Vortex dynamics within the cardiac left ventricle of the heart

Vortex rings are of fundamental importance across many branches of fluid mechanics. They have been observed in viscous starting jets, volcanic eruptions, jet propulsion, and in many biological flows. In this experimental investigation, a synthesised blood-like fluid will be used to study the vortex dynamics associated with the left ventricle of the heart. The vortices will be visualised and measured with a state-of-the-art laser-based flow measurement technique known as stereoscopic particle image velocimetry. Gaining a deeper understanding of the kinematics and dynamics of these vortical flow structures may play a crucial role in detecting cardiac dysfunction and in the development of future healthcare technologies.

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From radioactive particles to underwater light climates: turbulent boundary layer multiphase flows

Most flows in nature or in technological applications are turbulent, and many turbulent flows are interdispersed with particles which alter the dynamics of the fluid flow. Using advanced experimental laser-based flow measurement techniques, such as scanning stereoscopic particle image velocimetry, coupled with advanced mathematical modelling and computational simulations, we explore how inertial particles alter the structure of the turbulent boundary layer. A deeper physical understanding of these multiphase flows may allow us to predict the kinematics and dynamics of radioactive particles released into the atmosphere, gain a better understanding of the pneumatic transport of particulates in pipes, optimise the design and performance of particle separation systems, or gain insights into the deposition and transport of sedimentation on our sea beds.

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Pumping with no moving parts: innovative low-voltage micro-pumps

The integration of several components onto a silicon chip has long been a goal of micro-fluidics designers. With the ongoing development of Micro-Electro-Mechanical Systems (MEMS), we inch ever closer to the possibility of generating a lab-on-a-chip device. On many miniature devices, the transportation, mixing or control of fluid requires the use of a micro-pump — whether it is the movement of coolant through a micro heat exchanger, the delivery of a millilitre-size dose of insulin to a diabetic patient, or the transfer of biological samples through Micro Total Analysis Systems (TAS). In this experimental investigation, innovative low-voltage micro-pumps will be designed, developed and tested with a state-of-the-art micro-particle image velocimetry system.

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Mixing at the micro-scale: creating turbulence in micro-flows

Mixing at the micro-scale is notoriously difficult. The creeping flow of a viscous fluid through sub-millimetre channels is laminar and steady with a Reynolds number often smaller than 1. Consequently, efficient mixing and heat transfer to the fluid is slow since they are processes which are dominated by
diffusion and conduction. In this experimental investigation, novel micro-mixing technologies will be developed to create turbulence-like motions within micro-channels to ensure rapid fluid mixing and enhanced heat transfer for the development of the next-generation of lab-on-a-chip devices.

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**Smart skins: reducing the production of turbulence with surface plasma**

Over 50% of the total drag of a commercial aircraft is due to turbulent skin-friction drag. Therefore, the ability to reduce the skin friction over aircraft would lead to vast economic savings as well as wider health and environmental benefits through improved air quality. In this experimental investigation, innovative surface plasma actuator arrays will be designed to reduce the skin-friction drag of wall-bounded turbulent flows. The changes in turbulent boundary-layer structures will be measured with state-of-the-art laser-based flow measurement techniques such as laser Doppler velocimetry and particle image velocimetry, whilst the reductions in drag will be carefully monitored with thermal anemometry.

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**Harvesting more energy from the wind: smart rotor control using plasma virtual actuators**

Our demand for energy is increasing, and as we transition the UK to a low-carbon economy we must turn to reliable and renewable sources of energy. In this experimental investigation, innovative plasma actuator arrays will be developed to enhance the aerodynamic performance of wind turbines, allowing us to harvest even more energy from the wind. The changes in turbulent flow structures will be visualised and measured with a state-of-the-art particle image velocimetry system, whilst modifications to the instantaneous lift and drag forces of the wind turbine will be measured, simultaneously, with a custom-built force balance.

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**Hibernating turbulence: towards developing the next-generation of drag reduction devices**

To date, the most successful turbulence control technique is one which can only be used in liquid flows and is the dissolution of certain rheology-modifying additives to the working fluid. Additives can reduce turbulent energy consumption by as much as 80%, yielding an effect known as Maximum-Drag-Reduction (MDR). Recent cutting-edge, scientific research has found that MDR is closely linked to a low-drag state known as “hibernating turbulence.” In this experimental investigation, a high-molecular-weight polymer will be used to reduce the skin-friction drag of a turbulent boundary layer to the MDR regime in order to study the hibernating turbulence phenomena. Gaining a deeper physical understanding of hibernating turbulence may lead us to the next step: obtaining MDR in gas flows, which may transform the aerospace industry.

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**Turbulent vortex rings/puffs from various initial conditions and confinements**
This project will investigate the effect of various initial conditions (eg nozzle shapes or controlled perturbations) and ambient confinements (eg in cylindrical tubes) on the formation and the long term evolution of high Reynolds number turbulent vortex rings and/or turbulent puffs. Different initial and confinement conditions will firstly be designed and experiments will be conducted in the large vortex ring generator. Good spatial and temporal resolution can be achieved utilizing the existing high speed, high resolution cameras and a PIV system.

**Coherent structures, mixing efficiency in a turbulent starting jet with and without strong swirling component**

This project will be conducting data analyses on the existing PIV experimental data of a turbulent starting jet with and without swirling component. Both statistical independent and temporal resolved stereo PIV data are available. Physical interpretations of the observed coherent structures and turbulent/non-turbulent interface behaviours will be addressed by various mathematical tools (eg POD, DMD, wavelet analyses).

**Evolution of near field turbulence generated by mono-plane multi-scaled grids**

Data analyses will be conducted on the existing PIV experimental data of near field turbulence generated by mono-planed multi-scaled grid. Both statistical independent and temporal resolved data are available. Statistics and time responses of various physical quantitates will be compared among the flow fields generated by three types of grid.

**Experimental technique development and improvement on the in-house tomo PIV code**

This project aims to improve the existing in-house developed tomographic PIV code (written by MatLab and FORTRAN). More features (subroutines, e.g. multi-phase flow compatible) will be added and code structure will be improved to the existing working code to advance the performance (computation speed and accuracy). Subsequently the code will be tested in an experiment, eg two-phase vortex ring or two-phase boundary layer flow.

**Experimental study of multi-phase turbulent boundary layer flows**

This project aims to look at the interaction of the coherent structures in a turbulent boundary layer and the second phase inertial particles. Experiments will be conducted in the existing water channel and by utilizing 2D, stereo and the in-house developed tomo PIV or stereo-scanning PIV. The results will be used to support the PDF modellings in such flows.

**Coal combustion project**

This project will address the gasification and combustion process for coal using Direct Numerical Simulations (DNS), where the physical processes associated with turbulent flow will be addressed without any major physical approximation. The fundamental physical understanding obtained from DNS simulations will be utilised to develop more accurate combustion models for Large Eddy
Simulations (LES) and Reynolds Averaged Navier Stokes (RANS) simulations of pulverised coal particle laden combustion. In the present study new models will not only be devised based on analysis of DNS data (i.e., a-priori analysis). This exercise will give rise to high-fidelity computational tools for designing new generation boilers.

Flame wall interaction project

Understanding flame-wall interaction is pivotal for designing efficient Spark Ignition engines and industrial gas turbine combustors where turbulent premixed flame elements quench when they approach the cylinder walls. This flame quenching leads to unburned hydrocarbon fuel, and the associated heat transfer to cylinder wall leads to heat loss from the cylinder, and both of these act to reduce the efficiency of SI engines. Thus a thorough understanding flame-wall interaction will be gained here by carrying out Direct Numerical Simulations (DNS) of turbulent premixed flame-wall interaction in a simple configuration where all the relevant turbulent length and time scales are adequately resolved. This DNS data will subsequently be explicitly Reynolds averaged/LES filtered to assess the performances of existing models with respect to the corresponding quantities extracted from DNS data. Based on this a-priori DNS analysis modifications to the existing models will be suggested and new models will be proposed if necessary.

Non-Newtonian project

Natural convection in enclosed spaces has several applications including electronic cooling, solar collectors and heating and preservation of food. Although natural convection of Newtonian fluids in rectangular enclosures have been analysed extensively in the open literature, comparatively relatively little effort has been directed to the heat transfer of yield stress fluids. In this project natural convection of non-Newtonian yields stress fluids in rectangular enclosures will be analysed using numerical simulations. Bingham fluid is a special type of yield stress fluid, which exhibits a linear strain rate dependence of shear stress once. The effects of Bingham number, Rayleigh number, aspect ratio and the inclination with the vertical direction are going to be analysed in detail for both laminar and turbulent conditions. The simulation data will be analysed to obtain the correlations for mean Nusselt number as a function of nominal Rayleigh, Prandtl and Bingham numbers in addition to the angle with the vertical direction.

Scalar flux project

The usual modelling of turbulent scalar flux using gradient hypothesis fails to capture both the qualitative and quantitative behaviours of turbulent scalar flux in the context of Reynolds Averaged Navier Stokes (RANS) and Large Eddy Simulations (LES) under some conditions. Recent studies demonstrated that the relative strength of thermal diffusion to mass diffusion of the mixture has important effects on turbulent scalar transport in turbulent premixed flames. The relative strength of thermal and mass diffusion rate is characterised by Lewis number defined as the ratio of thermal diffusivity to mass diffusivity. The modelling of Lewis number effects on scalar flux transport in the context of RANS has been addressed before but its modelling in the context of LES is yet to be addressed. In the proposed project, Direct Numerical Simulation (DNS) data of turbulent premixed
flames will be explicitly filtered in order to carry out a-priori modelling of turbulent scalar fluxes in the context of LES.

**Stratified mixture project**

In several engineering applications combustion takes place in a configuration between the fully premixed and fully non-premixed regime. This kind of combustion is often referred to as stratified charge combustion. In this project Direct Numerical Simulations (DNS) of stratified charge combustion will be carried out where all the relevant length scale and time scales of turbulent reacting flow will be adequately resolved without any kind of turbulence modelling. The DNS data can be treated as an experimental data with infinite resolution. As a first step of this project, three-dimensional (3D) DNS with simplified chemistry will be used for fundamental understanding of the thermal aspect of the stratified charge combustion process. Based on this understanding detailed chemistry based 3D simulations will be carried out. The data will subsequently be used for developing Computational Fluid Dynamics (CFD) models for addressing turbulent stratified charge combustion.

**Welding model project**

In this project the heat, momentum and species transport in laser molten pool will be studied in detail based on Computational Fluid Dynamics (CFD) simulations. Under most practical operating conditions the molten pool convection is turbulent in nature. However, the modelling of turbulent transport in molten metal pool in dissimilar metal welding is yet to be done. As the dissimilar metal welding is inherently three-dimensional (3D) in nature, Detached Eddy Simulations (DES) simulations will be carried out for the present study. In order to keep the study simple and in order to have fundamental physical insight a dissimilar couple based on copper (Cu) and Nickel (Ni) will be investigated as Cu and Ni are completely miscible in both liquid and solid phase but have very different physical properties. A systematic parametric study will be carried out in order to examine the effects of process parameters on key features of the molten pool namely, maximum temperature, pool penetration and pool aspect ratio (ratio of width to depth).

**Phase-Space Numerical Methods For Studying Particle Transport In Turbulent Boundary Layers**

The transport, deposition and resuspension of particulates in turbulent boundary layer flow: The development and application of pdf models. The influence of turbulent structures on the dispersion of particles in turbulent flow: Model development, computational and experimental studies. The agglomeration and fragmentation of particles and droplets in turbulent flows: Computational studies using stochastic and moment based models.

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