Scientific and Financial Report

Challenging Turbulent Lagrangian Dynamics

Convenors:
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CONTENTS:

Figure 1: From left to right (first row from bottom): Elisabeth Guazzelli (ESF representant), Federico Toschi, Alfredo Soldati, Katepalli R. Sreenivasan, Detlef Lohse, Luca Biferale, Guy Pelletier, Said Elghobashi, Elisabetta De Angelis, Carlo M. Casciola, (second row) Misha Chertkov, Krzysztof Gawedzki, Zellman Warhaft, Alessandra S. Lanotte, Ramon van den Berg, Enrico Calzavarini, Roberto Verzicco, Massimo Cencini, Boris Jacob, Jeremie Bec, Giorgio Amati, (third row) Angelo Vulpiani, Agnese Seminara, Stefano Musacchio, Guido Boffetta, Roberto Benzi, Pui-Kuen Yeung, Andrea Mazzino, Antonio Celani, (fourth row) Bruno Eckhardt, Itamar Procaccia, Brian Sawford, Alain Pumir, Szymon P. Malinowski.

1 Financial Summary Report

The Workshop has been based on a total budget of 31508 **euro.** The event was financed primarily by the **European Science Foundation** (14000, euro), under the program ESF Exploratory Workshop. It has also benefited from contributions coming from the **Office of Naval Research** (7500 US$ [$\sim$ 5606 euro]), the Research National Agencies **INFN** (4000 euro) and **INFM** (2500 euro), the **CNR** Institute ISAC (4000 euro), and the **University of Tor Vergata (1402 euro)**.

The 14000 **euro** from the ESF grant have been used to cover the following expenses:

- Accommodation costs [partial covering of local costs, meal and lodging, of participants]: 6810 **euro**.
- Travel Costs of participants: 4798 **euro**.
- Local Costs [Advertising, stationery, equipment for presentation] 902 **euro**.
- Administrative Costs 1400 **euro**.

2 Executive Summary

The meeting has succeeded in bringing together participants with wide range of expertize, knowledge's and research interests: young and senior scientists from engineering, to mathematics, geophysics, experimental and theoretical physics with the common interest in the properties of transport in turbulent simple and complex flows, especially from the point of view of the Lagrangian dynamics.

As it is well known, the statistical description of turbulent phenomena can be performed choosing either an Eulerian -in terms of fields- or a Lagrangian - in terms of particles- point of view. The two approaches are equivalent and, if turbulence was fully understood, we should be able to translate Eulerian properties into Lagrangian ones and viceversa. We are still quite far from this point.

Lagrangian statistical formalism was pioneered by the meteorologist L. F. Richardson around 1920, but always suffered of the lack of good and reliable experimental studies of turbulent Lagrangian dispersion. Recently, important breakthroughs have been done on the theoretical side, then stimulating new highly sophisticated laboratory experiments and high resolution direct numerical simulations. So now, great amount of data are available and great theoretical challenges are on the ground.

The workshop gathered those scientists who mainly contributed to such advancements together with researchers working on similar problems in different contexts, such as bubbly flows, polymer transport, or rain droplets formation. The main idea was that some of the general understanding recently achieved in simple turbulent

flows could also give significant contributions to a wider range of problems - often more complex-, so stimulating new interdisciplinary approaches to the field.

With this aim, we organized the program with three long review talks (40 minutes) covering the experimental (**E. Bodenschatz** MPI, Germany), theoretical (**G. Falkovich**, head of the Complex System Department at the Weizmann Institute of Science, Israel) and numerical (**A. Celani**, INLN, France) achievements & open issues. Then each participant contributed with a short talk (20 minutes), going straight to the problem. Two long round tables, coordinated by four senior scientists, were organized to accomplish with the "exploratory" character of the workshop: they were employed to propose new approaches, sketch ideas and go to the core of the unsolved questions in the field. The informal discussions stimulated contributions from young scientists.
For some topics- e.g. heavy particles behavior or rain droplets formation-, the presence of experimental, theoretical and applied science researchers all involved in the field really stimulated fruitful interactions. This constitutes a positive outcome of the event.
The creation of a common European database, gathering together the results from experiments and numerical simulations, to which scientists could access for their different researches and analysis, was proposed. During the discussions, the urgent need to create a large community of scientists working on turbulence related research emerged more than once. This is in our opinion a very important result of the meeting, being the first step for the setting up of a European research network, where people share expertise, knowledge and scientific data.

3 Scientific Content & Results

When proposing the workshop, we stimulated participants to deal with the following main issues: Multi-particles behavior of passive tracers in non-ideal turbulent flows; Single and collective behavior of inertial tracers in simple flows; Lagrangian transport in complex flows and Scientific visualization. Finally the workshop activity has widely broadened the number of topics and dealt with experiments, theory, models and numeric, differently related to the turbulent Lagrangian dynamics. Some participants also contributed with material on some specific issues, relevant for the study of turbulent flows (instability, random number generators, ..). In the sequel, we concentrate on those issues that were mostly discussed both in the talks and in the round tables.
These can be listed as follows:

1 Lagrangian statistics

2 Inertial particles Lagrangian dynamics and statistics

3 Turbulent flows in the presence of bubbles

4 Transport properties in complex flows

5 Experiments, Theory, Numeric: Where do we stand?

1- Lagrangian statistics

About six talks [**B. Sawford** "A study of the connection between exit-time statistics and relative dispersion using a simple Lagrangian stochastic model"; **E. Leveque** "Lagrangian intermittencies in dynamic and static turbulent velocity fields (from DNS)"; **G. Boffetta**"Statistical properties of inertial particles in fully developed turbulence"; **B. Ecke** "Lagrangian dynamics in 2D turbulence"; **P.K. Yeung** "Lagrangian conditional statistics and small-scale intermittency in turbulence"; **G. Eyink** "The Lagrangian Vortex Mechanisms of Turbulent Cascades"] have been dedicated to the Lagrangian approach to turbulence, covering different topics. These have ranged from very general features -as the Lagrangian mechanism of vortex line stretching to explain the turbulent energy cascade-, to specific problems - such as the statistical behaviour of tracer tetrads in a turbulent flow. Relative dispersion - i.e. the separation process of two particles initially very close-, has been discussed in great detail, for $2d$ and $3d$ flows, in the case of experiments and of numerical simulations. This is a fundamental problem because of its connection to the behaviour of concentration fluctuations and because of the insight it provides into the spatial structure of turbulent flows. Stochastic modelization have been proposed: thanks to the great amount of data now available, many of these models can now be tested and their relevance can be systematically assessed.

2- Inertial particles dynamics and statistics

The interaction between turbulent fluctuations and the dynamics of inertial particles, that is finite-size impurities such as dust, is still difficult to capture in fully developed turbulent flows. Being the subject of major importance for many geophysical and industrial applications, we asked to researchers working in engineering and physics to expose their different point of views. In particular, the problem of particle cauterization or *preferential concentration* has been discussed at length, in the case of direct numerical simulations and experiments [**Z. Warhaft** "Preliminary Lagrangian Measurements of Inertial Particles in Wind Tunnel Turbulence"; **B. Eckhardt** "Clustering of inertial particles"; **J. Bec** "Clustering and collisions of heavy particles in turbulent flows"; **M. Cencini** "Inertial Particles in High-Reynolds turbulent flows"; **A. Soldati** "Particles turbulence interactions in boundary layers"]. We have compared observations made in simple synthetic flows, in homogeneous and isotropic turbulent flows, and in inhomogeneous and anisotropic flows (boundary layers). The most striking evidence is that cluster is a phenomenon present at various spatial scales: this demands new theoretical approaches.

3- Turbulent flows in the presence of bubbles

It is well known that bubbles dynamics is strongly coupled to that of the carrier

flow, and viceversa: however we still lack the neat understanding of such two-way coupling. On the experimental ground, one of the most interesting topic concerns the *drag reduction*, i.e. the decrease of the turbulent energy dissipation by the presence of micro-bubbles, dispersed in the flow. High resolution numerical simulations and high quality experimental data have been presented on the subject: it appears, that notwithstanding the accuracy of the measurements, there is not a complete comprehension of the drag reduction in bubbly flows. Several theoretical models can be formulated: further tests are needed. These issues have been discussed in the following talks [**R. van den Berg** "Drag reduction in bubbly Taylor-Couette turbulence"; **S. Elghobashi** "On drag reduction in a micro-bubble-laden spatially-developing turbulent boundary layer"; **E. Calzavarini** "Bubbles in a turbulent Kolmogorov flow";]

4- Transport properties in complex flows

Various talks have focused their attention on the transport properties in flows that can be generally defined as complex. Examples are: polymer transport in turbulent flows [**C.M. Casciola** "Dilute polymers in wall bounded flows: energy transfer and spatial fluxes"; **M. Chertkov** "Polymer Statistics in a Random Flow with Mean Shear"]; or transport properties in a Rayleigh-Taylor turbulent $2d$ and $3d$ flows [**A. Mazzino** "Rayleigh-Taylor turbulence in two dimensions"]; or transport in a suspension flow [**E. Guazzelli** "Particulate flow: can particles induce turbulence?"]; or transport of cosmic rays in astrophysical flows [**G. Pelletier** "Transport of Cosmic Rays in Tangled Magnetic Fields"]. Particularly, it has been discussed the problem of rain droplets formation in warm clouds. This is a problem of fundamental importance not only for atmospheric and climate research, but also for theoretical physics, because it deals with inertial particle behaviour, with clustering and collisions in turbulent flows, ...
Interesting features have emerged from the comparison of $3d$ geophysical and $2d$ numerical data, stimulating new interdisciplinary approaches to the field [**S. P. Malinowski** "Motion of cloud droplets observed in the laboratory turbulent chamber flow"; **A. Seminara** "Droplet condensation in turbulent flows"].

5-Experiments, Theory, Numeric: Where do we stand?

Three long reviews have been devoted to summarize the state-of-the-art in Lagrangian turbulence, with a particular attention to new challenging problems, such as e.g. that of inertial particles behaviour. On the experimental side, new techniques have been recently designed, giving a new impetus to the research in Lagrangian turbulence. In particular, the group of Prof. Bodenschatz which has mainly contributed to these advancements has now moved to Europe, so promoting new exchanges between scientists. As for the theory, there are not many rigorous results concerning heavy particle statistics, also because of the subject complexity. Particularly promising is the application in this field of tools borrowed from the study of random dynamical systems. Finally, the lecture concerning numeric has been of particular interest: in great detail, it has been explained how numerical simulations

can in a near future become a real alternative tool to experiments (because of the present computers memory limits, numerical simulations have not yet been able to describe all the degrees of freedom of a fully developed turbulent system, such as an atmospheric flow for example). This represents a real new challenge for our field.

4 Final Scientific Program

1 September 2005 - Thursday

17:00-20:00 Registration
20:00 Welcome dinner

2 September 2005 - Friday

09.00-09.15 Elisabeth Guazzelli - ESF presentation

09.15-09.55 Eberhard Bodenschatz - Review talk on experiments

09.55-10.20 Ramon van den Berg - Drag reduction in bubbly Taylor-Couette turbulence

10.20-10.50 coffee break

10.50-11.15 Alfredo Soldati - Particles turbulence interactions in boundary layers

11.15-11.40 Brian Sawford - A study of the connection between exit-time statistics and relative dispersion using a simple Lagrangian stochastic model.

11.40-12.05 Zellman Warhaft - Preliminary Lagrangian Measurements of Inertial Particles in Wind Tunnel Turbulence

12.05-14.00 lunch

14.00-15.30 Roberto Benzi and Detlef Lohse coordinate round table

15.30-15.55 Said Elghobashi - On drag reduction in a micro-bubble-laden spatially-developing turbulent boundary layer

15.55-16.20 Emmanuel Lévêque - Lagrangian intermittencies in dynamic and static turbulent velocity fields (from DNS)

16.20-16.45 Guido Boffetta - Statistical properties of inertial particles in fully developed turbulence

16.45-17.05 coffee and tea break

17.05-17.30 Agnese Seminara - Droplet condensation in turbulent flows

17.30-17.55 Guy Pelletier - Transport of Cosmic Rays in Tangled Magnetic Fields

3 September 2005 - Saturday

09.00-09.40 Gregory Falkovich - Review talk on theory

09.40-10.05 Szymon P. Malinowski - Motion of cloud droplets observed in the laboratory turbulent chamber flow

10.05-10.30 Bruno Eckhardt - Clustering of inertial particles

10.30-10.50 coffee break

10.50-11.15 Jérémie Bec - Clustering and collisions of heavy particles in turbulent flows

11.15-11.40 Michael Chertkov - Rayleigh-Taylor turbulence

11.40-12.05 Massimo Cencini - Inertial Particles in High-Reynolds turbulent flows

12.05-14.00 lunch

14.00-15.30 Itamar Procaccia and Katepalli R. Sreenivasan coordinate round table

15.30-15.55 Krzysztof Gawędzki - Multiplicative large deviations in a locally anisotropic Kraichnan flow

15.55-16.20 Robert Ecke - Lagrangian dynamics in 2D turbulence

16.20-16.45 Pui Kuen Yeung - Lagrangian conditional statistics and small-scale intermittency in turbulence

16.45-17.05 coffee and tea break

17.05-17.30 Angelo Vulpiani - What properties make a chaotic system a good Pseudo Random Number Generator?

17.30-17.55 Elisabeth Guazzelli - Particulate flow: can particles induce turbulence?

4 September 2005 - Sunday

09.00-09.40 Antonio Celani - Review talk on numeric

09.40-10.05 Enrico Calzavarini - Bubbles in a turbulent Kolmogorov flow

10.05-10.30 Andrea Mazzino - Rayleigh-Taylor turbulence in two dimensions

10.30-10.50 coffee break

10.50-11.15 Alain Pumir - Lagrangian Tetrad Dynamics and the Phenomenology of Turbulence

11.15-11.40 Carlo M. Casciola - Dilute polymers in wall bounded flows: energy transfer and spatial fluxes

11.40-12.05 Gregory Eyink - The Lagrangian Vortex Mechanisms of Turbulent Cascades

12.05-12.30 Uriel Frisch - Universality of complex singularities for the Euler equation

12.30-12.45 Concluding remarks and future outlook coordinated by Uriel Frisch

12.45-13.00 Conference closure

13.00-14.15 lunch

5 Final list of Invitees

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6 Statistical Data about Participants

We have been extremely pleased with the feedback from the community before and after the Workshop. We have received many requests from scientists overall the world asking to attend the Workshop even at their own expenses. We have been forced to decline these solicitations because of the constraints on the number of participants and on the nationalities imposed by the main sponsoring agency, the ESF.

Overall we have had **28 oral presentations**, 3 of which devoted to review talks.

Two round tables have also been organized. **Participants came from 8 different countries**. Speakers sponsored by the ESF grant came from:

- France (8);
- Italy (7);
- Germany (2);
- The Netherlands (3);
- Poland (1);
- USA (3).

We have carefully respected the geographical balance and the constraint to not cover more than 3 oversea invitees by using the ESF grant. Also concerning the distribution of ages among participants we succeeded to have a very good balance: ranging from young researchers around 30 years old (Bec, Cencini, Seminara, Mazzino, Calzavarini) to senior researchers (Sawford, Benzi, Sreenivasan, Procaccia). About 32% of the participants were younger than 40 years of age. The gender ratio was about 10%. About 75% of the participants of the workshop were from ESF countries.