

# JAPAN'S MICROGRAVITY COMBUSTION SCIENCE PROGRAM

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## Introduction

Most of energy used by us is generated by combustion of fuels. On the other hand, combustion is responsible for contamination of our living earth. Combustion, also, gives us damage to our life as fire or explosion accidents. Therefore, clean and safe combustion is now eagerly required. Knowledge of the combustion process in combustors is needed to achieve proper designs that have stable operation, high efficiency, and low emission levels. However, current understanding on combustion is far from complete. Especially, there is few useful information on practical liquid and solid particle cloud combustion. Studies on combustion process under microgravity condition will provide many informations for basic questions related to combustors.

In Japan, origin of the microgravity combustion was Kumagai's droplet combustion conducted about 35 years ago (ref. 1), and until now, most of studies on the microgravity combustion has been conducted for the droplet combustion. Recently, many types of studies on the microgravity combustion have been planed, started, and carried out by using the droptowers. They are droplet arrays, sprays, solid, coal particle cloud, and premixed gas combustion studies.

At last year, the biggest dropshaft facility in the world for the microgravity science was opened at Hokkaido. It produces 10 second of good quality microgravity field. Also, 4.5 second dropshaft facility is now under constructed and will be opened in 1994. The new sounding rocket operation was started from this year. Preparation of a space station combustion experiments has been started also from this year. Increasing opportunity for getting good microgravity field has stimulated recent microgravity combustion studies in Japan. The combustion scientists who do and hope to do the microgravity combustion have made the consortium, and it discusses with the government agencies on the governmental support microgravity combustion programs.

This presentation describes the Japanese microgravity facilities, recent research activities, and planed future activities.

## Microgravity Facilities

Droptowers: About six small droptowers of 5 - 20 m have been used for combustion research at universities and companies. Up to now, most of

microgravity combustion studies have been done by using these droptowers.

From October 1991, Japan Microgravity Center (JAMIC) opened its commercial operations at Kamisunagawa, Hokkaido (see Fig. 1). Capabilities of JAMIC facility are 10 second of free fall duration,  $10^{-5}$  g of microgravity level, 8 g of maximum deceleration level, 1000 kg of maximum payload weight, and 870 x 870 x 918 mm of experimental equipment mounting capacity.

The other big dropshaft facility is now under constructed at Toki, Gifu prefecture and will be opened in 1994. Its capabilities are 4.5 second of free fall duration,  $10^{-5}$  g of microgravity level, 10 g of maximum deceleration level, 650 kg of maximum payload weight, and 0.7 m diameter x 0.8m length of experimental equipment mounting capacity.

Parabolic flights: A small jet airplane named MU-300 is employed for the parabolic flight. Its capabilities are about 20 second of microgravity field,  $10^{-2}$  g of microgravity level, and two 700 x 450 x 900 mm experimental rack. Up to now, there has been no combustion experiments by using the parabolic flight.

Sounding rockets: A new sounding rocket named TR-1A has been operated from 1991. The microgravity level and duration are  $10^{-4}$  g and about 6 minute. The maximum payload is 750 kg and experimental equipment mounting capacity is 770 mm diameter x 2380 mm length. For the combustion experiments, it can be used after 1995. Preparation of TR-1A combustion experiments will be started from next year.

Space station Japan module: Preparation of microgravity Experiments in the space station "Freedom" has been started at this year. Combustion is planed as one of the space station microgravity experiments.

#### Recent research activities

Droplet and spray combustion: Effects of fuel nature on the burning process have been studied by using a free droplet method at atmospheric pressure by Hara and Kumagai (ref. 2). From this research, it has been found that the quasi-steady theory of droplet combustion cannot be applied for four kinds alkane fuel from n-heptane to n-decane.

The other droplet combustion studies are for the high pressure evaporation and combustion. For the evaporation, experiments have been done up to the ambient pressure of 5 MPa by Nomura et al (ref. 3). and the data were compared with results obtained at normal gravity condition. This experiments have been carried out by using 5 second droptower of University of Bremen, Germany, as a collaborative research. Quite different evaporation behavior compared with that of under normal gravity was observed at subcritical and supercritical condition.

Evaporation constant and evaporation life time were obtained for the various conditions.

Effects of oxygen concentration have been studied experimentally on the burning life time and on the carbon zone formation behavior around the droplet by Niwa et al. (ref. 4). The burning life time takes minimum at the critical pressure of fuel also in the low oxygen concentration.

Extinction diameter of a burning droplet was predicted theoretically by Niioka et al. (refs. 5 and 6). For the prediction, they used the extinction data of diffusion flame established in a stagnation flow on a liquid fuel and the analogy between its diffusion flame and the flame surrounding a liquid droplet. The droplet diameter at extinction was found to decrease rapidly with pressure, take minimum, and then increase.

Multi-components fuel problems have been studied experimentally by using a two-components fuel of n-heptane and n-hexadecane by Mikami et al. (ref. 7). This research used the NASA LeRC 2.2 second droptower as a collaborative research. Three-stage burning of the binary fuel droplets is observed, and the onset time of the second stage is compared with the previous theoretical predictions.

For the ignition, experimental studies are being carried out. Numerical studies have been done by Tsukamoto et al. (ref. 8), and the results will be compared with the experiments.

Experimental studies on ignition and combustion of droplets array have been started from this year. Also, studies on generation of homogeneous droplet cloud under microgravity have been started for preparation of the spray combustion research in the space station.

Others: Ignition of premixed gas by a hot surface has been studied experimentally and theoretically by Nagata et al. (ref. 9). Ignition delay under microgravity is shorter than that under normal gravity.

Fire spreading behavior over a paper honeycomb has been studied by Itoh et al. (ref. 10), and the effects of fire spreading direction, oxygen concentration, and honeycomb cell size were obtained and compared with that of under normal gravity. The fire spreading velocity does not depend on the honeycomb cell size under microgravity.

Flame propagation behavior through the coal particle cloud have been studied by using 10 second dropshaft to study the coal gasification process by Sato and Itoh. Nearly homogeneous particle cloud was obtained and spherical flame propagation was observed.

Demonstration experiments of 10 second dropshaft were conducted by some combustion experiments, such as candle burning, paper burning, string burning, and large solid fuel burning by Itoh et al. The candle did not extinguish during 10 second of microgravity. These studies will be continued as microgravity combustion science.

### Future research activities

Preparation of space station combustion experiments has been started from this fiscal year. Based on the discussion in the Japanese microgravity combustion consortium, spray combustion experiments are planned to do in the space. Details of experiments are being discussed and some experimental preparations will be started in this year.

Two large governmental research programs on microgravity combustion science by using 10 second dropshaft are planned for five years from next year to keep clean the earth by the fundamental combustion science point of view. This year is preparation for the next year. One program will be conducted as international research collaboration. Details how to conduct these have been started to be discussed and will also be discussed with the governmental agencies concerning microgravity combustion science in the world. In the Japanese side, many combustion scientists will participate these research programs.

### Concluding Remarks

Up to now, most of the research budget for microgravity science in Japan has been used for material science. But recently, the research budget for combustion is increased and then Japan's microgravity combustion science programs are being increased remarkably. Furthermore, 10 second dropshaft facility was opened in Japan at last year. Many Japanese combustion scientists will join the microgravity programs in the near future.

For the combustion scientist, it is required to explore the combustion phenomena in order to solve the emission problems from the combustors. Microgravity field is suitable for the fundamental combustion research. However, opportunity to use a good quality microgravity field of over 3 second is not so much for many combustion scientists because of the limited number of big facilities. Therefore, more effective use of the limited number of big facilities is important and should be discussed.

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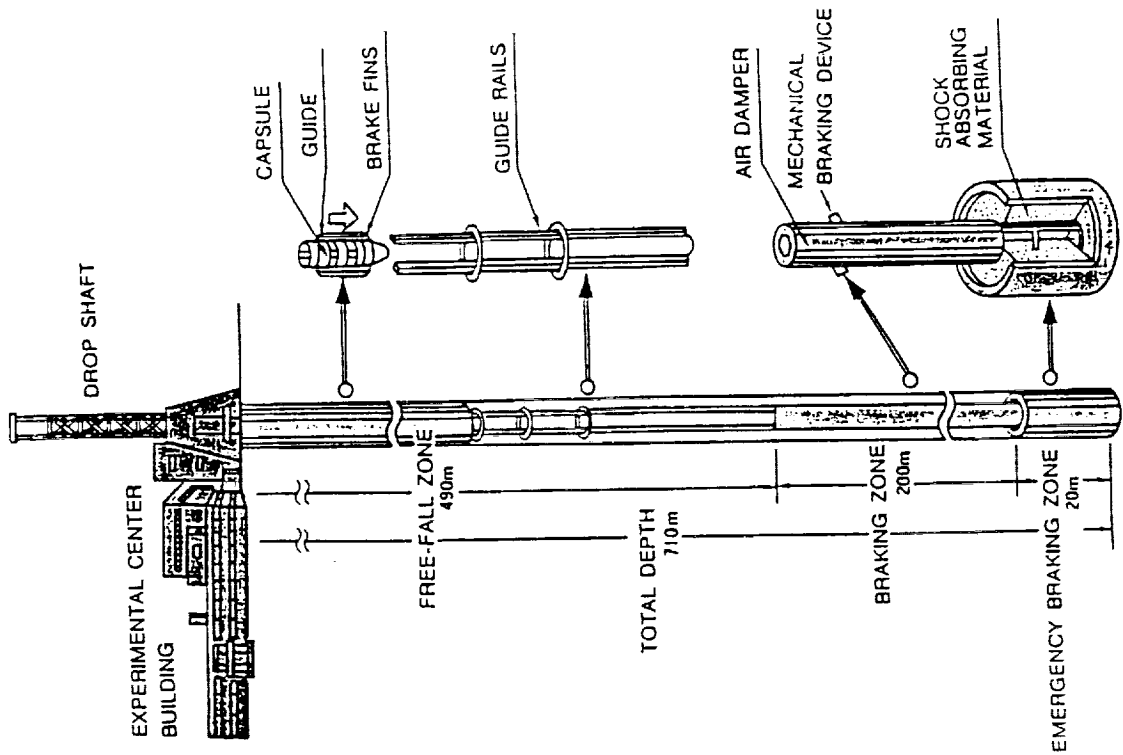
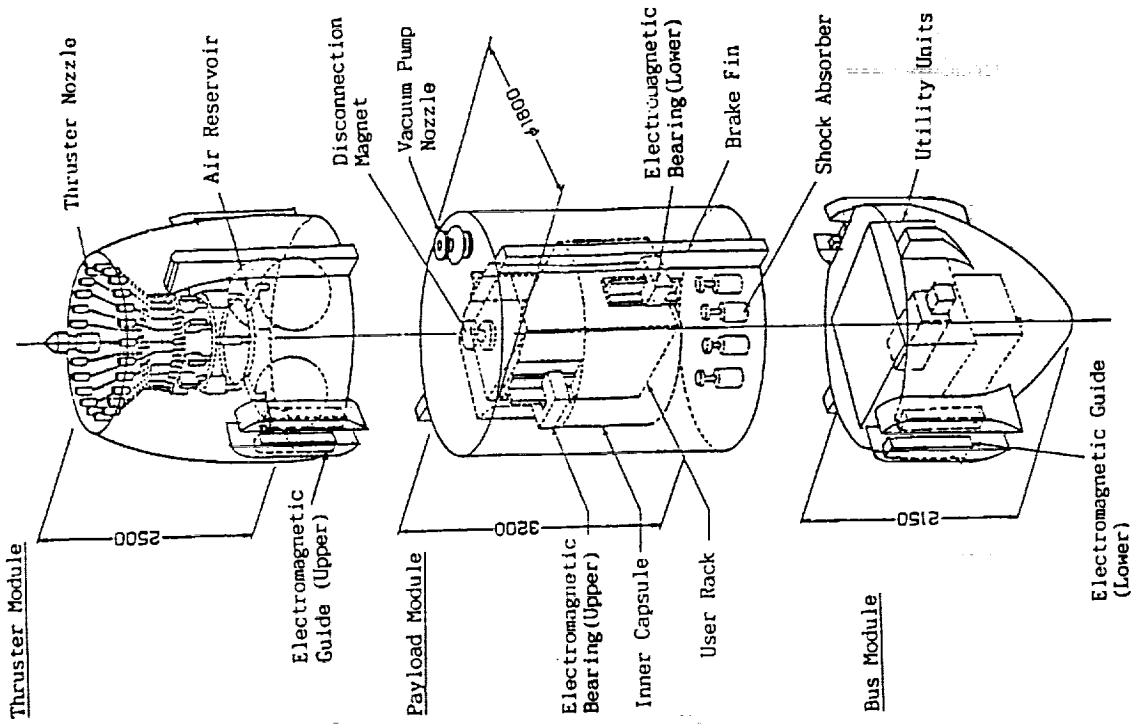


Figure 1.-Schematic of JAMIC 10 second dropshaft.

## **SESSION B - PLENARY SESSION**

(Chair, Kurt Sacksteder)

