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Seeing the Invisible: Projects on Flow Imaging from the Fluid Mechanics Lab

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Seeing the Invisible: Projects in Flow Visualization from the Bethel Fluid Mechanics Lab

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Abstract

Shadowgraph and schlieren imaging are popular flow visualization techniques because, despite the straightforward setup and reliance on very simple geometrical optics principles, they provide powerful methods for capturing high-quality images of what would otherwise be invisible flow phenomena. Application of these methods along with high-speed video recording can reveal detailed pictures of highly dynamic flow events that may last for just a fraction of a millisecond. These techniques are being utilized in the Bethel Fluid Mechanics lab course (PHY423/ENR423) and in a number of student-faculty research projects. We present snapshots of a few recent student-faculty projects utilizing shadowgraph and schlieren imaging.

Optical Imaging and Diagnostics of Shock Waves in a Supersonic Ping Pong Cannon

Optical diagnostics and high-speed video imaging techniques are utilized to characterize the compressible flow and shock waves in a supersonic ping pong cannon [1].

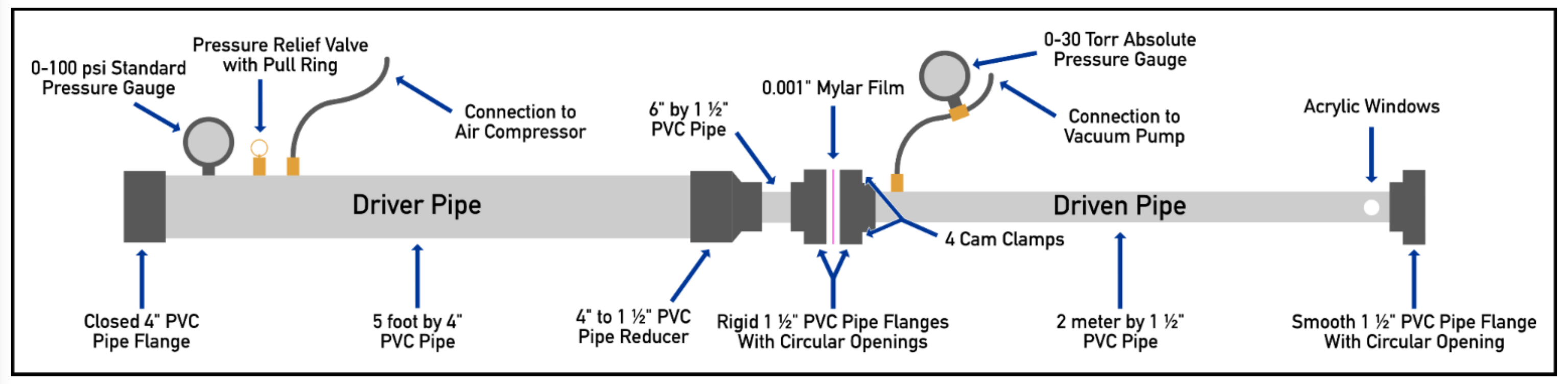
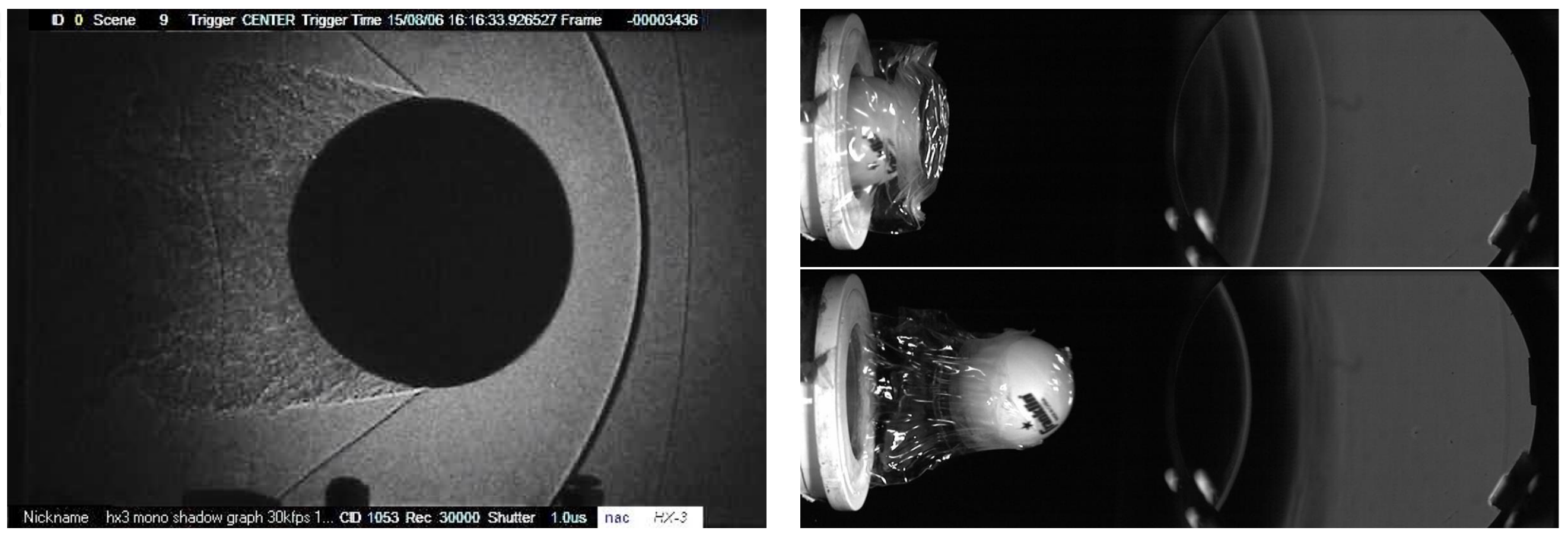


Figure 1: Supersonic ping-pong cannon. Upon rupture of a Mylar diaphragm, a pressurized driver pipe accelerates a ping pong ball down an evacuated driven pipe to speeds of up to Mach 1.4.

video



video

Figure 2: Shadowgraph image of the standing shock wave in front of the supersonic ping-pong ball (left); Schlieren imaging as the ball exits the cannon (right);

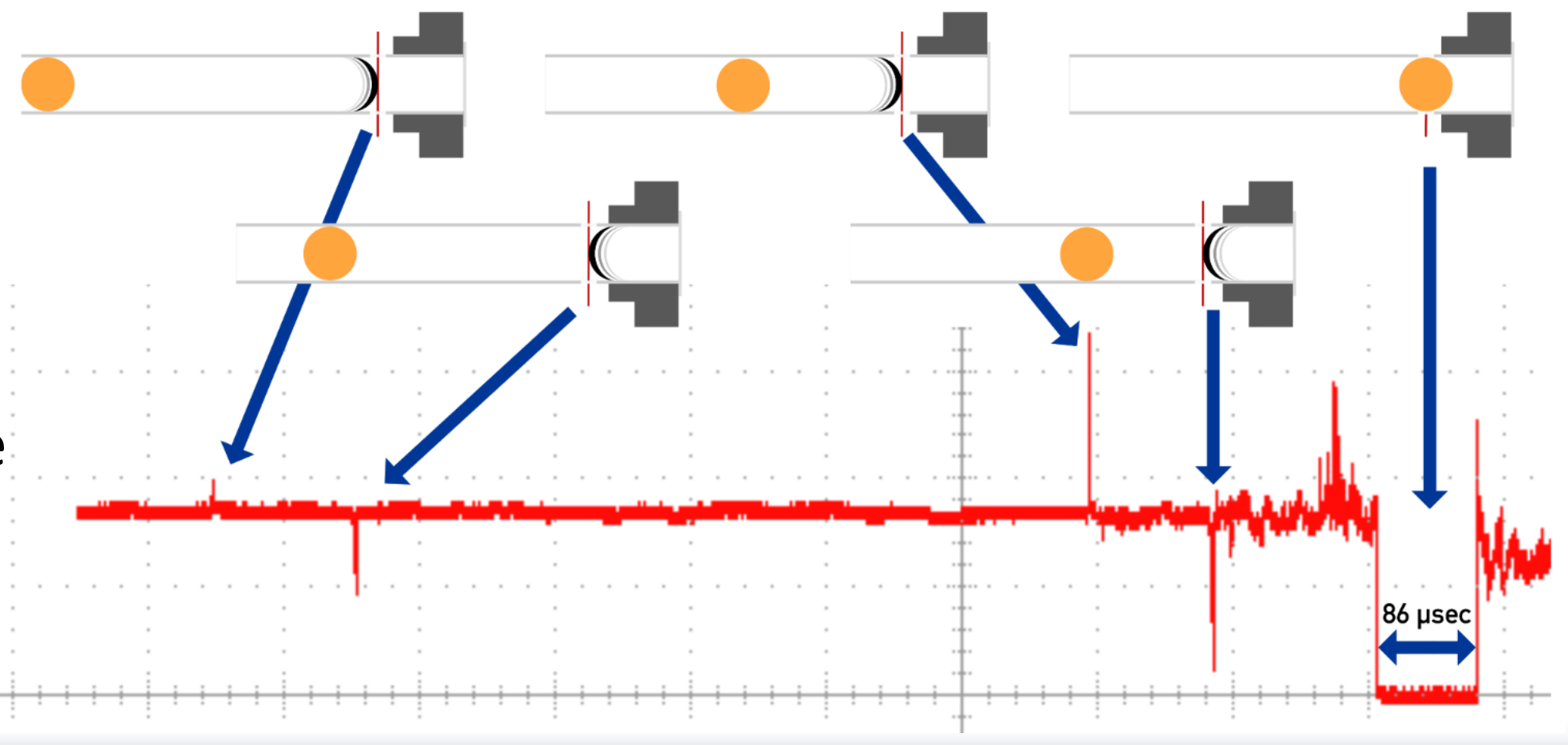


Figure 3: Typical oscilloscope trace using a "knife-edge" shock detection technique. Shock waves are displayed as voltage spikes in the signal, with the direction of the spike indicative of the direction of the shock propagation.

Supersonic Nozzle Flow

Experiments and numerical simulations are carried out in the Bethel Fluid Mechanics Lab to examine the highly transient startup flow from a small nozzle. The studies utilize complementary approaches based on experimental measurements and computational methods [2].

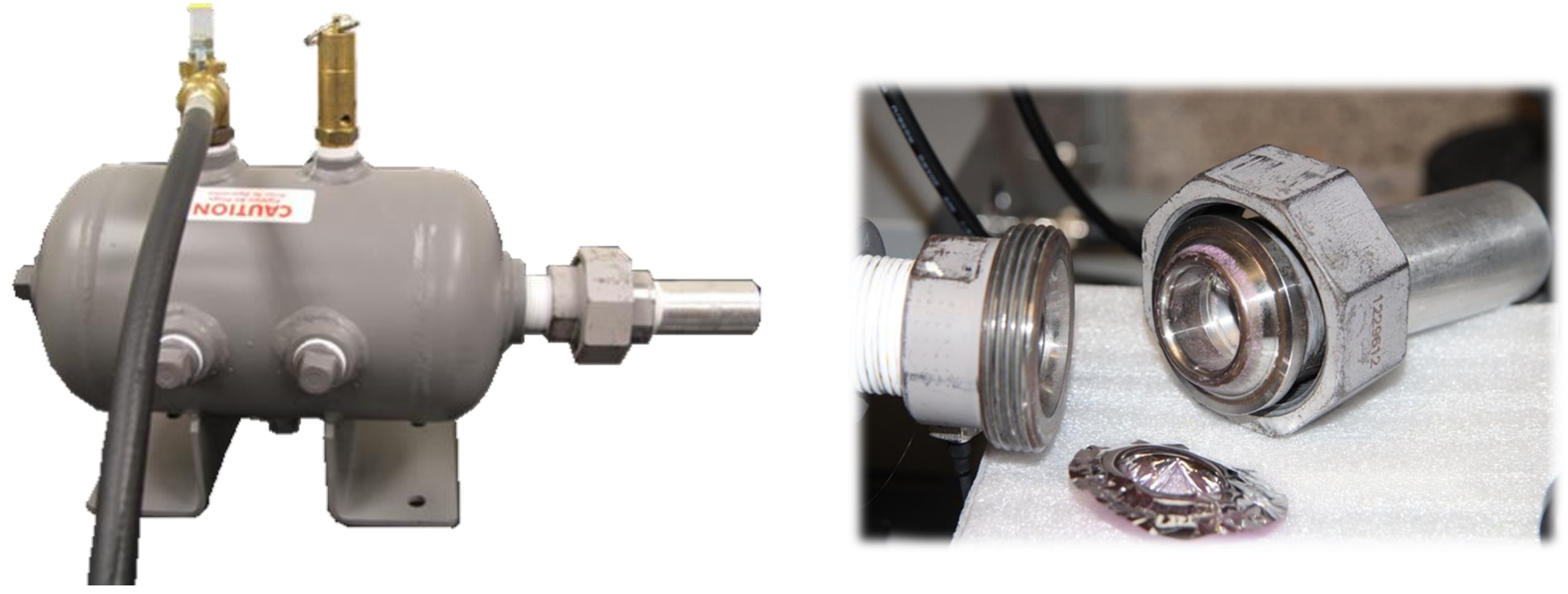
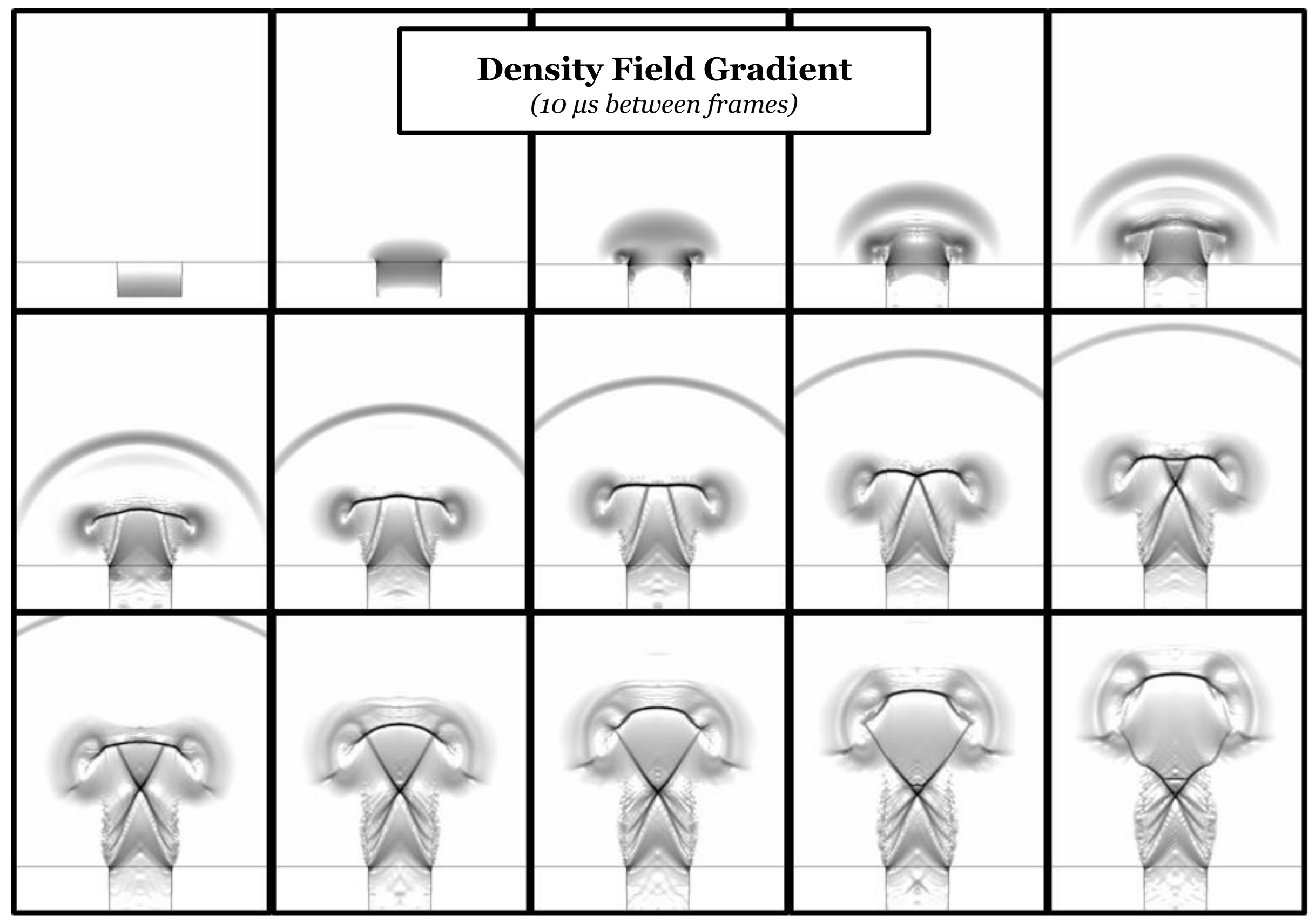


Figure 3: Flow through the nozzle is initiated by the rupture of a diaphragm positioned between the nozzle and a 1-gallon pressurized air tank.



video

Figure 4: Flow simulations provide a description of the unsteady, compressible flow in the tank, nozzle, and exterior surrounding area.

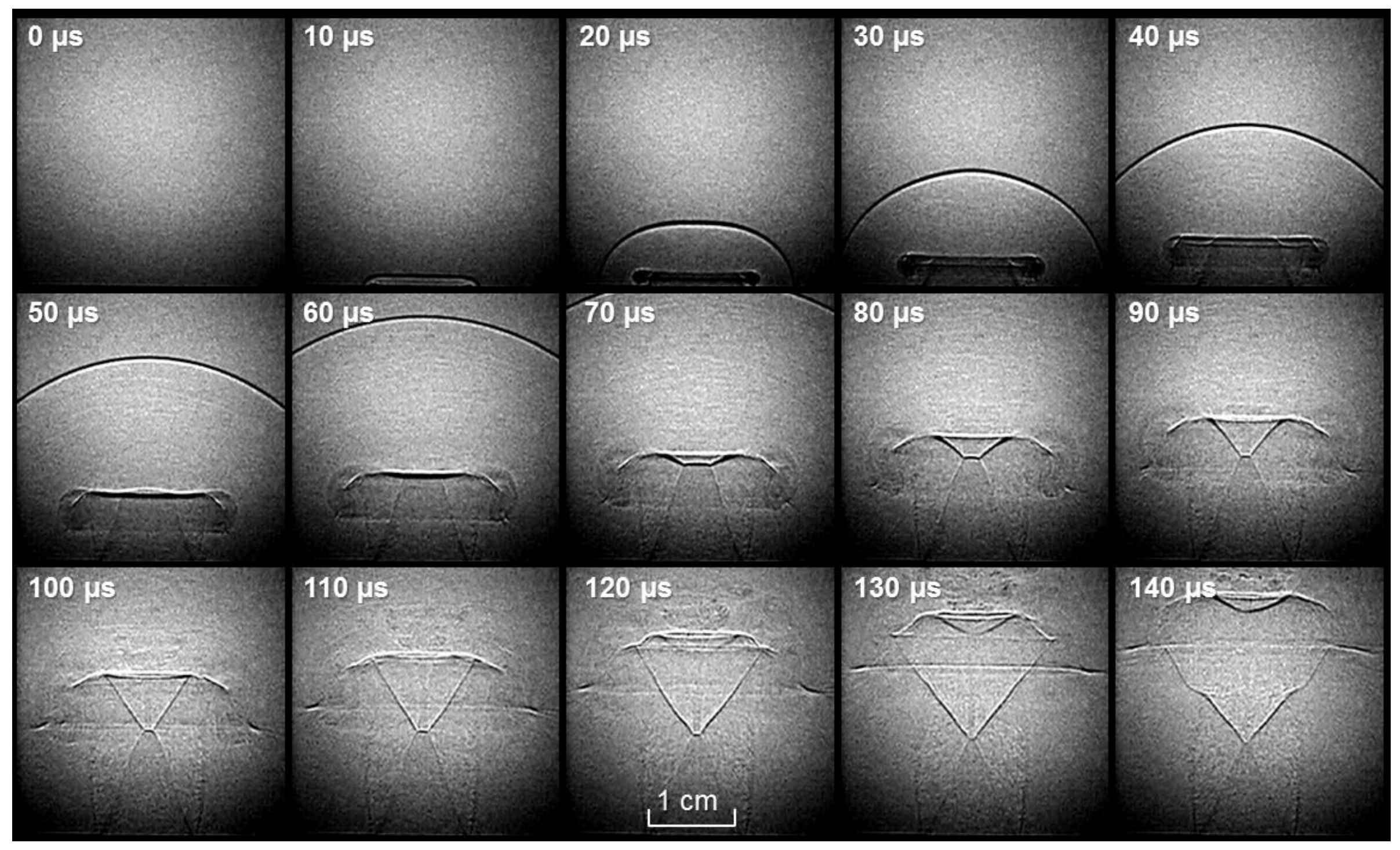


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Figure 5: High-speed video shadowgraphy captures the initial shock wave and compressible flow surrounding the nozzle exit at 100,000 frames/second..

A Smartphone Schlieren Imaging System

A smartphone schlieren imaging system was designed for application in the Bethel Fluid Mechanics laboratory. The system provides a low-cost alternative for project-based learning. The system is based on a single-mirror schlieren setup, with the smartphone flash serving as the light source and the smartphone camera as the detector. Adjustable mounts for the smartphone and mirror are 3D printed and secured to a common base, allowing for the apparatus to be relocated as a single, portable system [3].

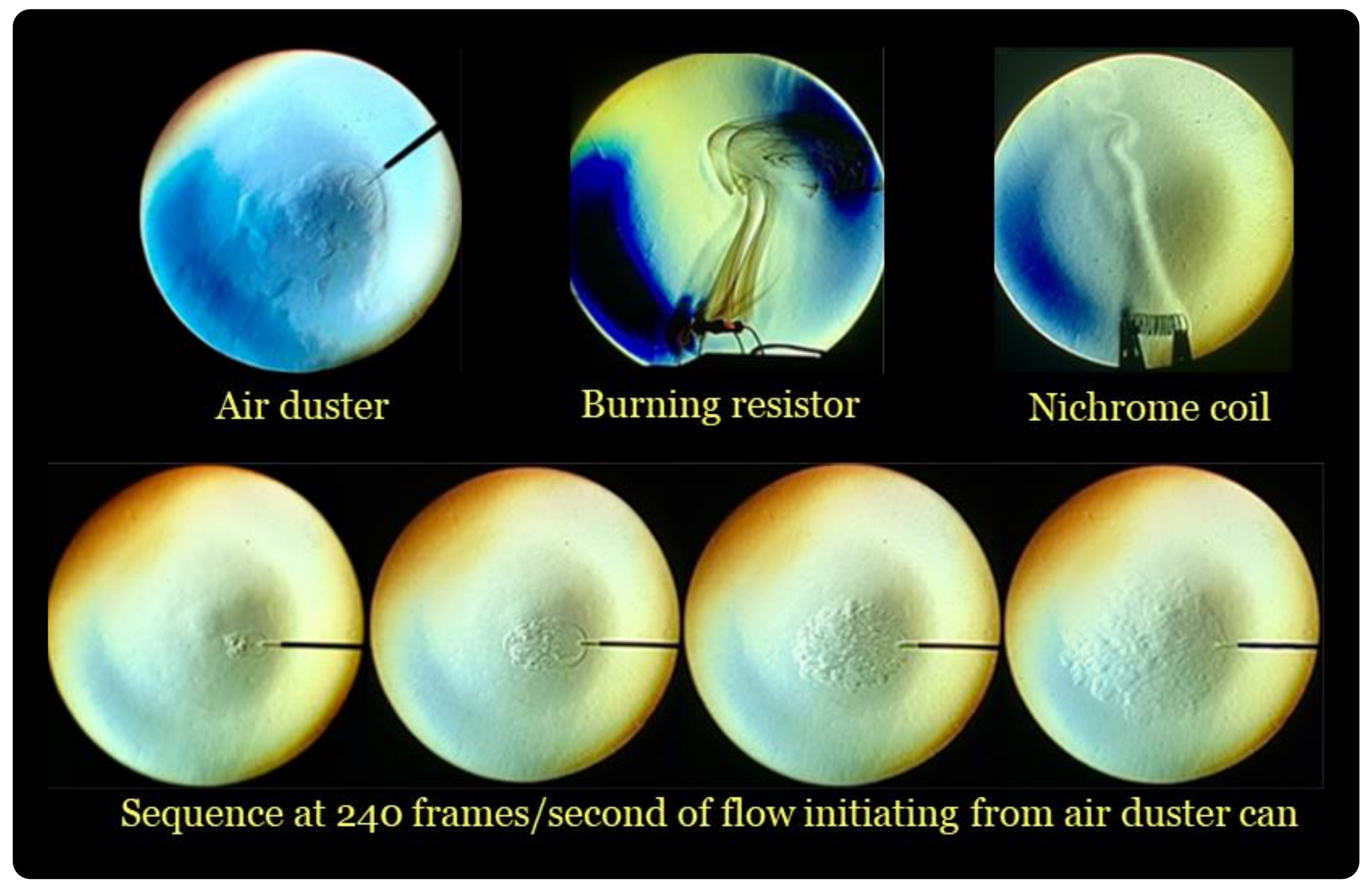

Figure 6: Sample images produced with the smartphone schlieren system.

References

(1) T.J. Barth and K.R. Stein, "High-speed optical diagnostics of a supersonic ping-pong cannon," *Journal of Visualized Experiments*, **193**, e64996, doi:10.379/64993 (2023).

(2) C.D. Fredrick, T.R. Greenlee, R.W. Peterson, A.J. Schaffer, K.R. Stein, and A.W. Woetzel, "Complementary studies on supersonic nozzle flow: Heterodyne interferometry, high-speed video shadowgraphy, and numerical simulation," *WIT Transactions on Modelling and Simulation* (ISSN: 1746-4064 Digital ISSN: 1743-355X), **59** (2015).

(3) K. Stein and G. Riermann, "A low-cost, portable, smartphone schlieren imaging system," 2022 ASEE Annual Conference & Exposition, Minneapolis (2022).

Acknowledgements

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