Large Eddy Simulation of Jets with Density Variation

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1. Introduction

The mixing of jets into an ambient with different density occurs in many applications including energy and propulsion systems as well as in nature. When the momentum is high, the situation of interest here, the influence of variable density effects dominates that of buoyancy. In nonreacting jets, the ratio of densities of the jet inflow and the ambient, $s = \rho_j/\rho_\infty$, is the overall control parameter. It has been proposed [7, 6] that the asymptotic self-similar evolution is that of an equivalent constant-density round jet with the nozzle diameter, d, replaced by $ds^{1/2}$. The axial decay rate of centerline values of concentration and velocity is thus *larger* for a lighter-than-ambient jet. In reacting jets, an equivalent diameter, $d(\rho_f/\rho_\infty)^{1/2}$ with ρ_f denoting the density at the flame has been proposed [7]. It has been reported by [5] that the spreading rate of the concentration field is independent of the density ratio. The same is found to be true for the centerline decay if the *effective* diameter is used. Instabilities are also of interest[3, 1]; *side jets*, corresponding to a self-excited mode, appear when $s < 0.7$.

2. Results

The evolution of a plane jet exiting from a nozzle of height h with a temperature variation and corresponding density variation is simulated. The filtered Navier-Stokes equations (compressible) are solved in a flow domain of size $30h \times 16h \times 8.4h$, employing $164 \times 128 \times 64$ points. A dynamic mixed model is used for the subgrid terms. The molecular transport terms are dropped so that, in principle, the molecular Reynolds number is infinite.

As an example, results on the evolution of the centerline velocity, ΔU_c, are shown. Fig. 1(a) shows that, as expected for a plane jet, $(\Delta U_0/\Delta U_c)^2$ eventually increases linearly as a function of x/h. Also, in agreement with published literature, a lighter-than-ambient jet exhibits a larger velocity decay. Fig. 1(b) replots the results using an equivalent slot width which, for a plane jet, turnns out to be hs. There is no collapse between the different cases showing that the observed variable-density effect in the region $x/h < 15$ differs from that in the self-similar far field. In the full presentation, we will report on the evolution of all Reynolds stresses, the approach to asymptotic self-similarity, and the development of flow instabilities.

In combustion formulations based on a conserved scalar, nonlinear dependencies such as $\rho(Z)$ and $Y_i(Z)$ in the case of infinitely-fast chemistry and, similarly, $\rho(Z;\chi)$ and $Y_i(Z,\chi)$ in the case of a flamelet approach introduce new subgrid terms. Here, χ denotes the scalar dissipation. The beta-pdf approach to determine the subgrid contribution based on a a scale-similarity model for the local, pointwise subgrid variance is often used. [4] propose a different approach, ARM, based on approximate deconvolution along with input of the Reynolds-averaged subgrid variance. In a detailed comparison of the two approaches by [2] in a plane jet, it has been found that ARM performs better than beta pdf for global nonlinearities such as polynomials, Z^n. Fig. 2 shows the crosswise profile of the averaged subgrid contribution for the case of $\rho(Z)$. (The strangely improved agreement with increased filter size is specific to this nonlinearity and does not occur in general!) For nonlinearities that are strongly localized in scalar space such as the Arrhenius dependence on temperature, a combination of ARM (for obtaining the local subgrid variance) plus beta pdf works better than using ARM by itself. We will further discuss the relative performance of ARM and beta pdf in the full presentation.

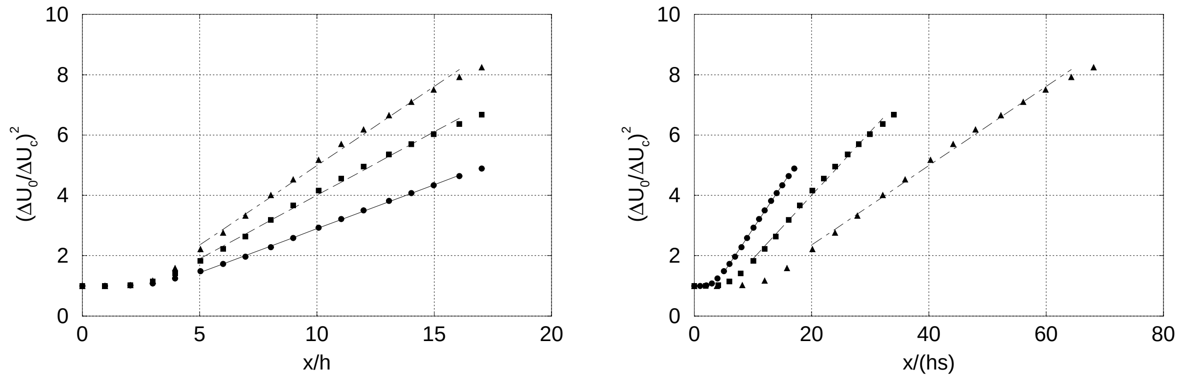

Figure 1: Centerline velocity decay for different density ratios: $s = 1.00$ (circles), $s = 0.50$ (squares), and $s = 0.25$ (triangles). On the right, the effective nozzle width, hs, is used.

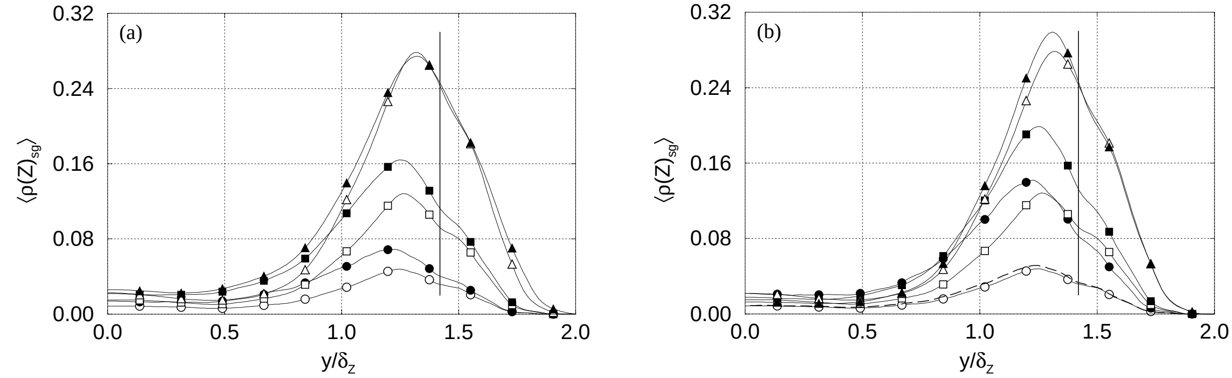

Figure 2: Prediction of the SGS part of $\rho(Z)$ by (a) the ARM model, (b) the beta-PDF model, at a downstream location $x/h = 11.0$. Hollow symbols correspond to exact values and solid symbols to model predictions. Circles, squares and triangles denote filter sizes of 4, 8 and 16, respectively. Dashed line in (b) corresponds to beta-PDF with *exact, pointwise* subgrid variance for $\Delta_f/\Delta_g = 4$. Vertical solid line indicates stoichiometric position, $\langle Z\rangle = 0.055$.

References

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