Hypersonic Shock-Induced Fuel Evaporation in Mono-Sized Dodecane Clouds

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Abstract

Detonation-based combustion engines have become a major topic of interest in the aerospace industry. In a detonation, the shock front and combustion/reaction zone are coupled, which causes a rapid increase in temperature and pressure, creating a high-pressure gain combustion system.

Liquid fuels have high energy density and are easier to store; however, to be able to achieve combustion, the fuel needs to undergo a series of processes. The liquid fuel droplets deform, atomize and eventually evaporate in order to mix with the oxidizer.

This study focuses on the fundamental physics and understanding of liquid fuel cloud evaporation and interaction with a hypersonic shock wave, in the context of detonation based combustion for hypersonic propulsion systems.

Methodology

Experimental testing regarding liquid fuel droplet physics, was performed at PERL detonation-driven shock tube facility (THOR). The facility uses a vacuum pump to lower the pressure to 0.14 Bar. Then, the Booster section is filled to 2 Bar with a stoichiometric mixture of ethylene and oxygen. The Driver section is filled with inert Helium. Finally, the Test Section is composed by three 2.54 cm diameter quartz discs along the sides and bottom of the wall allowing optical diagnostic access; three piezoceramic pressure transducers, where two characterize the shock speed and pressure, and the furthest upstream is used to provide a voltage trigger to the optical diagnostics; an Atomizer was placed right above the optical access, which injected a monodispersed cloud of liquid Dodecane droplets, a 5 µm and 10 µm diameter nozzle were used for the study.

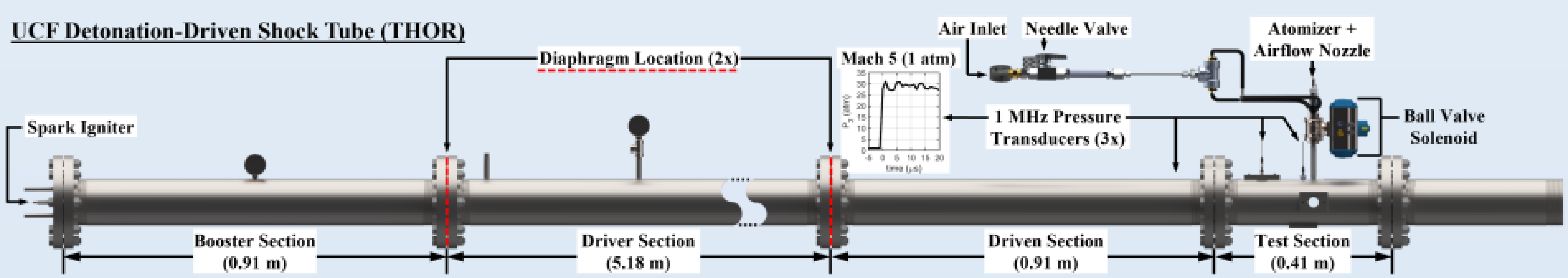

Figure 1: Schematic of experimental shock tube facility.

Diagnostics

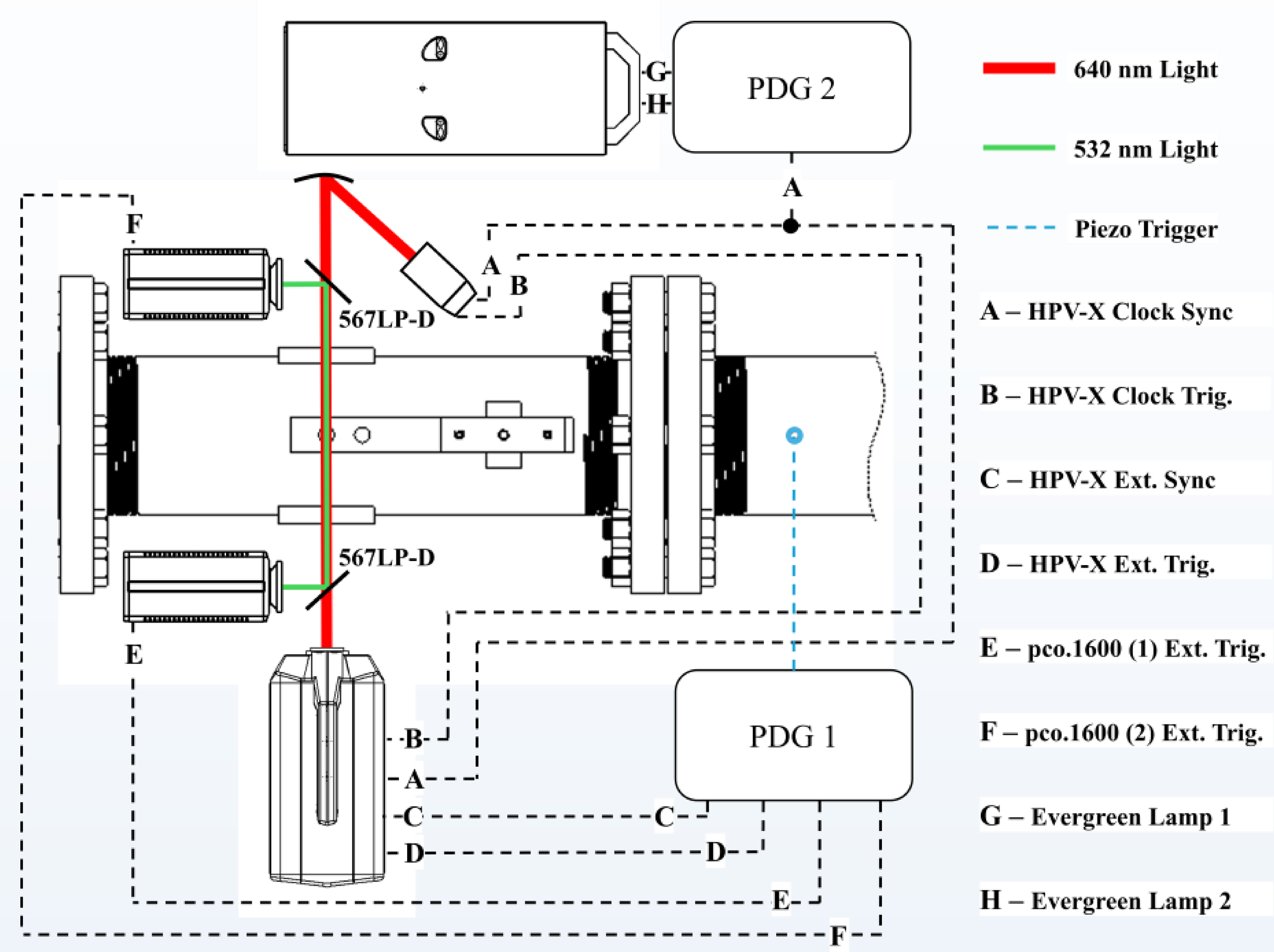

Figure 2: Wiring and light diagram for simultaneous Mie scatter/Shadowgraph diagnostic setup.

A dual Mie scatter/Shadowgraph optical setup was created to simultaneously characterize both liquid within the cloud and the shock location over time. For Shadowgraph, a Cavilux laser was used, the 10 ns conical beam focalize into a parabolic mirror, the light then travels through the side-wall optical access in the test section to a Shimadzu high-speed camera.

For Mie Scatter, an Evergreen laser was used, the 10 ns laser beam is transformed into a sheet when passing through a plano-convex and plano-concave-cylindrical lens, then the light is reflected 90º upward into the bottom window of the Test Section. After passing out the two side windows, the scattered light from the liquid cloud is reflected by two long pass dichroic mirrors into two PCOs 1600 cameras.

Results

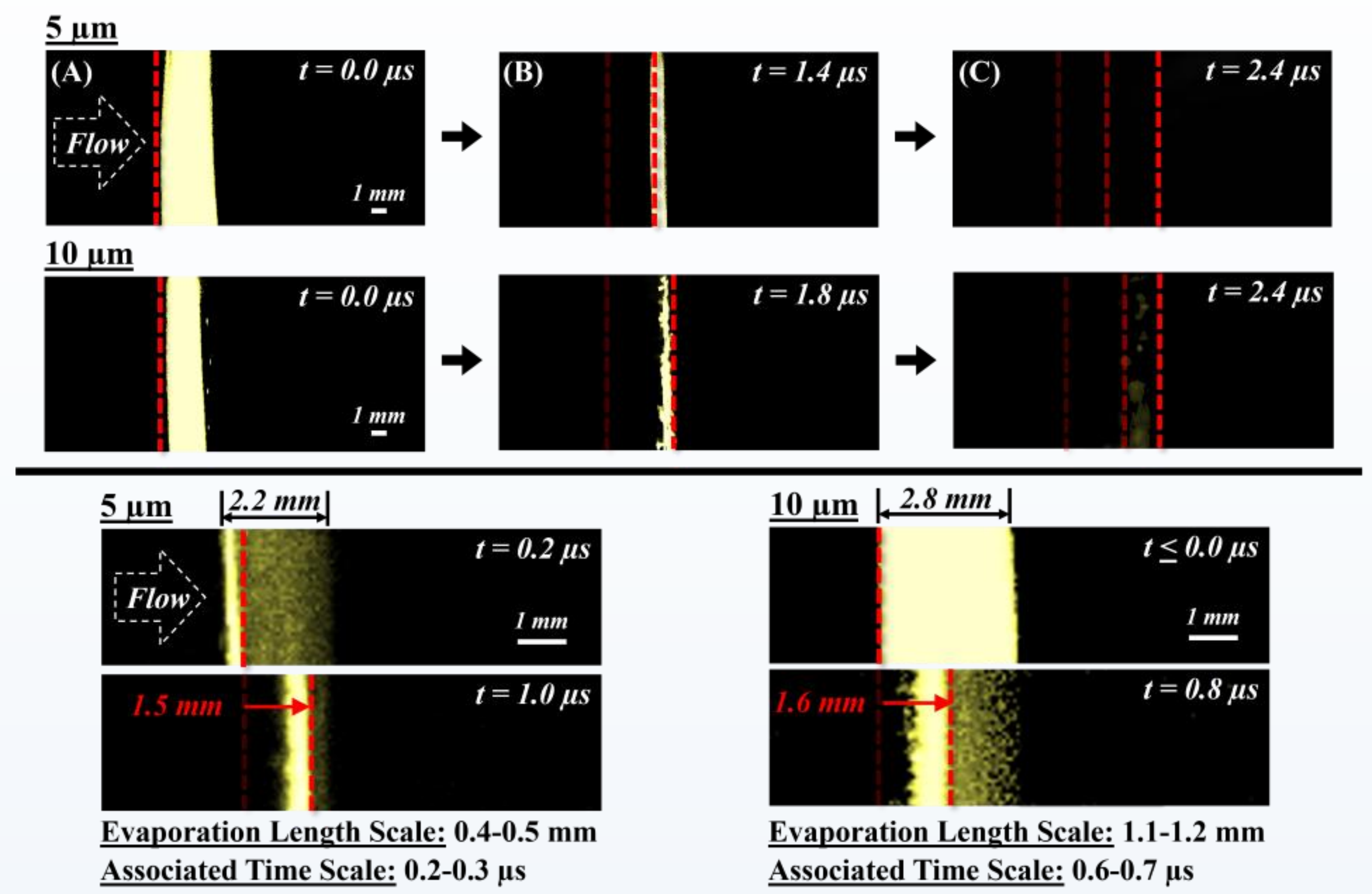

Figure 3: Results of the experiment.

The top half of Figure 3 presents three selected frames from multiple tests, with t = 0 defined as the instant immediately preceding the shock/cloud interaction. These images illustrate the loss of Mie scatter over time. For the 5 µm cloud, complete evaporation was observed just 2.4 µm after contact. The 10 µm cloud was also found to be near complete evaporation at this same time instance. For greater precision, the diagnostic setup was adjusted to use the Shimadzu camera for pure Mie scatter recording (bottom half of Figure 3). This allowed for measurement of the evaporation length scale (Xv) as the shock passed. The measured length scales were: 0.4 ≤ Xv ≤ 0.5 mm was observed for the 5 µm cloud, and 1.1 ≤ Xv ≤ 1.2 mm for the 10 µm cloud, Which correspond to an estimated evaporation timescale of 0.2 ≤ tv ≤ 0.3 µs for 5 µm and 0.6 ≤ tv ≤ 0.7 µs for 10 µm. These initial timescale estimates show good agreement with the absolute total evaporation times observed from the PCO images: 2.0 ≤ tv ≤ 2.1 µs and 2.4 ≤ tv ≤ 2.5 µs for the 5 and 10 µm clouds, respectively.

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