Moving Overlapping Grids with Adaptive Mesh Refinement for High-Speed Reactive and Non-reactive Flow

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Abstract

We consider the solution of the reactive and non-reactive Euler equations on two-dimensional domains that evolve in time. The domains are discretized using moving overlapping grids. In a typical grid construction, boundary-fitted grids are used to represent moving boundaries, and these grids overlap with stationary background Cartesian grids. Block-structured adaptive mesh refinement (AMR) is used to resolve fine-scale features in the flow such as shocks and detonations. Refinement grids are added to base-level grids according to an estimate of the error, and these refinement grids move with their corresponding base-level grids. The numerical approximation of the governing equations takes place in the parameter space of each component grid which is defined by a mapping from (fixed) parameter space to (moving) physical space. The mapped equations are solved numerically using a second-order extension of Godunov's method. The stiff source term in the reactive case is handled using a Runge-Kutta error-control scheme. We consider cases when the boundaries move according to a prescribed function of time and when the boundaries of embedded bodies move according to the surface stress exerted by the fluid. In the latter case, the Newton-Euler equations describe the motion of the center of mass of the each body and the rotation about it, and these equations are integrated numerically using a second-order predictor-corrector scheme. Numerical boundary conditions at slip walls are described, and numerical results are presented for both reactive and non-reactive flows that demonstrate the use and accuracy of the numerical approach.

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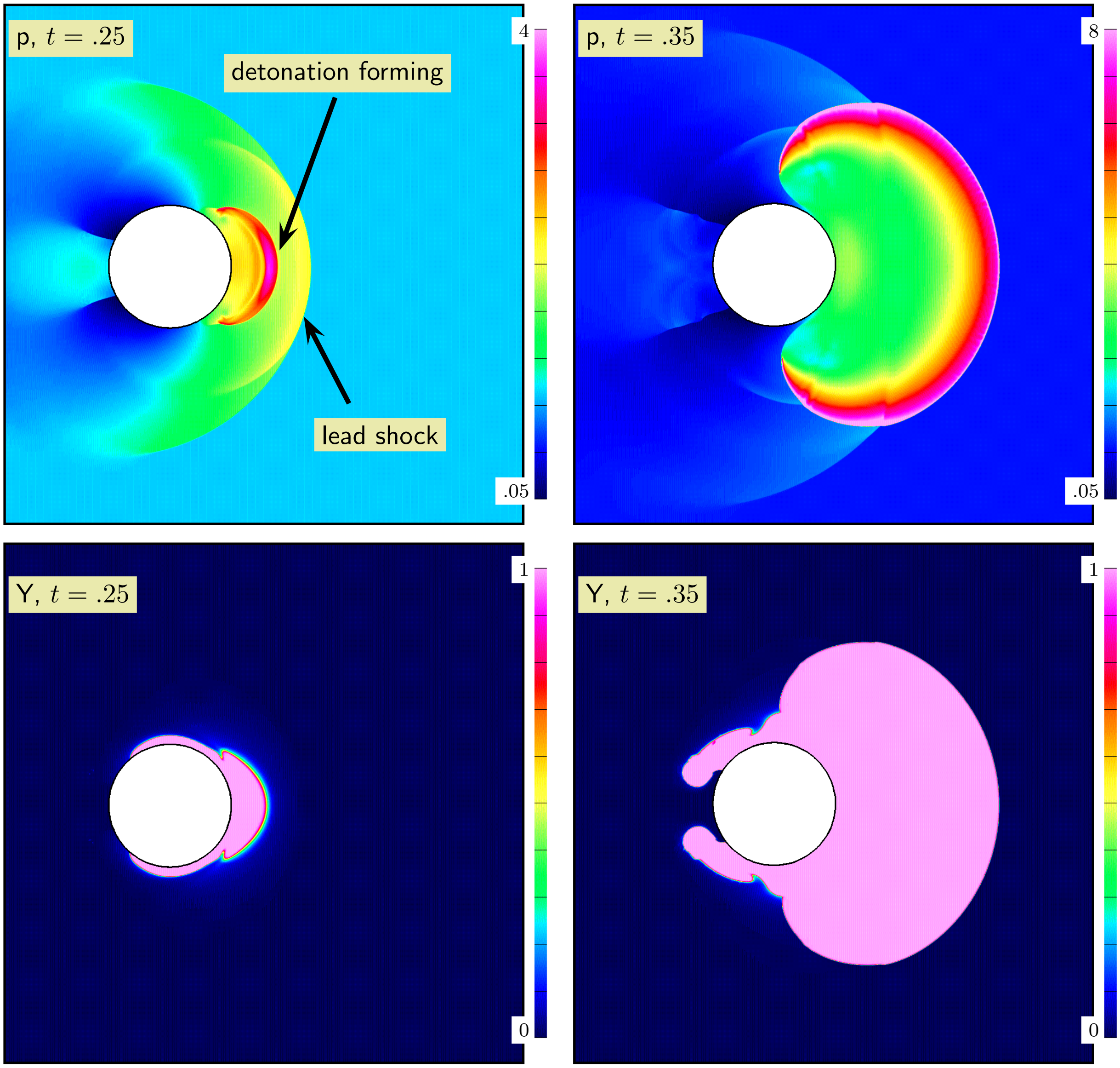

Fig. 20. Impulsive motion of a rigid cylinder in a reactive flow. Shaded contours of the pressure p and mass fraction Y at times $t = .25$ (left column) and $t = .035$ (right column) using grid $\mathcal{G}^{(4,2)}$.

The base grid, $\mathcal{G}^{(0)}$, for this calculation is chosen with a characteristic grid spacing $h \approx 1/160$ for all of its component grids. The resulting background Cartesian grid has 721×321 grid lines and approximately $230,000$ grid points. The total number of grid points on the base-level overlapping grid (background grid and 26 annular grids) is approximately $260,000$. A finer grid using AMR, $\mathcal{G}^{(1)}$, consists of the base-level grid together with one refinement level using $n_r = 4$. The total number of component grids on $\mathcal{G}^{(1)}$ ranged from 28 to about 400 during the calculation.

Numerical Schlieren plots of the solution are shown in Figure 22 for times $t = 0.3$, 0.5 and 0.9 using grid $\mathcal{G}^{(1)}$. The Schlieren plots are gray-scale shaded contours of the function $\mathcal{S}(\rho)$ defined by

$$\mathcal{S}(\rho) = \exp\{-\alpha\Gamma(\rho)\}, \qquad \Gamma(\rho) = \frac{|\nabla\rho| - \min|\nabla\rho|}{\max|\nabla\rho| - \min|\nabla\rho|}, \qquad |\nabla\rho| = \left(\rho_x^2 + \rho_y^2\right)^{1/2},$$

where α is an adjustable parameter that controls the contrast of the gray-scale plots. We use $\alpha = 15$ for all Schlieren plots. The gray-scale plots show clearly the leading detonation wave (thicker black