INTRODUCTION

New developments in understanding interfacial processes in turbulent flows

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Interfaces, across which fluid and flow properties change significantly, are a ubiquitous feature of most turbulent flows and are present within jets, plumes, homogeneous turbulence, oceans and planetary atmospheres. Even when the interfaces occupy a small volume fraction of the entire flow, they largely control processes such as entrainment and dissipation and can act as barriers to transport. This Theme Issue brings together some of the leading recent developments on interfaces in turbulence, drawing in many methodologies, such as experiments, direct number simulations, inverse methods and analytical modelling.

Keywords: turbulence; interfaces; direct numerical simulations; enstrophy; vorticity; planetary layers

1. Introduction

Turbulence represents one of the great scientific challenges.1 The well-known sketch of a free water jet issuing from a square hole into a pool, by Leonardo da Vinci, can be considered as one of the first studies on the structure of turbulence, showing a flow familiar to many, which revealed turbulence characteristics, with various scales of motion and a sharp separation between jet and vortices of small and large sizes, and waves at a distance. Many quotes refer to the relevance of turbulence as well as the high degree of its complexity. In the 1970s, Richard Feynman said that ‘Turbulence is the most important unsolved problem of classical physics’ [2], and earlier Sir Horace Lamb (in a speech to the British Association for the Advancement of Science in 1932) said that ‘when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic’. Interfaces in turbulence that define regions of contrasting velocity, density or scalar quantities (such as temperature

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1This volume is dedicated to Dr Tim Nickels, from the Engineering Department, University of Cambridge, who passed away in October 2010 and is a contributor to this volume [1].

One contribution of 9 to a Theme Issue ‘Dynamical barriers and interfaces in turbulent flows’.
or contamination) occur in very broad areas for fluid mechanics ranging from processes in buoyant jets created by breathing, the edges of wakes of self-propelled bodies (e.g. ships, submarines and aircraft), at the ‘eye of the storm’, at the thermocline in the ocean, atmosphere or in mountain valleys caused by diurnal heating/cooling, up to the planetary scale, by gradients of the Coriolis force, for instance, the Jovian bands, which have been widely observed and studied for three centuries.

Turbulence, as with many areas of physical science, carries the weight of historical methodologies to understand and interpret observations. Within the last 10 years, we are now faced with two important developments. The first development lies in the ability to record and store significant amounts of data. The size of datasets that are obtained from particle image velocimetry (PIV), laser-induced fluorescence and laser Doppler anemometry measurements from single experiments are now sufficient to swamp any PC. The datasets obtained from three-dimensional numerical calculations of the fluid motion must now be processed and interrogated on computer clusters and may generally involve looking at instantaneous representations of small subsets on high-performance computers. The use of such large datasets tends to degrade the types of diagnostics that can be applied. The second development, which largely has an impact on the first, is the use and application of new diagnostics tools to reduce the size of the datasets that are analysed. The traditional approach of averaging data over time, which itself is computationally challenging, largely ignores the large excursions from the mean that are typically observed near sharp interfaces. Conditionally averaging methods are increasingly being applied to evaluate processes that occur relative to these interfaces. The principal aim of this Theme Issue is to collate some of the cutting-edge experimental and computational methods that tackle this important area.

2. Organization of issue

The Issue opens with two experimental studies of turbulence, which highlight the significant progress made with laser-based tools for measurements and diagnostic tools applied to interpret the results. Worth & Nickels [1] describe a study of the fine three-dimensional structure that exists in homogeneous turbulence where the smallest scales are quantified using tomographic PIV. The smallest structures identified show thin shear layers of thickness comparable to the Taylor microscale and, while they occupy a small fraction of the flow, the enstrophy and velocity gradients are much larger than the RMS values. As such they make large contributions to the statistics of the flow. Westerweel et al. [3] considered the characteristics of the turbulent/non-turbulent interface at the edge of a non-isothermal jet where the turbulence is very inhomogeneous. The aim was to contrast the conditional statistics for temperature (which has a Prandtl number of 10, for water) against velocity. The main results demonstrated that the conditional jump in temperature coincided with the jump in velocity.

Da Silva & Dos Reis [4] applied direct numerical simulations to analyse the structure of coherent vortices that lie at the turbulent/non-turbulent interface of a jet. The simulations identified anomalous enstrophy diffusion at the interface.
which corresponded to the large-scale vortex structures (LSVS) sitting near to the interface. The nimbling process that largely controlled turbulent entrainment was generated by the viscous diffusion of vorticity from the LSVS.

Interfaces occur on much larger scales both in the ocean and in planetary atmospheres. Dritschel & Scott [5] considered the emergence of a jet and interfaces from an initially turbulent flow on a β-plane using contour dynamics. The most striking result was the emergence of these layers when the perturbation to the flow is strong, where the introduction of a weak jet is sufficient to control the long-term dynamics. Marcus & Shetty [6] consider the zonal winds on Jupiter. They apply an inverse method that computes the optimal dynamically consistent flow that agrees with the observed wind velocities. The results show that zonal potential vorticity does not change monotonically, and explanation as to the anomology was discussed. These powerful inverse methods are increasingly being applied across other areas of fluid mechanics.

Sharp interfaces within turbulence can play a role in screening one region from another. Davidson [7] provides a detailed discussion of the long-range interactions that occur in turbulence and uses this to develop explicit scaling laws for the decay of magnetohydrodynamical turbulence, rapidly rotating flows and stratified fluids. This array of scaling laws agree with published data. Davidson [7] identified that the weakness of the long-range interactions in these homogeneous flows still remains an important and open question.

Finally, following a successful Euromech 517 meeting on interfaces in turbulent flows, Hunt et al. [8] describe a timely review of the presentations and a discussion of the broad outstanding questions in this area. The research community in this area is beginning to make significant inroads in this topic, as seen from the collection of papers in this Theme Issue.

3. Concluding remarks

Interfaces are a common feature of many turbulent flows. As highlighted in this Issue, there have been many significant developments in this area, especially on the experimental and computational side, and embracing novel techniques (such as inverse methods) to analyse and interpret the flow. There are still gaps in our current knowledge, such as the effect of interfaces on long-range interactions and some of the physical processes that occur within and adjacent to these interfaces. Most of these challenges will probably be met by developing new diagnostic tools, first within idealized situations, before their application to the enormous datasets being generated through experiments and computations.

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References


