**8th. World Congress on Computational Mechanics (WCCM8)**
**5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)**
**June 30 –July 5, 2008**
**Venice, Italy**

# APPLICATIONS OF AN EFFICIENT LOW-MACH ALGORITHM TO BASIC VARIABLE DENSITY FLOWS

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**Key Words:** *Low-Mach, Pressure-Correction, Non-Premixed Combustion, Conservation, Stability.*

## ABSTRACT

Time-accurate simulations are more and more required (e.g. LES of reacting flows). The generally applied pressure-correction schemes can no longer be used, due to lack of stability. Instabilities arise when the density variations are too large. In many combustion applications, high density ratios appear (e.g. for methane-air combustion at atmospheric pressure, density ratios in the order of 10 near the flamefront are normal). Some tried to circumvent the stability problem by applying (unphysical) rescaling of the time derivative of the density [1]. In [2], we showed that, for a non-reacting flow, a good constraint for the velocity field can be formulated, such that the solution is stable. In [3] the propositions of [2] were extended towards non-premixed combustion simulations, making use of the mixture fraction as a conserved variable. A pressure-correction algorithm was obtained which (1) conserves mass, (2) conserves fuel mass and (3) is stable and robust, without the need for (unphysical) underrelaxation.

These three properties are obtained by introduction of a chemical operator $\mathcal{H}_C$ as $\rho = \mathcal{H}_C(\rho\xi)$ ($\rho$: density, $\xi$: mixture fraction). In case of pure mixing, the operator is linear. In case of combustion, however, $\mathcal{H}_C$ is highly nonlinear. A discrete equation for the pressure, follows from a constraint on the velocity field by combining the discrete equations of continuity and mixture fraction. Due to the nonlinearity of $\mathcal{H}_C$, a non-linear equation for the pressure is obtained, which can be linearized around the predicted solution for the velocity field ($u^*$):

$$\left(A - \frac{\mathrm{d}\mathcal{H}_C}{\mathrm{d}\rho\xi}\left(\vec{\rho\xi}^{\,*}\right) B\right)\vec{p'} = RHS,$$

where $\frac{\mathrm{d}\mathcal{H}_C}{\mathrm{d}\rho\xi}\left(\vec{\rho\xi}^{\,*}\right)$ depends on the chemistry model. For further details about the algorithm, we refer to [3,4].

The above algorithm is now validated on several cases involving non-premixed combustion. A Burke-Schumann Flame-Sheet chemistry model is applied. A first test case, posing a severe challenge for the

stability of the algorithm is the 1D test case of a step in density, with step height $(\rho_1 - \rho_0)$, which is convected by a constant velocity $U$. The solution is shown in Fig. 1. Further, a 2D laminar mixing layer of fuel and oxidizer, entering with the same velocity, is simulated. A converged solution for this case is shown in Fig. 2.

Extensive discussion of all results will be presented.

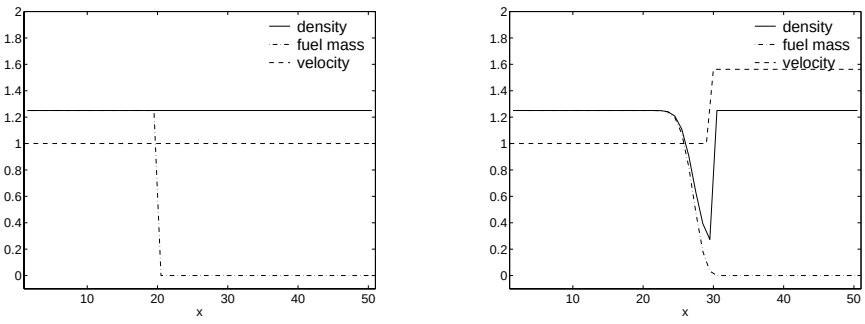


Figure 1: Density, fuel elements mass and velocity: initial field and state after 10 timesteps.

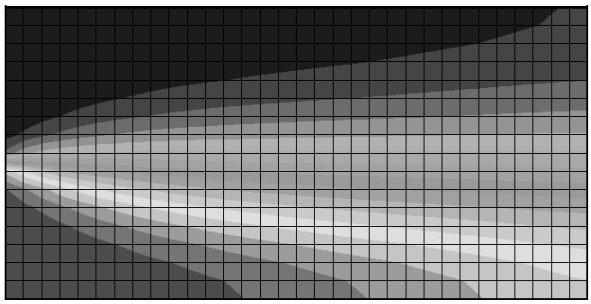

Figure 2: Converged solution of the mixing layer: mixture fraction field

## REFERENCES


[1] A. Kempf. “Large-eddy simulation of non-premixed turbulent flames”. *Fortschritt Berichte VDI*, **6**-513, VDI-Verlag, Düsseldorf, Germany, 2004.

[2] P. Rauwoens, K. Nerinckx, J. Vierendeels, E. Dick and B. Merci. “A stable pressure-correction algorithm for low speed turbulent combustion simulations”. *Proc. ECCOMAS CFD 2006*, Egmond aan Zee, The Netherlands, 2006.

[3] P. Rauwoens, J. Vierendeels and E. Dick. “A stable pressure-correction scheme for variable density flows, involving non-premixed combustion”. *Int. J. Num. Meth. Fl.* (in press).

[4] P. Rauwoens, J. Vierendeels and E. Dick. “A stable pressure-correction scheme for time accurate non-premixed combustion simulations”. *Flow, Turb. Comb.* (submitted).