

Petascale Numerical Simulations of Turbulent Combustion

E.R. Hawkes^{1,2}

¹School of Mechanical and Manufacturing Engineering

²School of Photovoltaic and Renewable Energy Engineering

The University of New South Wales, Sydney, New South Wales 2052, Australia

Abstract

To achieve very low NO_x emissions, recent generations of stationary gas-turbine systems have adopted lean premixed combustion modes. Lean operation reduces the combustion temperature and suppresses the formation of thermal NO_x. However, relative to stoichiometric flames, lean flames are thicker and propagate more slowly. When combined with industry trends of increasing combustion chamber pressures, which increases Reynolds number, a situation can arise where turbulence penetrates the inner structure of the flame, *i.e.* the Karlovitz number is high. The nature of combustion in this situation is relatively less well understood compared with the situation where turbulence does not penetrate the flame. In this paper, I will discuss the use of a set of petascale direct numerical simulations (DNS) of lean hydrogen combustion to examine high Karlovitz number flames. The simulations considered a detailed model of hydrogen oxidation, achieved a turbulence Reynolds number approaching 1000 and were performed on 120,000 processor cores on the Jaguar Cray XT5 at Oakridge National Laboratories. The flames will be examined from the perspective of a fractal model of their geometry. By examining the problem from two different but connected theoretical perspectives, it is proposed that for sufficiently high Karlovitz number, the relevant inner cut-off scale is the Obukhov-Corrsin length scale, while the fractal dimension approaches 8/3. These theories are contrasted with the prevailing views that the Gibson scale or the flame thickness are the inner cut-off and that 7/3 is the upper limit of the fractal dimension. The new results are shown to be supported by the DNS. The findings are then incorporated into a model of the flame surface area required in large-eddy simulations and excellent predictions of the DNS surface area are obtained for two versions of the model, one in which the fractal dimension is determined by a static expression, and another in which it is determined dynamically from the resolved scales by a Germano-like identity.

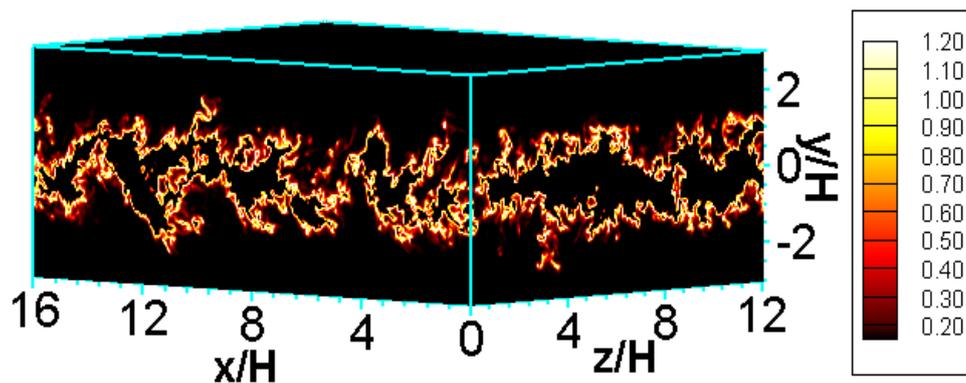


Figure 1: Slices through the domain showing local heat release rate normalised by the peak value in the laminar flame, on streamwise-transverse and spanwise-transverse planes.