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Flame Propagation and Burgers Turbulence: The Theoretical Connection

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Abstract

In the flamelet regime of premixed combustion, each portion of the flame front advances at a speed governed by local conditions. Random spatial variations of these conditions produce wrinkling, increase the flame surface area, and thus enhance the overall combustion rate ("speedup"). In turbulent fluids, the dominant perturbation of the front is advection by the flow field; in solid propellants, heterogeneous composition causes the local burning rate to vary. These two cases, in the weak-perturbation limit, are known to be equivalent to one another and to first-passage problems in geometrical optics and acoustics.

With the help of previous analysis by Alan Kerstein and classic results on rays in random media, the weak-perturbation front problem has been simplified. It reduces to a pressure-free fluid obeying the inviscid Burgers equation, with a random force that is correlated in space but white in time; the 4/3-power dependence of the front speedup on the perturbation is automatically obtained. The Burgers equation is widely studied as a model of turbulence and is also equivalent to the statistical-mechanics problem of a directed polymer in a random medium. An advanced field-theoretic approach to these problems, known as the replica method, has been extended to derive explicit upper bounds on the front speedup for arbitrary perturbation spectra. Numerical simulations in 2D indicate that these bounds are within 20% of true values.