Introduction to the Aerosol Shock Tube

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Introduction

We have recently developed a unique facility for studying the behavior of two-phase mixtures behind shock waves. This facility provides the capability to experimentally observe evaporation and combustion of aerosols in a well-characterized, spatially-uniform environment. We are focusing on small-diameter aerosols, typically 1-10 µm, which are currently receiving heightened attention because of their pertinence to computer modelling of complex flows and to liquid-fueled pulse-detonation engines. These two-phase experiments require multifaceted expertise in traditional engineering fundamentals, i.e., fluid mechanics, heat and mass transfer, etc., and also in the development and application of advanced laser diagnostics.

Overview

The diagram below shows the entire aerosol shock tube consisting of a driver section and a driven section separated by a thin diaphragm. The sections are 3.5 and 9.6 m in length, respectively, giving between 1-4 ms of test time, depending on the temperature and pressure conditions. There is a vacuum port located in the driven section to evacuate the tube and to help suck the aerosol into the tube from the endwall. There are also many pressure transducers that are used to measure the shock speed. Then at the far end of the driven section is the test section where the laser diagnostics are located.

Figure 1: CAD drawing of aerosol shock tube

The images below show schematically the three steps in the operation of the aerosol shock tube. The first step is to fill the shock tube with a nebulizer-generated aerosol of the test gas mixture. The second step is to heat and compress the aerosol mixture behind the incident shock which evaporates the fuel fully. The third step is to heat and compress the test gas mixture to the final conditions behind the reflected shock.

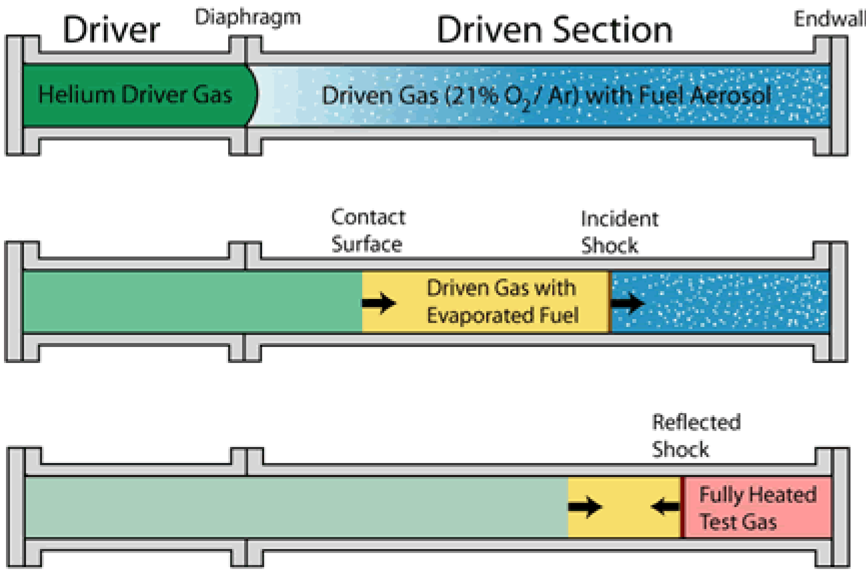

Figure 2: Aerosol shock tube operation

The aerosol shock tube uses an ultrasonic nebulizer to create the aerosol. Pictured below to the left is a close-up of a nebulizer. The gold disc is a piezoelectric transducer, which will expand and contract when an oscillating current is applied. The resultant vibration is strong enough to form micron sized droplets at the liquid surface. The picture below on the right shows the nebulizer creating a water aerosol in a cylindrical, glass container.

Figure 3: Ultrasonic nebulizer, made by Ocean Mist

The images below show a more detailed cross section of the aerosol shock tube. A liquid fuel aerosol is created using an ultrasonic nebulizer. The aerosol created has a lognormal size distribution with a count median diameter (CMD) of 2.8 µm. A dry bath gas is flowed over the surface of the liquid and serves to carry the aerosol into the shock tube through poppet valves in the endwall and down the shock tube. Once a uniform spatial distribution is obtained, all valves are closed and the shock tube diaphragm is broken.

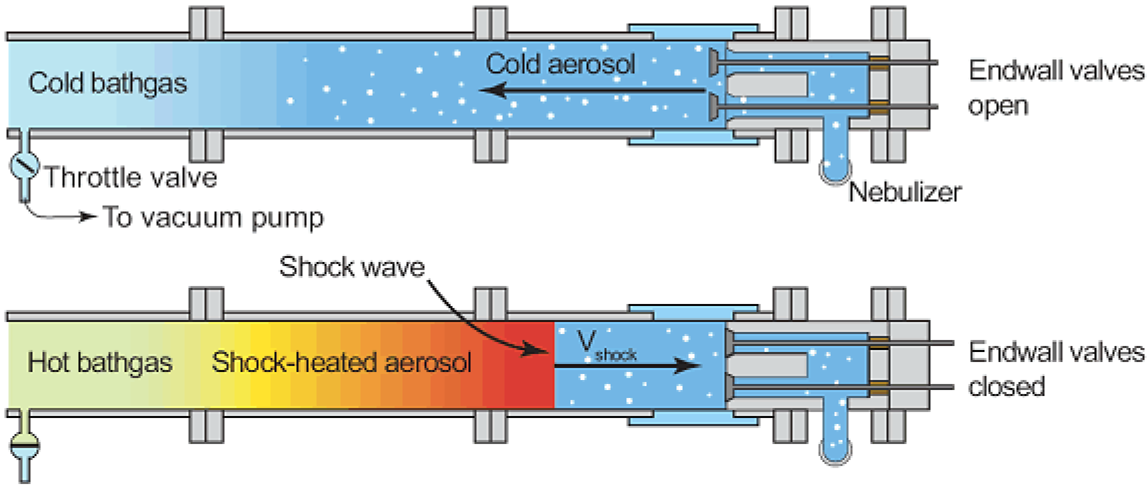

Figure 4: Aerosol shock tube filling and shocking

The following is an x-t diagram for the shock tube. Note that the aerosol particles move axially in the tube while evaporating, and stop moving when hit with the reflected shock.

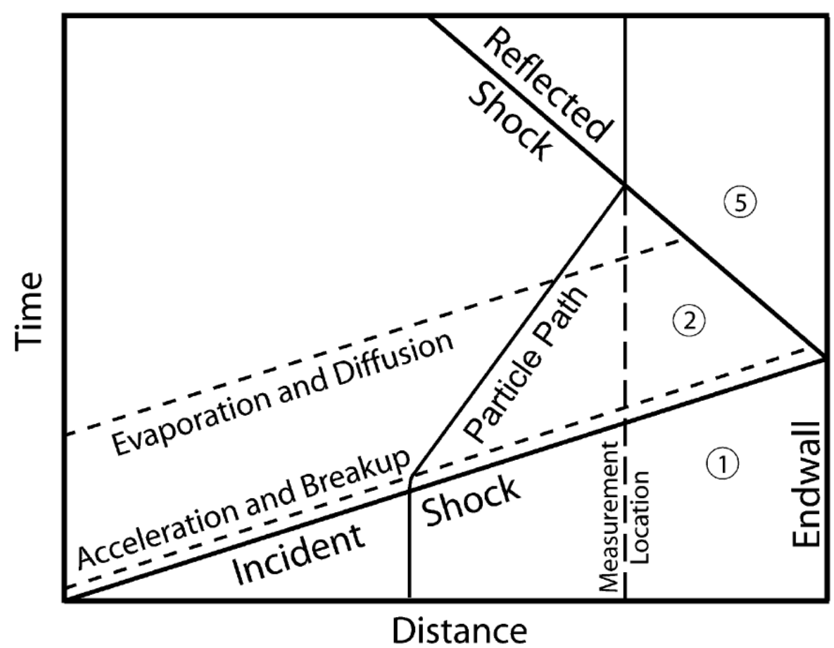

Figure 5: Aerosol shock tube x-t diagram {ref 1]

The test section connects to an existing circular-section driven section of the shock tube using a round-to-square transition section to satisfy the optical access requirements of these experiments.

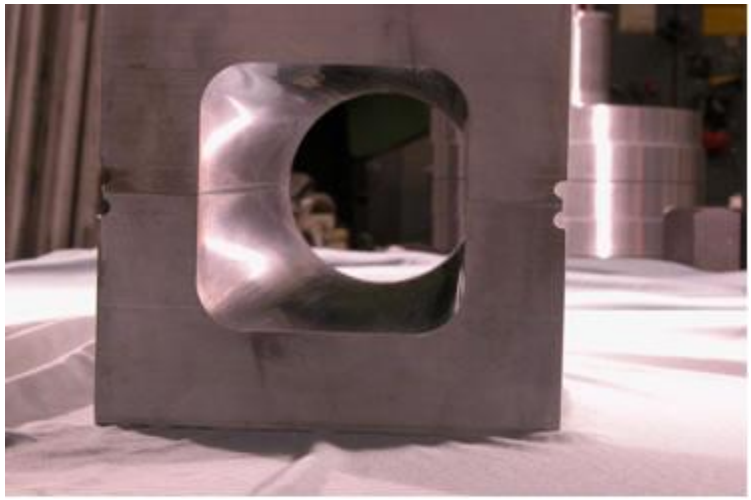

Figure 6: Round-to-square section

Fog produced by ultrasonic nebulizers is introduced to the shock tube through a specially-designed endwall that incorporates four poppet valves.

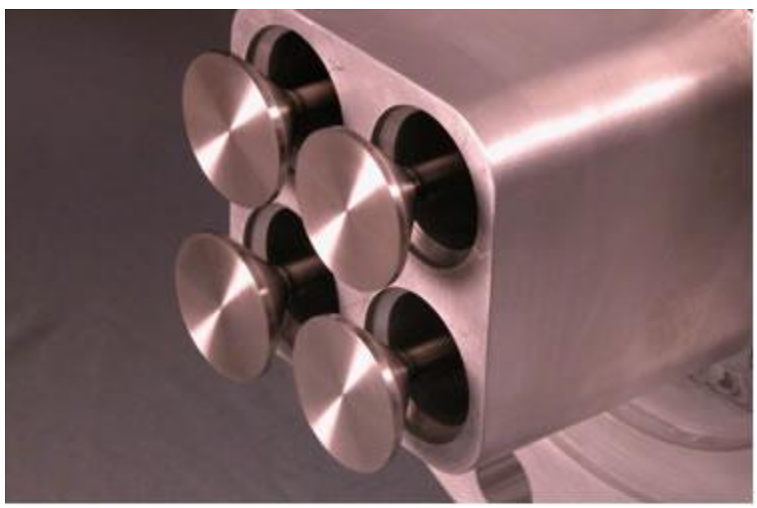

Figure 7: Poppet valves

By controlling the carrier-gas flowrate and tube pressure, the tube is filled with a spatially-uniform cloud of droplets. When outfitted with large windows, the test section has excellent optical access.

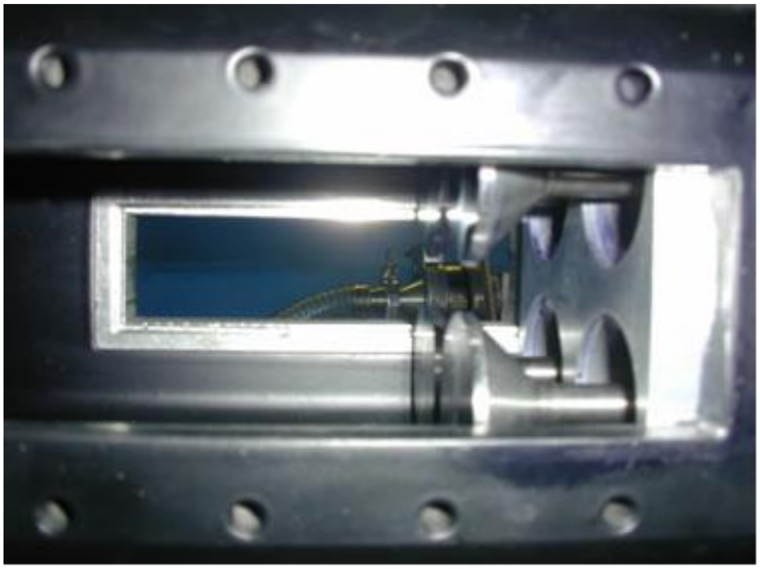

Figure 8: View of open poppet valves within shock tube

This shows the pneumatic cylinder that actuates the poppet valves. The fog is produced by the nebulizer which is located below the 90-degree elbow.

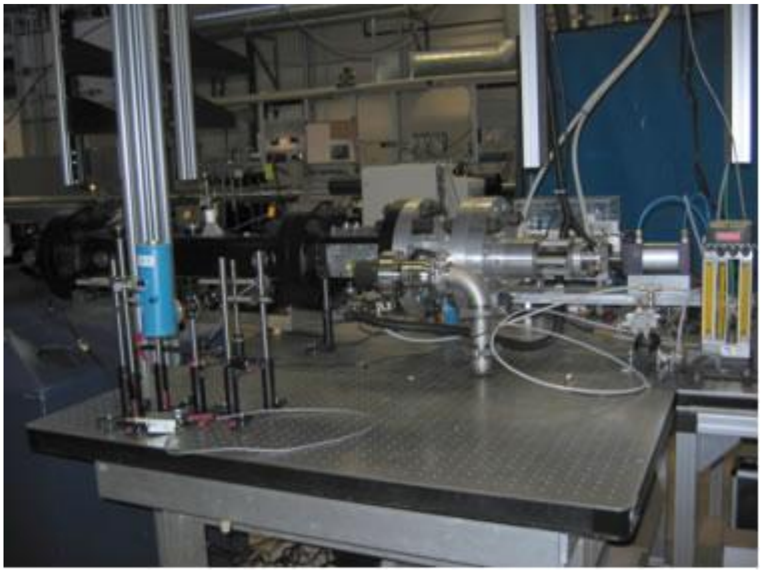

Figure 9: Optical table

Bird's eye view of the facility. Lasers are pitched through the shock tube test section toward detectors located in the foreground.

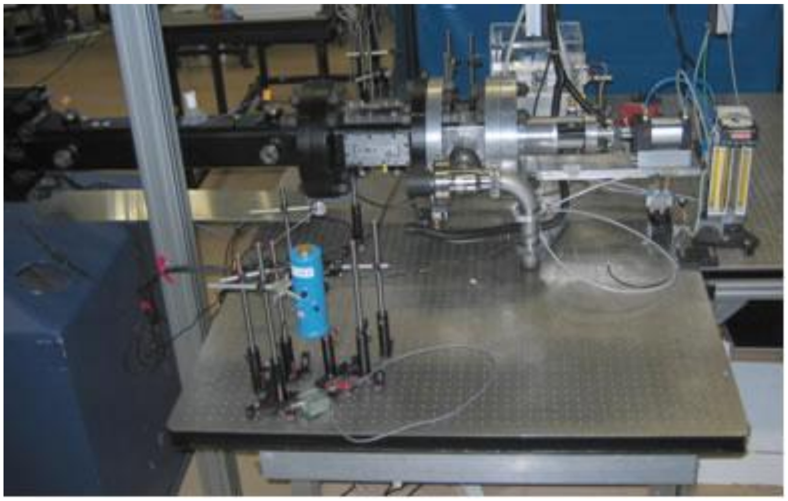

Figure 10: Optical table showing pneumatic rig from above

The shock tube valves, pumps, and data acquisition is controlled through a programmable touch-screen panel.

Figure 11: Touch-screen control panel

References

1. Davidson, D. F. (2008). Development of an aerosol shock tube for kinetic studies of low-vapor-pressure fuels. Combustion and Flame , 155 (1), 108-117.