

# DIAGNOSTICS IN JAPAN'S MICROGRAVITY EXPERIMENTS

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## Introduction

The achievement of the combustion research under microgravity depends substantially on the availability of diagnostic systems. The non-intrusive diagnostic systems are potentially applicable for providing the accurate, realistic and detailed information on momentum, mass and energy transport, complex gas phase chemistry, and phase change in the combustion field under microgravity. The non-intrusive nature of optical instruments is essential to the measurement of combustion process under microgravity which is very nervous to any perturbation. However, the implementation of the non-intrusive combustion diagnostic systems under microgravity is accompanied by several constraints. Usually, a very limited space is only available for constructing a highly sophisticated system which is so sensitive that it is easily affected by the magnitude of the gravitational force, vibration and heterogeneous field of temperature and density of the environments. The system should be properly adjusted prior to the experiment. Generally, it is quite difficult to tune the instruments during measurements. The programmed sequence of operation should also be provided. Extensive effort has been toward the development of non-intrusive diagnostic systems available for the combustion experiments under microgravity.

This paper aims to describe the current art and the future strategy on the non-intrusive diagnostic systems potentially applicable to the combustion experiments under microgravity in Japan.

## Raman Scattering

Raman scattering has the unique advantage of being able to provide spatially resolved measurements of temperature and all major species using only a single incident laser light without the need for tuning. It is essentially an instantaneous process occurring within a time of  $10^{-12}$  s or less. The Raman spectrum is species specific, temperature sensitive and linearly proportional to the species number density. Unfortunately, the scattered signal is very weak, hence it is usually difficult to assure the high signal interference ratio. Raman scattering is suited to combustion diagnostics in clean flame. Preliminary experiments under normal gravity include the thermometry of propagating flame(1) and species concentration and temperature measurements in the wake flame formed behind a pair of small porous spheres(2) and jet diffusion flame. The application of this technique to the microgravity

experiments is now under consideration.

### Rayleigh Scattering

Rayleigh scattering has been of interest since its cross section is approximately three orders of magnitude stronger than the one for vibrational Raman scattering. Since the Rayleigh scattering is an elastic process, the scattered light is unshifted in frequency, and hence not species specific. The employment of Rayleigh diagnostic is restricted to the measurements in a very clean environments free of particulate. Preliminary experiments carried out under normal gravity include the thermometry of propagating premixed flame(1) and turbulent jet diffusion flame, and the measurement of the fuel vapor concentration profile around a pair of spheres evaporating in a uniform stream of air(3), planar Rayleigh scattering for the visualization of the fuel concentration field in an unsteady and a steady circular turbulent jets(4). These experiences suggest that it is not so far ahead for this technique to be employed for probing species concentration and temperature in the combustion environments under microgravity. The high power laser and the highly sensitive optical detector are recommended in the installation of diagnostic system.

### Mie Scattering

Mie scattering is also an elastic scattering of light from particulate of which diameter is so large that  $d/\lambda \ll 1$  does not hold. The intensity of the scattered light is a complicated function of various physical parameters such as the number density, the optical size, the complex refractive index and the angle of observation. The comprehensive analysis has provided a library of scattering function for spheres and other geometries. Mie scattering is applicable to soot diagnostics in flame. Figure 1 shows the planar laser Mie scattering system(5) developed for two dimensional visualization of soot concentration field in a droplet flame under microgravity inside a drop tower. The optical system is consisted of a frequency doubled Nd-YAG laser to irradiate an envelope flame formed around a fuel droplet, an interference filter and a CCD camera. Mie scattering is also available for the droplet sizing in fuel spray flame. It has been proposed to employ a small angle forward scattering technique(6) for the measurements of droplet size and number density in a spray flame under microgravity.

### Laser Induced Fluorescence

Laser induced fluorescence(LIF) is the spontaneous emission of radiation from an upper energy level which has been excited by incident laser light. For the most flame radicals and minor species, the excitation to electric upper level requires a tunable laser light radiation with the wave length ranging from 200 to 600 nm which is conveniently accessed by tunable dye lasers or others either directly or via some readily available frequency conversion scheme. LIF possesses the capability of detecting the flame radicals and minor species at the level of ppm or less and hence has received a considerable attention. Fluorescence spectra are in general shifted in frequency from the incident laser light and hardly influenced by the interference from the spuriously scattered incident laser light and Mie scattering. The spectra are species specific. This technique requires the correction for the quenching that is the decay of the excited state of species to obtain the quantitative

data. Several attempts have been done to apply planar laser induced fluorescence(PLIF) for the combustion experiments under normal gravity. These include two dimensional visualization of radical concentration in flame(7)(8), fuel vapor concentration in isothermal mixing process and liquid density in a spray(9). These efforts have resulted in the development of the PLIF based combustion diagnostic system under microgravity as shown in Fig. 2. It has already been constructed and now available for the measurements of radicals in a various kinds of flames. Liquid phase thermometry in the droplet flame has been successfully done by using exciplex based fluorescence under normal gravity(10). Figure 3 shows the schematic diagram of the apparatus which is now being utilized for the remote probing of burning droplet temperature under microgravity inside a drop tower. A fuel droplet doped with a trace of naphthalene and TMPD is subject to the nitrogen laser excitation and the resultant fluorescence spectrum from the droplet is measured with an optical multichannel analyzer. Since the fluorescence spectra are temperature sensitive, droplet temperature is determined from the measured results of the spectra.

### Interferometry and Schlieren

Interferometric and Schlieren techniques have been widely employed for the visualization and the quantitative analysis of combustion processes, for flame geometry determination and for the measurements of density and temperature field in combustion. Michelson interferometry has been employed for the experimental study of autoignition of fuel droplet under microgravity. Figure 4 shows the experimental apparatus to visualize and quantify the instantaneous temperature field formed around a droplet which was subject to the hot ambient gas(11). Interferometric image is stored by a 8 mm video tape and analyzed by a high speed image analyzing system. Instrumentation of Schlieren is rather flexible and simple, hence most appropriate for the visualization of the heterogeneous density field due to temperature or concentration difference in the gaseous medium in a limited space. It has been employed for the study of turbulent burning velocity in a closed vessel under microgravity(12). The special attention has been paid to prevent the doubling of the image and to keep the long optical pass.

### Emission Spectroscopy

Instantaneous two dimensional concentration profile of OH around the array of fuel droplets during autoignition in high temperature gaseous environment was visualized under microgravity(13) by using a CCD camera with an image intensifier and an interference filter. The flame color could give us some data available for understanding combustion process. It has been reported the the flame color is well correlated with some kinds of experimental parameters under normal gravity(14). It has been attempted to extend its use to the combustion experiments under microgravity.

### Velocimetry

Both particle image velocimetry(PIV) and laser doppler velocimetry(LDV) are available for probing the flow field in the combustion environments under microgravity. PIV is preferential and the system which is similar to the one as shown in Fig. 2 has been constructed. Liquid phase PIV is based on either Mie scattering or fluorescence of droplets

which is subject to the irradiation of a sheet of frequency doubled or quadrupled Nd-YAG laser. Seed material is added to the gaseous medium as a scattering center in gas phase PIV.

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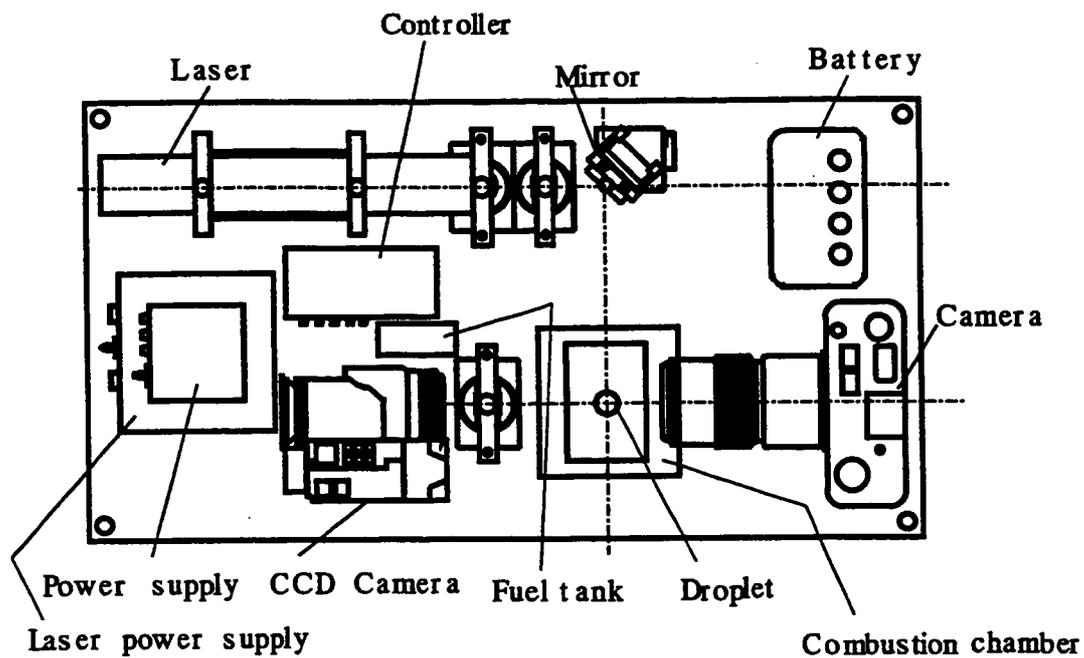


Fig.1 Planar Mie scattering for soot diagnostics

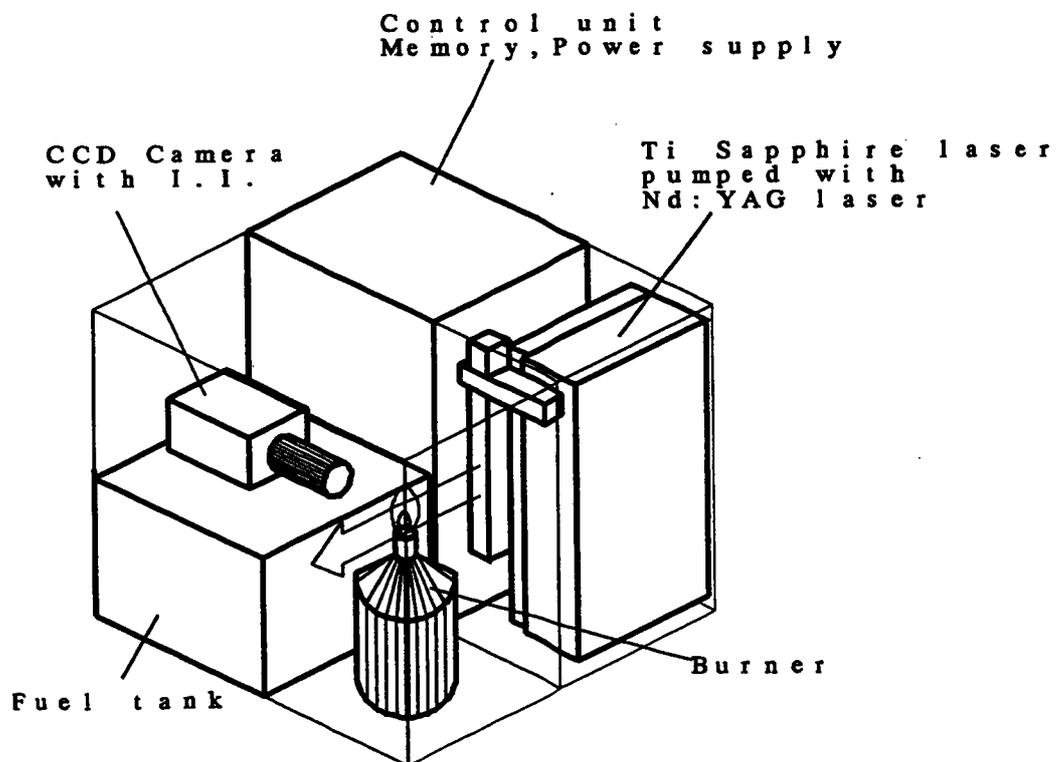


Fig.2 PLIF and PIV

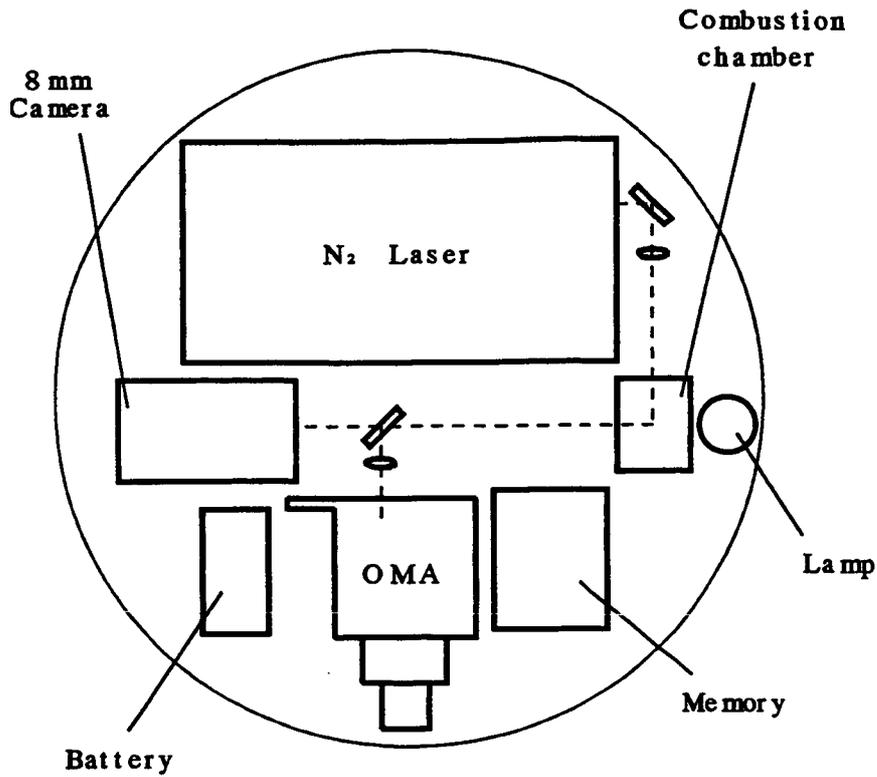


Fig.3 LIF thermometry

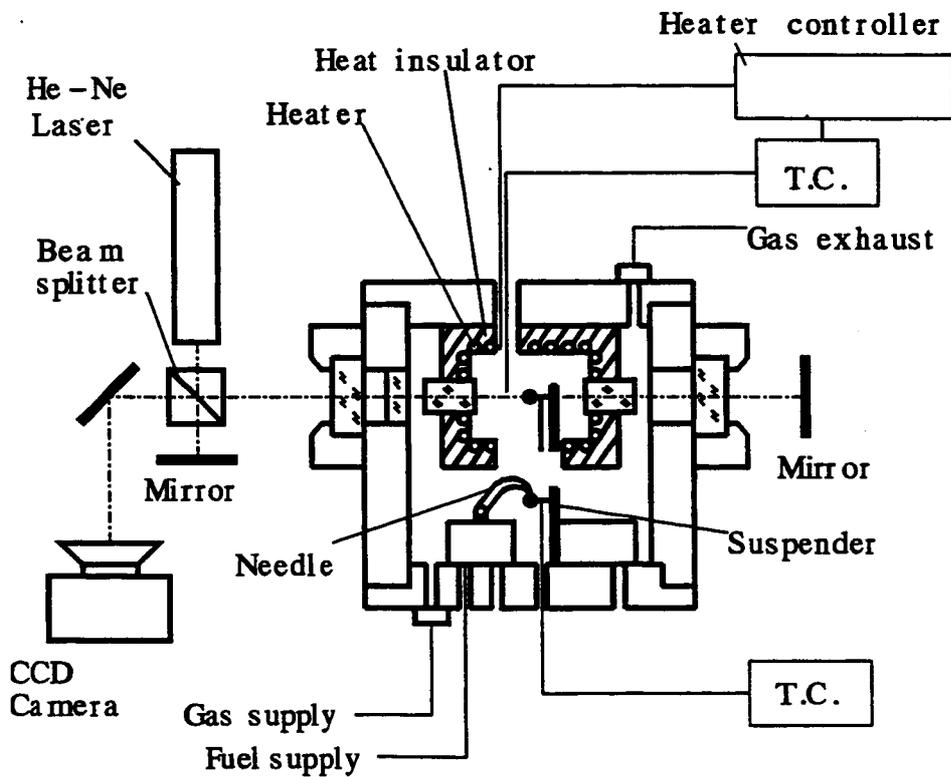


Fig.4 Michelson interferometry