

COMBUSTION OF UNCONFINED DROPLET CLUSTERS IN MICROGRAVITY

G. A. Ruff¹ and S. Liu²

¹NASA Glenn Research Center, Cleveland, OH (gary.a.ruff@grc.nasa.gov)

²Mechanical Engineering and Mechanics Department, Drexel University,
Philadelphia, PA (sg95x4sj@drexel.edu)

INTRODUCTION

Combustion experiments using arrays of droplets seek to provide a link between single droplet combustion phenomena and the behavior of complex spray combustion systems. Both single droplet and droplet array studies have been conducted in microgravity to better isolate the droplet interaction phenomena¹⁻⁴ and eliminate or reduce the confounding effects of buoyancy-induced convection. In most experiments involving droplet arrays, the droplets are supported on fibers to keep them stationary and close together before the combustion event. The presence of the fiber, however, disturbs the combustion process by introducing a source of heat transfer and asymmetry into the configuration. As the number of drops in a droplet array increases, supporting the drops on fibers becomes less practical because of the cumulative effect of the fibers on the combustion process. To eliminate the effect of the fiber, several researchers have conducted microgravity experiments using unsupported droplets. Jackson and Avedisian⁵ investigated single, unsupported drops while Nomura *et al.*⁶ studied droplet clouds formed by a condensation technique.

The overall objective of this research is to extend the study of unsupported drops by investigating the combustion of well-characterized drop clusters in a microgravity environment. Direct experimental observations and measurements of the combustion of droplet clusters would fill a large gap in our current understanding of droplet and spray combustion and provide unique experimental data for the verification and improvement of spray combustion models. In this work, the formation of drop clusters is precisely controlled using an acoustic levitation system so that dilute, as well as dense clusters can be created and stabilized before combustion in microgravity is begun. This paper describes the design and performance of the 1-g experimental apparatus, some preliminary 1-g results, and plans for testing in microgravity.

EXPERIMENTAL APPARATUS

To achieve the objectives stated above, it has been necessary to perform the following tasks: (1) design and fabricate a unique acoustic levitator that can stabilize a two-dimensional droplet cluster prior to combustion, (2) develop a method to introduce a specified number and size of droplets into the acoustic field, (3) develop a method to ignite the droplet cluster, and (4) assemble all of these components into a controllable experiment in a drop tower rig. The first three challenging items have been completed. Because of the unique nature and requirements of each of these components each task required the development and evaluation of new experimental apparatus. Work accomplished to date on these systems are described in this section.

Acoustic Levitator

As shown in Fig. 1, the single-axis acoustic driver assembly consists of two piezoelectric transducers in a sandwich configuration similar to that developed by Zhuyou *et al.*⁷ Aluminum

transmitter blocks are placed on both sides of the sandwich transducer and sized to create a plane standing wave in the material when oscillating at 20 kHz. A titanium stepped acoustic horn is tightly coupled to the forward transmitter to amplify the transducer displacement. The electrical power to the amplifier is provided by a 12-v battery. The signal generator has a dedicated internal battery. The tip of the horn is 29 mm in diameter and directs the acoustic wave towards the concave reflector (50-mm diameter). The shape of the reflector focuses the acoustic pressure field to produce an axially- and radially-varying pressure field between the driver and reflector that was quantified using a 3-mm diameter microphone. Because of the shape of the reflector, two axial pressure antinodes are produced when the driver and reflector are 20 mm apart. Radial sound pressure measurements were obtained at an antinode located 4 mm above the surface of the driver and are shown in Fig. 2. The pressure well that laterally stabilizes the droplet cluster is clearly seen and has a radius of approximately 4 mm. A sound pressure levels in excess of 160 dB can be produced in this apparatus.

Droplet Generator

An on-demand droplet generator was developed to introduce droplets into the acoustic levitator. Liquid fuel is placed in a 0.1-ml syringe having a 90-micron hypodermic needle attached at its end. The syringe assembly is mounted on a traversing stage controlled by a stepping motor. A piezoelectric screw positioner depresses the plunger of the syringe to form drops as small as 300 microns on the end of the needle. The liquid is charged to help break up the drop placed on the end of the hypodermic needle and to prevent the drops that are produced from coalescing in the antinode of the acoustic field. An induction charging system consisting of a copper ring mounted on the syringe and an adjustable 0 – 10 kV high voltage power supply charges the liquid as it passes through the needle.

Droplet Ignition

The droplet ignition system is practically the only component that can be copied from existing drop combustion experiments. However, most systems use two opposing hot wire coils to ignite drops. Because of the larger spatial distribution of drops in this experiment and the need to maintain symmetry of the heating process, two pairs of opposing hot wires were incorporated into the current ignition system.

Imaging system

The two-dimensional droplet cluster can be imaged from the side (along the plane of the cluster) and from the top (90 deg to the cluster) through a window mounted in the center of the reflector. A light sheet produced by a fiber optic illuminator is directed towards the plane of the droplet cluster. A 45-deg mirror is mounted above the acoustic reflector and allows the cluster to be viewed from the top through a window in the reflector. A CCD camera and microscope lens is positioned to view the cluster from either the side or the top. The image is transmitted to the computer to monitor the experiment and to a video recorder.

RESULTS AT ONE-G

As in several other microgravity investigations,^{1,2} methanol has been used in our initial tests of the acoustic levitator/droplet generator system. Figure 3 shows an image of a droplet

cluster containing 13 drops where the average drop size and spacing given in the caption. Based on the criteria given by Annamalai and Ryan,⁸ these clusters lie in the group combustion regime. More specifically, these conditions are between the internal and external group combustion regimes, where the flame front lies within the droplet cluster and both isolated drop and group combustion occurs. This will be investigated in future combustion experiments.

The evaporation rate of methanol drops was evaluated by forming single droplets and droplet clusters in the acoustic field and recording the time history of the decrease in drop size on video. Because these experiments are conducted in 1-g, the acoustic field was maintained during the evaporation process. Preliminary results for a single droplet and for both drops of a two-droplet array (Drop A and B) are shown in Fig. 4. The vaporization constant for the single drop in the acoustic field is very near the theoretical value for diffusion-controlled, quasi-steady droplet evaporation. Similar to Seaver *et al.*⁹ and Tian and Apfel,¹⁰ this implies that the acoustic field has little effect on the evaporation of a single, isolated drop. As expected, the vaporization rate for the two-drop array is less than that for the single drop with both drops evaporating at the same rate. However, this rate is below the theoretical vaporization rate for two droplets spaced at $l/d = 4.1$.¹¹ This will continue to be evaluated using clusters with increasing number of drops and containing drops of different composition.

CONTINUING WORK

While conducting tests at 1-g, work is progressing on the construction of the drop tower rig. In the drop tower, the droplet cluster will be formed and stabilized before the start of the drop event. As the experimental package begins to drop, the acoustic field can be terminated (or reduced substantially), making observations of the vaporization and combustion of unsupported clusters of large number of drops possible.

SUMMARY

In the current work, a single axis acoustic levitator has been designed and constructed. The design of the acoustic levitator provides both a vertical and lateral positioning force on the droplet cluster. By specifying the charge placed on the initial drop, stable clusters containing between 2 and 20 drops have been generated. Preliminary results of droplet vaporization in a resonant acoustic field at 1-g are consistent with those of previous researchers and will continue to be evaluated for larger numbers of drops in the cluster. Current work focuses on incorporating the entire apparatus into a drop tower test rig so that experiments can be conducted under microgravity.

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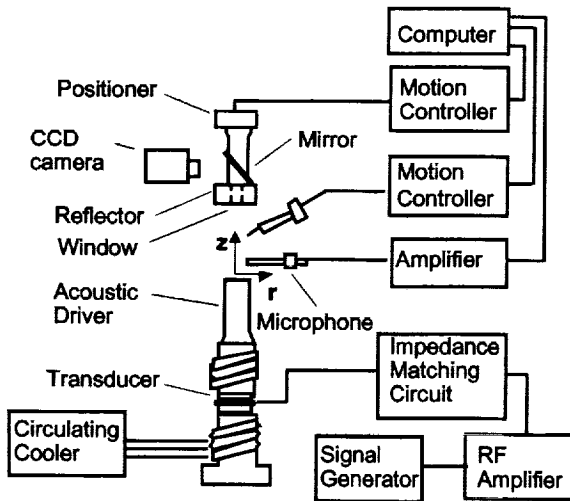


Figure 1. Drop levitation apparatus

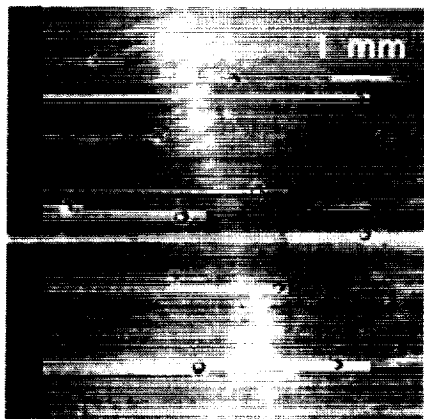


Figure 3. Droplet cluster containing 13 drops ($d_m = 190 \mu\text{m}$, $l/d = 11.7$, $G \approx 1.0$)

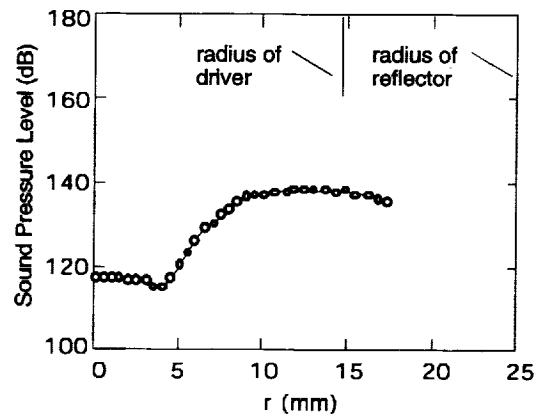


Figure 2. Radial sound pressure level 4 mm above the acoustic driver

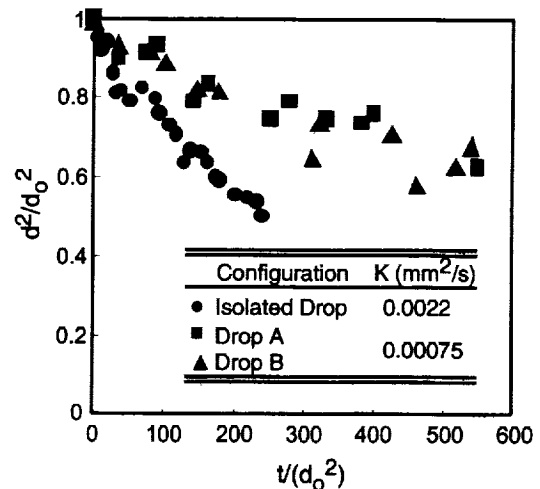


Figure 4. Comparison of methanol droplet evaporation (levitated single drop and two-drop array, $l/d = 4.1$)