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# ON WHY CONTROL OF TURBULENT FLOWS IS NON-TRIVIAL AND WHY IT IS POSSIBLE

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## INTRODUCTION

In spite of exaggerated beliefs and claims on universality of turbulent flows (e.g. as independence of statistics of excitation, boundary conditions and the nature of dissipation) it appears that turbulent flows are controllable. This is because many of their basic and "practical" properties (both in large and small scales) depend essentially on boundary and initial conditions, the nature of forcing, additives, etc.

One of the reasons of extreme non-triviality of control of turbulence is the lack of knowledge of basic and fundamental issues not only generally (such as absence of turbulence theory based on first principles), but those aspects that are vital for the issue of control and modeling which is used widely in the field of control, e.g. a popular opinion that *developing theories and models is of particular importance as the methodologies developed often can be used to achieve other objectives such as control of turbulent flows* [1]. One of such aspects is the much neglected issue of the generically nonlocal nature of turbulence as manifested, e.g. in the direct and bidirectional coupling of large and small scales [2]. This is the main concern of this talk. The reason for such a concern is wide employment of low dimensional approaches based, e.g. on the belief that the unresolved scales and processes associated with them can be adequately represented by a *set of relatively simple (e.g. diffusive-like) deterministic formulae* [3] or other "parameterizations" *representing key processes models without resolving them* [4]. In such an approach the role of small/unresolved scales are essentially underestimated, which thereby are abused assuming that they are 'slaved' to the explicitly treated part of the flow and serving mostly as a passive sink of energy. This is a major misconception and oversimplification due to neglecting the inherently nonlocal nature of turbulence.

## A SIMPLE EXAMPLE

We start from a simple example illustrating the issue of nonlocality. This is a fully developed turbulent shear flow in a plane channel. It is known that velocity and vorticity correlate weakly [2], which - taking the position that velocity fluctuations represent the large scales and the velocity derivatives represent the small scales - implies weak correlation between large and the small scales. Nevertheless, the coupling between the two is of utmost importance throughout the whole flow field. It is due to this same coupling - contrary to common beliefs - the flow in the proximity of the mid-plane is neither homogeneous nor isotropic at level of velocity derivatives, since the gradient of the Reynolds stress is essentially non-vanishing IN the mid-plane and is finite independently of the Reynolds number.

There is also evidence (unnoticed that it is such) about the coupling between the Reynolds stress and the field of the rate of strain tensor in a turbulent boundary layer [2, 5].

## ON LOCALITY VERSUS NONLOCALITY

Nonlocality is a broad, but much neglected issue. It is a generic internal property of turbulent flows and exists independently of the presence of mean shear or other external factors with different manifestations. In the context of control and modeling the nonlocality is manifested in a rich direct and bidirectional coupling between large/resolved and small/unresolved scales and comprises an essential part of the complex interaction between the multitude of the degrees of freedom in turbulent flows. On other aspects see [2, 6].

There is some contrast/conflict between the common view on dominance of local effects, though there are no rigorous grounds for the above view, and the fact that turbulence is more than suspect of being inherently nonlocal. Indeed, there is a variety of manifestations (including hard experimental evidence at very large Reynolds numbers) of direct and bidirectional impact-coupling of large and small scales which is essentially nonlocality: turbulent flows appear to be far more nonlocal than a theoretician would like to encounter. On the other hand, there are continuing attempts to single out at some "locality" and related "simpler" properties such as putting forward general hypotheses/assumptions on locality properties of turbulent flows, such as local homogeneity and isotropy of any turbulent flow at high Reynolds numbers (Kolmogorov 1941 and numerous followers), cascades and inertial range, several kinds of local equilibrium and self-similar states of turbulent flows, to mention few most popular with some acquired even a paradigmatic status. The common feature is the assumption that the turbulent motion at some point in time and space is defined by its immediate proximity. Hence locality.

The main reason for such attempts becomes clear because nonlocality is among the main reasons of the absence of a sound theory of turbulence, based on first principles, Landau, 1960, Kolmogorov, 1985, see [2, 6] for references.

There are also many other reasons why non-locality is indeed "bad". With nonlocality it is far from trivial, if not impossible, to use the experimental data – which are all limited in space and time – for "validation" of theoretical developments for, e.g., homogeneous flows, i.e., in "infinite" domains. Also, locality is necessary for the "physical foundation" in various low dimensional approaches in modeling of turbulence, etc.

Though even just looking at the equations for the small/unresolved scales it is straightforward to realize that these scales depend on the large/resolved scales via nonlinear space and history dependent functionals, i.e., essentially non-local both spatially and temporally and also bi-directionally, which makes low-dimensional description pretty problematic. On top of this low-dimensional approaches are generically deficient as, e.g. abusing and missing an essential part of physics and dynamics resided mostly with small/unresolved scales associated with such fundamental properties of turbulence as an essentially rotational and dissipative phenomenon.

So it is unlikely – and there is accumulating evidence for this – that relations between them (such as "energy flux") would be approximately local in contradiction to K41a hypotheses and surprisingly numerous (but futile) efforts to support their validity.

## CONCLUDNG REMARKS

We return to the main difficulty - absence of turbulence theory based on first principles, which is serious indeed when it comes to turbulent flows at high Reynolds numbers not accessible to DNS of NSE. In such a case models alone as inherently based on low dimensional approaches are not sufficient, and there is a need to study the fundamental nonlocal properties manifested in the rich direct and bidirectional coupling between large/resolved and small/unresolved scales via non-trivial experimental studies at high Reynolds numbers. We argue that such studies are expected to aid essentially in improving control and modeling, e.g. by reducing the uncertainties caused by low-dimensional approaches.

We illustrate the above points by experimental evidence at high Reynolds numbers (Taylor microscale Reynlods number exceeding $10^4$) with pointwise access to the full tensor of velocity derivatives, i.e. vorticity strain/dissipation, etc. These include the issue ill-posednes of the interial range, the 4/5 Kolmogorov law, anomalous scaling in the conventionally defined inertial range and, if time permits, some other.

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