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FLEX-2J および Group Combustion で行った複数移動可能液滴を含む燃料液滴列の燃え広がり現象観察

Observation of Flame Spread along a Fuel Droplet Array Including Movable Droplets in FLEX-2J and Group Combustion Projects

野村浩司 [1], 菅沼祐介 [1], 菊池政雄 [2], 三上真人 [3], **Daniel L. DIETRICH[4]**
Hiroshi NOMURA[1], Yusuke SUGANUMA[1], Masao KIKUCHI[2], Masato MIKAMI[3], and Daniel L. DIETRICH [4]
1 日本大学，Nihon University,
2 宇宙航空研究開発機構，Japan Aerospace Exploration Agency,
3 山口大学，Yamaguchi University,
4 National Aeronautics and Space Administration

1. Introduction

Spray combustion is widely employed to many types of combustors. Since liquid fuel is suitable for transportation vehicles due to its high energy density, spray combustion technology is needed even after alternative fuels such as biomass oil supersede fossil fuel. Flame spread between fuel droplets is an important mechanism especially for spray flame stabilization. In fundamental researches on flame spread between fuel droplets, a fuel droplet array fixed in the even spacing are often employed. However, fuel droplets in the spray combustor move freely. The droplet motion can also affect the growth of a group combustion flame after flame spread. The understandings of the droplet motion induced by flame spread and the influence of droplet motion on flame spread and flame growth will be important for the development and evaluation of advanced spray-combustion numerical simulations.

Interaction between flame-spread and droplet motion was investigated in order to obtain basic understandings of the spray combustion mechanism. On-orbit experiments were conducted in the Flame Extinguishment Experiment-2J project (FLEX-2J) and the Group Combustion project (GC). A n-heptane droplet array and a n-decane droplet array were employed to the experiments. Overview of observation results was presented in this report.

2. Experimental Apparatus and Procedure

In the FLEX-2J project, experiments were performed with the Multi-User Droplet Combustion Apparatus (MDCA)[1)] installed into the Combustion Integrated Rack (CIR) on the International Space Station (ISS). In the GC project, experiments were performed with the Group Combustion Experiment Module (GCEM)[2)] in the Chamber for Combustion Experiment (CCE) installed into the Multi-purpose Small Payload Rack (MSPR) on the KIBO module of the ISS. The almost same droplet array suspension system was employed for the both projects. In the FLEC-2J project, n-heptane was used as a high-volatility fuel. In the GC project, n-decane was used as a low-volatility fuel. The droplet suspension system employed to the FLEX-2J project was shown in **Fig. 1**. Droplet array was arranged on this suspension system consisting of a SiC fiber (diameter: 78 μm) and three ceramic beads. Fixed droplets were generated on the ceramic beads and movable droplets were generated directly on the SiC fiber. To stabilize the generated movable droplets at the initial position, anchor spots were made on the SiC fiber in even spacing of 4 mm. One anchor spot consisted of two slightly thinner zones etched with a CO_2 laser. The movable droplet was stabilized between these two thinner zones. The

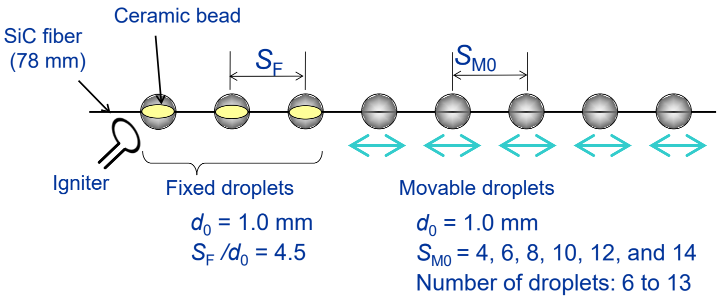

Fig. 1 Suspension system of fuel droplet array for FLEX-2J.

Table 1 Observation device.

Campaign	Image	Frame speed [fps]	Resolustion [pix/mm]
FLEX-2J	Direct	30	Variable
	Backlit	60	16.92
	OH chemiluminescence	30	9.2
GC	Direct	Still	24.1
	Direct	30	8.32
	Direct	500	64.04
	Backlit(HSC)	500	64.04

suspension system employed to the GC project was equipped with four ceramic beads for fixed droplets [3]. Droplet array was generated with sliding the droplet suspension system in the FLEX-2J project and with moving a glass needle of a droplet generation device in the GC project. Thirty seconds after the fuel droplet array generation, flame spread was i nitiated by ignition of the first fixed droplet arranged at the end of the droplet array. The first fixed droplet was ignited by a hot wire. Behaviors of a spreading flame and movable droplets were observed with the devices listed in **Table 1**. Initial droplet diameter and initial droplet spacing of movable droplet were varied.

3. Overview of the Observation Results

3.1 Flame Spread

Volatility of fuel strongly affected the flame spread behavior along a fuel droplet array including movable droplets. In the case of n-heptane, the premixed flame propagation [4] through the pre-vaporized layer around a droplet array occurred. **Figure 2** shows the behaviors of a flame and movable droplets during flame spread along a n-heptane droplet array. The fields of view of direct image and OH chemiluminescence image covered the whole droplet array. The backlit image captured droplets from the third fixed droplet to the sixth movable droplet. The origin of the time is the time when the hot wire was activated. At 0.533 s, the fixed droplets were ignited. The flame reached the other end of the droplet array at 0.6 s. In the case of fast flame spread, movement of movable droplets induced by the spreading flame was small and the effect of droplet motion on the flame spread behavior was little.

Figure 3 shows behavior of movable droplets and position histories of the center of movable droplets with position history of the leading edge of a spreading flame. The origin of the time is the time when the spreading flame reached the last fixed droplet. The first movable droplet started to move away from the spreading flame at the time of 0 s. Although the spreading flame reached the first movable droplet around 0.03 s, the first droplet did not ignite. It is supposed that temperature of the first droplet was too low to ignite. At 0.086 s, the first movable droplet coalesced with the second droplet before the flame spread to the first droplet occurred. Temperature drop of the firs movable droplet due to the coalescence with the cool second droplet led to the detachment of the spreading flame from the coalesced large droplet. The leading edge of the spreading flame moved backward, and a group combustion flame was stabilized around the fixed droplets without the flame spread to the movable droplets. In the case of n-decane, flame spread to movable droplet arrays arranged in the even spacing did not occurred. When movable droplets were arranged unevenly, flame spread from the fixed droplets to some movable droplets occurred [3].

3.2 Group Combustion after Flame Spread

Volatility of fuel did not influence behaviors of the movable droplets and the group combustion flame after the flame spread. **Figure 4** shows typical behaviors of a flame and movable droplets. The fuel was n-heptane. After the fixed droplets were burnt out around 1 s, the group combustion flame started shrinking and being rounded. During the shrink of the group combustion flame, the movable droplets coalesced with each other and gather to the center of the group combustion flame. Finally, all movable droplets became one droplet and evaporated completely. OH-chemiluminescence of the group combustion flame disappeared before the completion of the movable-droplet evaporation. The initial droplet arrangement influenced the behavior of the group combustion flame after flame spread. Other two types of the behaviors of group combustion flame were observed. One was the behavior that the group combustion flame split to plural flames and the other was the behavior that the group combustion flame kept the large cylindrical shape to the burn-out.

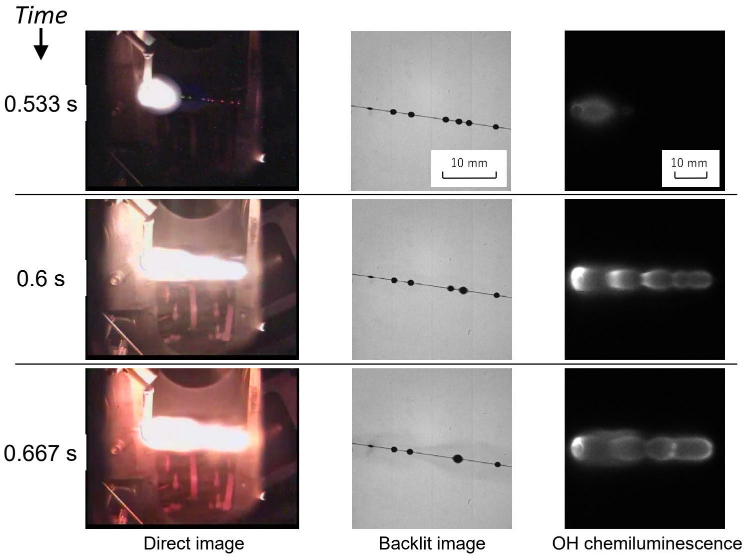

Fig. 2 Behaviors of a spreading flame and movable droplets for n-heptane droplet array.

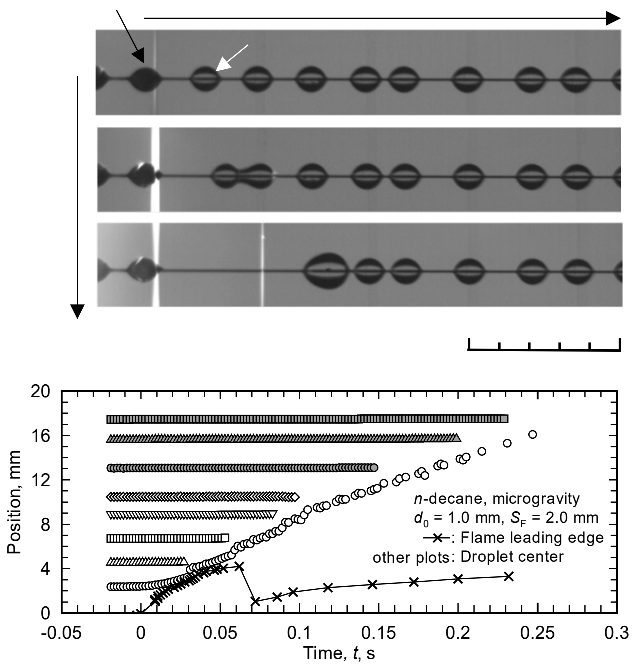

Fig. 3 Behaviors of movable droplets and position histories of movable droplets and flame leading edge for n-decane droplet array [3].

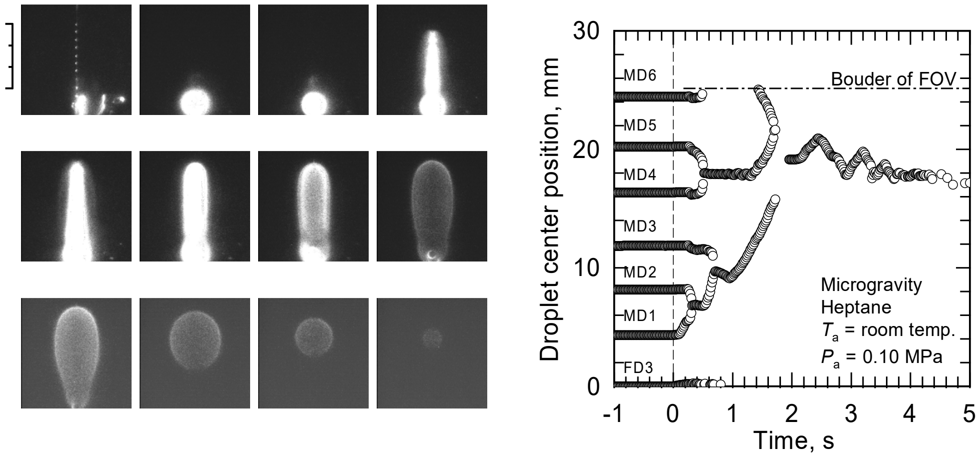

Fig. 4 Behavior of a flame around a heptane droplet array observed by OH chemiluminescence, and droplet position histories. Gain of flame images on the bottom row is increased more than the others.

4. Summary

Observations of a spreading flame and a group combustion flame of a fuel droplet array including fixed and movable droplets were conducted on the ISS. It was found that, in the case of a flame spreading fast along a fuel droplet array, the droplet motion induced by the flame spread did not influence the flame spread behavior. In the case of a flame spreading slowly along a fuel droplet array, the movable droplet motion prevented the flame spread. The interaction between the movable droplets and the group combustion flame growing after the flame spread were independent of the fuel volatility.

Acknowledgement

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