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Modeling of the scattering response of particulate obscurant clouds

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ABSTRACT

Obscurants are often clouds of dispersed particulate materials whose purpose is to mask a given object. The objective of this paper is to develop a simple discrete-ray/discrete-particle model in order to enable rapid assessment of the response of an obscurant cloud to an incoming high-frequency beam. The beam is decomposed into a set of discrete rays and the obscurant is represented by a discrete set of scattering particles. Ray-tracking is used to calculate the transient propagation of the rays and the absorption of energy by the particles. Examples are given, comprised of concentrated incident beams, their propagation into the obscurant cloud, and the subsequent reflection and transmitted aggregate response. Basic system trends are computed, varying the randomly dispersed particle shapes from spherical to oblate objects, which correlate the total amount of volume and surface area material available to interact with the beam and the overall scattering response. This allows further correlation of the obscurant cloud performance to the weight of the material, which is important for portable containers of dispersible obscurants, such as smoke grenades. Specifically, the model allows for rapid quantification of the modest reduction of scattering efficiency of flakes, relative to spheres, but which have significantly less weight than spheres. Thus, there is a trade-off between the weight of the dispersed system and its scattering efficiency.

1. Introduction

Obscurants, such as smoke, have been used throughout the ages to mask the presence of objects. The objective of this work is to develop a discrete-ray/discrete-particle model to rapidly calculate the scattering of a high-frequency beam encountering a cloud of particles comprising an obscurant.[1] One key motivating application for this work is optimization and control of released obscurants to mask incoming signals which may be used to locate the object being obscured. The full sequence of events for release of a cloud of packed obscurant particles, for example from a grenade or canister, begins with an initiated shock wave that rapidly rips open the container (typically a lightweight hardened cylinder of cardboard) which releases a packed powder of particles forming a cloud. In this paper we are primarily interested in the response of the cloud to incoming optical disturbances, and the effect of the shapes of the particles on the overall optical response. Also, because the weight of the canisters is of importance when they are carried, the question of whether one can utilize less weight-intensive flakelike materials, as opposed to powders containing heavier spherical powders is relevant. Thus, one component of interest in the present study is to develop a simple and fast computational tool, which captures the essential physics of incidence,

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[1] The present discrete-rate/discrete-particle model is a simple alternative to a full-blown continuum description employing Maxwell's equations.

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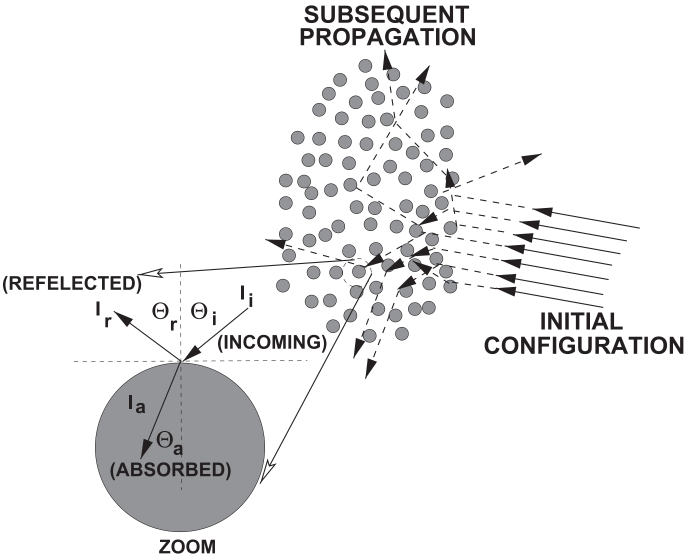

Fig. 1. A high-frequency pulse applied to a dispersed material, with a zoom on a reflection and absorption of an individual incoming ray and an individual particle.

absorption and reflection, and then use it to perform parameter studies on how the shape of the obscurant particles affect the overall response of a cloud to an incoming pulse of optical energy. In this work, we do not consider the problem of the dynamics of the disperse particles and the heat transfer, due to the interaction between the shock wave and the packed particles (Cabalo, Schmidt, Wendt, & Scheeline, 2002; Gregoire, Sturtzer, Khasainov, & Veyssiere, 2009; Hoover & Hoover, 2009; Kudryashova et al., 2011), which is beyond the scope of the present work. For studies of the evolution of heat and the dynamics (movement) of the particles, we refer the reader to Zohdi (2004, 2005, 2006a, 2006b, 2007, 2010, 2012a, 2012b, 2013, 2014). This entails an analysis of the dynamics of particulate clouds and flows, related to granular flow models, as well as coupled fluid-particle interaction problems, which are found in Duran (1997), Pöschel and Schwager (2004), Onate, Idelsohn, Celigueta, and Rossi (2008), Onate, Celigueta, Idelsohn, Salazar, and Surez (2011), Rojek, Labra, Su, and Onate (2012), Carbonell, Onate, and Suarez (2010), Labra and Onate (2009), Avci and Wriggers (2012), Leonardi, Wittel, Mendoza, and Herrmann (2014), Cante et al. (2014), Rojek (2014), Onate et al. (2014) and Bolintineanu et al. (2014).

In order to enable the ability to study the particulate cloud systems, we develop a discrete-ray/discrete-particle model for the characterization of the response of an obscurant cloud to a concentrated beam of high-frequency energy is the key objective of this work. Specifically, the interest here is on behavior of initially coherent beams (Fig. 1), composed of multiple colinear (collimated) rays (initially forming a planar wave front), where each ray is a vector in the direction of the flow of optical energy (the rays are parallel to the initial wave's propagation vector). It is assumed that the particles and surface features are at least an order of magnitude larger than the wavelength of the incident radiation, therefore "geometrical" ray tracing theory is applicable, and is well-suited for the systems of interest. Ray-tracing is a method that is employed to produce rapid approximate solutions to wave-equations for high-frequency/small-wavelength applications where the primary interest is in the overall propagation of energy.[2] Essentially, ray-tracing methods proceed by initially representing wave fronts by an array of discrete rays. *Thereafter, the problem becomes one of a primarily geometric character*, where one tracks the changing trajectories and magnitudes of individual rays which are dictated by the reflectivity and the Fresnel conditions (if a ray encounters a material interface). Ray-tracing methods are well-suited for computation of scattering in complex systems that are difficult to mesh/discretize, relative to procedures such as the Finite Difference Time Domain Method or the Finite Element Method. For review of the state-of-the-art in industrially-oriented optics, see Gross (2005). As alluded to, because of the complex, discrete, randomly dispersed particulate microstructure of an obscurant cloud, this type of system is extremely difficult to simulate using continuum-based methods, such as the Finite Difference Time Domain Method or the Finite Element Method. In the approach taken in this work, the beam is discretized into a set of rays and the obscurant cloud as a set of scattering particles (Fig. 1). Even in the case where this clear separation of length scales is not present, this model still provides valuable information on the propagation of the beam and the reflected response of the dispersed system.[3] An efficient discrete ray-tracking algorithm is developed to track the propagation of rays into the system. Quantitative examples are given, focusing on concentrated optical beams, their subsequent propagation, reflection and transmitted obscurant cloud response. Parameter studies are

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[2] Resolving diffraction (which ray theory is incapable of describing) is unimportant for the applications of interest.

[3] It is important to emphasize the regimes of validity of such a model are where the particle scatterers and surface features are larger than visible light rays: 3.8×10^{-7} m $\leqslant \lambda \leqslant 7.2 \times 10^{-7}$ m. Thus, the particles in this analysis are assumed to possess diameters larger than approximately 10^{-5} m (10 μm). For systems containing particulates smaller than this, one can simply use the model as a qualitative guide.