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Do we have a solution to the Turbulence Problem?

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In statistically homogeneous and isotropic turbulence, the average value of the inertial-range velocity increment between two positions in the flow is identically zero, and so to characterize the dynamics one often uses the root-mean-square value, or the p-th root of the p-th moment. When p is large, it allows one to probe rare and extreme events. A long-standing challenge in turbulence, usually attacked by various qualitative cascade models, is the evaluate the scaling exponents for how these various order moments of velocity increments scale with the separation distance. We hope to accomplish two major tasks in the presentation. First, we show that the turbulent motion at large scales obeys Gaussian statistics in the inertial interval at low Reynolds number, and that the Gaussian flow breaks down to strong turbulence with anomalous scaling at a universal Reynolds number. This scenario works also for the emergence of turbulence from an initially non-turbulent state. Second, we derive expressions for the anomalous scaling exponents of structure functions and moments of spatial derivatives, by analyzing the Navier-Stokes equations in the form developed by Hopf. We present a novel procedure to close the Hopf equation, resulting in expressions for various order structure functions, in the entire range of allowable moment-order p, and demonstrate that accounting for the temporal dynamics changes the scaling from normal to anomalous. For large p, the theory predicts the saturation of the exponents with p, leading to two inferences: (a) the smallest length scale varies as -1 power of the Reynolds number (not as the classical -3/4 power), and (b) velocity excursions across even the smallest length scales can sometimes be as large as the large-scale velocity itself. Theoretical predictions for each of these aspects are shown to be in excellent quantitative agreement with available experimental and numerical data.