IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

CSIRO

Project Title:	Frontiers of Chaotic Advection: Transport in Three-dimensional Volume-preserving Flows	
Project Number	**IMURA0330**	
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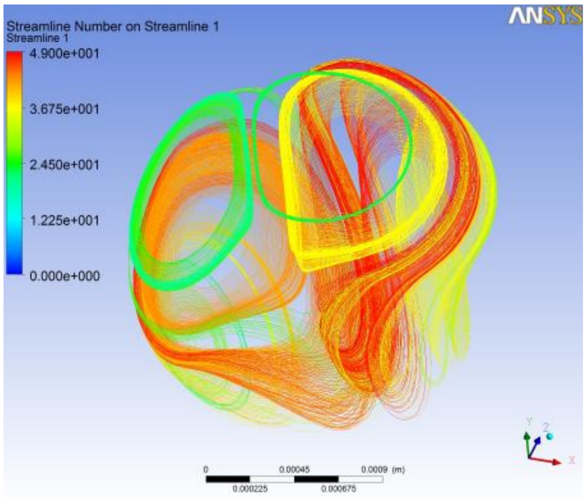
Research Academy Themes:

Highlight which of the Academy's Theme(s) this project will address?
(Feel free to nominate more than one. For more information, see www.iitbmonash.org)

1. **Advanced computational engineering, simulation and manufacture**
2. Infrastructure Engineering
3. Clean Energy
4. Water
5. **Nanotechnology**
6. **Biotechnology and Stem Cell Research**

The research problem

"Chaos" is usually associated with something that is "bad": undesirable vibrations, loss of particles in accelerators, difficulty in control, a source of noise, etc. However stirring and mixing via chaotic fluid motion is a case where chaos is ``good''. We want as much chaos as we can possibly get to have good mixing. In fact, we go to great lengths to eliminate or design away any vestiges of regularity. All practical applications of fluid chaos to date have been built on two-dimensional (2D) flows. However the real world is three-dimensional (3D) and there is a significant difference between 2D and 3D flows. Little is known about the mechanisms of transport in three dimensions – the reasons for this are the explosion of topological complexity that comes with three dimensions and local breakdown of the existing theory that describes mixing. But there are many opportunities to implement novel application of chaotic 3D flows , any most of these are yet to be uncovered. Examples of experimental (left) and numerical (right) visualisations of flows with potential for chaos are shown in the image below. In both cases fluid trajectories are highlighted using coloured markers.



Project aims

This project is a CSIRO-project, with CSIRO supervisors Dr. Guy METCALFE, Dr Dan LESTER

Our aim in this project is to contribute to the fundamental knowledge base of transport mechanisms in three-dimensions, and to use this knowledge to develop news ways of mixing fluids, chemical and biological species, particulates, etc. Because the vast majority of flow systems are three-dimensional, consideration of these mechanisms is of immediate importance to understanding and controlling fluid transport across a vast range of natural and engineered flows.

Expected outcomes

The expected outcome of this project will be new understanding of the routes to 3D chaos via perturbation away from 2D states. This knowledge will assist in classifying coherent structures in 3D flows and provide a connection with, and extension to, existing theory. This connection between the flow field and the mixing template can be extended to non-passive particles, non-passive dynamics, non-zero Re and large perturbations. One of these latter scenarios will be chosen in the third year of the Ph.D. in order to directly investigate a real world mixing application.

How will the project address the Goals of the above Themes?

Mixing, heat transfer and chemical reaction processes, products and technologies all rely on the characteristics of the underlying fluid flow. In particular, identifying how 3D flow control parameters can be adjusted to provide optimum outcomes in realistic 3D flows is currently unknown. This project will provide answers to some of these key questions. It will suggest new design principles for mixing, heat transfer and chemical reactions. These solutions will be derived via the mathematical and engineering-based models that will be used in the project. This project will be ideally suited to a multi-disciplinary approach, with expertise in Mathematics, Engineering and one or more of the basic Sciences being important to its success.

Some of the impact areas that could be addressed with the outcomes of this project are understanding and designing efficient processes in manufacturing (e.g. food and polymer processing, Benz 2011), micro devices (micro-electronics cooling, micro-reactors, lab-on-a-chip for molecular analysis e.g. Nguyen and Wu 2005, Kang *et al.* 2009), transport in the oceans (e.g. the gulf oil spill Mezic *et al.* 2010, the 'paradox of plankton' Scheuring *et al.* 2000), understanding the Earth's crust (e.g. ore body formation, *in situ* mining, geothermal energy extraction, contaminant remediation, dynamo action in MHD flow) and in medical and physiological applications in the human body (e.g. particulate transport deep in the lung, blood born pathogens around stenoses).

The knowledge generated in this Ph.D. project will form part of the understanding on which applications and inventions based on 3D chaotic flow are developed.

Capabilities and Degrees Required

The student for this project must have the following skills

- Good mathematical background, with a very good understanding of numerical methods
- Demonstrated experience with computer programming, either with a high level language (such as C, C++, FORTRAN) or expertise in developing applications with MATHEMATICA or MATLAB.
- Good communication skills and an ability to interact with people from different scientific backgrounds.
- Desirable is some background in Fluid Mechanics related to one of: Chemical Engineering, Geoscience, Atmospheric Science, Biology, Chemistry, Physics.
- Experience with dynamical systems is desirable although not essential

Additional costs and equipment

The student MUST have access at IITB to computational resources that are more high power than a typical desktop computer – this is I believe available. Licences for both Mathematica and MATLAB at IITB will be required.

Please provide a few key words relating to this project to make it easier for the students to apply.

Key Words: Chaos, mixing, transport, fluids, computational modelling, dynamical systems