Analysis of Explosion Dynamics from Dust Cloud Metal Particle using Thermal Infrared Imaging

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1 Abstract

Many working environments are at significant risk of explosions. Dust cloud explosions are especially insidious, as powdered material in suspension in the air is exposed to a lot more oxygen than "solid" flammable materials, and thus burn extremely rapidly. Moreover, dust cloud explosions are often caused by ordinary and otherwise harmless materials, such as flour, coal or pollen, that can be ignited by an unsuspicious source of energy, such as an electrical spark or a hot surface. Many powdered metals, such as aluminum oxide and magnesium, can also be dangerous explosives when they are in suspension in the air. The understanding of dust cloud explosions therefore is critical to ensure the safety of workers.

In order to study the thermodynamic processes involved in such explosions, scientists need to understand the characteristics of the ignition, the explosion and the propagation. The efficiency of an explosion is usually characterized by the quantity of energy that is released, by the velocity at which the thermally expanding gases are released and by the spatial and temporal evolution of the generated heat wave and released particles.

This paper presents the measurement results of a metal dust cloud explosion using high-speed infrared imaging. Our results show that highly sensitive Infrared Imagery with high temporal, and high spatial resolutions is an important tool for characterizing explosion dynamics. Indeed, we obtained direct measurement of the total energy released and of the active radius. The derived informations such as the local kinematics energy helps scientists to better understand the thermodynamics of the explosions. We demonstrated that high speed infrared cameras are the perfect tools to bring the explosion analysis and research to the next level.

2 Metal Particules Dust Cloud Explosion

Metal particles dust clouds are created using a mixture of different particles such as magnesium or aluminum oxides. Typical metal particles size is only a few microns in diameter. To simulate a dust cloud, metal particles are placed in small cone-type containers. (Figure 1, Left) Pressurized gas is then blown under each

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container to spread out the dust cloud. (Figure 1, Center). Finally, to initiate the explosion process, a hot thermal source is launched inside the dust cloud, generating a chain of explosion ignitions.

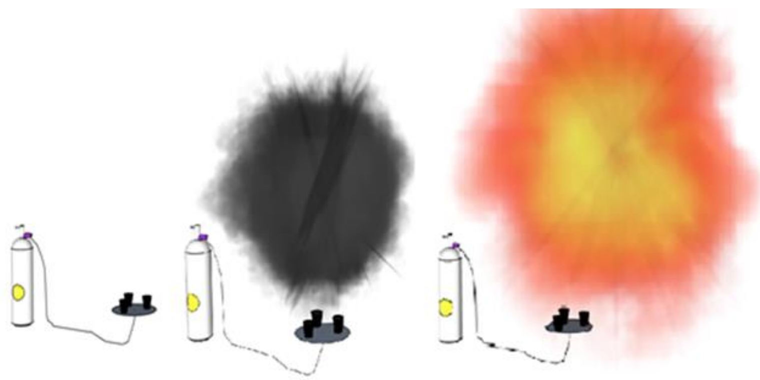

Figure 1. Metal particles dust cloud explosion

3 Field Test Experiment

Figure 2 illustrates the experimental setup used to demonstrate the benefits of analyzing the explosion with a high-speed thermal imaging camera. The Telops FAST-IR Camera is pointing perpendicularly to the explosion at a distance of 30 meters.

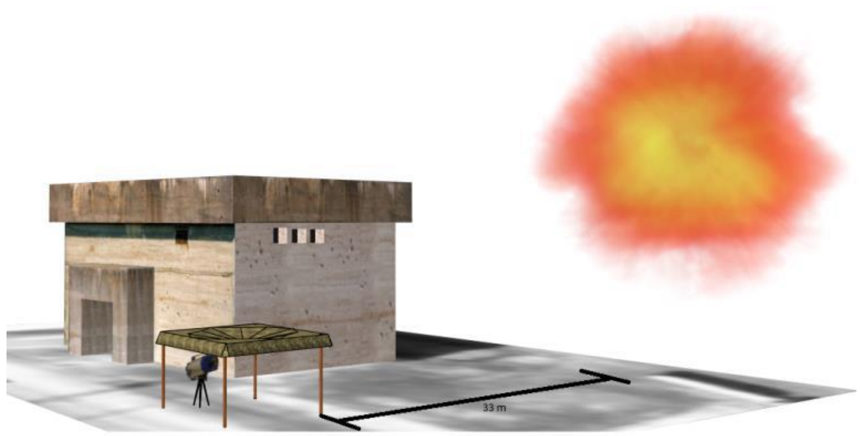

Figure 2. Experimental setup

4 Results and discussion

The results reveal an unprecedented capability of measuring key explosion characteristics. Figure introduces the step by step radiance signature evolution of the explosion. The time difference between consecutive frames is 666 microseconds. While the top left image illustrates the primary ignition point, the following five images reveal interesting details on the turbulent flow created by the secondary ignition points. The detailed analysis of the last three images allows for evaluating the metal particle explosion ignition propagation and ranging effect.

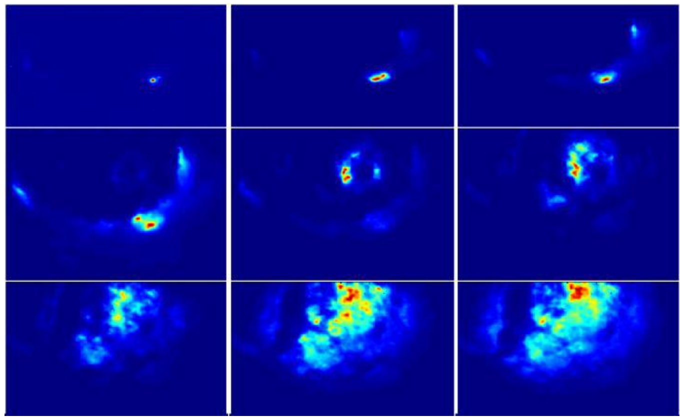

Figure 3. Step by step explosion

To better illustrate the secondary ignition points, a radiance difference between consecutive images is calculated and presented in Figure 4. Several individual ignition points (secondary) can be detected from the local peaks (between 35ms and 45 ms).

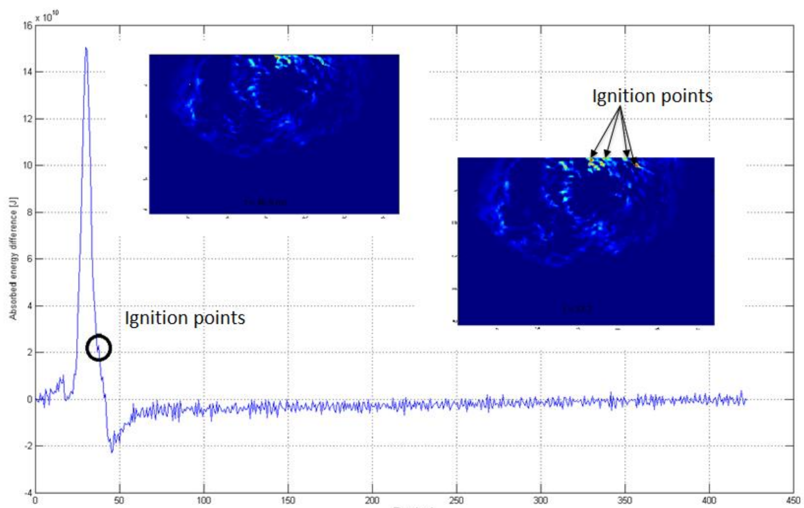

Figure 4. Explosion ignition point propagation graph

For instance, at about 38ms following to the beginning of the sequence, and roughly every 2 ms, peaks appear, indicating a difference in local radiance. These local peaks result from secondary ignition points propagating into the dust cloud. The ignition points effective range is calculated through a dynamic flow analysis based on a Telops proprietary pixel per pixel temporal radiance variation technique. This technique is illustrated in Figure 5. The small red vectors represent the flow direction, while the length of the vectors corresponds to the velocity of the expanding gas. From this map, local maximum reveals the ignition points. The local ignition points range is calculated from the flow speed and direction.

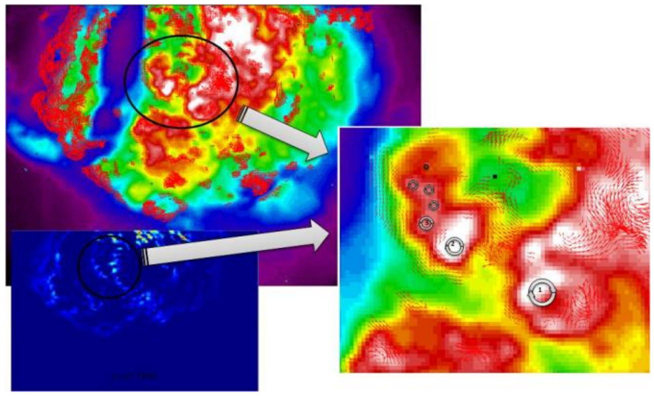

Figure 5. Flow direction and velocity analysis

High-speed infrared imaging also allows to compute the flow velocity profile resulting from an expending gas. As illustrated in Figure 6, the gas velocity surrounding the ignition point 1 is [U, V] = [3410, 5530] pixels/s, where U is the horizontal and V is the vertical velocity. From this result, local kinematics energy resulting from an isolated ignition point can be retrieved, helping to understand the local thermodynamic behavior. The high performance FAST-IR infrared camera also allows to provide critical information such as the total generated energy over time and the active radius of the total explosion. As shown in Figure 7, one finds the total emitted energy and surface temperature occurring during the explosion. In fact, the total energy peaks at about 40 MJ (equivalent to ~ 9 kg of TNT) after approximatively 5 to 8 ms following the primary ignition.

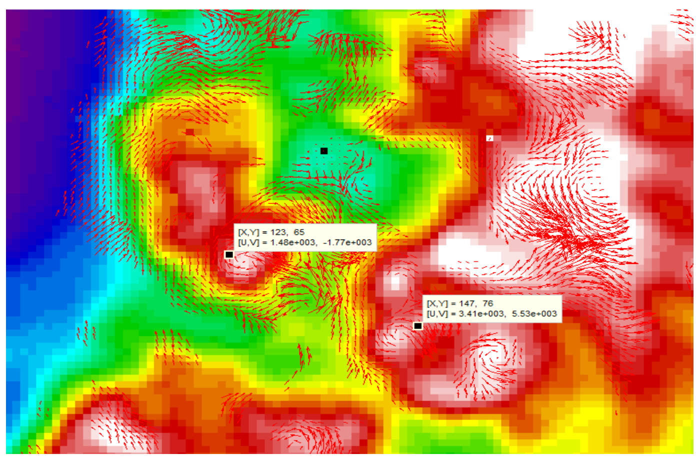

Figure 6. Expending gases velocity and direction

More than 25% of the total energy is released within this time frame. The maximum measured temperature is above 2700K. Moreover, the total explosion active radius of ~8.5 meters is directly calculated from the measured infrared frame shown on Fig.6.

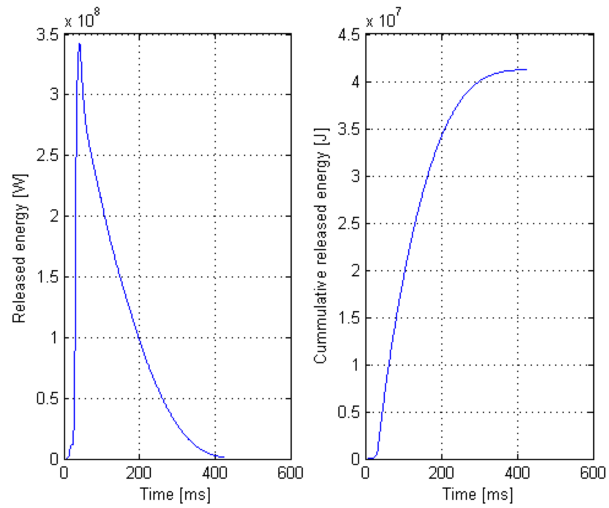

Figure 7. Energy released by the explosion

5 Conclusion

There are several key benefits to characterizing an explosion using high-speed infrared imagery. It allows for a direct measurement of the total energy released and of the active radius. Such data and derived information help scientists to better understand the thermodynamics of the explosion as well as the ignition and heat/particle propagation inside the active explosion area. All these phenomena can easily be recorded by the unique Telops FAST-IR infrared camera. Its unique high frame rate makes it the perfect tool to bring the explosion analysis and research to the next level.