# Numa Manson and the Detonation Structure

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Professor N. Manson has been the first scientist to suggest in 1946 an explanation for the structure of detonation waves.

Data collected by Campbell and Woodhead (1926) and later in the thirties by Bone's group have shown several regular luminous traces behind the leading shock. Those traces were travelling oblique to the main explosive wave. They were fairly obvious for detonations close to the limit of phenomena.

To the contrary of the classical 1D-approaches (CJ-, ZND-theories) and to explain those facts, Manson assumed that the gases directly behind the front of the explosive wave are the scene of a vibrating phenomena induced and sustained by the chemical reaction. Superimposed to the overall movement of the detonation wave there is a vibration motion with velocity components relative to the explosion front. By using the classical Rayleigh sound theory to those vibration motion Manson deduced, so, a relationship for the frequency of the vibrating phenomena, the tube diameter and the local speed of sound. A good agreement was obtained between the visible traces detected by several authors and the computed frequencies of those transverse vibrations.

Later, Taylor (1948-58) and Fay (1952) came independently to similar conclusions.

More elaborated techniques to record photographically the spin behaviour developed by Voitsekhovskii et al.(1957 and 1963) allowed to show that the vibration frequencies were related to the tangential motion of the trail behind the detonation head inducing acoustic oscillations. Their conclusions were extended to the high frequency regime when the detonation propagates in mixtures far from the limits.

It was corroborated independently by experiments in Troshin's group (1958) using the soot-track records.

In the sixties throughout the world, several groups investigated the gasdynamics of marginal detonation structure (Duff, White, Mitrofanov, Schott, Edwards, Steel, …). Their contributions were reviewed by Lee, Soloukhin and Oppenheim at the first Colloquium on Gasdynamics of Explosions in 1967.

The study of the chemical aspects of detonation structure was touched upon merely in Strehlow's papers (1969). He raised the question "How does the chemistry, by interacting with fluid dynamics, control the regularity of the phenomena?" and demonstrated that the nature of the chemical mixture influences to a large extent the size and shape of the cellular structure as the one collected on soot plates.

During that time Numa Manson's interests shifted toward developing new criteria of detonation stability based upon precise velocity measurements of the detonation waves. With his co-workers he tried to connect the occurrence of the vibration phenomena to the intrinsic stability and to extend it to systems far from the limits. In 1962, he discussed that approach at the "12ème Conseil de Chimie" of the Solvay International Institute in Brussels.

Further advances in the chemical viewpoint of detonations have been gained in the seventies. Among others, experimental attempts to vary the rate of heat release without modifying the overall amount of heat released was carried out in Louvain (Libouton et al. 1974). By adding compounds in traces either to accelerate, or to slow down the heat release rate, they have been able to decouple the kinetic- from the thermodynamic aspects of the detonation wave. Systematic variation of the composition of the initial gaseous mixture have been achieved in the work of Libouton and Van Tiggelen (1976) and the role of the kinetics on the limit mixtures have been examined by Libouton (1978).

The decoupling between the leading shock and the reaction zone was studied by looking at different stage along the cell length (Dormal et al. 1979). A better picture of the re-initiation process at the end of the detonation cell can be deduced that way (Libouton et al. 1981). Several parameters of the mixture composition modify to a large extent the induction process along the centre line of the cell (Dormal et al. 1983). The temperature dependence of the ratio ($\gamma = C_p/C_v$ ) and the high activation energy of specific elementary step play a role in the regularity of the cell structure as demonstrated by Jacques et al. (1981). Some computations of 2D structures have corroborated that viewpoint (Lefebvre et al.1993 and 1995).

The first attempt to provide a phenomenological description of the fine structure was performed in 1977 by Manzhalei and further discussed since then by several groups (Shepherd 1987, Borisov 1993, Vassiliev 1987 and Shepherd's group 2003, 2005).

A very important contribution to the understanding of the impact of the chemical kinetics to the detonation structure was made in Poitiers'group at the end of the nineties: Presles et al.(1996), Lamoureux et al.(2001) studied mixtures with gaseous nitromethane, (alone, or mixed with oxygen). A double cell structure was discovered and then investigated thoroughly. Such a behaviour is valid for nitro-compounds and for mixtures where $NO_2$ is the oxidizer (Desbordes et al. 2004 and Luche et al. 2006). It shows again the role of a complex heat release rate upon the detonation structure.

If the classical thermodynamic theory gives a correct description of the macroscopic properties (e.g. detonation speed), it may be concluded that the ultimate origin of the dynamic instabilities of the detonation waves is connected to the rate of the heat release itself governed by the actual chemical kinetics of the reaction mechanism.