

ANALYTICAL/NUMERICAL SOLUTION FOR CONFINED JET DIFFUSION FLAME (SANDIA FLAME C)

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Abstract— The aim of the present work is the development of a method based on the momentum transfer law to obtain the solution of confined jet diffusion flames. The Reichardt's equation is used to approximate the flow/mixture fraction and it is discretized based on the second order finite difference technique. All thermochemical variables are determined by the mixture fraction as the Sandia Flame C, used to check the results, is close to equilibrium. The semi-analytical/numerical results compare reasonably with the experimental data indicating that the method contributes to solve some jet flames at low cost.

Keywords— Piloted diffusion flame, Flame C, Low Mach-number, Semi-analytical solution, Mixture fraction

I. INTRODUCTION

A jet diffusion flame is an important example in non-premixed combustion, since the fuel and the oxidizer enter the chamber in separate streams. Combustion corresponds to a complex sequence of chemical reactions between a fuel and an oxidizer releasing heat and sometimes producing light too. Combustion is usually fast compared to molecular mixing, happening in layers thinner than the typical length scales of turbulence (Peters, 2000).

The length scale disparity in turbulent combustion inside a burner, for example, is very large: the burner has lengths of order $1m$, the containing energy eddies have diameters of order $1 - 10cm$, the small-scale mixing eddies are of order $1 - 10mm$, the flame thickness has dimensions which varies between $10 - 100\mu m$, and the molecular iterations characteristic lengths are very small, ranging from $1 - 10nm$.

Moreover, the time-scale disparity is also very large (Poinsot and Veynante, 2005) and, at least theoretically, all scales must be well predicted to obtain an adequate mathematical solution of a jet diffusion flame. Due to the exothermicity of combustion reactions, the temperature raises since the chemical reactions become faster, then the length scale is short.

Jets and jet flames seem to be simple; however, their structure is complex because a jet usually starts with a potential zone of 2 to 10 diameters length and ends with a turbulent plume which is very difficult to be simulated by the conventional numerical techniques, including RANS (Reynolds Averaged Navier-Stokes) and LES (Large-Eddy Simulation). The majority of jet and jet flame simulations found in the literature reveals a turbulent structure which is much coarser than that seen in the experiments.

To solve nonpremixed flames many approximate models are found in the literature (Williams, 1985; Liñán, 1991; Peters, 2000; Warnatz et al., 2001; Veynante and Vervisch, 2003; Fernández-Tarrazo *et al.*, 2006). A two-layer flame structure considers a very thin fuel consumption layer and a much thicker oxidation layer, hypothesis valid for stoichiometric and lean conditions and for moderately rich flames. Some models employ a formulation based on the mixture fraction for the flow and on the flamelet models for the chemistry. The basic idea of the flamelet modeling is that an instantaneous flame element embedded in a turbulent flow has a structure of a laminar flame (Peters, 2000). The flamelet equations correspond to a balance between the unsteady changes, the diffusive effects and the chemical reactions. Then the species mass fraction Y_i depend on the mixture fraction, on the scalar dissipation rate and on the time.

The initially chemical elements contained in the fuel are conserved during combustion; they can be calculated by the mixture fraction (Bilger, 1980; Law, 2006), a conserved scalar. The element mass fractions are not changed by reactive processes, they are changed by mixing and such is governed by diffusion. The mixture fraction axial decrease in a flame is similar to that of velocity decrease (Kuo, 2005); such velocity decrease depends on the mixing, which indicates the turbulent flow evolution.

The scalar dissipation rate turns an important quantity when analyzing turbulent combustion using flamelets (Peters, 2000). It can be seen as a diffusion coefficient acting on an infinitely fast chemistry model. For jet flames its mean value is of order 10^0 , and it may oscillate considerably.