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# DELAYED TURBULENCE DECAY CAUSED BY SWIRLER GRIDS

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**Abstract:** *The swirler grids offer an interesting profile of turbulence decay. First, they create a lattice of aligned vortices, which behave similarly as the Two-dimensional energy condensate (vortices are parallel as in thin layer flows). Thus turbulent kinetic energy (TKE) grows downstream. Later, due to mutual interaction, the meandering grows until it destroys the vortex alignment. Once the vortices are no more parallel, their interaction switch to classical 3D direct energy cascade and the turbulence decays similarly as past a regular grid. In this contribution, we show the downstream profile of TKE measured for several swirler grids.*

**Keywords: Mixing grid, Turbulent Kinetic Energy, Particle Image Velocimetry, Turbulence Decay**

## 1. Introduction

While the grid turbulence is generally understood as the best experimentally available realization of Kolmogorov (1991)'s homogeneous and isotropic turbulence (HIT), the nature often contain very different cases: especially the geophysical flows are often effectively two-dimensional, see Izakov (2013) containing inverse energy cascade of Alexakis (2023). Similarly, the technical applications do not satisfy with HIT: the length-scales are not distributed beneficially, the turbulence decay is too steep, and the cooling or mixing efficiency is not easy to homogenize along flow path. Fractal grids developed by Valente and Vassilicos (2011); Hurst and Vassilicos (2007); Discetti et al. (2011); Gomes-Fernandes et al. (2012) solve such issues by creating larger-scale turbulent structures at the beginning followed by decay from the small scales.

In this contribution we summarize recent attempts at the University of West Bohemia in Pilsen regarding the development of *swirler grids* focusing to the downstream decay of Turbulent Kinetic Energy (TKE) measured by using Particle Image Velocimetry (this method is best described by Adrian et al. (2000)).

## 2. Experimental setup

This limited-length contribution does not allow the full description of the setup. The wind tunnel is described by Yanovych et al. (2019, 2021). The swirler grid is introduced by Duda and Yanovych (2024). The PIV equipment at UWB is examined by Duda et al. (2020a). The method of individual vortices is developed by Duda (2021). The measurement with model of nuclear fuel assembly is described by Duda et al. (2026).

## 3. Results

### 3.1. Downstream development of Turbulent Kinetic Energy

Figure 1 displays the decay of Turbulent kinetic energy (TKE) past various grids developed at the University of West Bohemia The solid black line represents a regular square grid by Duda et al. (2020b). The green

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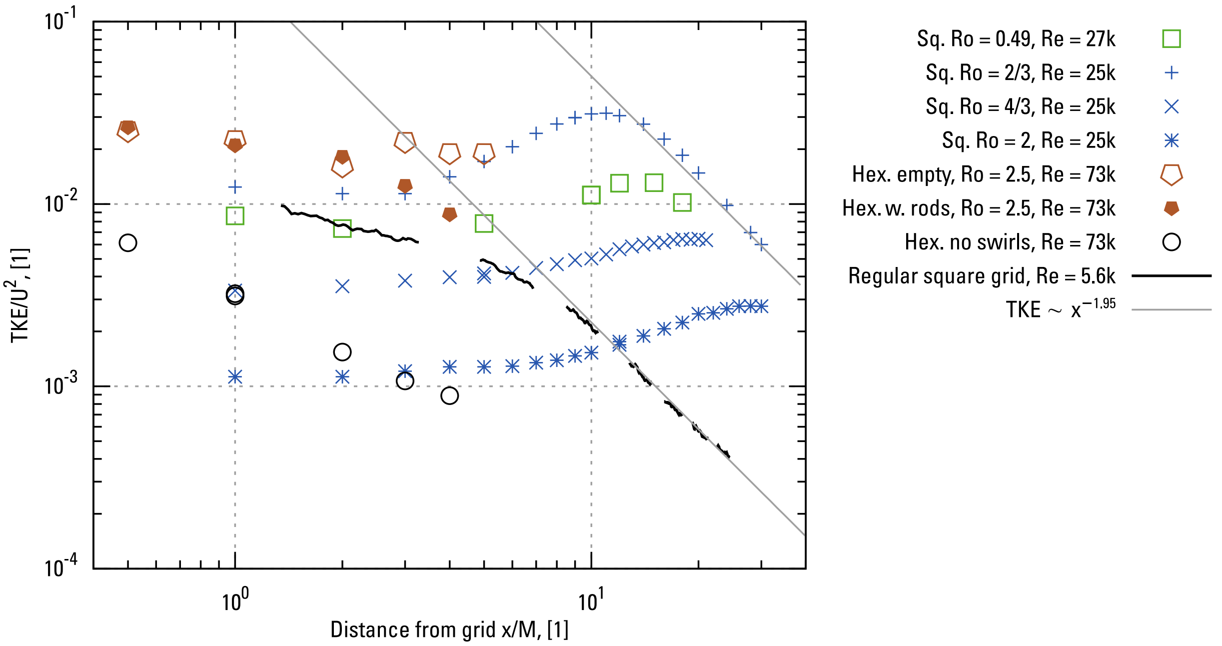


*Fig. 1: Turbulent kinetic energy as a distance downstream the grid for several cases explored at the University of West Bohemia in Pilsen. The data past a regular square grid is displayed as solid black line (–). The green square (□) represents the data past a simple swirl grid described by Duda and Yanovych (2024). The blue crosses (+, ×, ∗) represent the swirler grid of sine profile, those data are not published yet. The symmetry is square and three Rossby numbers are explored. The empty reddish pentagon (⬠) is grid of hexagonal symmetry with swirling element only in every second node. This grid is designed as a mixing grid for nuclear reactor of VVER type, thus, when the fuel rods are added, the significant damping through boundary layers appear; such data are denoted by filled pentagons (⬠). A basic spacer grid for VVER reactors with fuel rods is displayed by black circles (○).*

and blue symbols represent the swirler grids of square symmetry, while the reddish symbols play for grids of hexagonal symmetry developed to serve as mixing grid within the VVER nuclear reactors. The basic grid with no swirling elements (black ○) has been used by Duda et al. (2026) to explore the effect of random blockage of the spacer grid.

We see that TKE past the standard grid (black line) or past a swirler grid at large enough distances (blue times ×) decays according to power law with exponent $-1.95 \approx -2$ as observed by many classical studies, see e.g. Warhaft and Lumley (1978); Kurian and Fransson (2009); Grzelak and Wierciński (2015); Duda et al. (2020b). This decay exponent varies a little in dependence not only on the grid parameters like symmetry and blockage, but also by the methodology used for data fitting – e.g. if there is some *virtual origin* Mohamed and LaRue (1990) or not, and so on.

### 3.2. Observed scenario of the delayed decay

All the swirler grids display delayed decay of turbulence. The scenario is, that first some part of energy is hidden into the energy of vortices. As the vortices are located at stable positions, this energy does not contribute to the TKE (see Figure 2, where this fluctuation energy contribution is displayed at instantaneous snapshots). Later, the vortices start to *meander*, see Fig. 2(c) and the TKE signal grows. Later, the fluctuations in the vortex parameters grow exponentially; in other words, the larger the deviation, the stronger the advection of the neighboring vortex ⇒

$$\frac{\partial f}{\partial t} \sim f \Rightarrow f \sim e^t \qquad (1)$$

This stage is captured in Fig.2(d). When the alignment among neighboring vortices gets lost, the vortices transit into classical 3D interactions governed by *vortex stretching* and *reconnections*. Therefore, the direct energy cascade forms and the decay process converges towards the classical decay of TKE $\sim x^{-2}$. This regime can be observed in Fig2(e).

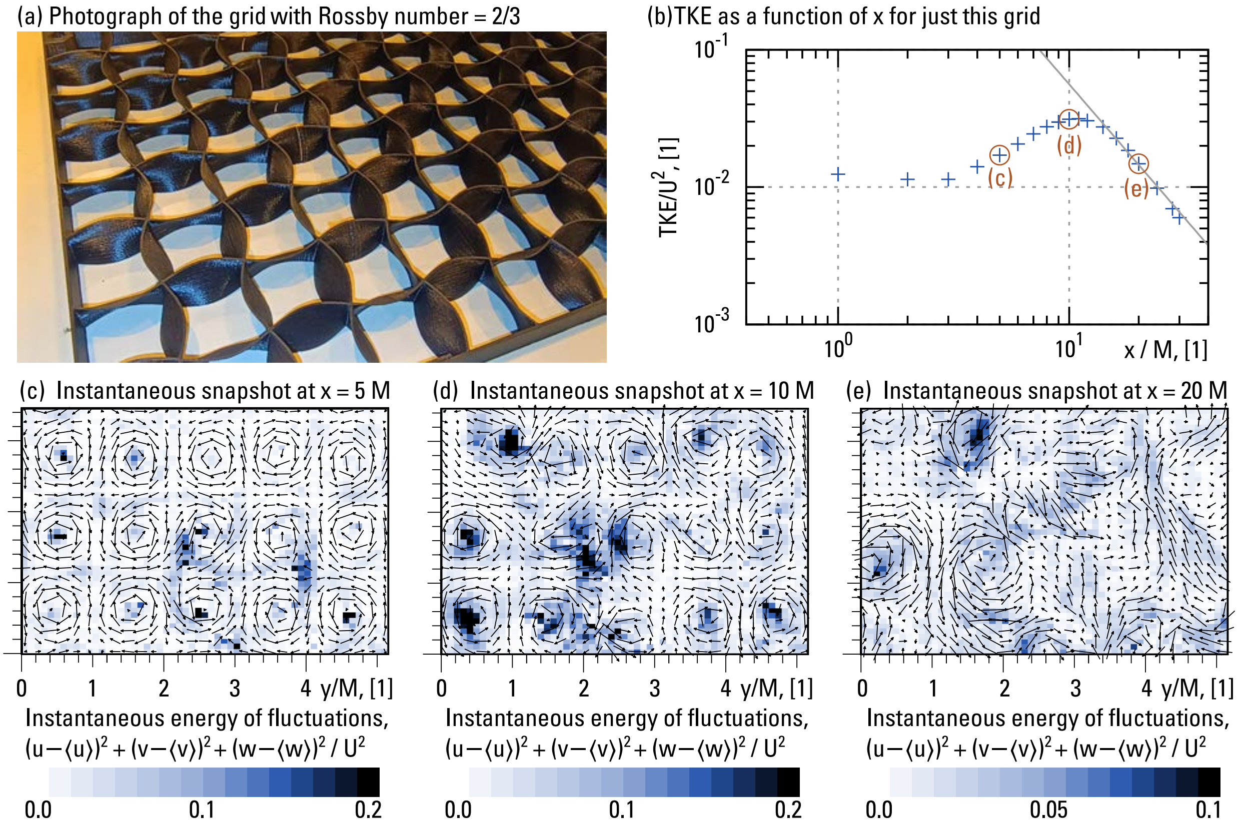


*Fig. 2: A small example of the measured data at the University of West Bohemia. Panel (a) shows the swirler grid of sine profiling with* $\mathrm{Ro} = 2/3$*, i.e. the smallest explored Ro (stronger initial vortices). Panel (b) displays the same data as Fig. 1, but for this grid only for sake of simplicity. The encircled points denoted (c – e) are displayed in corresponding panels (c – e) in a form of spatial map of instantaneous in-plane velocity magnitude. At (c) we see the regular grid of vortices already with deviations apparent by naked eye, panel (d) is the case with maximal TKE: the vortices are still mostly at regular grid positions, however their meandering is large*

### 3.3. Swirler grids for nuclear reactor fuel assembly

This behavior offers very interesting application for turbulent mixing, where we obey the quite steep decrease of mixing performance past classical grids. Instead, we can plan the position of maximal mixing and shift it downstream to an area, far from solid components. Especially, in the case of nuclear reactors, these mixing grids might homogenize the cooling performance along the fuel rods. We had tested this idea constructing the swirler-mixing grid adapted for VVER 440 geometry (Blanc (2022)), reddish pentagons ⬠ in Fig. 1.

The swirler grid for nuclear reactor has hexagonal symmetry and the swirler elements are more far from each other – the ”spacer” function of the grid has to remain, thus every odd node is circle touching fuel rods, while every even node can become swirler.

We tested the configuration of empty mixing grid (empty reddish pentagons ⬠) and the more realistic case with the fuel rods (filled). However, the rods are not heated, the flow can be considered as isothermal. In the close vicinity we observe very similar behavior in both cases – the vortices does not know about each other, neither about the fuel rods and their boundary layers. Since $x \sim 2M$ the data split into two branches: past the empty grid, TKE grows as expected from the other swirler grids, while the case with fuel rods display continuous decay, because the vortices are effectively separated by the fuel rods, thus they cannot multiply their meandering as described above. Instead, they slows down via interaction with boundary layers. Therefore, this attempt to control the mixing performance inside a nuclear reactor is a fiasco.

## 4. Conclusions

The swirler grids investigated in this study exhibit a characteristic delay in turbulence decay, caused by the initial formation of a stable lattice of aligned vortices. While this organized structure temporarily stores a significant portion of the fluctuation energy, the subsequent growth of vortex meandering releases this energy back into the flow and produces a downstream maximum of TKE. Once the vortex alignment collapses, the flow returns to a classical three-dimensional cascade with a decay rate comparable to that behind a regular grid. This mechanism offers a promising route for controlled positioning of enhanced mixing, although its applicability in nuclear-reactor fuel assemblies is limited: the presence of fuel rods suppresses vortex interaction and prevents the delayed-decay scenario from developing. Overall, swirler grids provide a promising tool for tailoring turbulence development in open flows, but their performance in confined geometries requires further refinement.

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