow in porous media. When a long gas bubbles advances at a constant speed through a tube initially filled with a viscous liquid, a thin liquid film is trapped between the liquid-gas interface and the channel walls and its thickness depends on the capillary and Reynolds numbers and channel cross-section geometry. Despite extensive theoretical and experimental literature covering flow in circular channels, the square/rectangular configuration has not been systematically explored, in particular for what concerns low viscosity liquids where inertial forces become important. We present a numerical study of the dynamics of long gas bubbles transported by a liquid flow within a square channel. The simulations are performed with the open-source CFD package OpenFOAM and the built-in Volume Of Fluid method, for Ca=0.001-0.5 and Re=1-1500. Our objective is to characterize average parameters such as bubble speed and wet fraction, and to extract local features of the liquid-gas interface such as the liquid film distribution on the channel cross-section and minimum values of the liquid film thickness as a function of the flow conditions. This study shows that, unlike the case of a confined long bubble flowing in a circular tube, the liquid film thickness measured around the bubble body decreases indefinitely as longer bubbles are considered. In agreement with the existing literature, the bubble shape becomes axisymmetric when Ca>0.04. Inertial effects yield a decrease of the film thickness till intermediate Re numbers, followed by a monotonic increase. When Re>1000, the formation of a thin film is retarded and the bubble shape remains axisymmetric even when Ca=0.01.

Numerical simulation of oscillatory flow in the print-zone

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Inkjet printing relies on creating a matrix of droplets that strike the media in a predetermined pattern, to form the printed content. The motion of the droplets creates a jet-like flow, which interacts with the shear layer produced by the paper motion to set-up a pair of counter-rotating vortices in the print-zone. Each main droplet typically has one or more satellites, which are usually much smaller than the main droplet, and which can either stream in the main droplet's wake, or be carried by the flow and be redeposited away from the main droplet. For certain configurations, this vortex pair becomes unstable and starts to undergo oscillatory motion, in which case, the image density variations caused by the satellite droplet misplacement appear as so-called 'tiger stripes' (Mallinson et al, 2016).

To investigate this flow phenomena, we have performed transient, three-dimensional numerical simulations of the Navier-Stokes and continuity equations. In this paper, we will compare two approaches for modelling the droplets: as Lagrangian particles, and as a body force. We will demonstrate good correspondence between the two approaches. The Lagrangian approach is more computationally intensive, requiring tracking of a multitude of droplets, and so the remainder of the study employs the body force approach.

We then proceed to explore the design space in terms of printhead-to-paper spacing (PPS), paper speed and print density. We identify conditions under which flow oscillations do and do not occur, and present results which show a variety of behaviours, including standing wave and unsteady.

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A new type of double-diffusive helical magnetorotational instability in rotational flows with positive shear

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The magnetorotational instability (MRI) can destabilize various natural and laboratory rotating flows with radially increasing specific angular momentum but radially decreasing angular velocity, which are otherwise linearly stable according to Rayleigh's criterion. One of the notable classes of such flows is Keplerian rotation of astrophysical disks, where MRI plays a central role, mediating outward transport of angular momentum and inward mass transport. The standard version of MRI (SMRI) with a purely axial magnetic field as well as the azimuthal MRI (AMRI), with a purely azimuthal field and the helical MRI (HMRI), with combined axial and azimuthal fields were extensively studied theoretically (e.g., [1,2,3]). AMRI and HMRI, were also obtained in liquid metal experiments [4,5], while the SMRI remains still elusive in lab.

In contrast to Keplerian-like rotation with decreasing angular velocity, much less attention is devoted to flows with radially increasing angular velocity, i.e., *positive shear*. Up to now, it was believed that such flows are very stable, even under magnetic fields. However, it has been recently shown that at high enough Reynolds numbers, Re ~ 10^6, they can in fact yield non-axisymmetric linear instabilities [6]. Besides, in the presence of magnetic fields, there exists a special type of AMRI for much lower Reynolds number but very strong positive shear [7].

This restriction to very strong shear makes this so-called Super-AMRI unlikely to be astrophysically significant. One of the few positive shear regions is a portion of the tachocline extending ±30◦ about the solar equator. However, even there, the shear measured in terms of the Rossby number, Ro, is only around 0.5, much less than the upper Liu limit (ULL) $Ro_{ULL} \approx 4.83$ required for Super-AMRI [7]. Given the general similarity between AMRI and HMRI, one might expect a similar threshold to hold for Super-HMRI too [8].

In this study, using the short-wavelength WKB approach combined with 1D linear stability calculations in a Taylor-Couette flow, we have uncovered and analyzed a new type of axisymmetric double-diffusive HMRI, which operates in dissipative, magnetized rotating flows with arbitrary positive shear, including $0 < Ro < Ro_{ULL}$ where MRI-s have been previously unknown (detailes are presented in Ref. [9]). The only prerequisites are that (i) the magnetic Prandtl number is neither zero (the inductionless limit) nor too close to unity, Pm ≠ 1 (Fig. 2) and (ii) the imposed magnetic field consists of both axial and azimuthal components. Both these conditions are satisfied in the near-equatorial parts of the solar tachocline, making it a likely astrophysical domain of applicability of this new type of HMRI, which can have important consequences for the stability and dynamo action in this region. In particular, due to its axisymmetric nature, this instability could also resurrect the idea of a subcritical solar dynamo.

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Session: Flows driven by buoyancy and/or Marangoni effect

Hysteresis and Hopf-Bifurcations in Thermally Convective Spherical Couette Flow

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In an annular spherical domain of separation d, cellular fluid motions may be sustained, either by differentially rotating the sphere's boundaries (Couette flow), or by imposing a sufficiently large temperature gradient across the annulus (Rayleigh-Bénard convection). In the first instance rotation imparts angular momentum to the fluid driving a large scale 2-cell flow (mode $l = 2$) symmetric about the equator, while thermal convection may sustain any mode l depending on d.

Using a minimal mode representation of the system, we numerically study the interplay between cellular motions sustained by rotation and those by thermal convection for a wide annulus $d > 1$. For Prandtl number $Pr > 1$ the system chooses a rotating state, for $Pr < 1$ a thermally convecting state. At intermediate Prandtl numbers of $Pr \sim 1$ we find that there is two forms hysteresis between these states as described by a cusp bifurcation. Within the region of bistability, transition between states is found to occur either via a saddle node or Hopf-bifurcation.

The instability of gyrotactically-trapped cell layers

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Several meters below the coastal ocean surface there are areas of high ecological activity that form thin layers of concentrated motile phytoplankton. Gyrotactic trapping has been proposed as a potential mechanism for layer formation of bottom-heavy swimming algae cells like *Chlamydomonas*, especially in flows where the shear stress varies linearly with depth (Durham, Stocker & Kessler, Science, vol. 323, 2009, pp. 1067-1070). In this study, we use a continuum model for dilute microswimmer suspensions to examine gyrotactic trapping in pressure-driven channel flows. While we find that a parabolic base flow does generate a thin layer with high cell concentration, an analysis of its linear stability reveals that the layer is hydrodynamically unstable due to negative swimmer buoyancy (i.e., a gravitational instability) for biologically relevant parameter values. Our results suggest that layers formed by gyrotactic trapping should be transient and, therefore, their nonlinear behaviours need to be considered for a more complete understanding of the layer's evolution.

Satellite droplet formation in the natural breakup of surfactant-laden liquid threads

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We report a numerical study of the natural break-up of Newtonian liquid threads whose cylindrical interface is coated with an initial concentration Γ of insoluble surfactant that induces surface elastic and surface viscous stresses, in addition to surface diffusion. The problem depends on five dimensionless parameters namely, the Laplace number, La, which compares liquid inertia with viscous forces at the bulk, the elasticity parameter, β, which is a dimensionless measure of the surfactant strength, the surface shear and dilational Boussinesq numbers, B_μ and B_κ, that compare the two surface viscous stresses with its shear bulk counterpart, and finally the surface Péclet number, Pe_s, that compares surface diffusion with advection. We perform an extensive parametric study in a nonlinear temporal approach, quantifying the influence of the control parameters on four key magnitudes: the normalised satellite droplet volume just prior to pinch-off, V_{sat}, the normalised mass of surfactant trapped at the surface of the satellite, Σ_{sat}, the break-up time, and the shape of the satellite drop at pinch-off. In the weak-surfactant limit, $\beta<0.125$, $B_\mu\to0$, $B_\kappa\to0$ and $Pe_s\to\infty$, we provide a new scaling law for V_{sat} and Σ_{sat}, namely $V_{sat}=\Sigma_{sat}=0.00421La^{1.64}$, valid for $0.05<La<2$. When $La<0.05$ both magnitudes become negligible, and for $La>10$, V_{sat} and Σ_{sat} reach a plateau of about 3% and 2.9%, respectively. For $\beta>0.125$ and $La>7.5$, V_{sat} displays a local minimum in β, but has small relative variations around the 3% value, while Σ_{sat} increases monotonically. For $La < 7.5$, there is a discontinuous transition in V_{sat} and Σ_{sat} at a critical value of elasticity $\beta=\beta_c(La)$ of order unity. The value of β_c is very sensitive to the Boussinesq numbers and to the surface Péclet number. Indeed, β_c decreases abruptly when, either the Boussinesq numbers increase, or the surface Péclet number decreases.

Revisiting the instability of non-wetting thin liquid films

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We revisit the two-dimensional linear stability properties of non-wetting, ultra-thin liquid films, considering the cases of clean and surfactant-laden liquid-air interfaces. The liquid film, initially at rest, is destabilised by long-range van der Waals forces. Surface stresses are modelled with the Boussinesq-Scriven constitutive equation, and their influence is quantified in terms of an elasticity parameter, β, and the surface shear and dilatational Boussinesq numbers, B_μ and B_κ, respectively. Surface diffusion of surfactant is also contemplated in the analysis, and measured in terms of a surface Péclet number, Pe_s. We perform a systematic comparison of the linear stability results obtained from the leading-order lubrication models, used in previous works, with those obtained from the Navier-Stokes equations. In particular, our results show that the leading-order lubrication equations fail to capture the linearised dynamics of the thin film when the capillary number, Ca, that compares the disjoining pressure with the capillary pressure, is of order unity or larger, independently of the values of beta, B_μ, B_κ and Pe_s. Numerical simulations of the fully nonlinear two-dimensional dynamics are under way.

Thermocapillary flow around an electrogenerated bubble during water electrolysis

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Electrolytic gas evolution has immense technological importance in many electrochemical processes. For long it has been speculated that there might exist surface tension gradient driven flow at the bubble interface although many differenct reasons were provided so as to the cause of the surface tension gradient [1, 2]. First experimental evidence of Marangoni flow at microelectrode was provided only recently [3]. In the present study, we establish the flow to be thermocapillarity driven by correlating numerical simulation of Marangoni flow at bubble interface and simultaneous measurement of fluid velocity and temperature in the electrolytic cell [4]. We show that the phenomenon is caused by localized high current density at microelectrode. In this contribution, we further elaborate the effect of the electrode size on the interfacial flow.

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Transition to Chaotic Marangoni Convection in Liquid Bridge

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Marangoni convection in a liquid bridge of high Pr-number is observed to make clear the flow transition phenomena resulting from a fluid instability utilizing microgravity conditions onboard the ISS. A silicone oil with a viscosity of 5 cSt, which corresponds to Pr of 68, is employed as working fluid and is suspended between a pair of solid disks (50 mm in diameter). Small amounts of fine particles are mixed into the liquid bridge for flow measurement using ultrasonic velocity profiler. One of the disks is heated, and another cooled, to impose a temperature difference on both ends of the liquid bridge. At first, the temperature difference is set to 50 K to fully develop flow. The heating disk temperature is gradually lowered with keeping cooling disk temperature constant. The flow transits from chaotic to oscillatory flow. The chaos analysis is performed on velocity and temperature data. We discuss the characteristics of chaotic behavior and transition process to chaotic Marangoni convection occurred in a liquid bridge.

LIQUID DIELECTROPHORESIS-ENABLED STUDIES OF DEWETTING

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A non-uniform electric field applied to a dielectric liquid creates a force which can actuate motion. When the electric field gradient is localized to the liquid-vapor or solid-liquid interface it is possible to create an interface-localized effect which can be used to modify the shape of the liquid-vapor interface or the extent of the wetting of the solid surface, respectively [1,2]. It is also possible to induce superspreading without the use of surfactants [3]. In this work we outline how such electric-field localisation can be used to induce liquid films on an otherwise liquid repellent substrate and study the dewetting dynamics when the electric field is abruptly removed [4]. We present a theoretical analysis supported by Lattice-Boltzmann simulations showing the dewetting from a liquid film to a single droplet. Our experiments encapsulate a full range of fluid-fluid combinations including droplet-in-air, droplet-in-liquid and air bubble-in-liquid. For our two-liquid droplet-in-liquid system we present data covering four orders of magnitude of inner-to-outer liquid viscosity ratios from 10^{-2} to 10^{2} on both hydrophilic and hydrophobic substrates. We analyse this data in terms of the Cox-Voinov hydrodynamic model and show excellent fits between experiment and data in the early time linear speed dewetting regime and the late time exponential approach to equilibrium.

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Thermoelectric instability in a vertical cylindrical annulus

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When an electric field is applied to a dielectric fluid with a permittivity inhomogeneity, it undergoes the dielectrophoretic (DEP) force which can be seen as a buoyancy force resulting from an artificial electric gravity [1]. In this study, the fluid is confined in a vertical cylindrical annulus with a hot inner surface and a cold outer one that produces the radial permittivity gradient. A high alternative electric potential is applied between the two cylinders. The resulting radial DEP force is able to destabilize the flow, leading to counter-rotating convection cells. Theoretical researches have considered microgravity conditions in order to focus on the DEP force, e.g. [2], but laboratory experiments have to involve the Earth gravity effect which modifies the stability conditions of the system.

The DEP force has been applied to silicone oil AK5 confined in a vertical cylindrical annulus with an inner radius of 5mm, an outer radius of 10mm and a height of either 30mm, 100mm or 300mm. Using PIV and Shadowgraph methods, it has been found that the first unstable regime takes the form of stationary columnar counter-rotating vortices. A stability diagram spanned by the thermal Raleigh number and the dimensionless electric potential has been built experimentally and compared to results from a linear stability analysis [3].

For a set of given control parameters, the experimental measurements of velocity and temperature have been compared to numerical simulations and showed a qualitative agreement. Indeed the columnar structure has been confirmed experimentally, numerically and theoretically and could be explained by simultaneous effect of the axial Earth gravity and the radial electric gravity.

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Symmetry-breaking in chemical channels

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Autophoresis, i.e. the ability to generate fluid flow from self-generated physico-chemical gradients, has received much attention recently to design artificial microswimmers. These self-propel by exploiting the gradients in chemical solutes in their immediate vicinity resulting from the chemical activity of their surface. In such applications, the chemically-active boundaries are that of a moving particle, and different routes to self-propulsion have been identified including chemical and geometric design asymmetries, and instability-based spontaneous symmetry-breaking when solutes are slowly diffusing.

Similar ideas can be extended to flow pumping and mixing in microfluidic channels with chemically-active walls and either a geometric or a chemical asymmetry of the channels is required in order to create a pump (i.e. a net flow through the channel). Here we show that in the absence of such design asymmetry (i.e. for uniform and symmetric channels) spontaneous mixing flows may still occur when solute advection is not negligible, although no net pumping is achieved. We will characterize this instability which results from the coupling of the viscous flow dynamics to the solute transport and will analyze the resulting cellular flows within the phoretic channel.

Parametrically excited Marangoni convection in a liquid layer covered by insoluble surfactant: Numerical simulation

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Horizontally infinite liquid layer with a deformable upper free surface covered by insoluble surfactant is considered. The heat flux at the bottom of the layer is periodically modulated with a zero mean value. In the absence of surfactant the longwave Marangoni convection is dominated by the slow mode of surface deformation. In the presence of surfactant, there is an additional slowly evolving variable, the surfactant concentration. In our previous research [1] we derived the set of nonlinear equations in the long-wave approximation under assumption that the horizontal spatial scale is larger than the typical vertical scale. Earlier, the bifurcation analysis near the threshold of the onset of Marangoni instability showed the existence of the subcritical as well as supercritical bifurcations. Here we investigate the nonlinear behavior of the system in the periodic domain numerically. We apply the pseudo-spectral method, expanding the variables of the problem – deviation of free surface, h, thermal disturbance, θ, and disturbance of the surfactant concentration, γ, - into Fourier series and then working in the wavenumber space. Evolution of patterns is investigated.
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Long-wave Marangoni instability in a heated liquid layer covered by insoluble surfactant: Nonlinear dependence of surface tension on temperature and concentration

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Though in many studies the dependence of surface tension on temperature and on surfactant concentration is assumed typically to be linear function, experiments on dilute aqueous solutions of long alcohol chains, water-oil-surfactant systems, ionic liquids etc. [1-3], as well as on stoichiometry–driven Marangoni convection in GaAs growth [4] reveal non-monotonic dependence of surface tension on temperature and concentration.

Here we assume that the surface tension function, $\sigma(T,\Gamma)$, can be represented by a quadratic polynomial with reference temperature T_0 and reference surfactant concentration Γ_0, as

$$\sigma(T,\Gamma)=\sigma_0+\sigma_1(T-T_0)+\sigma_2(\Gamma-\Gamma_0)+1/2[\sigma_3(T-T_0)^2+\sigma_4(\Gamma-\Gamma_0)^2+2\sigma_5(T-T_0)(\Gamma-\Gamma_0)],$$

where σ_0 is a reference value of surface tension, $\sigma_1=\partial\sigma/\partial T$ ($\sigma_1<0$), $\sigma_2=\partial\sigma/\partial\Gamma$, $\sigma_3=\partial^2\sigma/\partial T^2$, $\sigma_4=\partial^2\sigma/\partial\Gamma^2$, and $\sigma_5=\partial^2\sigma/\partial T\partial\Gamma$.

In our case, the linear approximation gives us standard linear Marangoni (M_L) and elasticity numbers (N_L), but in the nonlinear case there appear nonlinear Marangoni (M_Q), nonlinear elasticity number (N_Q) and nonlinear coefficient describing the change of the surface tension by simultaneous change temperature and concentration (S). For long-wave instability a set of amplitude equations using the scaling $k\approx B^{1/2}$ (k is a wavenumber and B is the Biot number) is derived. The analysis of amplitude equations is compared with the traditional case of linear variation of surface tension on temperature and concentration. This research was partially supported by the Israel Science Foundation (grant No. 843/18).

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Linear stability of evaporating falling liquid films

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In order to improve the understanding of the wavy dynamics of evaporating falling liquid films, we have performed a linear stability analysis of these flows by solving the classical Orr-Sommerfeld eigenvalue problem using a Chebyshev pseudo-spectral method. The key parameters of the analysis are: (i) the Marangoni number describing the relation between the thermocapillary and the viscous stresses, and (ii) the evaporation number, representing the ratio between the viscous and evaporative time scales.

By neglecting thermal effects, only one unstable mode (H-mode) is present because of the surface inclination. If thermocapillarity is weak, a new unstable mode (S-mode) is observed, which results from the change of surface tension due to the temperature gradient along the free surface. More interestingly, for a specic Marangoni number, the S-mode and H-mode combine into one unstable region, thus reinforcing each other, leading to a possible formation of dry spots.

When the liquid is volatile, a new instability is detected due to the vapour recoil which destabilises the flow in a similar fashion as thermocapillarity. On the other hand, the effect of mass loss does not directly affect the growth rate but instead it stabilises the flow as a result of film thinning which increases the viscous resistance to the flow. It was also found that flows going under quasi-equilibrium evaporation are more unstable than the ones under non-equilibrium evaporation. Moreover, vapour recoil and thermocapillarity enhance each other in the non-equilibrium evaporation case.

Finally our analysis was compared to the long wave theory analysis conducted by Joo et. al. (JFM, 230, 117-146, 1991). While the two models have excellent agreement if the wavenumber is small and the inertia is weak, the long wave theory completely breaks down when these requirements are not satisfied giving significant errors for both maximum growth rate and cut-off wavenumber.

Turbulent windprint on a liquid surface

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We investigate the effect of a light turbulent wind on a liquid surface, below the onset of wave generation. In that regime, the liquid surface is populated by small disorganised deformations elongated in the streamwise direction. Formally identified recently by Paquier et al. (2015), the deformations that occur below the wave onset were named wrinkles. We provide here a theoretical framework for this regime, using the viscous response of a free liquid surface submitted to arbitrary normal and tangential interfacial stresses at its upper boundary. We relate the spatio-temporal spectrum of the surface deformations to that of the applied interfacial pressure and shear stress fluctuations. For that, we evaluate the spatio-temporal statistics of the turbulent forcing using Direct Numerical Simulation of a turbulent channel flow, assuming no coupling between the air and the liquid flows. Combining theory and numerical simulation, we obtain synthetic wrinkles fields that reproduce the experimental observations. We show that the wrinkles are a multi-scale superposition of random wakes generated by the turbulent fluctuations. They result mainly from the nearly isotropic pressure fluctuations generated in the boundary layer, rather than from the elongated shear stress fluctuations. The wrinkle regime described in this paper naturally arises as the viscous-saturated asymptotic of the inviscid growth theory of Phillips (1957). We finally discuss the possible relation between wrinkles and the onset of regular quasi-monochromatic waves at larger wind velocity. Experiments indicate that the onset of regular waves increases with liquid viscosity. Our theory suggests that regular waves are triggered when the wrinkle amplitude reaches a fraction of the viscous sublayer thickness. This implies that the turbulent fluctuations near the onset may play a key role in the triggering of exponential wave growth.

Advection-driven transition to chaos in chemically active microdrops

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An individual chemically-active microdroplet that is suspended in the bulk of a reagent solution may excite the flow in the surrounding fluid even in the absence of preexisting asymmetries, such as gravity or inhomogeneous interfacial properties. In experiments, this spontaneous flow excitation allows active drops to self-propel with straight, helical, or chaotic trajectories. In this work, we propose a fully nonlinear spectral model of the droplet and surfactant dynamics and solve it numerically to elucidate the nonlinear dynamics of a solitary active drop and understand how individual drops "decide" what to do. We consider a drop that features two different mobility mechanisms converting the gradients of the reagent concentration into the flow at the droplet interface: diffusiophoresis and the Marangoni effect. In the absence of imposed asymmetries, the flow must originate from a symmetry-breaking bifurcation. In particular, it was demonstrated that symmetry-breaking may be enabled by advection of reagent around the drop. Accordingly, reagent advection is the only nonlinear mechanism included in our model. Our simulations reveal that, in addition to initiation of the symmetry breaking, advection may also play a key role in selection of a nonlinear flow pattern excited above the bifurcation threshold. Specifically, we demonstrate that weak advection is associated with the steady self-propulsion of the drop, while strong advection induces the onset of a chaotic flow. In addition, we show that the competition between diffusiophoresis and the Marangoni effect also affects the threshold of the onset of chaos. In particular, diffusiophoresis promotes the onset of higher-order modes of instability, thus facilitating the transition to chaos.

Bifurcation analysis of snowball Earth transitions in an implicit Earth system model

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Glacial deposits that are likely to have formed in the tropics led Joseph L. Kirschvink [1] to hypothesize a fully ice-covered globe during the Neoproterozoic: the global 'snowball' model. Additional support for this idea has come from climate models of varying complexity that show transitions to snowball states and undergo hysteresis under changes in solar radiation. In this work we apply large-scale bifurcation analyses to snowball Earth problems using a novel, implicitly formulated Earth system model of intermediate complexity (I-EMIC).

The I-EMIC contains a primitive equation ocean model, atmospheric heat and moisture transport, the formation of sea ice and the adjustment of albedo over snow and ice. With the I-EMIC, high-dimensional branches of the snowball Earth bifurcation diagram are obtained through numerical steady state continuations. Moreover, large-scale linear stability analyses are performed near major bifurcations, revealing the spatial nature of destabilizing perturbations.

We also briefly discuss how stochastic methods may accompany the I-EMIC to study noise induced behavior near major climate transitions. The implicit methodology provides an efficient computation of local probability density functions through the solution of a generalized Lyapunov problem [2]. In turn, such information on the system's local noise response may greatly benefit the computation of transition probabilities.

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Bifurcation in rotating plane Couette flow, revisited

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The problem of transition from laminar flow to turbulence in plane Couette flow subject to a span-wise system rotation is considered, where the fluid motion is governed by two non-dimensional parameters, R (shear-induced Reynolds number) and Ω (system rotation rate). This system has long been serving as a testing ground for comparing experimental and theoretical results towards understanding mechanisms of transition in fluid dynamics.

It is believed that the basic laminar state first loses stability to stream-wise independent disturbances with increasing R and/or Ω, resulting in the onset of a secondary flow with a stream-wise independent roll-cell structure (TV1), followed by successive supercritical bifurcations originating from three-dimensional instabilities of TV1. In the present paper, we re-examine this seemingly well-known instability property of TV1, especially for small R, and find some unexpected result.

We shall demonstrate that the solution branch for a three-dimensional tertiary flow with small stream-wise wavenumbers resulting from the afore-mentioned secondary instability connects with the so-called Ribbon flow, which is composed of two tilted vortex flows, elongated in the stream-wise direction with the same but opposite tilted angles.

Similar to TV1 this Ribbon flow bifurcates from the laminar basic state, and we find the bifurcation point coincides with that of TV1 in the limit of vanishing stream-wise wavenumber.

Thus, the stream-wise independent secondary flow, TV1, becomes unstable to disturbances with small stream-wise wavenumbers as soon as it bifurcates from the basic state, and so no stable stream-wise independent roll-cell structures can exist.

We conclude that the roll-cells, which are observed in experiments as the secondary flow, might actually be a three-dimensional tilted vortex flow with long stream-wise wave lengths, which exists intrinsically, being independent of the different types of boundary condition at the sides in experiments.

Stabilization of Blasius boundary layer with streamwise control

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The turbulent friction drag can be an order of magnitude higher than that in laminar case. Delaying the laminar-turbulent transition could be a possible way to reduce skin friction.

Choi et al. [1] suggested three different active control strategies by manipulating the streamwise, wall-normal and spanwise wall velocities. While the wall-normal velocity based control was extensively studied for the channel and the flat plate flows, the control considering the streamwise motion was neglected.

The purpose of the current study is to develop a tool based on linear stability analysis which can help judge whether a flow control technique has the potential to delay the laminar-turbulent transition. The code was used to test a new active control which was found promising based on [1].

The Orr-Sommerfeld equation was used to investigate the local stability of the flat plate flow described by the Blasius profile. A theoretical active control was applied on the wall which moves small panels in the streamwise direction proportional to the fluctuating wall shear stress. With the control the critical Reynolds number can be increased significantly. Further outcome of the study was that active controls might change the most unstable mode so that it is suggested to investigate more than one mode. The flow was investigated by the more conservative Reynolds-Orr energy equation, too. The result shows that the critical Reynolds-number can be increased by a factor of 2 with a small negative control parameter.

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Transient energy growth of optimal disturbances in viscous round jets

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We investigate the three-dimensional temporal non-modal stability of viscous round jets subject to the primary Kelvin-Helmholtz instability. Non-modal linear stability analysis is based on a direct-adjoint technique which enables to determine the fastest growing perturbation, or optimal perturbation, over a single period of the time-evolving two-dimensional base flow during a given time interval, $[t_0; T]$. We explore the sensitivity of the optimal perturbation to the following parameters:

- the azimuthal wavenumber of the mode, m;
- the injection time, t_0;
- the horizon time, T;
- the aspect ratio, $\alpha = R/\theta$, where R and θ are respectively the jet radius and the shear layer momentum thickness;
- the Reynolds number, $Re = U_j R/\nu$, where U_j is jet center-line velocity and ν the kinematic viscosity.

In particular, we focus on the influence of the azimuthal wavenumber, m, on the optimal energy gain as a function of the horizon time, T. In this context, for Re = 1000 and α = 10, the helical perturbations experience the highest energy growth. The short time dynamics of the perturbations, i.e. T < 5, are driven by the so-called Orr mechanism whatever the azimuthal wavenumber. For larger horizon times, the optimal perturbation leads to the development of an elliptic instability located within the vortex core for low values of the azimuthal wavenumber. When m is increased, the location of the optimal perturbation progressively moves towards the braid region, which is characteristic of an hyperbolic instability. Finally, we also consider the impact of the injection time on the contribution of the Orr mechanism to transient dynamics.

Session: Waves and turbulence

Evolving wave turbulence

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I will discuss evolving solutions for spectra of wave turbulence withing the dynamical, kinetic and reduced kinetic models. Analytical self-similar solutions and direct numerical simulations will be presented. The solutions will be discusses in the context of evolution preceeding formation of Kolmogorov-Zakharov spectra, nonequilibrium Bose-Einstein condensation, thermalization scenarios.

Session: Parametric excitation and control of instabilities

Wall-generated pattern on miscible interface under horizontal vibrations

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It is well known that a two-layer system of immiscible or miscible liquids is subject to the so-called frozen-wave instability under the action of horizontal vibrations. The subject of our talk is the theoretical and experimental investigation of flows in a miscible two-layer system below the threshold of the frozen-wave instability. The numerical analysis shows that in computations with periodic boundary conditions, which correspond to the case of infinitely extended layers, the parallel flow is stable, while the computations in a finite layers with solid lateral boundaries reveal an unusual distribution of concentration, which resembles a fish spine. A similar structure is observed in experiments. We show that this pattern is generated by the joint action of sloshing caused by horizontal vibrations, oscillatory flows in the Stokes boundary layers on the lateral walls, and the streaming flow in the oscillatory shear flow around the interface. The comparison of experimental observations and theoretical predictions is carried out.

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Stability of viscoplastic fluids down an incline plane

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Viscoplastic fluids are characterized by 1- they only can flow above a minimum stress (yield stress), and 2- above this stress, a viscosity decreasing with the shear rate. They are involved in a wide range of industrial applications, but also in natural events such as mud flows. During these mud flows, the surface can be destabilized and develop into roll waves, which should be taken into account in any risk assessment study. These Kapitza waves have been widely studied when the fluid is Newtonian, both experimentally and theoretically. In contrast, there are a few theoretical studies in the case of a viscoplastic fluid and, to our knowledge, no experiments were yet made.

We set up a model experiment to measure the primary instability of these waves : In a channel with a slope angle between 0 and 15° , as the previous study of Allouche & al (J.F.M , 2017), we establish a permanent flow using a model viscoplastic fluid (Carbopol 980). By perturbing the inlet flow rate, we generate surface waves at a controlled frequency, and we observe their evolution downstream with a laser sensor system, that measures the local fluid thickness.

Growth rates and neutral frequencies are obtained after processing the thickness signal. An experimental critical Reynolds number, under which the waves cannot develop, can be deduced.

We find this experimental critical number in quite good agreement with the theoretical prediction of Balmforth & Liu (J.F.M, 2004), provided that a critical Bingham number is carefully extrapolated from the experiment data.

Three-dimensional simulation of flows induced by flexural vibrations of thin long beams in a viscous fluid.

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The work is devoted to the study of flows induced by flexural vibrations of thin cantilever beams in a viscous fluid and their hydrodynamic influence on the beams. A three-dimensional model of interaction is considered, in which flexural vibrations of a beam are described according to the Euler-Bernouli theory, and the fluid motion around the beam is governed by the Navier-Stokes equations. The numerical implementation of the model is based on the finite volume method and realised in the OpenFOAM package. The solution of the problem is carried out in the range 1<KC <7 (where KC is the Keulegan-Karpenter parameter calculated by the amplitude of oscillations of the free end), 50<β<2000 (where β is the Stokes number), 10<L<30 (where L is dimensionless length of the beam). Flow around a beam in the investigated range of parameters are well structured. A fully developed three-dimensional flow is formed only in the vicinity of the free end of the beam, the size of this zone does not exceed 0.1L - 0.2L. In the rest of the region, flows in planes perpendicular to the axis of the beam prevail. These flows determine the main contribution to the damping hydrodynamic force acting on the beam. The structure of the quasi-plane flows varies along the length of the beam. In the considered range, five significantly different flow regimes are locolized. The observed structures are in good agreement with experimental observations [1], however, the boundaries of the regimes are not functions only of the local characteristics of the cross-section (KC_{loc}, β), as was assumed in previous studies, but also depend on KC and L. According to the calculations, the hydrodynamic forces and moments acting on the beam were evaluated. The results are in good agreement with the experimental measurements [2].

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Secondary instability induced by thermocapillary effect in half-zone liquid bridge of high Prandtl number fluid

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We investigate the secondary instability of thermocapillary-driven convection in a high-Pr liquid bridge (Pr = 4) of half-zone geometry via direct numerical simulation. The convection exhibits a three-dimensional time-dependent `oscillatory' state with a distinct azimuthal modal structure, that is, spatio-temporally periodic state after the onset of the primary instability. We indicate that the convection exhibits another transition to spatio-temporally quasi-periodic states by increasing the intensity of the thermocapillary effect. The proper orthogonal decomposition (POD) is employed in order to extract the variation of the flow structures before/after the secondary instability. After the primary instability, one finds the oscillatory flow with a fundamental azimuthal modal number. It is indicated that the flow field consists of the primary component with the fundamental modal structure of m_0, and the components with fundamental modal structures of higher harmonics of the primary components. Those components dominate the whole flow field. After the onset of secondary instability, additional components emerge in the flow; those components consist of the the fundamental azimuthal modal structures, which are different from higher harmonics of the primary flow field. We determine the onset condition or critical Reynolds number for the secondary instability $Re_c^{(2)}$ by monitoring the development of the energy of the newley arisen components. It is found that the secondary instability evaluated through decomposed flow structures via nonlinear simulation corresponds to that predicted through Floquet modes via linear stability analysis.

Spatiotemporal chaos and intermittency in a system of Ginzburg-Landau equations for nematic electroconvection

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In this work we investigate the transition from periodic solutions to spatiotemporal chaos in a system of four globally coupled Ginzburg Landau equations describing the dynamics of instabilities in the electroconvection of nematic liquid crystals, in the weakly nonlinear regime. If spatial variations are ignored, these equations reduce to the normal form for a Hopf bifurcation with O(2)xO(2) symmetry. Both the amplitude system and the normal form are studied theoretically and numerically for values of the parameters including experimentally measured values of the nematic liquid crystal Merck I52. Coexistence of low dimensional and extensive spatiotemporal chaotic patterns, as well as a temporal period doubling route to spatiotemporal chaos, corresponding to a period doubling cascade towards a chaotic attractor in the normal form, and a kind of in-out spatiotemporal intermittency that is characteristic for anisotropic systems are identified and characterized. A low-dimensional model for the intermittent dynamics is obtained by perturbing the eight-dimensional normal form by imperfection terms that break a continuous translation symmetry.

Impact of interface rheology on binary fluid particle coalescence

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Coalescence of fluid particles has been attracting a huge interest for decades, as a better understanding on it is crucial both to resolve natural phenomena such as the formation of the rain droplets, and to analyze the performances of multiphase engineering units. This work aims to narrow the gap between recent experimental findings on the coalescence time and the preexisting theoretical models in the literature, by investigating the explicit effects of the particle approach velocity, V, and the surface viscosities (shear and dilatational) on the coalescence behavior/time during the head-on collisions of two deformable particles. The drainage of the film emerging between the particles is modeled based on the lubrication theory, and the Boundary Integral Method (BIM) is employed to couple the tangential velocity of the interface, U, to the film drainage. The addition of the surface viscosities yields a second order differential equation, which governs U together with BIM. This requires a modification on BIM and the introduction of a set of new boundary conditions on both U and the tangential stress of the interface.

The results reveal the effects of V, the viscosity ratio and the surface viscosities on the coalescence time and the drainage behavior. For all values of the viscosity ratio, the Hamaker constant and the surface viscosities investigated, three distinct behaviors are observed as V increases: the linear, the dimpled and the multiple-rim drainage regimes. The critical values of V separating the regimes are provided as functions of the viscosity ratio, the Hamaker constant and the surface viscosities. In the dimpled and the multiple-rim drainage regions, the coalescence time shows significant dependence on the magnitudes of the surface viscosities, whereas in the linear region no such dependence is observed.

Effects of slowly-varying meniscus curvature in micro-channel flows with longitudinally-grooved superhydrophobic surfaces

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The flow rate of a pressure-driven liquid through a microchannel may be enhanced by texturing the no-slip boundaries with grooves aligned in the direction of flow. These grooves may contain vapour and/or an inert gas and can trap the liquid in the Cassie state, resulting in apparent slip. Then, at any given cross section, the meniscus takes the approximate shape of a circular arc whose curvature is determined by the pressure difference across the meniscus. Hence, the meniscus is typically protruding into the groove close to the inlet of the channel, only to be gradually drawn in as the channel is traversed and the pressure tends to its ambient value at the open downstream end. For sufficiently large Reynolds numbers, the variation of the meniscus shape and hence the flow geometry, necessitates the inclusion of inertial non-parallel flow effects. We capture such effects in the case of a slender channel and order one Reynolds numbers that are appropriate in applications. This is done by using a hybrid analytical-numerical method which allows the nonlinear three-dimensional (3D) problem to be solved as a sequence of two-dimensional (2D) linear ones in the channel cross-section, allied with nonlocal conditions that determine the slowly varying pressure distribution at leading and first order. We find that for realistic parameter values, inertial effects can significantly reduce the flow rate. However, for sufficiently large channel heights, inertial effects enhance the flow rate. Physical explanations of these phenomena are also given.

Modal and non-modal stability analysis of stratified Blasius flow

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Stratified shear flows occur in many hydrodynamical and geophysical applications, such as in oceans and in atmospheric boundary layers. In this context, we study the modal and nonmodal stability of a Blasius flow characterised by a stable temperature profile coupled with a density variation along the vertical direction. The dynamics of this flow is sensitive to the effects of three dimensionless parameters, namely, the Reynolds number (Re), the Richardson number (Ri) indicating the ratio of the buoyancy force to the shear one, and the Prandtl number (Pr), which represent the ratio between momentum and thermal diffusivity. Under the assumption of incompressible flow and using the Boussinesq hypothesis, modal and nonmodal linear stability analyses are performed for different values of Re, Ri and Pr parameters. An in-house Matlab code, using a direct-adjoint algorithm, is developed to analyse the asymptotic stability of the flow as well as to find the initial condition that maximises the transient energy growth of the system. Increasing the Richardson number, such one optimal perturbation considerably changes, becoming more and more inclined with respect to the streamwise direction instead of being streamwise-aligned as the streaky optimal perturbation found for unstratified Blasius flow. Therefore, the streamwise wave number of the optimal perturbation increases with the Richardson number. On the contrary, the optimal gain and the optimal time decrease with Ri, loosing the Re^2- and Re-dependence characterizing the unstratified Blasius flow, respectively (*Luchini*, 2000). This behaviour, which is linked to the competition between the Lift-up and Orr mechanisms, is studied in detail to determine the influence of stratification on the flow dynamics.

Transient dynamics of exact localized states in plane Couette flow

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From the early work of Emmons in the 1950s, localized perturbations have been commonly known to be the seeds of turbulence in spatially extended shear flows. In the recent years, the heavy use of localized initial conditions generated from turbulent states has led to much progress in our understanding of statistical transition to turbulence in pipe and plane Couette flows. Simultaneously, a number of studies investigating the invariant solutions of the same flows have promoted the dynamical systems viewpoint on transition. This resulted in the discovery of spatially localized equilibria and travelling waves in plane Couette flow found on two corresponding branches intertwined in a bifurcation pattern known as homoclinic snaking. In this talk, we will show how these exact localized states can be used to explore numerically the phase space of plane Couette flow at subcritical Reynolds numbers. We will first discuss homoclinic snaking and its role as a generator of localized initial conditions. Then, we will present a schematic of parameter space which summarizes the various regimes localized initial conditions exhibit and discuss the regimes in detail. Their most prominent characteristics, namely oscillatory dynamics and spot splitting, will be explained in terms of connections between the localized states and other exact solutions in plane Couette flow. In the end, if time permits, we will explore relaminarization control perspectives.

Pearling and fractal instabilities in merging soap bubbles

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Soap bubbles fascinate children and adults alike due to their beauty and fragility. Although soap bubbles are studied for centuries, their coalescence is still not very well understood.

The coalescence of centimeter-sized soap bubbles is studied with varying soap concentrations, below and above the critical micelle concentration (cmc). Applying a voltage to the bubbles ensures, that they carry the same charge, such that they repel each other slightly and do not merge instantaneously. The merging region is monitored via high-speed optical imaging. An interference pattern can be observed where the bubbles touch each other shortly before merging. This interference rings suggest, that the bubbles are forming a dimple before touching each other. Thus, an air bubble is entrapped between the soap bubbles.

Upon merging a water bridge is formed between both bubbles. The merging process starts at the edge of the interference area, where the distance between the two bubbles is smallest. The spreading rim of the water bridge deforms in a way that shows a fractal instability in the region where the interference patterns had been. The onset of the instability is controllable by the magnitude of the voltage. Beyond the interference region, the water bridge spreads smoothly. The fractal pattern occurs due to a varying propagation speed of the rim along its way through the area with the interference pattern. In some regions it propagates slower than in others, leading to a deformation of the rim and with that to a varying curvature. When these curved parts of the rim merge again, a soap column is formed which release small soap bubbles due to a pearling instability. The described patterns can only be found above the cmc. Below this concentration, only a slight deformation of the spreading water bridge can be found.

Influence of superhydrophobic surfaces on the laminar-to-turbulent transition in a channel flow

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SuperHydrophobic Surfaces are capable of trapping gas pockets within the microroughnesses on their surfaces when submerged by a liquid, with the overall effect of lubricating the flow on top of them. These bio-inspired surfaces have proven to be capable of dramatically reduce skin friction of the overlying flow in both laminar and turbulent regimes, although their effect in transitional conditions, in which the flow evolution strongly depends on the initial conditions, has still not been deeply investigated. In this work the influence of SuperHydrophobic Surfaces coating the walls of a channel on several scenarios of laminar-turbulent transition is studied by means of direct numerical simulations. A single phase incompressible flow have been considered and the effect of the micro-structured superhydrophobic surfaces has been modeled imposing a slip condition with given slip length at both walls. The flow evolution from laminar, to transitional, to fully-developed turbulent flow has been followed starting from several different initial conditions. When modal disturbances issued from linear stability analyses are used for perturbing the laminar flow, as in supercritical conditions or in the classical K-type transition scenario, superhydrophobic surfaces are able to delay or even avoid the onset of turbulence, leading to a considerable drag reduction. Whereas, when transition is triggered by nonmodal mechanisms, as in the optimal or uncontrolled transition scenarios, these surfaces are totally uneffective in controlling bypass transition scenarios, which are currently observed in noisy environments. Superhydrophobic surfaces can thus be considered effective in delaying transition only in low-noise environments, where transition is triggered mostly by modal mechanisms.

A reduced-order model for thermo-viscous fingering of magma flow in volcanic fissures

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A reduced order model for dynamics of hot magma flow through a thin, long volcanic fissure is developed. Magma flow through the fissure is modeled as a fluid with temperature-dependent viscosity flowing through a narrow slot. The side-walls of the slot are held at a lower temperature, mimicking the colder rock walls surrounding the fissure, thus cooling the magma as it flows. Flow and heat advection equations are averaged across the slot thickness using a weighted-residual integral boundary layer (WRIBL) technique. This modeling strategy allows us to incorporate the effect of non-Poiseuille flow profile in the slot arising due to temperature-dependent viscosity, unlike the Poiseuille flow-based Darcy models used in earlier works. The stability of a one-dimensional uniform flow of magma is investigated under both constant pressure and constant flow rate conditions. Linear stability analysis reveals that for sufficiently strong temperature-dependence of viscosity, one-dimensional flow of magma undergoes a thermo-viscous fingering type of instability. The uniform flow then gives rise to alternate interior bands of low-viscosity fast-moving and high viscosity slow-moving magma. The parametric regions of instability are further investigated and compared with earlier Darcy models. The uniform base state as well as its stability characteristics obtained from the WRIBL model are found to be qualitatively similar to the ones obtained by the Darcy model, though they may show significant quantitative difference. Further, we also investigate the nonlinear evolution of the banded-flow of magma inside the fissure.

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Session: Liquid films, drops, and bubbles

Electrostatic forcing of thin liquid films

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The dynamics of an interface between a conducting liquid and a passive ambient medium subject to both constant and periodic electrostatic forcing is investigated. Both fluids are assumed to be leaky dielectric, wherein the time scale for charge relaxation is much smaller compared to the time scale associated with flow. An inertial lubrication model for such a system is developed based on the method of weighted residual integral boundary layer. Inertial thin films are shown to become unstable to resonant Faraday modes at the onset, prior to the long-wave pillaring instability reported in the lubrication limit. For a perfect conductor – perfect dielectric fluid pair as well as a perfect dielectric – perfect dielectric fluid pair, Faraday modes arise necessarily due to mechanical inertia of the fluid. While for a pair of leaky dielectric fluids, an additional inertialess resonant instability due to charge dynamics at the interface is also possible. The response of the system in the latter case is akin to inertialess resonant instability reported in mechanically forced thin films with an insoluble surfactant at the interface. The inertial Faraday modes nonlinearly saturate to subharmonic or harmonic standing waves at low-forcing amplitudes. At higher forcing amplitudes, the interface may approach either wall depending on the liquid-gas holdup. For low liquid holdup, a perfect conductor – perfect dielectric fluid as well as a perfect dielectric – perfect dielectric fluid pair resembles a Rayleigh-Taylor system. Under constant DC forcing, the interface then exhibits sliding as it approaches the electrode and the interface undergoes horizontal translation. Under periodic forcing, the interface exhibits an oscillatory sliding behavior, approaching the wall in an “earthworm-like" motion. A typical leaky dielectric fluid, however, does not exhibit sliding dynamics due to the charge dynamics at the interface.

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Pattern formation at the liquid-granular medium interface in a rotating horizontal cylinder under libration

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We consider the interface between liquid and granular medium in an unevenly rotating (librating) horizontal cylinder. In a uniformly and rapidly rotating cylinder, granular medium forms an annular layer near a cylindrical wall and performs a solid-body rotation; the interfacial boundary is axisymmetric.

Under librations, in a reference frame corotating with the cylinder, the granular medium remains stationary, and the liquid oscillates at the frequency equal to the libration frequency Ω_l. The amplitude of azimuthal fluid oscillations φ is related to the magnitude of the modulation of the rotation velocity Ω_r by the condition $\varepsilon \equiv \varphi\Omega_l/\Omega_r$.

The oscillating fluid entrains the particles of the upper layer of the granular medium and provides conditions for the pattern formation. According to the observations, the patterns occur in a threshold manner. The shape of the bed forms is found to depend on the relative libration frequency Ω_l/Ω_r: at slow oscillations ($\Omega_l/\Omega_r < 1$), we observe regular patterns with steep and gentle slopes (dunes), in other cases axisymmetric patterns are observed. The azimuthal size of the dune-like bed forms is much larger than the size of axisymmetric patterns. In the supercritical domain, the bed forms do not remain stationary – fluid flow is able to pick up particles from the bed surface and to transfer them to the neighboring patterns and thereby provides conditions for the azimuthal drift of the bed forms.

The physical mechanism, which is responsible for the pattern formation, the spatial size and the drift velocity of bed forms in wide ranges of rotation rate, frequency and amplitude of oscillations are studied.

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Non-linear stability of magnetohydrodynamic flows

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Liquid metal flows occur in many technological applications including metallurgy, materials processing, and nuclear and thermonuclear reactors cooled by liquid metals. Such facilities contain pipes and devices such as pumps, valves, etc. in which laminar or turbulent flows can occur. For the design and operation of these liquid metal installations, it is significant to know exactly how flow regimes (laminar or turbulent) will be carried out from flow parameters including pressure gradient, viscosity, electrical conductivity, and external magnetic field.

It is generally accepted that turbulent flows appear due to the non-linear development of perturbations. Two theoretical approaches have been developed to explain turbulent flow [1]. In one, the turbulent motion develops from infinitely small perturbations of the laminar flow. An eigenfunction of the linearized MHD problem or optimal disturbances [2] can be taken as initial infinitely small disturbance. The small perturbations increase to a relatively large amplitude in which a non-linear interaction becomes large. According to the second point of view, the turbulent state at large Reynolds numbers attracts flow which is routed from the laminar state by any small finite amplitude perturbation. In this case the initial disturbance can be brought into flow by fluid injection[1].

For direct numerical simulations of disturbances we use the MHD solver [3] based on the spectral/hp element framework Nektar++. The stability of the Hartman flow and flows in 90 degree bends [4] was investigated. Both approaches for the initial disturbance are explored.

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When wind-waves become solitary waves

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It is common knowledge that when wind blows over a water surface it generates waves. However the instability mechanism, even close to onset, remains largely unknown. We recently revisited this challenging problem replacing water by various viscous liquids in a tentative to understand the influence of dissipation in this mechanism [1-3]. We observe that, when the liquid viscosity becomes few hundred times larger than water viscosity, the nature of the waves dramatically changes: instead of a regular wave train, the surface deformation is focused in sharp transverse structures, well separated by flat area, rapidly propagating on the surface without significant change in form. We call these new structures 'viscous solitary waves'. We report here first experimental description and model of this new instability.

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Simulation of extreme events and multistability with rare event algorithms applied to numerical atmospheric models

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A reliable quantification of the risk associated with extreme climatic events is crucial for policymakers, civil protection agencies and insurance companies. Studying extremes on a robust statistical basis with complex numerical climate models is however computationally challenging, since extreme events are rare, and thus very long and expensive simulations are necessary. This problem can be tackled using rare event algorithms. Rare event algorithms are numerical tools developed in the past decades in mathematics and statistical physics to reduce the computational effort required to sample rare events in dynamical systems. We will present rare events methods developed in the context of large deviation theory. We will show how it can be used to sample very efficiently extreme European heat waves in simulations with a comprehensive climate model and multistability of turbulent Jovian jets. Using these rare events methods rather than direct numerical simulations, we can accelerate the sampling of heat waves or change of the number of jets of the atmosphere of Jupiter by a factor of at least one thousand.
We can thus sample a very large number of trajectories leading to very rare events, which can be used to study their characteristic dynamics, and even observe ultra rare events that would have never been observed in a normal simulation. We will then discuss how these techniques can be applied to study a wide range of different processes with complex climate models.

Darcy-Benard-Bingham convection

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The Darcy-Benard problem is the porous medium analogue of the Rayleigh-Benard problem, and it consists of a uniform horizontal fluid-saturated porous layer which is heated from below. In the present paper we consider how this classical problem is altered when the porous medium is saturated by a Bingham fluid, rather than by a Newtonian fluid. Our basic model for the flow of a Bingham fluid in a porous medium that of Pascal which gives a piecewise linear relationship between the velocity and body forces such as the applied pressure gradient and buoyancy. It is characterised by having a range of values of the pressure gradient centred on zero within which there is no flow. It is assumed that the obvious isotropic extension of this Pascal model to two dimensions reflects the true dynamics of Bingham fluid flows in porous media. Computational convenience is gained by the adoption of a regularisation which softens the piecewise linear nature of Pascal's model.
First we show that the motionless basic state is linearly stable. Then, using the regularised Pascal model, we show that the critical Darcy-Rayleigh number increases without bound as the regularisation constant increases from zero (i.e. the equivalent of a Newtonian fluid) to infinity (i.e. Pascal model of a Bingham fluid). A weakly nonlinear analysis of the regularised Pascal model is undertaken and we find that there is a smooth transition from a supercritical bifurcation when the fluid is Newtonian to a subcritical bifurcation as the regularisation constant increases. Finally, fully nonlinear numerical simulations are presented. We find that fully nonlinear convection decreases in strength as the Darcy-Rayleigh number decreases, but that it extinguishes suddenly whilst well within a nonlinear regime as the solution curve passes a turning point. Thus nonlinear flow is governed at moderate values of the Darcy-Rayleigh number by a fold bifurcation into two solution branches, one stable and the other unstable.

Effect of surfactant concentration on wetting transition in an evaporative sessile droplet on a patterned surface

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Droplet wetting and drying on the patterned substrate surface has attracted more attention for the fundamental study and allocations in coating, printing, advanced manufacturing, etc. Further understanding the phenomena can help us to control the wetting and evaporation dynamics and particle deposition. We have designed the experiments for investigating the wetting and drying evolutions for the sessile droplets of the surfactant-water solution on a micro-patterned surface with the micropyramid islands. The distinct wetting transitions has been observed by varying the surfactant concentrations. They are also related to the drying history of the surfactant solution. The sessile droplet maintains an octagonal shape to the end of drying when the initial surfactant concentration is low. When the initial surfactant concentration is intermediate, the early formed octagon wetting shape develop into a square firstly and evolves to a stretched rectangle finally. When the initial surfactant concentration is higher, the droplet mainly exhibits the octagon-to-square transition on the patterned surface and the square shape is kept to the end of drying. It is found that the octagon-to-square transition occurs at a critical surfactant concentration. The surface energy change is analyzed to show the function of surfactant concentration on the droplet spreading over the micropyramid substrate surface. At high initial surfactant concentrations, the surfactant assemblies at the drying state are measure. The surfactant accumulates in the grooves between the neighbouring micropyramids near the contact line and forms the squire coffee ring. It enhances the pinning effect and leads to the suppressed the further square to rectangle transition.

Supercritical and subcritical bifurcations induced by viscous dissipation thermal instability in plane Poiseuille and plane Couette flows.

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Nonlinear stability analysis of plane Poiseuille flow (PPF) and plane Couette flow (PCF) when viscous dissipation is taken into account is performed. The impermeable lower boundary is considered adiabatic, while the impermeable upper boundary is isothermal. The linear stability analysis of thermal instability caused by viscous dissipation with no external thermal forcing was made by Barletta and Nield [J. Fluid Mech., 662, 475-492, (2010)] for PCF and by Barletta et al. [J. Fluid Mech., 681, 499-514, (2011)] for PPF. The onset of instability is described through the governing parameters $\Lambda=GePe^2$ and Pr, where Ge, Pe,and Pr are respectively the Gebhart number, the Péclet number and the Prandtl number. These authors found that longitudinal rolls are the preferred mode of convection. The current study focuses on the near-threshold behavior of longitudinal rolls by using a weakly nonlinear analysis. We determine numerically up to third order the coefficients of the Landau amplitude equation and investigate in detail the influences on bifurcation characteristics of the different nonlinearities present in the system. The results indicate that for both PPF and PCF (i) the inertial terms have no influence on the nonlinear evolution of the disturbance amplitude (ii) the nonlinear thermal advection term favors pitchfork supercritical bifurcations and (iii) the nonlinearities associated to viscous dissipation promote subcritical bifurcations. The global impact of the different nonlinear contributions indicate that independently of Ge the bifurcation is subcritical if $Pr<0.25$ ($Pr<0.77$) for PPF (PCF). Otherwise, for higher Pr there exists a particular value Ge^* of Gebhart number, such that the bifurcation is supercritical (subcritical) if $Ge<Ge^*$ ($Ge>Ge^*$). Finally, for both PPF and PCF, the amplitude analysis indicates that in the supercritical bifurcation regime, a substantial enhancement (reduction) in heat transfer rate is found for small Pr (moderate or large Pr).

Session: Flows driven by buoyancy and/or Marangoni effect

Stability of mixed convection flows under the effects of viscous dissipation

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The onset of thermal instabilities in mixed convection problems has been the subject of numerous investigations. Recently, it has been shown that viscous dissipation, often considered a negligible effect, can induce instabilities even without external forcing. In other words, differently from the classical Rayleigh-Bénard system where the vertical temperature gradient is a consequence of the prescribed boundary conditions, viscous dissipation is an internal heat generation mechanism which can also lead to unstable temperature gradients. In the present contribution, the effects of viscous dissipation on the convection onset for the so-called Poiseuille-Rayleigh-Bénard configuration is considered : in addition to the temperature gradient imposed in the external walls, thermal stratification is also a consequence of the volumetric heating induced by viscous dissipation. Results of the linear stability analysis suggest that the most unstable perturbations are in the form of stationary longitudinal rolls. Such instabilities are favored by the main flow rate, and for high values of the Prandtl number. A comparison with the pure hydrodynamic instability of the plane Poiseuille flow shows that, for highly viscous fluids, dissipation-induced instabilities may set in for lower values of the Reynolds number than the one needed for the onset of the pure hydrodynamic instability.

Shock Wave Structure in Isentropically Unstable Media

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Thermal instability significantly affects the dynamics of acoustic perturbations. Two competing processes of heating and cooling, depending on temperature and density of the medium, are considered. In a stationary case, the heating and cooling compensate each other. Any perturbation of the medium relative to the stationary state leads to the misbalance between heating and cooling causing the feedback between perturbations and heat release. The positive feedback results in thermal instability and leads to the growth of perturbations. This research is focused on the isentropic thermal instability which is responsible for the acoustic wave amplification and the formation of shock waves.

Previous studies considered the emerging structures using a nonlinear acoustic equation that describes perturbations up to the second order of smallness relative to the stationary state of the medium. Although this approach allows us to describe analytically observed shock wave structures and identify several characteristic types, it remains limited to weak shock waves.

The current study proposes a method for the analytical description of shock wave structures of any amplitude in a non-dissipative medium. It develops the Chapman-Jouguet model, used to describe shock waves during the detonation, for an isentropically unstable medium. The shock adiabat allows us to determine the magnitude of the discontinuity at the shock wave front. The equilibrium adiabat (a curve in P-V plane on which heating and cooling compensate each other) is used to determine a new stationary state of the medium behind the shock front. The velocity of the shock wave is determined using the Rayleigh line.

The proposed method can be used to determine the parameters of shock waves in the interstellar medium. The further development of the method for the magnetohydrodynamics will allow us to describe the parameters of shock wave structures in such a plasma medium as the solar corona.

Formation of droplets in laterally excited thin liquid films

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We investigate the dynamics of a two-dimensional liquid film bounded by a horizontal and planar substrate on the bottom side and its free surface on the other. The system is subjected to an external time-periodic excitation in lateral direction. A finite-differences method on staggered-grids for the full incompressible Navier-Stokes equations is presented. By applying the non-linear coordinate transformation $z = h(x,t)\cdot\check{z}$, which maps the free surface to a constant rectangular region, we avoid surface tracking and reduce the necessary interpolations. Taking the continuity equation into consideration, a sparse linear system for the pressure field can be obtained from the discretized Navier-Stokes equations. Its solution fulfills momentum as well as mass conservation obviating the need for pressure corrections.

Tangential forcings engender the formation of coarsening droplets. It is demonstrated that lateral excitations which break the horizontal mirror symmetry $x \rightarrow -x$, induce a non-vanishing mean flow causing a preferred direction of motion of the drops and hence accelerating their merging. These findings are in good agreement with those of a simplified model investigated in [1] and [2]. Our study also includes the case of the Rayleigh-Taylor configuration (film is on the underside of the substrate) allowing a comparison with the recently published work [3].

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Surface Undulations of Ultrathin Liquid Films Induced by Marangoni Flows

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The topography of thin volatile liquid films on planar solid substrates is investigated experimentally. The experiments are peformed with a unique setup. It combines a spin cast configuration (to form a micrometer thick film in the beginning of the experiments) with time-resolved, on-line, interference-enhanced optical reflection microscopy and image processing. Thus the film thinning and the film topography is investigated with nanometer resolution vertically, micrometer resolution laterally, and on time scales down to milliseconds. The films consist of mixtures of different liquid components, with different volatilities and different surface tensions. The individual liquid components wet the substrate surfaces completely. They form stable, planar, continuously thinning (due to the evaporation) films. With the mixtures however, it is observed that depending on the individual surface tensions, the evaporation properties, and the momentary film thicknesses, film surfaces may undulate and even rupture. It is proposed that Marangoni flows are the main cause of the film instabilities.

Stability analysis of weakly curved square duct flows

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Curvature in wall bounded flows enhances the formation of streamwise vortices through centrifugal instabilities, these structures are present for arbitrarily low curvatures in the case of duct flows. In this configuration, at relatively low curvatures, two stationary streamwise invariant vortices are observed. On the other hand, for high enough curvatures, the flow undergoes a Hopf bifurcation: two new vortices arise close to the outer wall, the flow becomes unsteady and eventually inhomogeneous in the streamwise direction. We study the flow in a bent square duct based on a weak curvature approximation, the equations are simple enough to be solved with a cartesian solver and involve one single control parameter. The model is validated by comparisons with existing literature results and is shown to be valid in the low curvature limit, capturing the steady two-vortices regime as well as the Hopf bifurcation. Streamwise-homogeneous, laminar flow solutions obtained for different values of the control parameter are used to perform a three-dimensional linear stability analysis. Moreover, non-linear simulations are realised in order to investigate the saturation in amplitude and the phase synchronization between streamwise modes, which is expected to be responsible of the turbulence localization (puff) at low Reynolds number regimes.

Dynamics and dissolution of bubbles in microchannels: role of transverse migration forces and Marangoni stresses

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This work focuses on the dynamics of a train of unconfined bubbles flowing in microchannels. We investigate the transverse position of a train of bubbles, its velocity and the associated pressure drop when flowing in a microchannel depending on the internal forces due to viscosity, inertia and capillarity. Despite the small scales of the system, the inertial migration force plays a crucial role in determining the transverse equilibrium position of the bubbles. Beside inertia and viscosity, other effects may also affect the transverse migration of bubbles such as the Marangoni surface stresses in presence of soluble surfactants, as well as the surface deformability for sufficiently large capillary number. The resulting migration force may balance external body forces if present such as buoyancy, centrifugal or magnetic ones. This balance not only determines the transverse position of the bubbles but, consequently, the surrounding flow structure, which can be determinant for any mass transfer process involved, as it will be demonstrated for bubble dissolution. Extension to droplet dynamics will finally be discussed, together with the presentation of a new micro-droplet generator.

A revised model for the effect of thermophoresis on the onset of convection in a horizontal nanofluid layer

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Natural convention of nanofluid has received much attention in the past decade due to its important application in electronic cooling devices. In order to discuss the heat transfer characteristics of nanofluids, a theoretical model for convective transport in nanofluids has been widely used in the literature in which the effects of Brownian diffusion and thermophoresis are taken into consideration. Numerous studies have employed such a model to analyze the onset of thermal instability (the Rayleigh-B'enard convection) in a horizontal nanofluid layer. However, this model still exists a problem due to an inappropriate assumption for the effect of thermophoretic diffusion in the simplification of conservation equations. The thermophoretic diffusion coefficient was always assumed to be a constant in the derivation of basic state solution. As a result, a linear profile of nanoparticle volume fraction across the fluid layer was obtained. However, such an assumption makes the thermophoresis invariably be a dominant factor even though the nanoparticle volume fraction is quite small, which is obviously incorrect since the thermophoretic diffusion coefficient actually depends on the magnitude of nanoparticle volume fraction. Because the instability behaviors depend heavily on the base state, it is important to obtain the correct base state and then the flow instability characteristics can be explored exactly. In the present study we propose a revised model for the effect of thermophoresis to obtain a proper base solution of nanoparticle volume fraction. A linear stability analysis is performed accordingly for the onset of convection in a horizontal nanofluid layer. The results provide a complete understanding for the instability behaviors of nanofluid in the Rayleigh-B'enard convection system.

Rheologcial Effect on the Onset of Thermal Instability in a Horozontal Nanofluid Layer

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As shown in the literature of experiments on the rheological characteristics of nanofluids, the viscosity is significantlly influenced by the concentration of nanoparticles. However, in the past studies of thermal stability analysis, the viscosity was almost assumed to be a constant , which may induce a certain of error since the nonhomogenity of concentration before the onset of instability may be large due to the effect of thermophretic motion. In fact, our recent study found that the nanoparticles before the onset may concentrate on the cooler side, distributing in a form of exponetial fuction of NA (where NA is a dimensionless parameter denoting the competation between the thermophoretic and Brownian diffusion motion of nanoparticles). This implies that as the thermophretic motion becomes more dominant, the viscosity near the cooler side may be much larger than the hot side, which obviously provides an additional stabilizing mechanism to overcome the destabilizing forces. This paper tries to take a viscousity model into account so as to show that the viscous correction is necessary in the thermal instability analysis.

Supersonic Flow Unsteadiness in Spiked Body Configurations

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The flow around a spike mounted blunt body moving at supersonic speed is investigated. The major advantage of mounting a spike is its ability to change the flow physics and thereby reducing the forebody drag. Along with the reduction of drag, the mounting of a spike generates flow unsteadiness. Three configurations are examined: flat, hemispherical and elliptical blunt bodies. Our aim is to distinguish between the mechanisms behind the unsteadiness associated which each one of the three configurations. First, the drag reduction achieved by the adopted test models are studied. It is found that the elliptical spiked body configuration generates the minimum forebody drag. Then the shock-related unsteadiness is addressed. For the case of a flat-face spiked body configuration, the violent pulsation mode of unsteadiness was found to be generating as reported by past studies. It is characterized by a periodic back and forth movement of the shock from the tip of the spike to the shoulder of the blunt body. While replacing the forebody geometry to a hemisphere, the strong detached bow shock wave, positioned ahead of the clean (without a spike) blunt body, is replaced with a system of weaker oblique shocks. The flow then separates, and a shear layer is formed between the point of separation and the hemisphere shoulder where the flow reattaches. Consequently, a shock related unsteadiness is observed to be induced due to the shear-layer instabilities (K-H type). Here a rise in the spectral density is observed at a wide range of frequencies. On performing similar tests on an elliptical spiked body configuration, the flow unsteadiness was found to be like that of a spiked hemisphere. However, the intensity of the unsteadiness was reduced. The time-resolved instantaneous shadowgraph images showed a reduction in the size of the large-scale turbulent structures compared to the case of spiked hemisphere.

Interfacial phenomena in vibrated immiscible liquids in microgravity

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A wide variety of interfacial phenomena can occur in vibrated fluid systems, depending on frequency, amplitude and forcing orientation. On earth, interfaces of moderate or large size are approximately flat and there is a qualitative difference between vertical and horizontal vibrations. In space, the absence of gravity means that flat density contours are no longer favored and curved interfaces replace them, which blurs the afore-mentioned distinction. Nonetheless, fluid behavior in microgravity can often be understood as a combination of typical phenomena observed on ground-based experiments and their interaction.

We consider the response to periodic forcing between 5 Hz and 50 Hz of an interface separating immiscible fluids under the microgravity conditions of a parabolic flight. Two pairs of liquids with viscosity ratios differing by one order of magnitude are investigated. By combining experiments with simulations, we describe a variety of dynamics including Faraday waves, which are typical of vertical forcing, harmonic and frozen waves, typical of horizontal forcing, and drop ejection. The effects of key parameters controlling pattern selection are analyzed, including vibrational forcing amplitude, viscosity ratio, finite-size effects, and residual gravity. Complex behavior, highlighted by the appearance of Faraday waves on the interface of a large columnar frozen wave structure, is observed. This type of solution was previously seen in miscible fluid experiments but is described for the first time here in the immiscible case. Complexity is expected due to the interaction of phenomena with different temporal and spatial scales.

Dynamics of polymer droplets post impact on hydrophobic surfaces

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Non-Newtonian droplet dynamics on (super) hydrophobic surfaces have garnered attention since the turn of this century. Bergeron et al [1] reported that droplet rebound can be suppressed by adding minute amount of polymers to the base fluid, thereby revealing a huge potential for reducing wastage of pesticides in agriculture. Subsequently, role of extensional viscosity, and normal stress or stretching of polymer chains near the contact line during droplet retraction were proposed as responsible factors for this suppression [1-3].

The present work aims to find out the threshold concentration for polymer droplet rebound suppression on superhydrophobic surfaces. Impact velocity and polymer (Polyacrylamide, PAAM) concentration were varied to study the influence of impact Weber number and Weissenberg number on the droplet dynamics. We believe that the magnitude of the Weissenberg number is the driving parameter responsible for rebound suppression and subsequent dynamics. In addition, thin filament formation , necking dynamics and temporal evolution of the drops during retraction will be presented.

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LINEAR FEEDBACK CONTROL OF MARANGONI CONVECTION IN A THIN FILM HEATED FROM BELOW

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We use the linear proportional control for the suppression of Marangoni instability in a thin film heated from below. Our keen interest is focused on the oscillatory mode that was recently revealed in the case of the thermally insulated substrate.

To stabilize the no-motion state of the film we apply two feedback control strategies. The principle of both control strategies is that we feed the information about instability back into the dynamics by changing the heat flux through the substrate that can affect the instability. The first strategy uses the interfacial deflection from the mean position as the criterion of instability onset. Within the second strategy the variable that describes the instability is the deviation of measured fluid temperature from desired, conductive values. We implement the second control strategy in two versions, according to which the fluid temperature is measured either in the middle of the layer or at the deformable free surface.

The present paper is devoted to finding the most effective control strategy to delay the onset of instability. We perform two types of calculations. The first one is linear stability analysis that is carried out within the Bénard-Marangoni problem for all wavelengths. The comparison of different control techniques shows that the control of the temperature deviation at the deformable free surface stabilizes the thin film heated from below most effectively.

The second type of calculations is analysis of the nonlinear amplitude equations that is derived using the lubrication approximation. The linear analysis of the amplitude equations is in a good agreement with the results for finite wavelengths. The weakly nonlinear analysis of the amplitude equations confirms the suppression of instability.

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Quasistationary states of a nonaxisymmetric cylindrical solid under translational vibrations in liquid

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The behavior of a solid in the form of elliptical cylinder in a horizontal rectangular container filled a viscous incompressible liquid under longitudinal translational vibrations is experimentally investigated. Experiments are performed with the solid, which density is greater than the density of the liquid. The various quasistationary states of the solid are found and investigated.

In the absence of vibrations, the solid is stable at the bottom of the cavity vibrations in the gravity field. At fixed amplitude of vibrations, the increase of frequency results in the turn of the solid long axis perpendicular to the axis of vibrations; the solid oscillates near the bottom of the cavity. With further increase of frequency the elliptical cylinder turns around in a threshold manner and gets a new quasistationary state at which the long axis is perpendicular to the cavity bottom. The orienting effect of vibrations is associated with the appearance of an averaged moment of force acting on the oscillating nonaxisymmetric solid in liquid. The further intensification of the vibrations leads to a loss of stability of the equilibrium position of the elliptical cylinder at the bottom of the cavity. The solid is repulsed from the bottom of the cavity in a threshold manner; the solid occupies a new equilibrium position at definite distance from the bottom. The return of the solid to the bottom, as well as its reverse turn, occurs in a threshold manner at decrease of frequency of vibrations. The experiments are carried out in a wide range of fluid viscosities, amplitudes and frequencies of vibrations, relative sizes and densities of solids. The governing dimensionless parameters of the problem are determined.

The obtained results can find application in the technological processes connected with the control over the solid inclusions in liquids.

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Control of hydro-thermal instabilities by a gas stream

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The investigation of the Rayleigh–Bénard and Rayleigh–Marangoni convections played a crucial role in the development of the nonlinear stability theory of fluids in planar geometry. Later, significant progress was made in understanding the nonlinear regimes of buoyant-thermocapillary convection in cylindrical columns. The latter problem can be considered as a paradigmatic example of nonlinear dynamics in essentially nonparallel flows. The mechanisms of instability have universal character, making it of great interest, far beyond its applications to engineering.

Consider a drop of liquid suspended between two flat concentric disks maintained at different temperatures. The dependence of the surface tension on temperature gives rise to thermocapillary Marangoni stresses acting along the free surface. If the temperature difference is small, the flow is a steady toroidal vortex – but if it exceeds a certain threshold, it triggers off an instability which may give rise to a number of time-dependent three-dimensional flow regimes by way of Hopf bifurcations. In particular, it may generate standing or traveling hydro-thermal waves or lead to chaos.

The ambient air flow, however, can significantly affect the flow dynamics: varying the gas temperature and/or velocity and/or its properties, one can choose one of a variety of dynamical regimes in the same experimental setup.

Session: Geophysical flows

Transient Ekman currents in models with time and depth dependent eddy viscosity

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The work examines response of the upper ocean to time-varying winds within the Ekman paradigm. Here, in contrast to all other works based upon the Ekman model and its extensions, we assume the eddy viscosity to be both time and depth dependent. For powerlaw depth dependence of eddy viscosity and arbitrary time dependence of wind we find exact general solution to the Navier-Stokes equations which describes dynamics of the Ekman boundary layer in terms of the Green's function. We show that accounting for time dependence of eddy viscosity is straightforward and that it substantially changes the response, compared to the predictions of the models with constant in time viscosity. We also examine the Stokes-Ekman equations which take into account the Stokes drift created by an arbitrary spectrum of surface waves and derive general solution for power law depth dependence of eddy viscosity and arbitrary time dependencies of wind and wave spectrum.

We also report a major limitation of the Ekman type models employed in modelling of the oceanic surface boundary layer. The Ekman current caused by a growing wind quickly becomes unstable with respect to inflectional instability, which breaks down the assumed horizontal uniformity (the characteristic spatial scales of instabilities are of the order of hundred meters). These instabilities of transient Ekman currents are fast and localised neras the surface, which suggests vertically localized spikes of dramatically enhanced mixing in the uppermost part of the water column. This picture is incompatible with the existing paradigm and suggests a need of its radical revision.

ID: **258**

Session: Shear flows, boundary layers, and related problems

Collapse in weakly stratified boundary layers

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High Reynolds number boundary layers are ubiquitous in nature and engineering context. Here we consider nonlinear evolution of the vorticity mode in the boundary layers(with and without weak density stratification). For simplicity the fluid is considered to be semi-infinite with either the "no-flux" or "no-slip" boundary condition.

We present a rigorous asymptotic derivation of a novel nonlinear evolution equation for the vorticity mode assuming the perturbations to be long compared to the characteristic thickness of the boundary layer; nonlinearity, dispersion and viscous effects enter the equation in the same order. The equation is an essentially two-dimensional generalisation of the Benjamin-Ono equation, We show that for a wide class of initial conditions the perturbations exceeding certain threshold blow up, i.e. the perturbation amlitude becomes infinite in finite time, while its width shrinks to zero. The weak density stratification in the bounday layer and the viscous effects were shown not to prevent the collapse from happening: these effects merely raise the collapse threshold.

Session: Stability of flows in porous media

Miscible-reactive viscous fingering in a porous medium

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The viscous fingering appears spontaneously when a fluid with a viscosity displaces another more viscous and hence less mobile one in a porous medium. For instance, the interface deforms into “fingers” when water displaces more viscous oil in underground reservoirs or when air *displaces more viscous glycerine*. This instability is detrimental to petroleum recovery as it increases mixing between the two fluids. It is, therefore, of interest to control such fingering instabilities.

In this presentation, we analyze the effect of chemical reaction on viscous fingering numerically in the case when chemical species lowers the viscosity of the system to define the optimal conditions on the chemical and hydrodynamic parameters for controlling fingering. The problem is modeled using basic fluid mechanics equations along with three reaction-diffusion-convection equations for the reactants and the product. The resulting problem is then solved using the Fourier spectral collocation method. The present simulation results show that depending on the parameters chemical reactions can enhance or suppress instabilities. We further analyze the dispersion curves obtained through the linear stability analysis at an initial time using an analytical solution and at a later time using the finite difference method. Both studies, simulations and linear stability analysis, predict that the flow speed, chemical reaction, and viscosity ratios are the main controlling parameters for the fingering instability.

The minimal seed for wall-bounded transition in the frequency domain

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In a linear frequency-domain framework, the most amplified instabilities are typically described by considering singular vectors of the resolvent operator of the linearized Navier-Stokes equations. In this study, we extend the methodology to take into account nonlinear triadic interactions by considering a finite number of harmonics in the frequency domain using a Harmonic Balance Method. To solve these equations, we use a global approach considering the full Jacobian of the problem. We demonstrate the framework on a zero-pressure flat-plate boundary layer by considering three-dimensional spanwise-periodic perturbations triggered by a few optimal forcing modes of finite amplitude. Optimal nonlinear forcing mechanics that lead to transition and maximize the skin-friction coefficient are identified using direct-adjoint looping. Two cases are considered, corresponding to fundamental and subharmonic forcing. The proposed frequency-domain framework identifies in a computationally efficient and accurate manner worst-case disturbances for wall-bounded transition.
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Influences of transversely isotropic rheology and translational diffusion on the stability of active suspensions

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Suspensions of self-motile, elongated particles are a topic of significant current interest, exemplifying a form of ‘active matter’. Examples include self-propelling bacteria, algae and sperm, and artificial swimmers. Ericksen's model of a transversely isotropic fluid (Ericksen 1960 *Colloid Polym. Sci.*173, 117–122 (doi:10.1007/bf01502416)) treats suspensions of non-motile particles as a continuum with an evolving preferred direction; this model describes fibrous materials as diverse as extracellular matrix, textile tufts and plant cell walls. Director-dependent effects are incorporated through a modified stress tensor with four viscosity-like parameters. By making fundamental connections with recent models for active suspensions, we propose a modification to Ericksen's model, mainly the inclusion of self-motility; this can be considered the simplest description of an oriented suspension including transversely isotropic effects. Motivated by the fact that transversely isotropic fluids exhibit modified flow stability, we conduct a linear stability analysis of two distinct cases, aligned and isotropic suspensions of elongated active particles. Novel aspects include the anisotropic rheology and translational diffusion. In general, anisotropic effects increase the instability of small perturbations, while translational diffusion stabilizes a range of wave-directions and, in some cases, a finite range of wavenumbers, thus emphasizing that both anisotropy and translational diffusion can have important effects in these systems.

Instability of 3D natural convection flow around cold and hot vertically aligned cylinders

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Investigation of three-dimensional instability of natural convection flow around a tandem of vertically aligned cold and hot cylinders enclosed by a cold cube is presented. The hot and cold cylinders aligned along the cavity vertical centerline are shifted downwards and upwards relative to the cavity center, respectively. The temperature gradient created by the cylinders results in development of oppositely directed hot and cold thermal plumes. The plumes meet and interact close to the cavity horizontal center-plane.

The numerical simulations were conducted by performing time integration of slightly perturbed flows. It was found that the flow undergoes transition to unsteadiness via either reflectional symmetry breaking or preserving Hopf bifurcation as a function of the distance between the cylinders; , and . The instability analysis is performed in terms of quantitative estimation of the values of the major oscillating harmonics, and qualitative investigation of the spatial structure of isosurfaces of the oscillating amplitudes and investigation of global reflectional symmetries of mean and bifurcated flows. It was found that the distance between the cylinders plays an important role in determining characteristics of the instability mechanisms governing the oscillatory flow.

The study demonstrates various scenarios typical of the investigated configuration and can be useful for validation of the corresponding experimental setups and for verification of future numerical results.

Ratchet flows in thin liquid films driven by two-frequency vibration

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In our recent paper [Sterman-Cohen, Bestehorn and Oron, Phys. Fluids (2018)], we studied the emergence of ratchet flows in isothermal thin liquid films deposited on the underside of a horizontal solid substrate and subjected to tangential two-frequency forcing consisting of the basic frequency and its double. It was found there that the driving mechanism for these flows is an asymmetry in forcing and consequently in the substrate displacement. We also showed there that the liquid flow rate along the substrate averaged over both spatial and forcing periods tends to a constant in the long-time limit.

We consider here several other types of two-frequency excitation of 2D thin liquid films deposited on the underside of a horizontal solid substrate when some of them are asymmetric as previously, whereas others are symmetric with respect to certain instant within the forcing period. Via numerical study of the set of longwave nonlinear evolution equations approximating the Navier-Stokes equations we find that ratchet flows emerge also under symmetric forcing.

The mechanism leading to the emergence of ratchet flows under symmetric forcing represents a combination of capillary and hydrostatic effects together with the asymmetry of the interfacial profile during longer nearly-static transients in one direction and shorter ones in the other direction.

It is also found that for moderate values of forcing amplitude, symmetric forcing renders the emerging ratchet flow to be pulsating unlike the asymmetric forcing resulting in a constant flow intensity in the large time limit. Larger forcing amplitudes may result in film rupture, whereas lower ones may cause to converge to the constant flow-rate ratchet flows after very long time transient. Ratchet flows emerge also in the case of stabilizing gravity under symmetric forcing, and the flow rate of the ratchet flow in the case of stabilizing gravity is lower than in the Rayleigh-Taylor unstable setting.

Linear stability analysis of high-Prandtl-number liquid bridges exposed to a co-axial gas flow

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The stability of thermocapillary flow in a liquid bridge between two solid rods kept at different temperatures under microgravity conditions is investigated numerically. The flow is primarily driven by thermocapillary stresses caused by temperature variations of the liquid gas interface and the thermocapillary effect. The overwhelming majority of previous investigations have simplified the problem by considering only the liquid phase, neglecting viscous stresses from the gas phase and assuming Newton's cooling law with a suitable reference temperature in the ambient atmosphere. Among the parameters governing the problem, the heat transfer between the liquid bridge and the ambient gas is the least understood. Therefore, we treat the full two-phase problem in which the liquid bridge is placed in a concentric cylinder and exposed to a nominally axial flow field. No restrictive assumptions about the boundary conditions at the interface are made and the balance of normal and shear stresses as well as heat transfer between the two phases are taken into account. The computational model allows the liquid-gas interface to be dynamically deformable, meaning that the exact shape of the interface is a part of the solution. Since the problem involves many non-dimensional parameters, we consider a liquid bridge of 5cSt silicone oil (Pr=68) and focus on the effect of the ambient gas on the onset of three-dimensional flow. Using a linear stability analysis, neutral thermocapillary Reynolds numbers are computed as functions of mean gas flow velocities and temperatures for several height-to-radius aspect ratios which are of interest for a planned space experiment.

Effect of the differential rotation on the stability of steady flow excited by oscillating core in a rotating spherical cavity

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The stability of steady flows excited by circular oscillations of a spherical core in a rotating spherical cavity with a fluid is studied. The core with density less than the fluid density is located near the cavity center and is acted upon by a centrifugal force. The gravity field directed perpendicular to the rotation axis leads to a stationary displacement of the core from the rotation axis. As a result, in the reference frame attached to the cavity, the core performs circular oscillation with frequency equal to the rotation frequency. We perform experiments with a free inner core and with the same core fixed on a fishing line. The latter excludes the differential rotation of the core and gives a possibility to investigate the pure contribution of the core oscillations into the resulting steady flow. We found that in spite of a great difference, the steady flows in all cases have the form of a system of nested fluid columns of circular cross section, which rotate at different angular velocities. With an increase in the amplitude of core oscillations, the axisymmetric flow experiences a series of shear instabilities. First, two-dimensional vortices appear near the rotation axis. After it, the Rossby wave appears, which manifests itself in the deformation of the tangent cylinder and has a retrograde phase velocity. The next type of instability is a regular system of 2D rolls, which manifests itself outside the tangent cylinder and propagates in the prograde direction. Experiments show that the presence of differential rotation of the core modifies the azimuthal velocity profile, resulting in different thresholds of instabilities in both cases. The difference is explained by the action of two independent mechanisms of flow generation (due to the differential rotation of the core in the Ekman layer and due to the oscillation of the core in the oscillating boundary layers).

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Steady flows excited by inertial modes in a liquid filled rotating cylinder

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The work is devoted to the experimental investigation of steady flows generated by oscillatory motion of the fluid in a non-uniformly rotating (librating) cylinder. Librations lead to the propagation of inertial waves, which are born near the junction of the side and end walls of the cavity. At some frequencies corresponding to one of the natural frequencies of the rotating fluid the inertial waves experience a spatial resonance, exciting so-called inertial modes. The latter are a system of vortices in which the direction of rotation of the fluid varies during the period of librations. It is found that the oscillatory motion in the fluid bulk leads to the appearance of intense steady flow in the Stokes boundary layer close to the side wall of the cylinder. The flow structure has the form of a system of averaged toroidal vortices located along the entire cavity wall. The number of vortices is determined by the axial wave number of the excited mode and does not depend on the radial wave number. It is shown that the intensity of the steady flow is proportional to the square of the libration amplitude. With a change in the librations frequency, the velocity of the steady flow changes nonmonotonically, experiencing a series of extrema corresponding to the resonant excitation of the inertial mode.

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Inertial range skewness of the longitudinal velocity derivative in locally isotropic turbulence

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Longitudinal velocity-derivative skewness is directly proportional to the rate of enstrophy generation, and hence is a key parameter for characterizing small-scale turbulence. In addition, the skewness is used for qualitative assurance of turbulence measurements, for example, level of noise and unsteadiness. Obtaining of skewness requires accurate measurements at the finest scales in the dissipation subrange, which is an onerous task. We define a derivative skewness of the inertial range scales that is readily accessible experimentally, and derive its value analytically. The results depend on the filtering procedure of small scales. Analytically derived inertial range skewness is compared with those computed by high resolution numerical simulations and obtained in laboratory experiments and in the MATERHORN field campaign. The computed and measured values were very close to the theoretical prediction.

An alternative definition of the derivative skewness in the full and the inertial range scales is examined to identify the effects of intermittency.

Real turbulent flows are often affected by external body forces such as buoyancy and Coriolis forces that act differently on different scales. The derivative skewness of the filtered velocity field with moving filtration cut-off may shed light on modification of spectral energy transport and vorticity dynamics by external forces.

Subcritical transition of plane Poiseuille flow as (2+1)d and (1+1)d DP universality classes

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Wall-bounded shear flows may maintain turbulence at Reynolds numbers below the critical value Re_c determined by linear stability theory. For instance, the plane Poiseuille flow even below $Re_c = 5772$ exhibits an intermittent turbulent structure called “turbulent stripe”, in which localized laminar and turbulent regions are alternately arranged regularly. At Re < 840, very isolated patches of turbulence, called a turbulent band, can be still observed. This subcritical transition phenomenon may be considered as a phase transition with a continuous change from turbulent to laminar flow. A recent large-scale channel experiment demonstrated the transitional flow as a (2+1)d directed-percolation universality class as an absorption state transition. However, since the turbulent band expands spatially and has a long life property, it is difficult for experiments to capture non-transient properties sufficiently. Therefore, a phenomenon as a universality class has not been yet elucidated. In this study, very large computational domains were used in our direct numerical simulation to analyze the plane Poiseuille flow. The temporal change of the turbulent fraction, and the spatial distribution of the localized turbulence were investigated through adiabatic decreasing in the Reynolds number from the fully-turbulence state. Scaling indices were evaluated for those statistics and compared with the reference values (α, β, $\mu_{||}$) of DP models to extract characteristics as the DP universality class. We found two regimes that exhibit scaling indices similar to different DP universality classes. One of them is found in the $1000 \lesssim Re \lesssim 1200$ and the scaling indices (α, β, $\mu_{||}$) revealed the features of the (2+1)d DP, while the other is in the $Re \lesssim 900$ with the scaling indices (α, $\mu_{||}$) of the (1+1)d DP. At intermediate Reynolds numbers between those regimes, combination and gradual change of the stripe and band structures were confirmed.

Self-sustained unsteadiness in over-expanded nozzles: a modal approach

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Shock wave-boundary layer interactions occurring in over-expanded rocket nozzles during start-up and shut-down are responsible for the so-called side-loads. Inside the divergent portion of the nozzle, the flow is strongly separated with a series of Mach disks. Such side loads appear to be driven by low-frequency self-sustained dynamics characterized by a non-axisymmetrical behavior. As part of ATAC research program driven by CNES, the intent of this work is to perform a fully three-dimensional linear stability analysis to investigate the potentially globally unstable nature of this mode.

Phoenix --an in-house code-- is used to solve both the linearized and the fully compressible URANS equations on multi-block structured grids with a parallel finite-volume approach. A time-stepper technique, integrated into the solver, allows computing both equilibrium states and leading eigenmodes, the latter by an Arnoldi algorithm.

The geometry considered is a truncated ideal contour nozzle with NPR equal to 9 (corresponding to a jet Mach number of 2.09). This ratio is the one for which the unsteadiness is the strongest, according to the experimental data.

The steady solution is computed by means of a selective frequency method (SFD) applied to the nonlinear solver. Global linear stability analysis is carried out about this steady solution and provides a non-axisymmetric unstable mode (m=1) at St=0.12, referring to the throat radius and total velocity of sound. Frequency and symmetry are in accordance with the experiments. The physical study of this mode shows some analogies with the screech phenomenon.

Session: Active fluids

Bacterial magneto-convection

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Magnetotactic bacteria are motile micro-organisms that synthesise nano-magnets. The presence of these magnets enables them to be directed by an external magnetic field which aligns their swimming direction. We use microfluidics experiments to show that an initial uniform distribution of bacteria under confinement is made unstable by the application of a magnetic field perpendicular to the channel walls. Dense suspensions of magnetotactic bacteria (magnetotacticum magneticum AMB1) are driven in glass micro-channels toward a channel wall by a magnetic field. The initial random spacing of the bacteria becomes unstable resulting in bacterial magneto-convection: bacterial plumes perpendicular to the wall emerge spontaneously and develop into self-sustained convection cells akin to Rayleigh-Benard convection. The plumes grow and merge and their dynamics is studied experimentally. Using a numerical model based on hydrodynamic singularities, we are able to capture quantitatively the instability observed in the cell suspension and its long-time clustering dynamics.

Stability of the Rotating-Disk Boundary Layer: Roughness Effects and Beyond

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Results of our computations [1-3] investigating the effects of surface roughness on the stability of the boundary-layer flow over a rotating disk will be summarized. The results reveal stabilising, that is energetically beneficial, effects on the dominant instability mode responsible for transition over rotating disks. This result is qualitatively consistent with the measurements in Ref. [4] which show drag reduction of up to 15% for disks with roughness patterns similar to those studied computationally in Refs. [1-2]. The agreement suggests that, in the long-term, our computational methods may enable the design of energetically optimized surface roughness for laminar-flow control in the applied context of new drag-reduction techniques in, for instance, aeronautics. Our results [1-3] for rough disks will be briefly compared to corresponding computational data by other authors who studied transition over rotating speed-modulated disks, rotating disks with compliant surfaces and rigid disks spinning in non-Newtonian liquids. The goal of this comparison is to highlight some qualitative similarities of the results for all these different scenarios.

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Jet instability in a rotating fluid

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PIV measurements are discussed investigating the dynamics of a turbulent jet developing subject to Coriolis effects induced in a rotating fluid. The research was conducted on Warwick's large-scale rotating turntable facility and it appears to be the first PIV study of jets in a rotating fluid. The measurements reveal how Coriolis effects substantially alter the flow dynamics of the jet in comparison to its non-rotating counterpart. In particular, the measurements confirm the existence of a time-periodic formation-breakdown cycle of the jet that was computationally predicted in Ref. [1]. The data analysis shows that the frequency of the formation-breakdown cycle increases linearly with the background rotation rate. The onset of the breakdown phase and of the reformation phase of the cycle can be characterized in terms of a local Rossby number employing an internal velocity and associated length scale of the jet. The critical values for this local Rossby number, for onset of breakdown and reformation, scale linearly with a global Rossby number based on the flow conditions at the source. The analysis of the experimental data suggests centrifugal instability as the potential origin of the formation-breakdown cycle.

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Feedback Control of Falling Liquid Films

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We discuss control of the instabilities of a falling liquid film, with the goal of either stabilising a uniform film or driving the system towards a known travelling wave solution or stationary state. Active feedback control, where inputs to the system are chosen in real time based on observations, is a highly potent tool to manipulate the dynamics and stability of the system. The choice of feedback control strategy requires some knowledge of the underlying dynamics, and we focus particularly on whether control strategies developed based on analysis of simplified long-wave models remain effective when used in more complicated systems. Working in two spatial dimensions, we use a variety of long-wave models and Navier-Stokes simulations to explore feedback strategies when the control is actuated via same-fluid blowing and suction through the wall supporting the flow, or through selective localised heating. These mechanisms affect the dynamics in qualitatively different ways, and behave quite differently when considering robustness to model choice.

Electrified thin liquid films

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We utilise electric fields to control the interface dynamics of thin liquid films on inclined flat substrates. For perfectly conducting films subject to an electric field in the direction normal to the substrate, we derive a multidimensional Kuramoto-Sivashinsky equation governing the weakly nonlinear interfacial dynamics. The electric field term is radially symmetric, nonlocal, and linearly destabilising with growth rates proportional to the cube of the wavenumber. For sufficiently large field strengths, the linear dynamics predicts rivulet formation analagous to the Rayleigh--Taylor instability. Below these field strengths, we observe a regime of rich pattern-forming dynamics. Electric fields may be used to destabilise thin films below the critical Reynolds number; the resulting dynamics are strongly multidimensional and qualitatively different from those due to inertial instabilities alone.

For perfect dielectric films on the underside of an inclined substrate, electric fields parallel to the flow direction may be used to stabilise the interface. With a range of low-dimensional models, we provide evidence that increasing field strengths may transition an absolutely unstable system to a convectively unstable one. We perform DNS of the problem with boundary conditions mimicing and experimental set-up. We validate the absolute/convective instability predictions of the low-dimensional models, and additionally show that the critical field strength for which the flow becomes convectively unstable is a good approximation for the field strength required to prevent dripping.

Phoretic and hydrodynamic interactions in dilute phoretic suspensions

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Janus phoretic colloids have recently attracted much attention as a canonical example of synthetic active fluids. In such fluids, individual agents self-propel at the microscopic scale in a viscous fluid and can interact leading to spontaneous nontrivial dynamics within suspensions on length scales much larger than the individual swimmer size, thereby profoundly altering the macroscopic flow properties. Such self-driven microswimmers propel themselves by converting chemical energy into mechanical work using their ability to catalyse a chemical reaction (activity) and to drive a slip flow at their boundary in the presence of a chemical gradient (mobility). By doing so, they generate stresses at the microscale and they modify the chemical concentration field, allowing for chemical and hydrodynamic interaction routes between individual colloids. In this work, we use a kinetic model to investigate the competition and interaction between the hydrodynamic and chemical couplings; these are fundamentally determined by the mobility and activity properties on the surface of the particle, which are design parameters that can be controlled and optimized. Using a combination of linear stability analysis and nonlinear numerical simulation, we will discuss the role of such design parameters in determining the onset of instabilities and subsequent nonlinear collective dynamics in dilute suspensions of chemically-active Janus swimmers.

Session: Multiphase and non-Newtonian flows

Two-phase wavy flow between two inclined plates analyzed using the Navier-Stokes equations

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The paper is devoted to a theoretical analysis of a co-current and counter-current gas-liquid flow between two inclined plates. We solved the Navier-Stokes equations for both phases and carried out a linear and nonlinear stability analysis of the basic steady-state solution over a wide variation of the liquid Reynolds number and the gas superficial velocity. As a result of the linear analysis, we found two unstable modes of the disturbances and computed the wavelength and phase velocity of their neutral disturbances varying the liquid and gas Reynolds number. The first mode is a "surface mode" that corresponds to the Kapitza's waves at small values of the gas superficial velocity. We found that the dependence of the neutral disturbance wavelength on the liquid Reynolds number strongly depends on the gas superficial velocity, the distance between the plates and the channel inclination angle for this mode. The second mode of the unstable disturbances corresponds to the transition to a turbulent flow in the gas phase and there is a critical value of the gas Reynolds number for this mode. We obtained that this critical Reynolds number weakly depends on both the channel inclination angle, the distance between the plates and the liquid flow parameters for the conditions considered in the paper. As a result of the nonlinear stability analysis, we found various steady-state traveling waves branching over the neutral curve of the "surface" mode and computed their characteristics at different values of distance between the plates, the channel inclination angle, the liquid and gas Reynolds number. Motivation for our study is the understanding of the flooding phenomenon and the droplets formation in an inclined channel where these independent parameters correspond to the experimental studies. We use the strict mathematical equations without any additional assumptions and this is a main new feature of the investigations.

Isotropic-anisotropic transition in diffusive transport of field-guided magnetohydrodynamic turbulence

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We consider single-particle diffusion in three-dimensional incompressible magnetohydrodynamic (MHD) turbulence in the presence of a background magnetic field. By tracking the trajectories of a large number of tracer particles in the flow, we find that as the background field increases, diffusion becomes anisotropic with larger diffusivity in the field-parallel direction. Moreover, the scaling of the Lagrangian velocity decorrelation time with the root-mean-square velocity shifts from -1 to -2 as anisotropy develops. These two transitions can be understood as a consequence of the coexistence of Alfven waves and small-scale turbulence in the system. This is different from, and arguably more physically relevant than, previous studies in MHD turbulence where the systems are designed to be dominated by either small-scale turbulence or a sea of weakly nonlinear interacting waves. In our setup, waves induce memory into the system while the coexisting small-scale turbulence attempts to remove it. The observed transition is a result of the competition between the two effects. We determine the critical background field strength at which the transition occurs.

Basic flows driven by thermal Marangoni effect in rectangular liquid film

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In special environments such as microgravity or microchannel, there is a demand for sophistication of fluid and/or particle transport technique using surface tension. A number of researches on thermocapillary convection have been carried out on liquid columns relevant to a system of high-quality single crystal formation by the floating zone method and on one-free-surface liquid films like a system in crucibles. As for a thin liquid film with two free surfaces, a demonstration at the International Space Station, done by Dr. Donald Pettit (2003), exhibited a unique behavior in which the bulk fluid was pulled to the hot side. Later, ground experiments and numerical simulations have been performed on the flow pattern formation caused by the thermal Marangoni effect. In our continuing study, the numerical analysis of the basic flow generated by the thermal Marangoni effect was carried out in rectangular-type liquid films with both front and back surfaces of the free interface. The static and dynamic interface deformations were considered in the simulation of the gas-liquid two-phase flow by the Volume-of-Fluid method. We successfully reproduced three patterns of steady flow observed in the experiment: DLF (double-layered flow), SLF (single-layered flow), and RSL (reverse single-layered flow). A phase diagram was constructed on the basis of the parametric study regarding the thickness and volume ratio of the liquid film. In the thick liquid film, two different patterns of DLF and SLF were confirmed depending on the volume ratio, while the three types of convection fields including RSL were observed in the liquid film thinner than a certain value. In addition, we found that the occurrence of SLF might be determined by the minimum local thickness in the liquid film. The pattern selection, or as a bifurcation, and mechanism of the three-dimensional basic flow would be discussed in detail.

Session: Shear flows, boundary layers, and related problems

Flow instability in weakly eccentric annuli

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This work is concerned with "gap instability" of flow in weakly eccentric annular channels. Temporal linear stability analysis has shown that, even for very small eccentricities (lower that 0.1) and Reynolds numbers (as low as 529), flow instability occurred in the form of travelling waves having characteristics that are very different from those of Tollmien-Schlichting waves. The unstable waves were triggered at mid-gap by an inviscid mechanism that is associated with the presence of inflection points in azimuthal profiles of the base velocity. The critical stability conditions have been determined for small eccentricities and the full range of diameter ratios. Experimental investigations of flow instability and disturbance growth in a specially designed, long annular channel are in progress.

Session: Multiphase and non-Newtonian flows

Secretive Instabilities in Evaporating Binary Mixtures: Pools and Sessile Drops

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Everyone has a secret and will do whatever to hold on tight to it! Evaporating drops or pools of binary liquid mixtures are no different – in fact, their secrets are tightly wrapped under their complex mixture physics and thermodynamics that manifest as a myriad of instabilities that they demonstrate. In this talk – I will present some of our latest work on pools and droplets. Both these geometries demonstrate a complex process governed by a delicate balance between capillary stresses, evaporation, hydrodynamic flow, mass diffusion and surface tension, with both thermal and solutal Marangoni stresses present. Using long-wave evolution equations for the free interface and the concentration for a liquid mixture layer subject to thermo/solutal-capillarity, van der Waals interactions and vapour recoil, we perform a linear stability analysis. We show two modes of instabilities, a monotonic instability mode and an oscillatory instability mode. Through transient simulations, we analyse how these instabilities depend on thermo/solutal stresses. In sessile evaporating droplets formed of mixtures, we show how spreading is enhanced. We examine the behaviour and stability of volatile wetting ethanol-water drops deposited onto heated substrates using both experiments and modelling. Evolution equations are derived for the film height, temperature and concentration field assuming two ideally mixed volatile components with surface tension linearly dependent on temperature and concentration in the presence of a pre-cursor film. Our simulations and experiments indicate that concentration gradients give rise to super-spreading and contact line instabilities, not previously seen in pure fluids, qualitatively and quantitatively agreeing with each other. While our multi-pronged approach has revealed some fascinating physics, these systems are pretty stubborn in withholding all of their secrets and more needs to be done!

The break of symmetry in annular sudden expansion flows

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This paper deals with the remarkable break of symmetry in the wake structure of an annular nozzle with a bluff body sudden expansion. The annular tube that feeds the nozzle is perfectly aligned and straight and has an overall geometry that is perfectly symmetric. The flow field is studied by means of time-resolved stereoscopic PIV measurements and Direct Numerical Simulation (DNS). A recirculation vortex forms in the wake of the bluff body stop. At low Reynolds number, the vortex structure is completely symmetric
and stable. No tangential velocities are noticeable. However, as the Reynolds number increases above a threshold value (Re=290), the vortex structure deforms spontaneously into a highly asymmetric shape. both in the experiments and numerical simulations. The asymmetric flow structure is highly unstable. It alternately rotates around the central axis of the nozzle in clockwise and counterclockwise direction.

Session: Stability of flows in porous media

Onset of convection in a horizontal porous layer with vertical pressure gradient saturated by a power-law fluid

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The onset of convection in a porous layer saturated by a power-law fluid is here investigated. The walls are considered to be isothermal, isobaric and permeable in such a way that a vertical throughflow is described. The threshold for a buoyancy-driven cellular flow is investigated by means of a linear stability analysis. This study consists in introducing disturbances of small amplitude. The disturbances are plane waves, that is, a normal modes stability analysis of the basic stationary solution is performed. The resulting problem is an ordinary differential equation eigenvalue problem which is solved numerically by coupling the Runge-Kutta method with the shooting method. Results are presented in the form of marginal stability curves, that represent the values of the control parameters such that the growth rate of the disturbances is zero. It is found that, among rolls, the most unstable modes are non-travelling and have zero wave-number. For this reason an asymptotic analysis for vanishing wave numbers is performed. The results of this asymptotic analysis are obtained analytically and display a very good agreement with numerical ones. It is found that vertical throughflow plays a destabilizing role for pseudoplastic fluids and a stabilizing role for dilatant fluids.

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Statistic characteristics of thermoconvectional structures in atmospheric boundary layer

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In recent decades great interest has been expressed in circulation structures in the atmospheric boundary layer (ABL) and its characteristic manifestations, in particular, such as thermoconvectional structures. The new method of acoustic sounding data treatment for getting these structures has been received. The structures have been measured under different wind and temperature conditions. Results obtained (in the A.M. Obukhov Institute of atmospheric physics experiments) from the acoustic sounding of the ABL over arid-steppe zones in southern Russia (Chernozemelskii raion, Republic of Kalmykia, July 2007, 2016). Profiles of the windvelocity components at heights of 400–600 m with a step of 20 m and a time resolution of 5 s have been got from observational data. The statistic characteristics: the duration of over-limit vertical velocity, the maximum velocity in this interval and the space scale along the X-, and Y-axis have been received. It is considered that convective structures move progressively during any relatively small time step with some averaged velocity. This time step has been taken empirically and amounted to 10 minutes. In such a value the spatial distribution of velocity field and its time variations have been reproduced favourably. The received statistic characteristics have been similar to Rayleigh distribution. This fact allows to use this distribution to forecast thermoconvectional structures and build the regional and global velocity fields.

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AVERAGED THERMAL CONVECTION EXCITED BY INERTIAL WAVES IN A THICK CYLINDRICAL LAYER OF FLUID AT ROTATION

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The work is devoted to the experimental study of thermal convection of a fluid in a cylindrical coaxial gap with the boundaries of different temperatures rotating about a horizontal axis. The case of a thick layer with a warmer inner boundary is considered. At this the centrifugal inertia force has a stabilizing effect on the system. Gravity, rotating in the cavity reference system, is a disturbing factor. Against a background of oscillations of a non-isothermal fluid relative to the cavity, caused by an oscillating external force field, inertial waves are excited. It was found that the interaction of inertial waves with a non-uniform temperature field leads to the generation of averaged convective flows. Waves experiencing multiple reflections from the cavity boundaries form the flows of non-isothermal fluid in the form of a system of azimuthal vortex that is not symmetrically located along the axis of rotation.

It is shown that vibrational convection, which is based on inertial waves propagating in a non-isothermal fluid, manifests itself even under the conditions of stable stratification (at fast rotation), while “classic” vibrational convection occurs in a threshold manner when the rotational speed of the cavity decreases and manifests itself in the form of two-dimensional shafts elongated along the axis of rotation. The influence of subthreshold convective flows increases with increasing temperature difference between the boundaries of the layer.

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A numerical study for the compression only effect of contrast agents

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Contrast agents are gas-filled encapsulated microbubbles that are used in novel biomedical applications such as targeted drug delivery and the medical imaging of vital organs. Their coating is usually a lipid monolayer or a polymeric material, with the former shells exhibiting a strain-softening behavior when subjected to acoustic disturbances which amounts to a preferential excursion from equilibrium during expansion. However, some experiments have revealed a counter-intuitive behavior of lipid monolayer shells since a compression only behavior has been reported where they pulsate mainly in the compression phase. In this study we investigate numerically this behavior. The Navier-Stokes and continuity equations are solved for the liquid, whereas the force balance and the kinematic condition are applied on the interface. We assume constant rheological shell properties and moreover, the dilatational and the shear viscosity of the membrane are treated separately. The overall problem is solved using the finite element method and the computational grid is constructed with the elliptic mesh generation technique. The numerical results reveal that contrast agents are possible to develop a compression only behavior when they are initially pre-stressed. The difference between the dilatational and the shear shell viscosity facilitates this effect and the presence of the wall accelerates its appearance. Moreover, it is found that for a given frequency there is a critical sound threshold above which the bubble exhibits the compression only response pattern. The numerical results are examined against the predictions of linear stability analysis and it is found that the critical threshold for the onset of the compression only effect is determined both from the static buckling threshold and from the threshold for parametric mode excitation, with the bubble possibly trying to achieve during compression the static non-spherical shape predicted by the relevant bifurcation diagrams.

Flows generated in rotating fluid by centrifugal waves on a liquid-liquid interface

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We study experimentally the dynamics of a system of two immiscible liquids at rotation in a horizontal cylindrical container. The liquids have different density and, at sufficiently fast rotation, are distributed uniformly along the cylinder length in the form of a column and an annulus. The rotating liquid-liquid interface is prone to the emergence of centrifugal waves [O.M. Phillips, J. Fluid Mech. 7, 340, 1960; N.V. Kozlov et al. Phys. Fluids 28, 112102, 2016], whose most readily observed mode is the azimuthal two-dimensional wave.

In laboratory experiments, two methods are applied for the wave excitation. First, at relatively slow rotation, the centrifugal waves are excited in a threshold way due to the gravity. In this case, the wave number m is determined by the radii ratio between the column and the cylinder and the density ratio between two liquids. The waves propagate in the retrograde direction in the rotating reference frame. Second, the translational vibrations normal to the cavity rotation axis are used to excite the resonant oscillations of the interface. In this case, a wave with $m = 1$ is excited in a resonant manner; depending on the frequency ratio, it may propagate either in the prograde or retrograde direction.

The case of high frequency and small amplitude of vibrations is considered. The flows generated by waves are studied using the particle image velocimetry. Theoretical analysis of steady streaming velocity and wave onset threshold is done.

The work is supported by Russian Science Foundation (grant 18-71-10053).

Session: Liquid films, drops, and bubbles

Forced motion of a cylinder within a liquid-filled elastic tube - a model of minimally invasive medical procedures

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This work analyzes the viscous flow and elastic deformation created by the forced axial motion of a rigid cylinder within an elastic liquid-filled tube. The examined configuration is relevant to various minimally invasive medical procedures in which slender devices are inserted into fluid-filled biological vessels, such as percutaneous revascularization, interventional radiology, endoscopies and catheterization. By applying the lubrication approximation, thin shell elastic model, as well as scaling analysis and regular and singular asymptotic schemes, the problem is examined for small and large deformation limits (relative to the gap between the cylinder and the tube). At the limit of large deformations, forced insertion of the cylinder is shown to involve three distinct regimes and corresponding time-scales: (i) initial shear dominant regime, (ii) intermediate regime of dominant fluidic pressure and a propagating viscous-peeling front, (iii) late-time quasi-steady flow regime of the fully peeled tube. A uniform solution for all regimes is presented for a suddenly applied constant force, showing initial deceleration and then acceleration of the inserted cylinder. For the case of forced extraction of the cylinder from the tube, the negative gauge pressure reduces the gap between the cylinder and the tube, increasing viscous resistance or creating friction due to contact of the tube and cylinder. Asymptotic and numeric computations are presented for the dynamics of the near-contact and contact limits. We find that the cylinder exits the tube in a finite time for sufficiently small or large forces. However, for an intermediate range of forces the radial contact creates a steady locking of the cylinder inside the tube.

ID: 313

Session: Waves and turbulence

On the Convergence of the Normal Form Transformation in discrete wave Turbulence Theory for the Charney-Hasegawa-Mima (CHM) Equation

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A crucial problem in discrete wave turbulence theory concerns extending the validity of the normal form transformation beyond the weakly nonlinear limit. One of the main issues occurs when the linear and nonlinear timescales are no longer separated, and some of the assumptions of wave turbulence theory no longer hold. This allows finite amplitude interactions to occur through terms which are usually eliminated through normal form transformations. The specific finite amplitude phenomenon which we wish to study is precession resonance.[1] We investigate this for the CHM equation, Galerkin-truncated to 4 Fourier modes. We first study this reduced 4-mode system from a dynamical systems point of view to understand the manifold structure of the resonance in phase space. By calculating the normal form transformation up to 7th order (keeping all resonances up to 8-wave resonant interactions), we then numerically calculate the rate of convergence of the transformation as a function of a scaling parameter of our initial conditions. Our findings show that the scaling amplitude at which the normal form transformation diverges is of the same order as the amplitude at which precession resonance occurs. This implies that precession resonance cannot be described in the classical theory of wave turbulence through normal form transformations, so a more general theory for intermediate nonlinearity is required.

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Session: Electrohydrodynamics

Modeling and simulation of nonlinear interfacial electro-capillary-gravity waves under horizontal electric field

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In this talk, we focus on the evolution of the interface between two immiscible dielectrics with different permittivities under a horizontal electric field. The competing forces resulting from gravity, surface tension and electric field are all considered. Based on thorough analyses of the Dirichlet-Neumann operators, a series of nonlinear models is derived systematically from the primitive equations in the Hamiltonian framework. For special cases, well-known weakly nonlinear models for long and short waves can be generalized via introducing extra electric terms. It is shown that the electric field has a great impact on the physical system and can change the qualitative nature of the interface. Particular attention is paid to the situation when both fluid layers are considered thin compared to the characteristic wavelength, and in such case the Rayleigh-Taylor instability can be regularized by considerably strong electric field. Steady-state solutions (periodic and solitary waves) and corresponding bifurcation structures to the primitive equations will also be presented, and compared with model equations.

Session: Shear flows, boundary layers, and related problems

STABILITY OF VORTICES APPEARING AND DEVELOPING ON A ROTATING BODY

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A convex body beginning to rotate makes many initial vortices on its surface. We numerically investigated the development of the boundary layer flows on a rotating inner cylinder enclosed by a coaxial stationary outer cylinder and the flows on a rim of a disk rotating in a stationary cylindrical casing. The two cylinders have stationary end walls at their ends and the aspect ratio of the difference of the radii to the length of the cylinders is from 3.5 to 7.0. The acceleration rate of the inner cylinder is from 0.0 to 84.0. The rotating disk is supported at the center of the casing and the flow field has a radial gap between the casing side wall and the disk rim and an axial gap between the casing end wall and the circular disk surface. The fraction of the disk thickness to the casing height is from 0.5 to 0.85. The main modes of the flows between the cylinders and in the radial gap of the disk rim are the normal mode with a radial inward flow on the end wall and the anomalous mode with a radial outward flow. Depending on the acceleration rate, the initial flows between the cylinders have 2 to 14 vortices in the meridional section. Many of these vortices have flat shapes with shorter axial sizes and they are not stable. This instability causes the vortex disappearance on the end wall and the collapse of vortex pairs. The final flows have 2 to 10 vortices, and about 30 routes to the well-developed flows are identified. In the radial gap of the disk, the initial vortices appear near the tips of the disk. While these tip vortices induce another vortices, Goertler-type vortices emerge spontaneously. Then, the normal 4-vortex flow and the anomalous 4-vortex flow evolve. The former flow is stable and changes to the final normal 4-vortex flow or the normal 2-votex flow. The latter is unstable, and it becomes the anomalous 2-vortex flow or the asymmetric anomalous 3-vortex flow. Some of these transitions are observed experimentally.

A general DO-field code for PDEs with quadratic nonlinearity.

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In [1], Sapsis and Lermisiaux presented the Dynamically Orthogonal field method (DO-method) which can be employed to compute the solution of time-dependent PDEs with stochastic forcing. Such fields can also be found from solving a Lyapunov problem [1], based on a local linearization of the equations, but this provides only covariances. With the DO-method, one can get also the skewness and kurtosis.
A downside of the method is that it is intrusive. One needs to derive for each set of PDEs the associated coupled system of PDEs to be solved. However, if we restrict to PDEs which consist of linear and bilinear forms, then one can construct a general approach. We built an implicit DO code for this case, which needs a mass matrix, a Jacobian matrix, and the possibility to evaluate the bilinear form. Also, a stochastic additive noise term should be supplied. In implicit simulation models, usually, a mass matrix and Jacobian matrix are readily available. It appears that the bilinear form can be evaluated from nonlinear additions to the Jacobian matrix. So only with a very mild effort on the simulation code one can get the bilinear form.
In our talk, we will show results from a variety of simulation models to which we have applied the approach, among which the Burgers equation and the QG-model for ocean flows [3]. Moreover, we will discuss parallelization aspects and possible improvements.

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Session: Parametric excitation and control of instabilities

Influence of Fourier contents of boundary on the flow dynamics

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Plane Poiseuille channel Flow modified using longitudinal groove (groove oriented parallel to the flow direction) has been studied. Groove shapes of practical importance such as triangular, trapezoidal and square have been considered. In the first part of the analysis, properties of two-dimensional undisturbed flow before the onset of instability has been studied. Secondly, critical conditions for the onset of instability has been determined for a wide range of geometric parameters. The linear stability analysis has been performed using the direct numerical simulation of the Navier-Stokes equations. In this work, we wish to answer the following questions 1. Which corrugation shape would result in the lowest drag and has the strongest destabilization potential for the Squire-like three-dimensional mode as observed in the sinusoidal groove. 2. What is the role of the Fourier content of the corrugated boundary on the flow dynamics?

Flow Measurement of Sub-Critical Marangoni Convection in High-Prandtl-Number Liquid Bridges in Microgravity

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This study reports the results of flow measurement of sub-critical Marangoni convection in high-Prandtl-number liquid bridges in microgravity (mg) environment. Two projects of mg experiments, so-called Marangoni Experiment in Space (MEIS) and Dynamic Surf, have been conducted on the Japanese Experiment Module Kibo on the International Space Station for understanding the Marangoni convection instability mechanisms. A liquid bridge of silicone oil with the Prandtl number of Pr = 67, 112, or 207 is suspended between the differentially heated supporting disks, and the temperature difference between those disks drives the Marangoni convection. Since the target flow regime in this study is a sub-critical one, Marangoni convection exhibits a steady and axisymmetric motion. The classical three-dimensional particle tracking velocimetry (3-D PTV) is optimized for better measurement of Marangoni convection under mg condition, which allows one to obtain the velocity fields inside the liquid bridges with acceptable accuracy. The present 3-D PTV measurements are performed to visualize Marangoni convection in liquid bridges with various geometries. The measurement results of flow velocities indicate that the Marangoni convection in shorter liquid bridges (say, for A < 1) exhibit a similar single convection roll regardless of Pr, where A is the aspect ratio (i.e., the relative liquid bridge height to the disk diameter). On the other hand, the results for longer liquid bridges (say, for A > 1) exhibit different flow patterns depending on Pr. Two axially aligned convection rolls are recognized for Pr = 67 and 112, while a single convection roll occupies the entire flow field inside the liquid bridge for Pr = 207. Such a change of flow pattern is considered to be caused by the effect of heat transfer through the liquid-gas interface, and the change of basic flow pattern may affect the instability of Marangoni convection.

Dielectric-heating-induced thermal convection in a parallel plane capacitor

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Convection driven by a thermally-induced dielectrophoretic force is investigated theoretically for dielectric liquid in a plane parallel capacitor with taking into account dielectric heating inside the liquid. A theoretical model is developed for efficient flow computation by averaging the momentum equation over a period of applied alternating electric field. Stability of the conduction state is determined by a linear analysis. Different from in a perfect dielectric liquid, the stability and the critical eigenfunctions depend significantly on the frequency of electric field.

A numerical simulation study for the effect of RF-coil position in the Bottom Seeded Solution Growth (BSSG) process of SiC

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The induction heating Top-Seeded Solution Growth (TSSG) process has been widely applied for SiC crystal growth. In this process, however, strong Marangoni convection in the melt, driven by free surface tension gradient, adversely affects the crystal quality. To improve crystal quality further, the Bottom-Seeded Solution Growth (BSSG) process has been proposed. In this technique, the seed crystal is positioned at the bottom of the melt. Thus, the Marangoni convection is expected to be minimized to obtain a more favorable carbon transport to the seed. To this end, a numerical simulation study has been carried out for the BSSG of SiC. The objective was to determine the effect of the location of the RF-coil on growth rate and its uniformity.

The simulation was carried out in three steps. (i) First, the computation of the induced electromagnetic (EM) fields by the RF-coil. (ii) Then, the computation of the temperature field in the whole furnace using heat generation density from the induced the EM fields of Step (i). (iii) Finally, the computation of carbon transport in the melt by solving the governing equations using the previously computed EM fields and the boundary condition obtained the thermal field (from Steps i and ii).

The simulation results showed that in BSSG of SiC the induced Lorentz force in the melt is dominant while the effects of buoyancy and interfacial forces are small. The average growth rate mainly depends on the temperature difference between the seed and the melt side-boundary, indicating that the average growth rate can be maximized by simply finding the best position for the RF-coil. However, it was found that changes in the coil position did not affect significantly the flow structures in the melt near the seed. Thus, any changes in the coil position will not provide an improvement for growth rate uniformity. It was concluded that for a better rate uniformity in this process, the system would need to be redesigned by considering a new geometry.

Challenges in the modelling of multiphase flow from large to small scales

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I shall describe Direct Numerical Simulations (DNS) of multiphase flows, with particular emphasis on two phenomena: a large scale, large Reynolds case, the atomization of liquid jets, and a small scale case, the moving contact line.

For atomization, we extended a lot of efforts on the quasi planar setup of the Grenoble group (Hopfinger, Cartellier, Matas and many others). The motivation of our numerical modeling of the setup is 1) to use a simple setup to investigate the possibility of converged simulations, 2) to examine the physical causes of the observed frequency of oscillation and its relation to the viscous stability theory of shear flows and 3) to shed light on the statistics of droplet formation and the log-normal distribution observed, which plays an analogous rôle to the Kolmogorov $k^{-5/3}$ spectrum in single phase turbulence. Numerically, "well balanced" Volume-of-Fluid methods for surface tension coupled with accurate curvature estimates by "height functions" are used. Care is taken to enhance the stability of the method in presence of large density ratios by using a consistent transport of momentum and Volume-of-Fluid around the interface (also categorized as a "momentum conserving" method). Several test cases are described that discriminate various variants of the method as regards their stability. In particular, the fall of a raindrop and the sudden acceleration of a drop with a large density ratio are studied. Large scale simulations are then performed that yield a statistical distribution of droplet sizes. The influence of upstream turbulence is studied. Care is taken to have sufficiently small Reynolds and Weber numbers so that a DNS is attainable.

The moving contact line is another phenomenon that makes detailed simulations difficult. We describe an attempt to model the contact line with the Navier-Stokes equations coupled with adequate boundary conditions, which may involve slip, the numerical imposition of an apparent contact angle, and possibly the Generalized Navier Boundary Conditions. These simulations will be compared to the result of molecular dynamics using potentials with hydrogen bonding adapted to the no-slip tendency of water. Application to wettability in microfluidic and porous environments will be discussed.