SIMULATION OF FLAME PROPAGATION IN A TUBE WITH OBSTACLES

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Summary A fictitious domain method is extended and implemented for time dependent combustion problems in non-regular closed domains. The propagation of 2D laminar methane-air flame in a tube with obstacles are simulated and studied.

BACKGROUND

A fictitious domain method (FDM) for partial differential equations has recently shown a most interesting potential for solving complicated problems from Science and Engineering [1-3]. The main reason for popularity of FDM is that they allow using of fairly structured meshes on a simple shape fictitious domain (typically rectangle in 2D) containing the actual domain, therefore allowing to use of fast solvers. Another important point is that the stability condition of the resulting scheme is the same as the one of the finite difference scheme [1]. Up to now a FDM was used for solving the problems of physics with Dirichlet boundary conditions. But many problems of science are Neumann problems (for example, like the combustion problems) and application of FDM to them has essential peculiarities.

PROBLEM FORMULATION AND NUMERICAL TECHNIQUE

A fictitious domain method is extended and implemented for combustion problems in non-regular domains. The most prominent example of those problems is the propagation of flame in a tube with obstacles. It is known that the combustion process of premixed gases in tubes or vessels is strongly affected by obstacles. For freely propagating flames grids or obstacles can cause violent flame acceleration and enhanced transition to detonation.

It is considered the cases when 2D flame propagates in a closed rectangular tube with obstacles and we focus our attention on its numerical solution by FDM approach to study the hydrodynamic structure of the flame. The combustible gas is a stoichiometric methane-air mixture. The study is based on the assumption of a low Mach number flow and uses a one-step global chemistry model of the methane-air laminar flame. The problem is simulated using unsteady conservation equations of energy, species, mass, momentum and equation of state. The transport coefficients, thermodynamic data, kinetic coefficients and numerical algorithm are given elsewhere [4-5]. The fictitious transport coefficients are

$$\lambda^{\varepsilon}(\vec{x}) = \begin{cases} \lambda, & if\ \vec{x}\in\Omega \\ \varepsilon, & if\ \vec{x}\in\Omega_f \end{cases}, \quad D^{\varepsilon}(\vec{x}) = \begin{cases} D, & if\ \vec{x}\in\Omega \\ \varepsilon, & if\ \vec{x}\in\Omega_f \end{cases}, \quad \xi^{\varepsilon}(\vec{x}) = \begin{cases} 0, & if\ \vec{x}\in\Omega \\ \varepsilon^{-1}, & if\ \vec{x}\in\Omega_f \end{cases},$$

where λ is the heat conductivity, D is the diffusion coefficient, Ω is the actual flow domain, Ω_f is the fictitious domain (obstacle domain), ε is the small positive parameter. Boundary conditions are non-slip and heat- and mass isolated at the solid boundaries and symmetric at the symmetry line. At initial time the gas mixture is at rest at a temperature of 300 K and pressure of $P_t(0)=P_0=10^5\,Pa$, $p_d=0$, $\varepsilon=10^{-6}$.

RESULTS

Figures 1,2 displays the samples of the temporal evolution of velocity fields and methane consumption rate contours in the upper part of the symmetric rectangular vessel with length $L=30\ l$ and cross section $5l\text{x}5l$ in presence of rectangular obstacles, where $l=0.5mm$. The flame is ignited at the centre of left vessel side. The Reynolds number $\mathrm{Re} = u_n l \rho_0 / \mu_0 = 12.3$, $u_n = 40\ cm/sec$ is the flame speed, the Prandtl number is 0.73, the Lewis number is 1.

CONCLUSIONS

A fictitious domain method is extended for combustion problems. A detailed simulation of flame propagation in the tube at various locations of obstacles is implemented and the results are analaized. It is found that the computational cost is almost the same as in the case of tube without obstacles.

References

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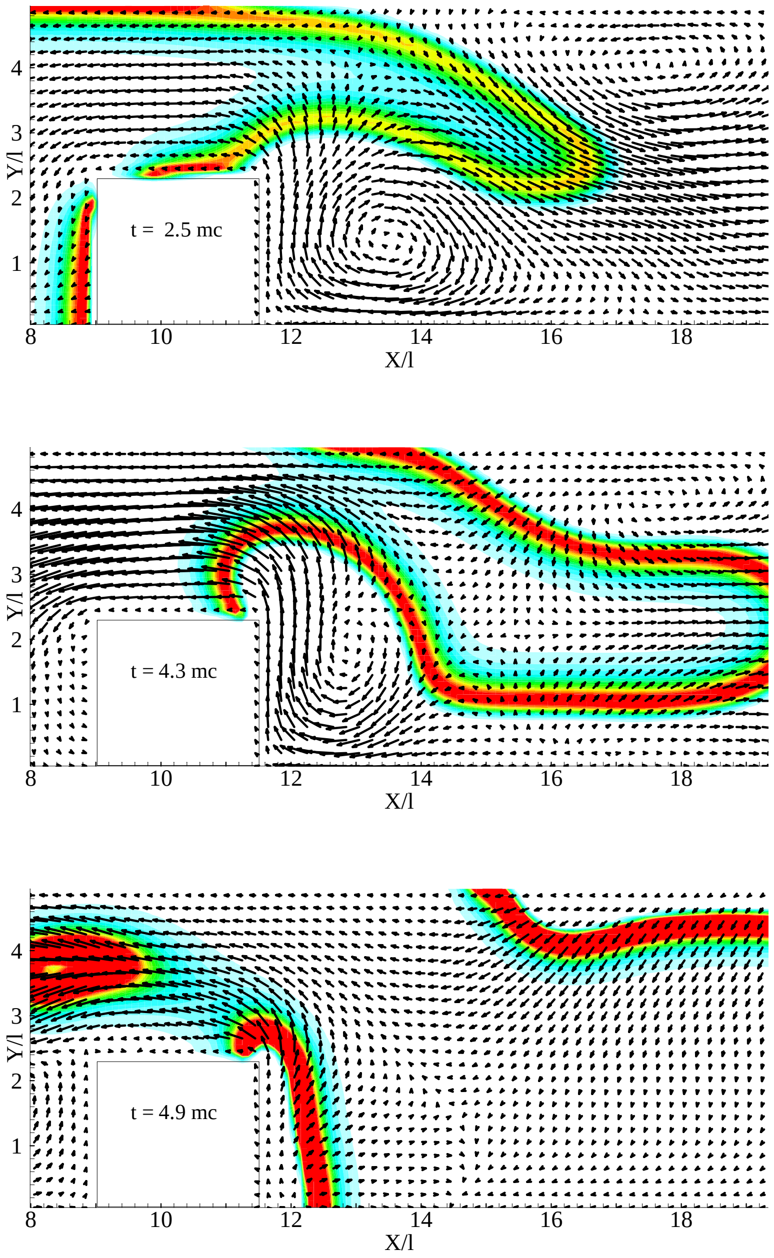

Figure 1

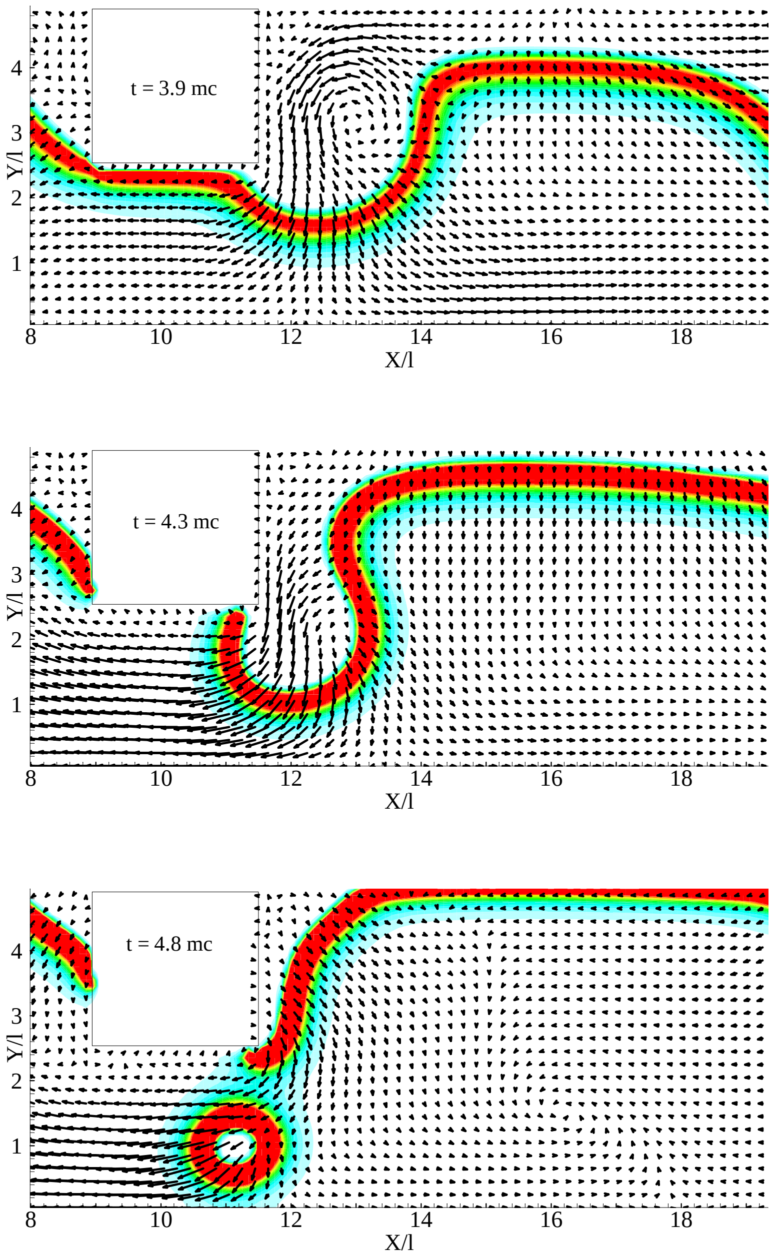

Figure 2

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