MEMORIAL LECTURES

G.I. Taylor Memorial Lecture

The clustering of particles in flow

Prof. Rama Govindarajan
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Turbulence often mixes in most ingredients into a flow, such as sugar in tea. However, it "demixes" solid particles, making them cluster in certain regions of the flow. This lecture will be about usual and unusual kinds of clustering displayed by particles, in model flows and in turbulence, in contexts such as the aggregation of plankton in the ocean and rain formation in clouds. We will lay some emphasis on singular features called caustics, where particle number density diverges.

P. L. Bhatnagar Memorial Speaker

Rotating Magnetoconvection with Diffusivities Parameterized by the Turbulence in the Earth's Fluid Core

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Rotating magnetoconvection (RMC) studies are important ingredient of Dynamo Theory with Natural Dynamos (e.g., Geodynamo) as well as problems in laboratory hydromagnetic experiments (see, e.g., [1]). Turbulent state of the fluid Earth's core (FEC) in our RMC models is parameterized by isotropic as well as anisotropic diffusive coefficients (IDC, ADC, respectively), because turbulent eddies formed by basic (anisotropic) forces are main transporters of momentum, heat and magnetic field. It can serve as the basic state convenient for stability study as each physical state. Our former papers ([2], [3], [4], [9]) were focused on the marginal modes, while the main aim of the current work is to analyse the fastest growing modes (F modes), with isotropic as well as anisotropic diffusion [8]. These modes of rotating magnetoconvection are the ones with the maximum growth rate (see, e.g., [1] and [5]).

Isotropies (IDC) as well as anisotropies (ADC) are further distinguished by values of molecular and turbulent diffusivities.

The linear stability analysis in term of normal modes in the form of horizontal rolls is applied on RMC model of horizontal fluid planar layer with IDC or/and ADC, rotating about vertical axis, and permeated by a horizontal homogeneous magnetic field, at vertical temperature gradient (in Boussinesq approximation). We consider the simplest boundary conditions by assuming stress free and perfectly thermally and electrically conducting boundaries, the upper and lower horizontal planes. We use some standard methodologies commonly applied in the instabilities problems (see, e.g., [6] and [7]). Non-dimensionalization implies dimensionless numbers, e.g. Elsasser (ratio of magnetic and Corolis forces), Ekman (ratio of viscous and Coriolis forces), Rayleigh and Prandtl ones, with new anisotropic parameter defined as ratio of horizontal and vertical diffusivities. The vectorial instabilities (velocity and magnetic field) are split into poloidal and toroidal components, determined like scalar instability (temperature) by horizontal components of wave vector and by growth rate. The Rayleigh number is expressed as function of the input dimensionless numbers, the wave vector components and of the growth rate. In study of the F modes, the growth rate is maximized over the horizontal components of wave vector at the fixed huge Rayleigh number, contrary to minimization of the Rayleigh number in the marginal modes analysis. The growth rate maximization gives the Elsasser number - Ekman number regime diagrams giving the boundaries between different possible modes in our RMC in fluid layer in the Earth's core conditions.

We also studied simplified problems. Historically, the most important approximation in [5] made by Braginsky and Meytlis was isotropic case, when partial time derivations of velocity and magnetic field instabilities are zero, and the mathematical complexity was crucially reduced. We name this approximation in [5] as isotropic T case. Isotropic G case is, when at IDC generally all partial time derivations (also of temperature instability) are non-zero. Both isotropic and anisotropic G cases describe the turbulent stay of the Earth's core better than corresponding T cases. The F modes in all cases T and G of rotating magnetoconvection models with ADC as well as IDC are determined by the maximum of the growth rate and the modulus of wave number which are independent of Elsasser and Ekman numbers, while the regions of dominance of individual modes among all possible modes in our RMC in Elsasser-Ekman regime diagrams depend on them.

For given anisotropic parameter, the maximum of the growth rate and corresponding modulus of wave number are the same in both cases T and G, and moreover that historically important study [5] of artificial T case gave these values equal to the general G case with naturally the same exponential time dependence of all instabilities (velocity, magnetic field and temperature). Finally, only the anisotropic G case is well suited for the Earth's outer core conditions with turbulent values of Prandtl numbers. Furthermore, the F modes contrary to marginal ones are much better related to all parameters typical for the Earth's core, e.g. Rayleigh number and Ekman number. The results on marginal and the F modes in isotropic and anisotropic conditions are used to compare the possible balances of forces in FEC - MAC balance (magnetic, Archimedean and Coriolis forces) or QG one (pressure gradient and Coriolis forces slightly influenced by magnetic force). Our RMC approach allows to easily deal with very huge wave numbers and Rayleigh numbers, and very small Ekman numbers, in particular in F modes case, what is not usually possible in the standard geodynamo simulations. This aspect and the growth rates search are useful to look for possible connections with the geomagnetic secular variation, because as it was shown anisotropic diffusivities are for FEC more convenient then isotropic ones.

REFERENCES

1. P.H. Roberts and E.M. King, Rep. Prog. Phys., 76, 096801, (2013).
2. T. Šoltis, and J. Brestenský, Phys. Earth Planet. Inter. 178, 27 (2010).
3. E. Filippi, J. Brestenský, and T. Šoltis, Geophys. Astrophys. Fluid Dyn. 113, 80 (2019).
4. E. Filippi and J. Brestenský, Astron. Nachr., 341, 369, (2020).
5. S.I. Braginsky and V.P. Meytlis, Geophys. Astrophys. Fluid Dyn., 55, 71, (1990).
6. S. Chandrasekhar: Hydrodynamic and Hydromagnetic Stability (Oxford: Clarendon Press, 1961) 1st ed.
7. P.H. Roberts and C.A. Jones, Geophys. Astrophys. Fluid Dyn., 92, 289, (2000).
8. J. Brestenský, E. Filippi, H.P. Rani, and N. Krishnendu: The Fastest Growing Modes in Rotating Magnetoconvection With Anisotropic Diffusivities in the Earth's Core Conditions, In Proceedings of the 21st Conference of Czech and Slovak Physicists, Bratislava (2023).
9. H. P. Rani, N. Krishnendu, Y. Rameshwar, J. Brestenský: Weakly Nonlinear Analysis of Rotating Magnetoconvection with Anisotropic Diffusivities in Earth's core near the Onset of Oscillatory Instability, In Proceedings of the 21st Conference of Czech and Slovak Physicists, Bratislava (2023).

B R SETH MEMORIAL SPEAKER

Mathematical Models and Numerical Methods for Incompressible Two-Phase Flows

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Accurate analysis of multiphase flows plays a vital role in various engineering applications and designs. These issues span a wide range of fields, including aerospace, mechanical, chemical, civil, and marine engineering. Examples of multiphase flows include fuel injection, atomization, boiling, free surface flow, cavitation, and liquid sloshing. Precisely resolving fluid-fluid interfaces and gaining a deep understanding of the underlying flow physics pose significant challenges in addressing these problems. Consequently, the development of precise and efficient computational methods to tackle real-world engineering challenges associated with multiphase flows is of paramount significance. This presentation will primarily focus on mathematical models and the advancement of cutting-edge numerical algorithms designed for simulating incompressible two-phase flows. The discussion will centre on the essential attributes required of mathematical models and their associated numerical methodologies. During the session, it will be demonstrated that a Pseudo/Artificial compressibility-based formulation, when used in conjunction with complete Riemann solvers, has the capability to accurately satisfy the exact jump conditions across the fluid-fluid interfaces, leading to highly accurate solutions for incompressible two-phase flows. Furthermore, a set of numerical results will be presented to highlight the effectiveness of Riemann solvers in delivering precise solutions.

A.S. GUPTA MEMORIAL LECTURE

Revealing complexity in convection problems

Prof. David Laroze

Director, Instituto de Alta Investigación, Universidad de Tarapacá, Chile

B KARUNESH MEMORIAL LECTURE

Dynamics of the falling drops and the crater created due to impact of drops on a deep liquid pool

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Abstract

Worthington (1908) first published different paradigms of drop impact on a liquid pool, using high-speed photography. Woodcock et al. (1953) explained the mechanisms of creation of crater in waterbody and capillary retraction dynamics. When a drop of a liquid passes through air and impacts on the liquid-air interface of a liquid pool, depending on the size and velocity of the drop, it may coalesce partially or completely. Based on the shape of the crater and its expansion and contraction time, the final outcome can be partial coalescence, complete coalescence, jet formation with or without bubble entrapment and splashing (Ray et al., 2015). In the case of droplet trains, long slender cavity formation due to multiple drop impact on a deep liquid pool was observed.

The large bubble entrapment takes place if the prolate shaped drop impacts onto a liquid pool. The talk focuses on the identification of the large bubble entrapment regime. The researchers have classified different forms of the bubble entrapment scenario on a velocity versus drop-diameter map (V-D map). On the traditional classification map, the large bubble entrapment zone occupies a small region. It has been identified that the entrapment of large bubble is a vortex driven phenomenon. The vortex deforms the interface and produces an elongated roll jet, which then collapses on the central axis to entrap the large bubble. However,

identification of the exact boundary of large bubble entrapment regime on the V-D map was a challenge. This talk is about an attempt to find out the exact regime of large bubble entrapment on the V-D map. Within the given range of aspect ratio variation of the impacting drop, it was possible to draw a conclusion about the boundary of large bubble entrapment regime (Deka et al., 2017).

Tongue shaped cavities are seen during the hydrophobic sphere impact, jet impact, and impact of a train of micro drops on a deep liquid pool. For the impact of multiple micro drops, the mechanisms, which lead to deep cavity formation and later bubble entrapment inside the liquid pool, are also presented in this talk. A train of high-speed micro drops impacting on a liquid pool can create a very deep and narrow cavity, leading to depths more than several hundred times the size of the individual drops. The investigations are performed in an air–water system at large values of Froude numbers, thus having a negligible effect of gravity.

Depending on the train length, the capillary wave generating from each drop impact affects the necking. The temporal variation of the neck radius reveals a power law behavior. We delineate the distinctive feature of pinch-off of the cavity in terms of the critical length of the train. Pinch-off is observed when the penetration depth of the cavity is more than three times the diameter of the cavity (Deka et al., 2018).

References:

A. M. Worthington, A Study of Splashes, Longmans, Green, and Co., (1908).

A. H. Woodcock, C. F. Kientzler, A. B. Arons, and D. C. Blanchard, Giant condensation nuclei from bursting bubbles, Nature 172, 1144 -1145, (1953).

B. Ray, G. Biswas and A. Sharma, Regimes during liquid drop impact on a liquid pool, Journal of Fluid Mechanics, Vol. 768, pp. 492-523, (2015).

H. Deka, B. Ray, G. Biswas, A. Dalal, P.-H. Tsai, and A.-B. Wang, The regime of large bubble entrapment during a single drop impact on a liquid pool, Physics of Fluids, Vol. 29, pp. 092101-1- 092101-13, (2017).

H. Deka, B. Ray, G. Biswas, and A. Dalal, Dynamics of tongue shaped cavity generated during the impact of high-speed micro drops, Physics of Fluids, Vol. 30, pp. 042103-1 – 042103-14, (2018)

INVITED LECTURES

Phase field approach to modeling anisotropic fracture

Amirtham Rajagopal

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Abstract

Fracture is one of the major failure modes in structures and computational modeling helps in understanding the crack initiation and propagation, which leads to the ultimate fracture of the materials at various material length scales, ranging from atomic to macro scales. Composites have been widely applied in various industries, as they can be modeled according to the required purpose, and can also provide high strength and stiffness at low weight. The mechanical response of the composite system at the micro-scale, having fiber, matrix, and fiber-matrix interface can be

considered to be isotropic. The composite system is anisotropic at meso and macro scales, where a composite lamina having fibers embedded in a matrix, or a composite laminate having different laminae stacked together is considered. Different failure modes are possible, namely, matrix/bulk cracking, deflection and or branching of crack at the interface, thickness penetration at the interface, and delamination. A thermodynamically consistent phase field formulation for modeling the interactions between interfacial damage and bulk isotropic/anisotropic fracture is presented. A regularization scheme is considered for both the interface and the crack phase field. A coupled exponential cohesive zone law is adopted to model the interface which has the contributions of both normal and tangential displacement jump components. For modeling mesoscopic failure, anisotropy is introduced into the elastic equilibrium by considering the distinct contributions of fiber and matrix in different modes. For simulating anisotropic fracture, a convex fracture energy function and a second-order structural tensor is introduced in the formulation, which acts on the gradient of crack phase field. The crack driving force also constitutes distinct contributions of matrix and fiber constituents.

Finite difference based stable numerical scheme to solve Stefan Problem

Prof. YVSS Raju
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A front-tracking fixed grid method for solving Stefan problem with moving phase change materials in any arbitrary (irregular) bounded domains will be discussed in this lecture. The numerical scheme is consistent, unconditionally stable and also produces second-order accurate results. We can also look at the influence of some of the physical parameters like Peclet number, Stefan number, material velocity etc., on the rate of change of phase.

Development of Advanced Composite Products for Aerospace Applications

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Advanced composite structures are used in modern aerospace vehicles because of its specific strength and weight advantage. We have developed largest Composite Rocket Motor Casing having 2.4mx 8 m length cylindrical thickness of 16 mm made with High Strength Carbon Fiber (T-700) & Epofine Resin using Filament Winding Technology on Large PU Foam Mandrel. The casing is Proof Pressure Tested up to 9.45 MPa and Structural Tested up to 2840 KN.

Composite airframe (2x 2.7 m) developed for the first time with An-isogrid triangular lattice structure with offset hoop bonds having integral bulkheads. Structural tested up to axial force of -238 KN and bending moment of 215 KN-m.

Composite airframe (2.4 x 1.07 m) using Aluminium alloy honey comb flex core with bi-directional carbon fabric face sheets with integral bulkheads. Number of cutouts made for mounting antennas, passengers and thrusters. Structural tested up to axial force of -412 KN and bending moment of 292 KN-m.

The payload fairing having 2m x 3 m length is configured with cylindrical and the ogive configuration, sandwich construction with carbon epoxy face sheets (1mm) and aluminium alloy super flex honeycomb core (14 mm) made in two halves using single tool.

Composite Propellant tank 325ltrs (650 x 1300 mm) over aluminium liner 1 mm thick made up of Carbon Fiber (T-700) Epofine Resin using Filament Winding Technology thickness of 2 helical and 1 hoop of 3 mm thickness is realized and Proof Pressure tested up to 40 bar.

Composite Helium gas tank 52ltrs (250 x 1250 mm) over Titanium liner 1 mm thick made up of Carbon Fiber (T-700) Epofine Resin using Filament Winding Technology thickness of 7 helical and 8 hoop of 12.5 mm thickness is realized and Proof Pressure tested up to 487 bar.

Numerical Simulation of Convective Geodynamic Processes and their Geophysical Manifestations

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The Earth has two giant convective systems in its deep interior, the mantle and the outer core. The mantle consists of mainly silicate minerals and convects in solid state, i.e., it is rheologically solid on short time-scales but behaves like viscous fluid on geological time-scales. Mantle convection is considered to be driving the rigid lithospheric plates of the Earth and controlling the plate tectonic processes. Beside the plate-scale convection, the mantle has another mode of convection in the form of mantle plumes. These narrow upwellings of hot mantle rocks are linked to outpouring of massive flood basalts, formation of Large Igneous Provinces, and breakup of supercontinents. The outer core is composed of mainly liquid iron along with the presence of small amount of light density elements. Contrary to the mantle convection, the outer core convects on a much shorter time-scales and generates the internal geomagnetic field through a geodynamo process that shields the planet from harmful cosmic radiations. These two systems are also coupled in terms of heat exchange across the core-mantle boundary. While the core contributes to the heat needed to drive mantle convection, the mantle controls the spatial pattern of the heat flux from the core. Convection in both these systems are studied by solving the Navier-Stokes equation in association with the energy balance equation, and in some cases also composition balance. Core convection has an additional magnetic induction equation to be solved and a Lorentz force term to be included in the Navier-Stokes equation. These highly nonlinear systems represented by coupled system of equations are solved numerically. Since direct observations of the deep Earth are largely not possible, exception being inclusions of mantle rocks in diamonds, surface geophysical observations coupled with numerical models of convection and dynamo process are used to gain insights into the internal dynamics of the Earth.

This presentation shall cover some of these aspects related to geodynamic processes in the Earth's deep interior.

Finite Element implementation on Invisible Energy Flow: Heatfunctions and boundary conditions

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Heat flow or energy flow cannot be visualized via experimental techniques although temperature is an experimental measured quantity. This work attempts to study the energy flow measurement via numerical tool based on finite element method. Energy flow is quantified via heatfunction (Π) which is visualized via heatlines. Finite element simulations carried out for velocity and temperature fields.

Subsequently, finite element method is implemented to obtain heatfunctions (Π). The efficacy of finite element method is demonstrated and is proved to be essential for heatfunction (Π) evaluations. Heatlines have been demonstrated for case studies involving natural convection. Heatline patterns during natural convection have been studied for different types of Dirichlet heatfunction boundary conditions. The enclosures with various shapes (square, curved, trapezoidal, tilted square and parallelogrammic) are considered with various thermal boundary conditions such as (a) Case 1: hot left wall, cold right wall and adiabatic horizontal walls, (b) Case 2: hot bottom wall, cold left and right walls and adiabatic top wall and (c) Case 3: hot bottom wall with other cold walls. Traditionally, the reference of heatfunction ($\Pi= 0$) is assumed at the adiabatic wall and the implementation of reference ($\Pi = 0$) may be non-trivial for the case with zero or multiple adiabatic wall(s). Various heatfunction (Π) boundary conditions have been formulated based on locations of $\Pi = 0$ for systems with more than one adiabatic walls (Case 1) or no adiabatic wall (Case 3). As test problems, $\Pi = 0$ is considered at the junctions of isothermal walls (Cases 2 and 3) or on the isothermal wall (Case 3). The governing equations are solved via the Galerkin finite element method at various Rayleigh numbers (103 and 105) and Prandtl numbers ($Pr = 0.015$ and 7.2). The magnitudes of the heatfunctions change drastically with the location of the datum of Π ($\Pi = 0$) whereas, the heat flow patterns remain same irrespective of the heatfunction boundary conditions. The gradients of heatfunctions or the heat flux along the active walls (hot/cold) are invariant of the choice of the reference ($\Pi = 0$). The local and average Nusselt numbers are also independent of the choice of $\Pi = 0$ and the Nusselt numbers are found to be identical with heatfunction gradients obtained with various locations of $\Pi = 0$. The analysis may be useful for heat flow visualization in various thermal systems involving complex thermal boundary conditions.

Graph Neural Network based deep learning methods for fluid flow applications

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The presentation will illustrate our experience of using this code with particular focus on the use of graph neural network as a tool for simulating fluid flow. A new particle trickle algorithm has been proposed to model fluid flow inlet condition. It is shown how the graph neural network architecture has enhanced extrapolation abilities to be able to simulate the fluid flow behaviour outside of conditions used in the training datasets.

Examples from the training datasets water ramp and multi-material are used to demonstrate the benefits of this techniques.

The code and datasets for the paper, “Learning to simulate complex physics with graph networks” is available on github (https://sites.google.com/view/learning-to-simulate).

Velocity and magnetic field in the liquid core of the Earth

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The MHD (induction and momentum equations) system of geodynamo equations is radically, but physically correct, simplified to a dynamic system for the convective Root-Mean-Square (RMS) velocity and the RMS magnetic field in the liquid core of the Earth. The study of stable stationary points of this system gives a significant excess of the critical level of the geodynamo and, accordingly, relatively large values of the RMS magnetic field of the order of 10 mT (100 Gauss) and highly nonlinear system.

The RMS velocity is on the order of 1 mm/sec, and the characteristic times are on the order of a thousand years, which is in good agreement with paleomagnetic reconstructions, the general geodynamo theory, numerical simulations and direct observations of the geomagnetic field. Relative geomagnetic energy is of order 10 -2 J/kg that is much more than kinetic energy ~10 -6 J/kg. This four order excess could hardly be managed with supercomputer (they mange just one order nowadays) in the nearest future for the complete 4D (3D plus time) geodynamo model. Unstable stationary points may be associated with excursions and reversals, and possibly (although unlikely) with an extremely rare catastrophic zeroing of the magnetic field.