JAPAN SPACE FORUM
AND
JAPAN AEROSPACE EXPLORATION AGENCY

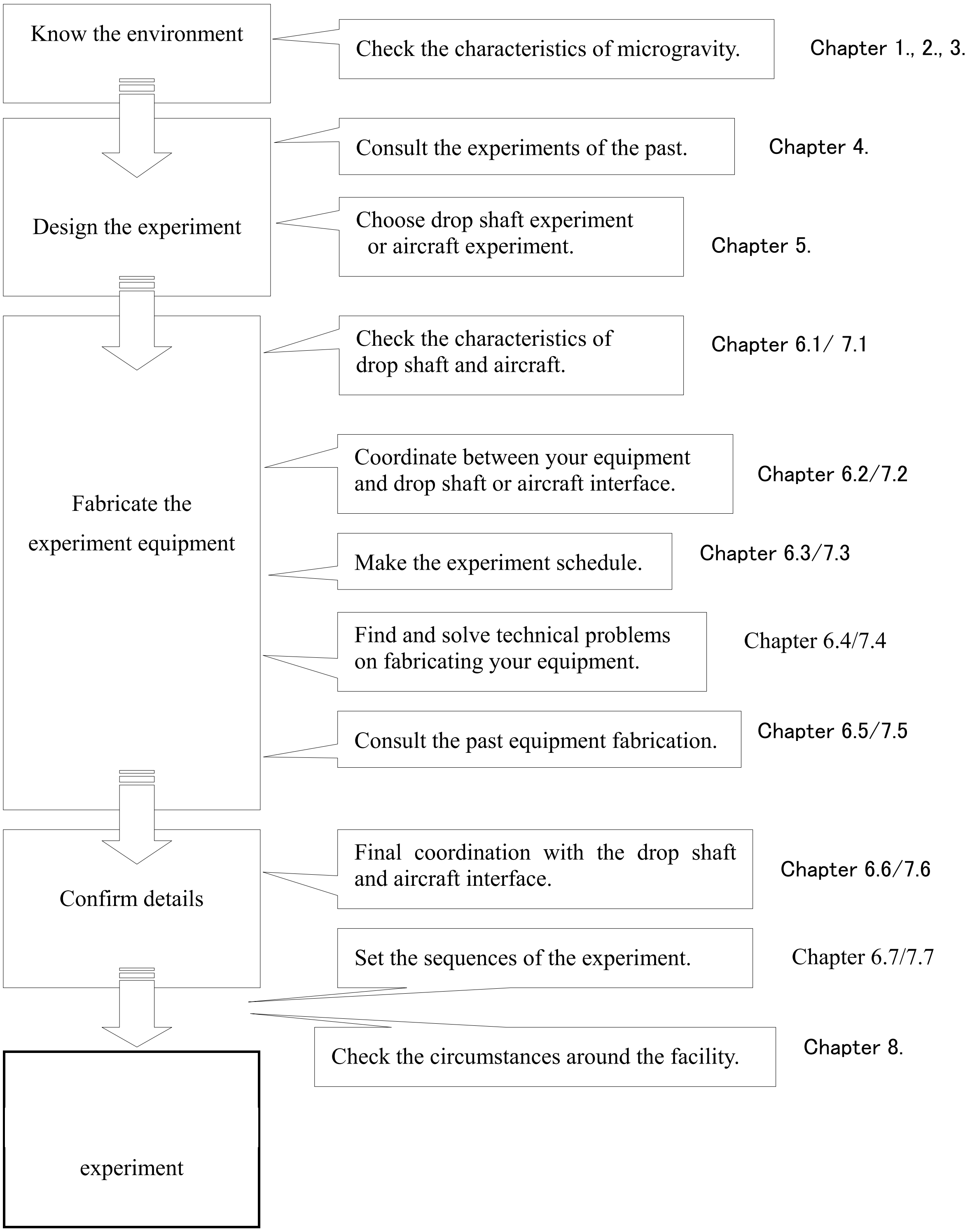
DROP SHAFT AND AIRCRAFT EXPERIMENT GUIDEBOOK

-For short duration microgravity experiments-

Revision May 2011

Contents

-Steps to Successful Experiment-



1. Preface

Japan Space Forum(JSF) has been supporting the "Ground-Based Research Program for Space Utilization" entrusted by Japan Aerospace Exploration Space Agency(JAXA) since 1997. Through this program, JSF has promoted many research proposals, and provided many researchers with opportunities of drop shaft and aircraft microgravity experiments. To enhance this solicitation study program, we planned to publish "DROP SHAFT AND AIRCRAFT EXPERIMENT GUIDEBOOK" by summarizing the experiment methods conducted so far.

On editing this guidebook, we organized a committee from experts familiar with drop shaft and aircraft experiments in three fields (physics and chemistry, life sciences and space utilization technology). At the process, we asked the researchers who have experienced in drop and aircraft experiments to inform their techniques to succeed. Fortunately, we could get adequate and useful information and instructions by the researchers. The collected information and instructions were used for review and reflected in this guidebook.

As mentioned on the previous page "Steps to Successful Experiments," this guidebook is positioned as a reference information to ensure the smooth progress of drop shaft and aircraft microgravity experiment by confirming each stages of it.

As advice from precursors, we hope this will be of any help to those intending to conduct drop shaft and aircraft experiments.

To make this guidebook even easier to use, we will keep reviewing. Your frank opinions will be much appreciated.

By Editors

(Editing responsibility lies with JSF.)

The Microgravity Laboratory of Japan (MGLAB) finished its operation in June 2010 and its drop shaft facility is no longer available. The descriptions on MGLAB in this guide book, however, still contain a substantial amount of useful information. Therefore, all the text are kept unchanged.

2. What Makes Microgravity So Interesting?

Compared with the bonding strength between atoms or molecules, gravity is of an ignorable level. Since gas and liquid have weaker inter-atomic or intermolecular bonding strength than solid, gravity easily cause their deformation, such as flow and diffusion. Therefore, the effect of microgravity appears more in gas or liquid than in solid. In addition, gravity always acts in a single direction as acceleration or force toward the gravity center of the earth. Under microgravity, however, there is almost no acceleration in a specific direction and all phenomena become isotropic and symmetric in three dimensions. This section compares phenomena observed under microgravity and on the ground.

2.1 Leviation of Substances

Under microgravity, liquid floats in space as a sphere because it is not deformed by the self weight and the surface atoms and molecules are attracted uniformly from inside. As a typical example, Figure 2.1 shows a water sphere formed by astronaut Mohri in space shuttle.

Figure 2.1 Water sphere containing an immersed flower produced by astronaut Mamoru Mohri in space shuttle

2.2 Mixture of Substances

Under microgravity, particles or substances of relative density do not separate but mix uniformly (Figure 2.2). This property allows to produce alloys and semiconductors from metals that cannot be fused on the ground.

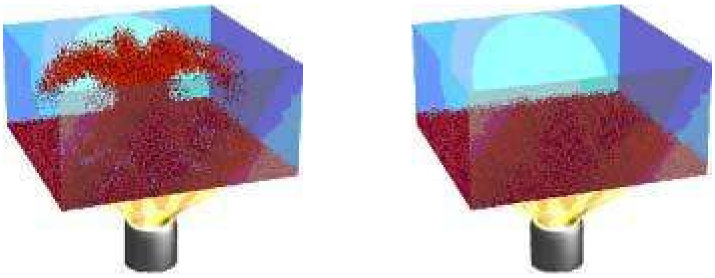
On the ground

Under microgravity

Figure 2.2 Mixing substances of different specific gravities

2.3 Suppression of Thermal Convection

Under microgravity where heat does not generate natural convection (Figure 2.3), phenomena hidden by convection on the ground are visible.

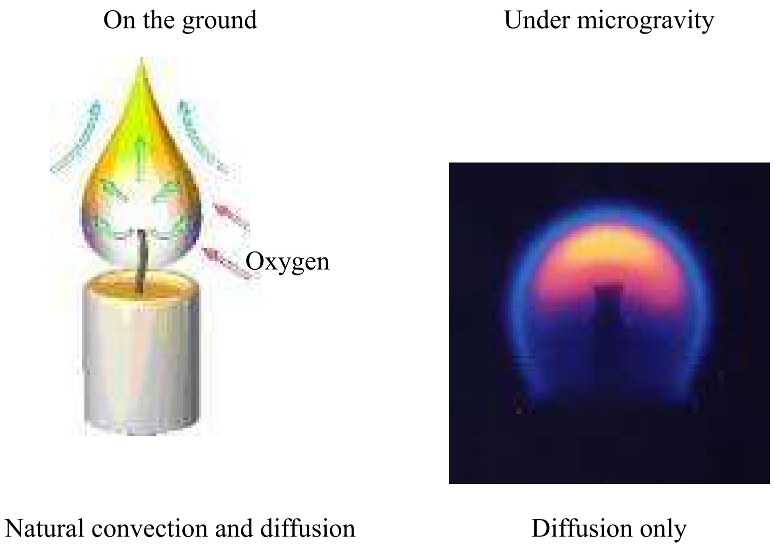


On the ground

Under microgravity

Figure 2.3 Natural convection

Figure 2.4 shows the microgravity influence on convection and diffusion with a burning candle. The wax that changed from liquid into gas diffuses evenly in all directions, forming a spherical flame. The flame will go out once all neighboring oxygen has been used up despite plenty of oxygen available because there is no thermal convection to draw oxygen to the flame.



On the ground

Under microgravity

Natural convection and diffusion

Diffusion only

Figure 2.4 Convection and diffusion in candle burning

Figure 2.5 shows the concept of Marangoni convection. The Marangoni convection is a current caused by the non-uniformity of surface tension attributable to a temperature or concentration gradient. This convection occurs even under microgravity.

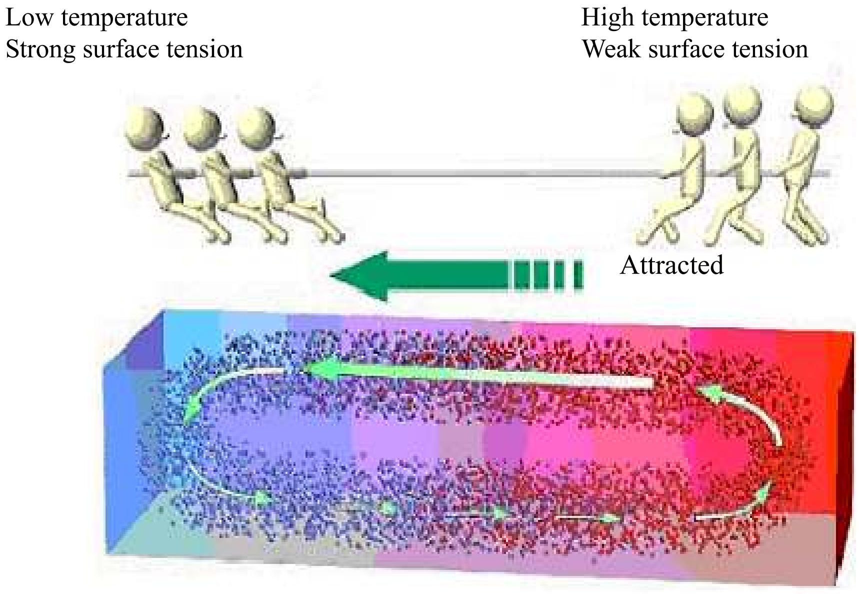


Figure 2.5 Mechanism of Marangoni convection generation

In addition, crystal or fine particle can grow greatly under microgravity where its structure is not affected by natural convection or self weight. Figure 2.6 shows glass microparticles produced on the ground and under microgravity. In the heat convection suppressed environment, we can conduct burning experiments, fluid experiments, and crystal growth experiments with various substances.

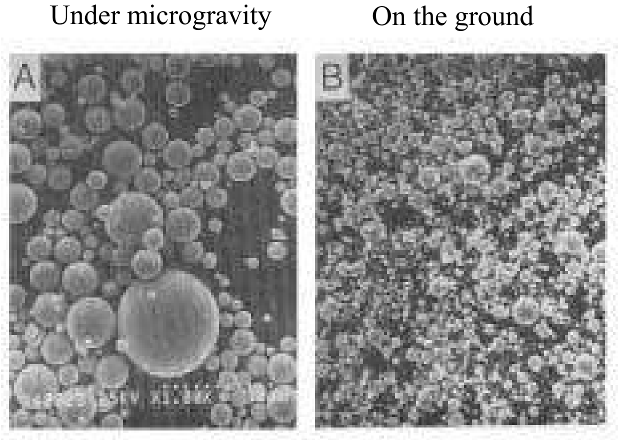


Figure 2.6 Growth of micro-glassparticles

2.4 Wetting

Figure 2.7 Water creeping up the wall of the plastic bottle under microgravity

Because of no deformation by self weight, the interaction at an interface becomes visible. If a glass becomes very wet with water, the water inside climbs up the wall and goes out of the glass. Molten metal in a melting pot also shows the same phenomenon.

References
- "Science Using Space Environment" supervised by Hiroo Inokuchi (Shokabo: March 2000)
- "Introduction to On-orbit Experiment" supervised by Osamu Odawara, the Japan Society of Microgravity Application (Kaibundo: April 2004)
- Figure 2.6 provided by Masaki Makihara, the National Institute of Advanced Industrial Science and Technology
- JAXA web site

3. Realizing Microgravity Environment

3.1 How to Realize Microgravity Environment

This section describes different methods of obtaining microgravity environment discussed in Chapter 2.

(1) Using circulation on a low or medium earth orbit

A flight vehicle circulating around the earth maintains a circular orbit at a uniform velocity, where the centrifugal force and centripetal force are equal and no force works in the longitudinal direction. In this state, objects inside the flight vehicle receive no gravity (microgravity). By utilizing this phenomenon, experiments are performed in a space shuttle or space station traveling on a circular orbit at an altitude of 300 to 400 kilometers. Microgravity of about $10^{-6}G$ (where G is the gravitational acceleration on the ground) can be assumed inside such a vehicle. Gravitational fluctuations caused by astronaut motions or other, however, significantly hamper experiments in a space laboratory.

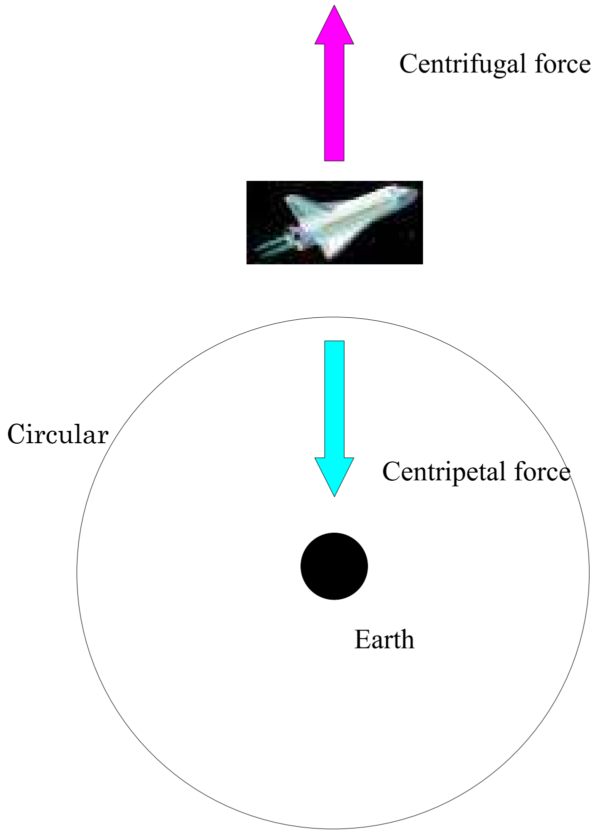
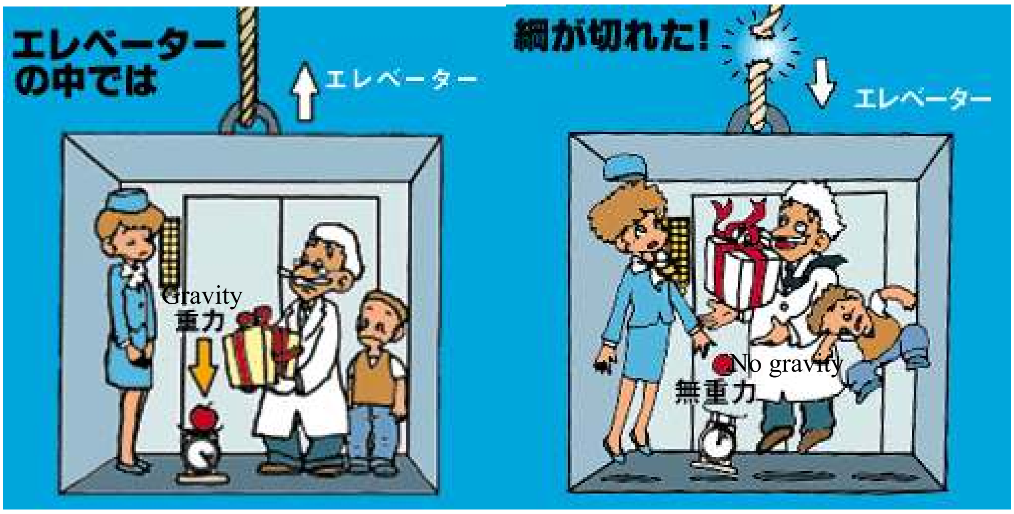


Figure 3.1 Using circulation on a low or medium earth orbit

(2) Using a free fall

An object inside an elevator will apparently lose its weight (microgravity) if the elevator cable breaks and the elevator starts a free fall. The weight is lost because the gravitational acceleration acting on the object and the acceleration of the free-falling elevator are virtually the same. The drop facilities use this phenomenon. In practice, air resistance and other factors deteriorate microgravity to about 10^{-5}G.



Inside an elevator ⇒ Cable break ⇒ Free fall and no gravity

Figure 3.2 Using a free fall

(3) Using parabolic motion

An object thrown diagonally from the ground falls in a parabolic curve. The falling object keeps the weightless (microgravity) state inside because the acting force are balanced at each momentary position. By using this phenomenon, an aircraft or rocket produces a weightless environment, regardless of its orientation. This parabolic motion is called parabolic flight. An aircraft flies at a lower altitude than a rocket and receives greater aerodynamic force. To achieve a parabolic flight, an aircraft adds offsets force by greater engine thrust. For this reason, an aircraft produces microgravity of about 1 to 3 × 10^{-2}G.

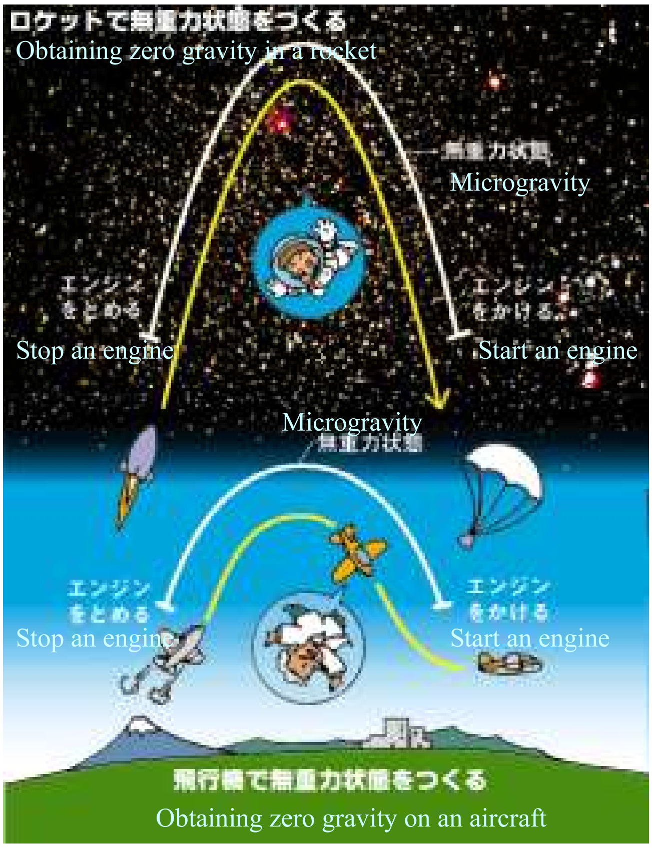


Figure 3.3 Using parabolic motion

3.2 Comparison of Microgravity in Different Methods

Figure 3.4 plots the positions of various microgravity production methods with the duration of microgravity environment on the horizontal axis and the level of gravity on the vertical axis.

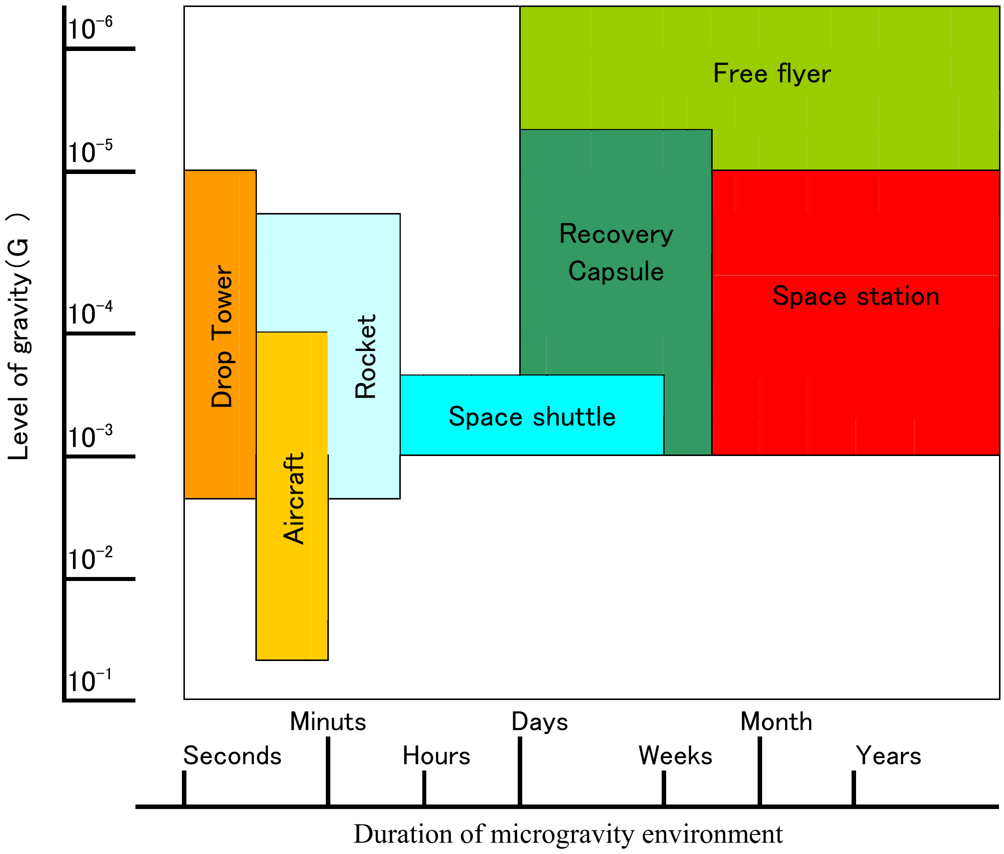


Figure 3.4 Comparison of microgravity production methods

3.3 Experiment under Microgravity Environment

In the field of material sciences, full-scale space experiment under microgravity environment began in the 1970s and now has a history of about 30 years until the current experiment on an earth orbit using the International Space Station(ISS). Over this period, numerous space experiments have been performed on aircraft, small rockets, and free flyers. Since the 1950s, simple short-duration microgravity experiments have also been conducted using drop towers.

References
- JAXA web site

4. Introduction of Microgravity Experiments Using Drop Tower and Aircraft

This chapter introduces some research in three fields that has been conducted using drop shaft and aircraft.

4.1 Physics and Chemistry

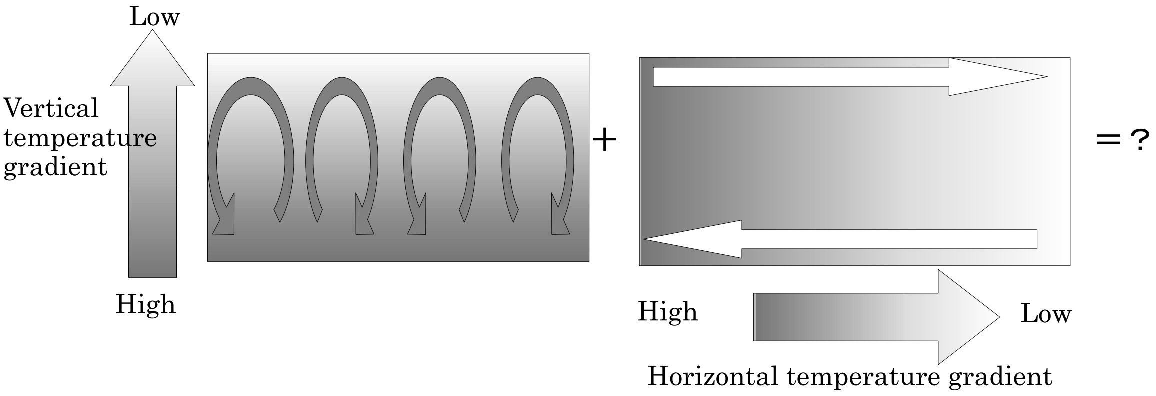
(1) Research on Marangoni convection in a liquid layer caused by bidirectional temperature gradient

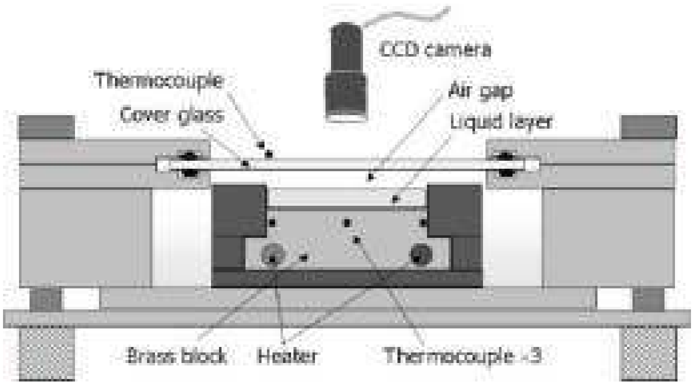
- *Mysterious pattern created by a liquid surface current* -

Hiroshi Kawamura, Tokyo University of Science (JAMIC drop experiment in 2000)

Experiment to induce a Marangoni convection field under microgravity by bidirectional temperature gradient

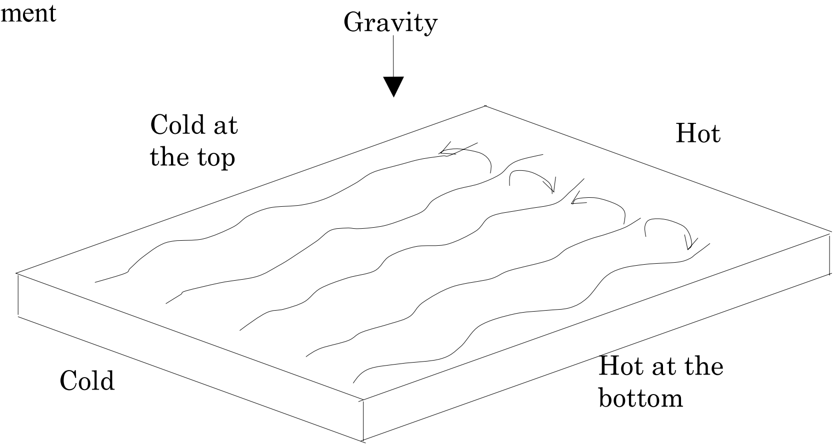
System and Outline of Experiment





To induce convection, constant heat was applied to the bottom of a thin liquid film (silicon oil) with about one mm thick. Horizontal temperature gradient was simultaneously applied from another heating apparatus. Aluminum powder was used as tracer particles to observe flow fields.

Results of Experiment



Conceptual diagram of convection induced by the bidirectional Marangoni effect

Formation of streaks

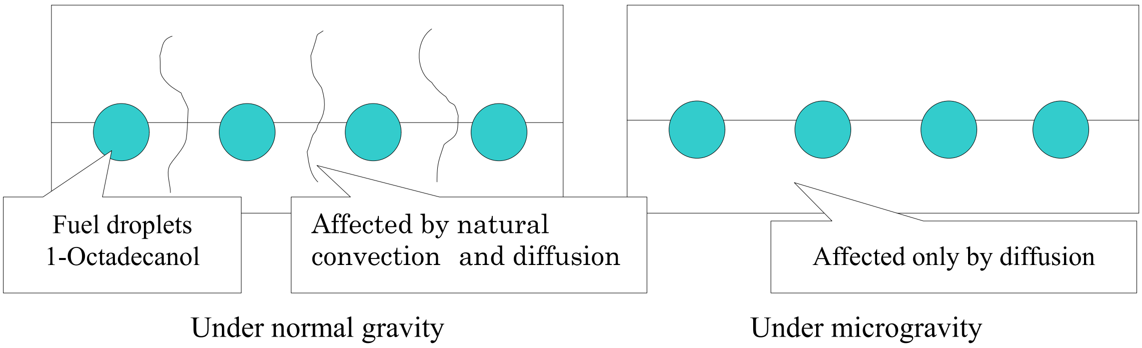
Findings: Under normal gravity with the temperature gradient heating, streaks and generated spiral convection were formed. With the constant heating, cell-like convection was generated by buoyancy-induced blowing. As a free fall begins, the convention was lost in the constant heating. In the former, however, convection in the horizontal direction remained due to the effect of the thermocapillary effect. The disappearance of the spiral flow pattern under the microgravity was a new finding in this experiment.

(2) Evaporation, ignition, and combustion of an array of fuel droplets in supercritical gaseous environments

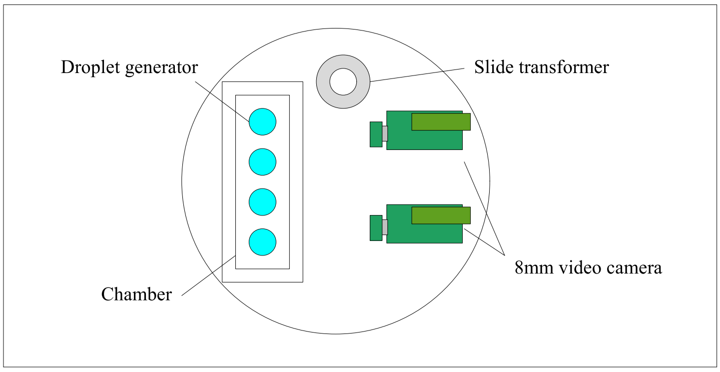
- Seeking the ideal engine for space -

Toshikazu Kadota, Osaka Prefecture University (MGLAB drop experiment in 2000)

Experiments on the combustion of an array of fuel droplets in supercritical gaseous environments under microgravity

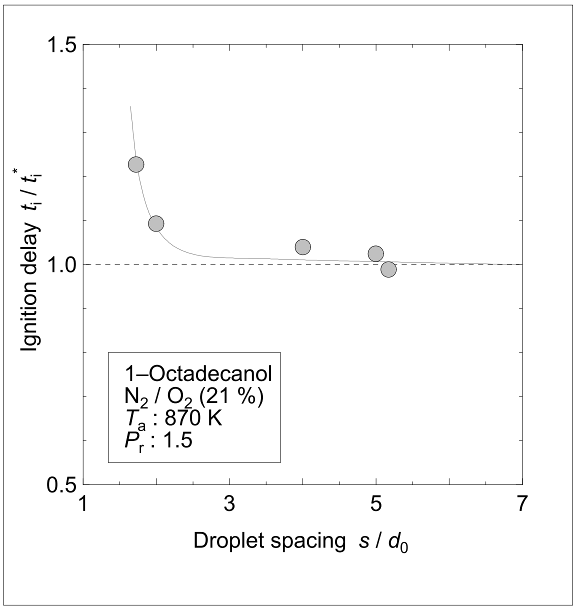


Experimental apparatus and procedure

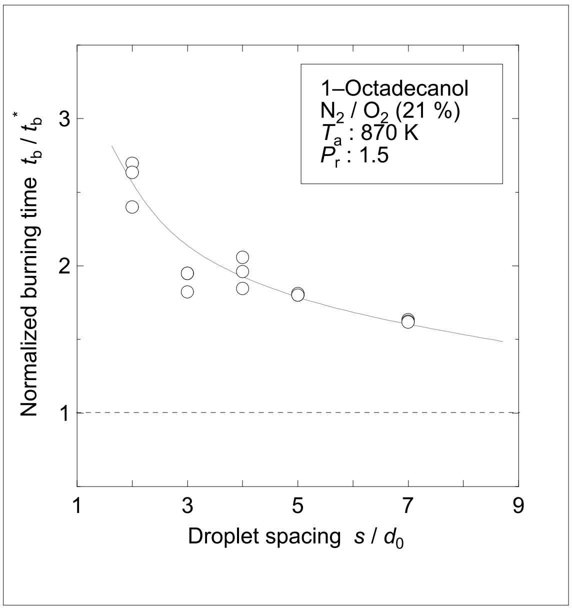


The combustion chamber is filled with high-pressure gas. An array of fuel droplets suspended on a tip of quartz fiber is inserted into the electric furnace installed on the upper portion of chamber resulting in spontaneous ignition and combustion.

Results of experiment



Influence of droplet spacing on ignition delay



Influence of droplet spacing on burning time

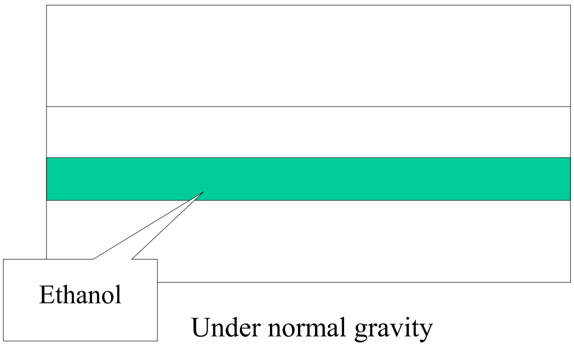
Findings: Reduced droplet spacing causes the suppression of evaporation of individual droplets affected by adjacent droplets, resulting in an increase in ignition delay and burning time. However, the influence of droplet spacing on ignition delay becomes less remarkable with an increase in ambient pressure.

(3) Analysis of interface transformation behavior based on hydrodynamic instability in a microgravity environment

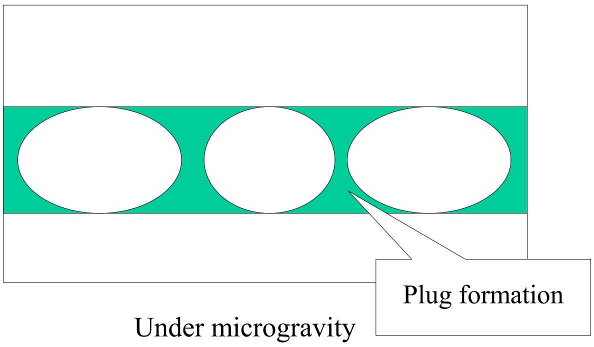
- What happens to water in a pipe under zero gravity? -

Mutsumi Suzuki, Tohoku University Graduate School (MGLAB drop experiment in 2000)

Experiment on the interface transformation of static gas-liquid phase liquid in a horizontal pipe under microgravity

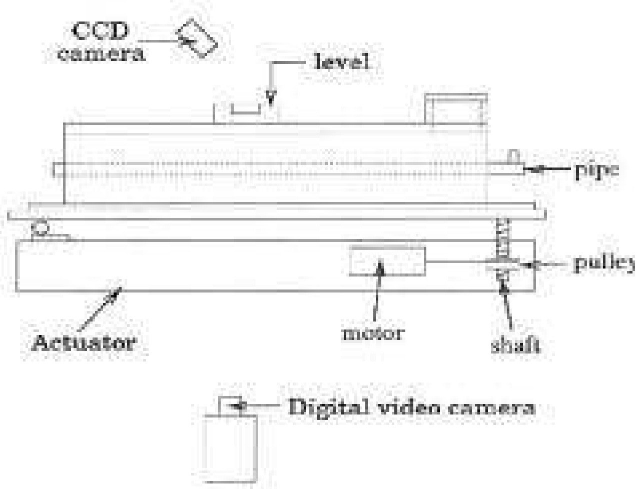


Under normal gravity



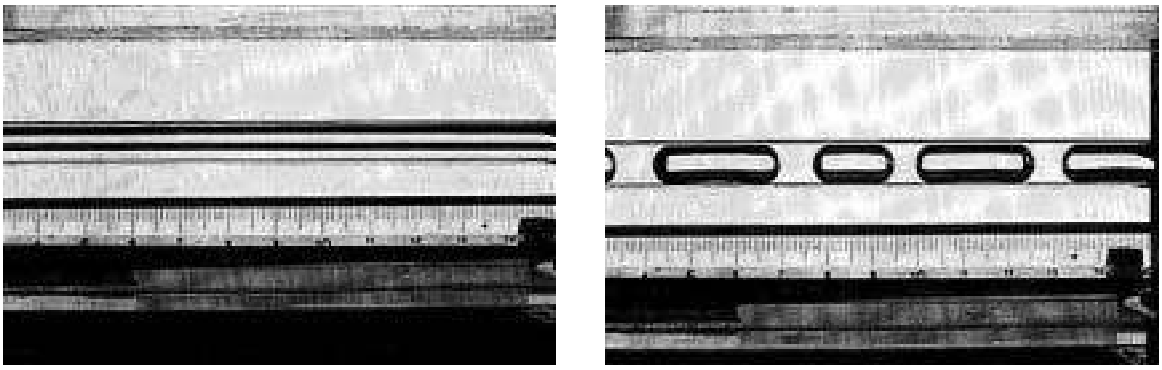
Under microgravity

System and Outline of Experiment



A glass pipe filled with ethanol was dropped in a static state (in the horizontal direction) and the interface behavior was observed with a digital camera.

Results of Experiment



Under normal gravity

Under microgravity

Details of observed section

As the volumetric ratio of the liquid is smaller, the plug formation time is longer. The plug spacing is not constant but varying.

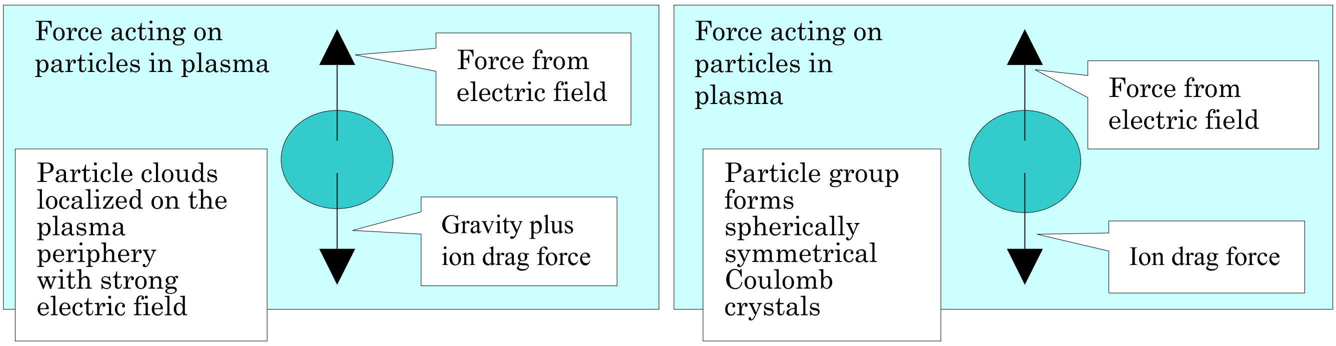
Findings: The average plug spacing was greater than the predicted value based on the theory of linear stability. Similar results were also obtained by an experiment on a vertical pipe (perpendicular).

(4) Dynamic behavior and growth of particles in plasmas under microgravity

- For production of diamond in space -

Satoru Iizuka, Tohoku University (DAS aircraft experiment in 2002)

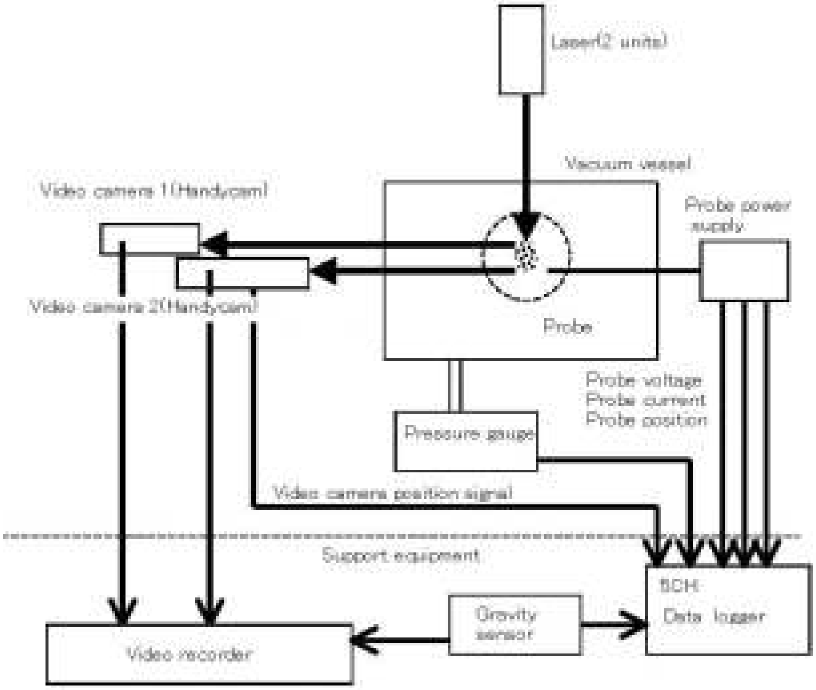
Experiment on the formation of particle cloud structure in plasmas under microgravity

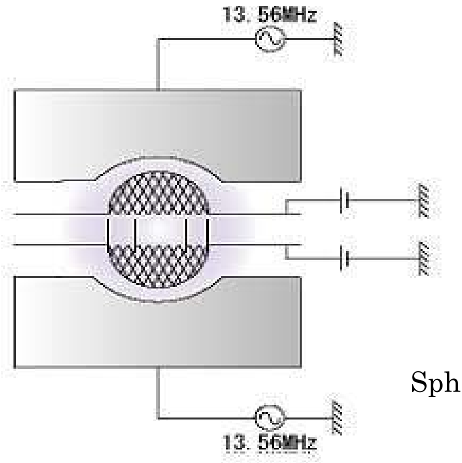


Under normal gravity

Under microgravity

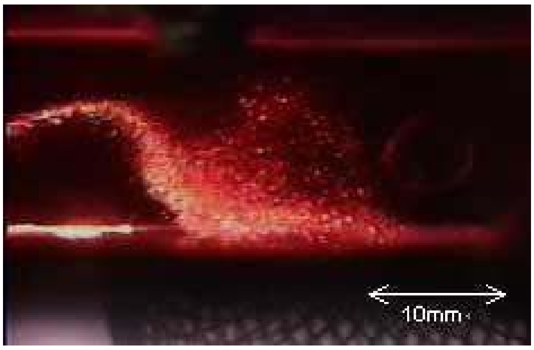
System and Outline of Experiment



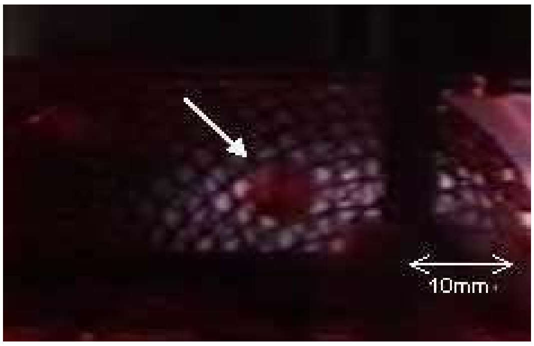


Spherical grid dage

Acrylic particles of 10 µm or larger diameter, supplied into argon plasma inside the spherical grid cage, were negatively charged and observed with cameras by laser sheet beam scattering.



Particle moving like an amoeba



Particle cloud sustained stably at the center of the cage

Findings: Particles with diameter from 10 µm to 6 mm are negatively charged in the plasma to form a particle cloud moving in a potential confined inside the cage. The particle cloud gathers at the center of the cage while changing its shape like an amoeba. After some time, the particles form a Coulomb crystal structure, maintaining a fixed distance from each other.

(5) Research by in situ observations of the heat and mass transfer patterns accompanying nucleation

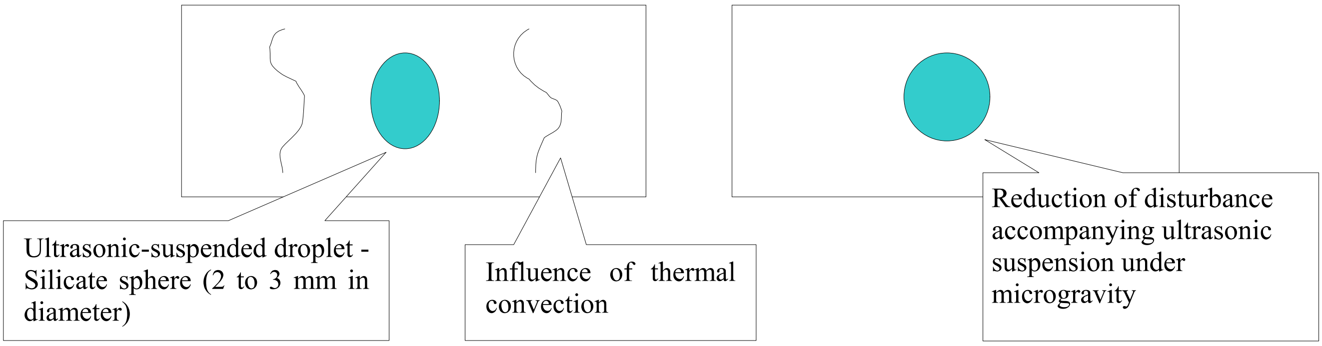
- Seeking the temperature profile of the primordial solar system -

Katsuo Tsukamoto, Tohoku University Graduate School (DAS Aircraft Experiment, 1999)

Experiment on crystallization of suspended molten spherules by hypercooling under microgravity

Under normal gravity

Under microgravity

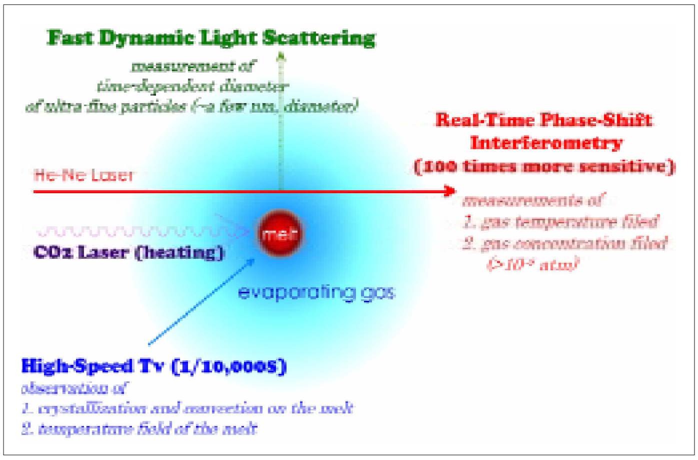


Ultrasonic-suspended droplet - Silicate sphere (2 to 3 mm in diameter)

Influence of thermal convection

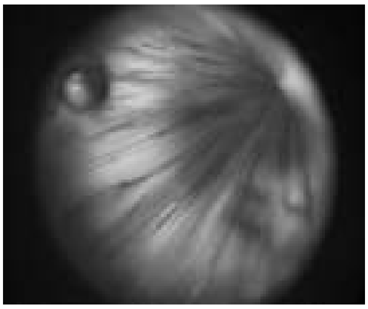
Reduction of disturbance accompanying ultrasonic suspension under microgravity

System and Outline of Experiment



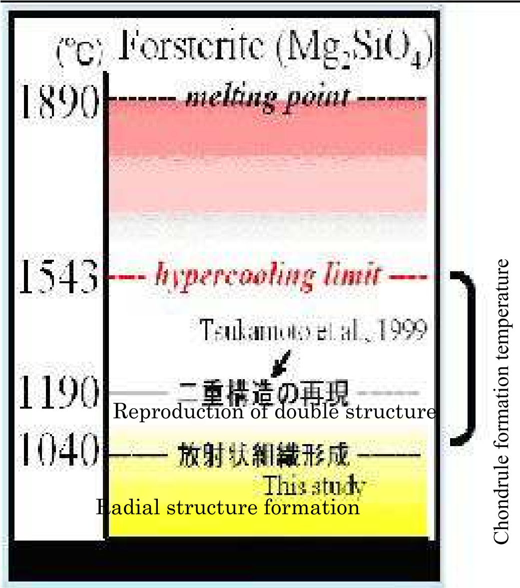
The crystallization process of silicate samples was observed (high-velocity video monitoring and temperature distribution measurement) after the samples were heated and molten by carbon-dioxide laser. To find the mechanism of gas evaporated from the surface of the molten sphere condensing into particles, the melt evaporated gas is sampled with vacuum tweezers.

Results of Experiment

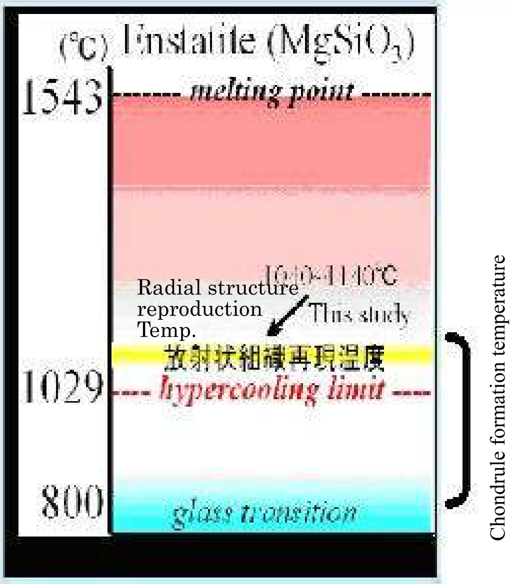


Hypercooled droplets can be expected to exist longer under microgravity because nucleation is greatly delayed. The photo at left shows a radial olivine crystal grown in the maximum hypercooling state (ΔT = 850 K). Olivine is a type of chondrule, a substance thought to be one of the fabricating blocks of the original planetary system. This experiment reproduced olivine for the first time under microgravity.

Structure comparison based on the above reproduction experiment or estimation based on the experiment of nucleation velocity clarified for the first time the temperatures that formed molten substances in the primordial solar system 4.6 billion years ago. The diagrams at right show the temperatures that formed chondrules. The experiment successfully formed crystals from hypercooled melt a magnitude larger than conventional hypotheses allowed.



1100 ~ 1600°C (ΔT – 300 ~ 800 K)



900 ~ 1200°C (ΔT – 350 ~ 650 K)

Findings: The velocity of crystal growth on the surface of melt is 10 to 1,000 times faster (about 1 mm/second) under microgravity than under normal gravity. Therefore, a theory of formation instability should consider not only heat conduction but also heat radiation. Under microgravity, a melt is vitrified with increased viscosity because the temperature in the cooling process approaches the glass transition temperature due to slow nucleation. Evaporated gas immediately forms microparticle crystals under microgravity (amorphous solids under normal gravity).

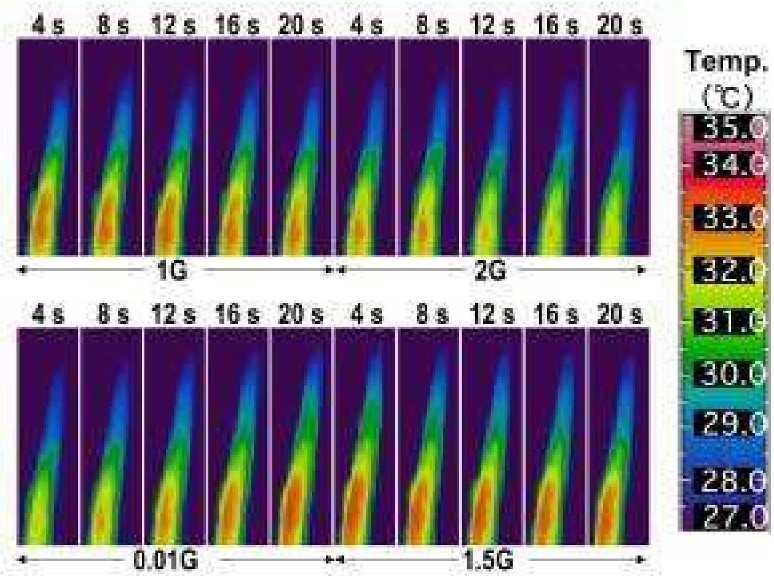
4.2 Life Sciences

(1) Influences of microgravity on heat and gas exchanges in plant leaves (Aircraft experiment)

Yoshiaki Kitaya (Osaka Prefecture University), Akira Tani (Tokai University), Eiji Goto (Chiba University), Takahiro Saito (Utsunomiya University), and Hideyuki Takahashi (Tohoku University)

To grow plants in space, it is necessary to develop cultivation equipment capable of controlling various environmental factors that differ from those on the ground. One of these factors is air convection that occurs on the ground due to gravity. Air convection helps plants with the intake of carbon dioxide and the emission of oxygen, water vapor and heat. Under microgravity conditions, air convection should be controlled artificially for the sound growth of plants. Therefore, we attempted to assess the influences of gravity levels from 0.01 g to 2 g on the carbon dioxide gas exchange (the net photosynthetic rate) and temperatures of plant leaves through parabolic airplane flight experiments (Figure 1).

Figure 1 Experimental apparatus on an airplane



Influences of gravitational changes on leaf temperature

Figure 2 Leaf temperature changes with gravitational changes

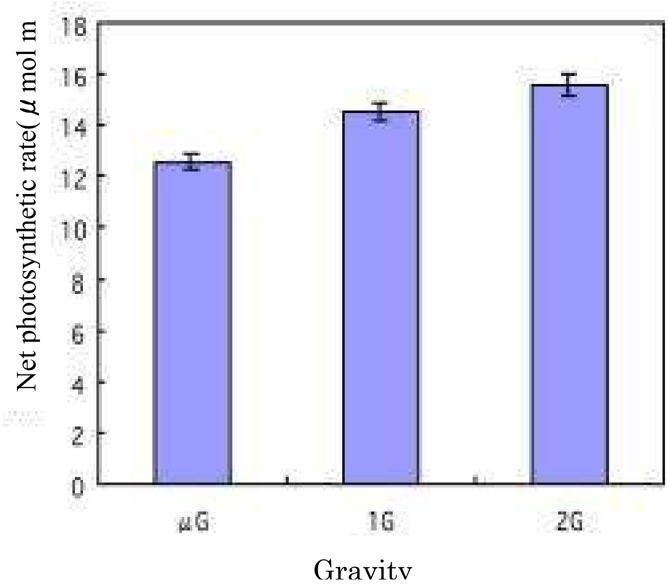


Figure 3 Influences of gravitational changes on net photosynthetic rate

Without forced air convection, the suppression of thermal convection was found to suppress heat and gas exchanges between plant leaves and the ambient air, causing a leaf temperature increase of 1-2°C (Figure 2) and a photosynthetic rate decrease of 20% (Figure 3) over just 20 seconds under a microgravity condition obtained in a parabolic flight experiment.

The results of the parabolic flight experiments indicate that the air current speed should be more than 0.3 m/s near leaves to promote plant growth through stimulating heat and gas exchanges. The direction of the air current from the canopy to the bottom of the shoots of plants was more appropriate than the opposite direction to promote growth of plants cultured at a high density. Excess leaf temperature would disorder the leaf physiological processes and retard plant growth.

(2) Aircraft experiment using human subjects

Yoshinobu Ohira and Fuminori Kawano, Osaka University

Antigravity muscle, soleus, is composed of 80 to 90 percent of slow-twitch fibers. In space, however, the loss of antigravity muscle activity is known to shift these muscle fibers to fast-twitch ones. Although muscle fibers and motor neurons, which innervate them, have similar characteristics, the effect of exposure to microgravity on the characteristics of motor neurons is not clear. This experiment, therefore, was performed to investigate the response of Hoffman reflex during a parabolic flight.

While the subjects were under the gravity of 1-G and 2-G and also microgravity during a parabolic flight by Diamond Air Service's small jet airplane (MU-300), the Hoffman reflex of the human soleus muscle was recorded along with blood distribution (in the chest, abdomen, thigh, and lower limb regions) in 5 seated subjects (Nomura et al., Neurosci. Lett. 316: 55-57, 2001). Stimulating electrodes were placed on the common peroneal nerves (Figure 1). Both M and H waves were recorded. The stimulation frequency was 1 Hz.

During the parabolic flight, no noticeable changes were observed in the period of latency from the stimulation of the soleus muscle to the emergence of M and H waves. In addition, the magnitude of M waves was not influenced by the changes in G level during the parabolic flight. But the magnitude of H waves was accelerated remarkably under microgravity (Figure 2). This magnitude, however, was not affected by 2-G or 1.5-G before and/or after microgravity exposure. Similarly, the H/M ratio rose remarkably under microgravity but was unaffected at 2-G or 1.5-G (Figure 3). These findings suggest that the excitation of the motor neuron cells, innervating the soleus muscle fibers, was enhanced in response to sudden exposure to microgravity. It is also reported that spaceflight caused a selective reduction of oxidative enzyme activity in only medium-sized motor neurons in the ventral horn at L_5 segmental level of spinal cord, innervating slow-twitch muscle fibers (Ishihara et al., Acta Anat. 157: 303-308, 1996). These results indicate a close relationship between changes in the characteristics of motor neurons and microgravity exposure.

According to the impedance analyses, the distribution of body fluid in the lower limb and thigh of seated subjects tended to increase during the exposure to microgravity. It is speculated that the blocked shift of body fluid toward lower extremity due to the compression of buttocks in hyper-G environment during the ascending phase of flight may be suddenly released, and thus fluid was shifted toward the lower extremity. Under microgravity, the body liquid distribution shifted toward the upper body in subjects maintained the upright position throughout the parabolic flight using a mille-sized jet airplane (G-II), on the contrary. As in the sitting subjects, the H-wave magnitude in the standing subjects also increased during exposure to microgravity (Unpublished data). Although the influence on the fluid distribution in the lower extremities was opposite between the sitting and the standing position, the H-wave magnitude in soleus muscle increased similarly under microgravity. Therefore, it is indicated that changes of the Hoffman reflex under microgravity are not necessarily related to the body fluid distribution.

Figure 1: Subjects during a parabolic flight. This photo shows that the subject maintained the standing position.

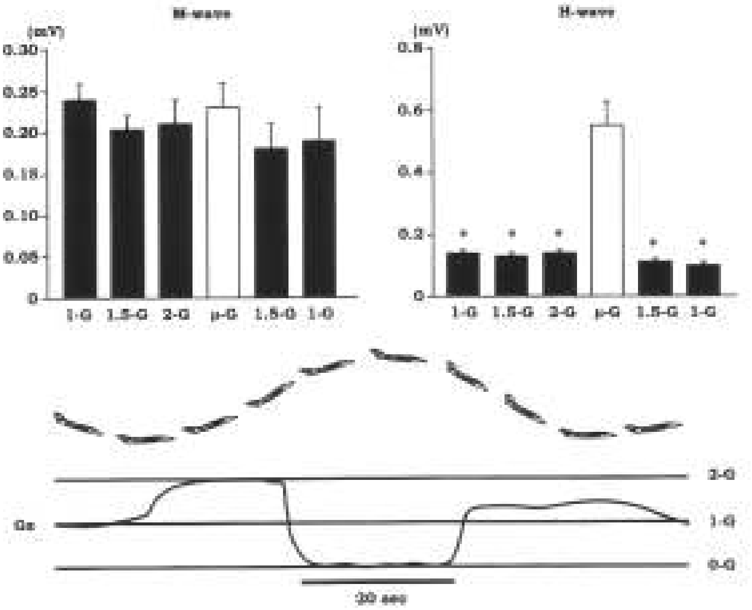


Figure 2: Changes in M-wave and H-wave magnitudes in human soleus muscle during a parabolic flight. Mean ± SEM. *: $p < 0.05$ vs. μ-G.

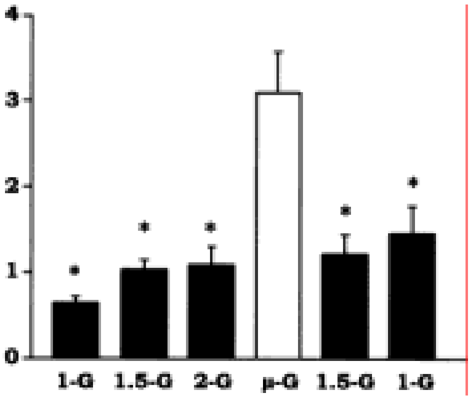


Figure 3: Changes in the H/M ratio in human soleus muscle during a parabolic flight. Mean ± SEM. *: $p < 0.05$ vs. μ-G.

(3) Aircraft experiment using laboratory rats

Yoshinobu Ohira and Fuminori Kawano, Osaka University

It is well known that a space flight causes an atrophy of soleus muscle, but its detailed mechanism is still unclear. Therefore, this experiment was conducted to investigate the responses of neural and muscular activities to exposure to microgravity.

During a parabolic flight using Diamond Air Service's small jet airplane (MU-300), we simultaneously recorded the electromyogram (EMG) of hindlimb muscles and both afferent and efferent neural activities, placing the electrodes at the L_5 segmental level of spinal cord in adult male Wistar rats. Data was recorded in conscious rats. All cables used to record bioelectrical activities were passed under the skin and connected to a transmitter (Dia Medical) attached to the head of the rat (Figure 1). Wireless recording was found to be effective, since the behavior of the rat under microgravity was unpredictable. The cage size was designed according to the transmitter capability. We used an FM transmitter to transmit the activity signals. No interference from the aircraft or other FM signals was seen in the transmitted signals inside the aircraft during the parabolic flight.

Under 1-G environment, the continuous activities of soleus muscle and both afferent and efferent nerves were observed. These activity levels, especially soleus EMG and afferent neurogram, were elevated when the environmental gravity was increased (Kawano et al., Neuroscience 114: 1133-1138, 2002). Under the microgravity, however, the soleus muscle activity immediately disappeared and the afferent neural activity also declined noticeably (Figure 2). Further, the efferent neural activity tended to decrease insignificantly. Once gravity was restored after microgravity, the activities of soleus muscle and the afferent and efferent neurograms returned to their levels at 1-G. Similar response, but not significant, was also seen in the EMG of lateral gastrocnemius muscle with respect to the same gravitational changes. No noticeable changes were seen in the activity of the tibialis anterior muscle during the parabolic flight. Under gravity at >1-G, the soleus muscle is generally stretched in response to the dorsiflexion of the ankle joint (Kawano et al., Am. J. Physiol. Regul. Integr. Comp. Physiol. 287: R76-R86, 2004). Under microgravity, however, the ankle joints are plantarflexed and the soleus muscle is passively shortened (Figure 3). Since the motor neurons innervating the soleus muscle fibers are distributed at the 5th lumbar vertebrae (Kawano et al., 2004), the decrease of muscle activity due to the shortened muscle length may caused the suppression of the afferent neural activity. It was also reported that compensatory hypertrophy of soleus muscle in response to amputation of synergists was suppressed, if the afferent input was inhibited by deafferentation (Ohira, Jpn. J. Physiol. 39: 21-31, 1989). These findings suggest that the decline in afferent neural activity has a close relationship with the muscle atrophy induced by exposure to microgravity.

Figure 1: A rat during a parabolic flight.

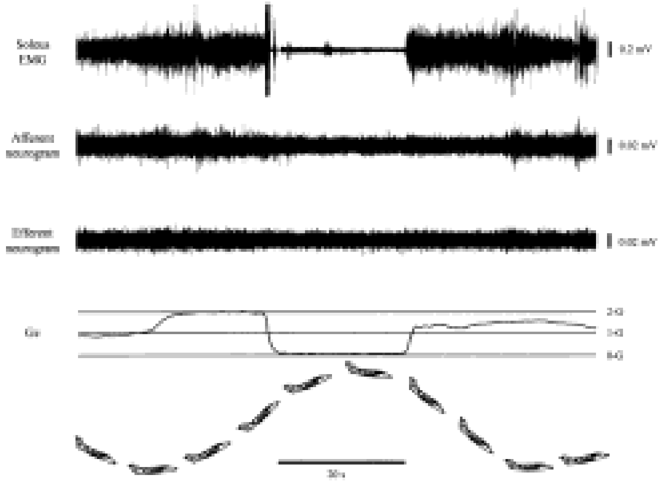


Figure 2: Changes in the soleus muscle activity and the afferent and efferent neural activity recorded at the 5th segmental level of the spinal cord of a rat during a parabolic flight.

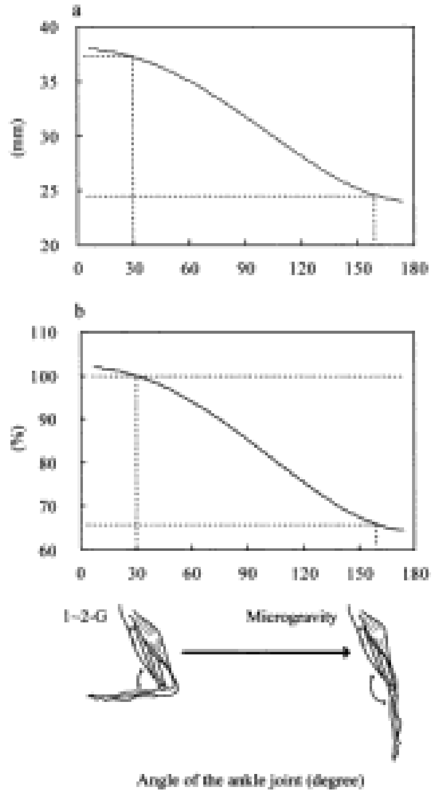


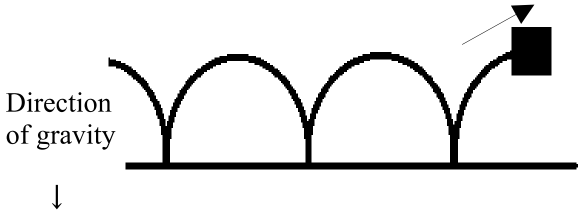
Figure 3: Relationship between the angle of the ankle joint and the soleus muscle length *in vivo* (a) and the percent length relative to the level at 30°C joint angle (100%, b).

4.3 Space Application Technology

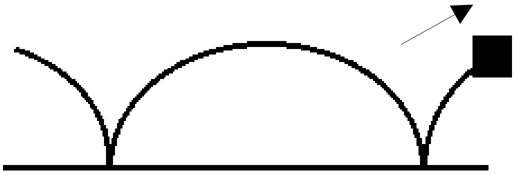
(1) Research on mobility mechanisms in microgravity environment (Drop and aircraft experiments) in 2002FY

- Planetary exploration robot research -

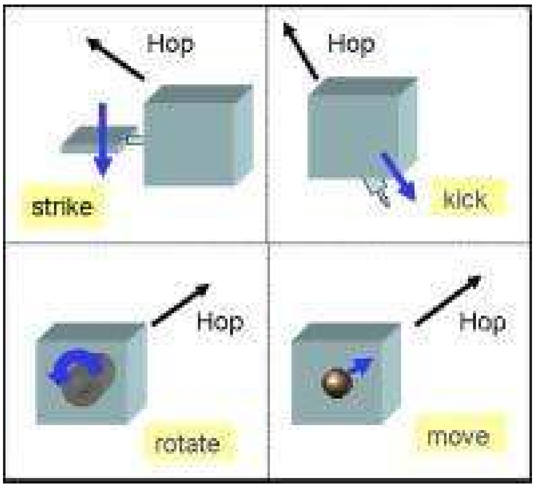
Takashi Kubota, ISAS



●Under normal gravity
One hop distance is short



●Under microgravity
One hop distance is long



Mobility mechanisms

Experimental apparatus for hopping and landing

Rotary hopping robot

● Description of experiment

For traveling under microgravity, we study moving methods by hopping. We fabricate some prototype robots with various mobility mechanisms. With the given torque and energy as parameters, we observe the hopping behavior, hopping orientations, and landing behavior of the robots in microgravity environment to evaluate the mechanisms. This is to prove that friction can be used positively as a means of moving an exploration robot on an asteroid or planet under microgravity.

● Results of experiments

(1) Hopping test

By dropping, we verified the mechanisms of various hopping methods, including torque hopping, energy accumulation hopping, and impulse force hopping. These mechanisms were proved to move a robot stably over a long period under microgravity.

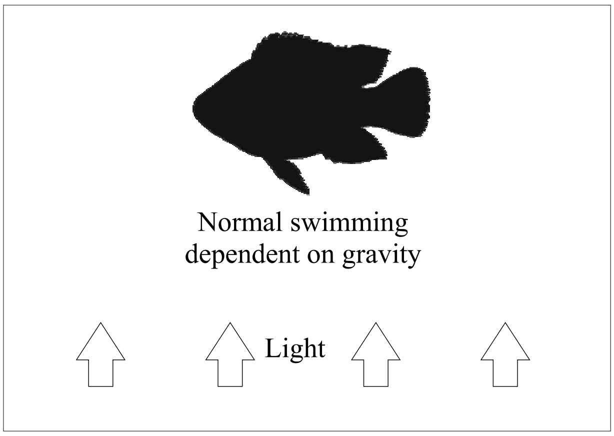
(2) Re-landing test

We released a spring-type robot by a spring mechanism and activated to see whether the desired landing behavior, a dampened landing with little bouncing, could be obtained. The mechanisms were proved effective.

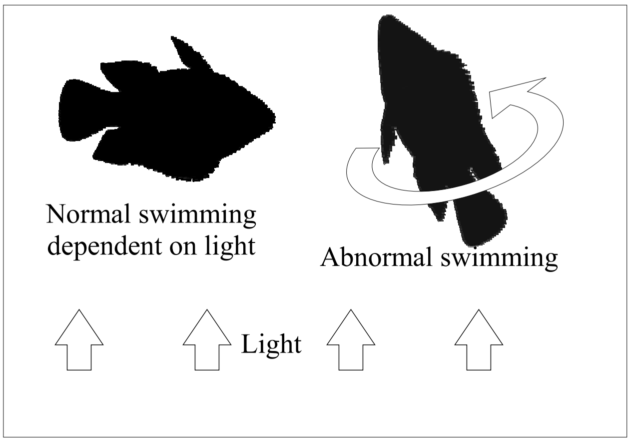
(2) Development of a large closed fish-breeding system making use of food chains (Aircraft experiment in 1998)

- Observation of the swimming behavior of fish under microgravity: Can fish swim under zero gravity?

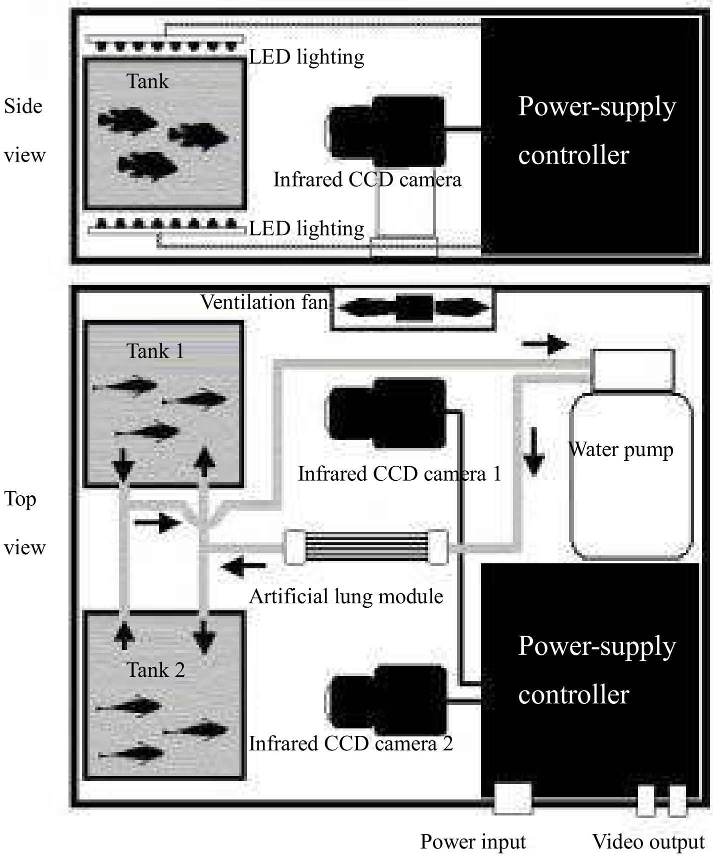
Toshio Takeuchi, Tokyo University of Marine Science and Technology



Under normal gravity



Under microgravity



Tilapia *Oreochromis niloticus*, a species of edible fish, were photographed and filmed with infrared CCD cameras when they were placed in a microgravity-proof, sealed observation tank that was mounted on a rack in the aircraft. Then their swimming behaviors under microgravity environment were analyzed.

LED light was supplied from a single direction. The fish were exposed to either visible light or near-infrared light according to the experimental conditions. Larval tilapia with total length of 2-4 cm were accommodated in a 10 cm² acrylic tank, and was supplied with oxygen by passing breeding water through an artificial lung module.

Results of experiments


Under normal gravity

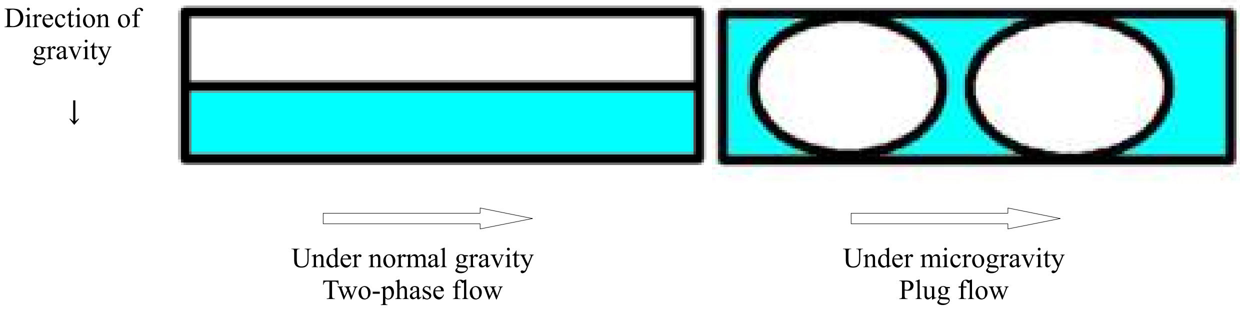

Under microgravity

Findings: When light irradiation of an emission wavelength < 750 nm was supplied, nearly all the experimental individuals could keep posture dependent on light (dorsal light response). When the fish were tested under infrared light irradiation of an emission wavelength > 750 nm, abnormal swimming behaviors, such as rolling and looping, were mostly observed. However, 10％ individuals showed the capacity for sensing the infrared light and conducted dorsal light response. Moreover, genealogical difference in the microgravity resistance was found in fish strains by analyzing swimming behaviors of the fish with different normal swimming rate throughout two generations.

(3) Development of a high-performance gas-liquid separator with Y junction (Drop and aircraft experiments in 1998)

- Simple gas-liquid separation process for two-phase gas-liquid flows under microgravity -

Terushige Fujii and Hitoshi Asano, Kobe University



Gas and liquid separation with a Y junction

This technique separates a two-phase flow of gas and liquid with a Y junction, a common pipe element (Figure 1), to extract the liquid. Figure 2 shows the results of a ground experiment with the ratio of mass flow rate at the exit (ex1) to that at the inlet (in) on the horizontal axis and the ratio of gas flow rate on the vertical axis. From this figure, we see that the gas flow rate depends on the ratio of mass flow rate and that only liquid can be extracted at the exit (ex1) with no gas flow when the junction angle θ is 90 degrees and the ratio of mass flow rate ratio is below the point marked with a down arrow. More liquid can be extracted as the value of θ is made smaller. Since gas and liquid cannot be separated completely, however, it is important to clarify the conditions of the down arrow.

Phase separation experiment under microgravity

Accurate observation of flow field (Drop experiment)

To clarify the influence of gravity on phase separation behavior at the junction, it is effective to observe changes of flow behavior while changing the gravity. Therefore, we selected a drop-tower experiment where normal gravity can be changed to microgravity smoothly not through excess gravity and the G-jitter under microgravity is small. From the results of an experiment (Figure 3), we see clearly that the transition to microgravity changes the flow behavior at the junction inlet and enables phase separation.

Measurement of gas-liquid separation performance (Aircraft experiment)

To evaluate gas-liquid separation performance quantitatively, it is necessary to create the phase-separation performance curves shown in Figure 2. However, 10 or more data points are needed about each inlet condition and it is not feasible to obtain all the required data points under microgravity. Therefore, we developed an experiment technique. The flow rate at exit 2 is gradually increased under microgravity to see the maximum flow rate where only liquid can be extracted. This technique was used for evaluation with the observation of phase-separation behavior. We selected an aircraft experiment considering the time required for measurements and the necessity of controlling the equipment during experiment.

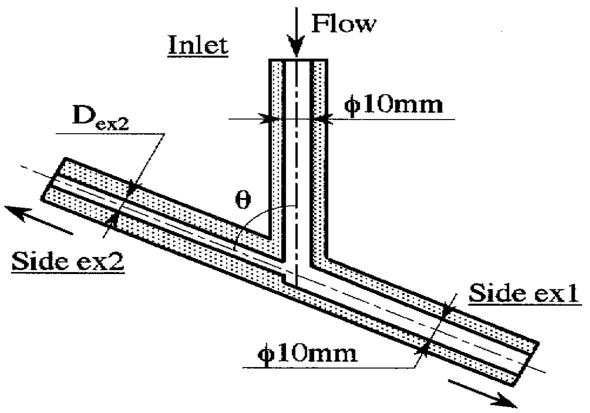


Figure 1 Junction configuration (installed on a horizontal plane)

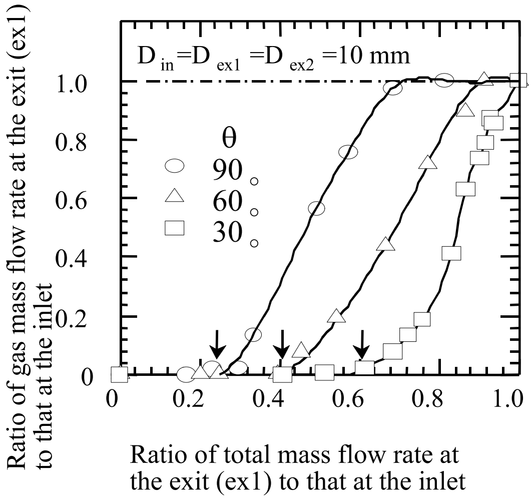


Figure 2 Phase-separation characteristics

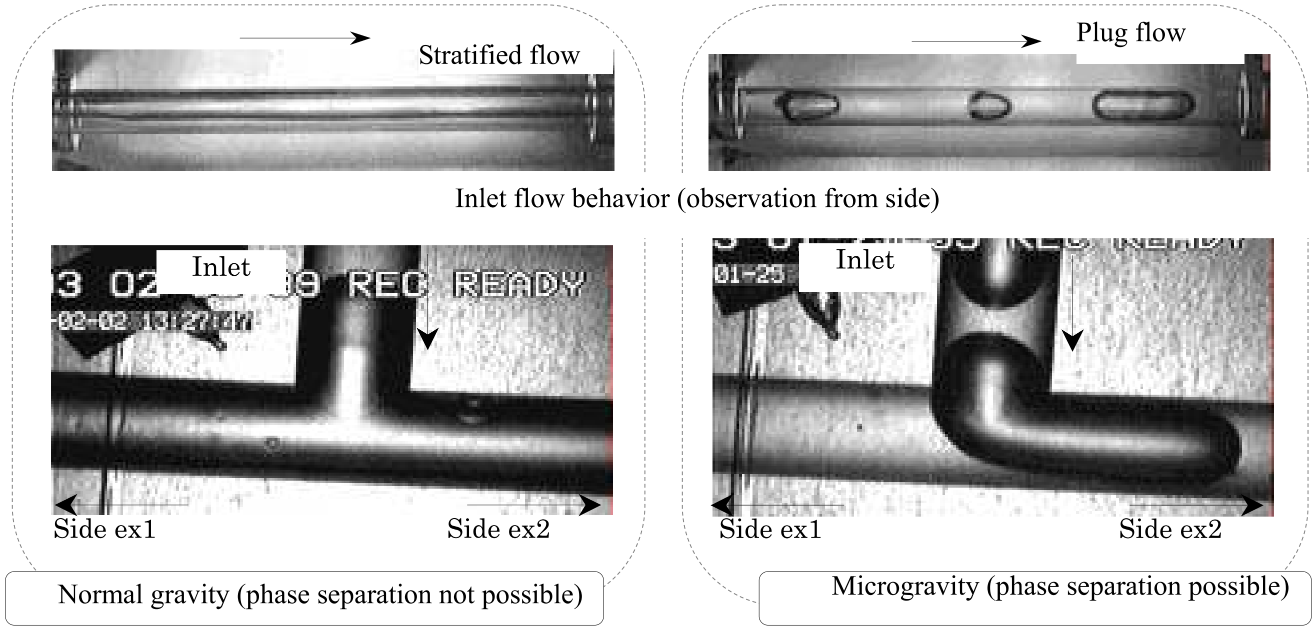
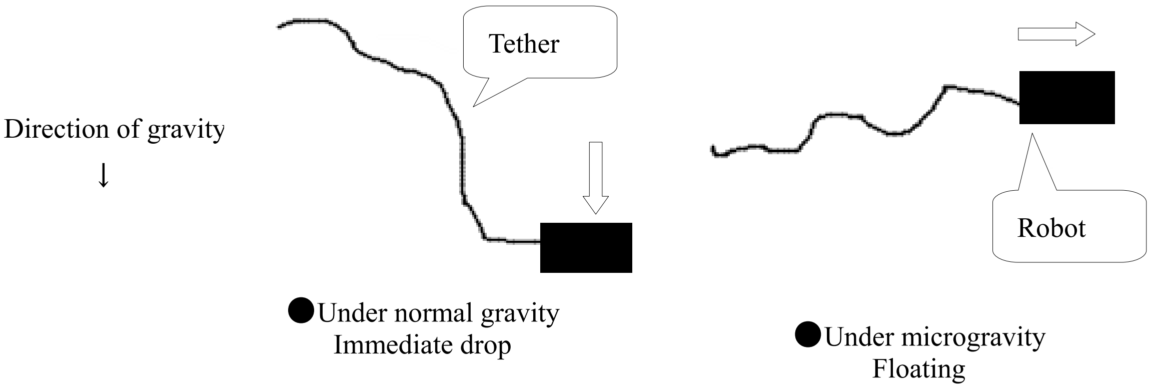


Figure 3 Phase-separation behavior (observation from top)

(4) Research on the dynamics and control of a tethered space robot under microgravity (Drop and aircraft experiments in 2001)

- Space robot research -

Masahiro Nohmi, Kagawa University



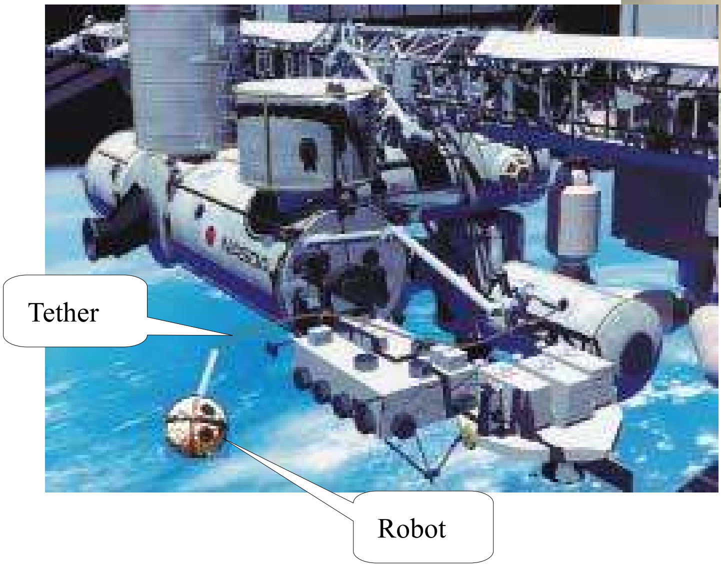
● Summary of experiment

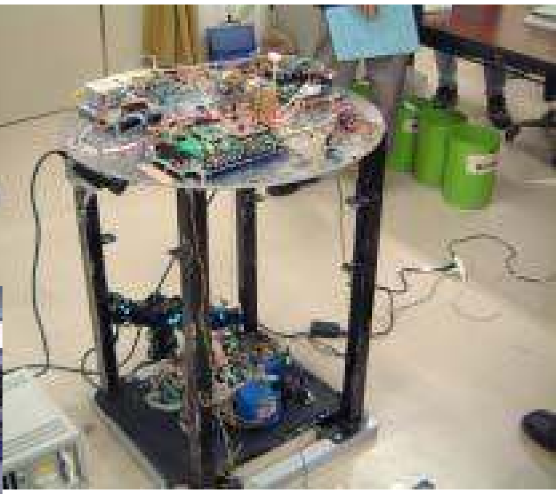
To develop a practical tethered space robot that has only been analyzed theoretically, we verify a method of controlling the orientation of a tethered space robot and analyze the behavior of the robot in this study. Especially under microgravity, tether is susceptible to large displacement or deformation. These experiments are focused on whether the tether tension can be utilized to control the orientation of robot under microgravity.

● Results of experiment

The drop experiment proved the effectiveness of the orientation control method. In the aircraft experiment, however, large disturbances made it difficult to obtain the desired results. Evaluation in the free space of the aircraft, however, proved the orientation control as effective. According to the results of experiment, a small robot (about 1.5 kilograms) is recoverable if the microgravity accuracy can be maintained to some extent.

Use of tether (image)





Experimental apparatus

(5) Droplet-flow convergence experiment (Drop experiment in 2002)

- Establishing radiator technology for space -

Tsuyoshi Totani, Hokkaido University

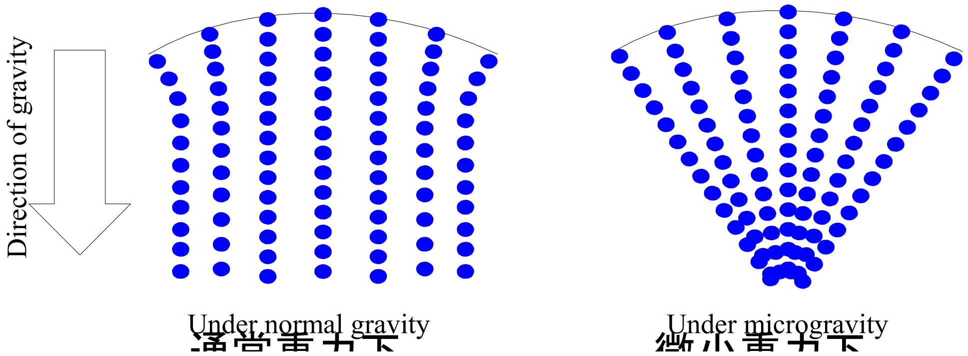


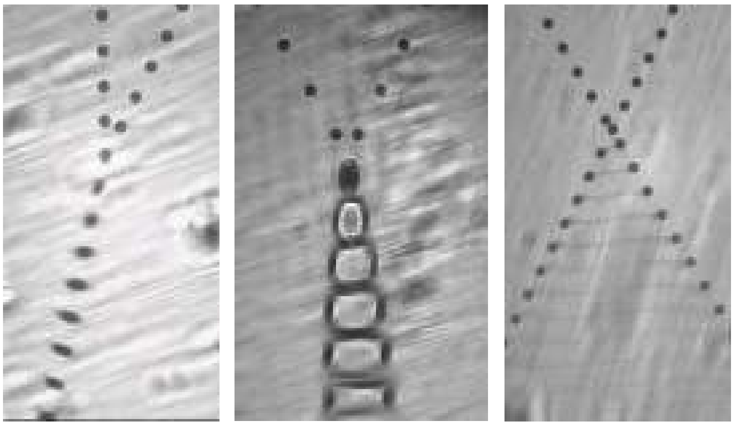
Figure: Differences in droplet-flow convergence between normal gravity and microgravity

● Summary of the experiment

This project is part of the elemental research on space radiators utilizing droplets. Under normal gravity, the gravity influences the flight path of the droplets as shown in the figure. Under microgravity, however, droplets can be gathered at one point. This allows the droplet collector to be small. In this experiment, we investigated the convergence behavior (the direction of the droplet flow and the coalescence and dispersion of droplets) of droplet flows from three droplet generators as well as the convergence behavior of droplet flows from curved droplet-generating orifices (three holes in a row). Data on the convergence of the droplet flows in space was taken and used as the basic data for evaluating numerical simulation programs.

● Results of experiment

In the photographs, the working liquid (silicon oil) looks black. Droplets from two droplet generators converge and then collide. Based on this experiment, we established a technique of converging droplet flows on one point under microgravity. In addition, droplets were found to show various behavior (from left: fusion, ring formation, and formation of string-like shapes between droplets) after collision.



5. Selection Criteria for Drop Shaft Experiment and Aircraft Experiment

5.1 Drop Shaft Experiment or Aircraft Experiment

There are currently two facilities in Japan offering relatively easy microgravity experiments: the Micro-Gravity Laboratory of Japan (MGLAB), operating drop shaft facilities, and Diamond Air Service (DAS), operating aircraft (MU-300 and G-II). Chapters 6 (Drop Shaft Experiment) and 7 (Aircraft Experiment) discuss these facilities in detail. This chapter presents the main criteria needed to decide whether to use drop shaft facility, aircraft, or both for your microgravity experiment.

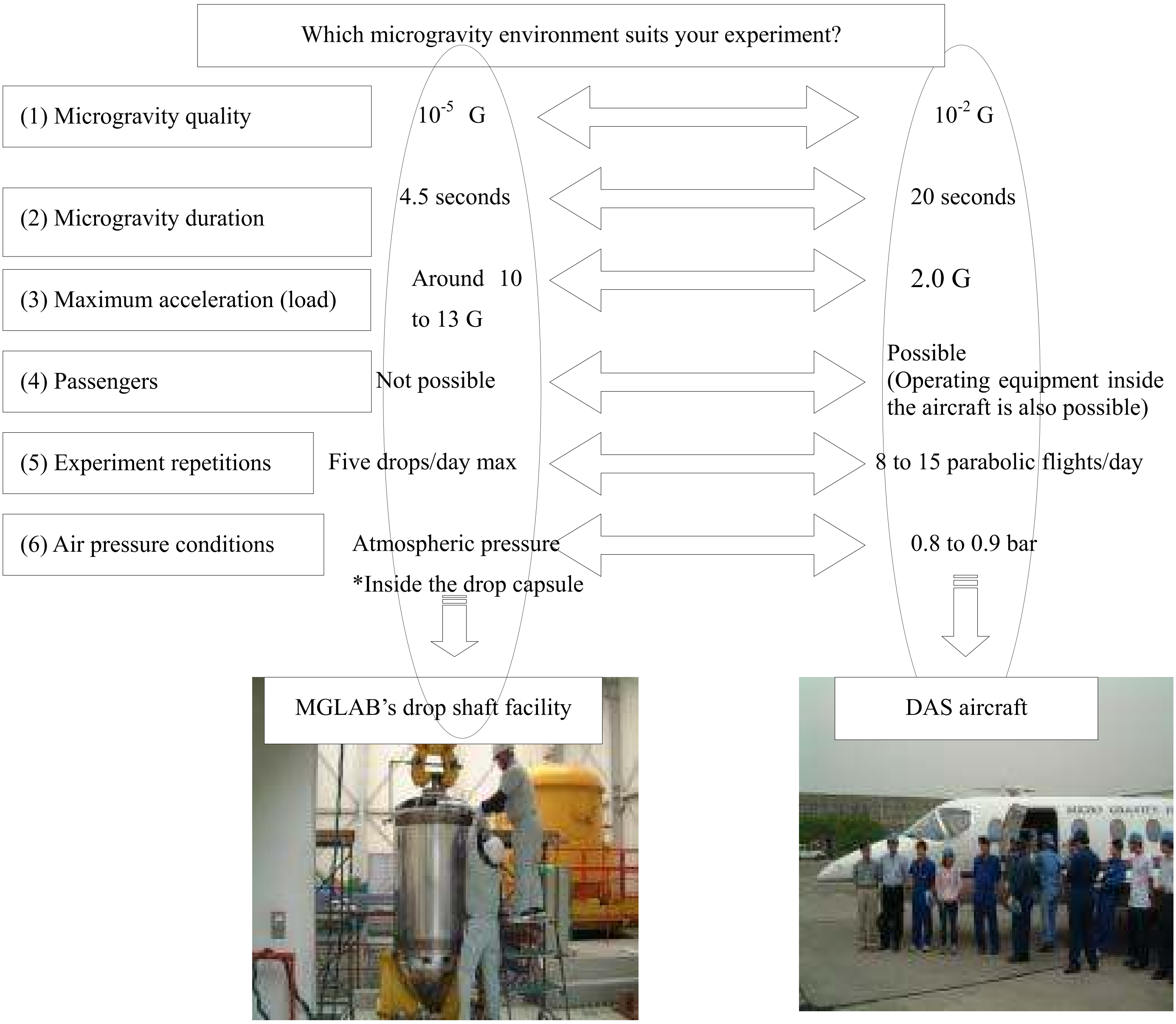


Figure 5.1 Drop Shaft Experiment or Aircraft Experiment?

5.2 Selection of Drop Shaft or Aircraft Experiment by Experts

(1) Reasons for selecting drop shaft experiment

1	Able to obtain microgravity of good quality
2	Able to observe initial reactions precisely
3	Takes long to change parameters each time

(2) Reasons for choosing aircraft experiment

1	Able to obtain microgravity of longer duration compare to the drop shaft experiment
2	Able to ascertain tendency in responses as a phenomenon
3	Able to change parameters manually while observing the results of experiment
4	Able to perform experiment on people

(3) Reason for choosing both types

1	Select drop shaft experiment for high-quality microgravity and aircraft experiment for long-duration microgravity.

6. Drop Shaft Experiment

This chapter describes drop shaft experiment using the drop shaft facility of the Micro-Gravity Laboratory of Japan (MGLAB). MGLAB finished its operation in June 2010. This chapter is kept only for reference.

6.1 Features of MGLAB Drop Shaft Experiment

It is important to know in advance about the facilities of MGLAB and their operational limitations. Only after confirming detail conditions of the facility, you should start designing your experiment and working out your experiment equipment concepts for fabrication. Your experiment will be more secure if you determine the final specifications while adjusting and confirming the interfaces with the MGLAB technical staff as required. You are recommended to refer to the Micro-Gravity Drop Shaft Experiment Facility User's Guide provided by MGLAB when necessary(See MGLAB Web site http://www.mglab.co.jp/).

This section gives main MGLAB specifications, features of experiment support system, and an overview of actual adjustment items you have to coordinate with the interface.

(1) Main MGLAB specifications

Table 6.1 Main specifications of the MGLAB drop shaft facility

Facilities operator	Micro-Gravity Laboratory of Japan (MGLAB)
Location	Toki City, Gifu Prefecture
Drop shaft depth	150 m total, 100 m for freefall
Microgravity duration	About 4.5 seconds
Microgravity level	10^{-5} G
Braking impact	About 10 to 13 G
External power supply	28 VDC/40 A, 100 VAC/12 A
Internal power supply	24 to 28 VDC/40 A, 100 VAC/12 A
Capsule command output	Relay contact output: 24 channels (alternated)
	Open-collector output: 5 channels (100 ms pulse)
Capsule dimensions	Diameter: 0.9 m, Height: 2.28 m
Payload area	Diameter: 0.72 m, Height: 0.885 m
Capsule weight	1,000 kg max (maximum payload weight: 400 kg)
Internal capsule pressure and temperature	Atmospheric pressure, room temperature
Drag compensation	Drop in vacuum (normally about 4.0 Pa)
Braking system	Friction damper and bellows damper
Number of capsules	2

(2) Production of short-duration microgravity environment at the drop shaft facility

The MGLAB drop shaft facility features a 150-meter vacuum drop tube for microgravity experiment. By this facility we can obtain microgravity environment as high as 10^{-5} G that lasts for 4.5 seconds. However, the size and power consumption of the experiment equipment are restricted. Since experiment is controlled remotely (unmanned), its sequencing is also restricted. The braking system can stop the capsule safely with rubber friction dampers. The first friction damper gives a sudden load of 10 to 13 G and then the capsule comes to a stop in the 50 meter braking zone. For details, see Figure 6.4 or the MGLAB Web site http://www.mglab.co.jp/ .

(3) Drop capsule

Figure 6.2 is a photo of the capsule loaded with experiment equipment, and Figure 6.3 shows the dimensions of the capsule.

- Size of experiment equipment: Experiment equipment must be designed to fit inside cylindrical space of 720 mm in diameter and 885 mm in height. (MGLAB lends researchers base plates for mounting experiment equipment.)
- Allowable weight of experiment equipment: The reference weight of experiment equipment alone is up to about 370 kg. The allowable payload weight including rack(s), base plate(s), and experiment equipment is 400 kg.
- A base plate is placed on a rack. Researchers may mount experiment equipment on the base plate freely as long as it fits inside the payload area.
- As Figure 6.5 shows, more than one rack can be used to carry experiment equipment. Middle racks can be positioned at 50-mm increments.
- After experiment equipment is loaded in the capsule, MGLAB will adjust the balance so that the offset weight of the entire capsule will be no more than 0.5 kgf·m. This prevents the capsule from tilting when it is dropped or detached.

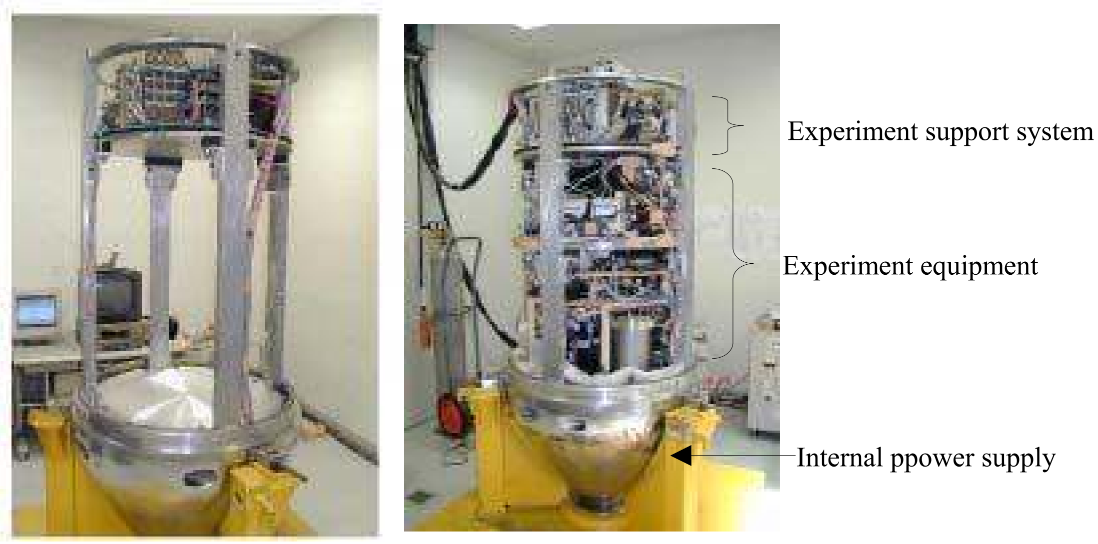


Figure 6.2 Unloaded capsule (left) and capsule loaded with experiment equipment (right)

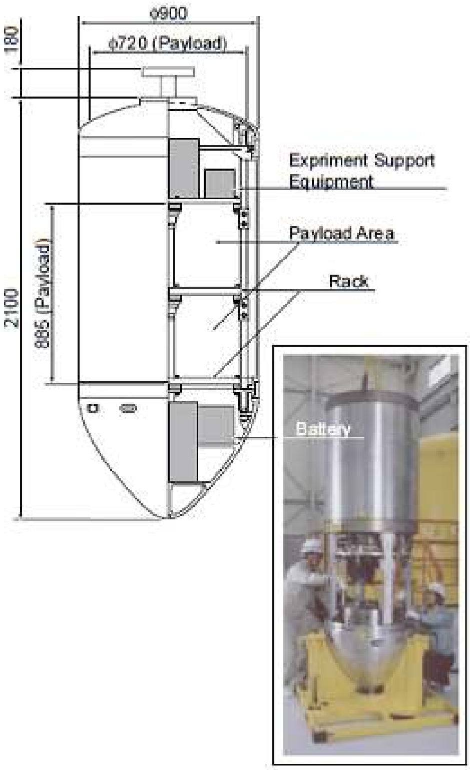


Figure 6.3 Drop-capsule payload area

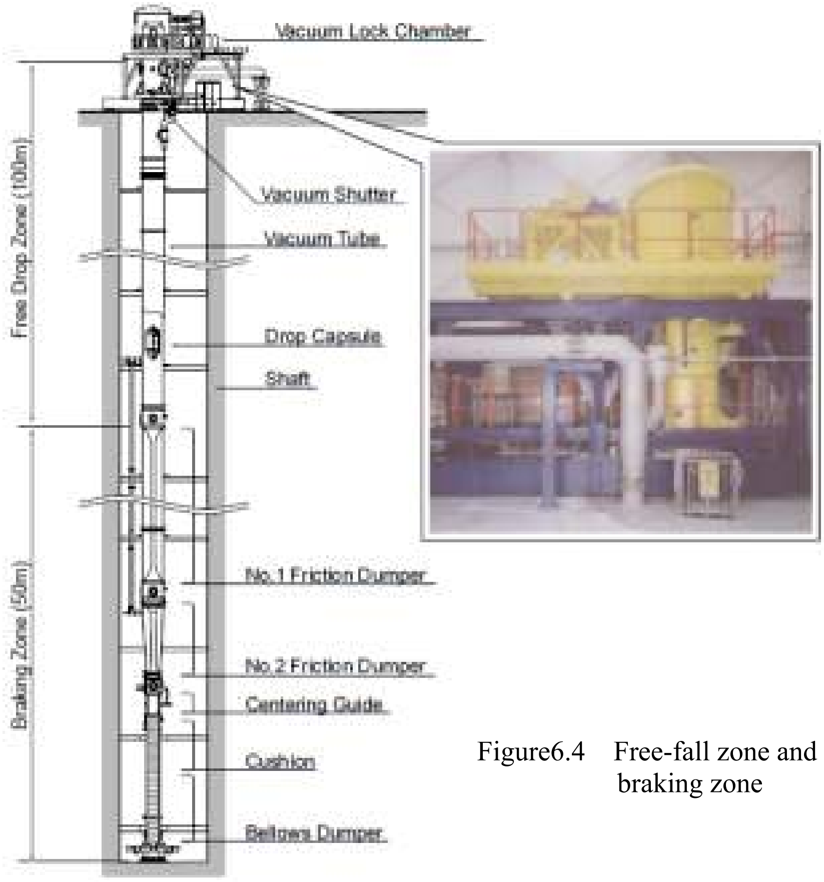
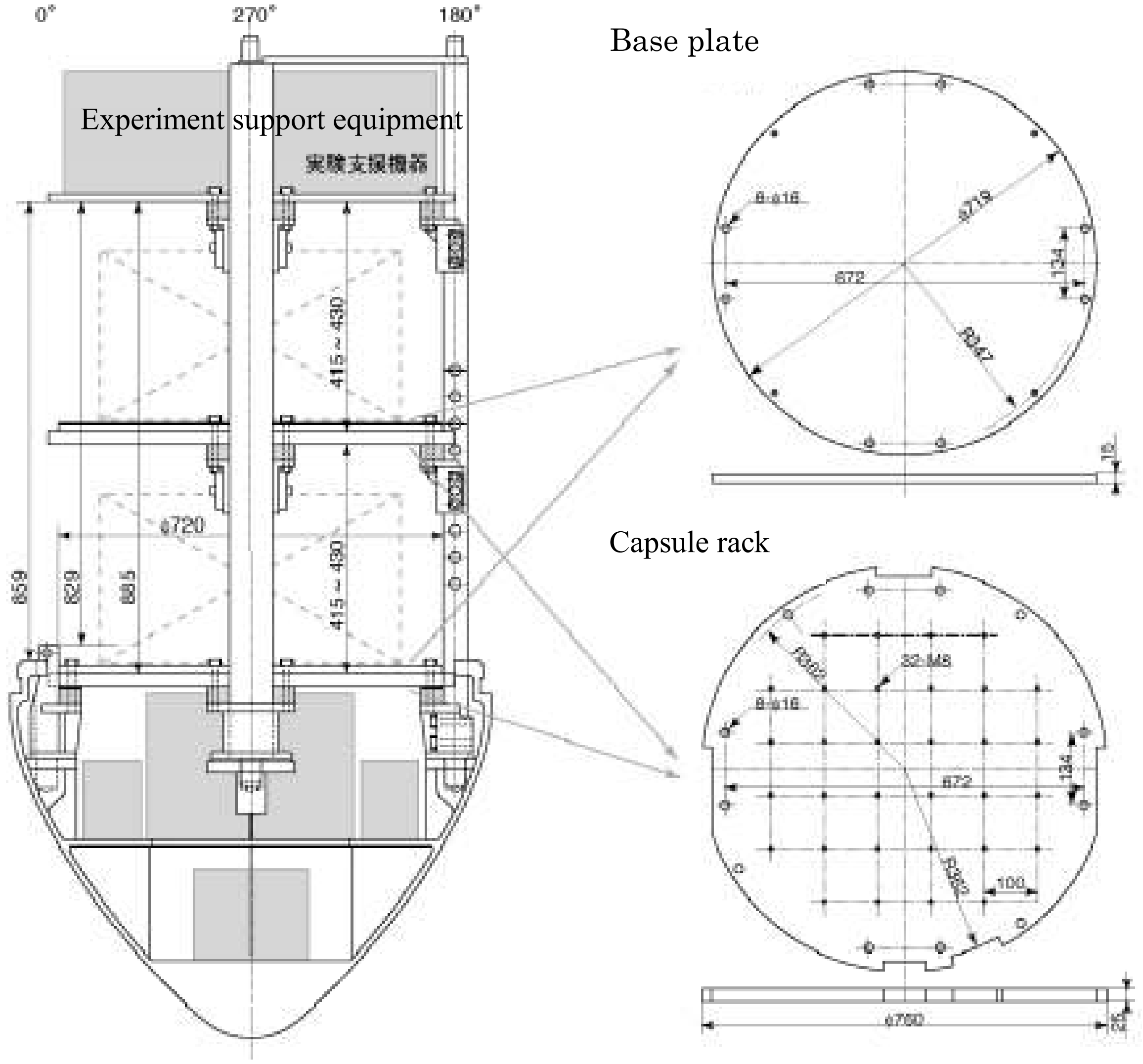


Figure6.4 Free-fall zone and braking zone



Unit: mms

Figure 6.5 Dimensions of capsule rack and base plate

(4) Specifications of short-duration microgravity environment obtained by the drop shaft facility

A: Characteristics of microgravity environment

- The microgravity accuracy in the direction of the earth's center of gravity is 10^{-5} G because of the capsule's free perpendicular drop. Horizontal Influence of gravity during the drop can be ignored in almost all cases.
- After the microgravity duration (4.5 seconds), the capsule with experiment equipment receives 10 to 13 G perpendicularly and about 4 G horizontally for braking.

B: Microgravity accuracy

The figure6.6 shows a graph of typical gravitational changes in the perpendicular direction during a drop shaft experiment.

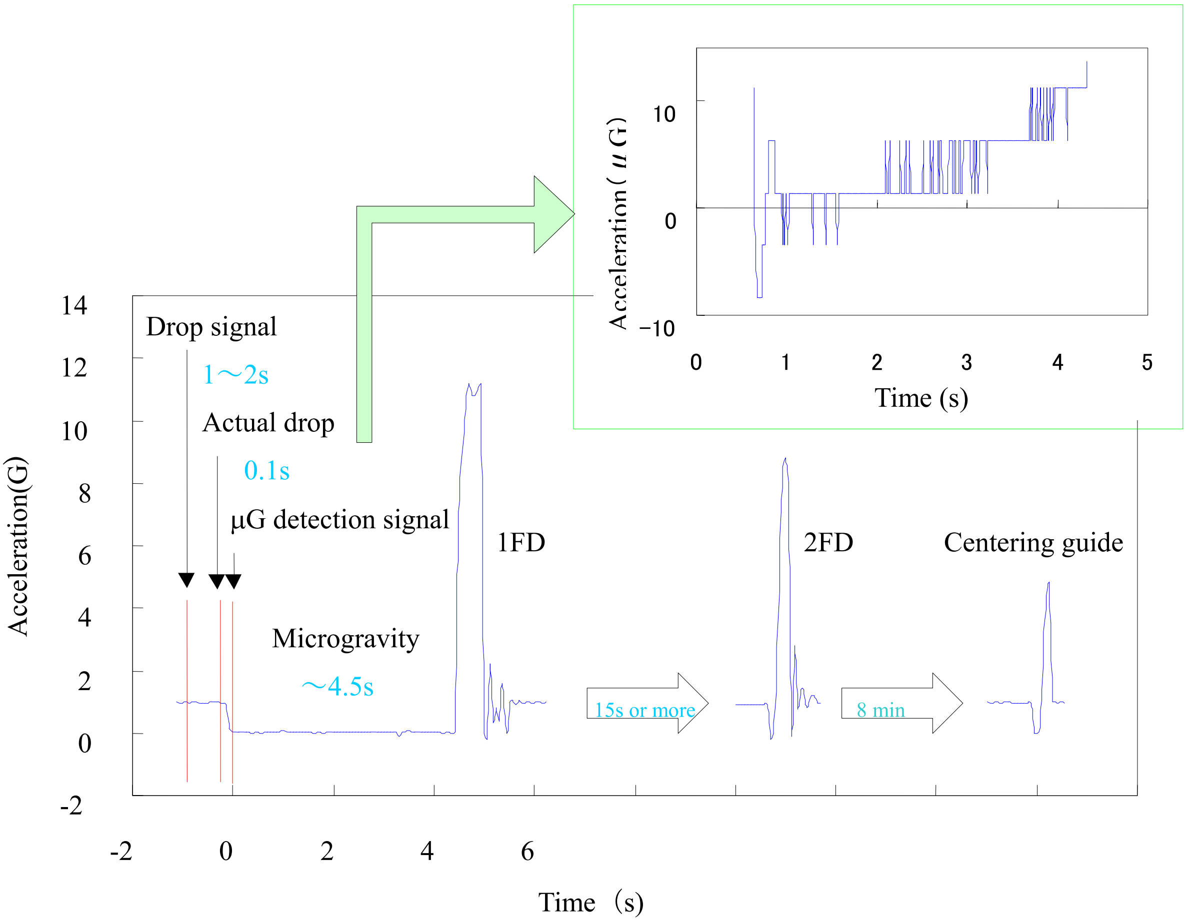


Figure 6.6 Graph of gravity changes

(5) Drop shaft experiment scheduling

A: Schedule for week-long experiment

Table 6.7 gives a general schedule for week-long experiment. Typically 10 to 15 drop shaft experiments are done over one week, although the period of experiment depends on the number of drops. Two teams of researchers can perform experiment by dropping different capsules alternately.

Table 6.7 Week-long schedule (an example)

	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT	SUN
Experiment equipment delivery/receiving inspection	🟥									
Outfitting experiment equipment				🟥						
Balancing/ final interface check				🟥						
Drop shaft experiment				#1	#2、#3、#4	#5、#6、#7	#8、#9	#10		
Equipment removal/shipment								🟥		

Table 6.8 Explanation of each operation step

Experiment equipment delivery/receiving inspection	Researchers check that the experiment equipment delivered has the same configuration and functions as when shipped.
Outfitting experiment equipment	Experiment equipment is loaded in the capsule and connected to the equipment support system.
Balancing/ final interface check	On the first drop day, the drop capsule is balanced after experiment equipment is loaded and installed. The drop capsule interface is also checked. The morning of the first day and even longer time may be spent on this work.
Removal and shipment of experiment equipment	Researchers are responsible for packing up experiment equipment and peripheral devices and arranging their shipping. MGLAB may pass the freight to a transport company on behalf of the researchers. Researchers are recommended to set the number of drops a little fewer for the final day of experiment by considering the time for dismantling and packing up experiment equipment and arranging its shipping.

B: Schedule for each drop shaft experiment

Figure 6.9 illustrates the sequence of operations from loading experiment equipment on the capsule until recovering the dropped capsule. From this chart, you see:

- steps when power is supplied to the experiment equipment and whether it is from an internal or external power supply;
- the timing of commands transmission to the experiment equipment; and
- the delay time until the drop command switch is pressed.

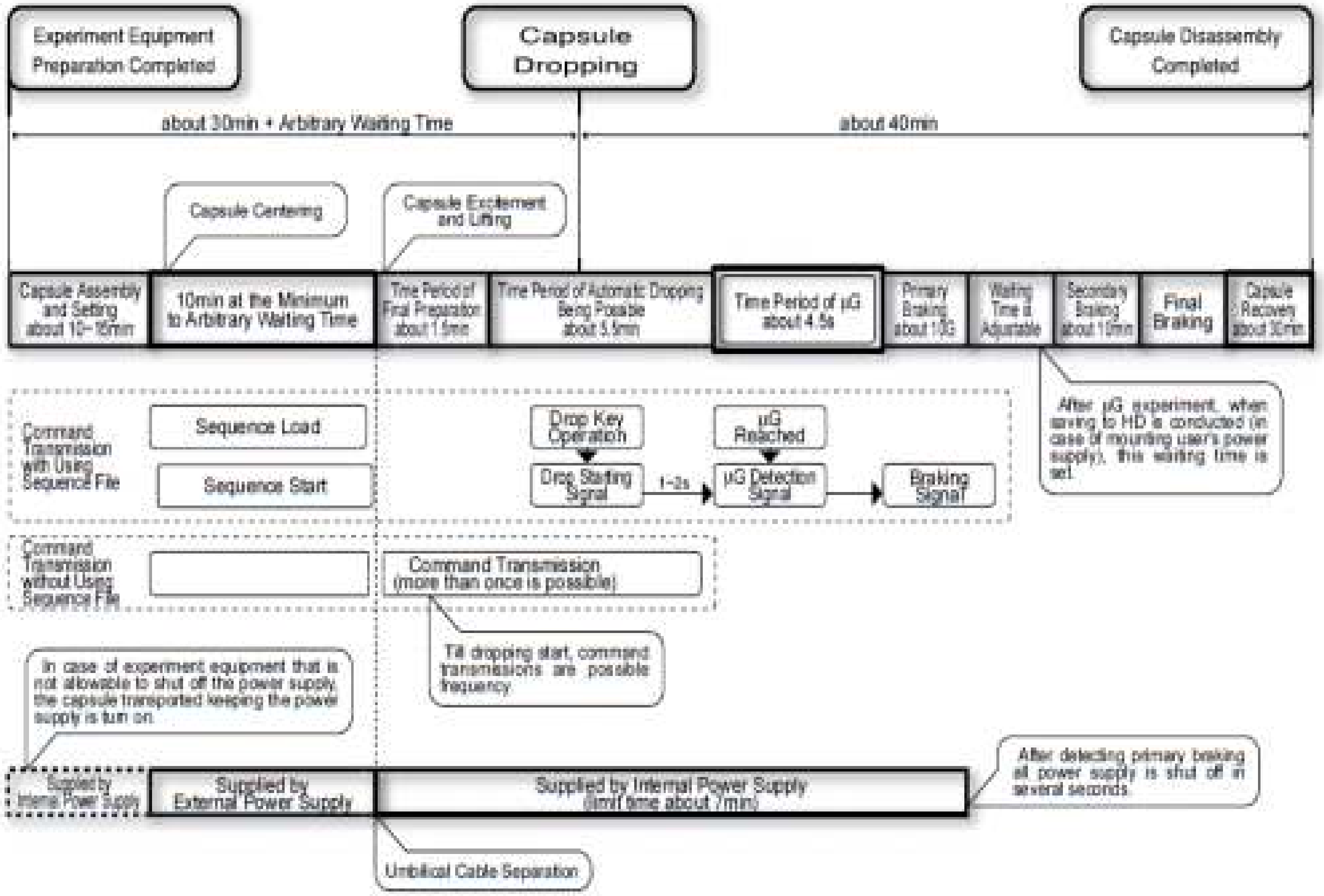


Figure 6.9 Experimental sequence for one drop

(6) Notes on using the drop shaft facility

The following is a summary of notes on using the drop shaft facility for experiment.

Table 6.10 Notes on the use of the drop shaft facility

	Item	Description
1	Design	Experiment equipment must be designed to fit inside cylindrical space of 720 mm in diameter and 885 mm in height. (MGLAB lends researchers base plates for mounting experiment equipment.)
2	After transfer	Researchers cannot touch experiment equipment after transfer to MGLAB. The time required for the first drop after transfer is about 30 min.
3	Weight	The reference weight of experiment equipment alone is up to about 370 kg. The allowable payload weight including rack(s), base plate(s), and experiment equipment is 400 kg.
4	Number of drops	The number of drops per day is normally five, although it depends on the preparation time needed between trials. This may be the total number of drops by two different research teams.
5	Capsule	Two capsules are dropped alternately. This allows two teams to use their assigned capsules independently with no interference each other.
6	During drop	By connecting necessary devices to the support system on the capsule, researches can monitor the progress of experiment and send commands to falling experiment equipment from the control room and also record experiment data in the support system. In addition, parameter changes and experiment equipment behavior during a drop (4.5 seconds) can be reset for automatic experiment.
7	Cycle time	After each drop, the capsule is lifted and reset. Since it takes about 40 min to lift the capsule, the total cycle time from experiment equipment transfer to recovery is about 70 min.

(7) Experiment support system

Connecting necessary devices to the support system on the capsule enables commands to be sent from the control room to the falling experiment equipment, data to be recorded in the support system, and the progress of experiment to be monitored in the control room.

MGLAB provides the following equipment and facilities to support smooth experiment.

A: Experiment support system in the capsule

- Power supply section, environment measuring section, data transmitting section, and recording control section

B: Related support facilities

- Experiment preparation room
- Analysis room
- Dedicated room (for life-science experiments), safety cabinet, refrigerator for research materials, cryogenic chambers, operation table for small animals, CO_2 incubator, etc.

Tables 6.11 and 6.12 list the equipment and facilities.

Table 6.11 List of MGLAB support equipment (See the User's Guide for details)

General-purpose uninterruptible power supply
Handheld oscilloscope
Quad switcher
Additional image circuit
Contact output/TTL output converter box
DV video cameras
Hi-8 video cameras
Separate VCRs
1000 fps high-velocity video cameras
Simple clean booth
Vacuum pump
Ultrasonic cleaner
Small compressor
Digital oscilloscope
Various interface connectors
Electronic balances
Fixed room-temperature chamber
Stereo microscope

Table 6.12 Facilities in the life-science experiment preparation room

Refrigerator
Cryogenic chamber (-40°C)
Cryogenic chamber (-80°C)
Safety cabinet
Operating table
CO_2 incubator
Autoclave

Meeting room

Analysis room (Internet connection available)

Preparation room

Control room

Dedicated room

Safety cabinets and other equipment

Figure 6.13 Rooms and facilities available from MGLAB

6.2 Interface Coordination Items

This section describes the interface items to be coordinated with the drop shaft facility for reference when starting to fabricate your experiment equipment.

(1) Mechanical interface

- Weight limitation

Check the weight of each planned device for experiment equipment to ensure that the total weight, including racks and base plates, will not exceed 400 kg.

- Space limitation

Ensure that the arrangement of experiment equipment will fit the payload area (a cylindrical area 720 mm in diameter and 885 mm in height).

In particular, ensure that experiment equipment will not contact a frame or rack in the capsule.

- Provision of base plates

Base plates can be borrowed from MGLAB in advance and incorporated into experiment equipment.

- Experiment equipment assembling

As Figure 6.3 shows, experiment equipment can be assembled on two levels. You can select how to use the room inside the capsule, for example, partitioning the room into two.

(2) Electrical interface

- Power-supply capacity

Experiment equipment loaded in the drop capsule can be powered by 24 VDC (40 A max.) and 100 VAC (12 A max.).

Table 6.14 Capsule power supplies

	Voltage	Maximum Current
DC Supply	24 VDC (internal voltage) 28 VDC (external voltage)	40 A
AC Supply	100 VAC	12 A

After experiment equipment is stowed in the drop capsule and placed in the vacuum chamber, the vacuum chamber is evacuated. During this time, an external power supply feeds power to the experiment equipment. After the external power supply is disconnected for drop preparation, the experiment equipment receives power from the battery in the capsule. Since the capsule must be dropped within about seven minutes because of the limited battery capacity, it is important to estimate the power consumption because. It may be necessary to prepare an extra own battery for experiment equipment.

- Checking the types and uses of power connectors on the capsule side

Check the connector specifications of the MGLAB support system in advance.

- Checking safety measures at the power input of experiment equipment

Check the circuit breaker or fuse connection and its capacity.

(3) Communication interface

- Items monitored from the control room

  Since output from experiment equipment before and after a drop can be monitored in the control room, determine monitor items and their numbers.

Table 6.15 Specifications of the capsule's A/D converter

No. of channels	6
Input range	-10 V to +10 V
Sampling time	10 ms
Resolution	12 bits (signed)

- Recording experiment data (analog and digital) with the onboard support system

  The onboard support system can record experiment data.

- Transmitting commands to experiment equipment (transmission not available during drop)

  Commands can be transmitted to experiment equipment from the control room.

Table 6.16 Capsule commands

Output format	No. of output channels
Relay contact output	24 channels (alternating)
Open-collector output	5 channels (100-millisecond pulse)

(4) Use of MGLAB equipment and facilities

MGLAB equipment can be borrowed or incorporated in experiment equipment or MGLAB facilities can be used during experiment.

(5) Other interface considerations

The items below must also be considered in fabricating experiment equipment. For details, refer to the Micro-Gravity Drop Experiment Facility User's Guide.

- Thermal interface

  During experiment, the temperature inside the capsule is 40°C or less.

- Grounding and isolation
- Electromagnetic compatibility
- In-capsule pressure

  The atmosphere inside the capsule is always close to atmospheric pressure.

6.3 Drop Shaft Experiment Flow

The following flowchart shows the work assignments of JSF, MGLAB, and researchers when implementing an experiment.

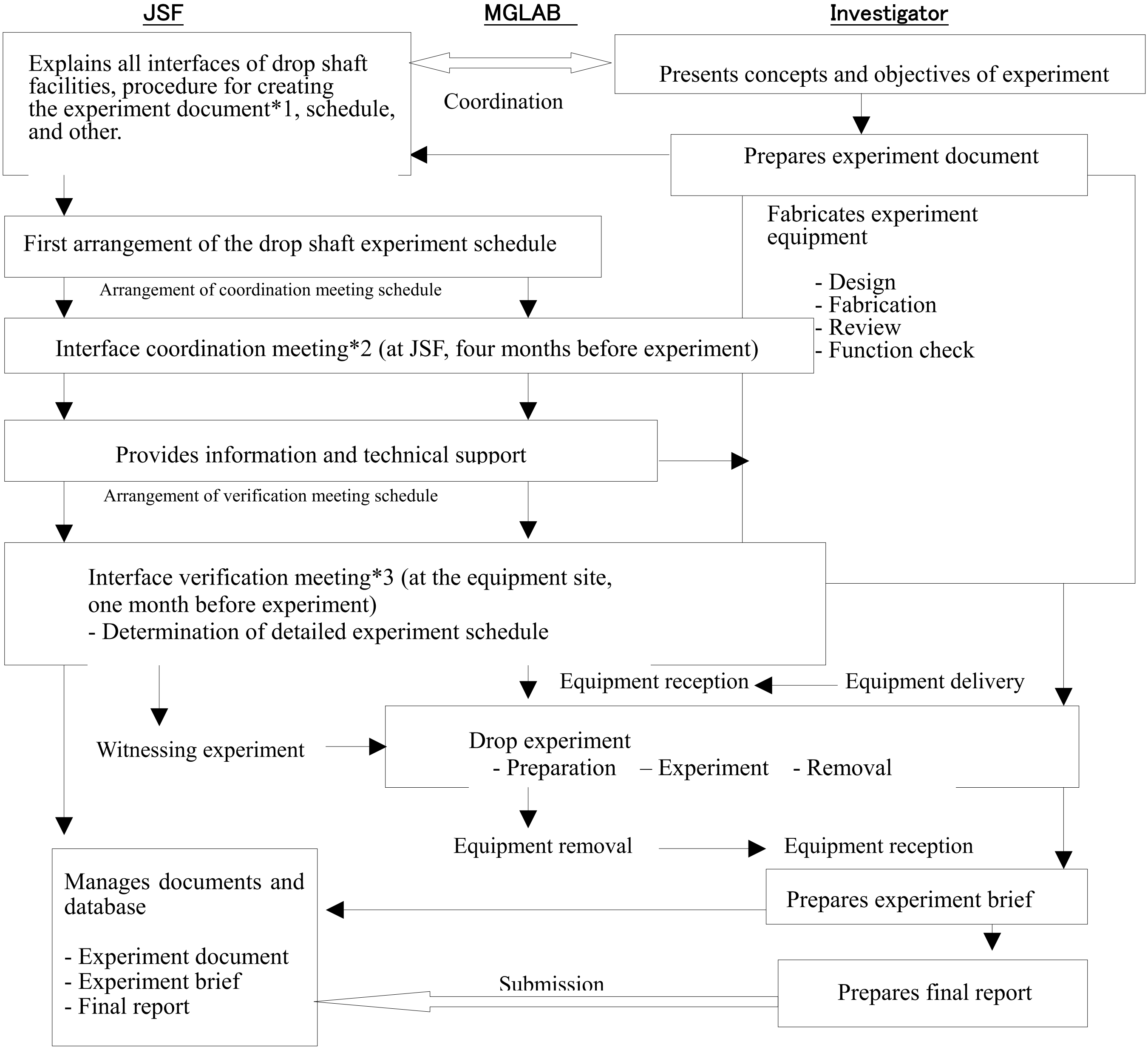


Figure 6.17 Drop shaft experiment flow

*1 Experiment document: Basic document about the drop shaft experiment, the experiment equipment to be used, and the execution procedure

*2 Interface coordination meeting: A preparatory meeting by the researchers, JSF, and MGLAB to ensure that the experiment equipment will meet the limitations of the drop shaft facilities (such as the size of the experiment area and power-supply limitations) and that the experiment equipment to be fabricated is suitable for the drop shaft experiment.

*3 Interface verification meeting: A meeting by the researchers, JSF, and MGLAB to verify the operation of the fabricated experiment equipment and to determine whether the experiment can be accomplished in the planned timetable.

6.4 Considerations at Experiment Equipment Fabrication

Section 6.2 outlined the minimum interface items to be coordinated with MGLAB during the development of experiment equipment for successful experiment using the drop shaft facility.
For experiment more efficient, safer, quicker, and less likely to fail until the last experiment operation, this section presents references based on valuable experiences of past experiments.

(1) Basic considerations
Although details are given in the following sections, the table below summarizes what to consider when fabricating experiment equipment.

Table 6.18 Basic considerations

Item	Description
Compactness	Fabricate compact experiment equipment to fit the racks, including computer controllers.
Automation	Automate experiment because experiment equipment cannot be operated manually once it has been transferred.
Robustness	Drop shaft experiment cannot be repeated if experiment equipment cannot withstand a braking impact of 10 G. If the structure is not strong enough, experiment equipment may be damaged or samples may leak out, adversely affecting other components or the battery at the lower part of the capsule.
Experiment preparation time	Design experiment equipment for quick setup. The turnaround time between drops should be about one hour to allow several drops a day.
Reference cycle time	70 min (from experiment equipment transfer to MGLAB until recovery)

(2) Interface considerations
The following interface parameters must be observed when fabricating experiment equipment.

A: Mechanical interface (weight, mounting, and placement)

Braking after a drop gives perpendicular force of 10 to 13 G and horizontal force of 4 G to the experiment equipment. Therefore, experiment equipment mounting needs to be devised (through bolt, L-bracket, and no pop-out). Whenever possible, place heavier components at the center and bottom of the payload area to prevent the capsule from tilting during a drop.

*Advice from past experiments

- Make the structure as simple as possible with marketed parts available anywhere (particularly electrical wiring and panel operation). Wherever possible, avoid assembling experiment equipment on site. If the equipment must be disassembled for shipping, minimize the number of connections to be made on site. To fit experiment equipment in a limited space, you should know that it is important to carefully determine the positions of cameras for capturing image data and take other measures. Instead of a hard disk, semiconductor memory is recommended. Nonvolatile memory (flash memory, etc.) is particularly preferable for storing data.
- Be sure to secure lightweight equipment firmly with Velcro fastener or packing tape (or even cloth band and L-bracket). Double-sided tape is not strong enough. For an experiment where samples or specimens move during a drop, place low-rebounding cushion materials at the bottom and around the equipment for protection from a braking impact.
- When installing equipment requiring fine adjustments, such as focusing a laser beam or microscope, consider vibration at capsule assembling and transportation and also the time until the drop.
- With two bathroom scales, the weight balance of experiment equipment layout can be checked.

Fabricate experiment equipment to fit the payload area while ensuring the balance of the center of gravity and the robustness.

Figure 6.19 Experiment equipment assembled on the base plate

B: Electrical interface

Work out the total power consumption by experiment equipment and ensure that the consumption will not exceed the power-supply capacity of the capsule. Use the minimum necessary length of wiring because extra wiring may float under microgravity and snag on experiment equipment or samples. Note also that 60 Hz AC voltage is used in the Gifu area.

*Advice from past experiments

- Design the power supply with some leeway by considering the time from when the experiment equipment is transferred until it is dropped. Also consider device interference and power-supply distribution well because the amount of available power is limited. The power supply will be stopped if experiment equipment consumes power beyond the power-supply capacity of the capsule after switching over to the internal power supply. Also beware that batteries may fall out of equipment switchboxes due to changes in gravity.
- Frequently check the battery levels of video cameras. In not a small number of past cases, no data was gathered because the batteries were overcharged.
- A 100 V uninterruptible power supply is easier to use than a DC-AC converter.
- Even when the calculated power consumption exceeds the power-supply capacity, the actual power consumption may be low.
- Electromagnetic valves could cause computers to malfunction, noise to appear in captured data, and other problems. To alleviate interference problems, use shielded wiring and block electromagnetic waves from the experiment equipment.
- The power supply from the capsule stops two seconds after braking begins. If you need power supply longer, prepare an independent power supply in the experiment equipment.
- Since there is no convection under microgravity, tungsten lights tend to become brighter due to blanket Influence and nichrome wires tend to fail easily. Therefore, it is advisable to devise measures, such as using halogen lights or ensuring nichrome wires have more than sufficient capacities.
- Fasten electrical wiring securely with packing tape or other. Employing a color scheme for wires and their corresponding equipment will reduce wrong connections.

C: Experiment start signal

A microgravity detection signal is available in the capsule. This signal is useful for starting behavior or triggering measurement. Determine the sequence of experiment operations and verify that command requests obey this sequence in a drop shaft experiment. The ground-level support system can be used to set command output at the trigger point (shown by the asterisk in Figure 6.20).

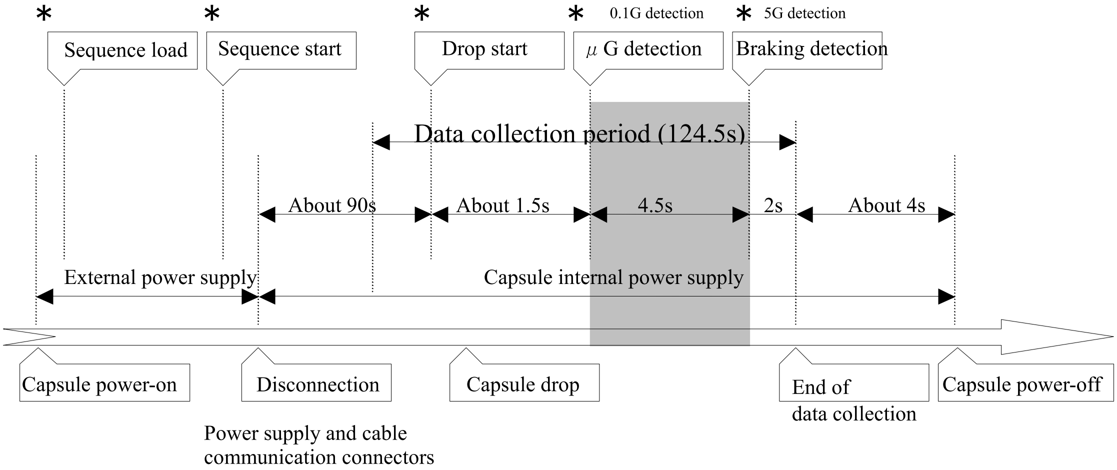


Figure 6.20 Drop shaft experiment sequence setup

Figure 6.21 Ground-level support system monitor screen

(3) Safety measures

A: Prevention of dispersion

- Phenomenon under microgravity

Particles, sand, and fragments used as samples in an experiment may disperse or float inside the capsule at the initial velocity under microgravity, causing a power short circuit or damage to devices or camera lenses. Airborne samples may pose problems for post-experiment analysis if they stick to the lens of an observation camera.

Judging from experiences, particles or fine grains do not disperse much under microgravity. Therefore, take greater care about dispersion by a braking impact.

- Anti-prevention measures

Basically, it is enough to enclose fine materials so that they will not disperse or float out of a given area. However, the following measures are actually taken:

- Building an enclosure of not easy-shattering glass or acrylic plastics when a transparent enclosure is needed to observe the state of samples under microgravity
- Immediately before the braking of the drop capsule, automatically and instantaneously covering the top of the container holding the sand or other fine materials from side and above

*Advice from past experiments

- Even after the equipment securing status is checked before the drop experiment, some factors may be lost in many cases. Note that the experiment equipment may be fabricated with gravity in mind.

B: Working with liquid

- Phenomenon under microgravity

Liquid, such as water or oil, can cause short-circuit or burnout because liquid forms a sphere and floats under microgravity. Take the greatest care about an unintentional leak or discharge of liquid.

On the ground, a pump circulates liquid in experiment equipment at a certain velocity using gravity. This circulation velocity cannot be achieved under microgravity, however, because the Influence of gravity is not nullified.

- Preventing liquid leakage

On the ground, a liquid container is generally checked for leakage mainly from the bottom and sides. Since the initial velocity drives liquid to the top of container under microgravity, however, it is necessary to check for leakage by turning the container or device upside down.

A common way to deal with leakage is to wrap or cover the container or device with a disposable pet diaper made of highly absorbent polymers developed by NASA. Liquid circulation in experiment equipment must be designed to avoid gravitational differentials even on ground.

*Advice from past experiments

- Absorbents for pets are the easiest to use. A rag may be used when the amount of liquid is small. Reliable measures are essential because liquid leakage can cause electrical system problems.

C: Hazardous material samples

An application for permission and safety procedures are necessary for most hazardous materials (such as cryogenic samples or propane fuels) regulated by international conventions. Therefore, schedule an experiment by considering the time necessary for completing these procedures.

D: Volatile materials

● Phenomenon under microgravity

Dry ice, naphthalene, and other materials that vaporize may abruptly increase pressures inside the capsule and impose abnormal pressures on experiment equipment. This is because the expansion volume of these materials under microgravity is several times that under normal gravity.

● Measures to handle volatile materials

Basically, it is the best to minimize such materials. When more materials are used, however, a buffering tank or similar device is often installed to release vapor.

(4) Specific considerations

A: Rush currents

● Capsule specifications

Since the capsule has an uninterruptible power supply, check that rush currents as well as the rated current of experiment equipment will not exceed the power-supply capacity of the capsule.

● Measures against rush currents

When rush currents are anticipated to surpass the battery capacity, either mount a supplementary battery or devise the startup method not to produce rush currents.

*Advice from past experiments

- The internal power supply stopped when a high-velocity power amplifier was switched on. We had to change the sequence so that the power amplifier would go on while the external power supply was being connected.
- An inverter driving a liquid pump failed to operate when the connector cable was disconnected from the drop capsule. We had to redesign the circuit to connect a separate power supply after the cable was disconnected.
- When using a vacuum pump, verify the initial current before experiment because currents several times greater than the rated current may flow at startup.

B: Air bubbles

● Phenomenon under microgravity

Since no buoyancy force is generated under microgravity, air bubbles remain attached to a heat transfer surface, such as a radiator. This phenomenon not only reduces the heat-exchange performance but is suspected to cause a power-supply failure.

Load by air bubbles entering a pump increases the electrical energy consumption and potentially accelerates the battery consumption.

● Removing air bubbles

Remove air bubbles wherever possible from tubing while on the ground. Deaerated water should be used. Remove air bubbles from traps by vibrating the tubing and gathering air bubbles at tubing bends. Note also that teflon or vinyl-polymer tubing allows easier manipulation than metal tubing.

*Advice from past experiments

- If air bubbles are not removed, bubbles will enter a pump chamber and produce extra load to burn out the electrical system or quickly consume the battery. Coating will prevent air bubbles from entering tubing. Design traps in experiment equipment and release bubbles from the traps to prevent them from entering the system.

C: Temperature and pressure

Temperature inside the capsule is kept at 40°C or less. Pressure is maintained at normal atmospheric pressure.

D: Optical systems

(a) Commercial DV (digital video camera, etc.)

- Phenomenon under microgravity

A commercial DV should be used by noting the mounting method and the field of view. The mounting method is also a concern when a CCD camera head is used because images often get skewed under microgravity. In other cases, the optical axis of the camera may go out of alignment, as load caused by its weight disappears under microgravity.

- Solution

Vibration occurs easily when the mounting is loose. This problem is often improved by adopting not single-support but double-support and inserting a cushion or other shock absorber. It is advisable to use a rigid optical stand separate from the base plate. Making the camera adjustable by remote control is very effective when optical alignment is critical.

(b) High-velocity cameras

MGLAB has a 1,000 fps high-velocity camera available as part of its support system. For shooting, design an optical path using mirrors or other. As mentioned above, mounting must also be considered well. Keep in mind that the frame rate, resolution, and shooting time are limited by the internal memory. The trigger input timing should also be reviewed. Since the exposure time is short, a light source of adequate light quantity is necessary.

Figure 6.22 High-speed camera of MGLAB

(c) Microscope photography

- Phenomenon under microgravity

An ultrahigh-power microscope focused on a sample on the plate at the ground level loses its focus under microgravity. This is because the camera greatly magnifies even a very slight change of the lens position.

● Solution

When using a microscope, secure firmly the movable part for focusing and do not allow the sample plate to move in the direction of gravity. Insert rubber or similar cushioning materials to prevent direct contact between the bottom of the microscope and the plate and a massive braking impact from causing distortion or warp inside.

*Advice from past experiments

- It is effective to improve the equipment for focus adjustment by radio control.

(d) Interferometer

When using an interferometer, consider the gravitational loading on mounting supports well.

*Advice from past experiments

- Use multi-point support or rubber or other cushioning materials for parts that pick up vibration easily. An interferometer should be firmly locked to prevent focusing errors.

(e) Laser

Use protective goggles as well as diffusers and shields, when working with high-output laser.

E: Special measures for life-science experiment

Certain problems arise in life-science experiments under microgravity. This section summarizes them.

(a) Inspection by the JAXA Animal Experiment Committee

- Experiment involving animals requires approval of the JAXA Animal Experiment Committee as well as approval of the institution where the experimenter belongs.

(b) Influence of gravity on experiment subjects not in the microgravity period

- Drop shaft experiment is subject to 10 to 13 G during braking after the microgravity period (about 4.5 seconds). It is difficult to identify the physiological phenomena caused purely by microgravity, especially when the subjects of the experiment are small animals, because of continuous loading on the subjects after the microgravity interval.

(c) Considerations for small-animal experiments

- Transport to the drop shaft facility and breeding time

  Rats have ever died when transported in large numbers in a small container. To avoid the Influence of transportation on small animals, you should breed your subjects at the experiment site (in the life-science experiment preparation room) for at least two or three days to acclimatize them to the environment of the facilities. It is important to properly prepare the breeding environment so that the subjects will not experience a large change from the conditions at your research laboratory.

- Surgical operation timing

  Unlike experiment in a fixed laboratory environment, experiment in an unfamiliar environment may cause small animals to move greatly due to stress or fear. Determine surgical operation timings appropriately so that implanted sensors will not come off.

- Disposal of euthanized small animals and their wastes

  You are generally responsible for removing all euthanized animals and their wastes from the drop shaft facility. In addition, take measures to prevent discharges from animals from dispersion during experiment.

- Securing small animals during experiment

  Small animals tend to move a lot during experiment due to unfamiliarity to the environment. You must consider ways of securing the animals suitable for the type of experiment you are performing. Animals may get stuck in normal wire mesh coverings; it is better to use an enclosure lined with nylon mesh to allow ventilation without the risk of the animals catching on something.

- Noise-reduction measures

  You can guard against noise by putting the experiment animals in a shielded box.

(d) Measurement problems encountered in small-animal experiments

Short of anesthetizing small animals, the only way to obtain data on the internal functions of small animals is to fix them from moving and retrieve data over a cable or to let them move but implant telemetry transmitters in their bodies. The size of telemetry transmitters remains a problem, as current transmitters are too large to implant in laboratory mice.

(e) Problems encountered in animal and biological experiments

Only very limited phenomenon can be studied in one experiment since observations over long periods are necessary. In addition, high-resolution microscopy cannot be avoided when observations at the cellular level are required. The problem with high magnification under microgravity is that focusing aberrations occur in the microscope that cannot be corrected.

*Advice from past experiments

- Ensure that experiment equipment can withstand both the drop of 4.5 seconds and the braking deceleration of 10 to 13 g.
- Plan all steps from breeding to disposing of test animals at the experiment facilities.
- Place a sheet around the test animals to prevent excrement and urine from floating through the drop capsule.
- Animals need to be stabilized for at least two days at the experiment facilities to acclimatize them to changes in their environment.
- In many cases, the animals receive shock and produce exaggerated introspection data. Some measures are needed.

6.5 Examples of Experiment Equipment Fabrication

Experiment equipment should be designed to be compact, energy efficient, and lightweight because of the limited space, withstanding weight, and power available at the drop shaft facility. These limitations necessitate considerations in designing and conducting experiments.
The following sections present some valuable examples of experiment equipment fabrication obtained with permission from the original experiments. These examples can also serve as references when designing experiment equipment for aircraft experiments.

(1) Temperature control

● Cooling

Peltier-element coolers are frequently used.

(2) Flow rate adjustment

● Handling liquid

Liquid must be handled with due care when a free gas-liquid boundary exists (such as when liquid does not completely fill a container). The wettability of liquid causes a liquid surface, such as that of water in a cup, to change (deform) greatly under microgravity.

[Problem]

In actual experiment, liquid stored in a reservoir tank may be fed through a tube. Under microgravity, the liquid may not flow, however, because the deformation of the liquid surface inside the tank draws the liquid surface away from the entrance to the tube.

[Solution]

To solve this problem, fill the reservoir tank to the full with the liquid and extract all free air. The tank must be designed exactly to accommodate the required amount of liquid.

In addition, if you make a hole in the tank of normal atmospheric pressure to equalize the pressures inside and outside the tank, the braking impact on the capsule may cause the liquid to splash out of the hole. To equalize the pressures while preventing this splashing, screw a bent pipe into the hole.

(3) Pressure adjustment

● Pressurization

[Problem]

At pressurization, gas may dissolve in liquid.

[Solution]

Use bellows to pressurize the working liquid without causing the gas to dissolve in the liquid.

- Preventing pressure increases inside the drop capsule

When designing a container of a sealed structure, ensure enough strength or use a safety check valve in the container by assuming internal pressure increases even when no pressure increases are anticipated from the experiment conditions.

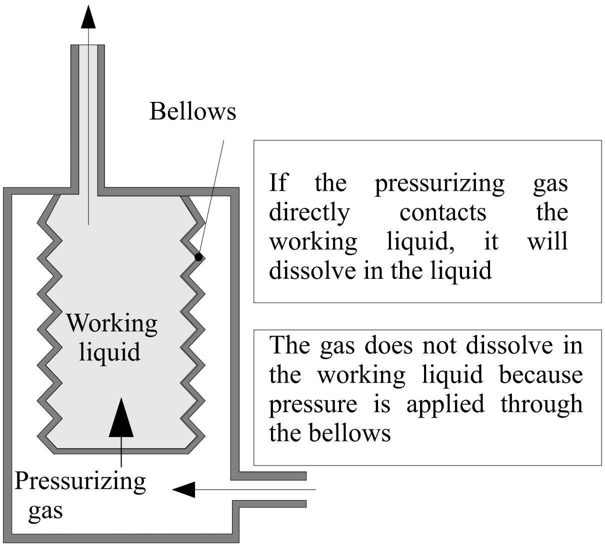


Figure 6.23 Pressure regulator using bellows

(4) Removal of bubbles (deaerating solution and experiment equipment with tubing)

- Removing air bubbles

Several experiments were ever conducted just to remove air bubbles. Air bubbles, however, rarely cause malfunctions during capsule drops because MGLAB's microgravity duration is as short as 4.5 seconds.

[Problem]

Though not directly related to microgravity, gas sometimes enters the liquid-transport tubing during the 30 minutes of waiting for a capsule drop at MGLAB. Gas infiltration causes a problem especially when droplets are generated because precise control is required over discharge amounts.

[Solution]

To solve this problem before experiment, run the liquid through the tubing to purge all gas and then prime the tubing to ensure proper liquid transfer in the experiment.

(5) Mixing samples

- Burning experiment

When creating premixed gas, use an agitating fan or other internal device since gas takes longer to mix than normally expected.

(6) Examples of experiment observation and analysis (measurement) methods

- Interferometer (types, advantages, methods)

*Michelson Interferometer (Assistant Professor Takahashi, Gifu University)

Interferometers show density changes as fringed patterns. They can be used for not only density measurement but also temperature measurement and gas density measurement with pressure information. Calibration is necessary for quantitative measurement.

The optical components of an interferometer, such as a laser and lenses, must be placed three dimensionally to fit the capsule, since the optical path becomes quite long for measurement over a wide field of view.

Interferometers necessitate precise mounting of each optical component. Therefore, use thick rods where needed and fabricate own bases for heavier components, as single-point mounts will not give sufficient support. The design must be robust enough for the components to withstand the gravity of the braking deceleration. The relative positions of the beam splitter and the two reflectors need to be firmly secured. Vibration is produced when a surface distorted under normal gravity is put into the microgravity environment and restores its original shape. Ensure your design is as rigid as possible to keep the vibration as short as possible. Thick optical plating can add rigidity to your design.

Use anti-vibration fixtures to ensure that vibration from fans, coolers, and other vibrating devices (such as fans on high-velocity cameras and Stirling coolers on thermography cameras) will not reach the interferometer. It is beneficial to fabricate a system that allows interference fringes inside the drop capsule to be adjusted by external commands.

Unlike the Mach-Zehnder interferometer, the Michelson interferometer passes light through an object of measurement twice. Since only one beam splitter is necessary, however, the Michelson interferometer is useful for working in tight limited space or for measuring a wide field of view (large beam splitters are expensive).

A block diagram and an implement sample of the Michelson interferometer are shown as follows.

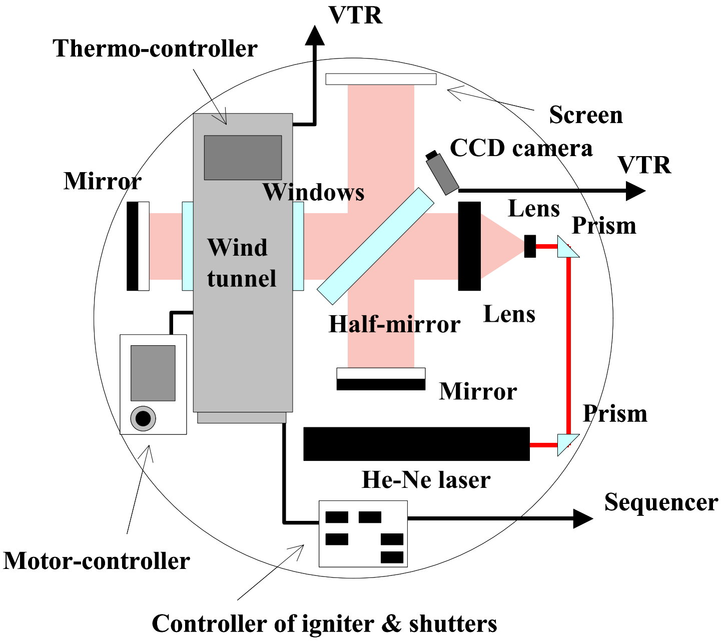


Figure 6.24 Block diagram of the Michelson interferometer

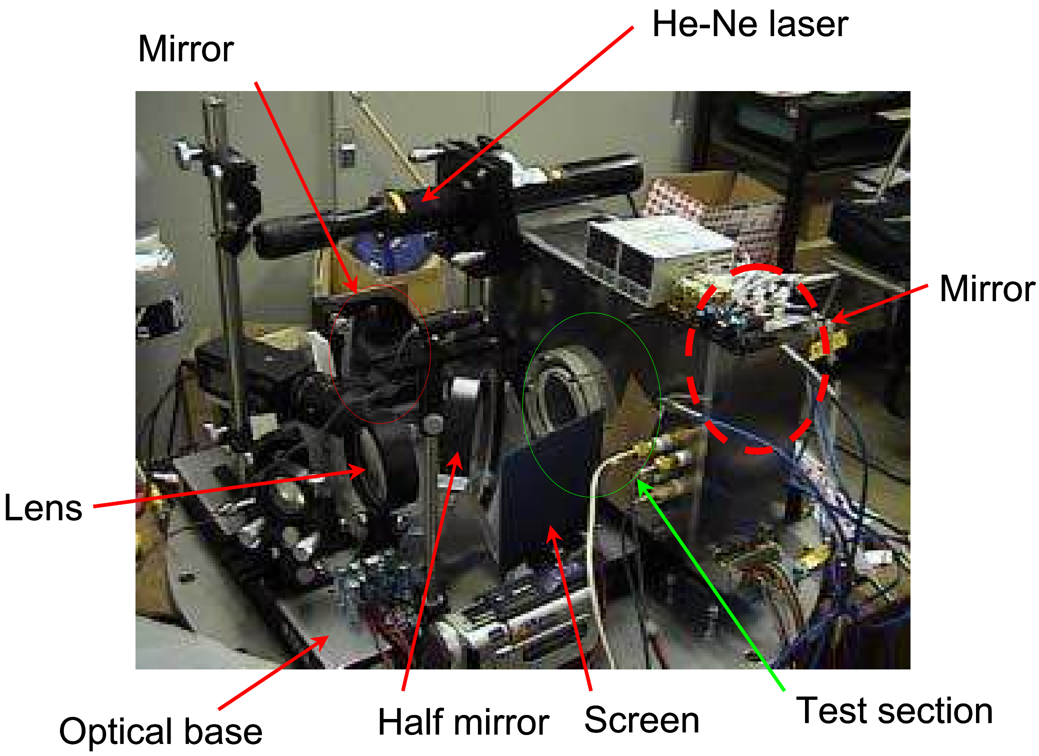


Figure 6.25 Implementation sample of the Michelson interferometer

- Video shooting and illumination (achieving sufficient resolution for analysis)

*Burning experiment

Flames under microgravity are darker than normally expected. With this in mind, set shooting conditions for direct image capturing.

Experiment equipment will be in complete darkness once it is installed inside the capsule. It is a good idea to photograph or film the burner position and other details before transferring experiment equipment to MGLAB.

(7) Other design considerations

- Spring-based ejection mechanism (Associate Professor Kubota, JAXA)

[Problem]

An ejection mechanism is needed for a drop shaft experiment where a sample is released at a certain velocity and observed about its behavior, such as impact or docking phenomena. In most cases, an electronic circuit is needed to eject a sample at the right time in response to a drop command or microgravity command. It takes time and money, however, to fabricate a reliable ejection mechanism this way.

[Solution]

The following is an ejection mechanism based on a far simpler theory. As the figure below shows, the weight of the sample placed on the ejection board stretches the springs under surface gravity (1 g) before a drop. Immediately after the start of a drop, microgravity reduces the weight of the sample to virtual zero, and the springs start to return to their natural length. The spring reaction lifts both the ejection board and the sample.

A block in the spring path will stop the ejection board, ejecting the sample at the final velocity of the board. Specific velocity can be obtained by carefully selecting the spring constant and the loading weight. The direction can also be controlled by attaching a movement guide to the ejection plate. A sliding bearing is recommended to minimize the guide friction. By using this theory, many different types of automatic ejection mechanisms can be devised for drop shaft experiments.

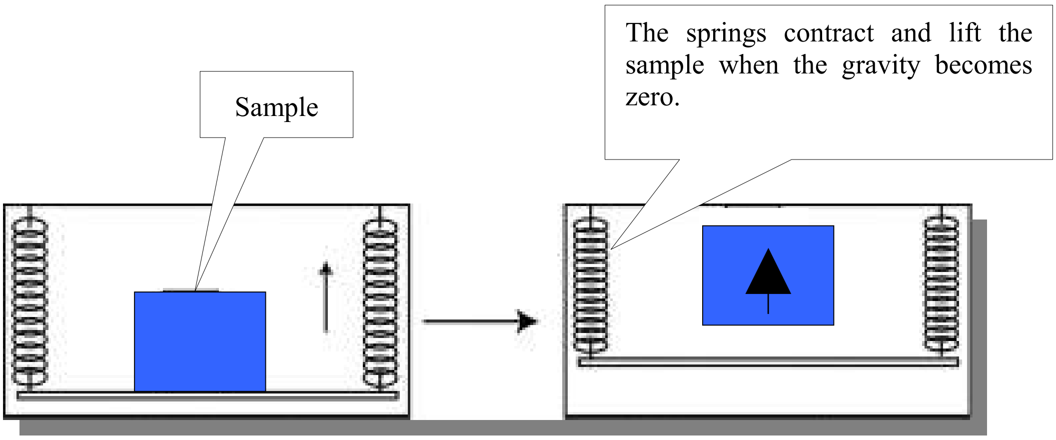


Figure 6.26 Spring-based ejection mechanism

6.6 From Experiment Equipment Fabrication to Final Experiment Preparations

This section introduces the sequence of the themes of "Ground-Based Research Program for Space Utilization", from the fabrication of experiment equipment, based on the previous sections, up to the day of experiment (Figure 6.17).

(1) Before fabricating experiment equipment (interface coordination meeting)
About four months before experiment, an interface coordination meeting is held (usually in Tokyo) with JSF and MGLAB staff to carefully discuss the interface between the drop shaft facility and the experiment equipment based on the experimentation design. Fabrication and improvement of the experiment equipment begin after this meeting.

- See the Micro-Gravity Drop Experiment Facilities User's Guide.
  - * MGLAB Web site <http://www1.ocn.ne.jp/~mglab/>

(2) Ground-level verification after fabrication
Experiment equipment is verified on the ground level to confirm whether the expected experiment is possible. Experiment preparations and troubleshooting continue for the final confirmation at the interface verification meeting.

(3) Final confirmation (interface verification meeting)
About one month before the scheduled experiment date, experiments meet with JSF and MGLAB staff (usually at the experiment equipment site) to verify the items below. The three parties determine together whether the planned experiment is feasible at the time while considering the improvement of the experiment equipment.

- On the ground, secure the experiment equipment on actual base plates for experiment and verify the experiment equipment operation systematically by simulating the interface with the drop shaft facility to confirm the mounting and the size (whether the experiment equipment will fit the capsule).
- Confirm whether the prescribed devices can reliably store data from the experiment.
- Reconfirm the mounting and the size (whether the experiment equipment will fit the capsule).
- Predetermine measures against experiment equipment faults under microgravity.
- Confirm the preparation time and power needed before starting the microgravity experiment.
- Determine the experiment equipment deliver date and the transportation method.

(4) Experiment equipment assembling and final operation check at the facilities
Experiment equipment is normally disassembled before shipping to meet weight limitations and to prevent damage from vibration during shipping. Thus, the following operations are necessary before

starting a drop shaft experiment:

- After arrival, assemble the experiment equipment enough for testing.
- Confirm the standalone operation of each device (samples).
- Confirm the interface with the support system at the drop shaft facility.
- Place the experiment equipment in the capsule and confirm its operation under conditions close to the environment of actual experiment.
- Confirm the preparatory operation and work time before experiment.

Figure 6.27 Experiments assemble their experiment equipment at the work site

(5) Immediately before drop shaft experiment

Immediately before drop shaft experiment on the day, final verification must be performed very carefully. To save the preparation time and avoid mistakes, it is recommend to make a checklist in advance and to follow the check items step by step. MGLAB staff will perform a conformance test on the interface with the support system at the facilities. The following items in particular should be verified:

- Confirm that the experiment equipment operate correctly.
- Confirm the experiment sequence.
- Reconfirm the interface between the experiment equipment and the support system.
- Validate the experiment equipment operation under microgravity.
- Confirm the method of capturing target data.

Figure 6.28 MGLAB staff assembling the capsule after receiving the experiment equipment

Figure 6.29 MGLAB staff moving the capsule to the chamber

6.7 Experiment Sequence and Precautions

This section gives an overview of the normal experiment sequence on the day of the drop and items to be aware of.

(1) Experiment schedule

The diagrams below illustrate typical daily schedules of experiment. Since two teams of experiments are working at the facilities most of the time, capsules are usually dropped 10 to 15 times in total over a week. Each team is assigned its own capsule for alternate dropping.

On the first day of experiment, the capsule balance is adjusted after loading and installing the experiment equipment in the capsule. A final check of the interface with the drop capsule is also done. The morning of the first day and even longer time may be spent on this work. Figure 6.30 gives an example timetable for the first day.

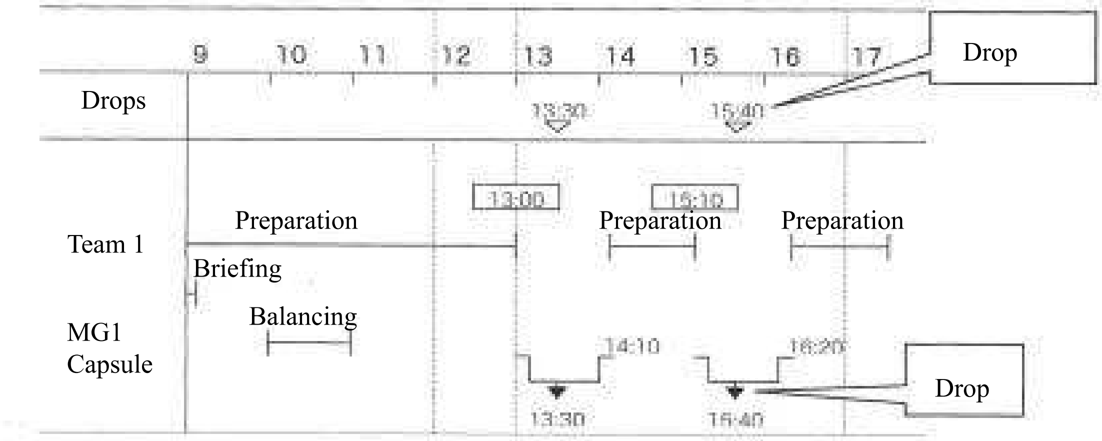


Figure 6.30 Experiment schedule for the first day schedule

The drop and preparations are repeated on the second day and later. The number of drops per day depends largely on the length of the preparations between trials. Figure 6.31 shows a typical schedule where the preparations between experiments take one hour; Figure 6.32 shows a typical schedule where the preparations take 30 minutes. As the preparation time becomes shorter, the number of drops per day increases.

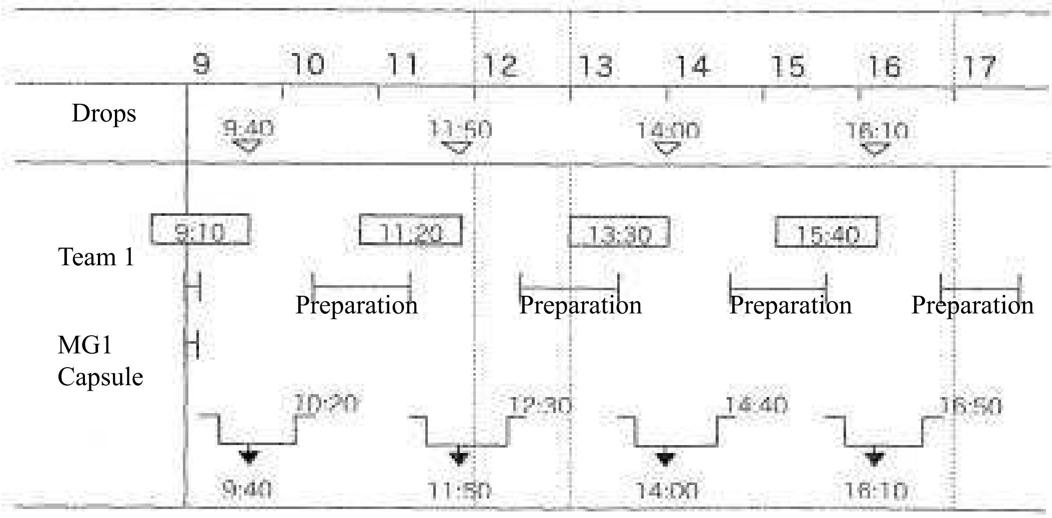


Figure 6.31 Experiment schedule for the second and later days (one-hour preparations)

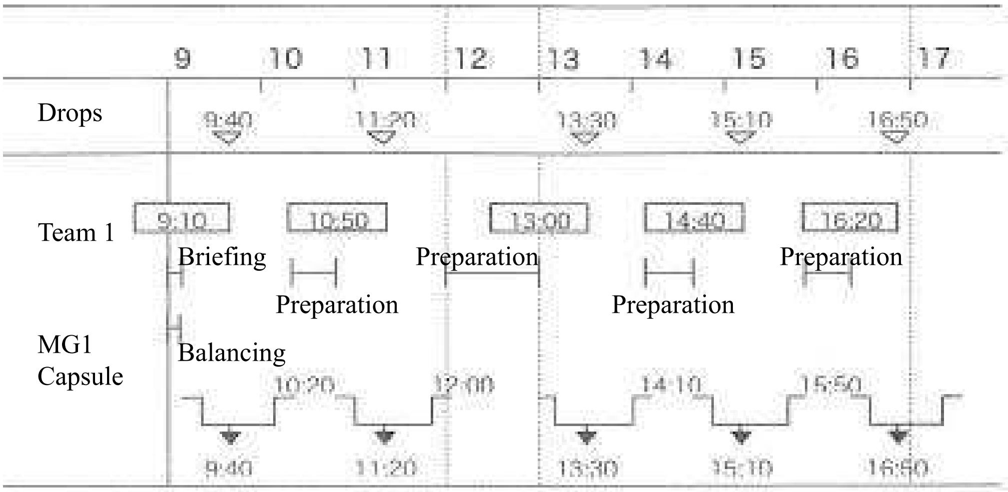


Figure 6.32 Experiment schedule for the second and later days (30-minute preparations)

When two teams of experiments conduct drop shaft experiments, MGLAB and the two teams work out the schedule together since two capsules are in operation at the same time. Figure 6.33 gives a typical schedule for two research teams.

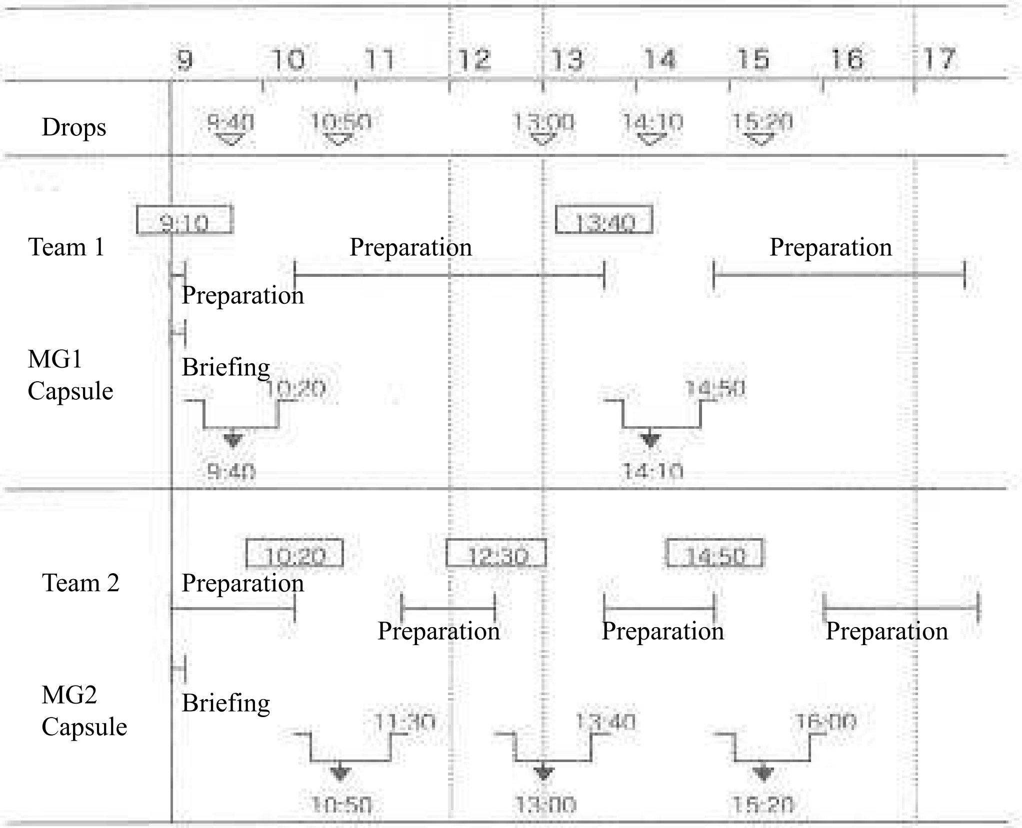


Figure 6.33 Experiment schedule for two research teams

In this case, the preparation time of one team will affect the schedule of both teams. When the preparation time of one team is extremely long, the other team may conduct consecutive drops.

Experiments are recommended to set the number of drops a little fewer for the final day of experiment by considering the time for dismantling and packing up experiment equipment and arranging its shipping.

(2) Before experiment

A briefing is held with the experiments in the morning on each day of drop shaft experiment to map out the day's drop schedule. When more than one research team is working at the facilities, the order of alternate drops is also decided at the briefing.

On the first day of experiment, the experiment equipment is loaded and installed in the drop capsule. When completed, MGLAB staff adjusts the balance of the drop capsule.

The experiments prepare their experiment equipment and samples before the drop start time set on the schedule of the day and transfer the capsule to the MGLAB staff. After the experiment equipment is transferred, it takes about 30 minutes to make the capsule ready for a drop. During this time, experiments can monitor data from their experiment equipment and remotely control the experiment equipment from the control room. Extra time can be added to the 30-minute wait period to set temperatures or other preconditions. A capsule drop command is sent from the control room. The drop command can be synchronized with the monitoring of data or images from the experiment equipment in the capsule.

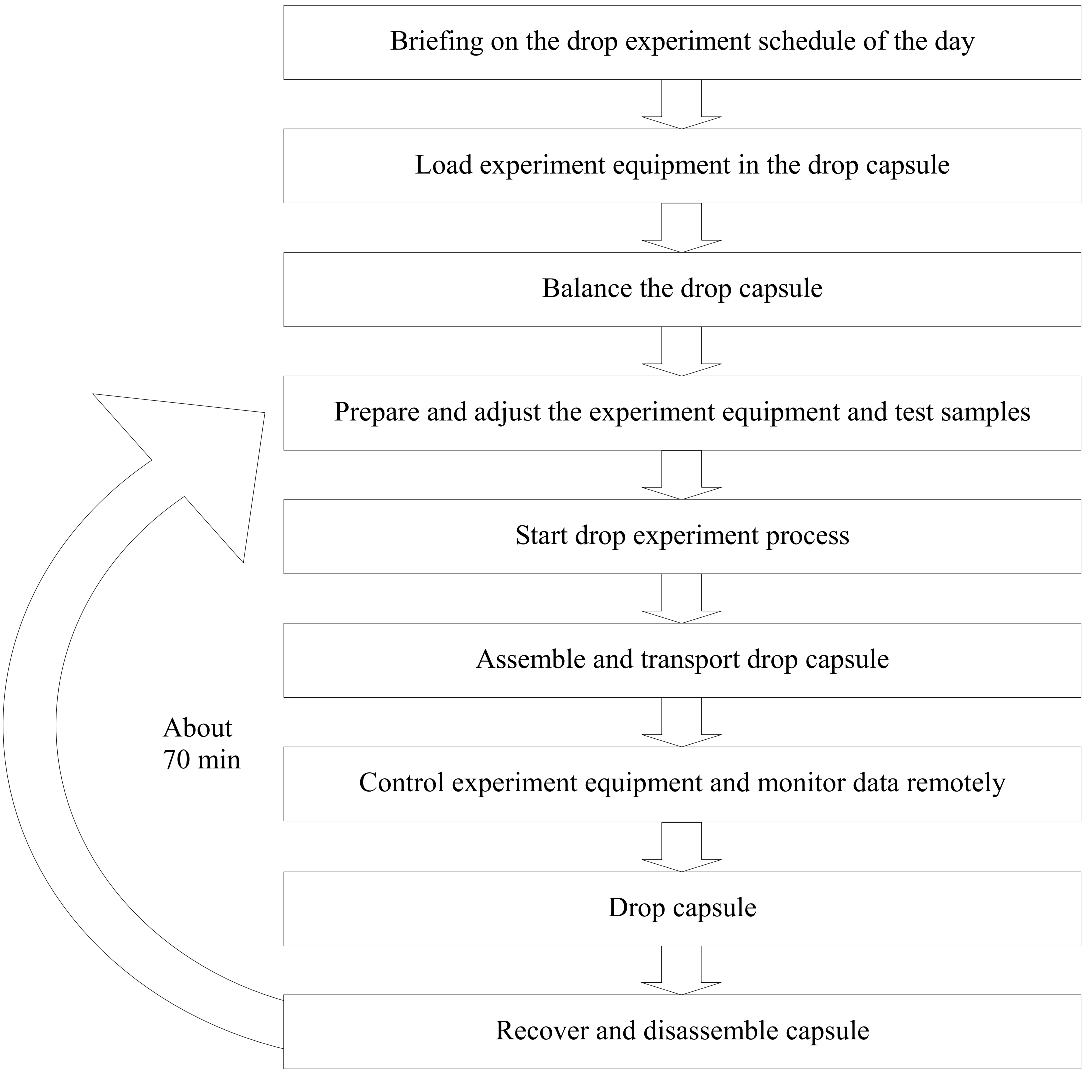


Figure 6.34 Experiment sequence

Figure 6.35 Briefing prior to experiments

(3) During experiment

Confirm that microgravity is a very unique environment.

*Advice from past experiments

- Experiment equipment is recommended to be as simple and automatic as possible. If you have space, fabricate two versions of experiment equipment in the capsule so that you can run two experiments in parallel.
- It is best not to change experiment conditions at the last minute if you suspect the reliability of the changes even slightly. This is true even if you suddenly have a good idea just before conducting the experiment. Last-minute changes often lead to errors or failures.

Figure 6.36 Witnessing microgravity from the control room

(4) After experiment

Capsule recovery after a drop takes about 40 minutes. The capsule's power supply is switched off for the recovery process. If continuous power supply is necessary, you will need to work out some means of providing power, such as incorporating a separate battery in the experiment equipment.

The cycle of "preparation time + 70 minutes for drop" is repeated. Preparation work should be kept as simple and standardized as possible since the time required to carry out preparations affects the number of drops that can be done in one day. It is recommended to verify all the preparation work in detail in advance and make a checklist for preparations.

*Advice from past experiments

- It is important to arrange the number of drops and the experiment time and consider the number of people necessary for experiment equipment setup. Be sure to reserve some leeway in both time and personnel. Prepare for unexpected circumstances so that experiment equipment will not be a make-or-break endeavor.
- Reserve enough leeway in your schedule for the time to go through observed or measured results and reflect them in the next experiment, the time needed to modify equipment, and the time to reload equipment in the capsule to alter the experiment.
- Conduct as many simulations as possible on the ground by the same procedure as in the actual experiment. Use a checklist to make final checks before transferring the experiment equipment to MGLAB. You will need to coordinate closely with the MGLAB staff in the experiment preparation stage for mutual understanding.

(5) Operating system

In principle, student-only experiments are not permitted. An overseer, such as a staff member from the research institution, must be present.

*Advice from past experiments

- I recommend manning experiment equipment with enough people to deal with unexpected events.

(6) Data supplied by MGLAB

After experiment, MGLAB provides data on the environment and other indicators recorded inside the capsule. The following data is provided:

- Log of the acceleration inside the capsule

  Chart of the three-axis acceleration in ranges of ±30 G and ±0.1 G during the drop.
- Temperature inside the capsule
- Humidity inside the capsule
- Pressure inside the capsule
- User's analog data

  This data is retrieved using the A/D converter in the capsule. The range is ±10 V in signed 12-bit notation. Up to six channels can be used.
- Log of user commands
- Data recording time

  The data recording time is from -2 to +6 seconds where 0 second is set by the microgravity detection signal.
- Sampling rate

  The sampling rate of the provided data is always 10 milliseconds.
- Data format

  Data is usually provided as a text file. If requested, data can be provided in CSV or Excel formats.

(7) Lessons in experiment mistakes from past experiments

1	We fabricated a liquid circuit for the experiment but the liquid did not circulate as we had hoped.
Cause	We did not consider the loss of gravity head at transition into microgravity.
Solution	We re-fabricated the circuit of almost the same height and liquid circulated successfully.

2	We could obtain no data or data with great noise only.
Cause	The braking deceleration made the connectors loose.
Solution	We managed to obtain data after fastening the connectors and separating power lines from signal lines as much as possible.

3	We could not obtain data after conducting experiment with volatile substances as samples.
Cause	Devices malfunctioned due to pressure increases after sealing the capsule.
Solution	We managed to collect data after installing an exhaust-gas recovery cylinder.

4	We lost high-velocity video data.
Cause	The battery died during the 40 minutes to recover the capsule.
Solution	We managed to collect data after increasing the number of batteries.

5	Braking damaged some of our experiment equipment and we had difficulties in purchasing replacement components.
Cause	We did not have any replacement parts because we did not foresee the possibility of experiment equipment damage.
Solution	It is important to prepare plenty of spares for parts that may wear out.

6	Our experiment equipment did not operate because of poor insulation.
Cause	We had tested the experiment equipment at our university while temporarily mounted on a wooden desk.
Solution	Since the base plate is aluminum, we resolved the problem by coating the problem areas with insulating paint or mounting wires between insulating materials.

7. Aircraft Experiments

This chapter introduces aircraft experiments performed on Diamond Air Service (DAS) aircraft.

7.1 Features of DAS Aircraft Experiments

Before planning your aircraft experiment, is it important to know well about the aircrafts and facilities of DAS. And you have to recognize the limitations of experiment operations in the aircraft. After these details have been confirmed, you need to go through a certain procedure(SEE 7.4) with JSF and DAS technical staff to perform your experiment.
This section introduces the basic specifications the aircrafts and facilities of DAS.

(1) DAS aircrafts

Table 7.1 Specifications of DAS aircrafts

Aircraft operator	Diamond Air Service	
Aircraft	MU-300	G-II (Gulfstream II)
Base airport	Nagoya Airport	
Airspaces used for experiments	Enshunada Sea airspace K and Noto Peninsula airspace G	
Parabolic flight	Takeoff to landing: About 2 hours/flight Experiment time: About 1 hour/flight Number of experiment tries: 8 to15/flight	
Microgravity duration	About 20 seconds	
Standard microgravity levels	X-axis (longitudinal direction of aircraft): 1×10^{-2} G Y-axis (horizontal (left/right) direction of aircraft): 1×10^{-2} G Z-axis (vertical (up/down) direction of aircraft): 1 to 3×10^{-2} G Flights can be arranged providing specific gravity other than these (such as 0.1, 0.5, and 2 G).	
Pilot calls	Two minutes to (two minutes before entering microgravity), One minute to, 30 seconds to, now (on entrance to microgravity) Additional calls at other times can be arranged.	
Maximum acceleration during parabolic flight (typical)	2.0G	1.8 G
Power supplies	28 VDC/25 A × 2	28 VDC/160 A
	100 VAC, 60 Hz, 1.5 kVA	100 VAC, 60 Hz, 3 kVA 100 VAC, 60 Hz, 4 kVA
Experiment space	1,500H×4,800L×1,500W mm	1,900H×6,500L×2,200W mm
Rack size	900H × 700L × 450W mm	1,100H × 650L × 550W mm
Temperature inside aircraft	20 to 30°C	15 to 30°C

Humidity inside aircraft	10 to 40%	
Pressure inside aircraft	About 0.9 bar	About 0.8 to 0.9 bar
Vibrations during parabolic flight	5 to 54 Hz, 0.25 mm amplitude	X and Y axis: 1,130 Hz; Z axis: 610 Hz
Mass of experiment equipment	100 kg/rack	150 kg/rack
	3 racks max	6 racks max
Number of researchers aboard	1 to 2/experiment	1 to 3/experiment
Safety standards	Same as those for normal cargo aircraft	

(2) How to obtain short-duration microgravity environment by aircraft

Aircraft fly in a parabolic-curve pattern for microgravity experiment. For about 20 seconds from the beginning until the end of the parabolic curve, a microgravity environment is held inside the aircraft. Three different flight patterns can be selected according to the objective of experiment.

A: Standard pattern

A microgravity environment is obtained for about 20 seconds on the horizontal axis in the figures below.

One minute before entering microgravity, the aircraft performs rapid descent and ascent to reach its maximum velocity at the point where microgravity begins (this maximizes the length of the microgravity duration). About 20 seconds before reaching microgravity, the MU-300 attains about 2 g in the perpendicular direction (about 1.8 G on the G-II).

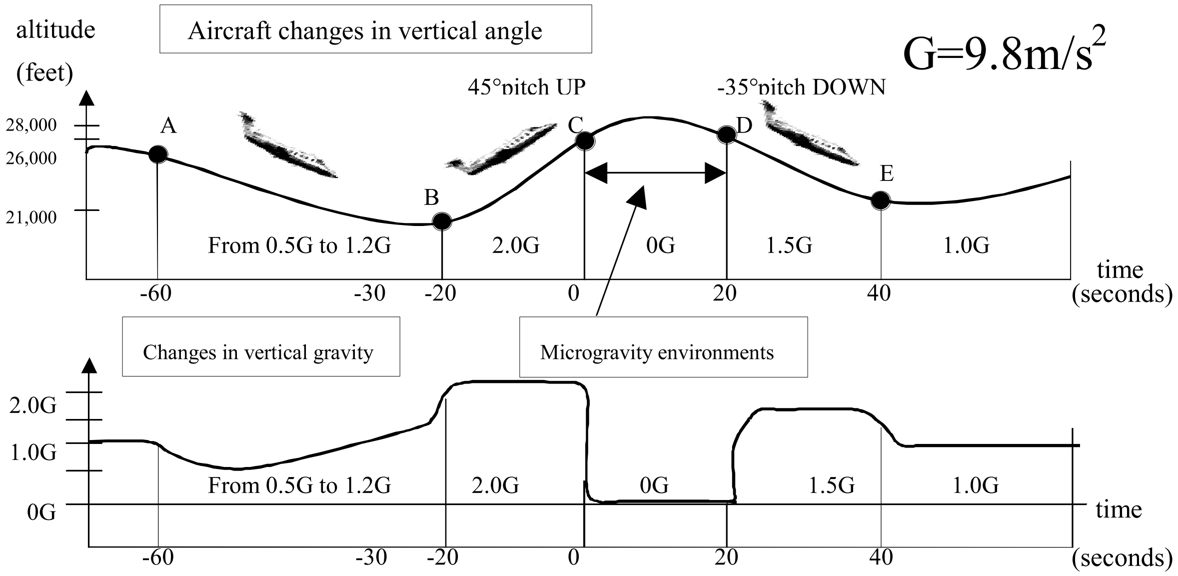


Figure 7.2 Graph of gravity changes

B: Minimal excess gravity pattern

The aircraft can perform parabolic flights where the maximum loading prior to entering microgravity is kept to about 1.2 G. Although this pattern makes the microgravity duration a little shorter (to about 16 seconds), no extreme gravitation changes occur before entering microgravity. This pattern is useful for certain types of experiments (particularly medical experiments).

C: Gravity changing pattern

Unlike the previous two patterns, this pattern can be adjusted as required to analyze the Influences of gravitational changes - microgravity, 0.2 G, 0.3 G, etc.

(3) Mounting racks for aircraft experiment

A: Size of rack on the MU-300

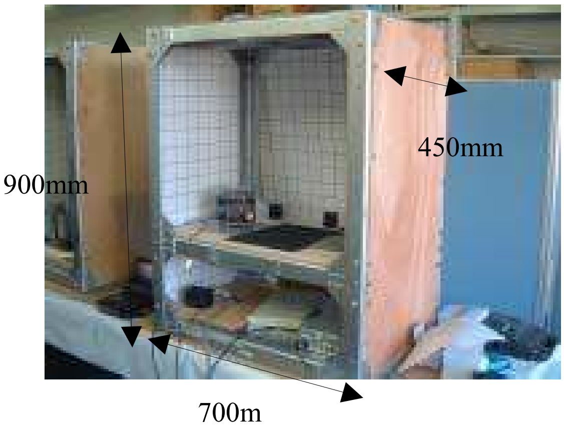


Figure 7.3 MU-300 rack

B: Size of rack on the G-II

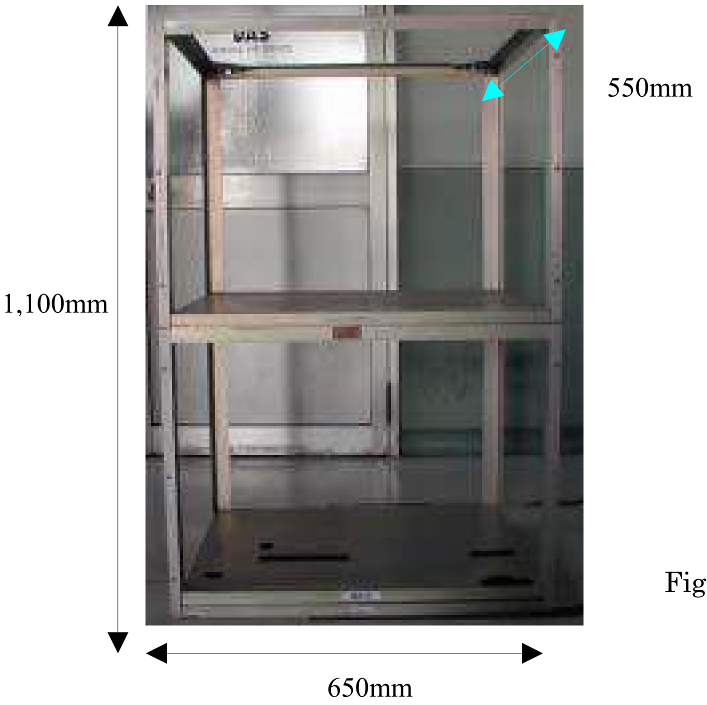


Figure 7.4 G-II rack

Research teams are given dedicated racks. Since a flight usually carries more than one team, however, interference with the experiment equipment of other teams may occur.

(4) Characteristics of short-duration microgravity environment in aircraft

A: Standard aircraft layouts

Figures 7.5 and 7.6 illustrate the standard interior layouts on the MU-300 and the G-II.

B: Adjustable layouts

The layouts in the figures are typical ones and their seat and rack positions can be adjusted.

In both the MU-300 and the G-IIA, a basic free-space layout (Figure 7.7) can be set up to reserve enough room for the free floating of people. The G-II can also be arranged for medical experiments involving small beds.

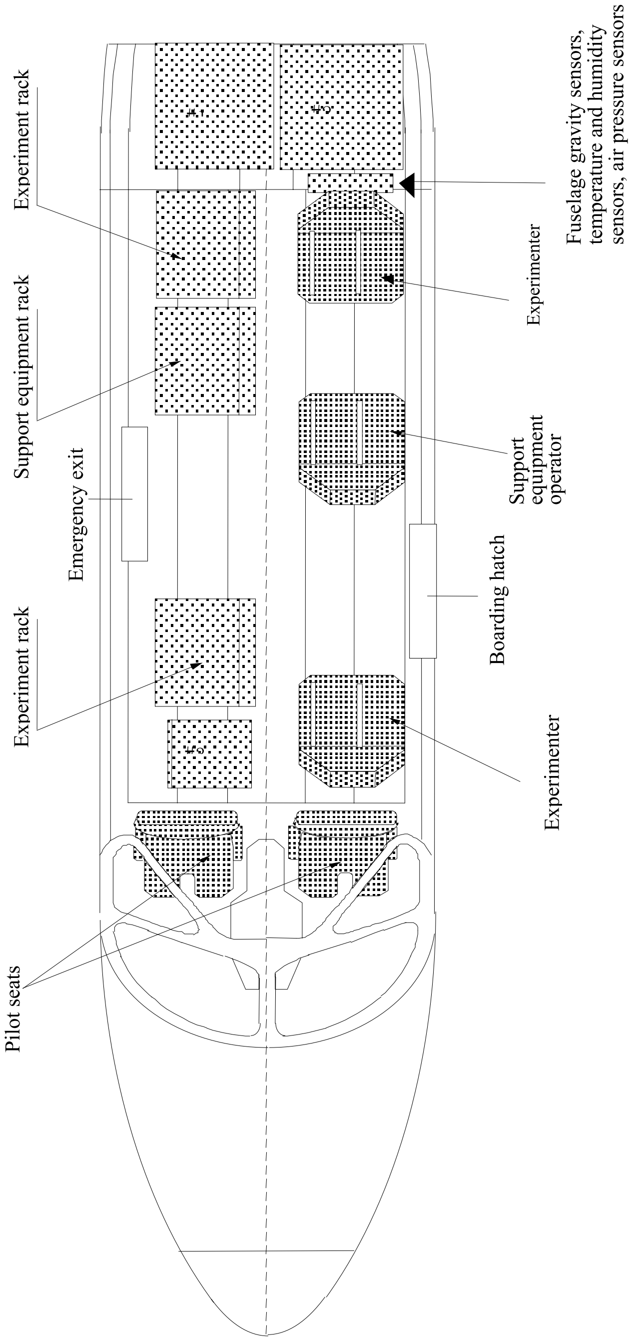


Figure 7.5 Standard layout (MU-300)

Figure 7.5 Standard layout (MU-300)

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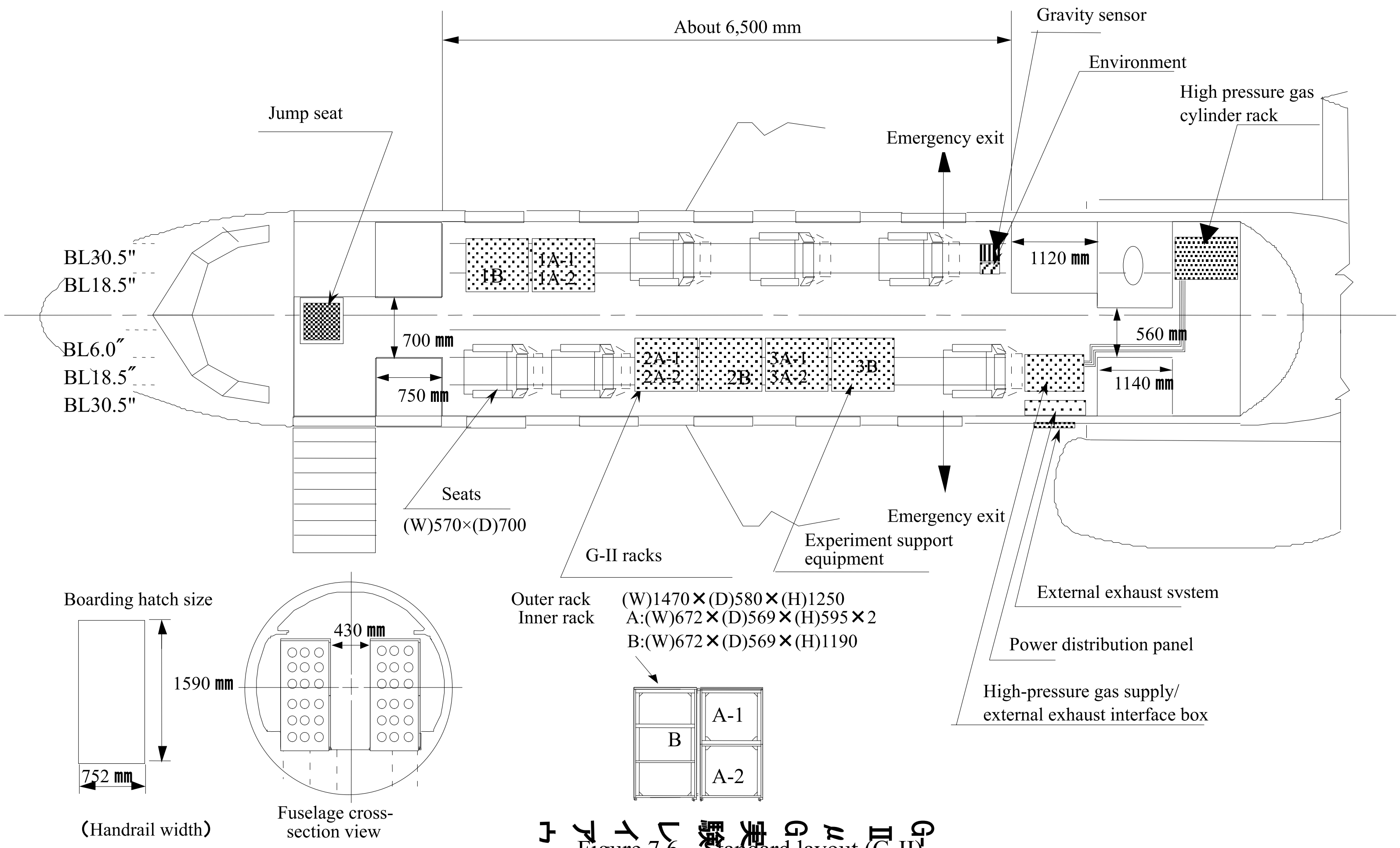


G-Ⅱ μG実験レイアウ

Figure 7.6 Standard layout (G-II)

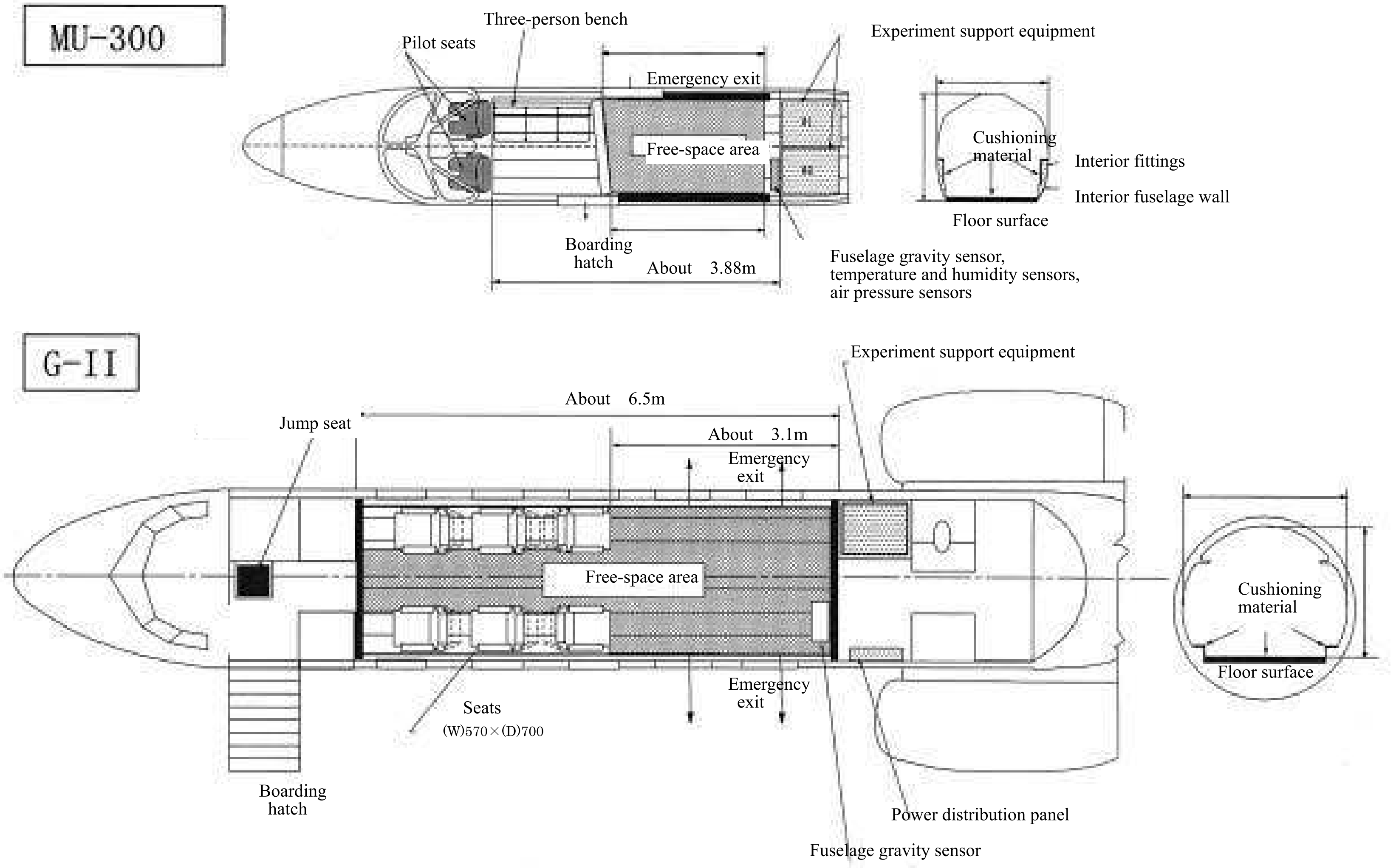


Figure 7.7 Standard free-space layouts

Figure 7.8 Microgravity-producing aircraft (MU-300 and G-II)

C: Quality of microgravity

The quality of microgravity in the aircraft is about 10^{-2} G but the duration is as long as about 20 seconds. The quality is only 10^{-2} G because of air resistance and turbulence in the airspace. The aircraft fly at low altitudes where the air Influence can be substantial. The engines have to give some additional thrust to overcome these Influence and maintain parabolic flight.

Figure 7.9 shows the coordinate axes of the aircraft, and Figures 7.10 to 7.14 provide graphs of the gravitational changes the aircraft experience along each axis, Gx, Gy, and Gz.

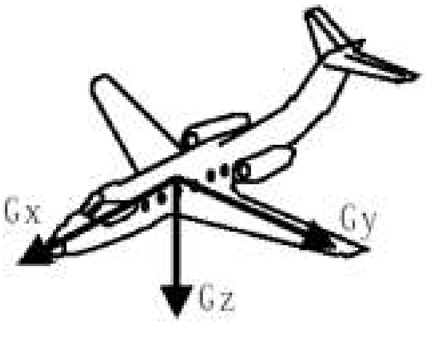


Figure 7.9 Three coordinate axes of aircraft

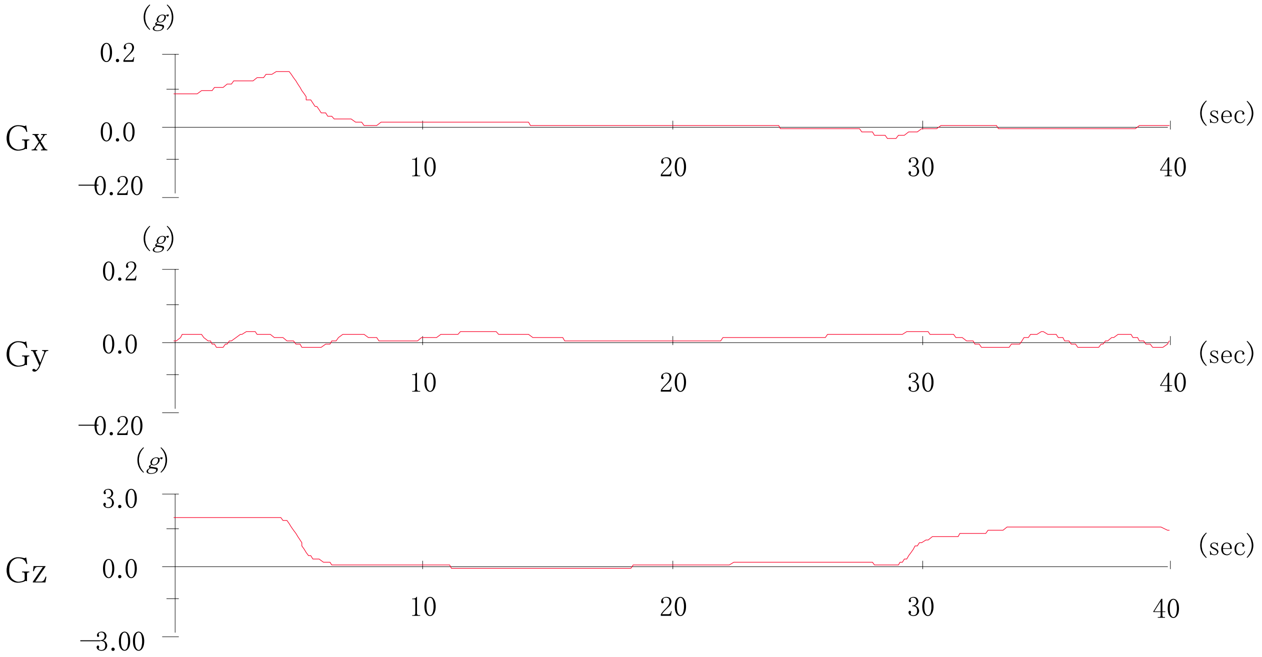


Figure 7.10 Measurements of gravity in the X, Y, and Z directions

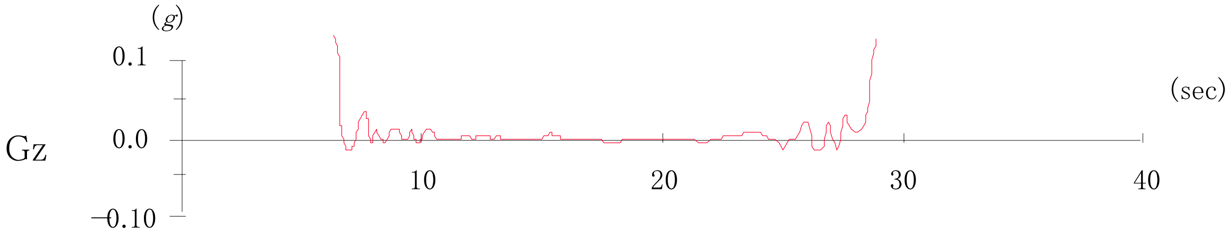


Figure 7.11 Normal Gz data
(measurements with the full Z-axis scale set to 0.1 G)

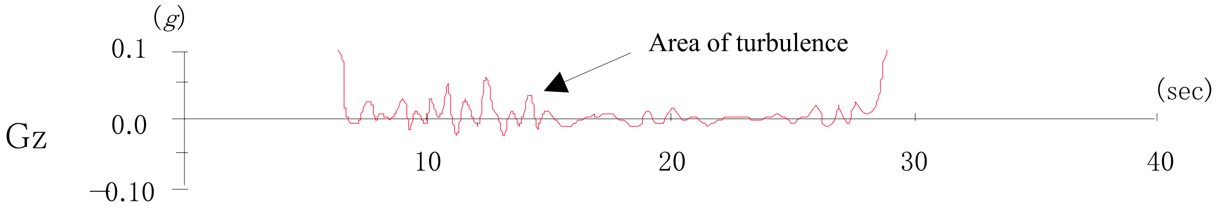


Figure 7.12 Gz data in rough conditions

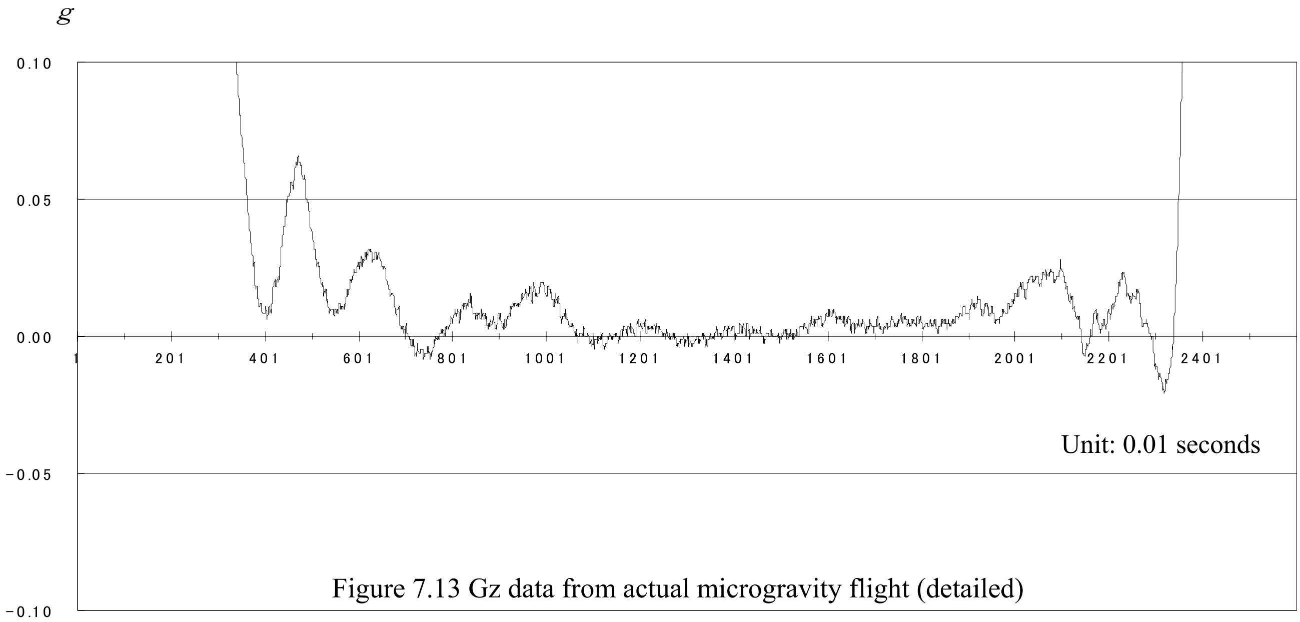


Figure 7.13 Gz data from actual microgravity flight (detailed)

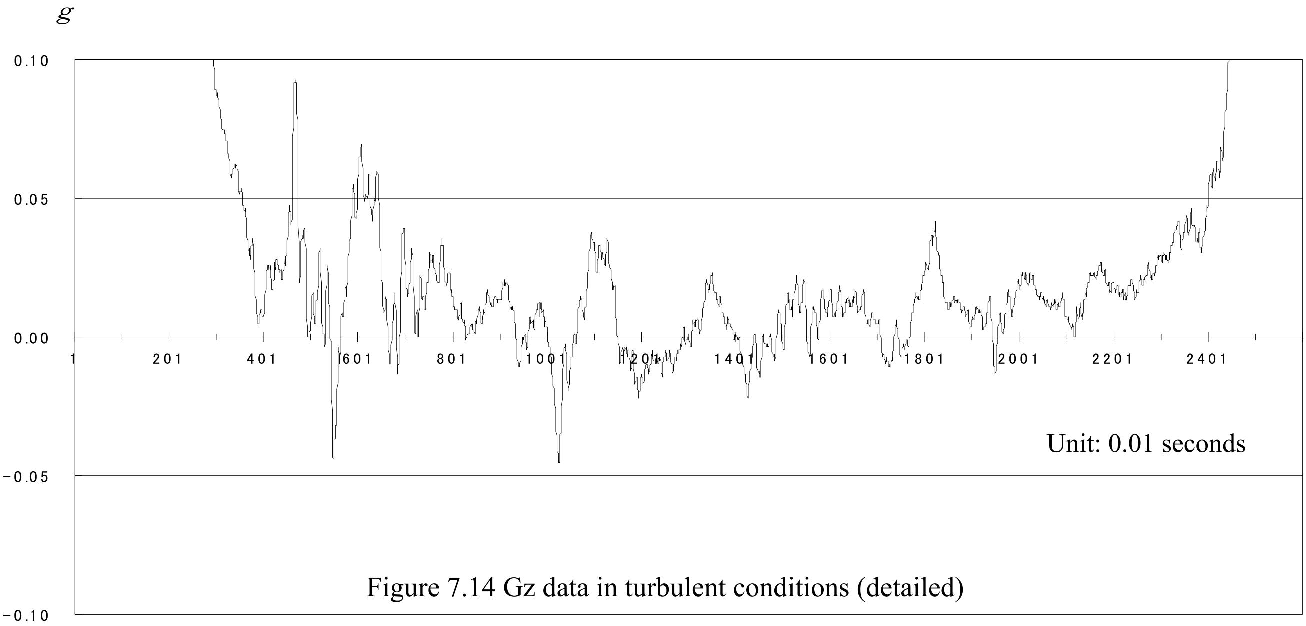


Figure 7.14 Gz data in turbulent conditions (detailed)

(5) Aircraft experiment sequence

A: Table 7.15 gives the normal schedule for an aircraft experiment.

An experiment generally requires about two weeks (considered as one cycle). Around five experiment flights are made during one cycle. The flight dates are worked out between the onboard research teams and JSF/DAS.

Table 7.15 Aircraft experiment schedule

1campaign （a typical example）

◀——————————————————▶

	MON	TUE	WED	THU	FRI	SAT	SUN	MON	TUE	WED	THU	FRI	SAT	SUN
Experiment equipment delivery／Receiving inspection	🟥					🟩	🟩						🟩	🟩
Outfitting experiment equipment	🟥					🟩							🟩	🟩
Ground-level interface tests	🟥					🟩	🟩						🟩	🟩
Onboard adjustments		🟥				🟩	🟩						🟩	🟩
EMI tests			🟥			🟩	🟩						🟩	🟩
Experiment Flights (Flights 1to 5)				#1	#2	🟩	🟩	#3		#4	#5		🟩	🟩
Interval day/ Flight preparation day						🟩	🟩		Interval			Prep.	🟩	🟩
Removal and shipment of experiment equipment						🟩	🟩				🟥	Prep.	🟩	🟩

Table 7.16 Description of work operations

Receiving inspection	Researchers check that the experiment equipment delivered has the same configuration and functions as when shipped. If there is no problem, experiment equipment should be delivered in a state of pre-assembling on the experiment racks.
Outfitting experiment equipment	The experiment equipment and experiment support system are placed and mounted inside the aircraft in the final layout for the experiment flights.
Ground-level interface tests	After loading on the aircraft, the experiment equipment is mounted on the experiment equipment racks and wired up to the experiment support system. Ground tests are conducted to see that there are no problems with the power supply or data recordings. The main check items are as follows: (1) Power consumption (2) Solid connections between the experiment equipment and the experiment support system (3) The experiment equipment works properly (4) The data recorder in the experiment support system records data properly. (5) The experiment equipment outputs the correct signals to the experiment support system. (6) The experiment equipment can be operated inside the aircraft.

Onboard adjustments	After installing the experiment equipment, final adjustments and function checks are conducted for the experiment flight.
EMI tests	Electromagnetic interference (EMI) tests are to ensure that there is no electromagnetic interference from the experiment equipment on the aircraft (cockpit instruments and communication and navigation systems) or from the aircraft system to the experiment equipment that adversely affects flight or experiment. These tests are done while the engine is conducting to simulate actual flying conditions. The experiment is repeated in the same sequence as it will be done in the air and electromagnetic interference is checked for at each step.
Experiment flights	After takeoff, it takes about 20 minutes to reach Airspace K (on the Pacific Ocean side) and about 30 minutes to reach Airspace G (on the Japan Sea side) where the experiments are done. During this time, researchers may get their experiments ready. Researchers, however, cannot leave their seats to make preparations until about five minutes after takeoff (when the seatbelt sign turns off). The duration of flight to the designated airspace is one hour when 8 to 15 experiment tries are normally made. The actual number of experiment tries depends on the preparation time needed between tries. Report any problem (including people getting sick) during experiment flight to the pilot no matter how trivial you may think it is. The pilot makes the final decision on return. Because of many environmental changes during flying, the moving and thinking abilities of people are limited to half those on the ground. To get the most benefit from the experiment flight, make all in-flight equipment operations as simple as possible and rehearse each operation on the ground before flying.
Interval day/flight preparation	For five flights per cycle, an interval day is set between flight days. The interval day can be used as a flight day if flights have been postponed due to poor weather conditions or as a preparation day if flights are on schedule to revise experiment parameters, analyze experiment data, and improve the experiment equipment.
Removal and shipment of experiment equipment	After experiment is completed, DAS will remove the experiment equipment from the aircraft while researchers are present. Researchers are responsible for packing up experiment equipment and peripheral devices and arranging their shipping. DAS may pass the freight to a transport company on behalf of the researchers.

B: Flight day schedule

Table 7.17 shows the typical events on a flight day from experiment equipment preparation and experimentation to preparation for the next day.

Table 7.17 Typical schedule for an aircraft experiment (one day)

Standard Flight time window: 11:20 to 13:40 Airspace G (12:00 to 13:00)				
Time	Step		Work operations	Power supply
8:00 ～ 10:00	Passenger check/experiment preparation		Verify those who will ride on the aircraft. Make preparations for experiment.	External power supply
	10:00	Determination of flight	Determine whether to fly.	
	Completion of experiment preparation		Complete experiment preparations. Turn off the experiment equipment power supply. Turn off the aircraft power supply. Remove all unneeded experiment equipment. Check mountings of experiment equipment and other onboard experiment equipment.	
10:00 ～ 10:15	Aircraft out of the hangar		Move (tow) the aircraft from the hangar to the outside parking area.	No power supply (about 15 minutes)
10:15 ～ 10:50	Fueling		Fuel the aircraft.	Power can be supplied from an external power supply if requested (one experimenter must be present).
	10:30 ～ 10:40	Preflight briefing	Make the final checks of flight procedure, experiment sequence, and researchers' requests.	
10:50	Boarding		Passengers board the aircraft.	
10:50 ～ 11:00	Preflight check		Start the donkey engine, inspect the navigation system, and enter flight data.	Power supply by request (prior testing necessary because power-supply interruptions and voltage drops may occur)
11:00 ～ 11:15	Engine start			
11:15	Experiment power supply on		Start the power supply to the experiment equipment.	Power supply from the aircraft generator
11:15 ～ 11:20	TAXI OUT		Move to runway (under own power).	
			Fasten seatbelts.	
11:20	11:20	Takeoff		

～ 13:40	～ 12:00	Start of experiment preparations	Once the aircraft has reached a safe altitude and the air current has become stable, the pilot instructs when to start experiment preparations. Unfasten seatbelts and start experiment preparations.	Experiment trial
		Five minutes before reaching the airspace	Pilot gives a five-minute notice before reaching the designated airspace.	
		Arrival at experiment airspace	Start experiment.	
	12:00 ～ 13:00	Experiment preparation completion	Researchers inform the pilot that the experiment is ready.	
		Two minutes before	Two minutes before entering microgravity (call by pilot).	
			Fasten seatbelts.	
		One minute before	One minute before entering microgravity (call by pilot)	
		30 seconds before	30 seconds before entering microgravity (call by pilot)	
		NOW	Microgravity start (now call)	
		End of microgravity	The microgravity state ends.	
		Normal flight	The aircraft returns to normal flight (call to start next preparation for the next trial).	
		Start of experiment preparations	Unfasten seatbelts and start preparations for the next trial.	
		Repeat steps until the end of airspace usage time.		
	13:00 ～ 13:40	End of experiment	Finish the experiment and return to Nagoya Airport.	
		Landing		
		Experiment power supply off	Turn of the power supply to the experiment equipment.	
		Aircraft powered down		Power can be supplied from an external power supply if requested (with one experimenter present).
13:45 ～ 13:50	Postflight briefing		Make a brief explanation of the flight conditions (air current state, microgravity conditions, etc.) and the experiment conditions (results and problems).	
14:00 ～ 14:20	Aircraft back to hangar		Move (tow) the aircraft from the outside parking area into the hangar.	No Power supply (about 20 minutes)
14:00 ～ 14:30	Lunch		(Lunch for people other than passengers is between 12:15 and 13:00)	External Power supply
14:30 ～ 15:30	Data analysis		Conduct the primary analysis of experiment data.	

15:30 ～ 16:30	Daily meeting	Discuss the results of experiment, problems, strategies, flight requests, and other details and verify the schedule for the next experiment flight.	
16:30 ～	Preparations for next experiment	Prepare for the next day’s experiment and adjust the experiment equipment.	

(6) Notes on aircraft usage

The table below summarizes notes about experiments onboard aircraft.

Table 7.18 Notes on aircraft usage

	Item	Description
1	Design	Assemble experiment equipment to fit the designated racks (MU-300: 900H × 700L × 450W mm, G-II: 1,100H × 650L × 550W mm).
2	After takeoff	It takes about 30 minutes to reach the experiment airspace after takeoff. The aircraft will stay in the experiment airspace for about one hour when 8 to 15 experiment tries can be made (the actual number of trials depends on the preparation time between trials).
3	Weight	MU-300 100 kg/rack, G-II: 150 kg/rack
4	Number of flights	One flight per day
5	Flight sharing	The aircraft generally carries more than one research team for shared experiment on each flight. In some cases, however, only a single research team may conduct experiment. In general, one rack is assigned for each subject of experiment.
6	During microgravity experiments	You may operate or control experiment equipment while the microgravity experiment is under way.
7	Cycle	Up to six experiment flights can be conducted over about two weeks at a pace of one flight per day.

(7) Experiment support system (on the aircraft and on the ground)

DAS has support system ready for aircraft experiment, including commonly used measurement data storage devices, video data storage devices, and racks for carrying experiment equipment on the aircraft, plus data processing experiment equipment on the ground. Experiment equipment can be connected to the support system on the aircraft for microgravity signal input into the experiment equipment and experiment data recording on the support system during experiment flights.

Table 7.19 List of experiment support system on DAS aircraft (MU-300)

Item	Support system	Available quantity	Available quantity per team
Power supplies	100 VAC (60 Hz)/15 A	15 A max	7.5 A
	28 VDC/25 A × 2	2 lines	1 line
	100 VAC (50/60 Hz)/5 A	1 line	Shared
Weight/rack	100 kg/rack maximum (900H × 700L × 450 mm)	1 or 2	100 kg/one
Vibration insulation devices	Vibration insulation devices (used with dedicated racks)	2 sets	1 set

Passengers	Including support system operator		3	1
Internal environment data	Signals for the gravity acting on the aircraft in three dimensions (analog -2 V to +5 V, 1 G/2 V)	Gx	1	1
		Gy	1	1
		Gz	1	1
gravity data system	Three-axis gravity sensor for experiment equipment		2 sets	1 set
	Gravity indicator (LED)		1 set	Shared
	Experiment start signal (12 V circuit, 5 V circuit, and short/open circuit)		2 channels	1 channel
Video data storage devices	CCD video camera (7.5 mm and 15 mm)		4	2
	DV-CAM (VCR)		4	2
	S-VHS (VCR) (optional)		2	1
	On-screen information (superimposition of gravity values, date, and time)		6 systems	3 systems
	5-inch CRT monitor		2	1
	5.6-inch LCD monitor		2	1
	Hi-8 video camera (8-mm camera)		2	1
	3-inch LCD monitor		2	1
	High-velocity video camera (recording length 28 minutes)		1 set	Shared
Measurement data storage devices	Signal conditioners (general use)		32 points	Shared
	Signal conditioners (for live subjects)		8 points	Shared
	Data logger	Records up to 26 channels	26 channels	Shared
	Data recorder	Records up to 26 channels	26 channels	Shared
High-pressure gas supply system	Supplies pressures up to 2.45 Mpa (25 kg/cm2)		2 lines	1 line
External exhaust system	Discharges about 100 L/minute		2 lines	1 line
Aircraft intercom system	Aircraft intercom		1 line	For all aboard

Table 7.20 List of experiment support system on DAS aircraft (G-II)

Item	Support system		Available quantity	Available quantity per team
Power supplies	100 VAC (60 Hz)/20 A		20 A max	11 A
	28 VDC/160 A		1 line	32A
	100 VAC (50/60 Hz)/35 A		35 A max	11 A
Weight/rack	150 kg/rack max (1,100H × 650L × 550 mm) 100 kg/rack max (MU-300 rack) (900H × 700L × 450 mm)		6 max	1 150 kg 100 kg
Passengers	Including support system operator		6	1
Internal environment data	Signals for the gravity acting on the aircraft in three dimensions (analog -2 V to +5 V, 1 G/2 V)	Gx	1	1
		Gy	1	1
		Gz	1	1
gravity data system	Three-axis gravity sensor for experiment equipment		2 sets	1 set
	gravity indicator (LED)		1 set	Shared
	Experiment start signal (12 V circuit, 5 V circuit, and short/open circuit)		2 channels	1 channel
Video data storage devices	CCD video camera (7.5 mm and 15 mm)		4	2
	DV-CAM (VCR)		4	2
	On-screen information (superimposition of gravity values, date, and time)		6 systems	3 systems
	7-inch LCD monitor		4	1
	Hi-8 video camera (8-mm camera)		2	1
	3-inch LCD monitor		2	1
	High-velocity video camera (recording length 28 minutes)		1 set	Shared
Measurement data storage devices	Signal conditioners (general use)		32 points	Shared
	Signal conditioners (for live subjects)		8 points	Shared
	Data recorder	Records up to 26 channels	26 channels	Shared
High-pressure gas supply system	Supplies pressures up to 2.45 Mpa (25 kg/cm2)		4 lines	1 line
External exhaust system	Discharges about 100 L/minute		3 lines	1 line
Aircraft intercom system	Aircraft intercom		1 line	For all aboard

Figure 7.21 Preparation room for life-science experiments

Figure 7.22-1 Experiment equipment inside the preparation room for life-science experiments: Safety cabinet

Figure 7.22-2 Experiment equipment inside the preparation room for life-science experiments: Cryogenic chambers

Figure 7.22-3 Experiment equipment inside the preparation room for life-science experiments: CO2 incubator(left) and Research refrigerator(right)

Table 7.23 Experiment equipment inside the preparation room for life-science experiments

Ground support system for life-science experiments	Preparation rooms for life-science experiments (about 25 m2)	3	Shared
	24-hour air conditioning		
	Around-the-clock power supply	100 VAC	
	Safety cabinet	1	Shared
	Research refrigerator (4°C)	1	Shared
	Cryogenic chamber (-40°C)	1	Shared
	Cryogenic chamber (-80°C)	1	Shared
	CO2 incubator	1	Shared

7.2 Interface Coordination Items

This section describes the aircraft interfaces that the experiment equipment must follow. Use this section as a reference when starting the development of experiment equipment.

(1) Mechanical interface

- Weight limitations

  Ensure that the total weight of all the experiment equipment to be loaded on the aircraft (including the weight of the rack) will not exceed 100 kg per rack (MU-300) or 150 kg per rack (G-II).

- Size limitations

  Lay out the experiment equipment to fit the rectangular racks that are 900H × 700L × 450W mm (MU-300) or 1,100H × 650L × 550W mm (G-II). Multiple racks can be used to carry the experiment equipment as shown in the diagram below. Make sure that the experiment equipment will not interfere with the rack frame or the mounting hardware.

- Lending of racks

  Racks are available from DAS to preassemble experiment equipment on a rack at your own facilities.

- Assembling experiment equipment

  Place experiment equipment on the racks so that it will not interfere with the rack frame or mounting hardware. Also mount the experiment equipment with some room for access to the bolt holes fastening the rack to its frame.

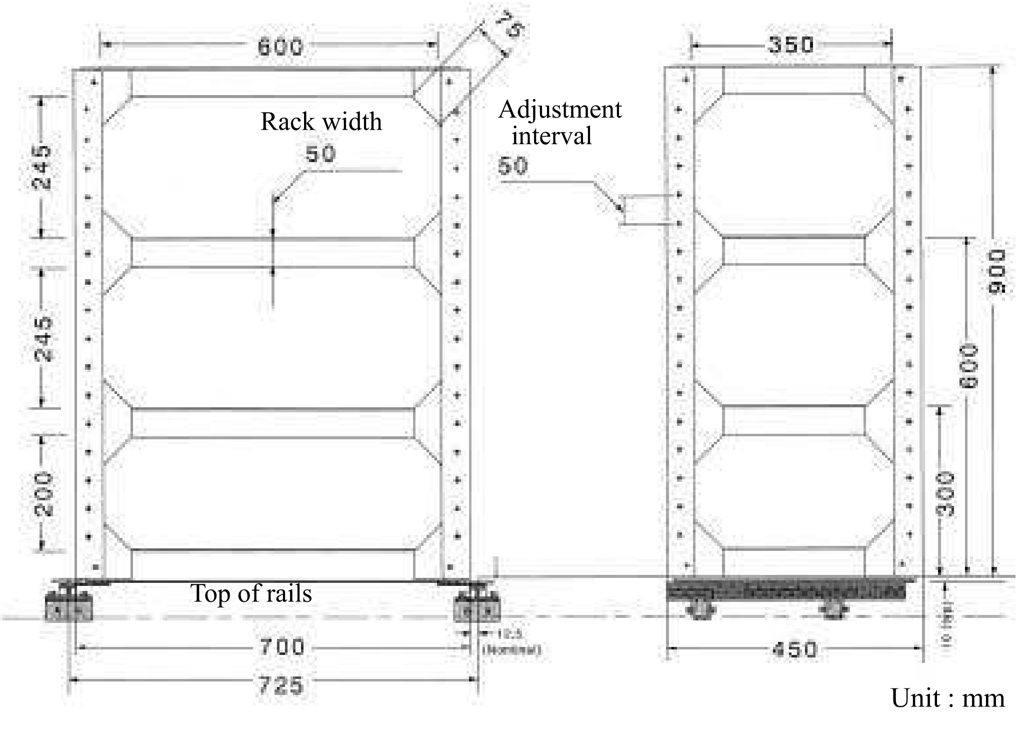


Figure 7.24 Rack interface (MU-300)

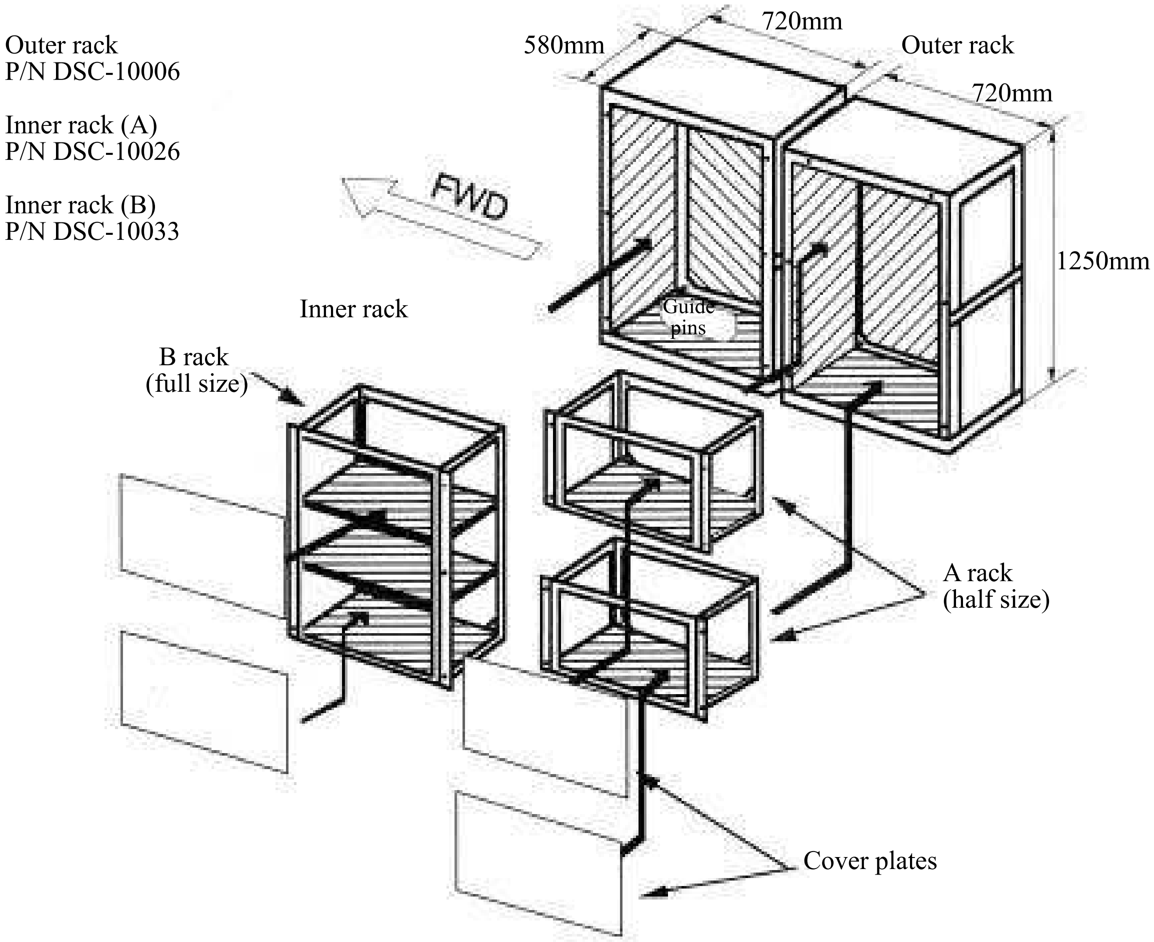


Figure 7.25 Rack interface (G-II)

(2) Electrical interface

- Power-supply capacity

A 28V DC supply and a 100V AC supply are available to power your rack-mounted experiment equipment.

Note that the power supply stops while moving the aircraft out of the hangar and while starting the engine. If experiment equipment needs to be powered during these periods, you will have to include an independent power supply, such as a battery, with experiment equipment.

- Check the power-supply connector types, applications, and cable lengths of the onboard support system.. And check the connection specifications of the support system. You must also consider the cable lengths and the distance from the experiment equipment to the support system.

Table 7.26 Power supplies to racks

	MU-300		G-II	
	Voltage	Maximum Current	Voltage	Maximum Current
DC power supply	28 VDC	25 A	28 VDC	160 A
AC power supply	100 VAC	15 A	100 VAC	30 A + 40 A

(3) Experiment start signals and data recording

- Microgravity detection signal specifications

The onboard support system outputs a microgravity detection signal. This circuit outputs a 5 V/100 mA signal for 25 seconds if the downward gravitational acceleration stays at 0.1 G or less for at least two seconds. The output duration of this signal, the detection level, and the initial microgravity duration can be adjusted independently at three steps. This enables you to specify the signal input to experiment equipment. This signal can also be enabled or disabled.

- Recording measurement data

The aircraft is equipped with measurement data recorders, such as signal conditioners (for general use and for live subjects) and data loggers that can store measurement data from experiment equipment. Their uses and specifications can be selected.

- Video data recorder functions

For example, the on-screen display unit can display the following information superposed with video signals (S or composite). The information can also be superposed on VCR with experiment video information for viewing on the monitor. Superimposing information is useful for post-experiment analysis.

    - Gravity sensor readings in the X, Y, and Z axes after an A-D conversion
    - Measurement values individually selected from the X, Y, and Z axes
    - Stopwatch function

- Other functions

Additional storage and photographic functions are available for observing and analyzing experiment data. You may select additional functions as needed to assist experiment analysis.

(4) Use of high-pressure gas system

- A system providing high-pressure gas (up to 25 kg/cm^2) to experiment equipment is installed at the rear of the aircraft. This system can be used to reduce the size of experiment equipment.

(5) Use of external exhaust system

- This system, actually consisting of two independent subsystems, evacuates unneeded gas out of the aircraft by utilizing the internal-external pressure differential. Gas is released to the atmosphere by opening a shut-off valve. This system must be used when an experiment emits smoke, odor, or large amounts of atmospheric gas because the inside of the aircraft is sealed. Fabricate experiment equipment so that gas will not circulate inside the aircraft and perform a thorough leakage check before flying.

(6) Use of DAS equipment and facilities

- DAS equipment can be borrowed or incorporated in experiment equipment or DAS facilities can be used during experiment.

(7) Safety considerations about experiment equipment

- The interior of aircraft is a small, sealed compartment shared by people and experiment equipment. Since the aircraft is pressurized, there is almost no ventilation or exhaust to outside. Fire, smoke, explosion, high temperature, high pressure, and oxygen consumption are all extremely hazardous to the aircraft operation. To avoid these situations, duplicate and triplicate safety mechanisms must be designed into experiment equipment against all possible failure modes.
- Safety certifications are required for all failure modes, including operator error, when carrying hazardous materials or conducting burning experiments. Safety certifications are needed to apply for experiment licenses from the Civil Aviation Bureau.
- You will have to coordinate closely with DAS's technical staff members on safety. Use fireproof materials in the fabrication of the experiment equipment. Wherever possible, avoid materials such as glass that can shatter easily. Place protective covers around lights and CRT monitors to prevent the dispersion of broken glass.
- Use electrical wiring with fireproof and heat-resistant sheathing. Select wiring suitable for the power. Use connectors and terminals to prevent aircraft vibration or gravitational changes from disconnecting wires or causing poor connections. In addition, cover connectors and terminals to prevent contact with spilled or dispersed objects.

7.3 Aircraft Experiment Flow

The following flowchart shows the work assignments of JSF, DAS, and researchers when implementing an experiment.

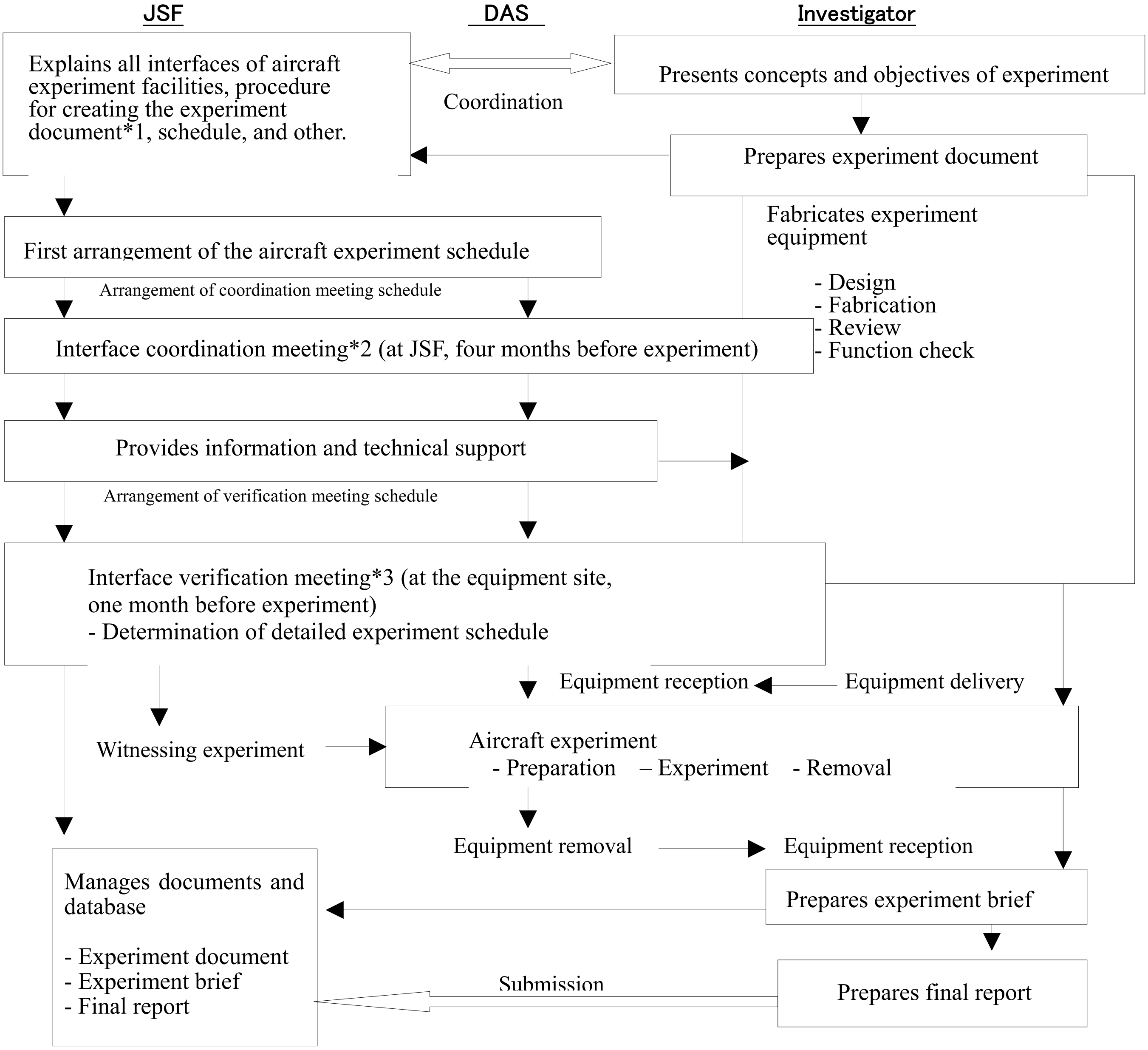


Figure 7.27 Aircraft experiment flow

*1 Experiment document: Basic document about the aircraft experiment, the experiment equipment to be used, and the execution procedure

*2 Interface coordination meeting: A preparatory meeting by the researchers, JSF, and DAS to ensure that the experiment equipment will meet the limitations of the drop shaft facilities (such as the size of the experiment area and power-supply limitations) and that the experiment equipment to be fabricated is suitable for the drop shaft experiment.

*3 Interface verification meeting: A meeting by the researchers, JSF, and DAS to verify the operation of the fabricated experiment equipment and to determine whether the experiment can be accomplished in the planned timetable.

7.4 Considerations at Experiment Equipment Fabrication

In Section 7.2 we have showed minimum interface items that must be considered on fabricating your experiment equipment for successful experiment using DAS aircraft.
In this section, for experiment more efficient, safer, quicker, and less likely to fail until the last experiment operation, we will present references based on valuable experiences of past experiments.

(1) Basic considerations

Table 7.28 Basic considerations

Item	Description
Compactness	Fabricate compact experiment equipment to fit the racks, including computer controllers.
Robustness	Securely fasten experiment equipment with DAS-specified belts or other fastening methods. Packing tape is not recommended.
Experiment preparation time	The time window for use of the experiment airspace is fixed. If your preparation takes too long, the experiment may be canceled. As the preparation time becomes shorter, the number of experiment tries increases.
Approval for hazardous materials	You will need to work with DAS early on(at least six months before experiment), because an application for a hazardous material license must be made to the Civil Aviation Bureau.

(2) Interface considerations

A: Mechanical interface (weight, mountings, placement)

Experiment equipment will receive force of up to 2 G before and after the microgravity period. Therefore, you will need to design special mountings (through-bolts, L-brackets, shifting restraints) for experiment equipment. It is important to consider experiment equipment placement with the center of gravity in mind.

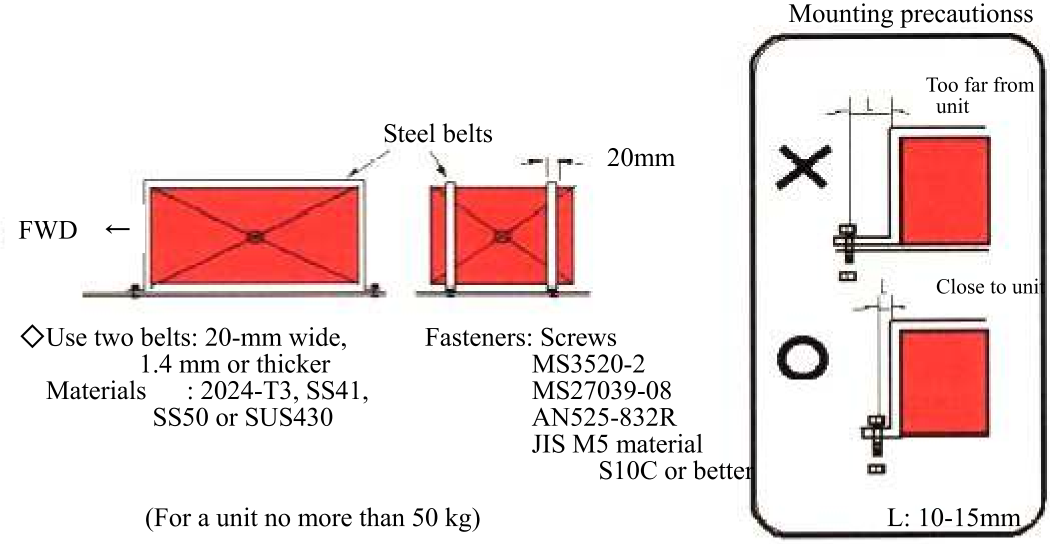
Figure 7.29 Experiment equipment secured with DAS-specified belts

*Advice from past experiments

- Make the structure as simple as possible with marketed parts available anywhere (particularly electrical wiring and panel operation). Stock up on components and parts in case of malfunctions. Wherever possible, avoid assembling experiment equipment on site. If the experiment equipment must be disassembled for shipping, minimize the number of connections to be made on site. To fit experiment equipment in a limited space, you should know that it is important to carefully determine the positions of cameras for capturing image data and take other measures. Instead of a hard disk, semiconductor memory is recommended. Because of aircraft vibration and high gravity, semiconductor memory (flash memory, etc.) is recommended.
- With two bathroom scales, the weight balance of experiment equipment layout can be checked.

Figure 7.30 Example of a memory slot reinforced against excess gravity

a.Mounting with steel belts (reference)



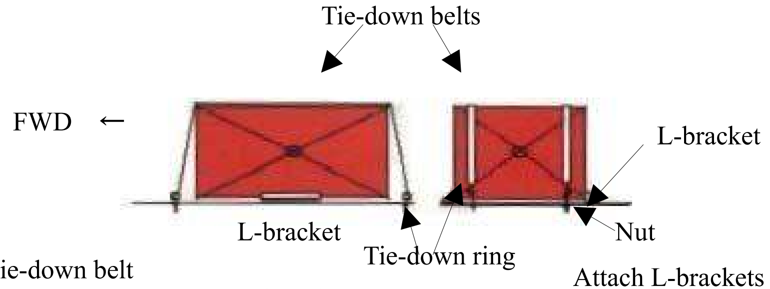
◇Use two belts: 20-mm wide,
1.4 mm or thicker
Materials : 2024-T3, SS41,
SS50 or SUS430

Fasteners: Screws
MS3520-2
MS27039-08
AN525-832R
JIS M5 material
S10C or better

(For a unit no more than 50 kg)

Figure 7.31 Rack mounting method (1)

b. Mounting with tie-down belts (reference)

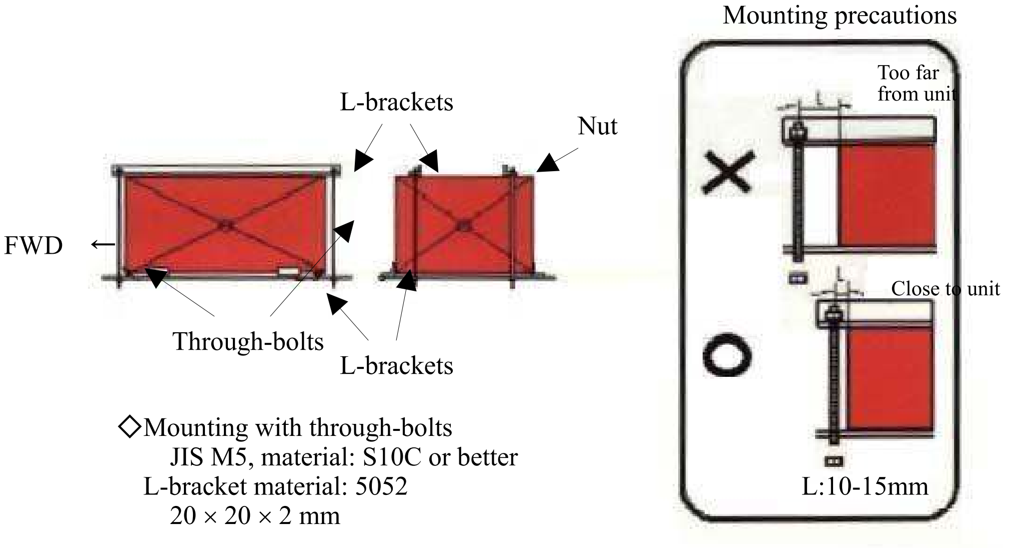


◇Tie-down belt
BL2 002 series Kito Belt, Tel: 03-3272-8471
Tie-down ring
(Eyebolt and eye nut)
Material : SS41
Thread section : M6
(For a unit no more than 50 kg)

Attach L-brackets on the sides
to prevent shifting sideways.
30 × 30 × 2 mm,
50-mm wide (5052)
Mounting screws (2)

Figure 7.32 Rack mounting method (2)

c. Mounting with fittings



◇Mounting with through-bolts
JIS M5, material: S10C or better
L-bracket material: 5052
20 × 20 × 2 mm

Figure 7.33 Rack mounting method (3)

B: Electrical interface

Work out the total power consumption by experiment equipment. The power-supply capacity differs between MU-300 and G-II. Note also that 60 Hz AC voltage is used in the Gifu area.

*Advice from past experiments

- In some cases, you will have to redesign experiment equipment because of the power supply from DAS is limited. It is important to consider device interference and power-supply distribution. In addition, faults that never occur on the ground may arise (such as connection fault caused by excess gravity, electrical short-circuit due to a floating object, or mechanical breakdown).
- Use electrical wiring with fireproof and heat-resistant sheathing. Select wiring suitable for the power. Fasten electrical wiring securely with tie clips or other fasteners to prevent short-circuit or disconnection caused by rubbing or vibration. Employing a color scheme for wires and their corresponding equipment will reduce wrong connections.
- There are several sources of noise during experiment, such as the flashing navigation safety strobes on the wingtips and terrestrial communications. EMI tests on all frequencies in use must be done on the ground. You may forget that noise affects not only experiment but also aircraft navigation. Note also that noise in the air may be greater than anticipated.
- Simple clamp meters are useful for measuring device power in advance.
- Since the back of the racks is almost impossible to reach, supply power using central taps and place all your switches on the front of the racks (facing the seats). A mirror is useful to check the back of devices.

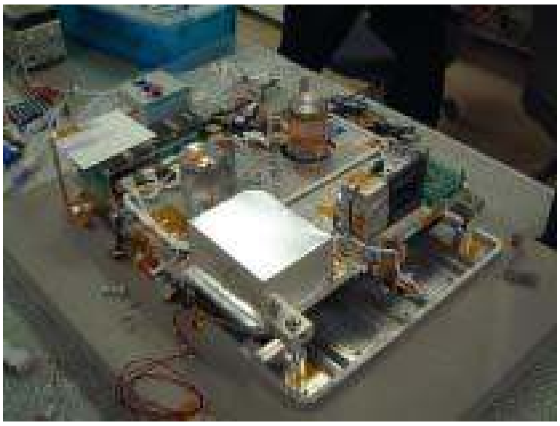


Figure 7.34　Power supply covered

Figure 7.35 Centralized power-supply tap and secured computer

C: Experiment start signal

The onboard experiment support system supplies a very useful experiment start signal. This signal can be used as a data synchronization signal when several devices such as video recorders and data loggers are recording experiment data. When using the experiment start signal, be sure to check its behavior and make sure it works consistently. It is also a good idea to fabricate experiment equipment with a shutdown mode and a manual mode.

The signal can be classified into two types:

(i) Auto mode: The start signal is output automatically after the accelerometer of the aircraft measures a gravitational acceleration in the Gz axis of 0.1 G or less for two seconds.

(ii) Manual mode: The experimenter can send this start signal by pressing a manual switch.

As the experiment start signal, a 5 V/1 A or 12 V/1 A signal can be used. The signal duration can be selected from 25, 40, and 60 seconds.

*Advice from past experiments

- Because of motion sickness, experiments sometimes have difficulties in operating their experiment equipment. Therefore, you should design your experiment so that its operation will be independent of the operator’s ability or endurance. One way is to fabricate both an auto mode and a manual mode for the experiment equipment operation. Place the control panel at the center and have the monitor face the passenger seat.

Figure 7.36 Aluminum foil around your components to block noise

D: Gravity data

Gravity data can be superimposed over video recordings (with the on-screen function) for easier and more effective reference. Text information such as gravity data, time, and stopwatch count are superimposed over the video signal. This text can be viewed on a monitor and stored with the experiment video on a VCR. This helps post-experiment analysis. The displayed information and display position can be set before each flight.

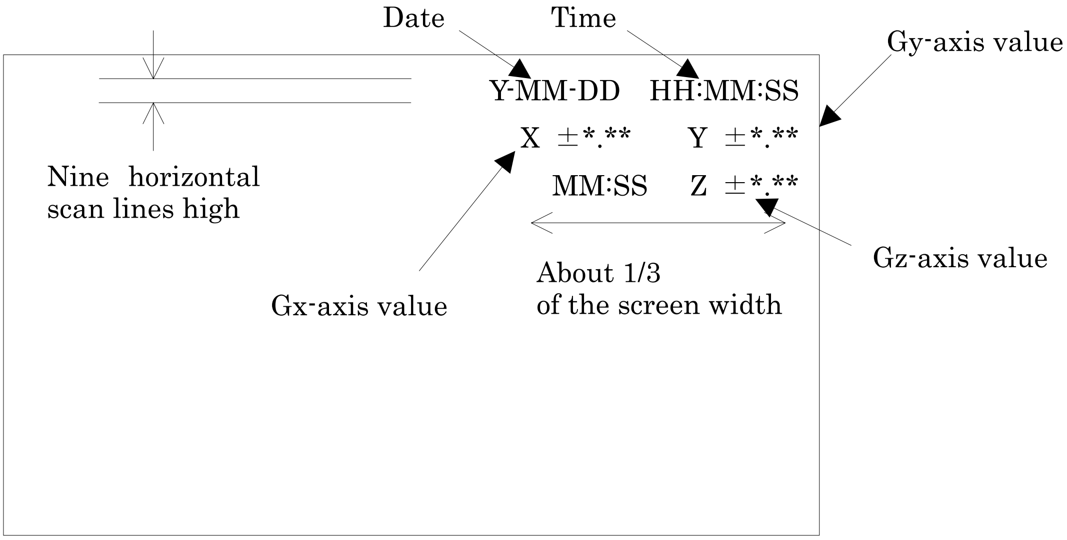


Figure 7.37 Screen display with superimposed text

Figure 7.38 Control panel/PC
(Control panel toward the passenger's seat and shielding the monitor from outside light with a gatefold cover)

Figure 7.39 Superimposed gravity data provided by DAS

Figure 7.40 Experiment controllers at hand for aircraft experiment (an example)

(3) Safety considerations

The interior of the aircraft is a sealed, pressurized environment when in flight. Consequently, due care must be taken in fabricating the experiment equipment and items taken aboard so that devices will not explode, emit smoke or odor, or leak liquid.

A: Preventing objects from dispersion

- Phenomenon under microgravity

  Parts, samples, and other hardware may float around under microgravity if they are not securely secured to racks. Floating objects may not only cause experiment equipment faults but also trouble the pilots or other researcher’s experiment, leading to cancellation of the experiment.

  Also bear in mind that experiment equipment will experience loads of up to 2 G before and after the microgravity interval.

- Solution

Special mounting designs (through-bolts, L-brackets, shifting restraints) for experiment equipment are necessary. Check that your components are placed according to their center of gravity. Place enclosures around objects that will disperse or float under microgravity to prevent them from spreading throughout the cabin. Fabricate enclosures from acrylic materials instead of glass. Use Velcro fasteners rather than packing tape.

*Advice from past experiments

- Even after checking the experiment equipment mounting prior to the aircraft experiment, something may be somehow overlooked in many cases. Conversely, note that the structure of your model does not depend on gravity and may deform or change shape suddenly under microgravity.

- Cover lights used for video recordings with metal screens in case they should break.

Figure 7.41 Light bulb covered with a metal screen in case it should break

Figure 7.42 Computer secured with metal brackets

B: Working with liquid

- Phenomenon under microgravity

Liquid, such as water or oil, can cause short-circuit or burnout because liquid forms a sphere and floats under microgravity. Take the greatest care about an unintentional leak or discharge of liquid. On the ground, a pump circulates liquid in experiment equipment at a certain velocity using gravity. This circulation velocity cannot be achieved under microgravity, however, because the Influence of gravity is not nullified.

- Solution

On the ground, a liquid container is generally checked for leakage mainly from the bottom and sides. Since the initial velocity drives liquid to the top of container under microgravity, however, it is necessary to check for leakage by turning the container or device upside down.

A common way to deal with leakage is to wrap or cover the container or device with a disposable pet diaper made of highly absorbent polymers developed by NASA. Liquid circulation in experiment equipment must be designed to avoid gravitational differentials even on ground.

*Advice from past experiments

- Absorbents for pets are the easiest to use. A rag may be used when the amount of liquid is small. Reliable measures are essential because liquid leakage can cause electrical system problems. When loading liquid experiment equipment, make reports to all parties as soon as possible because the schedule is tight. Keep in mind that it is extremely difficult to prevent liquid surfaces from deforming under microgravity once negative gravity is reached.

Figure 7.43 Pet absorbent sheets provide protection against liquid spills and leakage

C: High-temperature burners (temperature increases)

- Phenomenon under microgravity

  Passengers unfamiliar with the characteristics of microgravity sometimes accidentally touch high-temperature parts or surfaces.

- Solution

  Safety measures are essential to cope with temperature increases caused by the high temperatures or high pressures in burning and material experiments. For example, arrange a shielding plate so that you will directly touch high-temperature parts. Wear heat-resistant gloves if heated materials must be handled. Note that many experiments involving high temperatures do not proceed according to plan.

*Advice from past experiments

- Preparation work on experiments is done in the hangar, which is quite hot in summer and quite cold in winter. In summer, particularly, experiment equipment itself tends to get very hot. Experiments on animals can be prepared in the life-science experiment preparation room (which is temperature controlled), but you will have to watch over the animals carefully when they are taken out of the preparation room and placed on the rack.

D: Hazardous material samples

Transportation of explosive materials, flammable or combustible materials, radioactive materials or toxins, and other toxic materials is prohibited under Article 86 of the Aviation Law and Article 194 of the Act to Enforce the Aviation Law. Check if you can accomplish experiments using very limited amounts of cryogenic samples or propane fuel (out of concern for vaporization). DAS must apply for a license to carry hazardous materials under the Aviation Law. Therefore, please discuss such possibilities with DAS at least six months before experiment. Also notify DAS in advance if you intend to use magnetism in experiment equipment.

*Advice from past experiments

- You must deliberately arrange your schedule to deal with the large amount of preparation work, such as notifications to all parties, when using liquid components aboard the aircraft.
- Employ duplicate and triplicate safety measures to ensure that such problem as fire, explosion, or smoke will not occur.

Figure 7.44 Licenses needed to carry hazardous materials on aircraft

E: Exhaust system

For experiment using gas, design and fabricate experiment equipment so that the gas will not circulate inside the aircraft and perform a thorough leak check before flying. Utilize the onboard exhaust system to discharge gas or atmospheric gas emitted by experiment equipment. Since the aircraft compartments are small and sealed, be sure to include provisions so that unpleasant odors will not leak inside the aircraft.

Figure 7.45 Exhaust system on the aircraft (MU-300)

(4) Specific considerations

A: Pumps

- Phenomenon under microgravity

  Loading caused by air bubbles that enter pumps both increases the electrical energy consumption and potentially accelerates the battery consumption.

- Solution

It is best to keep pumps disabled under microgravity. Be careful of rush currents generated when large motors start and also air bubbles in liquid lines.

*Advice from past experiments

- If the external power supply is interrupted during vacuum pump operation, oil may leak and cause malfunctions. Using oil-free scroll pumps is recommended for microgravity experiment.

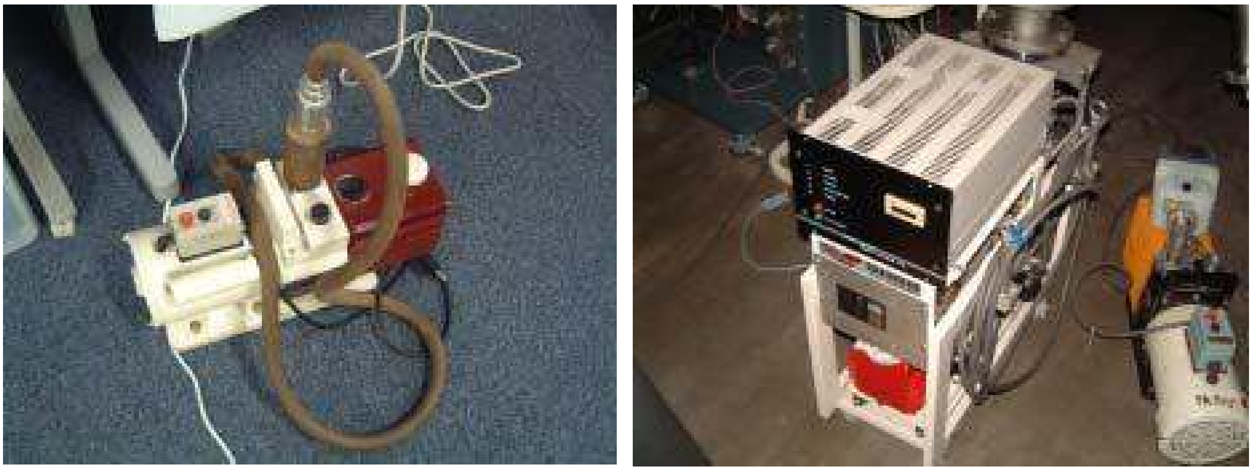


Figure 7.46 Vacuum pumps used by experiments

B: Rush currents

- Aircraft specifications

  Confirm in advance the power-supply capacity of the aircraft. Ensure that rush currents as well as the rated current of experiment equipment will not exceed the power-supply capacity.

- Measures against rush currents

  When rush currents are anticipated to surpass the battery capacity, either mount a supplementary battery or devise the startup method not to produce rush currents. Mount necessary devices on the rack.

*Advice from past experiments

- The internal power supply may stop when a high-velocity power amplifier is switched on. You may need to change the sequence so that the power amplifier will be on while the external power supply is connected.
- When using a vacuum pump, verify the initial current before experiment because currents several times greater than the rated current may flow at startup.

C: Air bubbles

- Phenomenon under microgravity

  Since no buoyancy force is generated under microgravity, air bubbles remain attached to a heat transfer surface, such as a radiator. This phenomenon not only reduces the heat-exchange performance but is suspected to cause a power-supply failure.

  Load by air bubbles entering a pump increases the electrical energy consumption and potentially accelerates the battery consumption.

- Removing air bubbles

  Remove air bubbles wherever possible from tubing while on the ground. Deaerated water should be used. Consider carefully the shape and routing of containers and tubing. Remove air bubbles from traps by vibrating the tubing and gathering air bubbles in tubing bends. Note also that Teflon or vinyl-polymer tubing allows easier manipulation than metal tubing.

*Advice from past experiments

- If air bubbles are not removed, bubbles will enter a pump chamber and produce extra load to burn out the electrical system or quickly consume the battery. Coating will prevent air bubbles from entering tubing. Design traps in experiment equipment and release bubbles from the traps to prevent them from entering the system.

D: Oil

- Oil leakage

  Do everything possible to prevent oil leakage since they can damage all experiment equipment and affect other passengers.

- Solution

  Prepare screens to clean up any oil mists that form. Securely tighten tubing and seals and set up oil mist traps for negative gravity.

E: Racks

Each team is usually provided with one rack. experiment equipment may be assembled as required in this space. The available resources (space, power, etc.) for aircraft experiment can be increased by request. Consult DAS technical staff members if you cannot get experiment equipment to fit the rack.

*Advice from past experiments

- Design experiment equipment to be compact so that it will fit the experiment rack.

Figure 7.47 Surrounding the subject with a blackout curtain to block outside light for better video recording

F: Optical systems

(a) Commercial DV (digital video cameras, etc.)

- Sunlight

  Sunlight will shine in through the cockpit window and the seat-side windows at unpredictable times because the aircraft is continually ascending, descending, and turning during the flight. Sunlight often interferes with shooting.

- Solution

  Blackout curtains are often used to block light from outside.

- Phenomenon under microgravity

  A commercial DV should be used by noting the mounting method and the field of view. The mounting method is also a concern when a CCD camera head is used because images often get skewed under microgravity. In other cases, the optical axis of the camera may go out of alignment, as load caused by its weight disappears under microgravity.

- Solution

  Vibration occurs easily when the mounting is loose. This problem is often improved by adopting not single-support but double-support and inserting a cushion or other shock absorber. It is advisable to use a rigid optical stand separate from the base plate. Making the camera adjustable by remote control is very effective when optical alignment is critical.

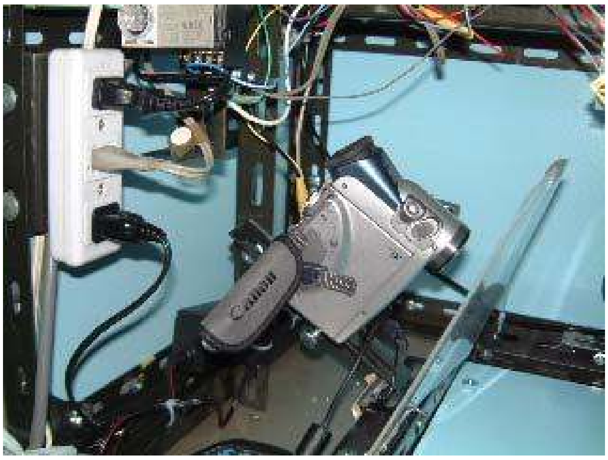


Figure 7.48 Camera firmly secured to counter the Influence of microgravity

(b) Microscope photography

- Phenomenon under microgravity

  An ultrahigh-power microscope focused on a sample on the plate at the ground level loses its focus under microgravity. This is because the camera greatly magnifies even a very slight change of the lens position.

- Solution

  When using a microscope, secure firmly the movable part for focusing and do not allow the sample plate to move in the direction of gravity. Insert rubber or similar cushioning materials to prevent direct contact between the bottom of the microscope and the plate and a massive braking impact from causing distortion or warp inside.

*Advice from past experiments

- It is effective to improve the equipment for focus adjustment by radio control.

(c) Interferometer

When using an interferometer, consider the gravitational loading on mounting supports well.

*Advice from past experiments

- Use multi-point support or rubber or other cushioning materials for parts that pick up vibration easily. An interferometer should be firmly locked to prevent focusing errors. Ensure the interferometer can withstand vibration at takeoff and when the start of the aircraft engines. Such device as a blackout curtain must be used to prevent laser beam of even low power from escaping between racks.
- Design the interferometer to withstand the extra gravity before and after microgravity.

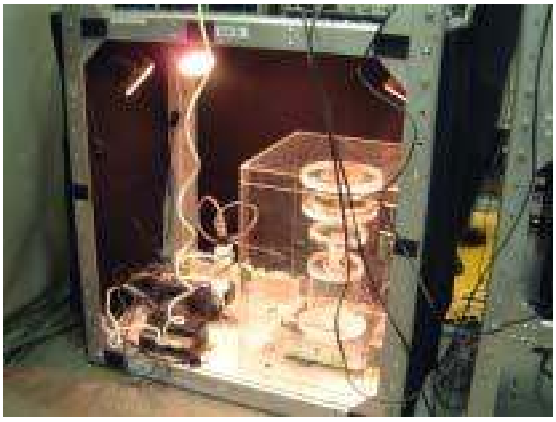


Figure 7.49 Experiment with different light mounting methods and positions

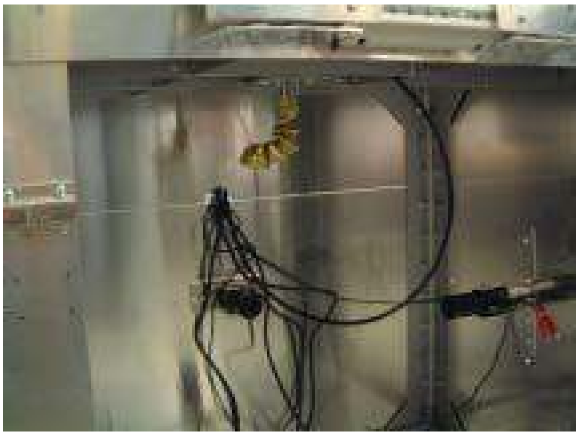


Figure 7.50 Experiment with CCD camera head

(d) High-velocity cameras

DAS has a 500 fps high-velocity camera available as part of its experiment support system. For shooting, design an optical path using mirrors or other. As mentioned above, mounting must also be considered well. The camera recorder must also be mounted on the experiments' rack.

Figure 7.51 High-velocity camera (mount recorder on rack as well)

G: Special measures for life-science experiments

Certain problems arise in life-science experiments under microgravity. This section summarizes them.

(a) Inspection by the JAXA Animal Experiment Committee and the Human-Experiment Ethics Committee

Experiments involving animals require approval of the JAXA Animal Experiment Committee as well as approval of the experiments' institution. Experiments involving people require approval of the JAXA Human R&D Ethics Committee as well as approval of the experiments' institution.

(b) Influence of gravity before and after the microgravity interval on experiment subjects

Experiment subjects receive about 1.8 to 2 G before the microgravity period (about 20 seconds) and about 1.5 G after the microgravity period. It is difficult to identify the physiological phenomena caused purely by microgravity, especially when the subjects of the experiment are small animals, because of continuous loading on the subjects after the microgravity interval. Therefore, initialization experiment is frequently conducted for comparison where data is collected during normal horizontal flight (at 1 G) without making a parabolic flight. Note that experiment equipment for valid initialization experiment must be fabricated in a way that eliminates non-gravitational factors as much as possible.

(c) Considerations for small-animal experiments

- Transport to the drop facilities and breeding time

  Rats have ever died when transported in large numbers in a small container. To avoid the Influence of transportation on small animals, you should breed your subjects at the experiment site (in the life-science experiment preparation room) for at least two or three days to acclimatize them to the environment of the facilities. It is important to properly prepare the breeding environment so that the subjects will not experience a large change from the conditions at your research laboratory.
- Surgical operation timing

  Unlike experiment in a fixed laboratory environment, experiment in an unfamiliar environment may cause small animals to move greatly due to stress or fear. Determine surgical operation timings appropriately so that implanted sensors will not come off.
- Disposal of euthanized small animals and their wastes

  You are generally responsible for removing all euthanized animals and their wastes from the drop facilities. In addition, take measures to prevent discharges from animals from dispersion during experiment.

- Securing small animals during experiment

  Small animals tend to move a lot during experiment due to unfamiliarity to the environment. You must consider ways of securing the animals suitable for the type of experiment you are performing. Animals may get stuck in normal wire mesh coverings; it is better to use an enclosure lined with nylon mesh to allow ventilation without the risk of the animals catching on something.

(d) Considerations for experiments on humans

- Safety manager

  Check the health of people who will be subject to aircraft experiment before flying. Where necessary, arrange for a safety manager (not necessarily a doctor) who can decide whether to cancel an experiment. At least one person other than the subjects must be present.

- Human experiments and Results of experiment

  Although it depends on the type of experiment, the original objective often cannot be reached if the subjects get airsick. Subjects need to be conditioned to the microgravity environment. First-time subjects are often too tense to provide useful measurements.

(e) Measurement problems encountered in small-animal experiments

Short of anesthetizing small animals, the only way to obtain data on the internal functions of small animals is to fix them from moving and retrieve data over a cable or to let them move but implant telemetry transmitters in their bodies. The size of telemetry transmitters remains a problem, as current transmitters are too large to implant in laboratory mice.

(f) Noise-reduction measures

Obtaining data from human or small-animal subjects often requires measuring very small currents or voltages. These measurements are very susceptible to noise from the aircraft (noise from the flashing wingtip strobes, terrestrial communications, ignition, and fuel pump operations) and onboard experiment equipment of other experiments. It is also wise to remember that the audible noise inside the aircraft is much louder than anticipated.

(g) Reliability of medical data

The medical community has certain standards regarding the validity of data obtained in aircraft experiments. Under these standards, data on each human subject must be obtained over at least six separate experiment flights (not parabolic flights) and aggregated from the measurements obtained.

(h) Problems encountered in animal and biological experiments

Only very limited phenomenon can be studied in one experiment since observations over long periods are necessary. In addition, high-resolution microscopy cannot be avoided when observations at the cellular level are required. The problem with high magnification under microgravity is that focusing aberrations occur in the microscope that cannot be corrected.

*Advice from past experiments

- Ensure that experiment equipment can withstand both microgravity for 20 seconds and excess gravity of about 1.8 to 2.0 G before and after the period.
- Plan all steps from breeding to disposing of test animals at the experiment facilities.
- Place a sheet around the test animals to prevent excrement and urine from floating through the drop capsule.
- Animals need to be stabilized for at least two days at the experiment facilities to acclimatize them to changes in their environment.
- In many cases, the animals receive shock and produce exaggerated introspection data. Some measures are needed.
- The flight times are subject to change because of weather conditions. The timings of surgical operations on animals (such as managing anesthetics) need to be planned accordingly.

*For experiments on human subjects

- Many times data from the first flight cannot be used when experimenting on subjects who are sitting or lying down. Satisfactory data cannot be collected in some instances because not enough flights were planned.
- Often useful data cannot be obtained until the subjects get used to microgravity conditions. Test flights (normal flights without any parabolic turns) or flights with moderate microgravity conditions are preferable to relax the subjects.
- The subjects must be prepared for microgravity conditions. Preparation before the flight is critical because experiments can rarely be corrected during flight.
- Electrodes attached to people occasionally come off due to the gravitational changes during the flight. Be sure to firmly attach electrodes with tape or by other means so that they will not move even under fairly heavy impacts.

Figure 7.52 Animal subjects placed in shielded boxes to prevent noise

7.5 Examples of Experiment Equipment Fabrication

Experiment equipment should be designed to be compact, energy efficient, and lightweight because of the limited space, withstanding weight, and power available at the drop facilities. These limitations necessitate considerations in designing and conducting experiments.

The following sections present some valuable examples of experiment equipment fabrication obtained with permission from the original experiments. These examples can also serve as references when designing experiment equipment for aircraft experiments.

(1) Temperature control

● Cooling

Peltier-element coolers are frequently used.

(2) Flow rate adjustment

● Maintaining phase boundaries in a liquid tank (Assistant Professor Asano, Kobe University)

[Problem]

Experiment with fluid runs the risk of gravity transition that causes the fluctuation of a gas-liquid boundary or creates air bubbles when using a gear pump to move liquid from a tank to the test section at a steady rate. Then the pump may not be able to maintain a stable flow rate and fail down.

[Solution]

An effective solution is to prepare a meniscus for keeping boundary in the liquid tank. In our experiment, we maintained a boundary by filling the bottom of the tank with a stainless-steel scrub brush to stop tiny air bubbles from reaching the pump. The two-phase gas-liquid flow, back from the test section, was fed tangentially into the cylindrical tank. By utilizing the centrifugal force, we separated the gas and liquid and evacuated just the gas from the center of the container.

We verified that this arrangement works even with liquid having weak surface tension, such as Fluorinert FC-72.

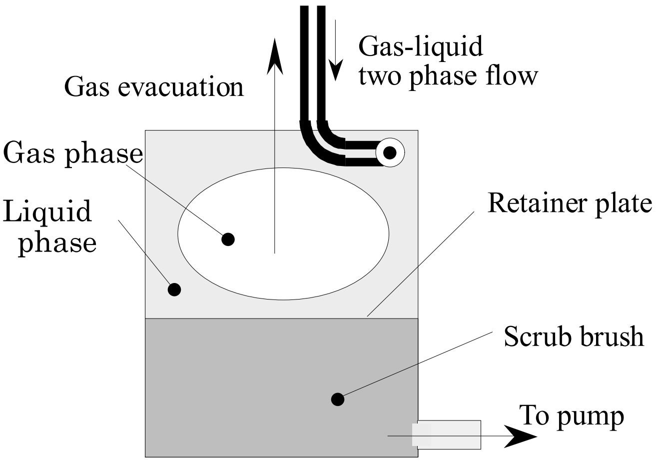


Figure7.53 Liquid-tank workaround to maintain the gas-liquid boundary

(3) Pressure adjustment

- Pressurization inside the aircraft

Take care about pressure changes inside the aircraft, as they sometimes cause operation to fail.

(4) Removal of bubbles (deaeration of solutions and experiment equipment with tubing)

- Removing air bubbles (Professor Totani, Hokkaido University)

[Problem]

If working liquid to be used in a vacuum are not fully deaerated (air bubbles removed), bubbles will emerge as the working liquid enters the vacuum.

[Reason]

Normal atmospheric pressure, under which working liquid are stored, dissolves air in the working liquid. When the working liquid is placed in a vacuum, however, the external pressure drops from atmospheric pressure to the vacuum and the dissolved air emerges as bubbles.

The absence of gravity is another reason why air bubbles emerge from the working liquid. Under gravity, the weight of the working liquid creates hydrostatic pressure. The hydrostatic pressure is greater at a deeper position in the liquid (for example, the hydrostatic pressure in 10 meters of water is one bar). This pressure means that air dissolves more easily at a deeper position in the liquid. Hydrostatic pressure, however, disappears under microgravity and causes the dissolved air to emerge as bubbles.

[Solution]

- Remove all air from liquid before experiment.
- Boil working liquid before use.
- Create a vacuum (easy if the liquid is circulated).
- Pass liquid through a screen or filter (cause a pressure loss to generate bubbles in advance).
- Use a pump of pulsating flow to drive out air bubbles trapped in bends of tubing by vibration.

- Onboard incubators for aquatic creatures (Professor Takeuchi, Tokyo University of Marine Science and Technology)

[Problem]

When using tap water for breeding, you must be aware of supersaturated air in tap water that was dissolved by water-line pressures. If unmodified tap water is used, air bubbles will emerge as the temperature or pressure changes.

[Solution]

To prevent air bubbles, lower the pressure first with a vacuum pump or aspirator and deaerate the water. Then re-aerate the water under the same pressure and temperature as those at the experiment site and add some oxygen.

To deaerate devices or tubing, install an bleeder on one breeding tank or container. The bleeder cock is effective in collecting and removing air bubbles trapped in connecting tubes. Removing air bubbles is easier if you select flexible and resilient tubing (such as thick silicon tubes).

Make experiment equipment components airtight by selecting good packing and sealing materials for containers that prevent infiltration of air from outside. It is important to conduct plenty of tests on the ground and check for air bubbles.

Figure 7.54　Aquarium used in an experiment

(5) Suppression of vibration

- Onboard vibration-isolation system

You should be aware of G-jitter, a phenomenon inherent to aircraft, when conducting microgravity experiment on aircraft. G-jitter refers to vibration caused by air currents and engine vibration. An onboard vibration-isolation system reduces the vibration. The vibration-isolation system is effective for damping vibration over 10 Hz but slightly amplifies vibration in the 1 to 5 Hz region. The vibration-isolation system limits the weight and dimensions of the experiment equipment. The center of gravity, the rigidity of experiment equipment, the wiring method, and other factors affect the vibration-suppression performance. All these factors must be considered when designing experiment equipment.

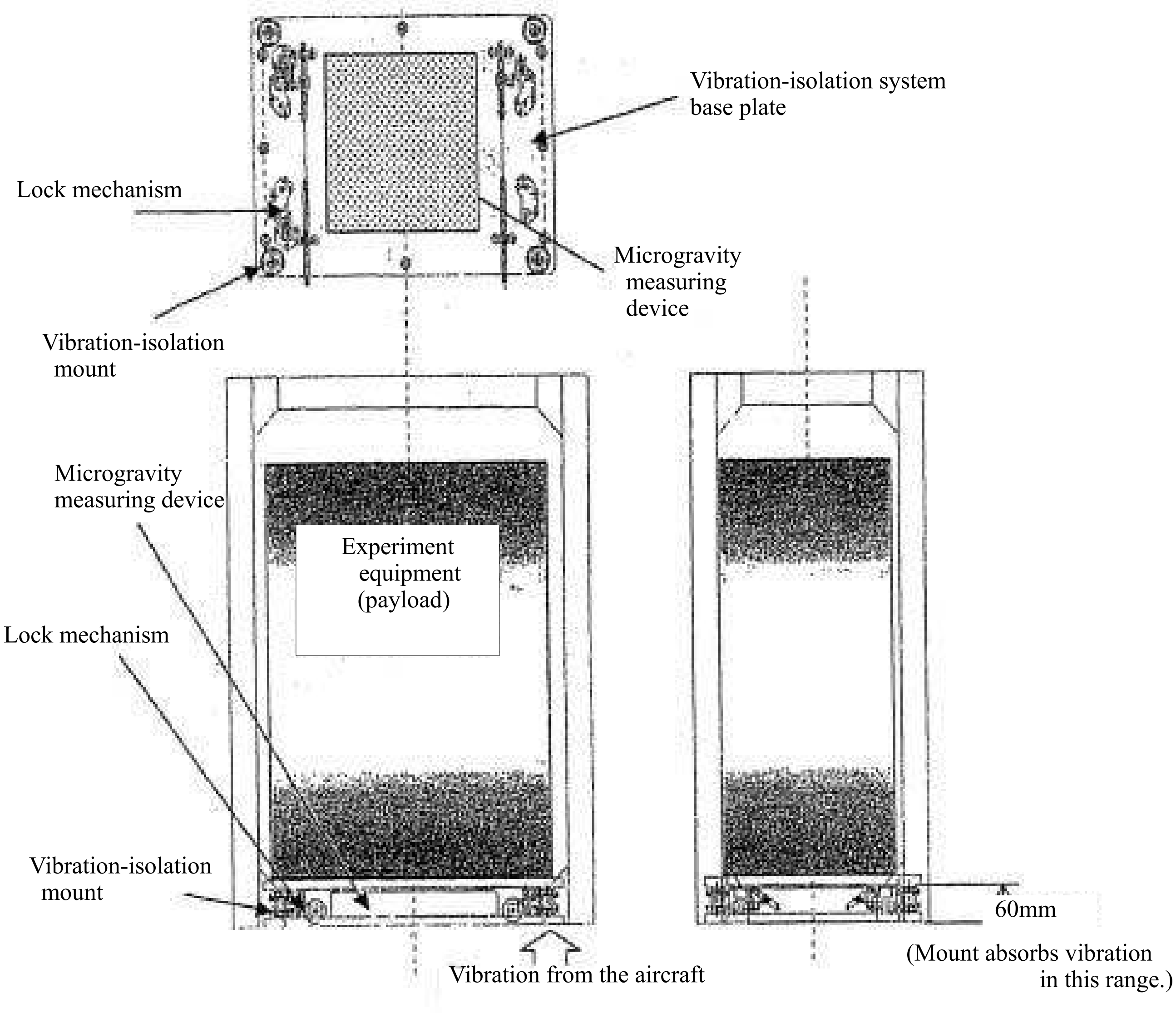


Figure 7.56 Diagram of the vibration-isolation system

(6) Examples of experiment observation and analysis (measurement) methods

- Interferometer (types, advantages, methods)

* Mach-Zehnder interferometer (Professor Maruyama and Research Assistant Komiya, Tohoku University)

[Mach-Zehnder interferometer and its applications]

The Mach-Zehnder interferometer is a two-beam interferometer conceived by L. Mach and L. Zehnder for aerodynamic research. The interferometer consists of a light source (S), a collimator (C), two beam splitters (BS1 and BS2), and two plane mirrors (M1 and M2), as shown in Figure 7.56. The elements are positioned diagonally at the corners of a rectangle. Monochromatic light, made parallel by the collimator, is divided into a reference beam and a test beam by BS1. These two beams are reflected respectively by M1 and M2 and remixed by BS2. The interference fringes produced by the two beams are observed with the detector (D). No interference fringes appear if the optical lengths of the reference beam and the test beam are identical. Interference fringes will appear when a transparent medium with an index of refraction that changes the optical length is placed in the test section (between M2 and BS2) on the test beam's optical path. One dark line appears for each multiple of the monochromatic light wavelength λ that the optical length changes by. The applications of the Mach-Zehnder interferometer include not only research of transparent media but also research on spatial refractive-index changes of gas. The Mach-Zehnder interferometer is also useful in visualizing phenomena accompanying refractive-index variations, such as thermal fields and density fields in transparent media.

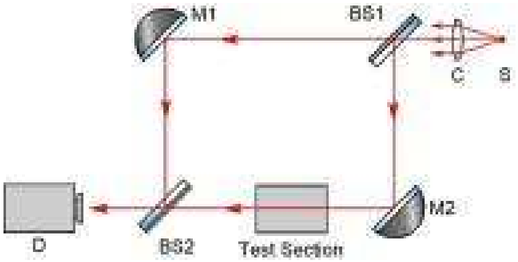


Figure 7.57 Theory of the Mach-Zehnder interferometer

[Fabrication of interferometer for microgravity experiment]

We recommend observing the points below when fabricating a Mach-Zehnder interferometer for Drop Experiment or Aircraft Experiments:

- Design the overall size of the interferometer to fit inside the designated rack.
- Design a thick optical base.
- Design the optical path as short as possible.
- Reduce the number of interferometer components and mount all components on the common base.

The Mach-Zehnder interferometer operates on the theory of separating and remixing monochromatic light. This requires quite a number of components and consequently techniques to align the resulting optical paths. It is not enough to place the interferometer components in their proper locations and align the optical paths under normal gravity. Microgravity throws the optical paths out of alignment because the gravity loading that has kept components symmetrical disappears. To prevent misalignments, the points given above are critical when fabricating an interferometer.

Figures 7.56 and 7.57 illustrate the Mach-Zehnder interferometer used in our laboratory for aircraft experiment. The red lines in the figures indicate the optical paths. The overall dimensions were 57W × 38H × 37D cm that fits both drop-capsule racks and aircraft racks. The beam splitter corresponding to BS1 is specially designed to combine the functions of BS1 and M2. Similarly, the other beam splitter provides the functions of M1 and BS2. This design markedly reduces optical axes and suppresses optical path fluctuations. Microgravity distortions of the optical axes were eliminated by reducing the overall optical path length and by fixing all components directly on the base instead of using poles or rods.

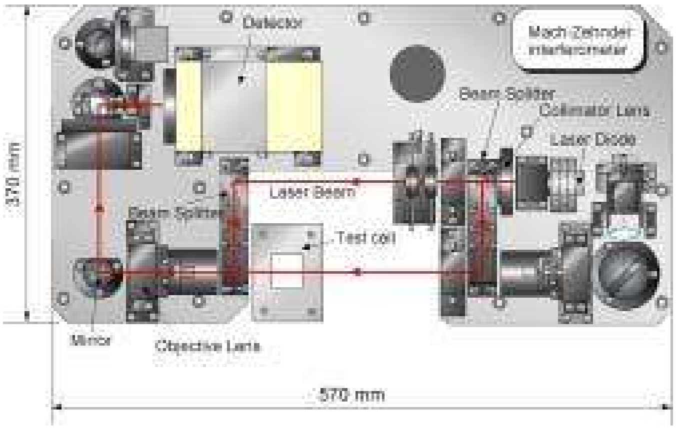


Figure 7.58 Mach-Zehnder interferometer for aircraft experiment

[Notes on usage]

If an interferometer is directly secured on a common rack for loading on aircraft or drop capsule, vibration from other experiment equipment will make it difficult to read the interference fringes. Putting the interferometer on vibration-isolation mounts can eliminate the high-frequency and low-frequency noise of other experiment equipment from interference fringe recordings and images.

In aircraft experiment, note that the Mach-Zehnder interferometer fixed on vibration-isolation mounts will receive the initial vibration from the rack when it enters microgravity. This may easily cause the visible laser beam to be emitted in an unexpected direction, posing a safety risk. For your protection, enclose the interferometer with a laser barrier.

We used a 25-mm-thick anodized aluminum plate for our interferometer base. We chose aluminum because any sturdier material would be too heavy to carry on the aircraft.

[Problem]

We placed the interferometer components on an optical breadboard and aligned the optical axes perfectly. After takeoff, however, the light disappeared from the camera's field of view soon after entering microgravity.

[Solution]

Since poles were used to fabricate the optical system, however, we believe a mirror or other element might have moved when we entered microgravity.

(7) Other design considerations

- Method for replacing samples

*Quick coupling (Professor Katani, Kobe University)

[Problem]

Quick swapping of samples is important to conduct as many tests as possible in a one-hour flight. This is a requirement.

[Solution]

We devised the quick coupling shown in the photograph from several different ones and connected it to our experiment equipment. We also devised a lock system to prevent the coupling from expanding under normal gravity and a simple switch to start releasing the coupling. This quick coupling allowed us to smoothly swap samples even in the confined space of the aircraft, letting us complete a sufficient number of tests.

Figure 7.59 Sample with quick coupling

7.6 From Experiment Equipment Fabrication to Final Experiment Preparations

This section introduces the sequence of the themes of "Ground-based Research Program for Space Utilization", from the fabrication of experiment equipment, based on the previous sections, up to the day of experiment (Figure7.27).

(1) Before fabricating experiment equipment (interface coordination meeting)
About four months before experiment, an interface coordination meeting is held (usually in Tokyo) with JSF and DAS staff to carefully discuss the interface between the aircraft and the experiment equipment based on the experimentation design. Fabrication and improvement of the experiment equipment start after this meeting.

(2) Verification tests on the ground after fabrication
Experiment equipment is verified on the ground level to confirm whether the expected experiment is possible. Experiment preparations and troubleshooting continue for the final confirmation at the interface verification meeting.

(3) Final confirmation (interface verification meeting)
About one month before the scheduled experiment date, experiments meet with JSF and DAS staff (usually at the experiment equipment site) to verify the items below. The three parties determine together whether the planned experiment is feasible at the time while considering the improvement of the experiment equipment.

- On the ground, secure the experiment equipment on actual racks for experiment and verify the experiment equipment operation systematically by simulating the interface with the aircraft facilities
- Confirm whether the prescribed devices can reliably store data from the experiment.
- Reconfirm the mounting and the size (whether the experiment equipment will fit the racks).
- Determine the experiment equipment deliver date and the transportation method.
- Predetermine measures against experiment equipment faults under microgravity.
- Confirm the preparation time and power needed before starting the microgravity experiment.

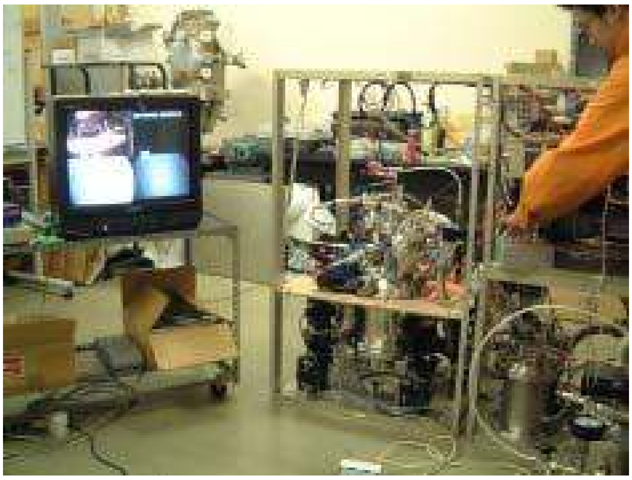


Figure 7.60 Careful verification of operation on the ground

(4) Experiment equipment assembling and final operation check at the aircraft experiment facilities (hangar)

Experiment equipment is normally disassembled before shipping to meet weight limitations and to prevent damage from vibration during shipping. Thus, the following operations are necessary before starting the aircraft experiment.

An escort by a DAS staff member is necessary when you enter DAS. If you are arriving by car, park in the visitor's parking lot in front of the Mitsubishi Heavy Industries Komaki South Plant main entrance and contact DAS. If you contact us from your hotel (the Airline hotel) or Nagoya Airport, we will send a car to pick you up.

DAS will provide you with working clothes. Experiment equipment is usually assembled in the hangar. Space is also available indoors for analyzing experiment equipment.

A: Work done outside the aircraft
- After arrival, assemble the experiment equipment enough for testing.
- Confirm the standalone operation of each device.

B: Work done after loading the experiment equipment inside the aircraft
- Confirm the interface with the experiment support system at the aircraft.
- Confirm the preparatory operation and work time before experiment.
- You may use the life-science experiment preparation room for life-science experiments.

Figure 7.61 Experiment equipment assembling in the hangar

Figure 7.62 Life-science experiment preparation room

(5) Immediately before aircraft experiment

Immediately before aircraft experiment on the day, final verification must be performed very carefully. To save the preparation time and avoid mistakes, it is recommend to make a checklist in advance and to follow the check items step by step. The following items in particular should be verified:

- Confirm that the experiment equipment operate correctly.
- Confirm the experiment sequence.
- Reconfirm the interface between the experiment equipment and the support system.
- Validate the experiment equipment operation under microgravity.
- Confirm the method of capturing target data.
- Take motion-sickness medication (provided by DAS) if you are afraid of getting airsick.
- Take DAS's safety training (on video tape).

(6) Submission of applications to DAS

Passengers must submit the following applications to DAS by the stated deadlines before conducting aircraft experiments.

- Passenger application (one month before experiment)
- DAS visit reservation (one week before experiment)
- Medical examination report, stating the blood pressure (95 to below 160), pulse rate (beats per minute, pulse irregularities), urinalysis data (protein and sugar detection), and internal medical examination results (day before experiment)
- Daily meeting sheet (for each flight after completing the day’s experiment)
- Final report on the aircraft experiment (after the entire schedule is completed)
- Passenger insurance (before the flight: DAS has group insurance but you can take out personal insurance as well)

Medical Examination Report

Company Name:
Examination Date:
Sex: Male/Female
Name:
Date of Birth:
Age:

Examined Item	Examination Results	Criteria
Blood Pressure	mmHg	(Systolic blood pressure: 95 to below 160 mmHg, diastolic blood pressure: 50 to below 95 mmHg, no orthostatic hypotension)
Pulse Rate	beats/minute	(Pulse rate: 90 beats/min or less)
Pulse Irregularities	Yes/No	(No pulse irregularities)
Urine Sample	Protein () Sugar ()	(No proteins or sugars)
Heart, Lung, or Internal Organ Defects	Yes/No	(No discernable heart, lung, or internal organ defects)
Diagnosis		(No other discernable irregularities)

I hereby certify that the patient has been examined as given above.

Address:
Name of Medical Doctor:
Signature

Figure 7.63 Sample Medical Examination Report

7.7 Experiment Sequence and Precautions

This section gives an overview of the normal experiment sequence on the day of aircraft experiment and items to be aware of.

(1) Experiment schedule

Below are typical daily schedules of aircraft experiment.

Experiment generally requires about two weeks (one cycle) when about five experiment flights can be made. Under ordinary circumstances, one flight (about two hours long) is made per day. One hour of this flight is allotted for experiment.

XX Aircraft Experiment No. 1, XX University, Fiscal 2004
Date: Month day, 2004 Airspace: K (10:00 to 11:00)

Time schedule

Before 08:20	Safety training, passenger confirmation, weather survey, experiment preparations, move aircraft out of the hangar
08:20	Determine if flight is possible
08:50 to 09:00	Preflight briefing
09:10	Boarding
09:40 to 11:20	Experiment flight
11:25 to 11:35	Postflight briefing
12:00	Lunch
13:00 to 14:30	Data analysis
14:30 to 15:00	Daily meeting
After 15:00	Preparation for the next day’s experiment

ZZ Aircraft Experiment No. 3, ZZ Laboratory, Fiscal 2004
Date: Month day, 2004 Airspace: G (12:00 to 13:00)

Time schedule

Before 10:00	Safety training, passenger confirmation, weather survey, experiment preparations, move aircraft out of the hangar
10:00	Determine if flight is possible
10:30 to 10:40	Preflight briefing
10:50	Boarding
11:20 to 13:40	Experiment flight
13:45 to 13:55	Postflight briefing
14:00	Lunch
14:00 to 15:30	Data analysis
15:30 to 16:00	Daily meeting
After 16:00	Preparation for the next day’s experiment

Figure 7.63 Typical experiment schedules

In

Figure 7.64 Experiment sequence

(2) Before experiment

Before the morning briefing on the day of experiment, experiments verify the operation of their experiment equipment on the aircraft and re-check the interface with the aircraft.

Although this depends on the weather, a flight is usually made between 09:40 and 11:20 (in Airspace K on the Pacific Ocean side of Japan) or between 11:20 a.m. and 13:40 (in Airspace G on the Japan Sea side of Japan). Samples must be loaded on the aircraft and the subjects must be ready about an hour before the flight. In case of a preparation delay, the flight can be bumped back to around 13:40.

At the preflight briefing, DAS staff will report the day's weather conditions, flight path, and experiment airspace. Experiments confirm their experiment equipment is ready and give any instructions to the pilot. If more than one research team is flying together, the order of operations is also decided at the preflight briefing. Make preflight preparations carefully and quickly when flying with another research team because preparation delays often cause scheduling problems with the other team.

Passengers board the aircraft 30 minutes before the flight. You will receive notifications about the flight conditions by radio. Experiment may be canceled and the aircraft may return in cause of a malfunction or ill passenger. Be sure to stay healthy and get enough rest on the previous evening because your ability to judge declines during experiment.

The pilot will describe the microgravity conditions experienced during the flight at the postflight briefing and the experiments give a brief summary of their experiment.

A daily meeting is held about two hours after return. Experiments give a brief on their results of experiment based on the data collected in the experiment. The experiment plan for the next day is also confirmed.

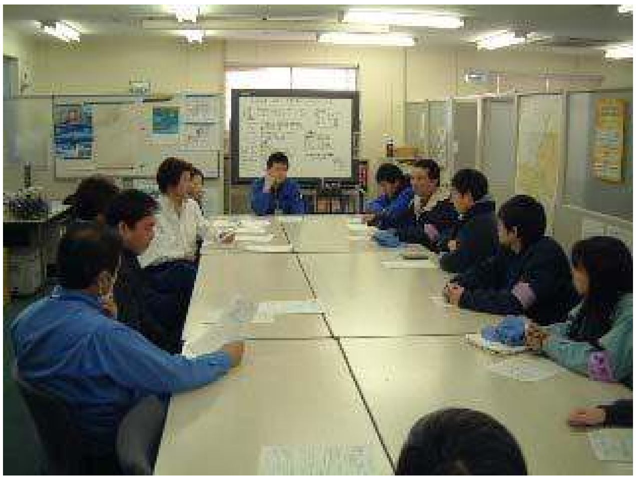


Figure 7.66 Briefing in progress

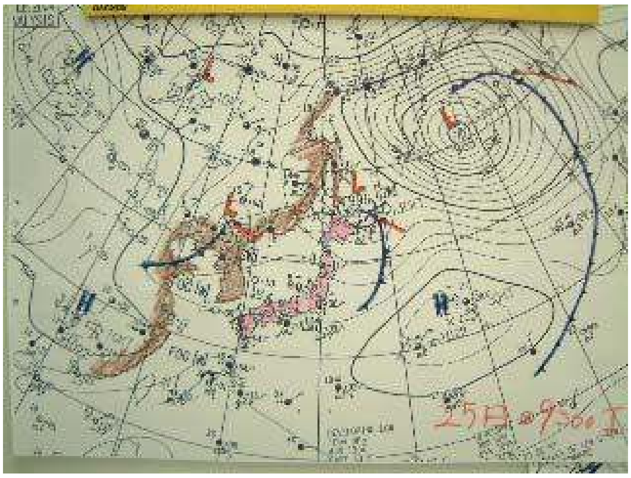


Figure 7.67 Weather forecasts given at meetings

(3) During experiment

Confirm that microgravity is a very unique environment. For aircraft experiments, it is recommended to take anti-motion sickness medicine from DAS at the beginning. Note that the pilot manually adjusts the temperature.

*Advice from past experiments

- Experiment equipment is recommended to be as simple and automatic as possible. If you have space, fabricate two versions of experiment equipment so you can conduct two experiments in parallel.
- It is best not to change experiment conditions at the last minute if you suspect the reliability of the changes even slightly. This is true even if you suddenly have a good idea just before conducting the experiment. Last-minute changes often lead to errors or failures. Remember the parabolic flight is quite short.
- Wear a ball-point pen with a neck strap for recording experiment values. Do not use mechanical pencil as the lead poses a safety risk if it breaks and floats around in the aircraft.
- To avoid operational errors and to handle accidents, create a experimentation manual and an accident handling manual you can carry aboard.
- The pilot calls pitch angles during flight. Do not confuse these with the microgravity period.
- A protective net is used as a partition between the pilot cabin and the passenger area when using the free space.

Figure 7.68 Intercom
(Two-minute warning and now signals - at entry into microgravity
- during flight over an intercom from the pilot)

(4) After experiment

Many experiments work on their experiments after the daily meeting to prepare for the next day.

*Advice from past experiments

- It is important to arrange the number of parabolic flights and the experiment time and consider the number of people necessary for experiment equipment setup. Be sure to reserve some leeway in both time and personnel. Prepare for unexpected circumstances so that experiment equipment will not be a make-or-break endeavor.
- Reserve enough leeway in your schedule for the time to go through observed or measured results and reflect them in the next experiment, the time needed to modify equipment, and the time to reload equipment on the rack to alter the experiment.
- Conduct as many simulations as possible on the ground by the same procedure as in the actual experiment. Use a checklist to make final checks before transferring experiment equipment to DAS. You will need to coordinate closely with the DAS technical staff members in the experiment preparation stage for mutual understanding.
- Keep in mind the difficulties not only in fabricating equipment but also in preparing the subjects when conducting life-science experiments.

(5) Operating system

In principle, student-only experiments are not permitted. An overseer, such as a staff member from the research institution, must be present.

*Advice from past experiments

- I recommend manning experiment equipment with enough people to deal with unexpected events.

1. Interior of the G-II 2. Interior of the MU-300

Figure 7.69 Aboard the aircraft

Figure 7.70 Flexible net between the pilot cabin and passenger area
(Prevention of floating experiment equipment or samples
from reaching the pilot during the flight)

(6) Data supplied by DAS

After experiment, DAS provides video taken during experiment flight along with gravity data.

Figure 7.71 DAS video experiment equipment

Figure 7.72 DV and mini-DV tapes that can be used at DAS

Figure 7.73 Space where experiments can analyze data and do other work
(an Internet connection is also available)

(7) Lessons in experiment mistakes from past experiments

1	A rotary pump overheated and stopped working during our experiment.
Cause	A blackout curtain to keep out light was placed near the pump that overheated under microgravity because of a lack of circulation.
Solution	We removed the blackout curtain.

2	The video images were distorted because the optical axis went out of alignment.
Cause	Microgravity skewed the image because the subject and the video camera were mounted separately.
Solution	We estimated the amount of skew and repositioned the video camera accordingly.

3	Microelectrodes for controlling the position of microparticles did not function.
Cause	The microparticles stuck to the electrodes under microgravity and acted as an insulating shield.
Solution	We improved the performance of microelectrodes by adjusting the microparticles' emission direction and using fewer microparticles.

4	About 10 percent of the animal subjects died during experiment cycle.
Cause	Exposure to microgravity and higher temperatures led to the high fatality rate.
Solution	It was necessary to anticipate and plan for a high fatality rate.

5	Experiments couldn't operate the experiment equipment well during experiment.
Cause	The passenger got sick and could not operate the experiment equipment in the proper sequence.
Solution	We took motion-sickness pills, prepared a checklist to take aboard, and grouped the controls together for easier access.

6	It took a long time to assemble the experiment equipment at the site.
Cause	We did not bring our usual tools.
Solution	You have to bring your own tools because the tools at the site are only suitable for aircraft.

8. Quick Reference Guide

~~8.1 MGLAB~~ (The facility was closed since June 2010)

(1) Access to MGLAB

Take a taxi from the nearest JR Chuo Line station, Toki City Station. It is about a 15-minute trip (2,500 yen). A free microbus shuttle runs once every morning (see (5) below). Make arrangements in advance to use the shuttle. You can come directly to the Micro-Gravity Research Center by car. Renting or having a car at your disposal is very useful.

(2) Tools available from MGLAB

MGLAB does not provide ordinary tools such as wrenches or sockets or common tools for researchers such as soldering irons, drilling machines, grinders, sanders, or cutters. Please bring your own tools.

(3) Hardware stores near MGLAB (selling tools and other supplies)

- Sunbicks Home Center (about 10 minutes by car) 0572-53-0088 (Toki City)
- Kahma Home Center, Mizunami branch (about 15 minutes by car) 0572-67-2031

(4) General consumer-electronics stores near MGLAB

- Eiden, Mizunami branch (about 15 minutes by car) 0572-68-5251

  Obtaining electronic parts : order by 6 p.m. to get next-day delivery
- Omron Two-Four Service (http://www.omron24.co.jp)
- RS Components (http://www.rswww.co.jp)

(5) Accommodations near MGLAB

- Business Hotel Toki, 0572-54-1001

  You can receive a discount when you make your booking by mentioning that you were referred by MGLAB. A microbus shuttle runs to the hotel on weekdays as scheduled below. Note that the time of the shuttle’s return varies. The shuttle does not normally stop at Toki City station. Make prior arrangements with MGLAB if you want to be picked up or dropped off at the station.

*Microbus schedule

- Morning: Business Hotel Toki (8:25 a.m.) > Toki City station (only by request, 8:30) > MGLAB (8:45)
- Evening: MGLAB (5:25 p.m.) > Toki City station (only by request, 5:40) > Business Hotel Toki (5:45)

(6) Delivery and shipping of equipment

Nippon Express and Seino Transportation are convenient. Seino Transportation is very convenient since its collection center is next door.

*Delivery services with offices near MGLAB

- Nippon Express (Tajimi office), 0572-22-7181
- Yamato Transport (Toki office), 0572-55-5300
- Seino Transportation (Toki office), 0572-55-2101

8.2 DAS

(1) Getting to DAS

Buses are available from the following train stations to Nagoya Airport (check the bus schedule in advance as buses do not run frequently). Take the bus to the final stop. Phone us from Nagoya Airport, and we will send a car to pick you up. If you are arriving by car, park in the visitor's parking lot in front of the Mitsubishi Heavy Industries Komaki South Plant main entrance and contact DAS. An escort by a DAS staff member is necessary to pass through security and enter DAS.

- JR Nagoya station (Tokaido Line)
- JR Kachigawa station (Chuo Line)
- Meitetsu Nishiharu station (Inuyama Line)

(2) Tools available from DAS

DAS does not provide ordinary tools such as wrenches or sockets or common tools for researchers such as soldering irons, mini-drill presses, air drills, grinders, or air sanders. Please bring your own tools. (Aircraft tools are all inch sizes.)

(3) Hardware stores near DAS (selling tools and other supplies)

- Cainz Home Center, Komaki branch (about 30 minutes by car) 0568-42-6000

Good supply of bolts, nuts, metal materials, and other hardware

- U Home, Komaki branch (about 15 minutes by car) 0568-76-6600

General hardware store

(4) General consumer-electronics stores near MGLAB

Computer stores

- Compmart, Komaki branch (about 20 minutes by car) 0568-74-0335
- Yachiyo Musen (about five minutes by car) 0568-28-2887

Obtaining electronic parts and materials

There is a large electronics market in Oosu, Nagoya, but a round trip takes about half a day

High-pressure gas

- Dainihon Aga Gas (Nagoya), 052-651-1291

Handles a wide range of high-pressure gas. Orders must be made in advance. They will deliver to DAS. Researchers are responsible for arranging orders.

(5) Accommodations near DAS

- Business Hotel Airline, 0568-28-4445

You can receive a discount when you make your booking by mentioning that you were referred by DAS. DAS will pick you up and drop you off on experimental flight days if you stay at this hotel. The hotel is about a 20-minute walk from the Nagoya Airport bus stop.

*If you are coming from Meitetsu Nishiharu station by bus to the hotel, get off at the Airport West stop (one stop before Nagoya Airport).

(6) Delivery and shipping of equipment

Nippon Express's Aero Box is convenient for shipping equipment. Simply pack experimental equipment in a standard size box (110 × 80 × 150) and have it sent.

*Delivery services with offices near DAS

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- Yamato Transport (Toyoyama Delivery Center), 0561-20-1111
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9. Where to Contact

(1) Space Utilization Promotion Department, Japan Space Forum (JSF)
Shin-Otemachi Building 7F, 2-2-1 Otemachi, Chiyoda-ku, Tokyo 100-0004
Tel.: 03-5200-1303
Fax: 03-5200-1421
E-mail: koubo@jsforum.or.jp
Web site: http://www.jsforum.or.jp

(2) ~~Micro-Gravity Laboratory of Japan (MGLAB)~~
~~Web site: http://www.mglab.co.jp/~~
~~●Headquarters (General Reception)~~
~~Ceratopia Toki 4F, 4 Takayama, Tokitsu-cho, Toki City, Gifu Prefecture 509-5121~~
~~Tel.: 0572-55-0408~~
~~Fax: 0572-55-0417~~
~~E-mail: mgoffice@rose.ocn.ne.jp~~
●~~Microgravity Research Center (For technical inquiries)~~
~~1221-8 Kawai, Izumi-cho, Toki City, Gifu Prefecture 509-5101~~
~~Tel.: 0572-55-6850~~
~~Fax: 0572-55-6833~~
~~E-mail: mgcenter@rose.ocn.ne.jp~~
●~~Tokyo Office~~
~~Hasegawa Building 3F, 1-17-8 Hamamatsucho, Minato-ku, Tokyo~~
~~Tel.: 03-3431-8048~~
~~Fax: 03-3431-8049~~
~~E-mail: mglab@fancy.ocn.ne.jp~~

(3) Diamond Air Service (DAS)
Web site: http://www.das.co.jp/
●Headquarters (Technical Department) (Inside the Komaki South Plant of Mitsubishi Heavy Industries)
1 Toyoba, Toyoyama-cho, Nishikasugai-gun, Aichi Prefecture 480-0293
Tel.: 0568-28-6500
Fax: 0568-29-1524
●Tokyo Office
Mitsubishi Juko Bldg. 13F, 16-5 Konan 2-chome, Minato-ku, Tokyo 108-8215
Tel.: 03-6716-4353
Fax: 03-6716-5835

- Guidebook Examination Committee (Physics and chemistry experiments)
  Hiroshi Iizuka, Tohoku University
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  Masahiro Nohmi, Kagawa University

- Public R&D Promotion Office, Space Utilization Promotion Department, Japan Space Forum
  Toru Fujishima, Kazumi Kogure, Keiji Fukui, Yasuo Suzuki, Sosuke Goto

- Technology Department, Micro-Gravity Laboratory of Japan
  Toshio Iwakami, Masaki Nokura

- Technology Department, Diamond Air Services
  Kojiro Kakei, Genzo Fukushima

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