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(Review)

The Student Zero-Gravity Flight Experiment Contest in Japan

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Abstract

In December 2013, the last parabolic flights for the Student Zero-Gravity Flight Experiment Contest in Japan were successfully conducted by JAXA with support of Japan Space Forum (JSF) and Diamond Air Service (DAS). In this paper, we describe the overview of the program and the parabolic flight experiment, and also the statistics and brief summary of all of the experimental themes conducted in the past 11 years.

Keyword(s): Education, parabolic flight

1. Introduction

More than a decade has already passed since the first microgravity experiments in the international space station (ISS), conducted as the Expedition 0 in 2000. Japan, the only Asian nation participating in the ISS program, developed the largest experimental module of the ISS, the Japanese Experiment Module (JEM), or "Kibo" (meaning "hope" in Japanese). By using Kibo, the Japan Aerospace Exploration Agency (JAXA) has played a leading role for the successful science operation in the ISS.

In order to fully utilize such valuable facilities in orbit, it is important to thoroughly validate the instruments under the microgravity (μg) condition before the flight. In Japan, parabolic flight experiments for validation of space missions have been provided by a private company, Diamond Air Service Inc. (DAS), since 1990. DAS conducted more than 8000 parabolic flights in the first 11 years[1)]. In each experimental flight with duration of 1 hour, 10 parabolic flights are conducted on average. Most of these opportunities have been used by Japanese researchers for the preparation of space experiments.

In 2002, National Space Development Agency of Japan (NASDA; one of JAXA's predecessors) launched an education program as a contest-type competition, using surplus resources during the research flights. Since then, this student program, "Student Zero-Gravity Experiment Flight Contest", was successfully continued to 2013 (see recent review article[2)] in Japanese). From the oversea, students in Southeast Asian countries had joined this program since 2006[3)].

In the U.S., "Reduced Gravity Student Flight Opportunities Program"[4)] started in 1997, after the two year trial program for Texas students. In this program, more than 5000 students experienced parabolic flights with KC-135 (1995-2004), McDonnell Douglas C-9 (2005-2008), and Boeing 727 (2009-present) aircrafts[5)]. The number of selected themes per year reached the maximum of 73 in 2003. The program name was changed to the "Reduced Gravity Education Flight Program" (RGEFP) in 2008 to reflect the fact that the program includes components not only for students, but also for teachers. Along with the original student program, several other education programs (e.g. SEED and HUNCH) are sharing the flight opportunities. In Europe, ESA started a student parabolic flight campaign in 1994, and had organized 9 campaigns for 273 experiments in total until 2006[6)]. The latest program "Fly your thesis!", which gives university students possibilities to fly their scientific experiments in microgravity, as part of their Master thesis, PhD thesis or research program[7)], was organized in 2009, 2011, and 2012. Currently, this program is on hold, while the French space agency "CNES" is running a similar program independently.

These world-wide activities of student flight program seem to prove its effectiveness. Also, the parabolic flight is truly unusual experience and attracts youngsters very much, being driving force for achieving the experiments.

In April 2014, JAXA announced that the original goals of the parabolic flight contest in Japan have well achieved, and decided to end the program[8)]. We believe that such unique contest could be continued by other organizations once financial issues are cleared. In this paper, we describe the student parabolic flight experiments conducted so far in Japan with hope for being a future reference. In the section 2, we give program overview. Technical specifications and constraints of flight experiments are summarized in the section 3. Experimental themes conducted so far are summarized in the section 4. Finally, we describe future possibilities of the student flight experiments in the section 5.

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2. Program overview

2.1 Purpose

This educational program with parabolic flights, in association with the ISS projects, aims to provide rare opportunities for students of various backgrounds, including not only science and technology but also liberal arts and education, to conduct microgravity experiments. It is expected that the experiments and activities by students eventually contribute to the increase of awareness for utilization of the space environment, and to the development of human resources for future space activity.

2.2 Selection Process of Flight Experiments

A selection committee was organized to evaluate submitted proposals, and to select flight experiments. The proposals were evaluated based on the following criteria.

- Microgravity relevance: whether the experiment fully utilizes the microgravity and hyper-gravity environments.
- Scientific contents: whether the logic and the experiment plan are consistent and match to the purpose of the proposed experiment.
- Team organization: whether the team is appropriately organized for effectively conducting the experiment.
- Feasibility: whether the equipment design is feasible to develop, and meets all safety and resource requirements of the aircrafts.

Experiments on humans and animals must secure permission of the JAXA's ethical review committee.

Statistics of submitted proposals and accepted themes by Japanese students are given in **Table 1**. The number of accepted themes depended on the surplus resource of the year. Six were the maximum case. Since 2006, Japanese students have shared the resources with those from Asian countries. In 2013, language of the proposal was changed from Japanese to English, in order to internationally promote this program later on.

2.3 Application Guidelines

An application should be prepared and submitted by students. The applicants must be students in a technical college (in this case the students must be at least in senior), a university or a graduate school located in Japan and should meet the following requirements:

A) The applicants should be fully responsible for conducting their experiments and for presenting the results in requested opportunities.
B) The applicants should have an instructor who can provide support for workspace and other indispensable resources, if necessary.
C) The applicants must be able to develop the equipment by their own.

There is no restriction on the area of research fields. The applicants (or supporting agency) must be responsible for all development and transportation costs for their own equipment, and also the costs for the required medical check-up.

2.4 Event Timeline

The event timeline of this program is shown in **Fig 1**. In nominal case, the call for proposal was released in April, which is the first month of the Japanese fiscal year, and the selection was made in July. For instruction of the flight experiment, students of selected teams were then gathered to the factory of DAS located inside a plant of Mitsubishi Heavy Industries near the Nagoya airport. After this interface coordination meeting, the students were requested to submit the aircraft experiment document. These documents were used to confirm if their instruments clear the security and resource restrictions for the aircraft to be used. Flight experiments were usually scheduled in December, and therefore students had about 4 months to assemble their instruments. One month before an experiment, an interface confirmation meeting was held in the laboratory of each team, in order to confirm the development status and to give detailed instructions to improve the instrument in terms of security and suitability as a μg experiment conducted in an aircraft.

Duration of one experiment campaign was 5 days including one spare date for bad weather. Detailed schedule at the DAS factory was as follows;

- Day 1 ― Inspection and rigging of instruments and tuning up in an aircraft.
- Day 2 ― Electromagnetic interference test in the aircraft.
- Day 3 ― First experimental flight
- Day 4 ― Second experimental flight
- Day 5 ― Spare date

In serious weather condition the flight might be canceled, but all of the experiments were completed as scheduled, because of an alternative flight area and spare date for compensation.

Table 1 Statistics of proposals and accepted themes

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	Total
# of proposals	24	30	31	26	45	42	38	28	19	19	29*	331
# of adopted teams	4	6	6	5	5	5	5	5	4	5	5	55
Physics	2	3	3	3	3	4	4	4	3	4	3	36
Bio/Medical	2	1	2	1	2	0	1	1	1	1	1	13
Liberal arts *etc.*	0	2	1	1	0	1	0	0	0	0	1	6

* Proposed in English

2.5 Reports and Presentations

After the flight experiments, students were requested to submit a quick report within 2 weeks and a final report in 3 months. Furthermore, the students were requested to present their results in an annual meeting of the Japan Society of Microgravity Application (JASMA). Their reports and presentations were reviewed by astronaut Mamoru Mohri, and members of JASMA, and the excellent presentations were given awards. In 2013, a delegate of the most-valuable team was dispatched to the 20th session of Asia-Pacific Regional Space Agency Forum (APRSAF) held in Hanoi, Vietnam to report their achievements to the delegates from countries in the region.

3. Flight Experiments

3.1 Overview

Approximately 20 seconds of μg condition could be achieved inside an aircraft through parabolic flight maneuver. A representative of the team conducted their own experiments during the parabolic flights. Students' experiments were usually conducted concurrently with JAXA's professional experiments.

The aircraft used for this program had been a Gulfstream II (G-II; see **Fig 2**) owned by DAS. The aircraft has two rear mounted jet engines. Its cabin space is 2.2 m wide and 6.5 m long. A typical layout inside the aircraft is shown in **Fig 3**. Four

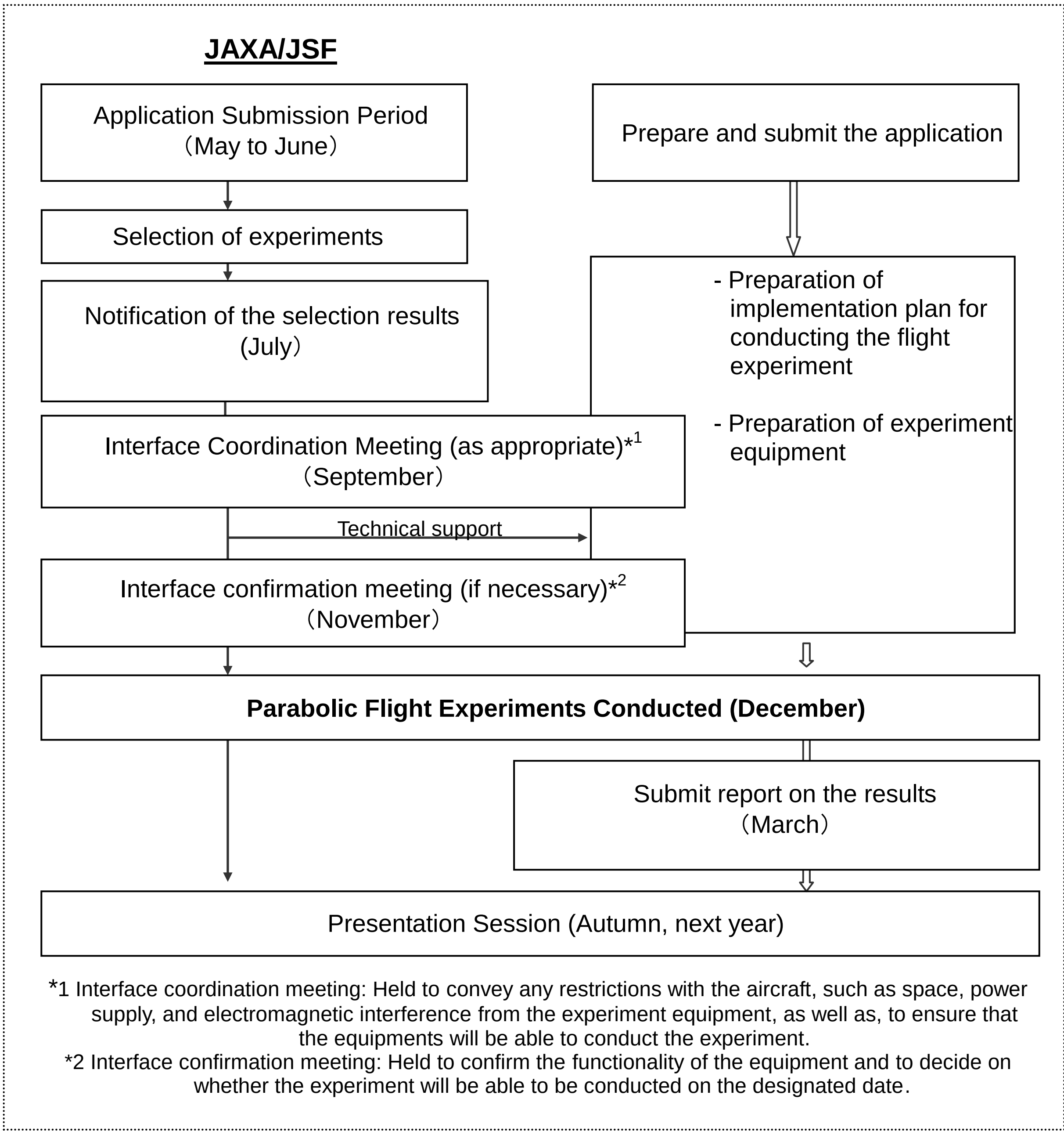

Fig. 1 Flow chart of the flight experiment contest

seats out of six were made available to students at maximum case. Experiment support system, such as the starting signal of μg condition, three axis acceleration data, etc. were provided to students, while JAXA's main experiments have a first priority to use the support system.

Students were given two flight opportunities. Only one member from each team flew in each flight. Usually, the parabolic flight maneuvers are successively conducted about 10 times with the interval of a few minutes. The longer the flight interval becomes, the less parabolic flights are conducted because of the time limit of 1 hour in a dedicated air zone.

Fig. 2 Gulfstream II (G-II), the aircraft used for the experiments

3.2 Requirements

As this program was conducted in the aircraft, the safety requirements were rather strict and must be satisfied. Unlike NASA and ESA program, free-floating movement of humans in microgravity was not allowed in this program, because of the limited cabin space. Any experiments that use liquids had to be contained in a sealed container. Hazardous materials were not allowed in the aircraft such as explosives, flammable liquids, gases, and substances, toxic substances, radioactive material, corrosives, miscellaneous dangerous substances and articles. Any experiments that use animals or insects had to be conducted inside sealed containers, so that they could not escape. Any experiments on animals and/or human beings were required to secure permission by the JAXA Ethics committee.

Available resources for the experiments were summarized as follows.

- Working space: the instrument should be installed inside a dedicated rack space (**Fig. 4**).
- Power supply: 1) AC 100V (±10%; 60Hz), with up to 3 A, 2) DC 28V (26~30V), with up to 5 A. These AC and DC powers may be used in parallel.
- Weight: 50 kg or less
- Onboard experimenter: one person

The equipment should be strong enough to withstand hypergravity condition up to 2G and fabricated with a special care not to scatter any pieces of breakable materials, which will float around inside the cabin space in the microgravity condition. Electric circuits should be fully insulated to avoid short-circuit, owing to floating materials.

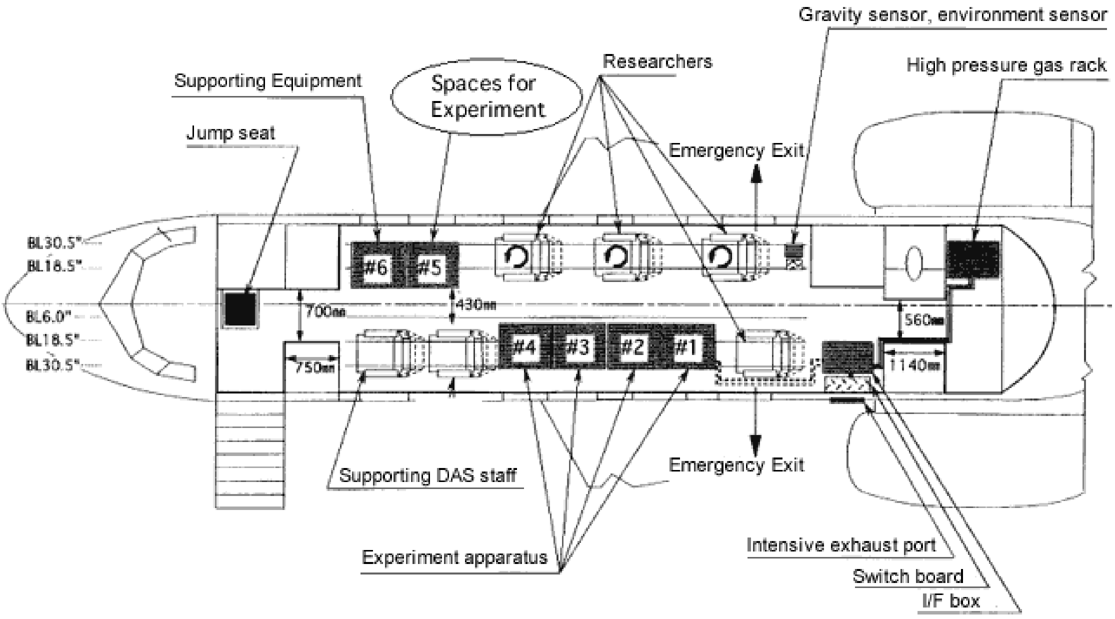

Fig. 3 Configuration inside the aircraft G-II

For medical experiments on a human body, a dedicated medical doctor had to be on call at the factory during the flights. Also, anyone to fly had to have a medical check-up and submit the results to DAS. The results were used to confirm if he/she satisfied all of the health requirements to experience parabolic flights.

Fig. 4 Experimental rack for 2 instruments (upper and lower space) with the size of 600×500×500mm³

At the factory, DAS engineers often support the students to finalize assembly of the instruments and to conduct the experiments successfully. There were sometime unexpected troubles and problems; transportation to the DAS factory seriously damaged student's instrument, students arrived at the DAS factory with technical problems unsolved *etc*. Most of these troubles and problems were sorted out with the help of DAS engineers.

4. Experimental Themes

The number of the experiments conducted by Japanese students was 55 in total, which consist of 36 physical science, 13 biological/medical sciences and 6 liberal arts. The number of the students involved was more than 400 and half of them actually experienced the parabolic flights. We tabulated the institutes of the participants, experiment titles, and observed samples for all of the conducted themes in Table **2**.

This list shows wide variety of interests. Results of 16

Table 2 Summary of experiments

Year	Institute	Title	Sample
2002 (1st)	Ochanomizu Univ.	Propagation of chemical wave under gravitational and magnetic fields	Co(II)-EDTA
	Nara Medical Univ.	Attitude control of upside-down catfish, *Synodontis nigriventris*, with vestibular compensation under microgravity	Upside-down fish, *Synodontis nigriventris*
	Univ. of Tokyo	Behavior of medaka fish under distributed gravity	Medaka, *Oryzias latipes*
	Aoyama Gakuin Univ.	Observation of the movement of liquid drop (wicking) along a wire with temperature gradient	Silicon oil on wire
2004 (2nd)	Tokyo Metropolitan Institute of Technology	Effects of gravitational acceleration on formation of coronets	Silicon oil
	Fukui Univ.	Vestibular system contributes human blood pressure control upon gravitational changing	Human
	Japan Woman's Univ	The distribution of humidity inside of clothing environment and the materials movement for clothes in changing gravity	Dressed silk, textile and knitted materials
	Univ. of Tokyo	Magnetic field analyzing experiment under microgravity, using ferrofluid	Ferrofluid
	Gakushuin Univ.	Spark of Japanese sparkler "Senko-Hanabi" under microgravity	Firework (sparkler)
	Tokyo Univ. of the Arts	The material experiment for the sculpture formed by music "Sound Wave Sculpture 2"	Flashing LED, feather, beads, bells
2005 (3rd)	Univ. of Tokyo	Water behavior in capillary tubes under microgravity	Capillary tubes
	Kyoto Univ.	Comparison of oxygen saturation in the upper and lower limbs under gravity-free condition	Human
	Ochanomizu Univ.	Analysis of growing frost under microgravity	Frost pattern
	Tama Art Univ. *etc*	Experiment for sculpture formed by music "Sound Wave Sculpture 3"	beads and liquid
	Hokkaido Univ.	Microgravity experiments for collision of droplets using airplane parabolic flights	Water droplets
	Fujita Health Univ.	Goldfish's vestibulo-ocular reflex and heart beat analysis under microgravity	Goldfish (10-15cm)
2006 (4th)	Univ. of Tokyo	Deformation of salt water mass in silicon oil rotating under microgravity	Salt water and silicon oil
	Tohoku Univ.	Oh! My big dream and soap bubbles	Bubbles
	Univ. of Tsukuba	Creating electromagnetic sculptures in microgravity	Small iron discs
	Kyoto Univ.	Comparisons of blood volume in the upper and lower limbs during exposure to hyper- and micro-gravity	Human
	Gakushuin Univ.	Science of candle flame under microgravity conditions – respect to Faraday's "The chemical history of a candle"	Candle flame

Year	Institute	Title	Sample
2007 (5th)	Ochoanomizu Univ.	Flying behavior of *Drosophila* under microgravity	Drosophila melanogaster
	Fujita Health Univ.	Behavior and eye movement of flatfish during microgravity	Flounder (15-20cm)
	Univ. of Tokyo	Qualitative observation of difference in wetterbility under microgravity environment	Water and silicon oil
	Kyoto Univ.	Gravitational level effects on electrodeposition transition metal nanowire using template	Copper nanowire
	Takamatsu National College of Technology	Attraction and repulsion experiments based on electrical characteristics of water	Charged water droplets
2008 (6th)	Kobe Univ.	Low Velocity Impact Experiments of Rubble-Pile under Micro Gravity	Glass beads and its sintered sample
	Univ. of Tokyo	Quantitative Analysis of Orbits of Rotating Balls under Microgravity Environment	Rotating balls
	Tsukuba Univ.	New formative possibilities using non-Newtonian fluids	Cornstarch solution
	Tokyo Gakugei Univ.	Video of zero-gravity experiments that can be used in elementary and junior high school science	Water temperature
	Chiba Univ.	The behavior of ping-pong ball and iron ball in the water under micro-gravity	Iron and ping pong balls
2009 (7th)	Tokyo Gakugei Univ.	Video Clip of the Micro-gravitational Experiments Which Can Be Compared With Students' Experiments in Science Class	Pendulum, spring, rubber string, Thermo sheet
	Kyoto Univ.	Effects of Different Gravity Levels on Blood Flow in Upper and Lower Limbs	Human
	Ochanomizu Univ.	Dew Condensation Process on a Surface under a Micro-Gravity	Dew on a mirror
	Univ. of Tokyo	Conjugate Conduction-Natural Convection Heat Conductance through Air Layer under Different Gravity	Hollow layers with different thickness
	Hokkaido Univ.	Ultrasonic Atomization under Microgravity	Water mist
2010 (8th)	Osaka Univ.	How do the movement of fins and muscle activity involve in the posture maintenance of carp fish?	Carp
	Hokkaido Univ.	Behavior of chemiluminescence under microgravity condition	Luminol, Diphenyl oxalate, and hydrogen peroxide water
	Hokkaido Univ.	In-situ observation for spread and deposition processes of small particles in liquid	Glass φ0.4-1.6mm Alumina particles
	Kyushu Univ.	Behavior observation of gas, liquid and solid compound under microgravity	Foaming bath agent
	Univ. of Tokyo	Research of membrane deployment characteristics for future applications in aerospace	Model membrane
2011 (9th)	Meiji Univ.	Visualization of water flow in porous media under microgravity	Water among beads
	Univ. of Tokyo	Measurement of droplet diameter suspended by optical tweezers under the microgravity	Droplets 30-50 micron in diameter
	Ochanomizu Univ.	Waterglass and sandglass under microgravity	Sandglass (glass beads, glycerol, silicon oil)
	Gifu Univ.	Parabolic flight-induced alteration of the behavior in mimosa	Mimosa
2012 (10th)	Ochanomizu Univ.	Bubble flower development	Bubbles of detergent with sugar
	Meiji Univ.	Water movement in experimentally-modeled soil void space under microgravity	Water in modeled soil
	Toyo Univ.	Non-invasive measurement of the right heart function during the gravity change	Human
	Waseda Univ.	Sampling of small regolith particles from asteroids utilizing alternative electrostatic field	Sampling mechanics
	Tohoku Univ.	In-situ observation of ice crystal nucleation at bubble surface	Ice crystal
2013 (11th)	Nihon Univ.	Research on dynamics analysis of inflatable membrane space structure	Inflatable Membrane
	Tokyo Gakugei Univ.	Rube Goldberg machine under zero-gravity that can be used in physics education	Rube-Goldberg machine
	Nagoya Univ.	Flow visualization within multiple-evaporators and condenser of loop heat pipe under microgravity	Loop heat pipe
	Kobe Univ.	Effects of exposure to microgravity on relationship between gas exchange and autonomic nervous system	Human
	Tokyo Univ.	Observation of three-phase heat transportation simulating a rice cooker and its comparison between microgravity and ground conditions	Boiling water and rice

programs (29%) were presented in professional journals and/or conferences. Some members of the artistic themes are now developing their career as a professional artist. Seven programs were reported in the major media, such as newspapers and TV programs. These show how the qualities of the experiments were high.

5. Future Possibilities

Compared with the similar parabolic flight programs in NASA and ESA, the Japanese student program was rather small in terms of the number of the participants and also the size of the aircraft in use. In both foreign agencies, the programs were changed from simple student program to more specific ones after several years of the operation. The NASA program is now a collection of programs with specific missions as discussed in the section 1. The ESA program is focused on semi-professional experiments proposed by graduate students.

Compared to these foreign programs, the Japanese program is still in the early phase. However, after 12 years since the launch of Japanese program, a definite community of μg users has grown in Japan. Below, we discuss some aspects and possibilities to consider future student program in Japan.

5.1 Internationality

Since 2006, students from Malaysia and Thailand had participated in the program, and ones from Vietnam newly joined in 2013. Proposals, written in English, were firstly reviewed in each country to select several candidates. Then, technical feasibilities of the candidates were reviewed by Japanese staffs. Based on these scientific and technical reviews, an international committee consisting of members from participating nations selected teams to join the program. The committee selected one team for each country. This activity was a part of a program promoted by the space environment utilization (SEU) working group of APRSAF. Starting from this parabolic flight program, the international collaboration has been getting matured and developed to a larger collaboration program, so-called Kibo-ABC (Asian Beneficial Collaboration through Kibo Utilization), which promotes “Kibo”/ISS utilization in the Asia-Pacific region.

Only three countries out of eight in the Kibo-ABC joined the student parabolic flight program. Therefore, it is preferable to increase the participant countries as many as possible. The change of official language from Japanese to English in 2013 could be a first step for an international solicitation.

5.2 Variation of Selected Themes

A wide variety of research field is observed for accepted proposals as given in **Table 2**. This is a good trend and should be encouraged. However, we point it out that all of the Japanese experiments in the 2013 campaign were made by graduate students and some of them seem to be sub themes of their supervisor’s projects. Such themes were usually well-developed and therefore tend to get high scores during the selection process. They could gain a substantial advantage when the proposals were written in English. A selection committee may need a new measure and also promotion activity to realize self-motivated experiments which are unique and challenging, in order to keep the variation of theme and uniqueness of the program.

5.3 To Space

There are education programs to conduct the student experiment in the ISS. For example, the National Center for Earth and Space Science Education (NCESSE) in the U.S. has conducted a space education program, Student Spaceflight Experiments Program (SSEP) for students in grade 5-16, since 2011. The participating students have proposed their own experiments conducted in fluids mixing enclosures with the volume of 7.7 mL (NanoRacks’ MixStix®).

JAXA has led a student experiment program using the ISS, Space Seeds for Asian Future (SSAF) in the framework of Kibo-ABC. In SSAF 2013, Azuki beans (*Vigna angularis*) were sent to Kibo and cultivated to video-record how they grow under microgravity and dark conditions[9]. The participating students conducted ground reference experiments, and finally compared the both results. This was a well-coordinated and prepared program, but categorically different from the student parabolic flight experiment, since the experiment itself was designed not by students but by the agency.

Statistics of the ISS utilization revealed that the distribution of research disciplines strongly depend on the partner agencies[10]. JAXA’s utilization is unique, i.e. more than 80% of the investigations were classified to biology and biotechnology. JAXA’s educational and cultural activities amount to about 5% of total investigations, while NASA’s one explains more than 25% of their investigations. These figures could reflect the guiding principle of space utilization in each partner. We believe that JAXA in collaboration with Asian countries could also provide opportunities for students to conduct space experiments in the ISS with a slight shift of their guiding principle.

6. Summary

In this paper, we describe the overall summary of the Japanese parabolic flight experiments for students. Compared to the similar programs in NASA and ESA, this program was rather small and in the early phase. However, after 12 years in operation, a definite community of μg users has developed including not only scientists but also artists, and seems to already mature and be ready for new phase of student program.

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