PROGRAM "AT A GLANCE"

Wednesday, July 16 2025, CISM (Piazza Garibaldi 18, Udine)	
8:30-9:30	Registration and Opening
9:30-10:10	Keynote Lecture: Anthony Wachs
10:10-10:40	Coffee break
10:40-12:20	Session 1
12:20-14:00	Lunch break
14:00-14:40	Keynote Lecture: Alfredo Soldati
14:40-15:40	Session 2
15:40-16:10	Coffee break
16:10-17:30	Session 3
19:30	Pizza dinner

Thursday, July 17 2025, CISM (Piazza Garibaldi 18, Udine)	
9:00-9:40	Keynote Lecture: Marco Rosti
9:40-10:40	Session 4
10:40-11:10	Coffee break
11:10-12:30	Session 5
12:30-14:00	Lunch
14:00-14:40	Keynote Lecture: Martin Sommerfeld
14:40-15:40	Session 6
15:40-16:10	Coffee break
16:10-17:10	Session 7
19:30	Social Dinner

Friday, July 18 2025, CISM (Piazza Garibaldi 18, Udine)	
9:00-9:40	Keynote Lecture: Gautier Verhille
9:40-10:40	Session 8
10:40-11:10	Coffee break
11:10-12:10	Session 9
12:10-12:50	Keynote Lecture: Mona Rahmani
12:50-13:00	Closing remarks
13:00-14:30	Lunch

LOCAL ORGANIZING COMMITTEE

René van Hout (Technion - IIT, IL) - **Chair**
Cristian Marchioli (University of Udine, IT) – **co-Chair**
Alessio Roccon (University of Udine, IT) - **Scientific Secretary**

SCIENTIFIC COMMITTEE

Jeremie Bec (Université Côte d'Azur, FR)
Donald Bergstrom (University of Saskatchewan, CA)
Mickael Bourgoin (Univ. Lyon, FR)
Luca Brandt (Politecnico di Torino, IT)
Wim-Paul Breugem (TU Delft, NL)
Filippo Coletti (ETH Zurich, CH)
Niels Deen (TU/e Eindhoven, NL)
Michael Fairweather (University of Leeds, UK)
Susumo Goto (Osaka University, JP)
Jason Hearst (NTNU, NO)
Santiago Lain (Universidad Autónoma de Occidente, CO)
Fredrik Lundell (KTH Stockholm, SE)
Andrea Mazzino (University of Genova, IT)
Jordi Pallares (Universitat Rovira i Virgili, ES)
Francesco Picano (University of Padova, IT)
Alain Pumir (École Normale Supérieure de Lyon, FR)
Jure Ravnik (University of Maribor, SI)
Anubhab Roy (Indian Institute of Technology Madras, IN)
Berend van Wachem (Otto von Guericke University, DE)
Romain Volk (École Normale Supérieure de Lyon, FR)
Greg Voth (Wesleyan University, USA)
Lianping Wang (Southern University of Science and Technology, CN)
Lihao Zhao (Tsinghua University, CN)

USEFUL INFORMATION

Registration Desk Hours
Wednesday, July 16: 8:30-9:30, CISM (Piazza Garibaldi 18, Udine).

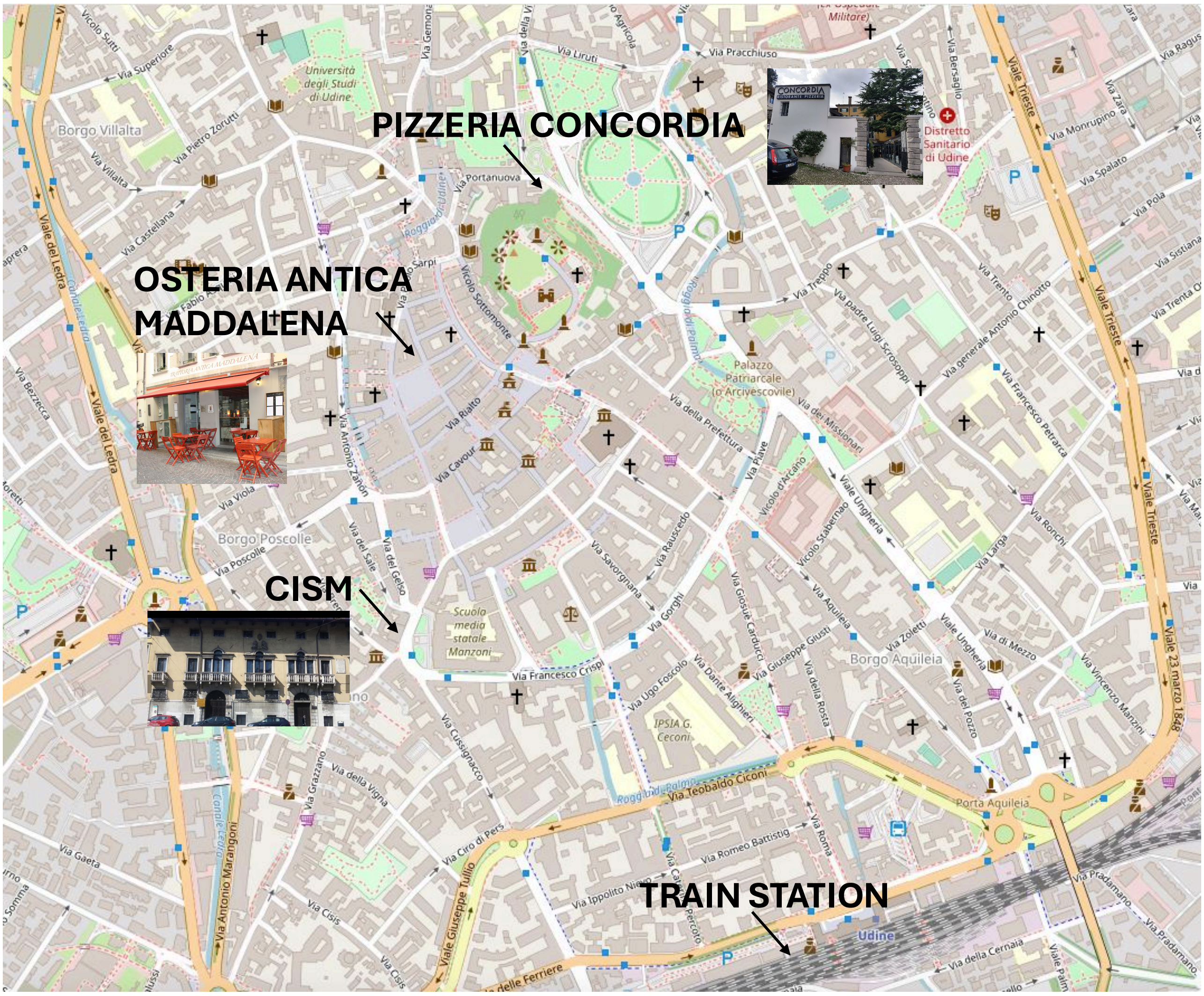
PIZZA DINNER

The Pizza Dinner will be held on Wednesday, July 16, 2025, at Pizzeria Concordia, piazza I° Maggio 9/A, Udine (19:30 -22:30).

SOCIAL DINNER

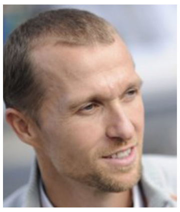
The Social Dinner will be held on Thursday, July 17, 2025, at Osteria Antica Maddalena, via Pelliccerie 4, Udine (19:30 -22:30).

MEETING VENUE



KEYNOTE LECTURES

Wednesday, 16 July 2025



9:30 – CISM

Chair: C. Marchioli

ON THE DYNAMICS OF FLOWS LADEN WITH ANGULAR RIGID BODIES

A. Wachs

University of British Columbia, CA

Wednesday, 16 July 2025

14:00 – CISM

Chair: S. Goto

PREFERENTIAL ORIENTATION AND ROTATION OF MICROFIBERS AND THEIR CONNECTION WITH SMALL SCALE TURBULENCE DYNAMICS

A. Soldati

TU Wien, AT

Thursday, 17 July 2025

09:00 – CISM

Chair: L. Brandt

HYDRODYNAMICS OF FLEXIBLE AQUATIC PLANTS

M. Rosti

Okinawa Institute of Technology, JP

Thursday, 17 July 2025

14:00 – CISM

Chair: M. Rosti

STRATEGIES FOR MODELLING NON-SPHERICAL PARTICLE TRANSPORT IN THE FRAME OF AN EULER/LAGRANGE APPROACH

M. Sommerfeld

Otto von Guericke University, DE

Friday, 18 July 2025

9:00 – CISM

Chair: R. van Hout

TRAPPING OF FLEXIBLE DISCS BY A VORTEX

G. Verhille

IRPHE Marseille, FR

Friday, 18 July 2025

12:15 – CISM

Chair: C. Brouzet

EFFECTS OF GRAVITATIONAL SETTLING ON AGGREGATION OF MICROPARTICLES IN TURBULENT FLOWS

M. Rahmani

University of British Columbia, CA

INSTRUCTIONS FOR SPEAKERS AND SESSION CHAIRS

1. Keynote talks will be assigned 35 minutes for presentation, plus additional 5 minutes for questions and change of speaker.
2. Regular contributed talks will be assigned 17 minutes for presentation, plus additional 3 minutes for questions and change of speaker.
3. Chair persons are kindly asked to strictly maintain the schedule, even in the case of no-show.
4. The conference room will be equipped with a PC (capable of displaying PDF and Powerpoint presentations) and an LCD projector. Laser presentation pointers can be provided upon request of the Chair person and depending on availability.
5. Speakers may use their own laptop. However, in order to minimize technical difficulties, they are also kindly invited to upload their presentation in the conference PC and test the presentation well beforehand.
6. Please prepare a good quality portable PDF version of the presentation in the case other formats are not supported by the PC.

ORGANIZERS

UNIUD
University of Udine

uniud.it

The University of Udine was founded in 1978 as part of the reconstruction plan of Friuli after the earthquake in 1976. Its aim was to provide the Friulian community with an independent center for advanced training in cultural and scientific studies. Udine and its University are a point of reference in a region that is historically a meeting place and crossroads of different worlds and cultures. Geographically situated in the center of the European Union, the University of Udine plays an active role in a close network of relations, committed to sharing its knowledge and ideas. Since its establishment, Udine University has pursued the policy of internationalization, aimed at preparing students and forging relations and partnerships with universities and institutions in Europe and the rest of the world.

TECHNION – IIT
Israel institute of technology

technion.ac.il

The Technion is one of the world's leading universities for training scientists and engineers. Its alumni fill central positions in the Israeli and global economies and spearhead basic and applied research both in academia and knowledge-rich technology industries. Technion alumni are prevalent in the management of industrial plants and construction companies, as well as in the fields of urban and regional planning, infrastructure and energy sources, and medicine. They are groundbreakers at the helm of Israel's high-tech revolution and played a key role in shaping the famous Start-Up Nation. Since it was founded 100 years ago, the Technion has proudly stood at the forefront of the national mission of training a highly skilled and knowledgeable workforce capable of boosting Israel's economic and physical security.

CISM
International Centre of Mechanical Sciences

cism.it

CISM, International Centre for Mechanical Sciences, is a no-profit organization, founded in 1968 to favor the exchange and application of the most advanced knowledge in the mechanical sciences, in interdisciplinary fields like robotics, biomechanics, environmental engineering and in other fields (mathematics, information and system theory, operations research, computer science, artificial intelligence). The principal activity of the Centre is the organization of courses, seminars, workshops, symposia, and conferences to present the state of the art of these sciences to researchers. It also provides advanced training for engineers operating in industry. CISM is funded by the Friuli Venezia Giulia Region, the Province of Udine and the city of Udine, and local public and private institutions, together with other member institutions in Europe and abroad. Further financial support comes from the National Research Council of Italy (CNR), and from UNESCO. CISM also has consolidated relations with AIMETA, ECCOMAS, ERCOFTAC, EUROMECH, GAMM, IFToMM and IUTAM.

EUROMECH
International Centre of Mechanical Sciences

euromech.org

The European Mechanics Society serves as a organization dedicated to the advancement of science and research within the broad field of mechanics. Recognizing this pursuit as a charitable endeavor, EUROMECH aims to foster a vibrant and collaborative European mechanics community. To achieve its objectives, EUROMECH undertakes a range of activities designed to stimulate scientific exchange and progress. These include the organization of European colloquia and conferences covering diverse topics within mechanics, as well as establishing strong connections between researchers and institutions engaged in this and related scientific disciplines. The society also plays a crucial role in collecting and disseminating relevant information and promoting scientific publications in the field. Recognizing the importance of future generations, EUROMECH is committed to supporting young scientists and awarding prizes and recognitions to those who make significant contributions. As a non-profit entity, EUROMECH operates selflessly, focusing solely on the promotion of science for the public benefit.

PROGRAM SUMMARY

July 16, 2022	**WEDNESDAY (DAY 1)**		
8:30-9:30	Registration	CISM	
9:15-9:30	Welcome from the organizers (van Hout, Marchioli)		
9:30-10:10	**KEYNOTE LECTURE:** A. Wachs – *On the dynamics of flows laden with angular rigid bodies*		C. Marchioli
10:10-10:40	Coffee break		
	Contributed talks – Session #1		A. Soldati
10:40-11:00	*Orientation dynamics of rapidly settling anisotropic particles in turbulence* (A. Roy)		
11:00-11:20	*Fibers settling in turbulence* (A. Gambino, S. Brizzolara, M. Holzner, F. Coletti)		
11:20-11:40	*Effect of free-stream turbulence on the trajectories of free-falling discs* (P. Alexandrou, C. Bose, I. M. Viola, A. Attili)		
11:40-12:00	*Dynamics of a group of cylinders falling at moderate Reynolds number in liquid at rest in a confined cell* (D. Letessier, V. Roig, P. Ern)		
12:00-12:20	*Settling dynamics of Kolmogorov-scale slightly-heavier-than-fluid ellipsoidal particles in isotropic turbulence* (S.V. Apte, N. Keane)		
12:20-14:00	Lunch Break		
14:00-14:40	**KEYNOTE LECTURE:** A. Soldati – *Preferential orientation and rotation of microfibers and their connection with small scale turbulence dynamics*		S. Goto
	Contributed talks – Session #2		A. Wachs
14:40-15:00	*Dynamics of long fibers in a turbulent channel flow* (D. Sun, J. Bec, C. Brouzet)		
15:00-15:20	*Supramolecular polymers for turbulent drag reduction* (F. Serafini, F. Battista, P. Gualtieri, C.M. Casciola)		
15:20-15:40	*Spinning rate of slender fibers as a probe for dissipation in wall turbulence* (V. Giurgiu, D. Zaza, M. Iovieno, A. Soldati)		
15:40-16:10	Coffee break		
	Contributed talks – Session #3		P. Ern
16:10-16:30	*CFD study of non-spherical particle transport and deposition in a realistic nasal cavity replica* (J. Wedel, N. Catalán, P. Steinmann, M. Hriberšek, S. Cito, S. Varela, J. Pallarès, J. Ravnik)		
16:30-16:50	*Experimental investigation of fiber-laden, coaxial round water jets* (D. Hasin, Y. Reingewirtz, R. van Hout)		
16:50-17:10	*Interaction of rigid, inertial fibers with vortical structures in the near-field of a co-axial jet* (A. Yosef, D. Hasin, Y. Reingewirtz, A. Mitra and R. van Hout)		
17:10-17:30	*Motion of Lagrangian point-particles in rotating turbulence* (F. Pizzi, D. Martin, G. Mamatsashvili, M. Rahmani, L. Jofre)		
19:30	Pizza Dinner	Pizzeria Concordia	

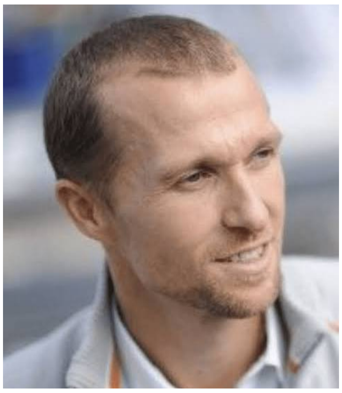
July 17, 2025	THURSDAY (DAY 2)	Venue	Chairperson
9:00-9:40	**KEYNOTE LECTURE:** M. Rosti – *Hydrodynamics of flexible aquatic plants*	CISM	L. Brandt
	Contributed talks – Session #4		A. Roy
9:40-10:00	*Accumulation of deformable neutrally buoyant particles in coherent vortices* (S. Goto, Y. Motoori, Y. Fujiki, H. Awai)		
10:00-10:20	*Dynamics of rotation of flexible fibers transported by a homogeneous and isotropic turbulent flow* (H. Poncelet, G. Verhille)		
10:20-10:40	*Slender heavy fibers in turbulent channel flows: Effects of fiber length, flexibility and fluid inertia* (D.J. Dhas, C. Marchioli)		
10:40-11:10	Coffee Break		
	Contributed talks – Session #5		A. Roccon
11:10-11:30	*Dispersion and tracking of spherical and non-spherical heavy particles in turbulence* (Y. H. Tee, P. R. Benonisen, K. Muller, R. J. Hearst)		
11:30-11:50	*Flow fluctuations after swarms of spheres and spheroids in settling* (M. Moriche, M.-García-Villalba, M. Uhlmann)		
11:50-12:10	*Turbulence in a suspension of settling non-spherical particles* (L. Brandt, L. Zhao, X. Jiang)		
12:10-12:30	*Particle-resolved simulations of suspensions of settling finite length cylinders* (X. Yuan, J-L. Pierson, O. Simonin, A. Wachs)		
12:30-14:00	Lunch Break		
14:00-14:40	**KEYNOTE LECTURE:** M. Sommerfeld – *Strategies for modelling non-spherical particle transport in the frame of an Euler/Lagrange approach*		M. Rosti
	Contributed talks – Session #6		S.V. Apte
14:40-15:00	*Fast predicting the trajectory of chip-like particles by integrating a DEM model with a CFD-based aerodynamic database* (B. Li, J. Lin, K. Luo, S. Wang, J. Fan)		
15:00-15:20	*A 3D incompressible direct numerical simulation solver based on vorticity-stream-potential formulation* (J. Tan, Q. Li, C. Pan)		
15:20-15:40	*A module Lagrange particle solver based on dynamic linked list* (Q. Li, C. Pan)		
15:40-16:10	Coffee Break		
	Contributed talks – Session #7		M. Sommerfeld
16:10-16:30	*Heat transfer in drop-laden turbulence* (A. Roccon, F. Mangani, F. Zonta, A. Soldati)		
16:30-16:50	*Efficient survival strategy for zooplankton in turbulence* (J. Qiu, N. Mousavi, B. Mehlig, L. Zhao, K. Gustavsson)		
16:50-17:10	*The limiting behavior of elastic turbulence* (P. Garg, M.E. Rosti)		
19:30	Social Dinner	Osteria Antica Maddalena	

July 18, 2025	Friday (DAY 3)	Venue	Chairperson
9:00-9:40	**KEYNOTE LECTURE:** G. Verhille – *Trapping of flexible discs by a vortex*	CISM	R. van Hout
	Contributed talks – Session #8		M. Rahmani
9:40-10:00	*Edge-effects in turbulent canopy flows* (G. Foggi Rota, E. Tressoldi, M.E. Rosti)		
10:00-10:20	*A robust convection module solver: applications in Interface capture and Hydraulics prediction* (Q. Li, Y . Yu, H. Ding, W. Wang, J. Zhao, C. Pan)		
10:20-10:40	*Unresolved Euler-Lagrange simulations of non-spherical particles with liquid injection* (N. Vanzetto, N. Deen, Y. Tang)		
10:40-11:10	Coffee Break		
	Contributed talks – Session #9		G. Verhille
11:10-11:30	*Hydrodynamic forces on a rotating helical particle in a viscous fluid flow* (Z. Li, Y. Li, C. Xu, L. Zhao)		
11:30-11:50	*Bidisperse elastic capsules: Effects of size and inertia on suspension rheology* (A. Mucalica, G. Gai, J. J Feng, A. Wachs)		
11:50-12:10	*Relative alignment of colliding rod-like particles in turbulence* (H. Luo[1], L. Zhao[2])		
12:10-12:50	**KEYNOTE LECTURE:** M. Rahmani – *Effects of gravitational settling on aggregation of microparticles in turbulent flows*		C. Brouzet
12:50-13:00	Closure		R. van Hout, C. Marchioli
13:00-14:30	Lunch		

ABSTRACTS ORAL PRESENTATIONS

Keynote lecture
On the Dynamics of Flows laden with Angular Rigid Bodies

A. Wachs
University of British Columbia, Canada



We discuss recent results on the dynamics of a single or multiple angular rigid bodies of aspect ratio 1 immersed in the flow of a Newtonian fluid. We analyze various data sets generated by particle resolved simulations that pertained to four specific flow configurations: (i) the flow past a single stationary rigid body, (ii) a single rigid body settling in an otherwise quiescent fluid, (iii) the transverse hydrodynamic force and torque exerted on a transversely rotating and moving rigid body, and (iv) multiple cubic rigid bodies settling in an otherwise quiescent fluid. In (i)-(iii), we use octree adaptive mesh refinement to properly capture the vorticity generation in the boundary layer around the angular rigid body that is key to the wake dynamics. In all cases, the Reynolds number computed with the rigid body characteristic length lies in the interval [10,400] where inertia is dominant. We examine these flows in terms of hydrodynamic force and torque, wake structure and suspension microstructure. Our work contributes to clarify the role of particle angularity in rigid particle-laden flows.

Keynote lecture

Preferential Orientation and Rotation of Microfibers and their Connection with Small Scale Turbulence Dynamics

A. Soldati
TU Wien, Austria

The straining and rotation in small-scale turbulence are governed by coherent structures: vortex tubes with strong rotation (high enstrophy) and strain sheets (high dissipation). These regions shape the dynamics of small particles through the local velocity gradient. For example, inertial spherical particles are expelled from vortices due to centrifugal forces and accumulate in strain-dominated zones. In contrast, inertialess elongated particles preferentially sample intense vortical structures and tend to align with the vorticity, making their rotation rates informative of small-scale turbulence. In this talk, we briefly review the physics of elongated particles in turbulence and present recent experiments from the TU Wien Turbulent Water Channel. We exploit the preferential alignment and clustering of elongated particles in vortices to perform novel optical Lagrangian measurements of their spinning (around the longitudinal axis) and tumbling (around transverse axes) rates. We use high-aspect ratio, mildly curved plastic fibers, slightly longer than the Kolmogorov scale. Their shape allows for unique 3D orientation tracking and homogeneous full-rotation datasets. These measurements, linked with turbulent flow properties obtained via DNS, enable insights into the motion, dispersion, and sedimentation of anisotropic particles relevant for understanding the behavior of microplastics in the ocean.

Keynote lecture
Hydrodynamics of flexible aquatic plants

M. Rosti
Okinawa Institute of Technology, Japan

Submerged vegetation plays a crucial role in aquatic ecosystems by promoting sediment retention, enhancing the transport of suspended species, and attenuating incoming waves. Flexible stems, which bend and sway with water currents, exhibit complex dynamics that, in turn, influence fluid motion. Using fully resolved and coupled numerical simulations with our in-house solver Fujin, we first examine the response of a single flexible stem to a monochromatic surface wave and to broadband turbulent flow. We then extend our analysis to flexible canopies - dense arrays of slender stems anchored to a substrate - exploring both their collective behaviour, such as monami waves, and the individual motion of stems and their interaction with the incoming flow. Our findings provide new insights into the hydrodynamics of submerged vegetation, shedding light on key natural processes while also laying the groundwork for innovative engineering applications.

Keynote lecture

Strategies for Modelling Non-Spherical Particle Transport in the frame of an Euler/Lagrange Approach

M. Sommerfeld
Otto von Guericke University, Germany

The importance of numerical calculations for supporting optimisation and lay-out of industrial processes involving dispersed multiphase flows is continuously increasing. In predicting dispersed gas-solid flows the general assumption made is that the particles are spherical. However, in most practical situations the particle shape deviates from spherical, either being irregular in shape or having a certain geometry, such as granulates or fibres. In such cases the fluid dynamic transport characteristics (i.e., forces acting on the particles) differ from that of spherical particles and using correlations derived for spheres may yield incorrect results. Additionally, in confined particle-laden flows wall collisions remarkably govern the particle transport. There are in principle three modelling strategies to consider non-spherical particles listed below with increasing modelling effort: (i) The simplest approach is using only averaged drag coefficients which are depending on the particle Reynolds number and the sphericity of the particle considering a fixed orientation with respect to the relative flow; (ii) The second approach applies for irregular shaped particles with sphericities of larger than about 0.7, where the instantaneous forces and moments on the particles are randomly generated from previously generated PDFs obtained by particle-resolved simulations; (iii) The most rigorous approach is valid for regular shaped particles with a defined major axis, like fibres and ellipsoids. Here the particles are tracked by additionally solving for the orientation, requiring resistance coefficients based on orientation and Reynolds number previously generated by particle-resolved simulations. These approaches will be validated through experimental studies obtained for different experimental flow configurations.

Keynote lecture
Trapping of Flexible Discs by a Vortex

G. Verhille[1], E. Ibarra[1] and F. Candelier[1,2]
[1] IRPHE - UMR 7342, CNRS, Aix-Marseille Univ., Centrale Méditerranée, 13013 France
[2] Aix-Marseille Université, CNRS, IUSTI UMR 7343, 13013 Marseille, France

In turbulent flow, particle clustering depends on how particles are either expelled or trapped by vortices. A first step in investigating the influence of flexibility on particle transport in turbulent flows is understanding their dynamics in vortical flows. In this talk, I will present an unexpected observation on the trapping of flexible discs heavier than the surrounding fluid in the vicinity of a vortex.

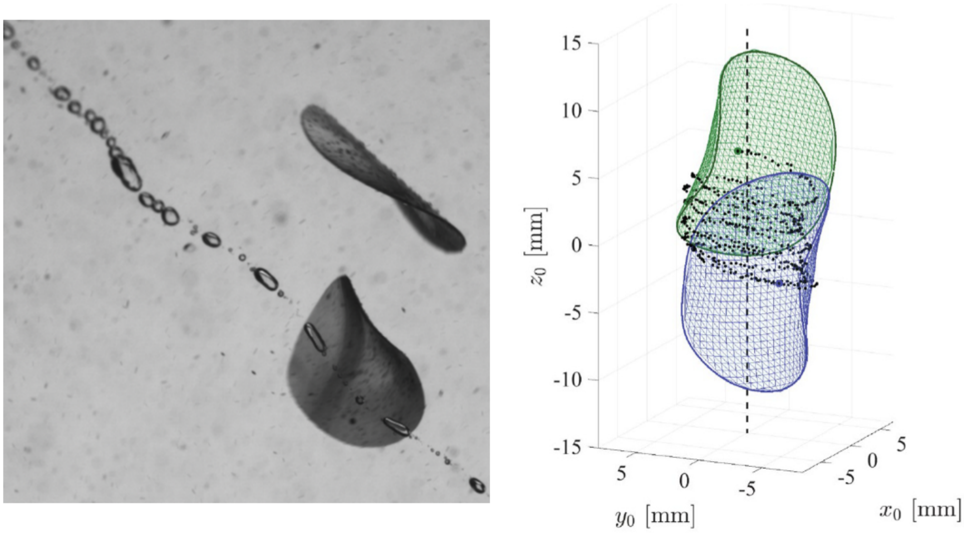


Figure 1: Illustration of two discs trapped by a vortex visualized thanks to bubble and the reconstruction of the trajectory and the shape of a trapped disc

Keynote lecture

Effects of Gravitational Settling on Aggregation of Microparticles in Turbulent Flows

M. Rahmani
University of British Columbia, Canada

Aggregation of microparticles is an important mechanism for the vertical transport of microplastics, mineral particles, and organic matter in natural aqueous environments. In particular, aggregation of particles of different sizes and densities changes the effective settling velocity of the original constituent particles, contributing to large fluxes of microplastics, diatoms, and carbon in the oceans. In these flow settings, particles have low inertia but relatively high settling velocities, making the interplay between gravitational effects and turbulence highly nonlinear. In this talk, we will focus on how the combination of turbulent shear and differential settling can contribute to geometric collision of microparticles in aquatic environments. We use direct numerical simulations of homogeneous and isotropic turbulence (HIT) coupled to the Lagrangian tracking of point particles. Binary collisions between pair particles are detected and upon collision particles merge into an aggregate with a statistical probability that represents their efficiency of aggregation. Our results reveal that for monodispersed particles, gravitational settling reduces the collision rate as the settling particles have shorter residence times within an eddy. Conversely, differential settling markedly enhances the collision rate for bidisperse particles with differing densities. Finally, we will discuss some aspects of the effects of aggregation efficiency or "stickiness" and the growth of biofilm on microplastics on their total aggregation rate.

Orientation Dynamics of Rapidly Settling Anisotropic Particles in Turbulence

Anubhab Roy[1]
[1] Department of Applied Mechanics, IIT Madras, Chennai - 600036, India

We investigate the orientation dynamics of an anisotropic particle, modelled as a spheroid, settling in homogeneous isotropic turbulence. At the particle scale, we assume viscous effects dominate, allowing analysis in the Stokes regime. When the particle's size is smaller than the Kolmogorov length scale, the surrounding flow can be approximated as a stochastic linear flow field. This approximation is particularly useful when the orientation dynamics of the spheroid, governed by the Jeffery equation (Jeffery, 1922), depends on the local fluctuating velocity gradient. The turbulent velocity gradient is modeled using the stochastic framework of Girimaji and Pope (1990), incorporating the log-normal distribution of pseudo-dissipation.

At distances exceeding the particle's longest dimension, convective fluid inertia plays a significant role due to either the background shear or particle translation. If the effects of fluid inertia due to the latter dominate, it induces an inertial torque that aligns the spheroid in broadside orientation. We explore the interaction between turbulent velocity gradient-induced torques and inertial effects from settling. Orientation dynamics are analyzed using a dimensionless parameter S_F, the ratio of the Kolmogorov time scale to the particle's settling time scale. For low S_F, the spheroid exhibits nearly isotropic orientation distributions, while for higher S_F, the rapid settling limit leads to preferential fluctuations normal to gravity. Using asymptotic methods, we derive moments of the orientation distribution in the rapid-settling limit and validate them numerically (Roy et al., 2023). The second-order moment, characterizing orientation fluctuations depends on S_F and the aspect ratio of the spheroid. The predictions from the rapid settling limit compare favourably with the numerical results. We also compute the fourth-order moment, measuring the effect of non-Gaussianity of the velocity gradient statistics, and show that the kurtosis increases with the increase in Taylor-scale Reynolds number.

References

G.B. Jeffery. Proc. R. Soc. London A, **102**, 715, 1922.

S. S. Girimaji, and S. B. Pope. Phys. Fluids, **2**, 242-256, 1990.

A. Roy, S. Kramel, U. Menon, G. A. Voth, and D. L. Koch. J. Non-Newtonian Fluid Mech., **318**, 105048, 2023.

Fibers Settling in Turbulence

Alessandro Gambino[1], Stefano Brizzolara[2], Markus Holzner[3], Filippo Coletti[1]
[1] Institute of Fluid Dynamics, ETH Zürich, Switzerland
[2] Institute of Science and Technology Austria (ISTA), Austria
[3] University of Natural Resources and Life Sciences (BOKU), Austria

In this work, we investigate the dynamics of heavy fibers settling in turbulence. We consider the general case in which fiber motion is influenced by both turbulence and gravity, whose effects have mostly been explored separately, and we ask two complementary questions: how does gravity affect fiber rotation in turbulence and how does turbulence affect heavy fiber settling. To address these questions, we conducted experiments in a turbulence tank at ETH Zürich, where fibers of different densities, lengths and thicknesses were tracked and their orientation reconstructed using a 3D particle-tracking velocimetry system. As exemplified in Figure 1(a), the fluttering motion of fibers settling in quiescent water (left) is destabilized by turbulence (right), which also causes large variations in the vertical velocity. For rotational dynamics, Figure 1(b) shows that heavier fibers (darker color) exhibit a shorter autocorrelation time τ_z for the vertical rotation rate. This results from gravitational drift, characterized by the ratio Sv_L of gravitational velocity to the root-mean-squared turbulent fluctuations, which causes fibers to experience a more rapidly changing flow velocity field, leading to a faster decorrelation. Our results are compared with data from neutrally buoyant fibers [1,2], which shows that inertia, conversely, produces a slower decorrelation of the tumbling rate due to the inertial filtering of velocity fluctuations.

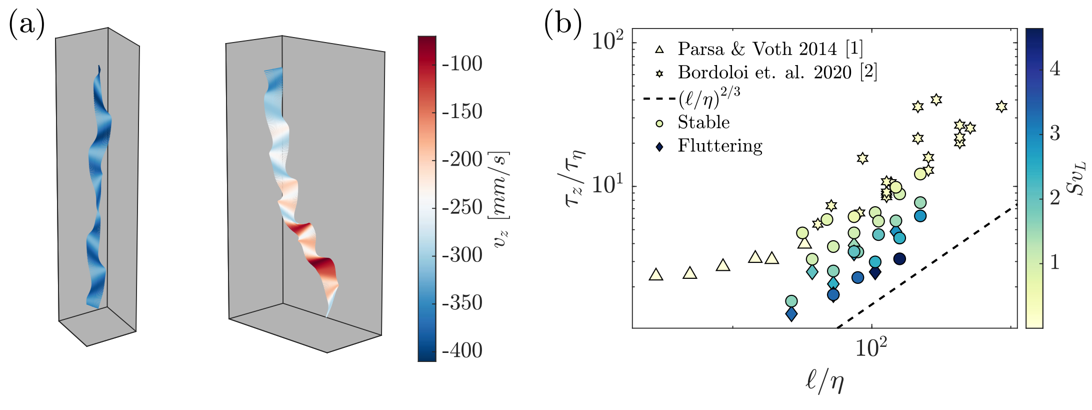


Figure 1:(a) Reconstructed trajectory of a 10-mm long steel fiber settling in quiescent (left) and turbulent (right) water. (b) Normalized fiber tumbling rate autocorrelation timescale color-coded with Sv_L. The measurements from [1] for neutrally buoyant fibers, along with the theoretical scaling they proposed, and [2] for inertial fibers are shown.

References

[1]: Parsa & Voth, *Physical Review Letters*, **112.2** (2014)

[2]: Bordoloi A.D. et. al., *Frontiers in Marine Science*, 7, 473 (2020).

Effect of free-stream turbulence on the trajectories of free-falling discs

P. Alexandrou[1], C. Bose[2], I. M. Viola[1] A. Attili[1]
[1] University of Edinburgh, EH9 3FD, United Kingdom
[2] University of Birmingham, B12 2TT, United Kingdom

March 15, 2025

The trajectories of free-falling discs in turbulence are investigated. Different free-falling regimes depend on the Archimedes number ($Ar = U_g d/\nu$), a measure of the ratio of gravitational forces against viscous forces based on the gravitational velocity $U_g = \sqrt{((\rho^* - 1)dg)}$, where g is the gravitational acceleration, ν is the kinematic viscosity, and ρ^* is the ratio between the disc and fluid densities. They also depend on the non-dimensional moment of inertia $I^* = \pi\rho^* t/64d$, where t is the disc thickness. The background turbulence is governed by the Taylor microscale Reynolds number (Re_λ) and the ratio of the integral length scale to the disc diameter, l/d. We investigate discs in the transitional regime ($Ar = 800$ and $I^* = 0.005$), interacting with turbulence characterised by $l/d = 6, 4$ and $Re_\lambda = 45$. Turbulence is statistically stationary in time, decays in the streamwise direction, and is homogeneous and isotropic in the spanwise directions. Turbulence is superimposed on a constant mean inlet velocity equal to the average terminal velocity in quiescent conditions (U_t), using the forward stepwise method (Xie and Castro, 2008). Figure 1 shows the time evolution of the vertical position (Z) of the disc for the three cases considered. The quiescent baseline exhibits planar oscillations that slowly transition to a stable spiral regime as observed by (Lee et al., 2013). For the same Re_λ, the $l/d = 6$ case exhibits an average terminal velocity 10% lower than a disc falling in quiescent flow, while for the $l/d = 4$ case it is only 5% lower. This is evidenced by their respective slopes seen in Figure 1.

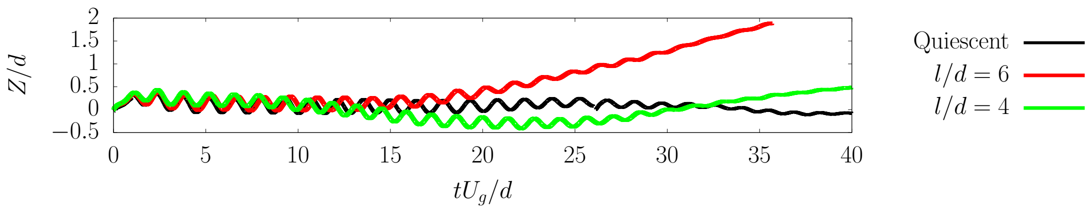


Figure 1: Time evolution of the vertical position (Z) for a disc in quiescent and turbulent conditions.

References

Z.-T. Xie and I. P. Castro. Efficient generation of inflow conditions for large eddy simulation of street-scale flows. *Flow, Turbulence and Combustion*, 81(3):449–470, 2008.

C. Lee, Z. Su, H. Zhong, S. Chen, M. Zhou, and J. Wu. Experimental investigation of freely falling thin disks. Part 2. Transition of three-dimensional motion from zigzag to spiral. *Journal of Fluid Mechanics*, 732:77–104, 2013.

Dynamics of a group of cylinders falling at moderate Reynolds number in liquid at rest in a confined cell

Dylan Letessier[1], Véronique Roig[1] and Patricia Ern[1]
[1] Institut de Mécanique des Fluides de Toulouse,
CNRS, INPT and Université de Toulouse, France

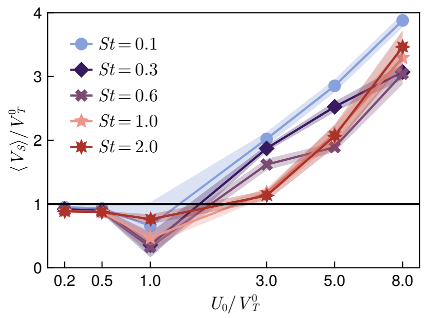
The inertial sedimentation of anisotropic solid particles within a liquid confined in a thin-gap cell was investigated experimentally. Groups with various particle numbers ($N_c \in \{50, 60, 100, 200, 333\}$) involving cylinders having aspect ratios ($\xi \in \{1, 3, 5, 10\}$), solid to fluid density ratios ($\frac{\rho_c}{\rho_f} \in \{1.4, 2.5, 2.7\}$) and settling velocities corresponding to moderate Reynolds numbers (50 to 200) were examined. For comparison, spherical particles were also included. These parameters conditions correspond to two distinct path regimes for the isolated cylinders: oscillatory trajectories for higher-density cylinders and rectilinear sedimentation for lower-density ones. In both cases, we observed the formation of sub-groups (termed objects of class N) composed of N cylinders in contact as well as spatio-temporal recombinations due to splitting or merging of these objects. Depending on the aspect ratio and density ratio of the cylinders composing the group, specific distributions of class-N objects are found. In addition, beyond the formation of individual objects, large-scale columnar structures emerge, characterized by vertical alignments of densely packed objects and alternating regions of ascending and descending fluid. These structures, driven by complex interactions between local clustering and global flow organization, persist throughout the sedimentation process. Despite its inner complex dynamics driven by hydrodynamic interactions, inter-particle interactions and confinement effects, the group is observed to sediment as a collective entity, with a constant sedimentation velocity exceeding that of an isolated cylinder in fluid at rest. This constant sedimentation velocity exhibits minimal sensitivity to particle number, Nc, and may be predicted from multi-scale information. Fluctuations in objects velocities are further analysed, and distinct mechanisms are identified for the horizontal and vertical components. Horizontal fluctuations are linked to intrinsic particle mobility, while vertical fluctuations are attributed to strong wakes and large-scale vertical streams. These vertical fluctuations are primarily influenced by particle aspect ratio, which affects the structural and spatial distribution of the objects.

The authors acknowledge financial support from ANR under the form of project "Muscats" ANR-19-CE05-0010.

Settling dynamics of Kolmogorov-scale slightly-heavier-than-fluid ellipsoidal particles in isotropic turbulence

S.V. Apte[1], and N. Keane[1]
[1]Oregon State University, Corvallis, Oregon, USA

Turbulent flow with suspended, non-spherical particles can be found in several applications such as sediment transport, spray droplets, microplastics in ocean, among others. Although turbulence with dispersed spherical particles has been studied extensively, modeling the dynamics of non-spherical particles in a turbulent flow has not been studied extensively. Motion of spherical particles in complex flows is typically captured using the point-particle model wherein the particle is assumed small compared to the smallest flow scale, and closure models are used for forces acting on the particle. In order to capture the dynamics of ellipsoidal particles, the point-particle model is extended by solving for the position, translational velocity, orientation, and angular velocity of particles at low Reynolds numbers. In this work, we investigate the differences in settling dynamics of ellipsoidal and spherical particles in (i) a cellular vortical flow such a Taylor-vortex, and (ii) homogeneous, isotropic turbulence. Settling dynamics are investigated by varying vortex strength or turbulence intensities relative to the particle settling speed in quiescent flow for multiple Stokes numbers. Enhancement and decrease in settling speed compared to that in quiescent fluid due to fast-tracking and loitering mechanisms, respectively, are investigated in detail. The length scales associated with the turbulence structures that strongly interact and influence settling dynamics are identified using the vertical fluid velocity and second invariant of velocity gradient tensors sampled by the particles, and the time scales are investigated using curvature angle statistics of inertial and fluid particle trajectories.



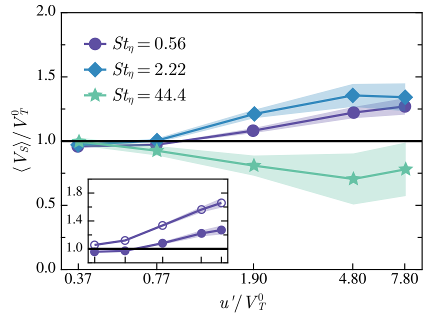


Figure 1: Normalized settling speed versus normalized intensity of spherical particles at different Stokes numbers in (a) Taylor-Green vortex, (b) isotropic turbulence.

References

S.Lain. *Advanced Computational Fluid Dynamics for Emerging Engineering Processes*. DOI: 10.5772/intechopen.81045, 2018.

Dynamics of long fibers in a turbulent channel flow

D. Sun[1], J. Bec[1,2] and C. Brouzet[1,2]
[1] Université Côte d'Azur, CNRS, INPHYNI, Nice, France
[2] Université Côte d'Azur, Inria, CNRS, Calisto team, Sophia Antipolis, France

The dynamics of fibres in wall-bounded turbulent flows is a topic of great concern in various fields, such as environmental science or pulp and paper industries. It has been extensively studied in the past decades (Voth and Soldati (2017); Shaik et al. (2020); Alipour et al. (2021)), but mainly focusing on rigid and relatively short fibres. Here, we investigate the dynamics of long fibres in a turbulent channel flow, using a combination of experiments and direct numerical simulations. We consider fibers whose length ℓ is of the order of the channel half-height h. In particular, we focus on the interplay between the pole-vaulting mechanism at the wall (Bec et al. (2024)), propelling long fibers toward the flow center, and inertia, accumulating fibers at the wall through turbophoresis (Dotto and Marchioli (2019)).

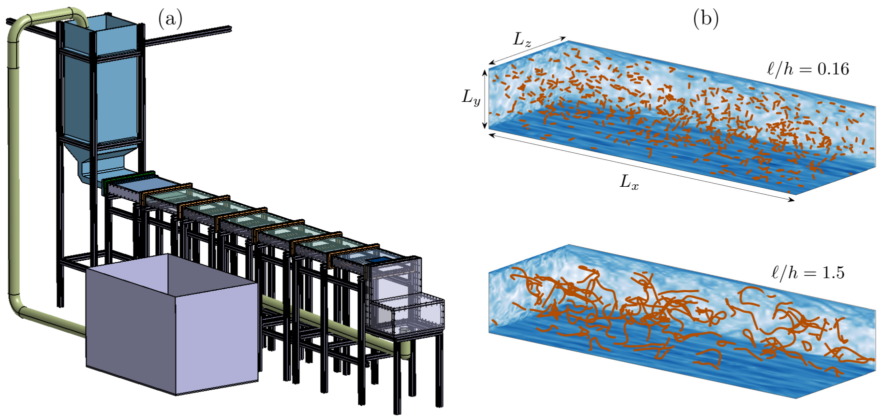


Figure 1: (a): Sketch of the experimental turbulent channel flow, with a total length of 4.5 m and a rectangular cross section of dimensions 40×400 mm^2. (b): Snapshots of fibers with different lengths in the flow obtained using the numerical simulations (adapted from Bec et al. (2024)). The mean flow is from left to right in both panels.

References

G. Voth and A. Soldati, *Anisotropic Particles in Turbulence*, Annual Review of Fluid Mechanics **49**, 249-276 (2017).

S. Shaik, S. Kuperman, V. Rinsky, and R. van Hout *Measurements of length effects on the dynamics of rigid fibers in a turbulent channel flow* Physical Review Fluids **5**, 114309 (2020).

M. Alipour, M. De Paoli, S. Ghaemi, and A. Soldati *Long non-axisymmetric fibres in turbulent channel flow* Journal of Fluid Mechanics **916**, A3 (2021).

J. Bec, C. Brouzet, and C. Henry, *Enhanced transport of flexible fibers by pole vaulting in turbulent wall-bounded flow*, Physical Review Fluids **9**, L062501 (2024).

D. Dotto, and C. Marchioli, *Orientation, distribution, and deformation of inertial flexible fibers in turbulent channel flow*, Acta Mechanica **230**, 597-621 (2019).

Supramolecular Polymers for Turbulent Drag Reduction

F. Serafini[1], F. Battista[1], P. Gualtieri[1] and C.M. Casciola[1].
[1] Dept. of Mechanical and Aerospace Engineering, Sapienza University of Rome

It took five decades from Tom's discovery before DNS demonstrated viscoelasticity as crucial in polymer-induced drag reduction (DR) – Sureshkumar (1997), De Angelis (2002). The polymer chain was modeled as a dumbbell with two massless beads connected by a nonlinear spring stretched by the solvent (FENE model). To make the model tractable, the Peterlin approximation was adopted (FENE-P model). Recently, see the review by Ching (2024), such approximation was removed by following every single dumbbell – Serafini (2022) – and the analysis was extended to multiple beads, Serafini (2024).

Covalently bonded polymers suffer from mechanical degradation, eventually rendering them futile. Here, we intend to move forward, addressing supramolecular polymers that can assemble and de-assemble, making them particularly interesting for DR. They also present anti-mist properties useful in preventing explosions, e.g., in the event of aircraft crashes. In the talk, besides presenting state-of-the-art and new numerical results for the more usual covalently bonded chains, a statistical mechanics model for supramolecular polymers will be illustrated, discussing preliminary results concerning their behavior in turbulence.

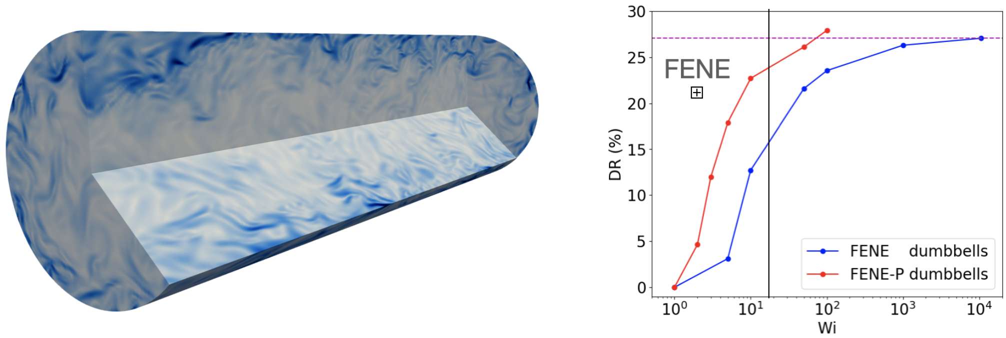


Figure 1: Flow structures in a drag-reducing polymer flow and comparison of DR between standard FENE-P and the present semi-Lagrangian approach.

References

R. Sureshkumar, A.N. Beris, and R.A. Handler. *Direct numerical simulation of the turbulent channel flow of a polymer solution.* Phys. Fluids, **9**(3), 743-755, 1997.

E. De Angelis, C.M. Casciola, and R. Piva. *DNS of wall turbulence: dilute polymers and self-sustaining mechanisms.* Computers & fluids, **31**(4-7), 495-509, 2002.

F. Serafini, F. Battista, P. Gualtieri, and C.M. Casciola. *Drag reduction in turbulent wall-bounded flows of realistic polymer solutions*, Phys. Rev. Lett., **129**(10),104502, 2022.

F. Serafini, F. Battista, P. Gualtieri, C.M. Casciola. *Polymers in turbulence: any better than dumbbells?*, JFM, **987**, R1, 2024.

E.S.C Ching. *Less is more: modelling polymers in turbulent flows*, JFM, **994**, F1, 2024.

Spinning Rate of Slender Fibers as a Probe for Dissipation in Wall Turbulence

V. Giurgiu[1], D. Zaza[1], M. Iovieno [2], and A. Soldati[1]
[1] Institute of Fluid Mechanics and Heat Transfer, TU Wien, 1060 Vienna, Austria
[2] Department of Mechanical and Aerospace Engineering, Polytechnic University of Turin, 10129 Turin, Italy

In the study of turbulent flows, obtaining information on the structure and dynamics of small-scale motions requires accurate knowledge of the components of the velocity gradient tensor (VGT). While direct numerical simulations provide a straightforward and accurate evaluation of the derivatives of the fluid velocity, experimental approaches face significant challenges, generally requiring three-dimensional velocity field measurements with high spatial resolution. In this study, point-particle direct numerical simulations and experimental measurements of small, slender fibers in turbulent channel flows are performed to evaluate the ability of fiber rotation rates to estimate VGT-related quantities. The investigation covers shear Reynolds numbers, Re_τ, ranging from 180 to 720, and considers fibers with high aspect ratio, small inertia, and lengths within the dissipative range of turbulence. In the central region of the channel, both numerical and experimental observations indicate that the mean squared angular velocity of the fibers around their longitudinal axis – commonly referred to as the mean squared spinning rate – provides a reliable estimate of the mean dissipation rate of turbulent kinetic energy. Numerical results further extend this finding to the near-wall region ($y^+ \gtrsim 20$).

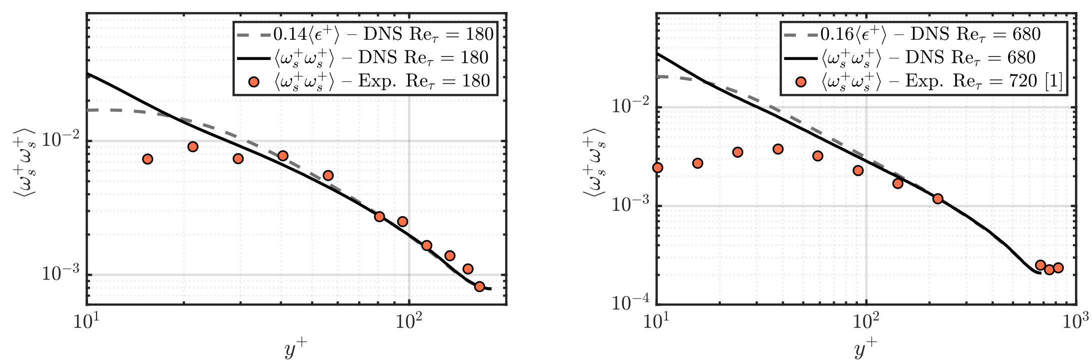


Figure 1: Mean squared spinning rate of slender fibers, $\langle\omega_s^+\omega_s^+\rangle$, obtained from numerical simulations and experiments, as a function of the wall-normal coordinate y^+, for different Re_τ. The mean dissipation rate, $\langle\epsilon^+\rangle$, scaled by a constant factor, is also shown.

References

[1] V. Giurgiu, G. C. A. Caridi, M. De Paoli, and A. Soldati. *Full Rotational Dynamics of Plastic Microfibers in Turbulence*. Phys. Rev. Lett. , **133**, 054101, 2024.

CFD study of non-spherical particle transport and deposition in a realistic nasal cavity replica

J. Wedel[1], N. Catalán[2], P. Steinmann[1], M. Hriberšek[3], S. Cito[2*], S. Varela[2], J. Pallarès[2], J. Ravnik[3]
[1] Universität Erlangen-Nürnberg, Germany
[2] Universitat Rovira i Virgili, Spain
[3]University of Maribor, Slovenia

Humans are constantly exposed to airborne pollutants. In recent years, the deposition of microplastic inside the human body emerged as a pressing problem of modern society, with microplastics found in organs such as the brain, leading to health concerns (Zarus *et al.* 2021). Further hazardous particles include asbestos fibers, causing diseases such as asbestosis and cancer. While many fibres inflict health issues, some can also be beneficial such as fibre-like drug carriers in the medical field. One of the main transport routes of these particles into the human body is through inhalation. As most particles are arbitrarily shaped and shape factors have been shown to fail to accurately predict their particle motion, (Wedel 2023), an accurate model for these particles is required. In general, due to the anisotropic shape, the orientation of the particles must be considered, making realistic particles dynamics far more complex than that of spheres. In this study, a numerical simulation of non-spherical particles in a realistic nasal cavity is performed using the superellipsoid transport model as presented in Wedel *et al.* (2023). In this context, large numbers of particles of different sizes and shapes, including spherical particles, were injected. Figure 1 shows the comparison of the deposition between ellipsoid and spherical particles of $d = 10\ \mu m$, illustrating that the particle shape strongly influences the deposition concentration.

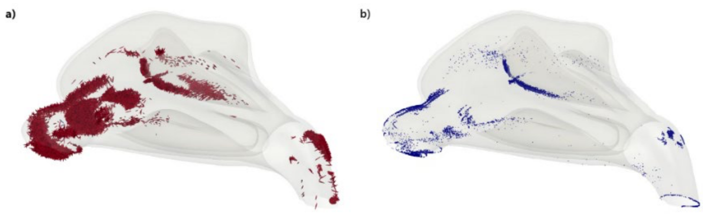


Figure 1: Non-spherical Particle deposition ($d = 10\ \mu m$): (a) fibers and (b) spheres.

References

Wedel, J., Steinmann, P., Štrakl, M., Hriberšek, M., & Ravnik, J. (2023). Shape matters: Lagrangian tracking of complex nonspherical microparticles in superellipsoidal approximation. *International Journal of Multiphase Flow*, *158*, 104283.

Zarus, G. M., Muianga, C., Hunter, C. M., & Pappas, R. S. (2021). A review of data for quantifying human exposures to micro and nanoplastics and potential health risks. *Science of the Total Environment*, *756*, 144010.

Experimental Investigation of Fiber-laden, Coaxial Round Water Jets

D. Hasin[1], Y. Reingewirtz[1] and R. van Hout[1]
[1] Technion - Israel Institute of Technology,
Faculty of Mechanical Engineering, Technion City, 320003 Haifa, Israel

Coaxial jets are extensively used in industrial and biomedical applications. They consist of inner and outer jets and exhibit wake or shear layer instabilities depending on the ratio between the outer and inner jet exit velocity, r_u. This research focuses on the differences in fiber kinematics when the same nylon fibers (about 1.5 mm long, Reingewirtz et al. (2024)) are issued from the inner jet into a coaxial jet at varying $r_u = 0$, 1.0, and 2.5. In all these three cases, the inner jet velocity was kept constant and r_u was changed by changing the outer jet velocity. As a result of changing r_u the inertial response of the fibers governed by the Stokes number, St, is different. Planar high-speed particle image velocimetry measurements were performed to resolve simultaneously the instantaneous flow field as well as the fiber motion. These measurements enabled to quantify important instantaneous fiber-flow quantities such as the slip velocity and rotational slip from which fiber Reynolds numbers were estimated. Differences in these quantities as a result of changing r_u and implications on force calculations will be discussed. In addition, following Baker et al. (2022), fiber tumbling rates were calculated. This study provides a detailed analysis of fiber-flow coupling, focusing on flow regime characteristics, fiber slip characteristics (velocity and rotational slip), and fiber tumbling rates at various velocity ratio case.

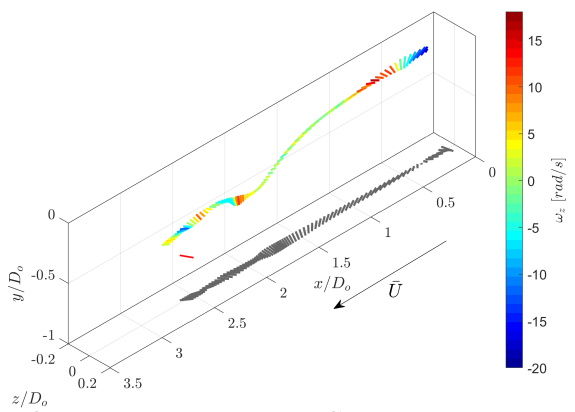


Figure 1: Example of a fiber track at $r_u = 1.0$. Colors indicate the value of the component of the tumbling rate ω_z.

References

Y. Reingewirtz, Hasin, D., van Hout, R. *Fiber-flow interaction in the near field of a coaxial round jet.* Physical Review Fluids, **9**, 2024.

L. J. Baker, F. Coletti. *Experimental investigation of inertial fibers and disks in a turbulent boundary layer.* Journal of Fluid Mechanics, **943**, 2022.

Interaction of Rigid, Inertial Fibers with vortical structures in the Near-Field of a Co-Axial Jet

A. Yosef[1], D. Hasin[1], Y. Reingewirtz[1], A. Mitra[2] and R. van Hout[1]

[1] Technion - Israel Institute of Technology, Faculty of Mechanical Engineering, Technion city, Haifa, 3200003, Israel

[2] Technion - Israel Institute of Technology, Faculty of Aeronautics, Technion city, Haifa, 3200003, Israel

This study explores the interaction between rigid, inertial fibers and vortices in the near-field of turbulent coaxial jets consisting of an inner round, and an outer annular jet (Reingewirtz et al., 2024). Coaxial jets occur in various engineering applications including particle transport. The flow field of a coaxial jet depends on many parameters, such as the ratio between the outer and inner jet velocity, $r_u = U_o/U_i$, nozzle geometry, and absolute velocity magnitudes (Hasin et al., 2025). The near-field region is characterized by shear layers producing coherent vortices that govern mixing and momentum transfer. In this research, mm-sized fibers were introduced into the inner jet and the interaction between the fibers and near-field vortices was measured using time-resolved particle image velocimetry (PIV). The measurements were conducted at $r_u = 1.0$ and 2.5, and especially for $r_u = 2.5$, the shear layer vortices had a significant impact on fiber motion, alignment and rotation. In this talk, a detailed analysis of the fiber motion (translation and rotation) as well as the relative position/alignment between the fiber and the instantaneous inner shear layer interface and vortices are analyzed. At $r_u = 2.5$, fibers were propelled from the inner jet across the inner shear layer into the outer jet resembling a "sling effect". This study reports on the fiber translational and rotational motion as it interacts with the coherent inner shear layer vortices and crosses the inner shear layer boundary at $r_u = 2.5$. These results provide a foundation for developing predictive models for fiber behavior in coaxial jet flows.

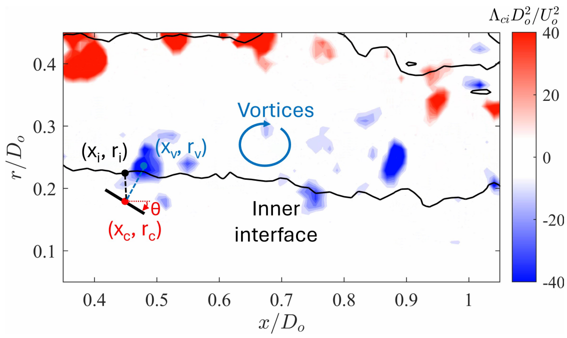


Figure 1: Snapshot of fiber superposed on the instantaneous, normalized swirling strength distribution.

References

D Hasin, A Mitra, and R van Hout. Coaxial round water jet at velocity ratios close to unity, part i: Mean and turbulent flow characteristics. *International Journal of Heat and Fluid Flow*, 112:109650, 2025.

Y. Reingewirtz, D. Hasin, and R. van Hout. Fiber-flow interaction in the near field of a coaxial round jet. *Physical Review Fluids*, 9(10):104305, 2024.

Motion of Lagrangian point-particles in rotating turbulence

F. Pizzi[1], D. Martin[1], G. Mamatsashvili[2,3], M. Rahmani[4] and L. Jofre[1]
[1] Department of Fluid Mechanics, Universitat Politècnica de Catalunya
Barcelona 08019, Spain
[2] Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400,
D-01328 Dresden, Germany
[3] Abastumani Astrophysical Observatory, Abastumani 0301, Georgia
[4] Department of Chemical and Biological Engineering,
The University of British Columbia, Vancouver, BC V6T 1Z3, Canada

The interaction between large-scale vortices and the underlying three-dimensional turbulent fluctuations raises fundamental questions [Pizzi et al. (2022); Smith and Waleffe (1999)], particularly regarding the statistical properties of rotating turbulence and its effect on Lagrangian particle dynamics [Biferale et al. (2016); Monroy et al. (2017)]. To date, most studies on particle laden turbulence have focused on homogeneous and isotropic turbulence (HIT) [Brandt and Coletti (2022)], overlooking the ubiquitous importance of rotation, which fundamentally alters the turbulence dynamics. In fact, rotating turbulence introduces anisotropic flow structures that significantly impact particle clustering, dispersion, and preferential concentration, making its study essential for both fundamental and applied research. For example, the particle preferential concentration, which is controlled by the Stokes number, may significantly differ from the isotropic case (see Fig. 1).

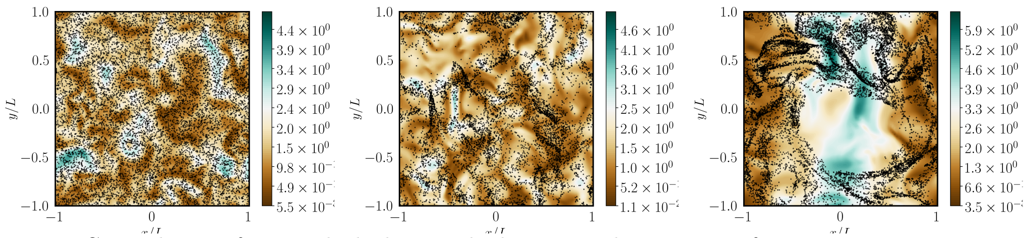


Figure 1: Snapshots of particle-laden turbulent simulations. Left: Homogeneous isotropic turbulence (HIT) with tracer particles. Center: HIT with particles having a unitary Stokes number. Right: Rotating turbulence with particles having a unitary Stokes number.

This study aims to provide insights into the behavior of tracer, light, and mildly heavy particles using a state-of-the-art high-fidelity direct numerical simulation solver [Jofre et al. (2023)]. It focuses on weak and strong rotation conditions with the objectives of: (i) analyzing preferential concentration as a function of Rossby and Stokes numbers, and (ii) examining the influence of rotation on particle trajectories and properties such as acceleration and helicity. This preliminary results serve to expand the current limited model about e.g. planetary formation and especially microplastic in the oceans [Pizzi et al. (2024); Rahmani et al. (2022)].

Acknowledgement

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Sklodowska-Curie grant agreement no. 101151441.

References

L. Biferale, F. Bonaccorso, I. M. Mazzitelli, M. A. T. van Hinsberg, A. S. Lanotte, S. Musacchio, P. Perlekar, and F. Toschi. Coherent structures and extreme events in rotating multiphase turbulent flows. *Phys. Rev. X*, 6:041036, 2016. doi:10.1103/PhysRevX.6.041036.

Luca Brandt and Filippo Coletti. Particle-laden turbulence: Progress and perspectives. *Annual Review of Fluid Mechanics*, 54(Volume 54, 2022):159–189, 2022. doi:https://doi.org/10.1146/annurev-fluid-030121-021103.

LluÃs Jofre, Ahmed Abdellatif, and Guillermo Oyarzun. Rhea: an open-source reproducible hybrid-architecture flow solver engineered for academia. *Journal of Open Source Software*, 8:4637, 2023. doi:10.21105/joss.04637.

P. Monroy, E. Hernández-García, V. Rossi, and C. López. Modeling the dynamical sinking of biogenic particles in oceanic flow. *Nonlinear Processes in Geophysics*, 24(2):293–305, 2017. doi:10.5194/npg-24-293-2017.

F. Pizzi, G. Mamatsashvili, A. J. Barker, A. Giesecke, and F. Stefani. Interplay between geostrophic vortices and inertial waves in precession-driven turbulence. *Physics of Fluids*, 34(12):125135, 2022. doi:10.1063/5.0131035. URL `https://doi.org/10.1063/5.0131035`.

F. Pizzi, M. Rahmani, C. Romera-Castillo, F. Peters, J. Grau, F. Capuano, and L. Jofre. Impact of coagulation characteristics on the aggregation of microplastics in upper-ocean turbulence. *Advances in Water Resources*, 193:104798, 2024. ISSN 0309-1708. doi:https://doi.org/10.1016/j.advwatres.2024.104798.

Mona Rahmani, Akanksha Gupta, and LluÃs Jofre. Aggregation of microplastic and biogenic particles in upper-ocean turbulence. *International Journal of Multiphase Flow*, 157:104253, 2022. ISSN 0301-9322. doi:https://doi.org/10.1016/j.ijmultiphaseflow.2022.104253.

Leslie M. Smith and Fabian Waleffe. Transfer of energy to two-dimensional large scales in forced, rotating three-dimensional turbulence. *Physics of Fluids*, 11(6):1608–1622, 06 1999. doi:10.1063/1.870022.

Accumulation of deformable neutrally buoyant particles in coherent vortices

S. Goto, Y. Motoori, Y. Fujiki and H. Awai
The University of Osaka, Toyonaka, Osaka, 560-8531, Japan

There exist coherent vortices in turbulence. This is also the case even in developed turbulence at high Reynolds numbers, implying that turbulence is composed of the hierarchy of coherent vortices with various spatiotemporal scales (Goto and Motoori, 2024).

Therefore, interactions between particles and turbulence can be regarded as those between particles and coherent vortices. This view is useful when we investigate particle behavior in turbulence. For example, we can explain the clustering of inertial particles in turbulence by the simple mechanism that heavy (or light) small particles are swept out from (or attracted by) coherent vortices.

Interestingly, however, a non-spherical particle can be expelled or attracted by a vortex even if it is neutrally buoyant. Our numeral simulations by the immersed boundary method have demonstrated that an elongated spheroidal particle is repeatedly attracted and expelled by a vortex. We have also shown that a simple model can explain this behavior of an elongated particle (Fujiki et al. 2024).

The behavior of a deformable particle is further interesting. In the present study, we have conducted direct numerical simulations of a hyper-elastic neutrally buoyant particle around a vortex to discover the following phenomenon (Fujiki et al. 2024). The particle is first deformed by straining flow around the vortex [figure 1(b)], migrates into the vortex due to the effect similar to an elongated rigid particle [figure 1(b,c)]; and then, when it reaches the central region of the vortex, the deformation is relaxed for the particle to stay there [figure 1(d)]. This behavior implies the possibility that deformable neutrally buoyant particles can make clusters in coherent vortices in turbulence.

References

S. Goto and Y. Motoori. *Hierarchy of coherent vortices in developed turbulence.* Rev. Mod. Plasma Phys. **8**, 23, 2024.

Y. Fujiki, H. Awai, Y. Motoori and S. Goto. *Attraction of neutrally buoyant deformable particles towards vortex.* Phys. Rev. Fluids, **9**, 014301, 2024.

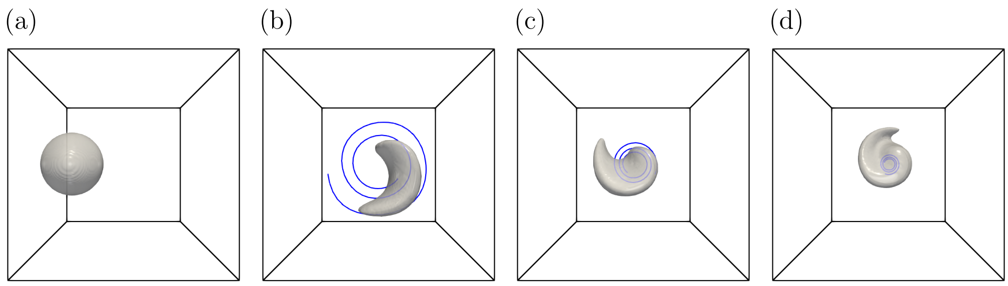


Figure 1: Accumulation of a deformable particle in a vortex, which is located at the center of the figure.

Dynamics of rotation of flexible fibers transported by a homogeneous and isotropic turbulent flow

H. Poncelet* and G. Verhille*
* Institut de Recherche sur les Phénomènes Hors Équilibre, Marseille, France

The dynamics of anisotropic particles in turbulence is a topic of interest for several research groups, with motivations ranging from understanding its fundamental aspects (particles alignment is closely related to their preferential alignment within coherent structures), to industrial applications (papermaking, textile...) and environmental flows (plastic pollution in the ocean, cloud crystal formation...). Most of the existing studies are focused on rigid particles (Oehmke et al., 2021); studies on flexible fibers tend to be either numerical or focused on the statistics of particle deformation.

We present here the first experimental study on the dynamics of flexible fibers in turbulence. We will begin by briefly describing the algorithm used for the 3D reconstruction and comparing our deformation statistics with the current literature. Then we will discuss the relationship between the fibers deformation and their rotational dynamics. Figure 1 displays the normalized tumbling rate $\langle \dot{p}^2 \rangle \tau_k^2$, *i.e.* the rotation of the end-to-end vector of the fiber, as a function of the normalized fiber length L/η_k. This graph shows an increase of the rotation rate with the fiber flexibility, which we will discuss.

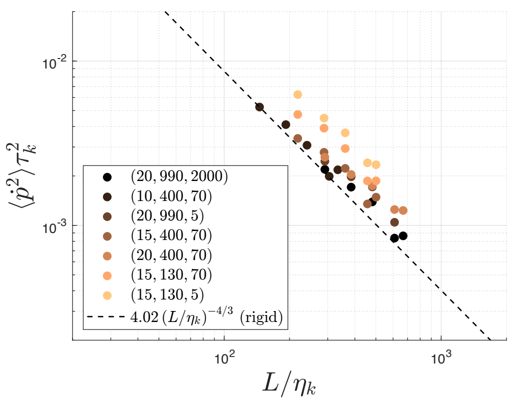


Figure 1: Tumbling rate of the flexible fiber as a function of the fiber length, respectively normalized by the Kolmogorov time τ_k and the Kolmogorov length η_k. The color of the symbols codes the flexibility of the fiber: it goes from dark to bright with the flexibility. The legend is written as followed: (L, d, E) in (mm, µm, kPa) (respectively length, diameter and Young's modulus). The dashed line represents the rigid case (Oehmke et al., 2021).

References

Theresa B. Oehmke, Ankur D. Bordoloi, Evan Variano, and Gautier Verhille. Spinning and tumbling of long fibers in isotropic turbulence. *Physical Review Fluids*, 6(4):044610, April 2021. ISSN 2469-990X. doi:10.1103/PhysRevFluids.6.044610.

Slender heavy fibers in turbulent channel flows - Effects of fiber length, flexibility and fluid inertia

D.J. Dhas[1], and C. Marchioli[1]
[1]Department of Engineering and Architecture, University of Udine, Italy

Suspensions of slender fibers in turbulent flows are ubiquitous, especially in the form of microplastic pollutants that plague our atmosphere and marine ecosystems. A large body of literature exists on the dynamics of flexible fibers whose densities are in the same order as that of the suspending fluid, as would be the case for most marine microplastics. However, relatively little attention has been given to the heavy fibers possessing large density ratios suspended in turbulence, akin to microplastics in the atmosphere. On account of this, we focus on flexible fibers possessing large density ratios of the order 10^2 to 10^3 with respect to the fluid, suspended in a turbulent channel flow with shear Reynolds numbers $Re_\tau = 300$ and 600. We incorporate the effects of fluid-inertial torques by exploiting the model proposed by Dabade et al. (1), in conjunction with the viscous torque as given by Jeffery (2). Subsequently, we investigate the combined role of fiber length, flexibility, and particle and fluid inertia on the collective dynamics of fibers by means of performing direct numerical Euler-Lagrange simulations.

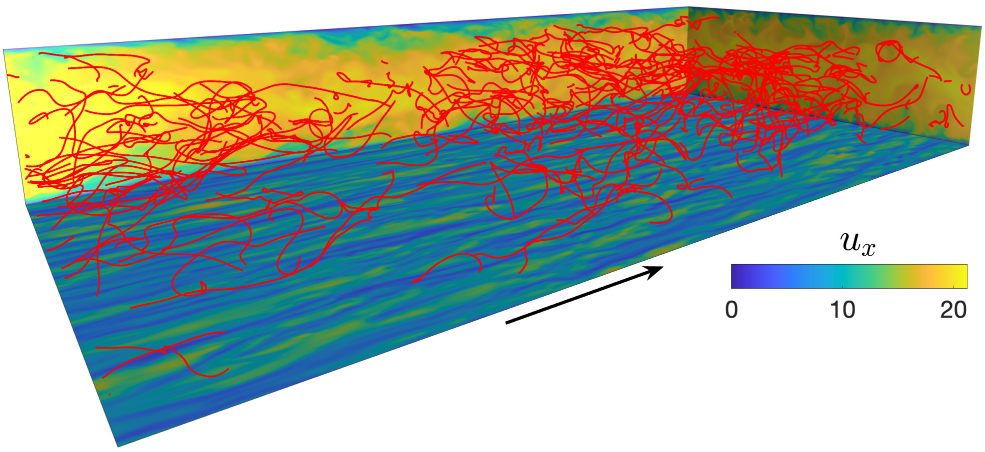


Figure 1: Instantaneous distribution of a random collection of flexible fibers of length $L_0^+ = 380$ in a turbulent channel flow with shear Reynolds number 300. The side and bottom panels display the stream-wise component of the velocity (u_x), with the bottom cut at $z^+ = 10$. The fiber thickness is magnified for better visualization.

References

[1] Dabade V., Marath N.K. & Subramanian G., *Effects of inertia and viscoelasticity on sedimenting anisotropic particles.* J. Fluid Mech, **778**, 133–188, 2015.

[2] Jeffery G.B., *The motion of ellipsoidal particles immersed in a viscous fluid.* Proc. R. Soc. Lond, **102.715**, 161–179, 1922.

Dispersion and Tracking of Spherical and Non-spherical Heavy Particles in Turbulence

Y. H. Tee[1], P. R. Benonisen[1], K. Muller[2] and R. J. Hearst[1]
[1]Norwegian University of Science and Technology, Trondheim, Norway
[2]ETH Zürich, Zürich, Switzerland

The issue of plastic debris accumulating on ocean floors is a growing concern. Ocean currents and turbulence can break down plastic waste into smaller particles, which travel far before settling on the seabed. To understand the settling and dispersion of these particles, we conducted a large-scale study tracking the 3D positions of negatively buoyant particles of various shapes and sizes in turbulent flow. Experiments were conducted in the NTNU water channel facility, which has a test section 11 m long and 1.8 m wide, filled with water up to 0.53 m. An active grid was added at the entrance of the test section to generate freestream turbulence. We investigated four flow conditions with freestream velocities of 0.25 m/s and 0.38 m/s, and turbulence intensities of 4% and 9%. Particles of four geometries (sphere, circular cylinder, square cylinder, and flat cuboid) and two sizes (6 mm and 9 mm) were 3D printed using Tough 1500 resin. Each particle was released individually 30 mm under the free surface at $h = 500$ mm, and 200 drops were recorded for each shape and size at each flow condition. A stereoscopic imaging system with two GoPro HERO 12 cameras tracked the particles' 3D positions. The cameras were calibrated using a linear ray-tracing technique and corrected for image distortion. Figure 1(a) and (b) show the superposition of 10 sample wall-normal trajectories and streamwise velocities of 6 mm spheres when $U_\infty \approx 0.38$ m/s and $TI \approx 9\%$, respectively. The corresponding mean streamwise flow profile at $x = 0.5h$ from the release location, measured separately using particle image velocimetry, is plotted on top of Figure 1(b) as a black dotted curve. Preliminary results show that even for symmetric particles like spheres, their settling trajectories are non-linear and deviate from each other, indicating dispersion starts immediately after release. Particle velocities fluctuate significantly due to freestream turbulence, varying widely even at the same wall-normal location. Depending on the encountered turbulence structures, particles may either lag or lead the mean flow. At the colloquium, we will present how the settling and dispersion of non-spherical particles compare to that of spheres.

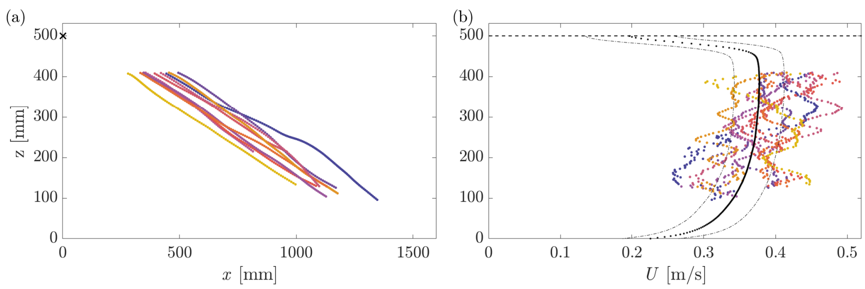


Figure 1: Colored dotted curves in (a) and (b) show 10 sample wall-normal trajectories and streamwise velocities of 6 mm spheres. Black dotted curves in (b) show the wall-normal profiles of mean streamwise velocity (U). Black dashed-dotted lines mark the mean profiles offset by the turbulent fluctuations $TI \approx 9\%$, respectively. Black $\times$ in (a) and horizontal dashed lines in (b) mark the particle release height.

Flow fluctuations after swarms of spheres and spheroids in settling

Manuel Moriche[1], Manuel-García-Villalba[1], Markus Uhlmann[2]
[1]TU Wien, Institute for Fluid Mechanics and Heat Transfer, Vienna, Austria
[2]KIT, Institute for Water and Environment, Karlsruhe, Germany

We analyze the flow fluctuations generated by two sets of particles (spheres and spheroids) settling under gravity in an inflow/outflow configuration. We use a vertically non-periodic configuration that allows us to capture the fluctuating flow left behind the settling particles. The particles have the same volume $V = \pi D^3/6$ (where D is the diameter of a sphere with same volume) and same density ratio $\tilde{\rho} = \rho_p/\rho_f = 1.5$, and the aspect ratio of the spheroids is $\chi = d/a = 1.5$, where d is the equatorial diameter and a the length of the symmetry axis. We select the Galileo number $Ga = U_g D/\nu$, where $U_g = \sqrt{(\tilde{\rho}-1)\, gD}$, such that in both sets of particles a single particle would settle in the steady oblique regime. Triply-periodic configurations in this parametric point have shown clustering behavior (Moriche et al., 2023).

In the case of spheres the Galileo number is $Ga = U_g D/\nu = 178$ and for the spheroids $Ga = 152$. The figure shows the particle distribution for both cases and the flow fluctuations for the case of spheres. In the talk we will also show the flow fluctuations obtained for the case of spheroids, focusing on the differences among the two particle shapes.

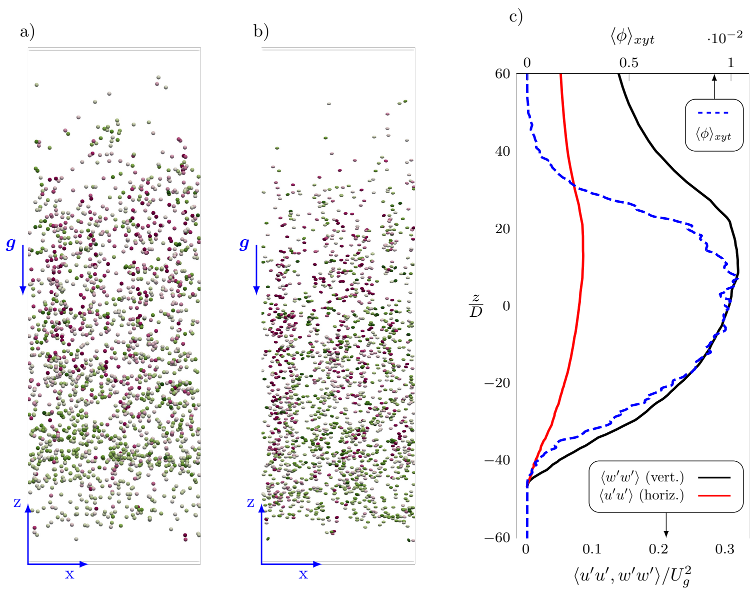


Figure 1: Particle distribution of a) spheres and b) spheroids. c) Averaged solid volume fraction ($\langle\phi\rangle_{xyt}$) and vertical (w') and horizontal (u') flow fluctuations for the case of spheres.

References

M. Moriche, D. Hettmann, M. García-Villalba, and M. Uhlmann. On the clustering of low-aspect-ratio oblate spheroids settling in ambient fluid. *J. Fluid Mech.*, 963:A1, 2023.

Turbulence in a suspension of settling non-spherical particles

L. Brandt[1], L. Zhao [2] and X. Jiang[1,2]
[1]Department of Environmental, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, 10129 Turin, Italy
[2] AML, Department of Engineering Mechanics, Tsinghua University, Beijing, China

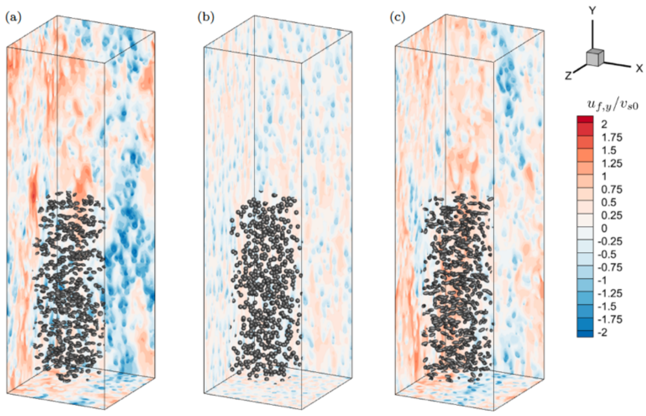


Figure 1: Snapshots of the simulation results for the cases with (a) oblate particles, (b) spherical particles and (c) prolate particles at volume fraction φ = 5%.

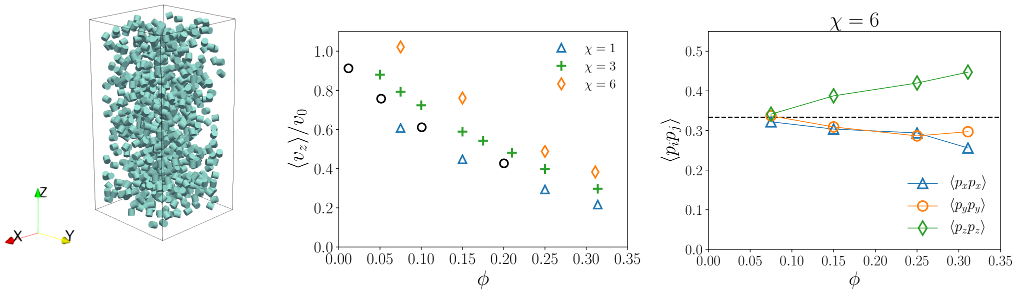
In this study, we investigate the turbulence induced by the sedimentation of spheroidal particles in an initially quiescent fluid and the particle dynamics by means of the particle-resolved direct numerical simulation (PR-DNS). We consider oblate spheroid, sphere and prolate spheroid at fixed Galileo number Ga=80 with density ratio 2 at volume fraction 1% and 5%. Oblate and prolate particles are found to form column-like clusters as a consequence of the wake-induced hydrodynamic interactions. This effect, together with the change of particle orientation, enhances the mean settling velocity of the dispersed phase. In contrast, spherical particles do not exhibit clustering and settle with hindered velocity in the suspension. The local accumulation of oblate/prolate spheroids serves as the major mechanism to promote the particle-particle collisions in dilute suspensions.

Furthermore, we examine the pseudo-turbulence induced by the settling particles and report a non-Gaussian distribution of the fluid velocity and a robust -3 power law of the energy spectra. By scrutinizing the scale-by-scale budget, we find that the anisotropy of the particle-induced pseudo-turbulence is not only manifested by the uneven allocation of turbulent kinetic energy among the different velocity components, but also by the anisotropic distribution of energy in spectral space. The fluid-particle interactions inject energy into the vertical velocity component, thus sustaining the turbulence, while pressure redistributes the kinetic energy among the different velocity components. The redistribution and non-linear transfer of the energy are also intensified in presence of particle clustering, which reduces the anisotropy of the particle-induced pseudo-turbulence.

Particle-resolved simulations of suspensions of settling finite length cylinders

X. Yuan[1], J-L. Pierson[2], O. Simonin[3] and A. Wachs[1]
[1] Department of Mathematics, University of British Columbia, Vancouver, BC, Canada
[2] IFP Energies Nouvelles, Solaize, France
[3] Institut de Mécanique des Fluides de Toulouse (IMFT), Université de Toulouse, CNRS, Toulouse, France

Liquid-solid fluidized beds are commonly encountered in various chemical engineering processes. The dynamics of these systems is usually studied and potentially optimized at the macro scale via Euler-Euler or two-fluid models. The averaging procedure to derive these models and their closure terms has been widely studied in the past for spherical particles in a liquid flow (Jackson, 2000) but the literature is scarcer on non-spherical particles such as cylindrical particles routinely used in the chemical industry. Therefore, we derive the two-fluid equations for cylindrical particles embedded in a liquid based on volume averaging technique for the fluid phase and on the kinetic theory for the solid phase. In contrast to spherical particles, particle orientation plays a significant role in the derivation of the equations and in the closure terms. This orientation can be characterized by the tensor $< p_i p_j >^p$, where p_i is the unit orientation vector of particle i and $<>^p$ is the ensemble average operator over all particles in the system. We rely on particle-resolved direct numerical simulations (PR-DNS) (Wachs et al., 2015) to close the Euler-Euler set of equations. The selected flow configuration is a suspension of settling finite length cylinders in a tri-periodic domain illustrated in Figure 1a. We vary the aspect ratio χ, *i.e.* the cylinder length to diameter ratio, from 1 to 6 and the solid volume fraction ϕ from 0.075 to 0.3. We also set the Archimedes number to 50 and the solid to fluid density ratio to 3 in order to investigate a moderately inertial regime.



(a) (b) (c)

Figure 1: (a) Flow configuration at $\chi = 1$, (b) Average settling velocity as a function of solid volume fraction. The empty circles refer to settling spheres (Seyed-Ahmadi and Wachs, 2021), and (c) Orientation tensor at $\chi = 6$. Please note that the gravity acceleration is oriented along $z-$.

Fast predicting the trajectory of chip-like particles by integrating a DEM model with a CFD-based aerodynamic database

Bingchen Li[1], Junjie Lin[1], Kun Luo[1,2*], Shuai Wang[1] and Jianren Fan[1,2]
[1] State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, China
[2] Shanghai Institute for Advanced Study of Zhejiang University, Shanghai 200120, China

**Author to whom correspondence should be addressed: zjulk@zju.edu.cn*

This study proposes a novel method for accurately predicting the movement of chip-like particles with high-aspect-ratio by integrating the Discrete Element Method (DEM) with a Computational Fluid Dynamics (CFD)-based aerodynamic database, overcoming the limitations of the conventional CFD-DEM coupling approach. The accuracy of the CFD-based aerodynamic database is validated through a quantitative comparison with experimental data, demonstrating strong agreement between the predicted and experimental trajectories under various conditions in the high-speed wind tunnel. Furthermore, a database independence analysis confirms that the aerodynamic coefficients of chip-like particles remain independent of the Reynolds number and scaling factor.

The simulation results indicate that chip-like particle trajectories are highly sensitive to initial pitch angles, with smaller pitch angles promoting enhanced flipping motion and displacement. Furthermore, the thickness of chip-like particles has a significant impact on the trajectory behavior: as thickness increases, particles exhibit more pronounced descents and reduced flipping motion. An increase in the scaling factor leads to greater descent and reduced rotation for equal-density particles, while for equal-mass particles, it enhances the tendency of motion along the inflow direction. The proposed method provides a fast and accurate approach for predicting the motion trajectories of high-aspect-ratio chip-like particles, while also offering deeper insights into the influence of shape properties on their motion behavior.

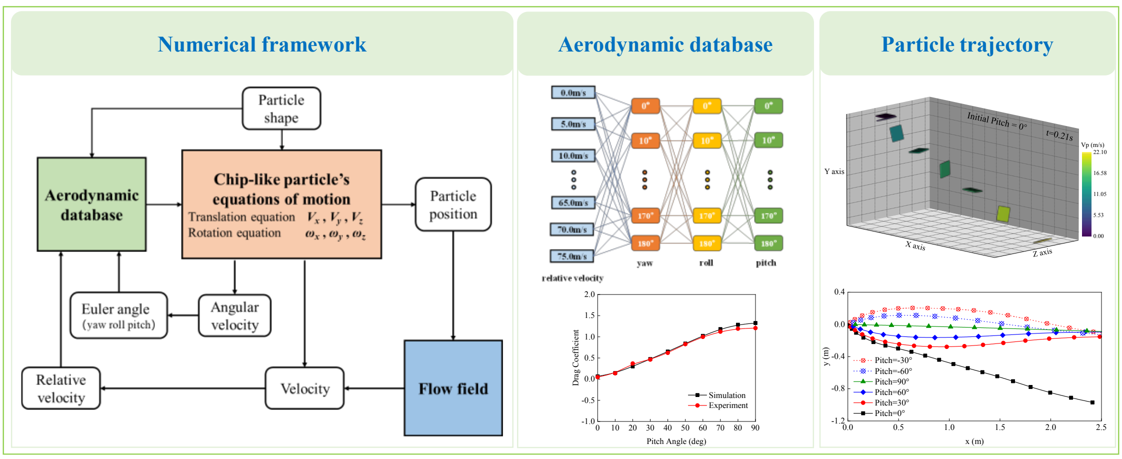


Figure 1: Graphical abstract of the proposed method for fast predicting chip-like particle trajectories.

As expected, the first closure term in the momentum equation is the average fluid-particle force which can be related to the settling velocity. Figure 1b plots the average settling velocity normalized by the terminal velocity of a single isolated cylinder (Clift et al., 1978) as a function of the solid volume fraction. For all aspect ratios, the average settling velocity decreases as the solid volume fraction increases due to the classical hindrance effect in a manner similar to spheres (and more generally to any particle shape). Remarkably the average settling velocity of the longest cylinders considered $\chi = 6$ at the smallest volume fraction $\phi = 0.075$ is slightly higher than the settling velocity of a single isolated cylinder. Figure 1c reveals that the cylinders increasingly orient themselves along the direction of gravity when the solid volume fraction increases.

References

R. Clift, J.R. Grace, and M.E. Weber. Bubbles, drops, and particles. 1978.

R. Jackson. *The dynamics of fluidized particles*. Cambridge University Press, 2000.

A. Seyed-Ahmadi and A. Wachs. Sedimentation of inertial monodisperse suspensions of cubes and spheres. *Physical Review Fluids*, 6(4):044306, 2021.

A. Wachs, A. Hammouti, G. Vinay, and M. Rahmani. Accuracy of finite volume/staggered grid distributed lagrange multiplier/fictitious domain simulations of particulate flows. *Computers & Fluids*, 115:154–172, 2015.

A 3D incompressible direct numerical simulation solver based on vorticity-stream-potential formulation

Jiaxin Tan[1], Qing Li[1] and Chong Pan[1,2]
[1] Tianmushan Laboratory, Beihang University, Hangzhou, PR China
[2] Fluid Mechanics Key Laboratory of Education Ministry, Beihang University, Beijing, PR China

Vortex dynamics are crucial for understanding complex turbulent phenomena and physical scenarios in various industrial applications. Given this, A 3D vortex direct numerical simulation (DNS) solver based on high-order finite difference method (FDM) has been developed for incompressible fluid flow in the vorticity-stream-potential formulation on collocation grids. The vortex DNS solver contains three parts: the first part is the vortex dynamics equation, which serves to update the vorticity; the second part is the calculation of rotational velocity based on the stream function; the third part is the calculation of the irrotational velocity using the potential function. The final velocity is the sum of rotational velocity and irrotational velocity.

Numerical simulations of forced isotropic turbulence, which ensure stationarity for statistical sampling, continue to play an important role in the study of fundamental features of turbulent phenomena. The in-compressible homogeneous isotropic turbulence in a triply periodic domain $\Omega = [0, 2\pi]^3$ is simulated using the large scale energy forcing method proposed by Chen et al.. As shown in Figure 1, the developed solver exhibits robust numerical stability and a high level of accuracy, making it an invaluable tool for turbulence and multiphase flow research.

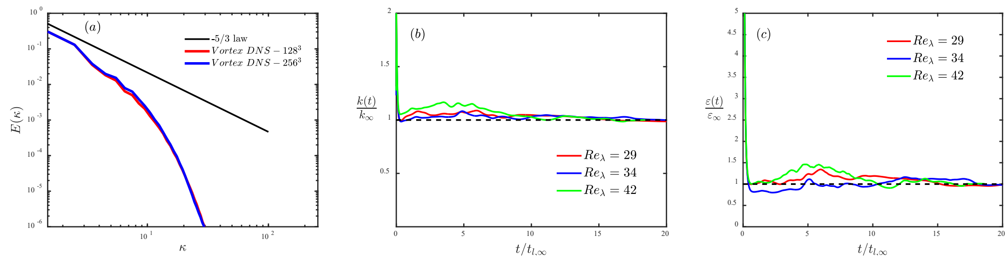


Figure 1: (a) Average energy spectra at the stationary state for $Re_\lambda = 29$ obtained with resolutions of 128^3 and 256^3. The time development of turbulent kinetic energy (b) and turbulent dissipation rate (c) for three Taylor-Reynolds numbers.

References

E. Weinan, J.G. Liu. Finite difference methods for 3D viscous incompressible flows in the vorticity-vector potential formulation on nonstaggered grids. J. Comput. Phys, **138**(1), 57-82, 1997.

S. Chen, G. D. Doolen, R.H. Kraichnan, Z. S. She. On statistical correlations between velocity increments and locally averaged dissipation in homogeneous turbulence, Phys. Fluids A: Fluid Dynamics. **5**(2), 458-463, 1993.

A module Lagrange particle solver based on dynamic linked list

Q. Li[1] and C. Pan[1,2]
[1] Tianmushan Laboratory, Hangzhou, China
[2] Beihang University, Beijing, China

Taking into account of compressible and multi-physical effects, a MPI-Point Particle Direct Numerical Simulation(PP-DNS) Solver based on **dynamic linked list array** is developed, in coupling with a compressible flow solver of carried phase. The traditional way uses the Euler array to assign the memory to dispersed particle phase, but at expense of MPI communication efficiency. In view of this, the dynamic linked list array is used to allocate memory to dispersed particle phase to remedy this problem, while **the exchange of particles between neighbors is realized by MPI blocking communication**, as Fig 1 shows. A series of DNS validations with reference case have been done, in terms of multi-physical cases and two canonical cases at incompressible limit asymptotically.

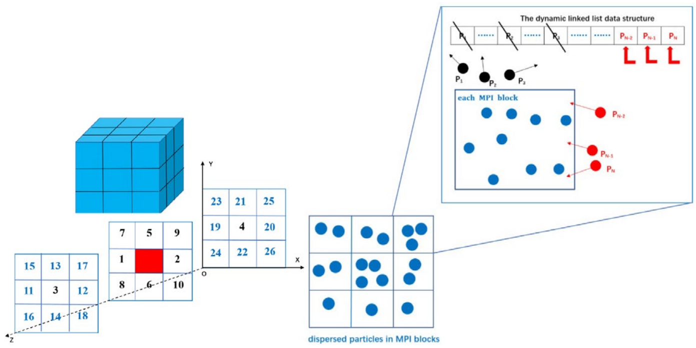


Figure 1: Communication of particles between neighbor MPI blocks based on dynamic linked array. ***From: Li et al.,Acta Scientiarum Naturalium Universitatis Pekinensis(2024).***

References

Q. Li et al. MPI Solver of Particle-Laden Compressible High Enthalpy Flow: Numerical Method and Validation., Acta Scientiarum Naturalium Universitatis Pekinensis(in Chinese). 60, 1 (2024).

C. Marchioli et al. Statistics of particle dispersion in direct numerical simulations of wall-bounded turbulence: results of an international collaborative benchmark test., International Journal of Multiphase Flow. 34, 879–893 (2008).

T. Zhou et al. Nonmonotonic effect of mass loading on turbulence modulations in particle-laden channel flow., Physics of Fluids. 32, 043304 (2020).

Heat transfer in drop-laden turbulence

A. Roccon[1,2], F. Mangani[2], F. Zonta[3], and A. Soldati[1,2]
[1]Polytechnic Department of Engineering and Architecture,
University of Udine, 33100 Udine, Italy
[2]Institute of Fluid Mechanics and Heat Transfer,
TU-Wien, 1060 Vienna, Austria
[3]School of Engineering, Newcastle University, Newcastle Upon Tyne, UK

We investigate the heat transfer process in a multiphase turbulent system composed by a swarm of large and deformable drops and a continuous carrier phase. For a shear Reynolds number of $Re_\tau = 300$, a constant drops volume fraction of $\Phi = 5.4\%$, and a Weber number of $We = 3.0$, we perform a campaign of direct numerical simulations (DNS) of turbulence coupled with a phase-field method and the energy equation; the Navier-Stokes equations are used to describe the flow field, while the phase-field method and the energy equation are used to describe the dispersed phase topology and the temperature field, respectively. Considering four Prandtl numbers, $Pr = 1, 2, 4$ and 8, we study the heat transfer process from warm drops to a colder turbulent flow. Using detailed statistics, we first characterize the time evolution of the temperature field in both the dispersed and carrier phase. Then, we develop an analytic model able to accurately reproduce the behaviour of the dispersed and continuous phase temperature. We find that an increase of the Prandtl number, obtained via a decrease of the thermal diffusivity, leads to a slower heat transfer between the dispersed and carrier phase. Finally, we correlate the drop diameters and their average temperatures.

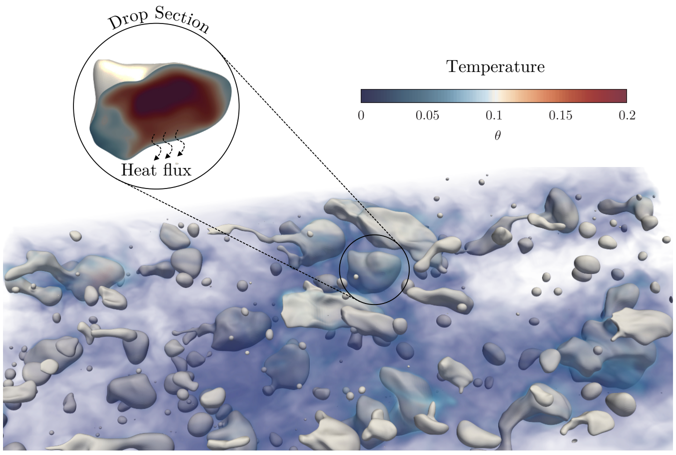


Figure 1: Rendering of the computational setup employed for the simulations. A swarm of large and deformable drops is released in a turbulent channel flow.

References

F. Mangani, A. Roccon, F. Zonta and A. Soldati. *Heat transfer in drop-laden turbulence.* J. Fluid Mech, **978**, A12

Efficient survival strategy for zooplankton in turbulence

J. Qiu[1], N. Mousavi[1], B. Mehlig[1], L. Zhao[2], and K. Gustavsson[1]
[1] Department of Physics, Gothenburg University, Sweden
[2] AML, Department of Engineering Mechanics, Tsinghua University, China

Zooplankton can detect their predators by hydrodynamic signals, triggering powerful escape responses. Turbulent strain tends to mask the hydrodynamic signal, disturbing these organisms or even causing physical damage. Zooplankton learn to avoid these regions, but it is not known how they accomplish this. In our recent studies [1, 2], we investigated the swimming strategies to avoid high strain regions in turbulence. Zooplankton were modeled as point-like microswimmers that can change their swimming speed according to the hydrodynamic signals. Quasi-optimal strategies were found by combining reinforcement learning and simulations of microswimmers in turbulent flows. We found a simple strategy that the microswimmer start to swim when the magnitude of strain rate is above a threshold, and stops otherwise. However, given the signals of the sign of gradients of squared strain, better strategy was found, exhibiting high robustness and efficiency in homogeneous isotropic turbulence and turbulent channel flows. The success of these strategies is explained using a second-order theory for the strain rate along the Lagrangian trajectories of microswimmers.

References

[1] Mousavi, N., Qiu, J., Mehlig, B., Zhao, L., & Gustavsson, K. (2024). Efficient survival strategy for zooplankton in turbulence. Physical Review Research, 6(2), L022034.

[2] Mousavi, N., Qiu, J., Zhao, L., Mehlig, B., & Gustavsson, K. (2025). Short term vs. long term: Optimization of microswimmer navigation on different time horizons. Physical Review Research, 7(1), 013258.

The limiting behavior of elastic turbulence

P. Garg[1] and M.E. Rosti[1]
[1] Complex Fluids and Flows Unit, OIST, Okinawa, Japan

Polymer molecules are the proto-typical example of anisotropic particles that are well known to strongly interact with and consequently modify fluid flows. Most famously the addition of even a small amount of polymer molecules is known to lead to drag reduction in inertial turbulent flows. Strikingly, at low Reynolds numbers, polymer solutions have been shown to lead to a novel spatio temporally chaotic state, known as 'Elastic turbulence'. This state has been shown to share several characteristics of turbulent flows, such as intermittency, even in the absence of inertial effects. A comprehensive understanding of elastic turbulence still remains elusive (Steinberg (2021)).

In this talk, we present results on the limiting behavior of elastic turbulence as the relaxation time of the polymer molecules is increased. We use the continuum approach where the polymer solutions are modeled using the Oldryod-B constitutive equation coupled to the Navier-Stokes equation. This coupled set of equations is solved numerically by using the in-house solver *Fujin*, which has been extensively validated. We adopt the logarithmic formulation of the constitutive equation for the polymer tensor, which allows us to go to unprecedentedly high values of the Deborah number. To focus on the fundamental physics behind elastic turbulence, we focus on a periodic domain. We discuss the limiting behavior of both the fluid velocity and the polymer stress tensor. Finally, we would also discuss how our numerical results could be used to motivate a theory for elastic turbulence, which is still lacking.

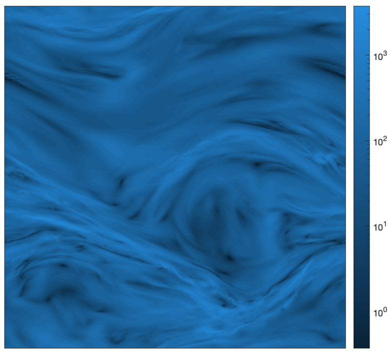


Figure 1: An instantaneous 2D snapshot of the magnitude of the vorticity field in elastic turbulence.

References

Victor Steinberg. Elastic turbulence: an experimental view on inertialess random flow. *Annual Review of Fluid Mechanics*, 53(1):27–58, 2021.

Edge-effects in turbulent canopy flows

Giulio Foggi Rota[1], Elisa Tressoldi[1] and Marco Edoardo Rosti[1]
[1] CFF Unit, Okinawa Institute of Science and Technology Graduate University, Japan.

The flow modulation induced by canopies of submerged vegetation (Foggi Rota et al., 2024) often proves beneficial for the retention of sediments and the enhanced mixing of suspended species. Aquatic plants are typically organised in well-delimited patches, alternating with non-vegetated regions of the bed. This discontinuity induces the formation of distinct flow structures (Löhrer and Fröhlich, 2023).

Here, we perform fully resolved numerical simulations of the turbulent flow along the streamwise edge of a flexible vegetation patch (as in the experiments of Unigarro Villota et al., 2023), shown in panel a of figure 1. We consider a half-channel flow setup of height H, where the flow is driven along the x direction at a bulk Reynolds number $Re_b = 5000$. Half of the bottom wall is empty, while the other half is covered by flexible stems, equally divided between the left and the right side of the domain. The complex interaction between the turbulent flow and the flexible stems is accurately captured by our well-tested solver *Fujin*.

In panel b of figure 1, we observe the fully bi-dimensional mean flow established in the $y-z$ plane. Streamwise-oriented vortices form at the edge of the patch and impinge on the stems, inducing their irregular deflection. At the Colloquium we will further characterise the turbulent flow and its coherent motions, relating them to the behaviour of the flexible stems. We will also discuss the dependence of the results from the rigidity of the stems.

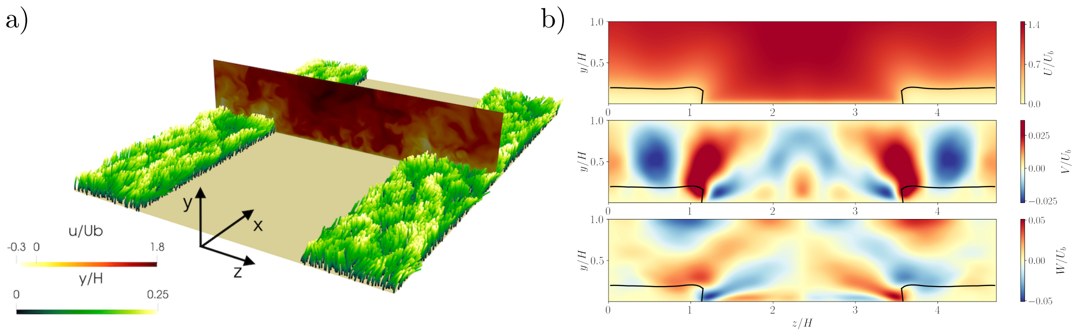


Figure 1: **Turbulent flow along the streamwise edge of a flexible vegetation patch.** Panel a shows the computational domain, with the stems coloured according to their deflection, and a transversal slice of the streamwise velocity fluctuations, scaled by the bulk velocity U_b. Panel b shows the mean flow components in the $y-z$ plane, with the mean envelope of stem deflection outlined by the black line.

References

G. Foggi Rota, A. Monti, S. Olivieri, and M. E. Rosti. J. Fluid Mech., **989**, A11, 2024.

B. Löhrer, and J. Fröhlich. Proc. Appl. Math. Mech., e202300256, 2023.

S. Unigarro Villota, M. Ghisalberti, J. Philip, and P. Branson. Water Resour. Res., **59**, e2022WR032570, 2023.

A robust convection module solver: applications in Interface capture and Hydraulics prediction

Q. Li[1], Y. Yu[1] , H. Ding[1], W. Wang[2], J. Zhao[2] and C. Pan[1]
[1] Tianmushan Laboratory, Hangzhou, China
[2] Xi’an University of Technology, Xi’an, China

Convection solver is important for DNS simulations. Traditionally, for turbulence, one needs non-dissipative scheme (e.g.Compact Finite Difference) to resolve smallest scale with minimal numerical dissipation but at risk of suffering from Gibbs phenomenon when encountering the sharp discontinuity; while for the liquid-gas interface, one needs upwind diffusive scheme (e.g.WENO5) to capture the sharp discontinuity, but at expense of smearing the small scale details. Given these, we develop a robust scheme to reconcile these. Firstly, we use split convection to separate the conservative advective term into sub conservative and non-conservative parts. Secondly, we develop a Taylor corrected Compact FD scheme for non-conservative part, which is O(10) less stiff than the uncorrected Compact FD; Finally, a WENO5 is employed for the conservative part. The developed convection scheme is firstly implemented in a vortex DNS solver which is used to test various HIT benchmarks, in comparing with spectral results. Then it is implemented as VOF solver and de Saint-Venant solver(for hydraulics), respectively, so as to test discontinuity problems. All the validations are in good agreement with references. The convection scheme developed can capture the sharp discontinuity, meanwhile resolve the small scale details such as Decay turbulence dissipation and sharp interface pattern, as Fig 1 shows.

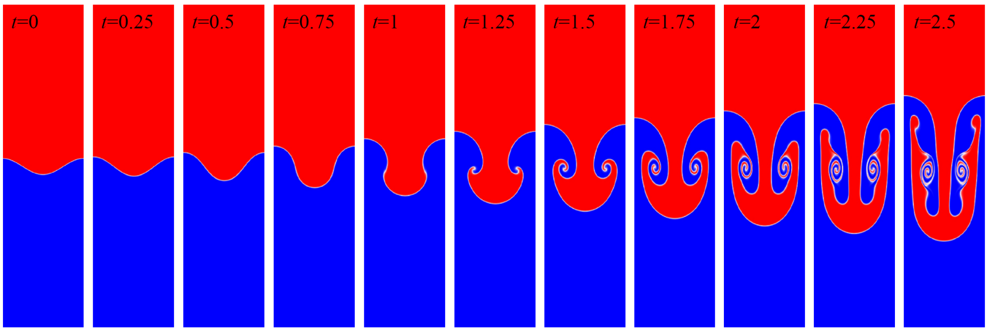


Figure 1: Temporal evolution of Rayleigh-Taylor instability interface profile. *From: Yu et al. internal group work.*

References

H.Ding et al. The Taylor correction algorithm for Compact Finite Difference Schemes (in preparation, LI Qing as corresponding author)

Y.Yu et al. A hybrid scheme based interface capture method. Part 1: Twophase immiscible flow without phase change.(preparation for JCP, LI Qing as corresponding author)

W.Wang et al. A robust DNS solver for de Saint-Venant system of equations., (in preparation, LI Qing as corresponding author)

Unresolved Euler-Lagrange simulations of non-spherical particles with liquid injection

Nicola Vanzetto[1*], Niels Deen[1,2], Yali Tang[1,2]

[1] Power and Flow group, Department of Mechanical Engineering, Eindhoven University of Technology, The Netherlands.
[2] Eindhoven Institute for Renewable Energy System, Eindhoven University of Technology, the Netherlands

*Email address: n.vanzetto@tue.nl

My project is at early stage, thus this short abstract is intended for a poster presentation in the conference.

Abstract

Fluidized bed reactors are widely used in chemical, pharmaceutical and food industries. In these processes, particle-particle interactions play a very important role to the reactor performance, ultimately the product quality. With the presence of liquid in the reactor, inter-particle interactions are fundamentally different from that at dry condition. A fundamental understanding of the micro-mechanisms of wet particle interactions and their macroscale impact is essential for a reliable prediction and precise control of the particle size evolution. The open literature has been significantly limited to relatively idealized systems involving e.g., water and spherical particles. In contrast, real processes often involve non-spherical particles and viscoelastic fluids. For this reason, this study aims to advance the state-of-the-art towards a better understanding of wet agglomeration of non-spherical particles, focusing on spherocylinders as a first step.

In order to understand the interplay between microscale particle phenomena and macroscopic flow dynamics, an approach based on Computational Fluid Dynamics – Discrete Element Method (CFD-DEM) will be used, with the use of DNS-derived closure models for description of effective particle-liquid interactions. In such an unresolved Euler-Lagrange model, representative of non-spherical particles and the contact model are crucial. In this (poster) presentation, I will present our evaluation (with test cases) on different shape description models, including multi-sphere model, bonded-sphere model, super-ellipsoid model, and polyhedral model, as well as several contact force/detection approaches proposed in literature.

Keywords: Fluidized bed agglomeration, liquid bridge, non-spherical particles, Computational Fluid Dynamics – Discrete Element Method

Acknowledgement

The current study is funded by the Dutch Research Council (NWO) with a project number OTP19951, with co-finance made by Tetra Pak, Nestlé, and Evonik.

Hydrodynamic forces on a rotating helical particle in a viscous fluid flow

Zhi Li[1], Yansong Li[1], Chunxiao Xu[1], Lihao Zhao[1,2]
[1]AML, Department of Engineering Mechanics, Tsinghua University, Beijing, PR China
[2]Laboratory of Flexible Electronics Technology,Tsinghua University, Beijing, PR China

Helical shapes play a crucial role in biological locomotion and microrobot propulsion. Among the earlier contributions, Purcell (1997) analyzed the propulsion efficiency of rotating helical propellers using resistive force theory. Rodenborn et al. (2013) investigated the axial hydrodynamic forces acting on translating and rotating helical particles with resistive force theory, slender body theory (SBT), and experimental methods. Subsequently, Shan et al. (2013) measured the thrust generated by the rotating helical particles with different pitch angles in experiments. Despite these advances, the non-axial hydrodynamic effects of rotating helical particles remain insufficiently studied.

In this study, we theoretically analyze both axial and non-axial hydrodynamic forces on a rotating helical particle using the slender body theory by Lighthill (1960). Additionally, we employ the immersed boundary method (IBM) to resolve the interactions between a rotating helical particle, with helical radius of 0.053 and a thickness of 0.015 scaled by half of its total length, and the surrounding fluid flow. As shown in figure 1, the flow field induced by the rotation of the helical particle exhibits a chirality-dependent asymmetry in the y direction at its two ends. This asymmetry of the flow field leads to an asymmetric distribution of the force along the helical particle in the y-direction, ultimately generating non-axial hydrodynamic forces on the particle. The effects of the helical particle's geometry, including the pitch angle, radius, and thickness, on the non-axial hydrodynamic forces will be systematically studied. More detailed results will be presented in the workshop.

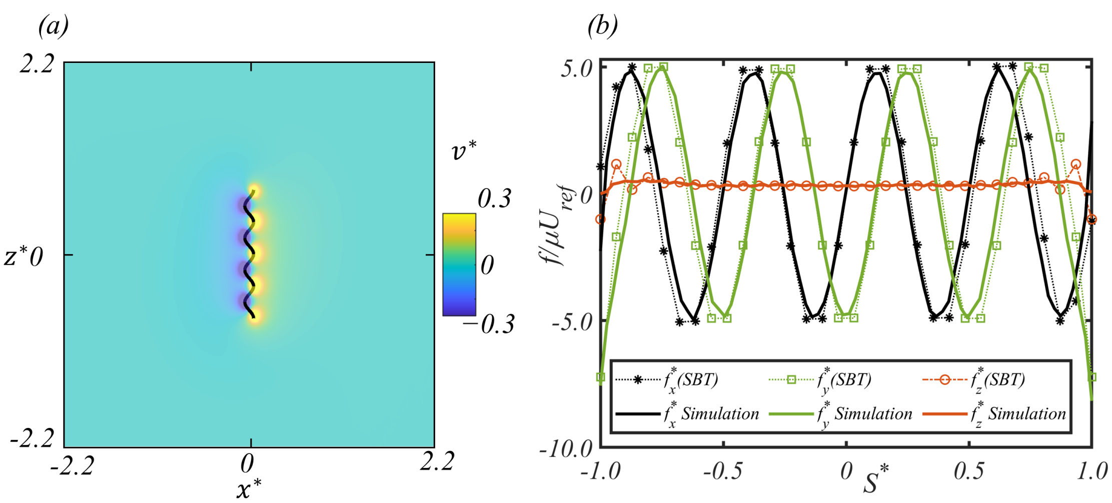


Figure 1: (a) Velocity contour in the y direction of the flow field induced by an axially rotating helical particle. (b) Force distribution on the rotating helical particle, obtained by Lighthill's slender body theory and IBM simulations.

References

M.J. Lighthill. *Note on the swimming of slender fish*. J. Fluid Mech, **9**, 305-317, 1960.

E.M. Purcell. *The efficiency of propulsion by a rotating flagellum*. Proc. Natl. Acad. Sci. U.S.A, **94**, 11307-11311, 1997.

B. Rodenborn, C. Chen, H.L. Swinney, B. Liu, and H.P. Zhang. *Propulsion of microorganisms by a helical flagellum*. Proc. Natl. Acad. Sci. U.S.A, **110** ,E338-E347, 2013.

Z. Shan, W.M. Keith, P. Victor, G.G. Jesus, and J.S. Alexander. *The flow field and axial thrust generated by a rotating rigid helical particle at low Reynolds numbers*. Exp. Therm Fluid Sci, **46**,1-7, 2013.

Bidisperse Elastic Capsules: Effects of Size and Inertia on Suspension Rheology

A. Mucalica[1], G. Gai[2], J. J Feng[1,3] and A. Wachs[1,3]

[1] Department of Mathematics, University of British Columbia, Vancouver, BC, Canada.

[2] Institut de Mécanique des Fluides de Toulouse, IMFT, Université de Toulouse, CNRS, Toulouse, France.

[3] Department of Chemical & Biological Engineering, University of British Columbia, Vancouver, BC, Canada.

Suspensions of deformable capsules serve as canonical models for a wide range of biological and engineered soft particle systems, where particle deformability significantly influences flow behavior. In many practical contexts-including blood flow, inertial microfluidics, and industrial suspensions-such systems are inherently polydisperse, with particles varying in size or stiffness. Prior studies have shown that polydispersity can strongly impact particle distribution and transport in confined flows (Thota et al. (2016); B. Mustin et al. (2010)), and that rigidity-driven segregation plays a central role in biological phenomena such as platelet margination (X. Zhang et al. (2020); K. Sinha, D. Graham. (2016)). Recent work on monodisperse deformable capsule suspensions has demonstrated that inertia alters deformation, rheology, and microstructure in significant ways (G. Gai et al., 2025). Yet, the combined effects of size disparity and flow inertia in deformable capsule suspensions remain poorly understood.

In this study, we investigate the deformation, dynamics, and rheology of bidisperse suspensions of elastic capsules in inertial shear flow using high-fidelity, particle-resolved simulations. We systematically vary the total volume fraction, relative volume fraction, and Reynolds and Capillary numbers to assess how size disparity and flow inertia influence bulk rheological behavior and microstructural organization. Our results reveal that increasing polydispersity leads to a reduction in effective viscosity, particularly at high volume fractions and under inertial conditions. We also observe the formation of hydrodynamically induced bridge structures, which contribute to stress anisotropy and microstructural heterogeneity. Finally, we propose new empirical correlations to predict capsule deformation and suspension viscosity across the studied parameter space.

These findings advance our understanding of how polydispersity and inertia interact in suspensions of deformable particles, with implications for microfluidic device design, blood flow modeling, and the processing of soft particle-laden flows.

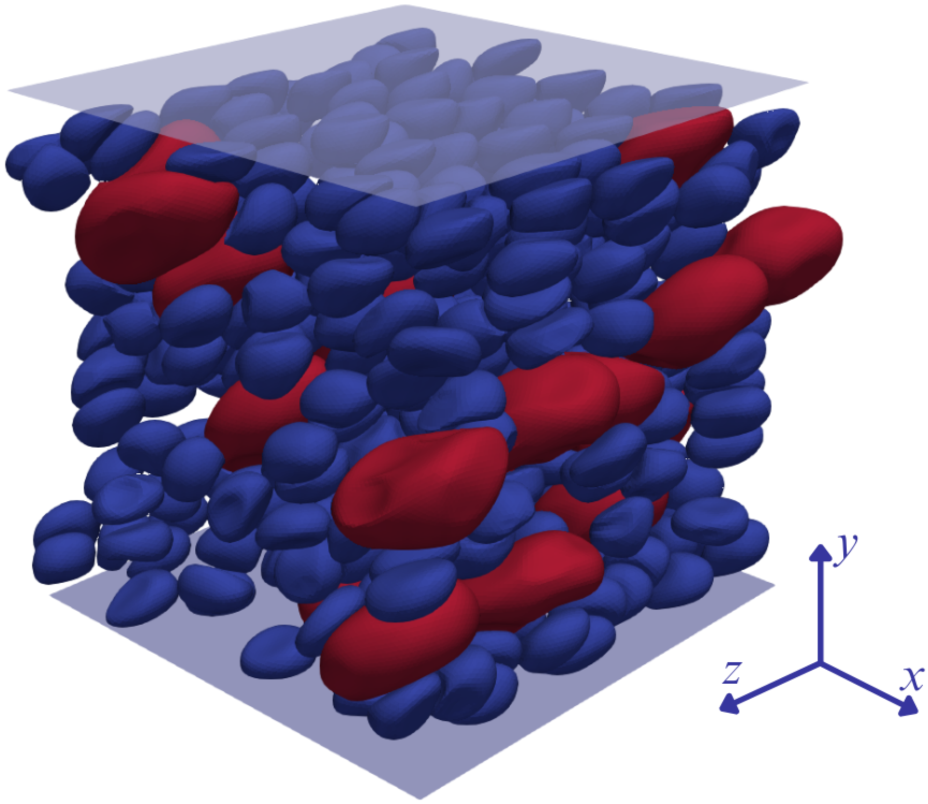


Figure 1: Illustration of a dense suspension of bidisperse elastic capsules in a simple shear flow.

References

K. Thota, B. Owen, T. Krüger *Deposition of particles from polydisperse suspensions in microfluidic systems.* Physics of Fluids, **35**, 2016.

B. Mustin, B. Stoeber. *Deposition of particles from polydisperse suspensions in microfluidic systems.* Microfluid Nanofluid, **9**, 2010.

X. Zhang, et al. *Flow-induced segregation and dynamics of red blood cells in sickle cell disease.* Physical Review Fluids, **5**, 2020.

K. Sinha, D. M. Graham. *Shape-mediated margination and demargination in flowing multi-component suspensions of deformable capsules.* Soft Matter, **12**, 2016.

G. Gai et al. *Deformation, dynamics and rheology of immersed elastic capsules in an inertial shear flow.* J. Fluid Mechanics, 2025.

Relative alignment of colliding rod-like particles in turbulence

Haoran Luo[1], Lihao Zhao[2]
[1] Xingjian College, Tsinghua University, 100084 Beijing, China
[2] AML, Department of Engineering Mechanics, Tsinghua University, 100084 Beijing, China

The collisions among rod-like particles in turbulence play an essential role in various natural and industrial processes, yet the physics of relative alignment of colliding particles has remained unknown. Here, by conducting direct numerical simulations, we illustrate the number density distribution of elongated passive particle pairs in homogeneous isotropic turbulence, against their relative angle at the collision instant. Two distinct power laws are recognized to characterize the variation of the aforementioned distribution. Furthermore, we interpret the relative alignment mechanism of the elongated colliding pairs by investigating their historical effect over several Kolmogorov timescales before collisions. We reveal that elongated colliding pairs with perpendicular relative alignment undergo more dispersion in both velocity and distance compared to the parallel pairs, and are less likely to neighbor each other. Our results provide some insights into the collision behavior of non-spherical particles in turbulence. More detailed results will be present in the workshop.

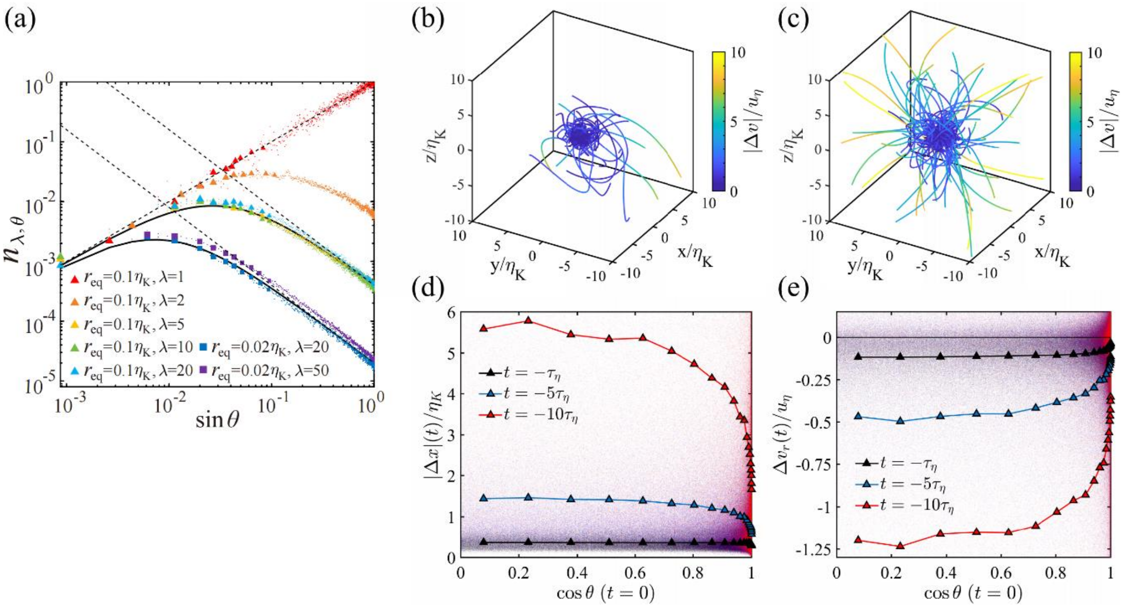


Figure 1: (a) The number density distribution of elongated neighboring pairs against their relative angle. The trajectories of 200 elongated colliding pairs with (b) parallel and (c) perpendicular relative alignment, over ten Kolmogorov timescales before collisions. (d) The historical separation distance and (e) radial relative velocity of 200,000 elongated colliding pairs.