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# On the thermomechanics and footprint of fragmenting blasts

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ABSTRACT

In this paper, a mathematical model is developed to simulate the progressive time-evolution of an object that fragments, which may contain biohazardous materials or materials that may thermally degrade into a toxic state. Estimates are made for the blast radius that one can expect for a given amount of detonation energy and the resulting atmospheric heating of fragments. The atmospheric heating of the fragments is important, since if the heating is sufficiently high, the biohazardous material can be neutralized. If the material is not heated sufficiently, then the location in which it lands can be considered as "contaminated". This analysis is useful is determining safe areas after such a blast. Ascertaining the temperature of the fragments is extremely difficult to measure in experiments, thus motivating the development of the model. The model balances the released energy from the initial blast pulse with the subsequent kinetic energy and then numerically computes the trajectory of the fragments under the influence of the drag from the surrounding air and gravity. Preliminary field experiments with explosives are described and the results are compared to the output from the model. The subsequent drag heating of the material is then computed in order to ascertain the temperature of the blast fragments.

## 1. Introduction

Understanding the blast fragmentation of objects that contain biohazardous material has wide-ranging applications, especially with respect to emergency management, and limitation of human exposure. Events involving explosions and biohazardous materials include accidents at chemical production or water treatment facilities that may release clouds of toxic industrial material, or even deliberate destruction of either chemical or biological weapons of mass destruction production facilities of both state and non-state actors. Both examples involve interaction of a blast with a container of material that can be either solid, liquid, or a mixture of both. These events can lead to the release of aerosol clouds that can carry hazardous material long distances, potentially exposing many people to toxic material. Specifically, the main objective of the present study is to construct a model which captures the essential physics of detonation and blast envelope growth, as well as subsequent atmospheric drag heating of the resulting fragments. The computed heating can be used to ascertain the survivability of small-scale biohazardous material contained within the blast fragments. For example, in many scenarios, heating can either kill microorganisms, chemically degrade chemicals, or create new, potentially hazardous, chemicals. It is thus essential to understand atmospheric heating.

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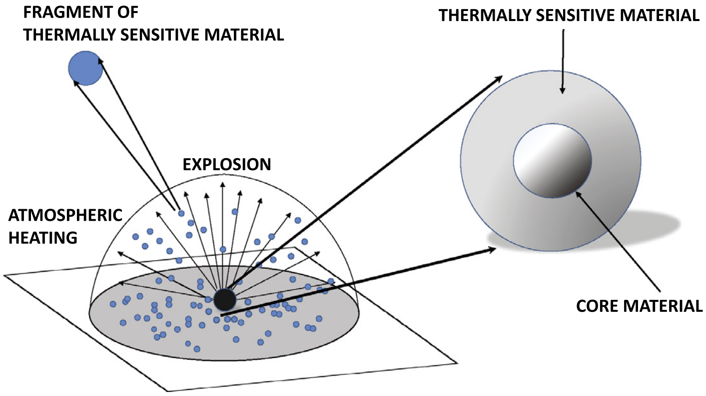

**Fig. 1.** Explosion of an object containing biomaterial experiencing atmospheric heating.

**Fig. 2.** Still frames from the field experiments.

As a model problem, we simulate an explosive device as a sphere that is hollowed out with an energetic material in the center (Fig. 1). The shell is extremely thin and is simply present to separate the inner core of explosives from the surrounding blast material which is to be tracked. In this work, we do not consider detailed models for the interaction between the shock wave and the packed fragments (see for example Cabalo, Schmidt, Wendt, & Scheeline, 2002; Gregoire, Sturtzer, & Khasainov, 2009; Hoover & Hoover, 2009; Kudryashova et al., 2011) nor the chemical aspects which are beyond the scope of the present work.

## 2. Motivation via experiments

The result from a set full scale field experiments with high explosives and ballistic gelatin motivates the desire to predict the dispersal of material by the blast as well as understand the effects of atmospheric heating. The primary conclusion that could be drawn from these experiments is that aerosols generated from a blast containing toxic materials cannot be assumed to be inactivated by the blast itself (Cabalo et al., 2016). For example, this result is in agreement with the findings of Eshkol and Katz (2005), and Kanemitsu (2005), where Hepatitis B was transmitted from a suicide bomber to survivors of the blast.

To summarize the set of experiments, we detonated blocks of ballistic gelatin with high explosives on a test range to explore the survivability of fragmented (particulate) material, as shown in Fig. 2. Ballistic gelatin was used in the test due to its well understood mechanical properties and relevance to previous human injury studies, and it is a thermally sensitive material that melts at approximately 40 °C. An aerosol particle sizer and a UV-fluorescent particle counter that was selectively sensitive to the protein of the ballistic gelatin monitored aerosols generated. A small amount of bacterial spores had been mixed into the gelatin, so that we could detect deposition of even very small amounts of material on witness plates. The use of living material also permitted an assessment of thermal damage to the material since temperatures in excess of 70 °C will kill the microorganisms. Although these experiments were far from quantitative, we could draw the conclusion that interaction of material with a detonation fireball was minimal, so that it cannot be assumed the detonation will consume the hazardous material. Although the ballistic gelatin we used melts at low temperatures in comparison to temperatures found in the blast, a large amount of solid gelatin was collected on the test pad. Furthermore, witness plates located approximately 100 m away from the blast site, collected aerosol fragments bearing viable organisms. These were detected by swabbing the witness plates with wetted wipes, and plating rinse onto agar plates. Bacterial colonies were then counted. Significant transient concentrations of aerosol (approximately 1000 particles/L) only attributable to the gelatin were detected. Again this means it cannot be assumed the heat and pressure from the blast will consume hazardous material, even if the proportion of high explosive to hazardous material is high.

The result of the test also highlighted the need for a good model. There are numerous possible configurations of containers of possible hazardous materials versus a blast, ranging from a large chemical tank to storage sites of weapons of