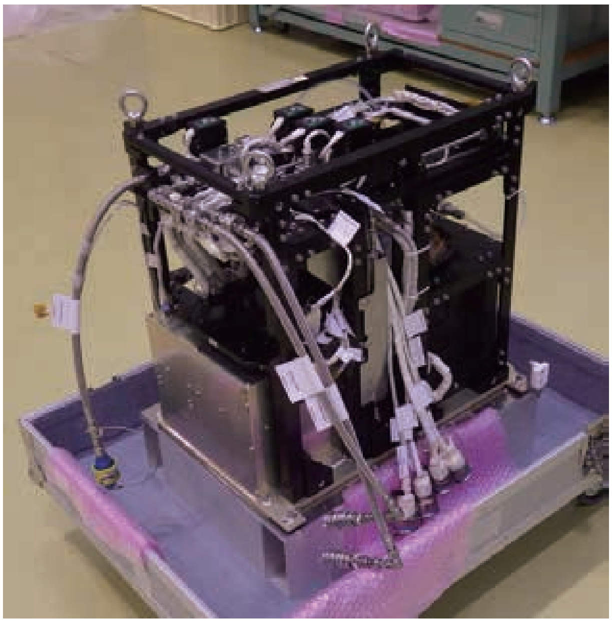
“KIBO” of the Space Station Succeeded in First Combustion Experiment

Group Combustion Experiment Module (GCEM) for the Japanese Experimental Module “KIBO” of the International Space Station

When observing a combustion phenomenon on the earth, fuel droplets are small and the phenomenon (reaction) is fast, so detailed observation is difficult. On the other hand, when performing experiments in space, the effect of gravity is very small, and correspondingly fuel droplets can be increased in size, thus enabling scaled-up detailed observation. In light of this, we developed a combustion experimental apparatus for space experiments.



Group Combustion Experiment Module (GCEM)

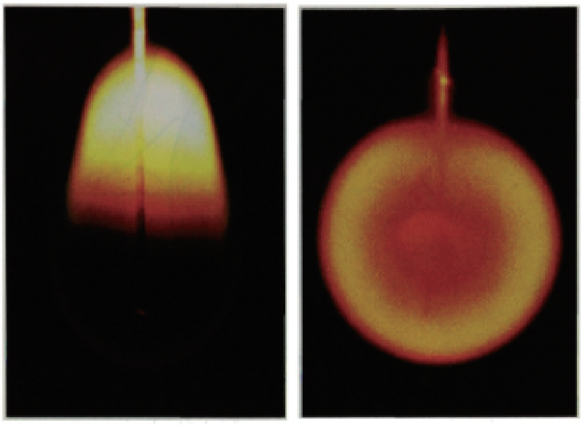
Background of research

Although there is little chance to directly visually observe combustion in combustors such as automobile and aircraft engines and industrial furnaces, a technology for efficiently combusting liquid fuel to convert it into thermal energy is important enough to determine the performance of a combustor. For such combustors, widely employed is “spray combustion” that sprays fuel as fine droplets to combust them. If the efficiency of combustion can be improved even a little, the impact of the improvement on industry is quite large.

However, the spray combustion involves a very complicated phenomenon in which phase changes and chemical reactions are mixed, and therefore the development of spray combustors is still very much dependent on rules of thumb. In order to overcome this problem and aim for a further increase in efficiency, a numerical analysis code enabling the prediction of spray combustion behavior with high accuracy should be put into practical use.

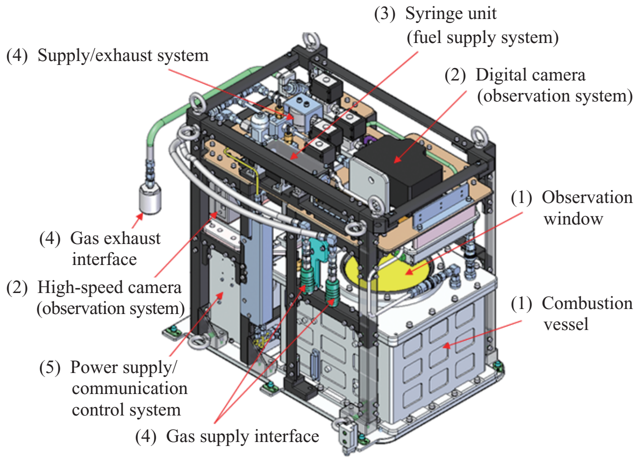
Roles of Group Combustion Experiment Module (GCEM)

To verify a model serving as a key for the above-described



Difference in droplet flame between under normal gravity and under microgravity environment

Source: Oyo Buturi Vol. 62, No. 4 (1993), pp. 329-335 "Can candles burn in microgravity?" (KONO Michikata and NIIOKA Takashi)



Outline of Group Combustion Experiment Module (GCEM)

numerical analysis code, an experimental approach is required.

The detailed observation and analysis of a droplet group flame-spread phenomenon requires using droplets (whose diameter is approximately 1 mm) having larger size than that of droplets in actual spray, and experiments on the earth is greatly affected by natural convection. This is the reason to perform the experiments under microgravity environment. Using the invariable and good quality microgravity environment on orbit makes it possible to observe the droplet group flame-spread phenomenon without being affected by natural convection.

In order to respond to such a need, Group Combustion Experiment Module (GCEM) was developed as a first combustion experimental apparatus for the Japanese Experiment Module "KIBO" of the International Space Station (ISS). Past experiments on orbit include some examples performed by the National Aeronautics and Space Administration (NASA) with a single droplet or a small number of droplets as a target or targets. However, GCEM has a big advantage of being able to perform the experiments with not only a group including a small number of droplets in an elemental arrangement pattern, but a group including randomly dispersed droplets (up to approximately 150 droplets) closer to actual application (spray) as a target.

Experiments performed in GCEM

GCEM satisfies required specifications to enable the following three types of experiments. Note that fuel used for the experiments is n-decane.

(1) Experiment 1

To observe the flame spread of a droplet group element (including 5 droplets) and that of a randomly dispersed droplet group (including up to 152 droplets).

(2) Experiment 2

To observe the flame spread of a droplet group that is linearly arranged and movable in the linear direction, and also observe the moving behavior of droplets themselves.

(3) Experiment 3

To observe flame spread between or among droplet clusters including 2 to 5 droplets.

Outline of GCEM

GCEM includes the following main sub-systems, and is operated mounted in a Multi-purpose Small Payload Rack in "KIBO".

(1) Combustion vessel

The combustion phenomenon is generated inside the vessel. The details will be described in the next section.

(2) Observation system

It includes a high resolution digital camera and a high speed camera (only for Experiment 2), and takes photographs of the phenomenon.

(3) Fuel supply system

It includes a syringe unit filled with n-decane and a fuel supply mechanism for pushing the syringe at a regular amount, and supplies the fuel into the combustion vessel.

(4) Gas supply/exhaust system

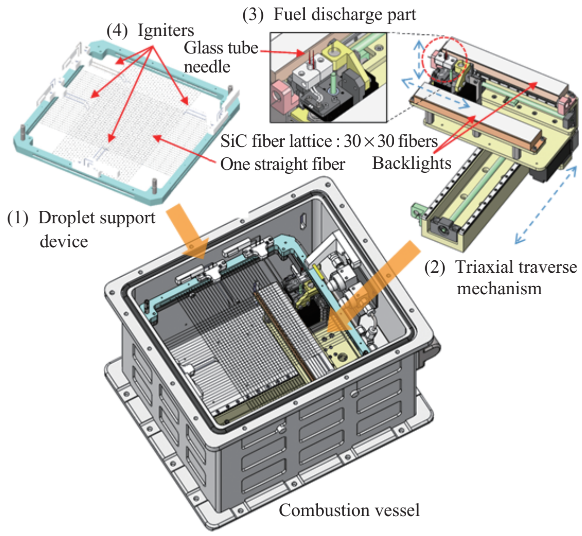
It controls the supply of air from a cylinder filled with atmospheric gas, the supply of nitrogen from ISS, and the discharge of atmosphere inside the combustion vessel.

(5) Power supply/communication control system

It receives electric power supplied from the Multi-purpose Small Payload Rack to distribute it to respective devices. It also comprehensively controls GCEM while communicating with the earth (such as performing telemetry communication and receiving commands).

Outline of combustion vessel

Inside the combustion vessel, the following devices are installed, and a fuel droplet group is produced and ignited.



Outline of combustion vessel

(1) Droplet support device
Two sets of 30 SiC fibers (whose diameter is approximately 14 µm) are stretched lengthwise and crosswise respectively in a lattice shape at intervals of 4 mm, and each of the lattice points supports a droplet having a diameter of approximately 1 mm. In addition, another SiC fiber having a diameter of approximately 78 µm is also stretched, and used to support a movable droplet in Experiment 2.

(2) Triaxial traverse mechanism
In order to form droplets at predetermined positions in the droplet support device one by one, a fuel discharge part is moved triaxially. In addition, a backlight is also installed, and used for backlight photographing to measure the diameters of droplets.

(3) Fuel discharge part
It discharges the fuel from a glass tube needle (whose diameter is approximately 50 µm) to form droplets in the droplet support device.

(4) Igniter
Four hot-wire igniters are installed (including backups), and by applying current to the igniters, the flame spread of droplets is started.

Necessary conditions for GCEM

Necessary conditions particularly important for GCEM are as follows. The details of each item will be described below.
(1) Security of fire safety
(2) Usability for on-orbit operation
(3) Highly accurate droplet generation

Security of fire safety

Experimental apparatuses operated in the ISS must not only satisfy functional requirements for respective missions, but undergo safety inspections to prove various types of safety. Since GCEM must unavoidably handle “fire” because of its purpose, it was carefully designed particularly in terms of fire safety.

A fire hazard is a critical hazard that may endanger the safety of ISS crews, so safety design allowable for the simultaneous occurrence of two malfunctions is required for the apparatus.

On the other hand, the combustion phenomenon at a combustion experiment phase relates to “fire” that must be intentionally generated. Accordingly, by designing the apparatus to confine a region allowable for the generation of the “fire” only within the combustion vessel and enclose it in the vessel, the combustion phenomenon was made handleable as “fire” under control.

Usability for on-orbit operation

Multiple crews reside in the ISS, and it is possible to entrust various types of work on the experiments. However, crews’ working time must be shared among various experiments performed in the ISS, and is therefore a very valuable resource. Accordingly, the amount of work to be entrusted to crews is required to be kept minimum necessary.

In GCEM, work to be entrusted to crews is limited to the assembly and disassembly of the experimental apparatus, the replacement of an air cylinder for filling atmospheric gas and a fuel syringe, and so on, and the combustion experiment is designed to be operable only by remote operations from the earth.

A total of approximately 200 experimental conditions are

Assembly of GCEM by Astronaut Onishi
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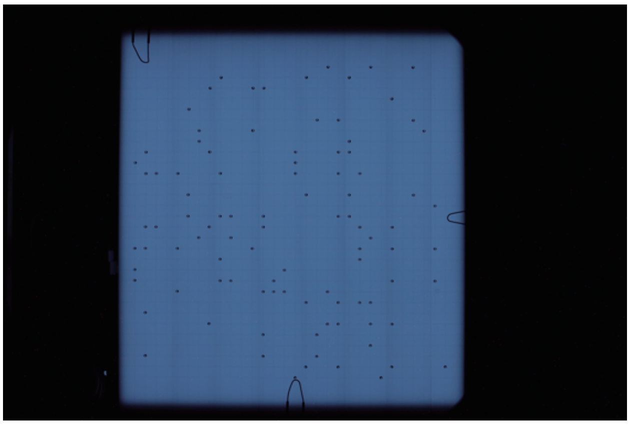

Generation of 97-droplet group under microgravity
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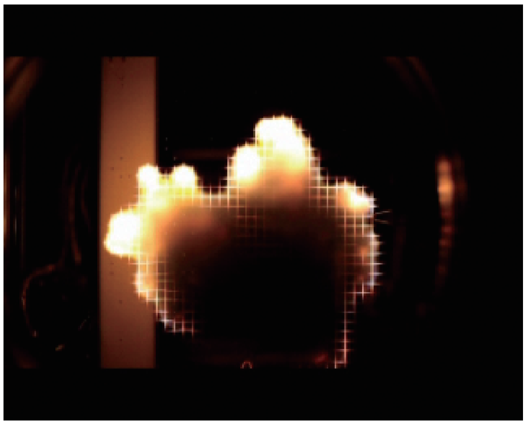

Combustion of 97-droplet group under microgravity
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planned, so the operation sequence of the experimental apparatus under each condition is defined by an "experimental sequence file" prepared for that condition. By issuing a command from the earth to read and execute a corresponding file, one experimental condition is automatically operated.

Highly accurate droplet generation (Challenge to target diameter ±5%)

In the sense of determining initial conditions at the start of combustion, the accurate generation of droplets is very important. The accuracy of a required droplet diameter is set to a target diameter ±5% (the target diameter is normally 1 mm).

Although n-decane as the fuel is relatively low volatile, it takes approximately 30 minutes to generate a droplet group including approximately 150 droplets, and therefore the effect of evaporation is not negligible. When simply continuing to generate droplets having a diameter of 1 mm for 30 minutes, there appears a difference in size between droplets generated in an early stage and those generated in a late stage. In GCEM, by taking account of an evaporation estimate to control a fuel discharge amount, the generation of a droplet group including droplets whose diameter was uniformly controlled to the target diameter was successfully achieved.

As a result of generating a randomly distributed droplet group (97 droplets) to check the accuracy of generated droplets at the time of initial on-orbit verification, an achievement rate of 95% or more was obtained under the condition of the droplet diameter 1 mm ±5%.

Results of on-orbit operation

On February 17, 2017, after the completion of the initial on-orbit verification, GCEM generated a randomly distributed droplet group (97 droplets) and succeeded in observing the flame-spread phenomenon of the group under microgravity environment first in the world.

After that, Experiments 1 to 3 described above are being carried out, and data is steadily being collected (as of June, 2017).

Next step

We were able to successfully perform the first combustion experiment in the Japanese Experimental Module "KIBO" of the ISS using GCEM. GCEM is continuously being used for the on-orbit operation, and basic data on the droplet group combustion is being accumulated (as of June, 2017).

As the next step, subsequently to the apparatus for the liquid fuel (fuel droplet group), a combustion experimental apparatus for solid material is also under development, and in order to acquire basic data contributing to the establishment of the standards for fire safety in space, we will continuously perform a challenge.

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