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Implementation of large scale shadowgraphy in hydrogen explosion phenomena

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ABSTRACT

The purpose of this study is to determine the performance of a portable large-scale shadowgraph system for use in hydrogen combustion experiments. Previous large-scale shadowgraph and schlieren implementations have often been limited to background-oriented techniques which are subject to noise. The system built is based on a large-scale shadowgraph technique, developed by Settles, which allows for noise-free visualization. We performed jet release, unconfined flame and detonation experiments in hydrogen mixtures. Shadowgrams taken were compared to a Z-schlieren system. Large-scale shadowgraphy offered high-quality visualization of hydrogen explosion phenomenon.

Introduction

Shadowgraph and schlieren visualization techniques are common and easy to implement in small scale [1]. For viewable areas exceeding approximately one meter, these methods become difficult to realize. Some of the primary issues with large scale visualization are the cost and availability of large optical components. Recently, Settles developed an affordable large-scale shadowgraphy system for visualization of explosions and gunshots [2]. We seek to determine the performance of this system as it pertains to issues in hydrogen gas dynamics research, specifically hydrogen releases, flames, and detonations.

In order to construct a large-scale shadowgraphy system there are two prerequisites. The first is a powerful light source to illuminate a large area. NASA's Orion space vehicle was studied in a large-scale background-oriented schlieren (BOS) technique using a large array of LEDs [3]. A 2.74 m square flow field was generated surrounding the vehicle [3]. The light from a large LED array does not have to be focused for used in BOS. However in shadowgraphy, the light has to be focused to a single beam which is difficult to achieve with a large LED array. In visualizing flames, detonations, and explosions in laboratory experiments, the light produced by these phenomena can overpower the light source. When this occurs only the brightest parts of the phenomena are visible while the non-luminescent features, such as shock waves, cannot be resolved. High intensity light sources such as the argon bomb have been developed to overcome this issue [4]. The argon bomb has been used in ballistics and shaped-charge explosive research [4,5]. The light produced by an argon

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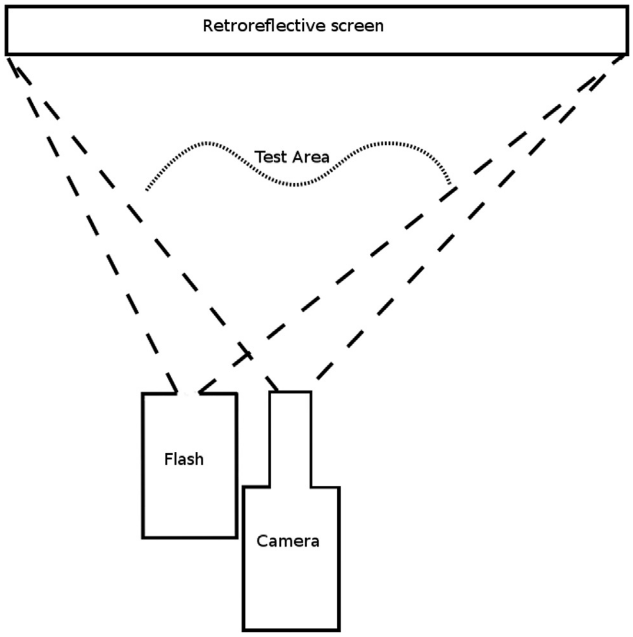

Fig. 1 – Top-view sketch of the retro-reflective shadowgraph technique by Edgerton [7].

bomb has a duration of approximately 100 μs, ideal for capturing pictures of high speed events [4]. While an argon bomb produces intense light, its short duration makes it impractical for low-speed events where the evolution of the flow field is monitored by multi-frame video cameras. An arc lamp produces high intensity light continuously. Light can be easily directed from a small opening for use with optical equipment. The arc lamp's potency in large-scale shadowgraphy has been previously demonstrated making it a strong light source candidate [2].

The second criteria for large-scale shadowgraphy is the background. Historically, outdoor BOS was used first. However the non-uniformity of the outdoor background made it difficult to obtain high-quality images [6]. Replacing the outdoor background with a grid removes the non-uniformity however, both grid and outdoor based BOS techniques produce noisy shadowgrams [3]. Large mirrors remove noise by providing a plain uniform surface and have high reflective ability. Settles demonstrated their functionality in large-scale schlieren [1]. Despite their advantages, large mirrors are very expensive and generally unavailable for dimensions exceeding 50 cm. Edgerton developed a relatively inexpensive and simple technique that removes most of the noise in large-scale shadowgraphy by using a retro-reflective screen [7,8]. The screen reflects light back towards its origin, giving it a higher reflective ability compared to outdoor backgrounds, diffuse surfaces, and grid backgrounds. Edgerton's technique was used to make shadowgrams of vortices around helicopter rotor tips up to 1.5 m in radius [9]. Settles modernized and improved Edgerton's technique using an arc lamp and video camera. He produced shadowgrams of explosions and gunshots in a viewable region 2.4 m long [2]. The retro-reflective screen is flexible enough to be rolled into a tube, cheaper than mirrors and, minimizes background noise while reflecting most incident light making it ideal for use in shadowgraphy.

The large-scale shadowgraph system implemented in this paper uses an arc lamp for a light source, and retro-reflective screen as a background surface. The scope of the paper is limited to applying large-scale shadowgraphy in hydrogen phenomena, specifically jet releases, flames, and detonations. Hydrogen releases focus on jet release experiments modeling the sudden failure of a pressure vessel. Unconfined

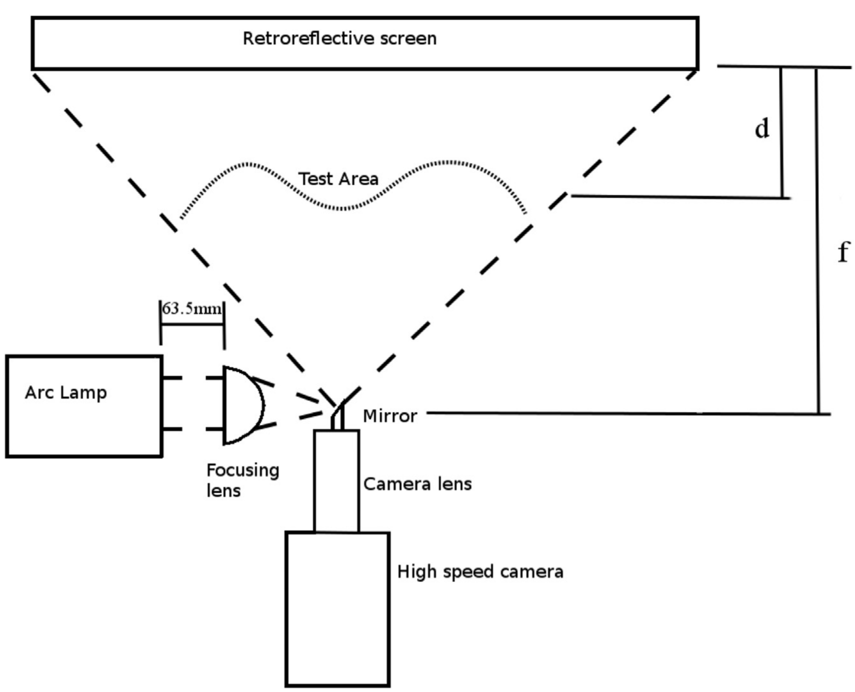

Fig. 2 – Top-view illustration of our retro-reflective shadowgraphy system.