CENTER FOR FLUID MECHANICS
AND
THE FLUIDS, THERMAL AND CHEMICAL PROCESSES GROUP
OF
THE DIVISION OF ENGINEERING
Seminar Series

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Goodbye Navier-Stokes. Onsager's Legacy to Fluid Mechanics

This talk begins by pointing out the surprising fact the fundamental equations governing continuum fluid mechanics and transport processes neither explicitly involve, nor require, the notion of velocity. Next, it is pointed out that Euler's (1755) assumption founding fluid mechanics some 250 years ago, namely that* $\mathbf{m} = \mathbf{n}_m$, is a constitutive assumption rather than an empirical fact of nature, contrary to what we learned as students. We discuss evidence for and against his relation. Since the validity of the Navier-Stokes-Fourier equations, and indeed the foundations of fluid mechanics, hinges on the correctness of Euler's implicit hypothesis, the issue is not moot. Irreversible thermodynamics, in the form of the Second law, plays a key role in framing the discussion. We refer here not to the usual side issue of demonstrating the positivity of the fluid's viscosity and thermal conductivity, but rather to the crucial role that Onsager's Reciprocal Theorem plays in resolving the question of whether Euler was right! Finally, some recent applications of the speaker's recent theory of diffuse-volume transport, which is closely related to the Euler question, are cited, including the ability to predict, in nonisothermal liquids, the existence and extent of particle thermophoresis, thermal diffusion, and thermal transpiration. Previously, the mechanism underlying these exotic transport processes was understood only for rarefied gases, and then only in gas-kinetic molecular terms, rather than in terms of hydrodynamic phenomenology.

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* $\mathbf{m}$ = momentum density (per unit volume), a dynamical quantity appearing in the Cauchy linear momentum equation embodying the principle of momentum conservation;

$\mathbf{n}_m$ = mass flux, a kinematical quantity appearing in the continuity equation embodying the principle of mass conservation.

Euler's hypothesis, $\mathbf{m} = \mathbf{n}_m$, is equivalent to supposing that the fluid's "*momentum velocity*" $\mathbf{m}/\rho$ is equal to the fluid's "*mass velocity*" $\mathbf{n}_m/\rho$, enabling use of the single symbol $\mathbf{v}$ as an abbreviation for both of these quantities, and thereby introducing the notion of "velocity" into fluid mechanics.

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