Effect of Reflection Type on Detonation Initiation at Shock Focusing

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Abstract

Shock wave reflection from concave surface causes its converging and produces zones with extremely high pressures and temperatures. This is a shock-focusing phenomenon and being organized in combustible mixture can produce initiation of detonation [1,2]. Experimental and numerical studies [3] of shock wave focusing at parabolic reflectors in inert media showed, that depending on the focal parameter and Mach number of the incident shock wave three different types of reflection are organized. These types are divided according to the sequence of intersection of reflected shock waves relative to the time moment of triple points collision. The present work describes the peculiarities of detonation initiation due to focusing depending on the types of reflection [3].

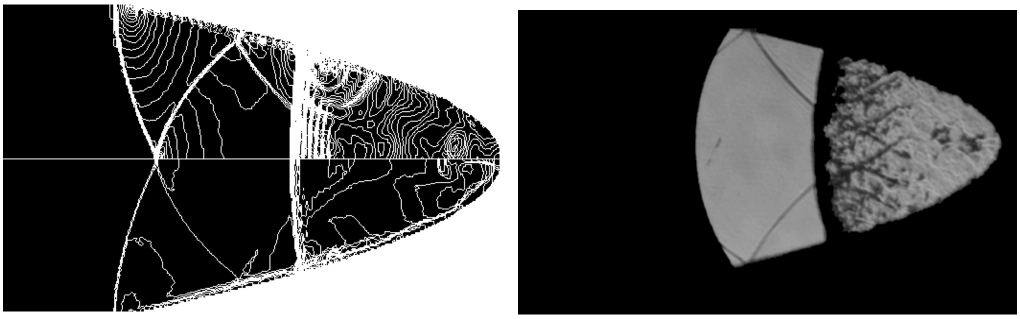
Numerical model

The gasdynamics part of the problem is described by the set of two-dimensional unsteady Euler equations. These equations were solved by Lax-Wendroff method including FCT – algorithm for shock capturing. Detailed chemistry mechanism was implemented in the solution scheme by time splitting technique and using CHEMKIN-II package. The computation domain was the upper half of rectangular shock tube and contains 324 x 81 grid points. Space resolution was uniform $\Delta x = \Delta y = 0.3$ mm. The shape of the reflectors is approximated by successive small steps with double grid refinement nearby guard cells. The left boundary conditions are constant Mach number inflow and reflection conditions at the upper surface and centerline of the reflector. Reflector shape was set by canonic parabola equation: $y^2 = 2px$, where p – focal parameter ranging from 0.45 cm to 1.35 cm.

Results of computations

Examples of snapshots representing detonation development in 15% H_2 + 85% Air mixture due to focusing at parabolic reflectors for two particular cases are represented in Fig. 1 and Fig.2. The choice of focal parameters provides limiting types of reflection mentioned in [3]. Numerical contours presented in Fig. 1 a (p = 0.45 cm) correspond to case when shocks reflected from lateral surfaces intersect before focusing and Fig.1b shows laser – schlieren shot obtained in experiments performed in 54 mm rectangular shock tube facility in SWL RWTH – Aachen. Fig. 2 (p = 1.35 cm) matches the case when focusing occurs without influence of secondary shocks.

In both cases ignition usually starts in gasdynamics focus followed by detonation initiation after triple points collision (detailed pattern not shown here). It confirms the conclusion [3] about the key role of triple points interaction in focusing phenomena as well as the findings [4] on the possible mechanism of detonation re-initiation. After initiation, detonation in deep parabola (Fig.1) propagates out of reflector apex in diverging geometry. A system of reflected shock waves ahead of detonation front does not produce any significant influence on the detonation propagation dynamics.



a) b)

Figure 1

Numerical a) and experimental b) snapshots illustrating detonation initiation due to focusing at parabolic reflector (p = 0.45 cm) at T_0 = 298 K, P_0 = 0.2 bar, M = 2.4, 15% H_2 + 85% air;
upper halfspace in Fig. 1 a) - pressure contours, lower halfspace in Fig.1 a) - temperature contours.

In the case of short parabola (Fig.2) the flowfield can be more complex. The increase of the intensity of initiating shock wave (or, alternatively, using the combustible mixtures with higher reactivity) causes the change of initiating process. In this case the ignition occurs along the slip line behind the mach stem of the incident shock wave. Thus, the initiating event takes place before the focusing process and combustion proceeds in converging geometry. The detonation front inside reflector takes a typical "butterfly" shape. It is demonstrated in left part of frame, where position of reaction front can be identified by the contour of maximal [H] – concentration. At the same time, the maximal pressures and temperatures (except a thin layer nearby detonation front) are located inside region **A**. Such a very non-uniform structure holds till the moment when detonation leaves reflector cavity.

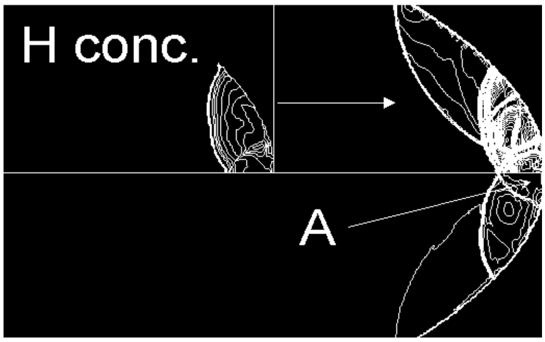
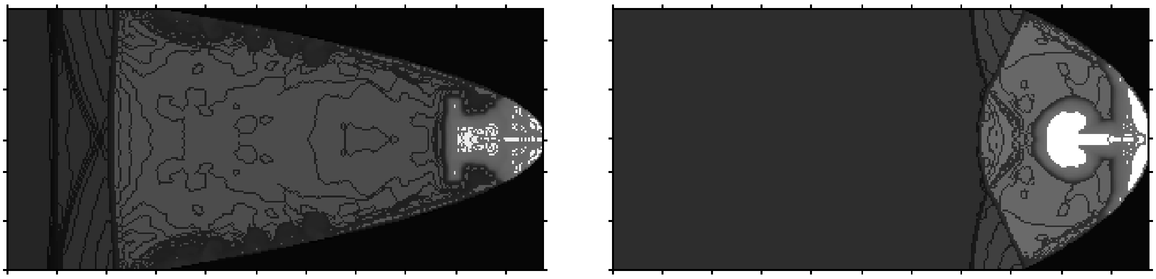


Figure 2

Numerical snapshot illustrating detonation due to focusing at parabolic reflector (p = 1.35 cm) at T_0 = 298 K, P_0 = 0.2 bar, M = 2.4, 15% H_2 + 85% air;
upper halfspace - pressure contours, lower halfspace - temperature contours.

Presented two examples of detonation development demonstrate the complex dynamics of interaction between combustion fronts and a system of reflected shock waves in the course of focusing process. However, even more complicated flow patterns can be obtained when the energy released due to focusing is insufficient for direct detonation initiation. These cases are referred as mild ignition event and could be characterized by the formation of separated structure consisting of the flame core and reflected shock wave. Corresponding temperature maps are represented in Fig. 3a,b for lower Mach numbers of initiating shock waves. Ignition in the gasdynamics locus does not lead to the producing of a detonation front, but the wrinkled zone of burned-out combustion products is formed inside reflector cavity. The process of self-ignition stops and flame front lags behind reflected shock wave. Further combustion development is conditioned by small – scale turbulence process as well as diffusive phenomena, which are not included in current numerical model.



a) b)

Figure 3

Numerical temperature contours showing unsuccessful detonation initiation due to focusing at parabolic reflectors a) p = 0.45 cm, M = 2.0 ; b) p = 1.35 cm, M = 2.25 at T_0 = 298 K, P_0 = 0.2 bar, 15% H_2 + 85% air

Conclusions

The performed numerical simulations of the shock wave focusing process in reactive media showed, that the main mechanism of detonation initiation is the energy release in the initiating center after triple points collision in the gasdynamics locus of reflector cavity. The types of reflection pointed out in [3] are responsible for the intensity of initiating center due to the different mach configurations. The system of reflected bow-shocks does not influence on the propagation of the detonation wave significantly. At the same time, alternative mechanism of detonation initiation was marked, which is conditioned by the ignition behind the incident shock wave at the slip lines nearby reflector surface. If the intensity of initiating center in focusing region is sufficiently low then the mild modes of ignition are realized.

References

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