Titles and Abstracts

Viscoelastic instabilities in microfluidic flows

Amy Q. Shen
Micro/Bio/Nanofluidicis Unit, Okinawa Institute of Science and Technology Graduate University
Okinawa, Japan

Microfluidics has emerged in recent years as a versatile platform of manipulating fluids at small length-scales, and in particular, offers a large range of deformation rates and direct visualization of resulting flow fields, providing unique opportunities for capturing the flow instabilities of viscoelastic fluids in real time. By using the subtractive three-dimensional (3D)-printing technique of selective laser-induced etching (SLE), glass microfluidic devices can sustain very high flow rates, provide access to little-explored flow regimes, and enable flow visualization from multiple planes of observation, allowing the quantitative study of 3D flows[1,2].

In this talk, I will highlight microfluidic platforms involving microfluidic cylinders to investigate the intricate viscoelastic instabilities of complex fluids. To model synchronized or coupled motions of motile objects (e.g., cilia) translating in biological fluids, we present the first example of viscoelastic fluid-structure interaction in a glass microfluidic device containing free-standing microfluidic circular cylinders[3,4]. Our studies demonstrate that slender bodies in viscoelastic flow can exhibit highly correlated dynamics, which sheds insight on the analogous processes in biological systems. To expand this system, we further study the coupling between the viscoelastic fluid and the micropillar arrays, and discover the spontaneous emergence of metachronal waves in the system. We suggest that the waves originate from pulses of localized high elastic stresses propagating through the elastic wakes that form around the pillars. The occurrence of the wave is chaotic and shows characteristic fingerprints of elastic turbulence[5].

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Numerical study of viscoelastic upstream instability on the flow past a cylinder in a narrow channel

Peng Yu(余鹏), Peng Sai

Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen 518055, PR China

In this study, we numerically simulate a viscoelastic fluid flow past a cylinder in a confined narrow channel. Two-dimensional numerical simulations based on the FENE-P model are performed by using the open-source CFD platform OpenFOAM and the rheotool toolbox. To stabilize the simulation, the square root reconstruction method is adopted and the molecular dissipation effect is considered. Our numerical results demonstrate that the viscoelastic upstream instability reported in previous experiments for low-Reynolds-number flows can be successfully reproduced by using the macroscopic viscoelastic constitutive relation. The influences of the cylinder blockage ratio (BR), the Weissenberg number (Wi), the viscosity ratio (β) and the maximum polymer extension (L) on the non-dimensional recirculation length (L_D) are examined. The upstream recirculation is observed when Wi is beyond a certain critical value Wi_c and BR is larger than around 16.7%. Near the onset of upstream recirculation, L_D and Wi exist Landau-type quartic potential within specific parameter spaces. The bifurcation process may display subcritical behaviour, depending on β and L^2. The parameters β and L^2 have nonlinear influences on L_D. This work may advance our theoretical understanding of this new instability mechanism in viscoelastic wake flows.

Asymptotic analysis of the linear and weakly nonlinear instability in viscoelastic pipe flows

Ming Dong(董明)

Institute of Mechanics, Chinese Academy of Sciences

It has been proven that the Newtonian pipe flow is stable for infinitesimal perturbations for all Reynolds numbers, however, recent numerical works has shown that the polymer-solution pipe flow can support linear unstable mode, which is known as the centre instability because its perturbation profile is concentrated around the pipe centreline. In this talk, I will first present an asymptotic analysis of the linear centre instability, and confirm the accuracy of its prediction on the dispersion relation by comparing with numerics. Then, I will perform the weakly nonlinear analysis based on the asymptotic system, and show the bifurcation feature of the viscoelastic instability at finite amplitudes.

Linear nonmodal analysis of viscoelastic fluid thermo-convection in a channel

Zhenze Yao[1,2], Cailei Lu[1,2], Mengqi Zhang[3], **Kang Luo(罗康)[1†], Hongliang Yi(易红亮)[1,2†]**

[1]School of Energy Science and Technology, Harbin Institute of Technology, Harbin, CN
[2]Key laboratory of Aerospace Thermophysics, Harbin Institute of Technology, Harbin, CN
[3]Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, 117575 Singapore

We report a comprehensive nonmodal linear stability analysis of the Rayleigh-Bénard (RB) convection and the Rayleigh-Bénard-Poiseuille/Couette mixed convection in viscoelastic fluid with Oldroyd-B configuration. Due to the presence of the primary bifurcation in viscoelastic RB convection, the instability may be stationary or oscillatory for weakly elastic fluid and strongly elastic fluid respectively. In the case without shear flow, i.e. the classical RB system, it is found that the fluid viscoelasticity leads to the nonnormality of RB convection control operators, so as to causes a kind of new transient energy growth. Under marginally stable case, the maximum transient energy amplification $G_{\max}$ reaches its maximum at the primary bifurcation point, and the value of maximum $G_{\max}$ may be up to 10^2~10^4. In addition, decreasing Prandtl number Pr and increasing viscosity ratio β enhance the maximum energy amplification

G_{max}. Energy analysis suggests that positive buoyancy force work rate is the only destabilizing factor, and the increase of phase difference between perturbation temperature and perturbation wall normal velocity from 0 is the underlying mechanism for the transition from stationary instability to oscillatory instability. The evolutionary spatial patterns of optimal initial conditions of oscillatory instability are exhibited to enhance the comparative understanding with experimental results. In the presence of shear flow, two velocity profiles, Poiseuille flow and Couette flow are considered. The spanwise disturbances can achieve the greatest perturbation energy amplification, and similar to the case of pure bounded shear flow, $G_{max} \propto Re^2$ and T (oscillation period of $G(t)$ curve) $\propto Re$ also hold. Besides, compared with Poiseuille flow, Couette flow has a greater energy amplification under the same parameter values, and the lift-up mechanism still plays an important role by inducing the generation of streamwise streaks. For higher *Re* case, input-output analysis suggests that increasing *Ra* enhances perturbation energy amplification, and causes its transition from shear-dominated to heat-dominated. The fluid viscoelasticity enhances these both energy amplifications, especially the heat-dominated energy amplification. In addition, for heat-dominated amplification, the optimal spanwise wavenumber γ_{opt} to achieve the maximum transient energy growth, is not affected by the type of shear flow and is lower than that for shear-dominated amplification. Energy analysis indicates that, at higher *Re*, the temperature field does not directly devote to transient energy growth through positive buoyancy force work rate, while it indirectly changes the energy production against shear flow for shear-dominated amplification and the polymer stresses work rate of viscoelastic fluid for heat-dominated amplification, which can provide some clues into the transition from laminar flow to elasto-inertial turbulence under the action of a temperature field.

Key words: Viscoelastic fluid; thermo-convection; linear nonmodal analysis

Email addresses for correspondence: luokang@hit.edu.cn, yihongliang@hit.edu.cn

High weissenberg number problem in numerical simulation of viscoelastic fluid flow

Wenhua Zhang(张文华)

Department of Energy and Power Engineering, Tianjin University

The high Weissenberg number (Wi) problem (HWNP) has long been a challenge of high-Wi viscoelastic fluid flow simulation, that is, the numerical simulation is prone to become divergent at moderate and high Wi (~1 and above). At present, loss of symmetrical positive definite (SPD) property of the conformation tensor is recognized as an important reason for HWNP. To guarantee the SPD property of the conformation tensor, several researchers conducted a series of work, for instance, the artificial viscous diffusion (AVD) method, the continuous decomposition and Cholesky decomposition

methods, the well-known log-conformation representation (LCR) method, and so on. Although a variety of techniques have been proposed from different aspects to deal with HWNP, it has not been solved fundamentally, especially the simulation of viscoelastic turbulence at high Wi is still a very difficult problem. These methods often come at the cost of sacrificing computational accuracy. It is also worth noting that the values of the conformation tensor at grid interface when dealing with the convective term of constitutive model are all obtained by the component-based interpolation method which ignores the error caused by tensor interpolation. In recent series of studies, we demonstrate that the error of the tensor interpolation can be the source of the loss SPD property of the conformation tensor. To solve this problem, we propose a tensor-based interpolation technique to develop essentially SPD (ESPD) schemes for the constitutive equations, which can not only reduce this error but also assure the smoothness and boundedness of rotation, translation, and scaling of the conformation tensor as well as its SPD property to a great extent.

Turbulent flows with polymers

Marco E. Rosti

Okinawa Institute of Science and Technology Graduate University

Turbulent flows containing modest amounts of long-chained polymers have remained an intriguing area of research since the discovery of turbulent drag reduction. Here, we perform direct numerical simulations of statistically stationary, homogeneous, and isotropic turbulent flows of dilute solutions of polymers at various Reynolds and Deborah numbers. At large Reynolds number, we present evidence that there is a range of scales r over which the energy spectra and the structure functions show new scaling consistent with recent experimental results. In particular, we find that for small wavenumbers k, the kinetic energy spectrum shows Kolmogorov–like behavior which crosses over at a larger k to a novel, elastic scaling regime, $E(k) \sim k^{-\xi}$, with $\xi \approx 2.3$. We uncover the mechanism of the elastic scaling by studying the contribution of the polymers to the flux of kinetic energy through scales, and show that this elastic behaviour is non-monotonic in the Deborah number. At low Reynolds number, our simulations show that elastic turbulence, though a low Reynolds number phenomenon, has more in common with classical, Newtonian turbulence than previously thought. In particular, we find power-law spectra for kinetic energy $E(k) \sim k^{-4}$, independent of the Deborah number. In real space, as expected, the velocity field is smooth, but, crucially, with a non-trivial sub-leading contribution. Interestingly, the results show clear evidence of intermittency and multifractality.

Well-posedness of the free boundary problem for the incompressible elasticity

Zhao Wenbin(赵文彬)

Peking University

In this talk, we consider the free boundary problem for the incompressible elasticity with the physical boundary condition. By deriving the evolution equation of the free surface in the Eulerian coordinates, we prove the FBP is always stable under the assumption that the deformation matrix is not degerate. With the optimal regularity estimates of the free surface, we can derive the a priori estimates without loss of regularity and prove the local well-posedness.

Flow instability and bifurcation in viscoelastic pipe flows

Mengqi Zhang(张蒙齐)

Department of Mechanical Engineering, National University of Singapore; New National University Research Institute, Suzhou Industrial Zone

Recent studies revealed that viscoelastic (polymeric) pipe flows can be linearly unstable, in contrast to the stability of the Newtonian pipe flows. The new linear instability was found to be a center mode with the eigenfunction concentrating in the center part of the pipe (Garg et al. 2018). We carried out linear stability analysis and transient energy growth analysis to further explore the linear dynamics of the center mode. It is found that an Orr mechanism (along with the critical-layer mechanism) is at play in the conformation tensor field, contributing to the total energy growth.

From a nonlinear point of view, the linear instability implies a possibility of supercritical bifurcation in viscoelastic pipe flows, again, in contrast to the subcritical Newtonian pipe flows. We applied a multiple-scale expansion method to study the bifurcation of the viscoelastic pipe flows. It is found that both supercritical and subcritical bifurcations exist in this flow. We calculated the boundary between the two bifurcations in terms of viscosity ratio (related to the polymer concentration) and our theoretical prediction gave a value about 0.785 (below which, the flow is supercritical; vice versa), qualitatively close to the experimental observation around 0.855. A scaling for the Landau coefficient has also been found.

Bamin Khomami
Department of Chemical and Biomolecular Engineering

TBA

Simulation scheme for particle suspension flows with locally-averaged equations

Ryohei Seto(瀬户亮平)

Wenzhou Institute, University of Chinese Academy of Sciences, Wenzhou, Zhejiang 325001, China

Colloidal particles in viscous liquids are usually very passive; their inertia is negligible and just follows the surrounding flow. However, when connected particles form some structure and interact with boundaries, they can be no longer obedient and collectively resist the flow. Contact friction plays a critical role there; it works as a particle bonding force in flow-induced transient structures. We are developing a new coarse-grained simulation scheme to capture such flow and particle-dynamics coupling phenomena. Our approach is a kind of CFD-DEM; based on a two-fluid model, we formulate the respective equations of motion and demonstrate the concept by implementing them with the LF-DEM and a primitive finite difference method for locally-averaged velocity fields.

Yongjun Jian(菅永军)

Inner Mongolia University

TBA

Numerical simulation of high-Wi viscoelastic drag-reducing turbulence

Hong-na Zhang(张红娜)

Department of Energy and Power Engineering, Tianjin University

Viscoelastic fluid widely exists in nature and engineering field. The unique rheological properties make viscoelastic fluids show different flow patterns from Newtonian fluids,

such as turbulence drag reduction effect at high Re number, elastic turbulence at very low Re number and elastoinertial turbulence phenomenon recently discovered. These unique flow patterns provide potential thermal flow control ideas for different engineering fields. For a long time, numerical simulation of viscoelastic fluid flow faces the challenge of the well-known high Wi numerical problem, which significantly limits our understanding on viscoelastic turbulence especially under strong elasticity. Moreover, the viscoelastic drag-reducing turbulence has been investigated for several decades. The recent introduction and discovery of elastoinertial turbulence has overturned the long-term understanding of drag-reducing turbulence, and it is urgent to further explore the essence and mechanism of drag-reducing turbulence on this basis, and construct the correlation between turbulent flow states of viscoelastic fluids. In this talk, we will talk about our recent progress on the development of the numerical methods for high-Wi viscoelastic turbulence, the new understanding of elasto-inertial turbulence as well as the drag-reducing turbulence based on our numerical methods.

Experimental observation of the elastic range scaling in turbulent flow with polymer additives

Heng-Dong Xi(郗恒东)

Northwestern Polytechnical University

A minute amount of long-chain flexible polymer dissolved in a turbulent flow can drastically change flow properties, such as reducing the drag and enhancing mixing. One fundamental riddle is how these polymer additives interact with the eddies of different spatial scales existing in the turbulent flow and, in turn, alter the turbulence energy transfer. Here, we show how turbulent kinetic energy is transferred through different scales in the presence of the polymer additives. In particular, we observed experimentally the emerging of a previously unidentified scaling range, referred to as the elastic range, where increasing amount of energy is transferred by the elasticity of the polymers. In addition, the existence of the elastic range prescribes the scaling of high-order velocity statistics. Our findings have important implications to many turbulence systems, such as turbulence in plasmas or superfluids where interaction between turbulent eddies and other nonlinear physical mechanisms are often involved.

Linear instability of a two-dimensional viscoelastic liquid film under the coupling effect of electrostatic field and parametric resonance

Bo-qi Jia(贾伯琦)[1], Ping Wang[2], Qi Yang[3], **Qing-fei Fu(富庆飞)**[4,*], Bo-shu He[1,†]

1.Institute of Combustion and Thermal Systems, School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, China

2.Beijing Institute of Control Engineering, Beijing 100190, China

3.Rocket π (Beijing) Aerospace Technology Co., LTD, Beijing 100071, China

4.School of Astronautics, Beihang University, Beijing, 100083, China

A two-dimensional temporal linear instability analysis is performed for a charged liquid viscoelastic film on a vertically oscillating plane in the presence of an electrostatic field. The viscoelastic fluid, described by the Oldroyd-B model, is intended to be a Taylor–Melcher leaky dielectric, while the ambient gas is treated as perfectly dielectric. Results show that the oscillations induce parametric unstable regions. The parametric unstable regions can be superimposed on the inherent unstable region when the oscillation frequency is small because the frequency in the inherent unstable region is non-zero. The electric field has a complex effect on both inherent and parametric instabilities. The effect of the electrical relaxation time is dominated by the electrical Bond number and dimensionless distance. The relative permittivity has a destabilizing effect. However, the effects of electrical relaxation time and relative permittivity in the parametric unstable region are negligible. The viscosity and elasticity have non-monotonic effects on the inherent instability but have a monotonous effect on the parametric instability. The increase of Bond number has a stabilizing effect. The effect of density ratio is not constant in the inherent unstable region, according to the electrical Bond number and Bond number. However, the increase of density ratio has a monotonously stabilizing effect on the parametric instability. Finally, an experimental study was performed and the results verified that the electrical field can increase the wavenumber of the surface standing wave.

Key words: charged liquid films, electrostatic field, temporal linear instability, viscoelastic fluids, parametric instability

New directions and discoveries in elastic instability and turbulence in viscoelastic channel flow

Victor Steinberg
Department of Physics of Complex Systems

I present a short review of the experimental results on viscoelastic planar channel flow obtained for the last 5 years. For shortly described at the beginning viscoelastic flows with curved streamlines, where super- or subcritical normal mode instabilities at Wi_c are observed and characterized, the instability mechanism has been explained and verified experimentally. Moreover, at $Wi \gg Wi_c$ a transition to chaotic flow, called elastic turbulence (ET), was discovered, and ET has been characterized experimentally and explained and characterized theoretically and numerically. Contrary to this, viscoelastic straight channel flow, proved linearly stable similarly to Newtonian parallel shear flows, exhibits instability directly to a chaotic flow different from ET with consequent secondary instability to ET and further reveals unexpected drag reduction (DR). Thus, three chaotic flow regimes are observed and, in addition, in all of them elastic waves were discovered and characterized. Furthermore, in all flow regimes, coherent structures (CSs) of self – organized velocity fluctuations are detected, and they display cycling self-sustained process synchronized by elastic waves. This surprising finding together with DR provides evidence that in spite of some similarity with CSs in Newtonian parallel shear flows novel, the key role of the elastic waves in energy transfer from the main flow to velocity fluctuations should be investigate. First step in this direction is made in a discovered elastically driven Kelvin-Helmholtz-like instability as a secondary instability in viscoelastic channel flow, contrary to its proved stability about 30 years back. Further on, it is also considered in the explanation of occurring DR, where the role of the elastic waves turns out to be decisive. Finally, I shortly explain universality in properties of viscoelastic channel flows with different intensity of external perturbations, mechanism of vorticity amplification by elastic waves, and discovery of stochastic resonance in close vicinity and above non-modal elastic instability.

A nonlinear constitutive model for entangled symmetric dendrimers

Zhongqiang Xiong(熊钟强)[1] and Wei Yu(俞炜)[1*]

[1] Department of Polymer Science and Engineering, Shanghai Jiao Tong University, Shanghai, China

An orientation-stretch coupled constitutive equation is suggested for symmetric Cayley tree-like dendrimers, which can self-consistently describe the linear relaxation

spectrum and nonlinear viscoelastic behavior. The molecular stress is determined by the orientation-stretch coupled conformation tensors of all segments. The linear relaxation spectrum is determined according to hierarchical arm retraction with the branch point hopping and dynamic tube dilation. Under strong flows, the orientation relaxation time and the stretch relaxation time are affected by the convective constraint release effect and branch point withdrawal. The coupling between the segmental orientation and stretch in each generation is represented in the evolution of the coupled conformation tensor, while the possible stretch coupling among different generations is ignored. The predictions on both linear and nonlinear rheological behaviors are well consistent with the experiments, proving the rationality in treating the coupling problems.

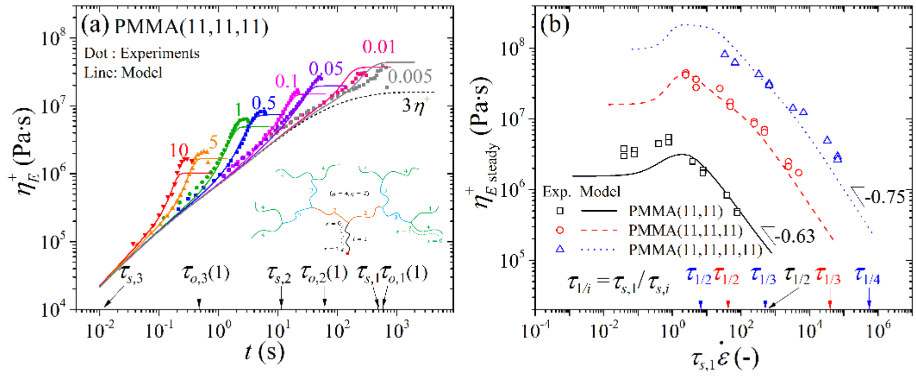

Figure 1: Comparisons with start-up experiments by a three-generation PMMA sample: (a) The transient behavior of the extensional viscosity, (b) the relationship between steady extensional viscosity and the innermost Rouse Weissenberg number, which indicates that the evident stretch of the inner core contributes to the start of strain rate thinning (where $\tau_{s,i}$ denotes the stretch relaxation time of the i^{th}-generation).

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The Onsager principle in the dynamics of Soft Matter

Masao Doi

Wenzhou Institute University of Chinese Academy of Science

The Onsager principle is a variational principle proposed by Lars Onsager in 1931 in his celebrated paper on the reciprocal relation in non-equilibrium thermodynamics. The principle is important in the physics of polymer and soft matter. Almost all kinetic equations which have been used to describe the dynamics of polymer and soft matter are derived from this principle.

In this talk, I will show that the Onsager principle is useful in solving these equations. Since it is a principle of minimization, it can be used to get approximate solutions of the equations. Here I review the principle from an application point of view. I take examples from capillary hydrodynamics, gel dynamics and flow of viscoelastic fluids.

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Dynamics of Viscoelastic Filament based on Onsager Principle

Jiajia Zhou(周嘉嘉)

School of Emergent Soft Matter, South China University of Technology, Guangzhou

We developed a thermodynamic model for viscoelastic filaments. Starting from a free energy model characterized by the filament geometry and microscopic chain extension, we derived evolution equations using Onsager variational principle. Based on this framework, we interpret the formation of beads-on-string structure from phase separation point of view. We further investigated elastocapillary thinning of Oldroyd-B fluid. Without assumption of the axial stress, we can derive the exponentially thinning behavior of Oldroyd-B model.

Key Words： viscoelasticity; surface tension; Onsager principle

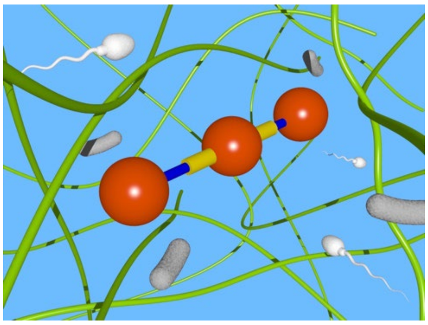
A three-sphere microswimmer in a structured fluid

Shigeyuki Komura

Wenzhou Institute, University of Chinese Academy of Sciences,

Wenzhou, Zhejiang 325001, China

We discuss the locomotion of a three-sphere microswimmer in a viscoelastic structured fluid characterized by typical length and time scales [1]. We derive a general expression to link the average swimming velocity to the sphere mobilities. In this relationship, a viscous contribution exists when the time-reversal symmetry is broken, whereas an elastic contribution is present when the structural symmetry of the microswimmer is broken [2,3]. As an example of a structured fluid, we consider a polymer gel, which is described by a "two-fluid" model. We demonstrate in detail that the competition between the swimmer size and the polymer mesh size gives rise to the rich dynamics of a three-sphere microswimmer.



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Mesoscopic modelling of the microstructure and rheology of spherical and plate-like particle suspensions

Dingyi Pan(潘定一)[1, 2, *], Jinhe Wang[1], Yixuan Liang[1]

[1] Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, China
[2] State Key Laboratory of Fluid Power & Mechatronic Systems, Hangzhou 310030, China

This paper numerically investigates the relation between the evolution of microstructure and rheological responses of both rigid sphere and plate-like particle suspensions. We introduce electrostatic repulsive and van der Waals attractive forces between interacting particles. Along with hydrodynamic and frictional forces, we have managed to establish a numerical model for rigid sphere particle suspensions. Our simulations prove that Debye length and repulsive strength amplitude play different roles in the rheology of particle suspensions. The former mainly affects the slope of the first shear thinning while the repulsive amplitude has great influence on the viscosity after shear thickening. With increasing attractive forces, shear thickening is obscured in dense suspensions and eventually shear thinning with high viscosity is observed. According to the analysis on the evolution of microstructure, this phenomenon is closely related with the formation and breakup of particle clusters during shearing.
With Core-modified dissipative particle dynamics (CMDPD) method, we have modelled plate-like particle suspensions. The research on plate-like suspensions begins with the dynamics of plate-like particles. For systems where no-slip condition is

satisfied between flakes and fluid, a particle would rotate with shearing according to Jeffery's orbit. When the slip length is large enough, a plate-like particle can attain stable orientation in shear flow. This rotation and orientation have great influence on the rheology of plate-like particle suspensions with low volume fraction. While for suspensions with higher volume fraction, the piled-up and detachment of particles influence macroscopic rheological responses.

Direct Numerical Simulation of Viscoelastic Turbulent Spanwise-Rotating Plane Couette Flow

Yabiao Zhu[1,2], Fenghui Lin[1], Jiaxing Song[3], **Nansheng Liu(刘难生)**[1], Xiyun Lu[1], & Bamin Khoammi[4]

[1]Department of Modern Mechanics, University of Science and Technology of China, Hefei, Anhui, 230026, PR China

[2]Yangzhou Collaborative Innovation Research Institute, Shenyang ADRI, Yangzhou, Jiangsu 225000, PR China

[3]Department of Chemical and Biomolecular Engineering, University of Tennessee, Knoxville, TN 37996, USA

Wall-bounded turbulence (WBT) under the coupled effects of fluid elasticity and system rotation, two important factors widely encountered in industrial fluid flows, is one of the challenging scientific problems that are fundamental to the research area of nonlinearity and complex flows. This talk is dedicated to viscoelastic spanwise-rotating plane Couette flow (RPCF) with special interest on the flow transitions and underlying mechanisms of WBT under the coupled effects of elasticity and rotation via direct numerical simulations (DNS). We explore the novel transition in viscoelastic WBT and the mechanistic understanding of polymer-turbulence interactions in those distinct turbulent states when varying the effects of elasticity and rotation. Specifically, we report several novel findings including spanwise-rotation-driven flow transitions from a drag-reduced inertial to a drag-enhanced elasto-inertial turbulent flow state followed by full relaminarization at weak elasticity; polymer-induced flow relaminarization of RPCF and commensurate drag enhancement at moderate rotation; the existence of a MDE asymptote at high rotation and elasticity. It presents a universal picture for the coupling of polymer chains and turbulent vortices in the viscoelastic RPCF.

Tiger-striped flow marks in injection molding of polymers

Wei Yu(俞炜), Xinyang Zhao, Fengyi Hou

Advanced Rheology Institute, School of Chemistry and Chemical Engineering, Shanghai Jiao Tong University

Tiger-striped flow marks are known as periodical gloss variations along the flow direction on the surface of injection parts of polymers. It may appear in various polymeric materials, both amorphous and crystalline, including pure polymers, polymer blends, and particle-filled polymer composites. The characteristics of tiger stripes (such as the induction length, period, and width of stripe) rely on the composition of polymeric materials, processing conditions, and geometric features. Although different mechanisms have been suggested, direct prediction of the formation of tiger-striped flow marks is still a significant challenge. In this work, we suggest a new wall-slip mechanism to explain the in-phase tiger-striped flow marks. Rheological experiments were used to reveal the slip boundary condition of the crystallizing polymer. The dynamic boundary condition was then used in the flow analysis.

Microswimming in Viscoelastic Fluids

Gaojin Li(李高进)

Shanghai Jiao Tong University

Microswimming in viscoelastic fluids is ubiquitous in various fields such as microbiology, colloid and interface science, analytical chemistry, and bioscience. In many scenarios, the surrounding fluid media exhibit viscoelastic properties, significantly impacting the speed, kinematics, swimming modes, and hydrodynamic interactions of microswimmers with environment and other swimmers. To understand these effects, this presentation will first discuss the electrophoresis motion of a spherical particle in a viscoelastic fluid. Through an analysis of the fluid velocity and stress inside and outside the double layer surrounding the electrophoretic particle, this work elucidates the variations in the slip velocity of the corresponding squirmer model and establishes a realistic physical model for microswimming in viscoelastic fluids. Building upon this foundation, I will further discuss the numerical results of squirmer swimming in proximity to a solid surface and the collective motion of rod-like swimmers in viscoelastic fluids. Comparison between numerical results and experimental observations will also be presented.

Similarity for dissipation-scaled wall turbulence

Shunlin Tang (唐顺林)1,† and R.A. Antonia2

[1]Center for Turbulence Control, Harbin Institute of Technology, Shenzhen 518055, PR China
[2]School of Engineering, University of Newcastle, NSW 2308, Australia

In this paper, we put forward a hypothesis for turbulent kinetic energy, Reynolds stresses and scalar variance in wall-bounded turbulent flows, whereby these quantities, when normalized with the kinematic viscosity, mean turbulent energy dissipation rate and scalar dissipation rate, are independent of the Reynolds and Péclet numbers when they are sufficiently large. In particular, there exist two scaling ranges: (i) an inertial-convective range at sufficiently large distance from the wall over which a 2/3 power-law scaling emerges for all quantities mentioned above; (ii) a viscous-convective range between the viscous-diffusive and inertial-convective ranges at large Prandtl number over which the normalized scalar variance is constant. The relatively large amount of available wall turbulence data either provides reasonably good support for this hypothesis or at least exhibits a trend that is consistent with the predictions of this hypothesis. The relationship between the proposed scaling and the traditional wall scaling is discussed. Possible ultimate statistical states of wall turbulence are also proposed.

Microflows of Viscoelastic Fluids with Fractional-order Constitutive models

Xiaoping Wang(王晓萍), Haitao Qi(齐海涛)*

School of Mathematics and Statistics, Shandong University, Weihai 264209, PR China

Recently the microflows of viscoelastic fluids have attracted widespread attention due to the fact that microfluidic devices are often used to analyze biological fluids, polymer solutions, which exhibits non-Newtonian fluid properties, such as shear thinning and thickening, and viscoelastic effect. The presence of these additives in aqueous solution often leads to complex rheological properties and gives rise to distinctive power laws in the creep response (i.e. the strain varies as $\gamma(t) \sim t^{\alpha}$ and also in the corresponding frequency response (i.e. the elastic modulus varies with frequency as $G'(\omega) \sim \omega^{\alpha}$). Such power-law responses are not well described by canonical rheological models. The fractional viscoelastic constitutive models with only a few parameters are proved to be a powerful tool for describing the wide range of microstructural relaxation processes in a power-law material. However, the application of fractional-order constitutive models in microchannel flow is still in early stages. In this talk, we will introduce our analytical and numerical works on the electro-osmotic (EO) flow of viscoelastic fluids with fractional-order constitutive relationships in micro-channels. Our work open possibilities for designing lab on a chip based microfluidic devices transporting non-Newtonian fluids by means of EO mechanisms.

Incompressible limit of two dimensional compressible viscoelastic systems with vanishing shear viscosity

Xiufang Cui(崔秀芳)

Lanzhou University

This work concerns the incompressible limit of compressible viscoelastic systems when the shear viscosity converges to zero. The incompressible limit is characterised by the large value of the volume viscosity. In the limit, the dispersive effect of pressure waves disappears and the global convergence to the limit system around an equilibrium is justified with the help of vector fields and the “ghost weight" method.

Uniform Bound of the Highest-order Energy of the 2D Incompressible Elastodynamics

Yuan Cai(蔡圆)

Fudan University

This talk concerns the time growth of the highest-order energy of the systems of two dimensional incompressible isotropic Hookean elastodynamics. This two dimensional systems are nonlocal quasilinear wave equations where the unknowns has slow temporal decay. By observing an inherent strong null structure, the global well-posedness of smooth solutions near equilibrium was first proved by Zhen Lei where the highest-order generalized energy may have certain growth in time. We develop novel energy estimate strategies and show that the highest-order generalized energy is uniformly bounded for all the time.

Polymer additives induced axial-aligned small-scale structures in a turbulent von Kármán flow

Feng Wang(王封), Yi-Bao Zhang, Heng-Dong Xi(郗恒东)

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China

The weakening of the flow structures is found to be one of the key characteristics of drag reduced wall-bounded turbulent flows by polymer additives. Even in homogeneous isotropic turbulence, one can observe the significant inhibition of the vortical filaments, resulting in a decrease in kinetic energy dissipation. A large number of direct numerical simulations have been performed, revealing the interaction between the polymers and the fluid flow. There is, however, a lack of detailed experimental studies especially on the influence of polymers on turbulent small-scale flow structures. In this study, we measure the three-dimensional velocity field in the central region of the von Kármán swirling (VKS) flow using the Tomographic PIV system. Our results confirms that the flow at the center is axisymmetric and slightly anisotropic. The strain and enstrophy, scalars that describe the strength of small-scale flow structures, are greatly reduced after adding small amounts of long-chain polymers. In addition, in terms of the production terms, it is found that polymers can not only suppress their magnitudes, but modify the distribution, leading to a more symmetrical one. Among the three eigenvalues of rate of strain tensor, the largest one and the smallest one become more symmetrical and more dominant relative to the middle one, which exhibits more axisymmetric anisotropy features at small scales than that in Newtonian case. As instantaneous snapshots are further examined, the flow structures are found to be more rare and more aligned with the axial direction of VKS. The fact that in the polymeric VKS flow the vortical structure becomes longer, thicker and more parallel to the mean flow resembles that was observed in the wall-bounded turbulent flows.

Wellposedness of weak solutions to viscoelasticity

Xianpeng Hu(胡先鹏)

The Hong Kong Polytechnic University

In this talk, we will discuss some recent progress in the mathematical analysis for the viscoelastic fluid flow. Global existences of weak solutions will be the main subject. The oscillation and concentration of approximating solutions are two main obstacles. A variant of "effective viscous flux" turns again to be a key tool to deal with the weak stability.

Influence of polymer additive on flow past a hydrofoil

Yongliang Xiong(熊永亮), Haoyu Wang, Sai Peng

Department of Mechanics, Huazhong University of Science and Technology, Wuhan, China

Flow over a hydrofoil is phenomenologically interesting and has practical importance. For instance, the vortex-induced vibration due to the vortex-shedding phenomenon is a major problem in different domains such as marine propeller and hydraulic machinery. Previous studies suggest that the ejection of polymer solutions at very low flow rates at the tip of an elliptical hydrofoil is an effective way of delaying the onset of cavitation. In this talk, we focus on the viscoelastic flow past a hydrofoil (NACA0012) and the effect of the polymer additives on both the drag and lift forces for various flow configurations is examined. Both the direct numerical simulation and experiments are performed to investigate the modification of wake pattern due to the addition of polymer. The influence of polymer additive is modelled by FENE-P model in order to simulate a non-linear modulus of elasticity and a finite extendibility of the polymer macromolecules. Simulations were carried out at a Reynolds number of 1000 with angle of attack varying from 0 to 20 degrees. In the experiment, the PAM concentration varies from 0 to 100PPM. The results show that the influence of polymer on the flow behavior of the flow past a hydrofoil exhibits different flow regimes. In general, the addition of polymer modifies the wake patterns for all angles of attack in this study. Consequently, both drag and lift forces are changed as the Weissenberg number or the concentration. While the drag of the hydrofoil is enhanced at small angles of attack and reduced at large angles of attack.

Viscoelastic flow dynamics of human blood based on microfluidic experiments and multiscale simulations

Shuo Wang(王烁)[1], Keqin Han[1], Xiaojing Qi[1], Shuhao Ma[1], **Xuejin Li[1*]**

[1] Department of Engineering Mechanics, Zhejiang University, Hangzhou 310027, China

Blood is a non-Newtonian viscoelastic fluid, primarily composed of blood cells suspended in blood plasma. Changes in blood rheological properties are typically associated with blood disorders; therefore, understanding the flow dynamics and rheological properties of blood allows us to assess how blood viscosity impacts cognitive functions and provides guidance for therapeutic interventions. By combining dynamic microfluidic experiments with multiscale simulations, we systematically investigate blood viscoelasticity, encompassing various levels including whole blood, single red blood cell (RBC), sub-cellular membrane, and intracellular cytosol. Our

study demonstrates the crucial role of viscoelastic properties in blood rheology, RBC deformation and flow dynamics in spleen slits and microvessels with the endothelial glycocalyx layer, illustrating viscoelastic changes in both healthy and diseased conditions.

Key Words: *Viscoelastic flow, Blood rheology, Red blood cell, Multiscale modelling*

Droplet trapping and releasing due to viscoelastic oscillation

Chiyu Xie(谢驰宇)

School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing 100083, P. R. China

Many important applications in the food industry, biological systems, and recovery of fluids from the subsurface involve multiphase flow dynamics where one of the phases is a non-Newtonian, viscoelastic fluid. In our recent experiments, we observed permanent trapping of an oscillating, non-wetting droplet in a converging-diverging micro-channel when aqueous, viscoelastic fluids are injected. Classical theories based on the balance between capillary and viscous forces suggest that the droplet size should decrease with increasing flow rates of a displacing Newtonian fluid, and completely be displaced at high injection rates. However, droplets in viscoelastic fluids cannot be removed by increasing flow rates due to the oscillation; the oscillation amplitude linearly increases with the Deborah number (De), which further inhibits the droplet's passing through the constriction, "permanently".

We perform lattice Boltzmann (LB) modeling of wetting viscoelastic fluids that displace non-wetting, trapped droplets in two different pore geometries: a converging-diverging channel and a "dead-end" pore geometry. Disordered streamlines are found in both cases, although the Reynolds numbers (Re) are below 1. In the converging-diverging geometry, a vortex downstream of the droplet is found to directly prevent the droplet from entering the throat, explaining the trapping phenomenon. We also find that the self-rotational time of the vortex is just around the viscoelastic relaxation time, which illustrates that the disorder of streamlines in viscoelastic fluids is due to elastic instability. Therefore, the viscoelastic oscillation is a new form of elastic instability in the presence of another fluid. In the "dead-end" pore geometry, we further find that the viscoelastic oscillation can also help to release trapped droplets from their original hard-to-displace positions.

These results show a new important mechanism of viscoelastic fluid for enhanced fluid recovery and also the possibility of manipulating droplets using elastic instability.

Keplerian turbulence in Taylor-Couette flow of dilute polymeric solutions

Fenghui Lin(林锋辉)

Department of Modern Mechanics, University of Science and Technology of China

Keplerian turbulence in Taylor-Couette flow (TCF) of dilute polymer solutions has been investigated via direct numerical simulations (DNS) for the shear Reynolds number (Re) ranges from 10^2 to 10^4. The penetrated coherent structures that span across the gap with smaller axial length scales than the gap width are demonstrated to persist for all the considered Re, which results in a scaling regime for the angular momentum transport and the characteristic length scale. Specifically, the angular momentum transport reflected by Nu_ω is shown to scale with the shear driving force denoted by Re as $Nu_\omega \sim Re^{0.43}$. The exact relation between the Newtonian kinetic energy and polymeric energy dissipation rates and the angular momentum transport has been derived and shown to agree well with present DNS data. Moreover, it is demonstrated that in viscoelastic Keplerian turbulence, Nu_ω mainly comes from the effects of elastic stresses, while the convective fluid motions make less contribution. This study has paved the way for future systematic investigations on the scaling relations in TCF of dilute polymeric solutions.

Hydrodynamic instabilities in viscoelastic Taylor-Couette flow

Dongdong Wan(万冬冬), Mengqi Zhang(张蒙齐)

Department of Mechanical Engineering, National University of Singapore

Taylor-Couette flow, owning to its simple geometry but rich dynamics, is one of the mostly studied flow configurations both experimentally and numerically in the field of fluid dynamics. When dilute polymer solutions are used as the fluid medium, the associated viscoelasticity brings more complexity into the flow system. Investigating such flow's instability can be helpful in promoting our understanding of the flow transition mechanisms and the subsequent viscoelasticity-modified inertia turbulence, elastoinertial turbulence or purely elastic turbulence, depending on the parameter setting. The parameter space is so large that the literature on the flow instability up to now still only covers a small portion of it, even though the easiest research dates back to 1960s. Specifically, significant parameters include the inner cylinder-outer cylinder radius ratio, the Taylor number or alternatively the Reynolds number defined based on the cylinder rotation speed, the solvent-to-solution viscosity ratio, the Weissenberg number or alternatively the elasticity number. Additionally, in the framework of

stability analysis, both the axial wavenumber and the azimuthal wavenumber are important because a linear instability can be triggered in the flow by various types of disturbances being axisymmetric, non-axisymmetric or helical. From the weakly nonlinear perspective, the flow bifurcation at the primary linear criticality can be subcritical or supercritical, again depending on the parametric point. By revisiting this flow problem, our current research work is dedicated to providing a more complete stability diagram of this classical flow system in larger parameter space, partially aiming to unravel new flow physics in extreme parameter settings as inspired by some recent discoveries of novel center-mode instabilities in viscoelastic plane Poiseuille flows.

Constitutive equation for dilute suspensions containing compressible and distortable bubbles

Hu Sun(孙虎)[1], Qingfei Fu(富庆飞)[1,2]*, Lijun Yang[1,2]

[1] School of Astronautics, Beihang University, Beijing 100191, PR China

[2] Aircraft and Propulsion Laboratory, Ningbo Institute of Technology, Beihang University, Ningbo 315800, PR China

ChinaCorresponding author: Qingfei Fu

A theoretical constitutive equation for dilute bubble suspensions incorporating both expansion and shear effects is derived by analyzing the deformation process of a single bubble and its surrounding flow field. The findings reveal the presence of a non-linear coupling stress containing both the expansion rate and shear rate of the macroscopic flow. This suggests that previous linear superposition approach, which assumes the effects of spherical compressible bubbles and distorted bubbles with constant volume to be separate, do not accurately describe the rheological behavior of bubble suspensions. To investigate the impact of this coupling effect, the constitutive equation is simplified for a specific flow field with simple shear and uniform expansion. A new dimensionless number, Ex, is introduced to describe the relative importance of expansion effects versus shear effects in this flow field. Analyses indicate that this coupling effect results in an expansion-dependent viscosity, $\mu(Ex)$, which is similar to the well-known shear-dependent viscosity. Specifically, the equivalent shear viscosity of the suspension increases due to bubble expansion and decreases due to compression, with this effect being particularly significant in low shear flow fields with large pressure changes. Additionally, the expansion rate of the suspension has an impact on other rheological parameters, such as normal stress differences, but the main region of influence shifts to the high shear rate cases.