

Subgrid LES modeling of an evaporating spray turbulent mixing: DNS a priori tests

Cecile Pera, Luc Vervisch, Julien Réveillon and Pascale Domingo
INSA de Rouen and UMR-CNRS-6614-CORIA,
Campus du Madrillet, BP 8,
FR-76801 Saint Etienne du Rouvray Cedex, France

LES of turbulent spray flames imposes the careful description of turbulent mixing between air and an evaporating liquid fuel. To help in subgrid modeling development, a three-dimensional DNS of grid turbulence has been developed in which a turbulent spray is evaporated (fig. 1). The spray is composed of about one million droplets and basic control parameters of spray and turbulence have been varied to generate a variety of representative conditions.

The mixture fraction Z and its subgrid fluctuations are basic ingredients of nonpremixed turbulent combustion modeling. The DNS data are filtered to perform a priori tests of closures for the subgrid mixture fraction variance \tilde{Z}_v . Because of the vapor source, the mixture fraction is not a passive scalar and its variance cannot be estimated from usual modeling.

A first option consists of estimating \tilde{Z}_v from the resolved field, using a dynamic formulation [1] of the scale similarity assumption [2]. This closure was found successful in the case of gaseous fuel injection, however, fig. 2 suggests that the presence of local vapor sources at small scales, restricts the prediction capabilities of the scale similarity assumption

An alternative option is to solve a balance equation for \tilde{Z}_v , in which a fuel source $\bar{\rho}\tilde{S}^+$ and a subgrid mixture fraction dissipation rate $\bar{\rho}\tilde{\chi} = \overline{\rho D|\nabla Z|^2}$ need closures, in addition to the usual subgrid turbulent transport term. A dynamic formulation is proposed and tested for the fuel vapor source, $\bar{\rho}\tilde{S}^+$, in which a dynamic correlation coefficient is determined to close an expression first proposed in a RANS context [3]. Figure 3 confirms the validity of this approach.

Two additional subgrid closures are discussed for the scalar dissipation rate $\bar{\rho}\tilde{\chi}$. A usual equilibrium hypothesis, leading to a gradient type closure, is first tested. Then, a combination of a linear relaxation with a dynamic formulation is proposed (fig. 4). The analysis of the DNS database demonstrates that the modeling of $\bar{\rho}\tilde{\chi}$ is highly sensitive to the spray topology and, at this stage, no definitive conclusion can be drawn concerning its closures.

[1] Pierce, C. and Moin, P. *Physics of Fluids*, 10(12):3041–3044, 1999.

[2] Cook, A. W. and Riley, J. J. *Phys. Fluids*, 8(6):2868–2870, 1994.

[3] Hollmann, C. and Gutheil, E. Modeling of turbulent spray diffusion flames including detailed chemistry. In *Twenty-Sixth Symposium (Int.) on Combustion/The Combustion Institute*, pages 1731–1738, 1996.

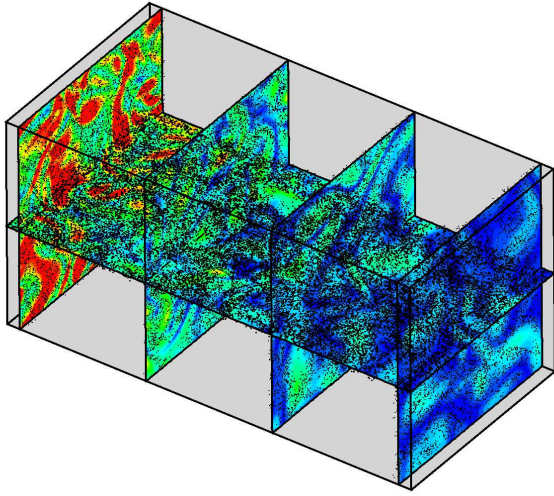


Fig. 1: Snapshot of the computational domain. Iso-lines: Vorticity. Points: evaporating droplets

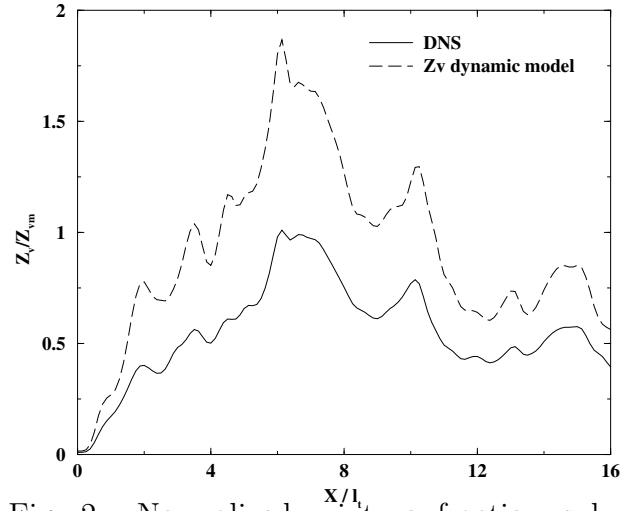


Fig. 2: Normalized mixture fraction subgrid variance. Comparison between DNS (line) and dynamic scale similarity assumption (dash line).

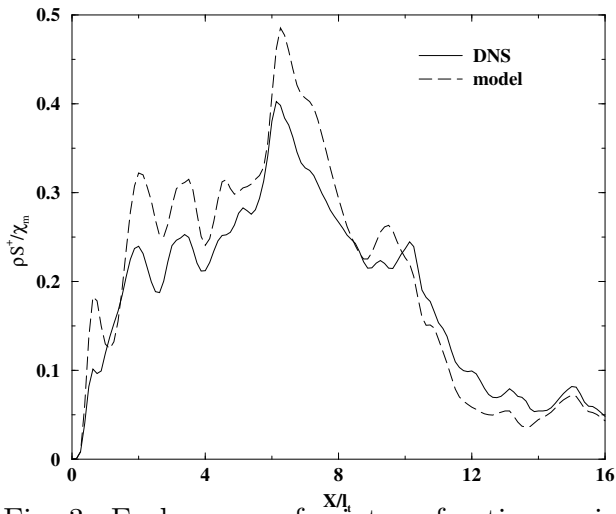


Fig. 3: Fuel source of mixture fraction variance. Comparison between DNS (line) and dynamic closure (dash line).

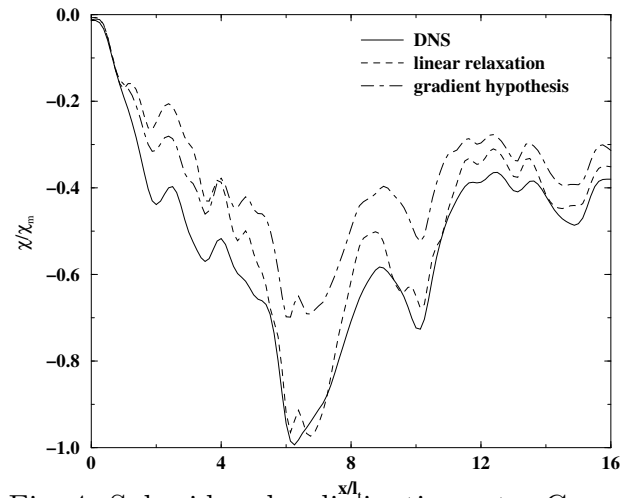


Fig. 4: Subgrid scalar dissipation rate. Comparison between DNS (line), dynamic equilibrium closure (dash line) and dynamic linear relaxation (dot dashed line).