2007-2008

Graduate Seminar Series

The Department of Mechanical Engineering – Engineering Mechanics

Proudly Presents

Professor Georges Gioia
University of Illinois

Thursday, Apr. 24, 2008 3:00 – 4:00 p.m. Room 112, ME-EM Bldg.

"Nikuradse meets Kolmogórov, or: How to derive the diagram from the spectrum"

A diagram published in 1933 remains among the weightier contributions to experimental turbulence ever. In that diagram, Nikuradse plotted six log-log curves evincing the dependence on the Reynolds number (Re) of the friction coefficient (f) of the turbulent flow in six pipes of fixed roughness. (The roughness of a pipe is the ratio r/D, where r is the size of the roughness elements that line the interior of the pipe and D the diameter of the pipe.) The diagram starts at the onset of turbulence, at a Re of about 2,000, with the rise of all six curves united in a single bundle. At a Re of about 3,000, the bundle bends downward to form a marked *hump* and then it plunges in accord with Blasius's empirical scaling, $f \sim \mathrm{Re}^{-1/4}$ as one by one in order of decreasing roughness the curves start to careen away from the bundle. After leaving the bundle, which continues to plunge, each curve sets out to trace a spacious *belly* as it steers farther from the bundle with increasing Re, grazes through the bottom of the belly and begins to rise, then flexes towards a terminal, constant value of f that is in keeping with Strickler's empirical scaling, $f \sim (r/D)^{1/3}$. For seventy years now, our understanding of these curves has been aided by little beyond a pictorial narrative of roughness elements being progressively exposed to the turbulence as Re increases. Here we identify the eddies that effect most of the momentum transfer between the viscous layer and the turbulent flow, and derive an expression for f in terms of the characteristic velocity of those eddies, υ_s. Then we use Kolmogórov's spectrum for the inertial range to determine υ_s, and show that the resulting expression for f gives a gradual transition between the scalings of Blasius and Strickler, but fails to give the hump or the bellies of Nikuradse's diagram. To obtain an expression for f that also gives the bellies, we include an exponential spectrum for the dissipation range. Last, to obtain an expression for f that also gives the hump, we include von Kármán's spectrum for the energy-containing range. This final expression for f is in minute qualitative agreement with Nikuradse's diagram; it affords a way of interpreting successive portions of the diagram as manifestations of the varying habits of momentum transfer; and it reveals the existence of close ties between two milestones of experimental and theoretical turbulence. This research is being performed in collaboration with Nigel Goldenfeld, Pinaki Chakraborty, Nicholas Gutenberg, and Carlo Zuñiga.

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