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Fragment Tracking in Hypervelocity Impact Experiments

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Abstract

Space debris impacts of in-orbit satellites cause varying degrees of fragmentation, ranging from minor damage to catastrophic breakup. In this paper, we introduce an experimental measurement approach for studying the fragmentation effects of hypervelocity impact in the laboratory. We demonstrate this method by investigating a hypervelocity impact on a thin aluminum bumper plates and tracking individual fragments in the debris clouds. The setup involves a thin laser plane illuminating the debris cloud fragments, which are recorded with a high-speed video camera. The image sequence is analyzed, yielding spatio-temporal information about each fragment in the debris cloud. This allows individual fragment size and velocity information, previously not available, to be calculated.

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Keywords: Hypervelocity impact; Fragmentation; Particle tracking.

1. Introduction

With the growing population of space debris in orbit around Earth, the probability of operational satellites undergoing hypervelocity impact (HVI) is increasingly likely [1]. Every impact event creates new fragments, which further contribute to the space debris problem. In order to determine the risk to satellites operating in any given orbit,

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researchers have created orbital debris models based on space debris tracked on from earth, as well as satellite fragmentation and breakup model predictions [2][3]. The breakup model relies on a combination of ground based experiments as well as explosions and collisions observed in orbit [4]. Improved understanding of HVI phenomena, particularly fragmentation, will allow more accurate breakup models to be developed, which in turn can lead to better orbital models and risk assessment and prevention for satellites.

Hypervelocity impact fragmentation experiments often involve a spherical projectile impacting a thin target plate leading to fragmentation of the projectile and part of the target. The experiment is often instrumented with high-speed cameras or radiographs which capture images of the debris cloud as it develops. These images can provide us with an understanding of the general characteristics of the fragment cloud under HVI, such as the shape of the debris cloud, but cannot provide detailed descriptions of the individual fragment sizes or velocities. The high-speed images are often supplemented by the use of a witness plates or soft catcher which can provide insight into the composition of the fragments and the spray angle of the debris [5], but cannot offer time resolved information.

In this paper, we present a measurement technique that is able to capture both spatially and temporally resolved fragment data from HVI experiments by using a laser sheet and a high-speed video camera. At our institute, we have performed HVI experiments with this technique on thin aluminum bumber plates, as well as Carrara marble blocks, and Seeberg Sandstone blocks [6]. Here, we focus on the results of the experiments of aluminum spheres on thin aluminum bumper plates and demonstrate the measurement method's capabilities in resolving individual fragment velocities and sizes.

2. Experimental Setup

Figure 1 shows a schematic of the experimental setup used to capture fragmentation data from a HVI on thin bumper plates. The setup involves using an 18W continuous wave laser to create a thin sheet of light placed parallel to the expanding debris cloud. Perpendicular to this laser sheet, a high-speed video camera, capable of micro- to nanosecond exposure times and framerates of up to 10 million frames per second, captures an image sequence of the fragment cloud. With this setup, the laser only illuminates a thin plane of the fragement in the debris cloud leading to simplified images being captured by the camera. With only a thin layer of fragments, instead of all the fragments in the debris cloud being overlaid on top of each other in the same image, individual fragments can be identified and tracked from frame to frame of the high-speed video sequence. Because of the cylindrical symmetry of the debris cloud, we can increase the spatial resolution of the images by observing only half of the debris cloud as show in Fig. 1.

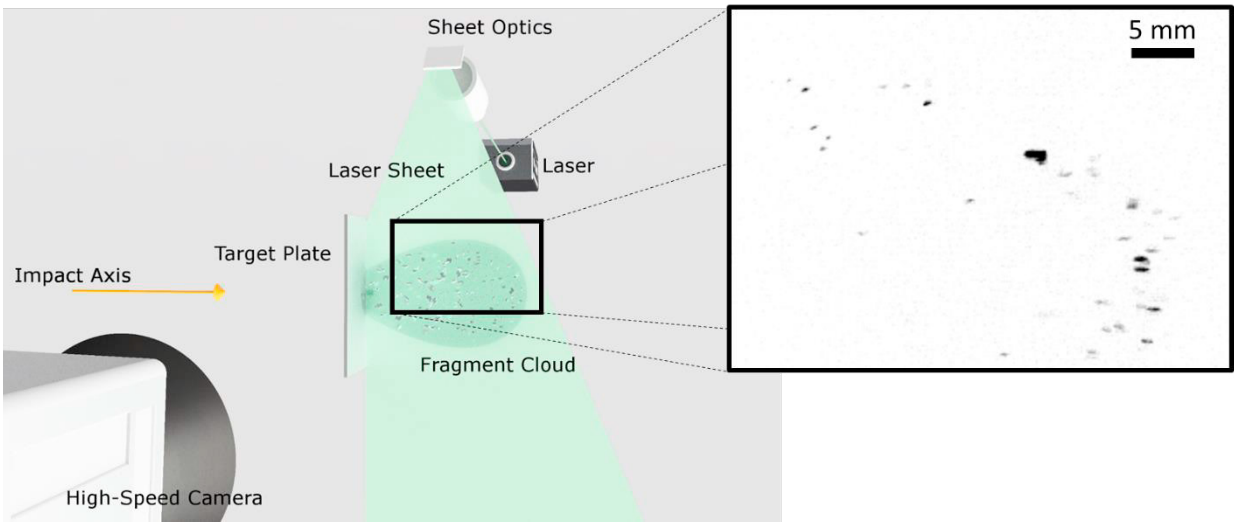

Figure 1: Experimental setup for measuring individual fragment velocities and sizes. A laser sheet illuminates a thin plane of the debris cloud and a high-speed camera records the illuminated fragments. The blow-up box on the right shows one image from the experiment (intensity inverted).