Pressure Profiles in Detonation Cells with Rectangular or Diagonal Structure

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Introduction

Recently Hanana et al. [1] have characterized two modes of detonation propagation in square tubes, called rectangular and diagonal 3D structures. The diagonal mode has a similar pattern on the soot imprint as the so-called planar mode that was described by Biller [2] as a canted mode of propagation with respect to the walls of the detonation tube. Attempts of numerical modeling of 3D structure of self-sustaining detonations have been performed recently. Among them Williams et al. [3] were able to mimic only the rectangular mode, and Dorofeev et al. [4] the diagonal mode which is called "type 2" by them. Since both modes are well documented experimentally and numerically we have tried to investigate the pressure evolution with time at several stations in the cell structure as it was achieved already in the past for rectangular tubes [5] and [6]. It requires to record simultaneously the pressure, the local velocity as well as the detonation structure left over on plates covered by soot and located in the test section of the tube. This paper presents experimental evidences of both cellular structures and pressure measurements recorded along the centerline of the detonation cell.

Experimental Results

The experimental data have been collected from detonation runs in an aluminum tube 9m long with a cross section 9.2x9.2 cm^2. The cellular structure is recorded on soot plate and the pressure measurements are performed using piezogauges 3mm in diameter (PCB Piezotronics Inc.). Two to six pressure gauges are located along the centerline of the tube and are flush-mounted with the soot plate. Additional gauges are used to measure the average detonation velocity. More details on the experimental are reported elsewhere [1]. The initial conditions of the studied mixture are given in Table 1. In those experimental conditions, the number of transverse waves travelling in opposite direction is always two. Figure 1 shows typical soot prints. We observe two type of structures: structures with slapping waves (Fig. 1(a) and (b)) and a structure without slapping wave (Fig. 1(c)), called the 'diagonal mode' (D). In the case exhibiting slapping waves, the position of the latter is more often located at mid-cell of the printed cellular structure (Fig. 1(a)) and is called 'rectangular-mode-in-phase' (Ra). Sometimes the slapping wave is located at the apex of the printed cell (Fig. 1(b)) and is called 'rectangular-mode-out of-phase' (Rb). In a few cases the slapping wave occurs randomly between these two extreme cases. Figure 1 shows also soot records from the front view of the detonation: figures 1(a) and 1(b) show a rectangular shape of the imprints, and fig. 1(c) shows that, in the D-mode, the aspect of the soot imprint is diagonal. The overall detonation characteristics (average detonation velocity, D, the cell length, L, and the cell spacing, λ) are summarized in Table 2. A schematic diagram of this motion is depicted on Fig. 2, for Ra and D modes. In the D-mode, the axes of the transverse waves are canted at 45 degrees to the wall, accounting for the lack of slapping waves. The relative pressure profiles along the centerline as been recorded and typical curves at different locations (x/L) are plotted on Fig. 3. The plot shows the evolution of the delay time between the front shock

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and the first interaction of the transverse waves, for the three previously described propagation modes. The data of the relative pressure peak intensities have been plotted according to the relative position (x/L) inside the detonation cell (Fig. 4). The behavior of the pressure intensities throughout the cell is typical of each individual modes. There is a clear-cut difference of the first peak evolution for the Ra-mode. A first decaying curve is observed in the first part of the cell $x/L < .5$ and a second one for position $x/L > .5$. For Rb and D-mode the first pressure pulse decreases continuously from the apex to the end of the cell. The decaying character of the first pressure peak inside the cell is more pronounced for D mode than for Rb mode. The dissimilar behavior of the first pressure peak is related to the occurrence of a slapping wave in the cell, the propagation of the different modes of detonation can thus be discriminated easily from the pressure records.

Discussion

The properties of the diagonal structure show some similarities with those of detonation structures in round tube (multiple heads spinning detonation). The most common detonation structure, the one exhibiting slapping waves, is actually a superposition of 2 two-dimensional orthogonal structures. We called such a structure a 'rectangular structure' because the triple point lines are running parallel to the tube walls. The structure exhibiting no slapping wave at all is basically a three-dimensional structure that we called 'diagonal structure' because the triple point lines propagate diagonally in the tube. Contrary to previous thoughts, the diagonal structure is neither marginal, nor rarely or randomly observed. The way detonation ignition occurs is the key parameter to induce one or the other type of structure and we were able to obtain a given mode almost at will. Besides, the reflection of the transverse wave structure on the soot plate elucidates also the double decay pressure curve noticed for the detonations running in mode Ra. That behaviour stresses out once again the double 2D character of the rectangular mode (Ra) of detonation structure, as reported in reference [1].

References

1. M.Hanana, M.H. Lefebvre, P.J Van Tiggelen, *Proceedings of the Int'l Colloquium on Advances in Experimental and Computation Detonations*, St Petersburg, Sept 98, under press.
2. J.R. Biller, *Tech. Report, AAE 73-5-UILI-ENG-73/0505*, Univ. of Illinois, 1973.
3. D.N. Williams, L. Bauwens and E.S. Oran, *26th Symp. Int. on Combustion*, pp. 2991-2998, 1996.
4. S.B. Dorofeev, A.A. Efimenko, A.S. Kochurko and A.E. Tchugunov, *Int. Rep. of the Scientific Office for R&D in Idustrial Risks, IRIS-91/2*, Moscow, pp.32-37, 1991.
5. J.C. Libouton, M. Dormal, and P.J. Van Tiggelen, *Progress in Astro. And Aero*., 75, pp. 358-369, 1981.
6. P.J. Van Tiggelen and J.C. Libouton, *Annales de Physique Française*, 14, pp. 649-660, 1989.

Table 1 : Initial conditions of the studied mixture.

		Mixture Composition of Reactants		
Detonation Chamber	Initial pressure (kPa)	Hydrogen (%)	Oxygen (%)	Argon (%)
High Pressure	40.8	66.6	33.3	0.0
Low Pressure	6.8	20.0	10.0	70.0

Table 2: Detonation velocity and cell sizes from the soot imprints.

	Average velocity (m/s)	*Cell spacing (mm)*	*Cell length (mm)*
Rectangular structure, Ra	1420	92	163
Rectangular structure, Rb	1410	92	164
Diagonal structure	1450	92	120

(a)

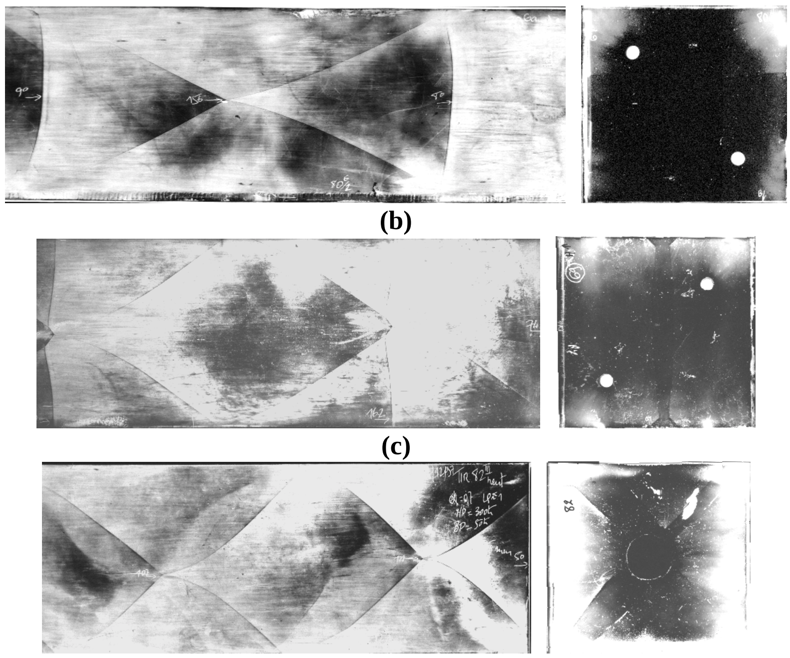

Fig. 1: Three types of multidimensional structures recorded on soot plates. Structure with slapping waves, rectangular type, (a) in phase and (b) out of phase, and structure without slapping waves, (c) diagonal type.

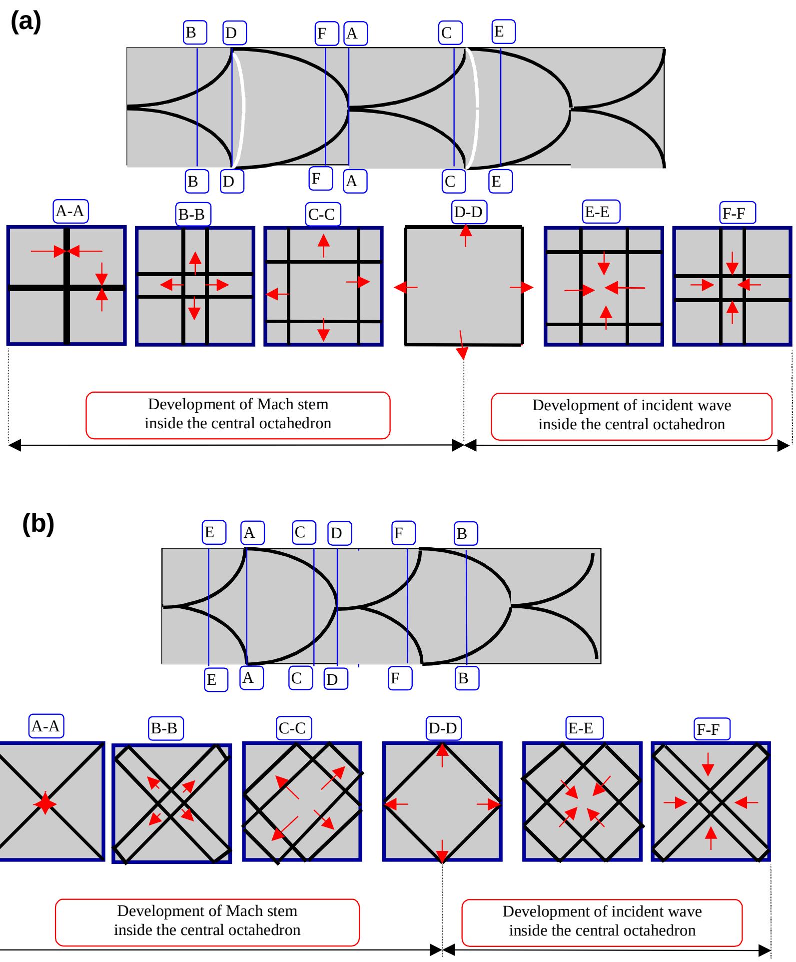

Fig 2: Schematic diagram of the front shocks at different locations of the cycle of the detonation cell. (a) Rectangular Ra and (b) diagonal D mode detonation cell. The arrows show the motion of the triple point lines.

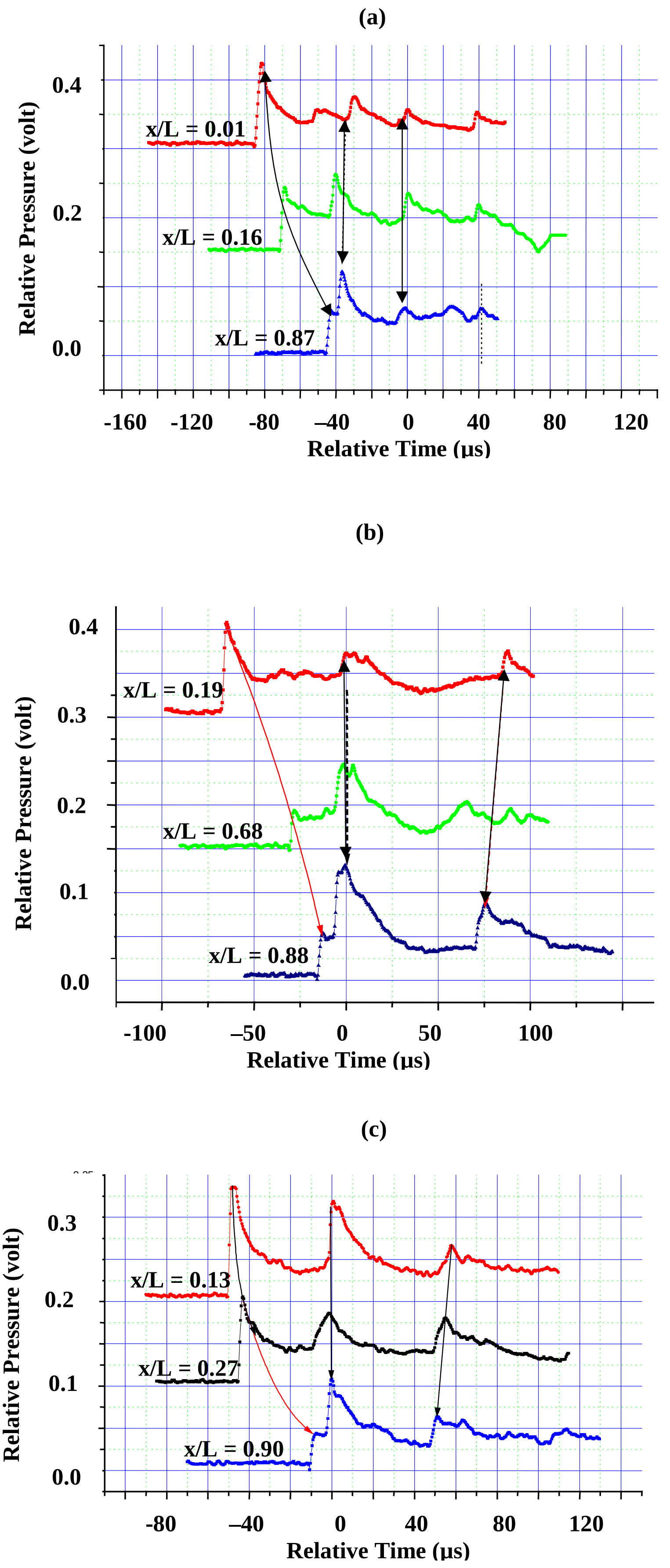

Fig. 3: Evolution profiles of the pressure on various loci of the centerline of the detonation cell (x/L). (a) Rectangular mode Ra, (b) rectangular mode Rb and diagonal mode D

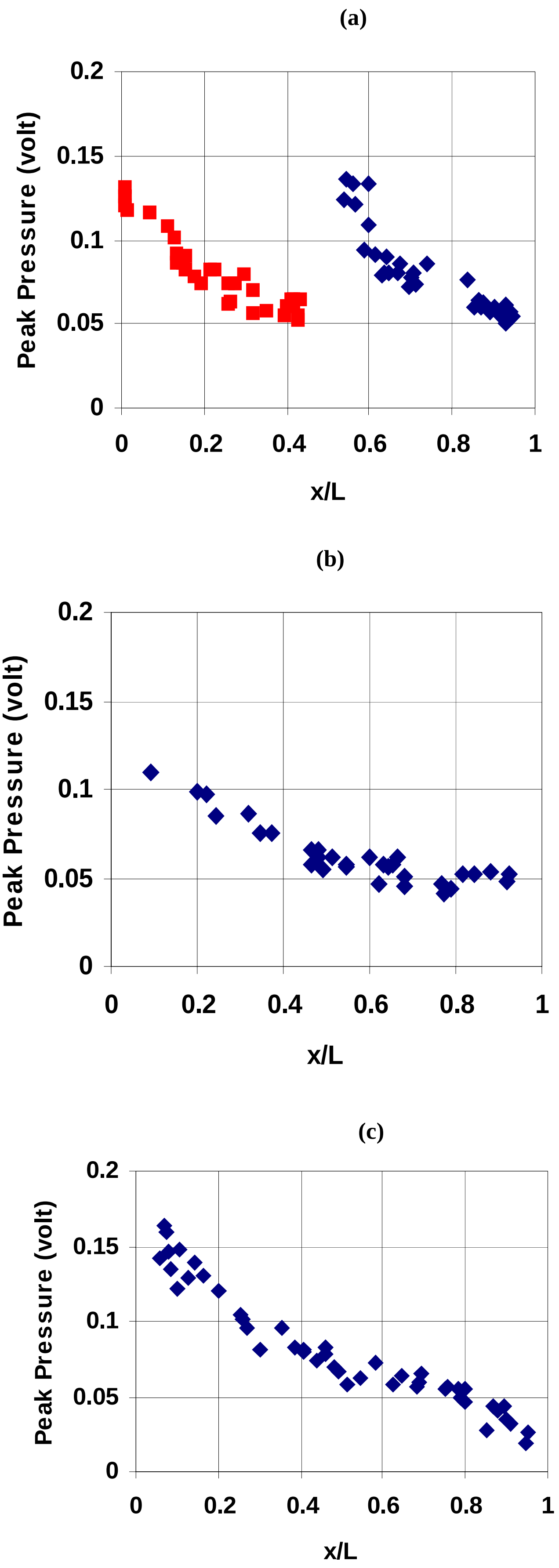

Fig. 4: Evolution of the pressure along the centerline of the detonation cell. (a) Rectangular mode Ra, (b) Rectangular mode Rb, and diagonal mode D.