Secondary Combustion of Detonation Products with Surrounding Air Experimental Characterization of Fireball Dynamics

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1 Problem statement

This article focuses on the secondary order phenomena in time, occurring when a condensed high explosive (HE) detonates. To be more precise, we focused on the secondary turbulent combustion between detonation products (DP) and air, in open space. The problem under consideration there is the turbulent mixing in a fireball, created by the detonation of spherical charge. In such a problem, DP expand at high velocity which drives a strong blast wave. Because of the very large density ratio across the fireball interface, hydrodynamic instabilities growth and induce turbulent mixing.

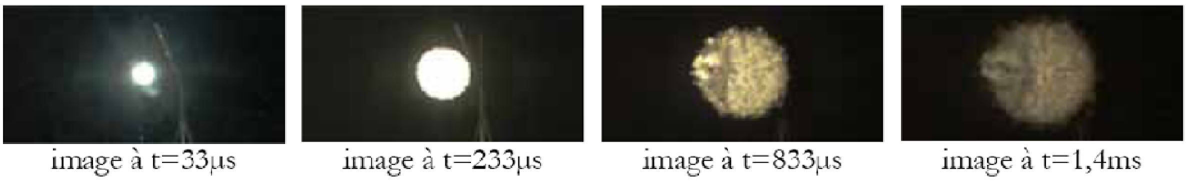

Figure 1 Movie abstract of CEG experiment: expanding fireball vs. time

Thanks to 1D spherical hydrodynamic theory and with an appropriate couple of equation of state, it's easy to plot (x,t) shock waves diagram and the theoretical smooth interface trajectory vs. time (Fig.2). In such a calculation, mixing effects are neglected, whereas post-combustion influences energy release time scales [1,2,5]. The true radius of the fireball is an important characteristic data of each explosive formulation. Although explosion of a condensed charge has been investigated for a long time, characteristic time and amplitude of heat release during this chemical interaction are not well known. As a result, the afterburning effect of classical high explosives is a major concern for the last fifteen years in the defense community (see ref.). Several authors describe in [3,4] simulation tools for 2D or 3D calculations of complete spherical detonation. For instance, adaptative mesh refinement techniques can be used to track turbulence in expanding DP and to determine post-combustion rate.

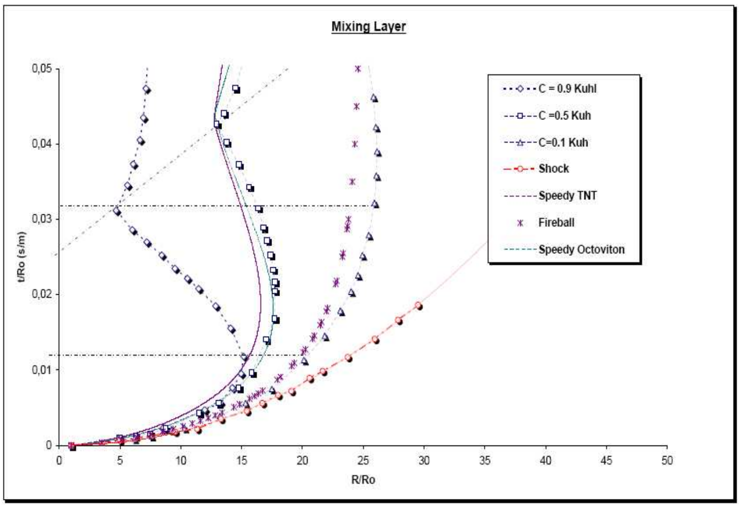

Figure 2 Classical (x,t) shock wave diagram and theoretical radius of the DP / air interface vs. time for TNT and HMX based HE - 1D CEG spherical code “Speedy G” and A.Kuhl AMR calculation results [2,3]

But to validate numerical codes, there is still a lack of experimental knowledge. The problem is there to be able to measure useful data as gas density, local average pressure or temperature, etc. Optical diagnostics can be applied to obtain information about spherical charge explosions. Density-sensitive visualization methods like shadowgraph or interferometer have been commonly used [5]. But all mentioned techniques can at best yield a density distribution. Other properties as temperature or velocity would have to be measured by others devices. Recently, researchers published results of non intrusive and time-resolved optical methods to measure fireball light emission (one or two colour pyrometers, time-integrated spectroscopy techniques) [6,7,8,11,12]. CEG keeps on developing several experimental configurations to characterize the fireball dynamics. Here we describe the experimental setup developed to bridge our lack of knowledge and typical results of spherical detonation of HE in free field. Our study has two main objectives:

- To produce experimental data to help validate new multiphase and multispecies hydro-codes or analytical models. That’s the reason why we focused on spherical detonation experiments with few input parameters. Output data must be directly comparable to numerical simulation results.
- To compare “heat” impulse and optical properties of DP and to quantify energy release.

2 Spherical detonation – Free field experiments

Spherical detonation in free field experiments are described in this article, as well as a new temperature measurement technique dedicated to such experiment. Indeed, CEG developed with Paris X University a non-intrusive two-color infra-red pyrometer to measure the temperature of hot gases in an expanding fireball. First experimental results are qualitatively in good agreement with published data in opened literature. The expected output data are:

- Near field incident overpressure time history and R(t), the fireball radius in visual spectrum,
- Duration of light emission in visual spectrum, or L(M,t) and T(M,t), respectively the luminance and an estimated temperature in a “point” M of the external fireball surface.

<u>Experimental setup:</u>

Since 2006, “Height of Burst” (HOB) experiments have been improved to track not only shock waves propagation but also to assess secondary combustion effects. Both TNT and HMX-based high explosives (with or without metallic particles), as well as non ideal charges, were tested, in order to vary the oxygen balance, and thus the afterburning phenomena.

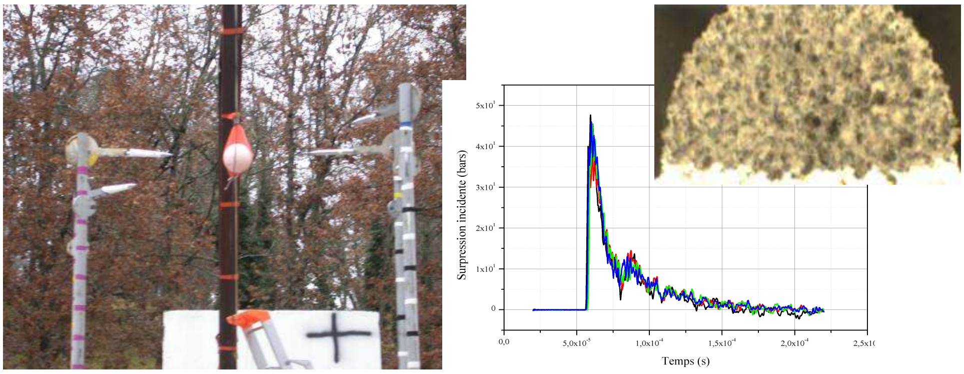

Figure 3 HOB Experimental setup Left: Spherical charge and pencil probes Right: typical fireball and overpressure recorded signal.

Two digital cameras with identical optical heads were applied to resolve fireball radius. Extracts from typical sequences of high-speed digital video are shown on Fig.1. Optical aberrations are measured to 2 % maximum full field, thanks to calibration images. The use of a supersensitive10 bit sensors matrix was chosen with respect to its ability to catch fast events (1024*1024 pixels @ 5000 fps). Only one parameter (exposure time) can be chosen in order to perform a best measure of the fireball radius. The time signature of the blast-pressure event is obtained thanks to side-on transducers placed at varying distances from the explosive source. We commonly used piezo-electric transducers and home made pencil probes (Fig.3) with specific wire connection to avoid unwanted frequencies.

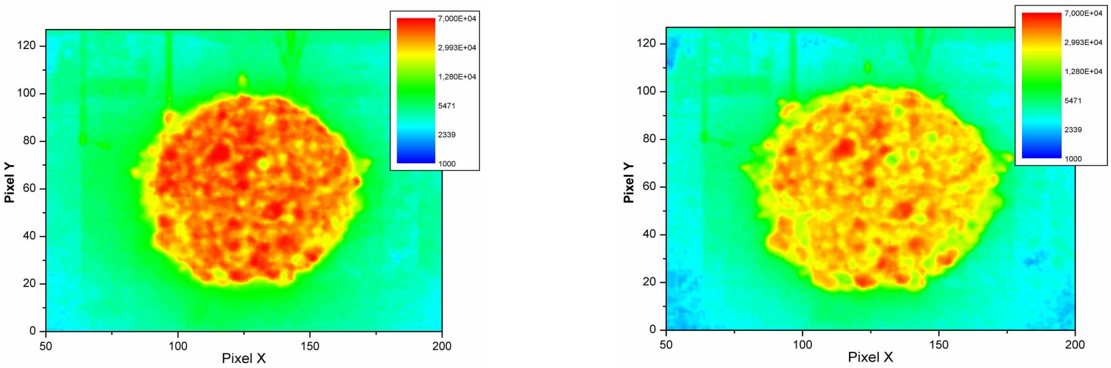

Figure 4 Pseudo color analysis of fireball thanks to 2^{16} grey levels - Instabilities length scale at two different times.

<u>Two colour pyrometer</u>

As we explained above, media we want to explore have a lot of specificities: high expanding velocity, strong temperature gradient, etc. Because of 3D characteristics of this turbulent flow, we had to develop a measurement chain able to record a thermal cartography. Expanding fireball is a mix of solid particles (carbon, metal particles) and hot gases. Spectral emissivity or absorption are directly linked to temperature, emission surface, concentration of particles, etc. It’s impossible to know that properties everywhere within the fireball. Because of all these reasons, we decided to develop a method based on two “colour” radiative transfer of solid particles. As it is described in [9,10], this technique allows to throw off view-finding and to limit emissivity influence on results quality. The basic principle is to perform a simultaneous luminance measurement on two distinct wavelengths in the infra red spectrum (respectively 4 and 4.7 µm). For that, we use an infrared camera with a large detector matrix, and an optical system to create two separated images of the fireball through pass bands filters (Fig.5).

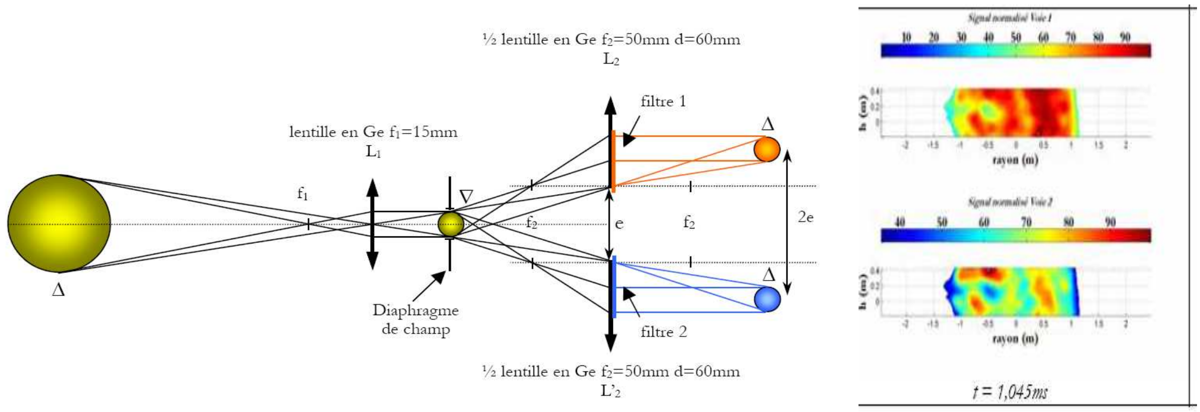

Figure 5 Optical system to separate initial object and temperature map along fireball radius

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Acknowledgement

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