On the characterization of the fine-scale intermittency of turbulence

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Some characterization of the fine-scale intermittency of turbulence is attempted utilizing the method of Kuo and Corrsin [J. Fluid Mech. **50**, 285 (1971)] and the "envelope method" of Sreenivasan [J. Fluid Mech. **151**, 81 (1985)]. It is found that the outcomes of these techniques are sensitively dependent on the details of the methods, and hence cannot be interpreted with complete confidence. © *1995 American Institute of Physics.*

Although the existence of dissipation scale intermittency in high Reynolds number turbulence is well established, our understanding of the phenomenon is still incomplete. Its traditional characterization (Batchelor and Townsend,[1] Sandborn,[2] Kennedy and Corrsin[3]) has been via power spectra, flatness, probability distribution functions, and so forth. More recent work has focused on multiplier distributions (Chhabra and Sreenivasan[4]) and multifractal measures (Meneveau and Sreenivasan,[5] Prasad *et al.*[6]).

A different approach, also statistical in nature, is inspired by the consideration of vortex structure (Townsend,[7] Corrsin,[8] Tennekes,[9] Saffman[10]). In the latter approach, one asks for information on quantities such as the average width of the vortex elements, their frequency of occurrence, average distance between them and the scaling of such quantities with Reynolds numbers. The two approaches are not necessarily exclusive.

The chief uncertainty associated with the latter method is that there is no unambiguous means of extracting the fine scales from a measurement of velocity. The technique in current use is bandpass Fourier filtering. Another source of ambiguity lies with the exact definition of active (or intense) regions. The most rigorous work has been done by Kuo and Corrsin[11] who used their intuition to pick the active part of a trace and we refer to this procedure as the Kuo–Corrsin technique.

Sreenivasan[12] presented an alternative technique for demarcating active regions using the envelope of the filtered signal. He also presented a model for the statistics of fine scales assuming a Gaussian distribution for the amplitudes of velocity.

We will try to reproduce the results of Kuo and Corrsin and Sreenivasan using their respective techniques and characterize the intermittency of the fine scales of turbulence, the robustness of its statistics and compare it with that of white noise.

For our computations, we use velocity data recorded in the atmosphere two meters above a building which was 18 meters high. The mean velocity was 6.0 m/s and the microscale Reynolds number was 150. We refer the reader to Zubair[13] for further details.

Fourier bandpass filtering was used to extract features of different scales (see Ref. 13 for further details). Bandpass filtering can be characterized with two parameters: the midband frequency (f_m) and the fractional bandwidth ($\Delta f/f_m$), where (Δf) is the width of the passband. Following Kuo and Corrsin, we have used a constant fractional bandwidth of 0.52.

Having obtained the bandpass filtered traces, our goal is to characterize their intermittency using both the Kuo–Corrsin and the envelope techniques. The intermittency factor (γ) and the pulse frequency n are primary characteristics of intermittency. γ is computed as the fraction of time during which the signal is active, and n is the frequency with which active regions occur.

The intermittency factor γ computed from the Kuo–Corrsin technique (see Ref. 13 for details) is shown in Fig. 1 along with the results of Kuo and Corrsin.[11] The Kuo–Corrsin graph drops off more steeply than our results. In particular, the value of γ drops off to around 0.1 for high midband filtering frequencies. Kuo and Corrsin presented this trend and the low value for γ at high filtering frequencies as evidence for the intermittency of the fine scales. Our γ, on the other hand, shows a gentler trend and does not drop below 0.3. These discrepancies are likely due to the subjectivity in the choice of threshold or because intermittency characteristics are not robust among the different flow conditions. γ is sensitive to the exact choice of threshold particularly for high f_m (Ref. 13).

We depict the pulse frequency of the active regions in Fig. 2 along with the pulse frequency inferred from the report of Kuo and Corrsin. Their graph has a peak at $f_m/f^*>1.4$, a feature which we did not observe. Here $f^*=U/2\pi\eta_k$ is the Kolmogorov frequency. n is markedly sensitive to the choice of threshold particularly for higher f_m. Overall, we find that both our results for the intermittency factor and the pulse frequency depart from those of Kuo and Corrsin.

Next, we present the intermittency factor and pulse frequency characteristics computed using the envelope technique which has a procedure to choose an unambiguous threshold. The variation of pulse frequency (n) with threshold for white noise is shown in Fig. 3. The variation of n agrees with the predictions of the Gaussian model, $n/n_p = le^{-(l^2-1)/2}$ (Ref. 12), where n_p refers to the peak value of n. As anticipated by the model, γ and n/n_p are independent of the fractional bandwidths $\Delta f/f_m$ from 0.14 to 0.52.

Thus the graphs for γ and n and the validation of several

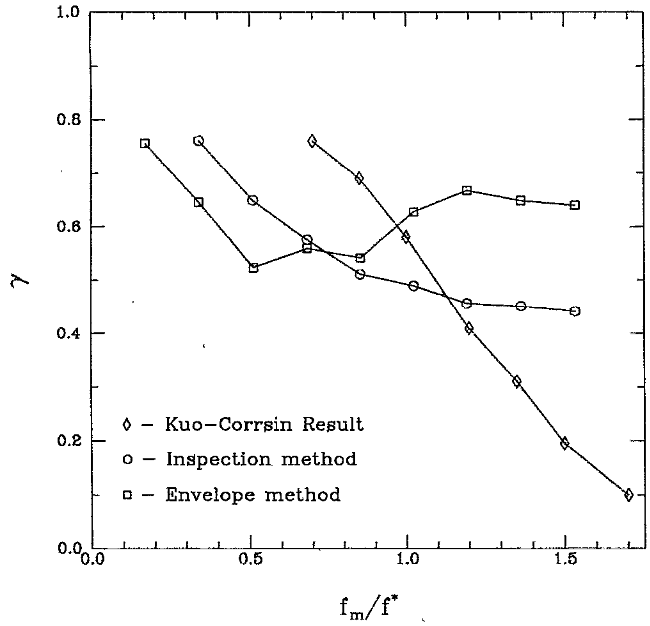

FIG. 1. Intermittency factor (γ) as a function of the midband filter frequency from the Kuo–Corrsin technique and envelope techniques.

other predictions[13] verify the Gaussian model for intermittency to a reasonable degree.

The variation of the intermittency factor with threshold for turbulence velocity data is shown in Fig. 4. These γ val-

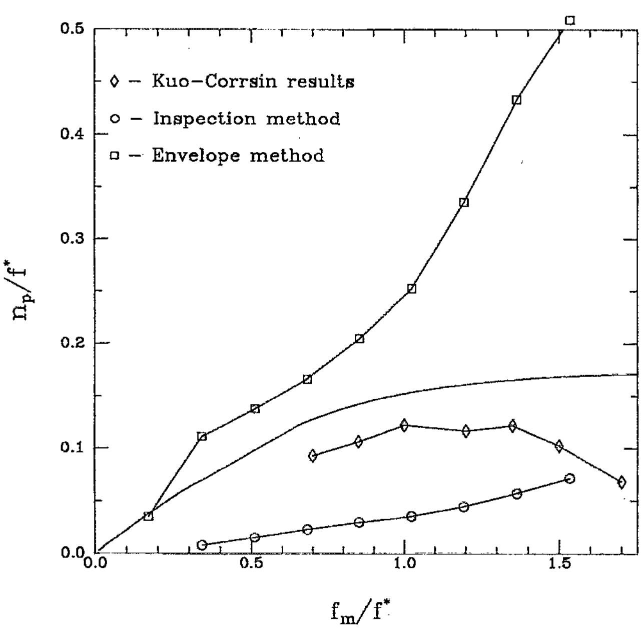

FIG. 2. The normalized pulse frequency from the Kuo–Corrsin and envelope techniques versus the midband filter frequency. The results of Kuo and Corrsin, our results based on their technique and the results from the envelope technique are shown. Note that n_p obtained from the Kuo–Corrsin technique is not strictly the peak frequency. It has been used in this graph for notational convenience for comparison with the envelope method where it is the peak pulse frequency. The solid line shows the prediction of Sreenivasan.[12]

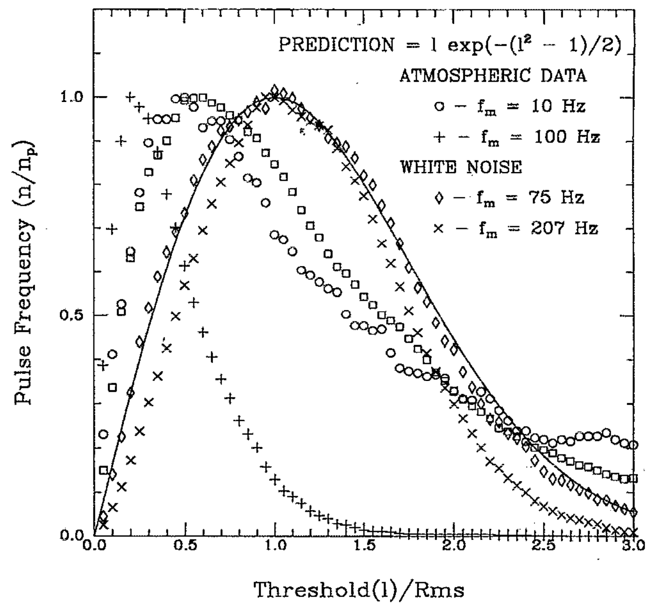

FIG. 3. Pulse frequency versus threshold for traces of random white noise and turbulence velocity data filtered at several midband frequencies. The solid line is the prediction of the Gaussian model. The threshold at each f_m has been normalized by the root-mean-square value of the trace.

ues differ from the prediction of the Gaussian model. The variation of pulse frequency with threshold also differs from the predictions of the Gaussian model (Fig. 3). In this figure the pulse frequency n peaks at a much lower threshold than predicted for midband frequencies in the range of $0.03<f_m/f^*<1.4$ and for fractional bandwidths from 0.14

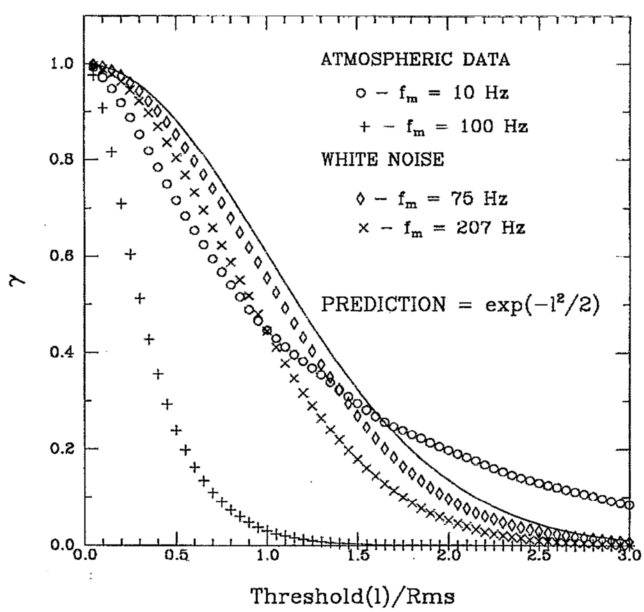

FIG. 4. Intermittency factor versus threshold for traces of white noise and atmospheric velocity data filtered at the indicated midband frequencies. The solid line is the prediction of the Gaussian model. The threshold at each f_m has been normalized by the root-mean-square value of its trace.

to 0.52. We conclude that the intermittency characteristics of turbulence velocity are quite different from those for white noise and that Gaussian statistics are a poor approximation for the fine scales of turbulence.

Next, we consider the intermittency characteristics of turbulence velocity data. The intermittency factor computed using the envelope method is shown in Fig. 1. It remains approximately flat in contrast with the steep decline reported by Kuo and Corrsin and the mild decline that we obtained using their technique. (Note that smaller γ corresponds to greater intermittency.)

Figure 2 shows the pulse frequency computed with the envelope and the Kuo–Corrsin techniques and the prediction due to Sreenivasan.[12] The n_p values from the envelope method are approximately four times as great as those from the Kuo–Corrsin method. This increase may be due to the choice of threshold in the envelope technique which maximizes the pulse frequency.

The pulse frequency for the scale range of $f_m/f^* < 1$, where the data has structure, show a similar monotonic increase for both techniques. However, for higher frequencies, where the data are noisy, the results from the envelope technique and Kuo–Corrsin technique diverge. This divergence is expected as n_p increases proportionate to f_m/f^* for noise for the envelope technique, whereas in the Kuo–Corrsin technique, this rise is offset by the smoothing. Thus the characteristics of n_p are dependent not only on the signal itself but also on the details of the technique used.

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[1] G. K. Batchelor and A. A. Townsend, "The nature of turbulent motion at large wave numbers," Proc. R. Soc. London Ser. A **199**, 238 (1949).

[2] V. S. Sandborn, "Fine-scale intermittency of turbulence," J. Fluid Mech. **6**, 211 (1959).

[3] D. A. Kennedy and S. Corrsin, "Spectral flatness factor and 'intermittency' in turbulence and in non-linear noise," J. Fluid Mech. **10**, 366 (1961).

[4] A. B. Chhabra and K. R. Sreenivasan, "Scale-invariant multiplier distributions in turbulence," Phys. Rev. Lett. **68**, 2762 (1992).

[5] C. Meneveau and K. R. Sreenivasan, "The multifractal nature of turbulent energy dissipation," J. Fluid Mech. **224**, 429 (1991).

[6] R. R. Prasad, C. Meneveau, and K. R. Sreenivasan, "Multifractal nature of the dissipation field of passive scalars in fully developed turbulence," Phys. Rev. Lett. **61**, 74 (1988).

[7] A. A. Townsend, "On the fine-scale structure of turbulence," Proc. R. Soc. London Ser. A **208**, 534 (1951).

[8] S. Corrsin, "Turbulent dissipation fluctuations," Phys. Fluids **5**, 1301 (1962).

[9] H. Tennekes, "Simple model for the small-scale structure of turbulence," Phys. Fluids **11**, 669 (1968).

[10] P. G. Saffman, *Lectures in Homogeneous Turbulence* (Springer, New York, 1968).

[11] A. Y. Kuo and S. Corrsin, "Experiments on internal intermittency and fine-structure distribution in fully turbulent fluid," J. Fluid Mech. **50**, 285 (1971).

[12] K. R. Sreenivasan, "On the fine-scale intermittency of turbulence," J. Fluid Mech. **151**, 81 (1985).

[13] L. Zubair, "Studies in turbulence using wavelet transforms for data compression and scale separation," Ph.D. thesis, Yale University, 1993.