AIP | Physics of Fluids

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Citation: Phys. Fluids **23**, 119101 (2011); doi: 10.1063/1.3657088
View online: http://dx.doi.org/10.1063/1.3657088
View Table of Contents: http://pof.aip.org/resource/1/PHFLE6/v23/i11
Published by the American Institute of Physics.

Comment on "Dissipation and decay of fractal-generated turbulence" [Phys. Fluids 19, 105108 (2007)]

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(Received 28 July 2011; accepted 5 October 2011; published online 7 November 2011)

We comment on the experimental results of Seoud and Vassilicos "Dissipation and decay of fractal-generated turbulence" [Phys. Fluids **19**, 105108 (2007)] and show that, although their main observation that $C_\epsilon \sim Re_\lambda^{-1}$ for the fractal square grid-generated turbulence is essentially correct, their quantitative estimations of turbulent quantities depending on small scales (e.g., ε, λ, Re_λ, and C_ε) are biased by their anemometry system. © *2011 American Institute of Physics*. [doi:10.1063/1.3657088]

In a paper that one of us co-authored[1] about the decay of fractal square grid-generated turbulence, it was shown that the energy dissipation rate at moderately high Reynolds numbers ($\mathcal{O}(10^2) < Re_\lambda < \mathcal{O}(10^3)$) did not follow the expected high Reynolds number scaling $C_\varepsilon \equiv \varepsilon L_u/u'^3 \approx const$ (where u' is the r.m.s. streamwise velocity and L_u the longitudinal integral scale). Instead, it was found that $C_\epsilon \sim Re_\lambda^{-1}$ during the turbulence decay suggesting a depletion of the Richardson-Kolmogorov cascade, possibly due to the particular initial conditions imposed by the fractal object. These observations have been subsequently confirmed by Ref. 2 but with quantitatively different numerical values of Re_λ and C_ε, as can be inferred from their data.

We address this issue in the present note by repeating some of the measurements of Ref. 1 using two constant temperature anemometry (CTA) systems. The first system is the same used by Seoud and Vassilicos[1] for their measurements, the A. A. Lab. AN-1005 CTA (also used in Ref. 3) and the second is a DANTEC Streamline CTA. We also compare both measurement results with the data from Ref. 2 which were recorded using a DISA 55M10 CTA system. All the measurements are performed in the same wind-tunnel and all the anemometers operated a $d_w = 5$ μm diameter and $l_w = 1$ mm sensing length hot-wire. The turbulence is generated by a space-filling fractal square grid with a blockage ratio of 25% and a thickness ratio of $t_r = 17$ (see Fig. 1(c) in Ref. 1).

The recordings with the DISA 55M10 and the DANTEC Streamline yield virtually identical statistics within experimental error and high frequency noise considerations. However, the data acquired with the AN-1005 system are significantly different concerning high frequency statistics such as velocity derivative moments. Comparing the energy spectra of the velocity signal acquired with the AN-1005 system with those acquired with the Streamline CTA (see Fig. 1), it is observed that the spectra of the former data roll off faster for the same location and inlet velocity. This is unexpected since all square-wave tests indicated that the cut-off frequency was sufficiently high (in the AN-1005 system by one order of magnitude larger than in the two other systems used here) to avoid high frequency attenuation problems. However, we measured the actual frequency response of the anemometers (by implementing a sine-wave test) and found that our AN-1005 unit exhibits problems in its in-built signal conditioning unit and its in-built square-wave test. It could be clearly identified that (1) the actual −3dB cut-off frequency did not correspond to the estimation via the square-wave test and (2) the −3dB cut-off is about 6kHz (but depends on the amplifier gain), consistent with the observed roll-off of the measured turbulence spectra.

The immediate consequence of an artificial high frequency attenuation (in fact a low-pass filter) is that the turbulent energy dissipation rate ε is underestimated and the Taylor micro-scale (using the isotropic definition $\lambda^2 \equiv 15\nu u'^2/\varepsilon$) is overestimated. Nevertheless, other turbulent quantities do not depend on high frequency statistics such as the mean velocity U, the velocity component r.m.s. u', v', shear stress $\overline{uv}$, and the integral scale L_u. Derived quantities such as the turbulence production terms are not meaningfully affected by this high frequency bias either.

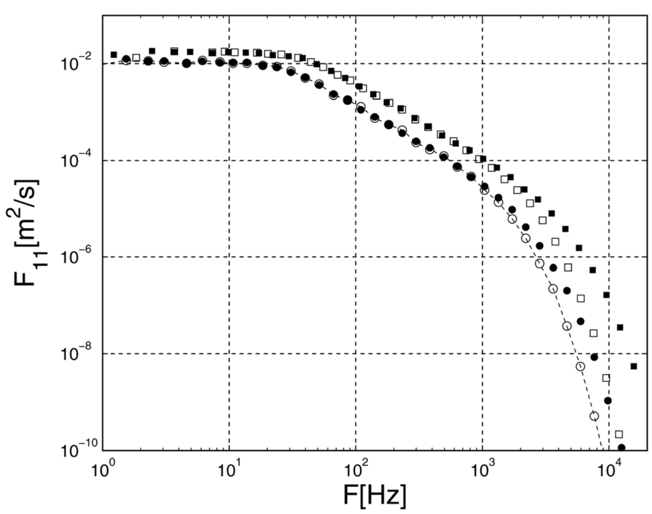

FIG. 1. Comparison of the longitudinal energy spectra located 1850 mm downstream of the fractal square grid measured with two anemometry systems at two inlet velocities U_∞: (○) AN-1005 CTA $U_\infty = 10$ m/s, (•) Streamline CTA $U_\infty = 10$ m/s, (□) AN-1005 CTA $U_\infty = 15$ m/s, and (■) Streamline CTA $U_\infty = 15$ m/s.

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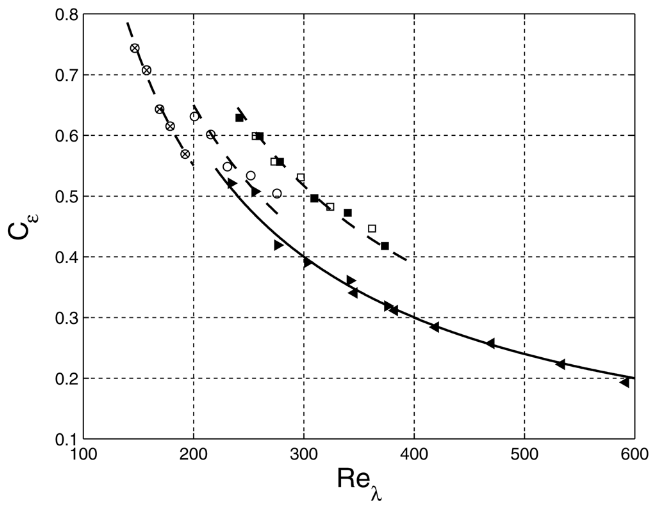

FIG. 2. Normalised energy dissipation C_ε versus Re_λ during the decay of turbulence generated by the fractal square grid with thickness ratio $t_r = 17$ in the region $0.5 < x/x_* < 1.1$, measured with different anemometers. (⊗) DISA 55M10 $U_\infty = 5$ m/s, (■) DISA 55M10, $U_\infty = 15$ m/s, (○) DANTEC Streamline, $U_\infty = 10$ m/s, (□) DANTEC Streamline, $U_\infty = 15$ m/s, (▶) A. A. Lab. AN-1005, $U_\infty = 10$ m/s, and (◀) A. A. Lab. AN-1005, $U_\infty = 15$ m/s. Solid and dashed lines follow $\propto Re_\lambda^{-1}$.

As a result, the presented numerical values of the Taylor-based Reynolds number $Re_\lambda = u'\lambda/\nu$ are inflated and values of the normalised energy dissipation rate C_ε are deflated, although the reported functional form of $C_\epsilon \sim Re_\lambda^{-1}$ during decay has been confirmed to hold by the present data and by the data from Ref. 2 (see Fig. 2). The data taken with the AN-1005 system also hide the different ways that C_ε depends on two different Reynolds numbers: a global Reynolds number Re_0 based on the inlet velocity and the spatially local Re_λ at a fixed value of Re_0. This important difference was picked up by the present data and by Ref. 2 who used a DISA anemometer, but not by Ref. 1 who used the AN-1005 anemometer. Note that the actual Re_λ range for the fractal square grids is smaller than the range presented in Ref. 1, but it is still higher than conventional regular grid experiments by a factor between 2 and 5.

Finally, we take the opportunity to make two short comments on the work by Hurst and Vassilicos[3] which used the same anemometry system as Ref. 1 but focused mostly on large scale turbulence statistics of three different classes of fractal grids. Specifically, it is to be noted that (1) their Re_λ estimates may be somewhat inflated for all their grids including the regular ones and (2) the decay exponents obtained from their λ-based power-law fitting method are likely biased because it estimates the location of the virtual origin from the linear fit of λ^2 versus x. The overestimation of λ^2 leads to an overestimation of the absolute value of this virtual origin.

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