Detonation in supersonic radial outflow

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1 Introduction

Using numerical simulations, we study a supersonic two-dimensional flow of an ideal reactive gas emanating radially out of a source. The flow is described by the reactive Euler equations with a one-step Arrhenius chemistry. It is found that the geometry admits a steady-state circular self-sustained detonation. We compute its structure and investigate its dependence on various parameters of the problem, such as the conditions of the incoming flow and the mixture thermodynamic and chemical properties. The supersonic flow from the source is assumed to be non-reacting so that the initial expansion is adiabatic. Such flow accelerates during the expansion and at some distance, r_s, from the source, the flow speed can reach the detonation speed for a given mixture. Therefore, one expects a standing detonation to exist at about r_s. Indeed, the solution of the steady-state reactive Euler equations shows that such detonation structure exists (see Fig. 1). It is a self-sustained detonation as there exists a sonic point near the end of the reaction zone. In many cases, we have found that a double-valued solution exists for a given incoming flow.

To understand the stability of the steady solutions, we perform two-dimensional numerical simulations that start with the steady solution as the initial condition. We find that generally, the detonation undergoes the usual cellular instability. Numerically, it was found that the steady solution either expands or collapses. The steady solution which has a square-wave-like structure usually gives the collapsing pattern. The detonation structure with a narrow reaction zone is seen to expand radially, albeit rather slowly. The expansion can be prevented by placing a number of rigid obstacles in the flow a short distance behind the steady detonation-shock position. Several reflected shock waves are formed and the detonation tends to stand, on average, some short distance ahead of the obstacles (see Fig. 2).

The detonation dynamics in this geometry depends strongly not only on the mixture parameters, but also on the incoming flow conditions, such as the Mach number, M_0, at the exit of the source, the stagnation enthalpy, H, of the mixture, and the radius of the source, r_0.

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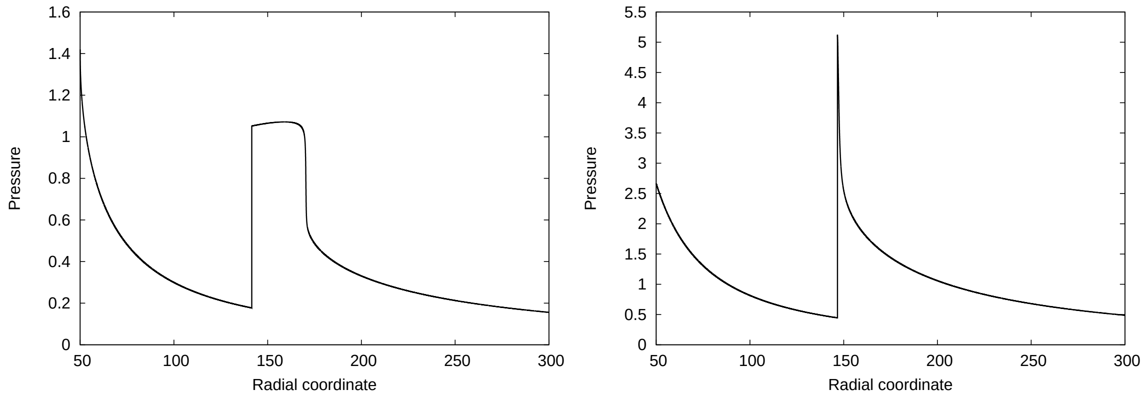

Figure 1: Two types of steady detonation profiles. The left figure corresponds to the square-wave-like detonation. Parameters (left): $\gamma = 1.2,\ Q = 10,\ E = 30,\ r_0 = 50,\ \rho_0 = 1,\ p_0 = 1.40,\ M_0 = 1.0,\ H = 2.1Q$. Parameters (right): $\gamma = 1.4,\ Q = 10,\ E = 30,\ r_0 = 50,\ \rho_0 = 1,\ p_0 = 2.70,\ M_0 = 2.0,\ H = 1.75Q\left(\gamma^2 - 1\right)$. Here γ is the ratio of specific heats, Q is the heat release, E is the activation energy, ρ_0, p_0 are the density and pressure at the source, respectively.

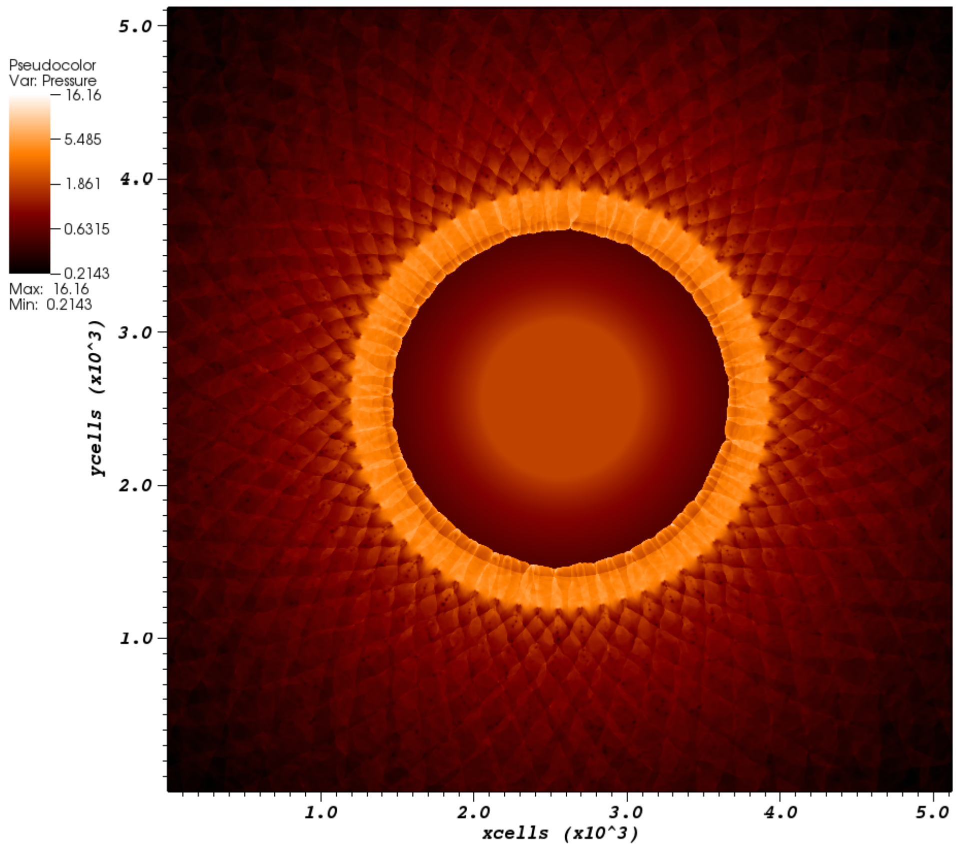

Figure 2: Standing detonation ahead of a row of obstacles at $t = 800$ half-reaction times.