Entering “A NEW REALM” of KIBO Payload Operations
- Continuous efforts for microgravity experiment environment and lessons learned from real time experiment operations in KIBO -

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Abstract. On January 22nd, 2011 (JST), KOUNOTORI2 (H-II Transfer Vehicle: HTV2) was successfully launched from Tanegashima Space Center toward the International Space Station (ISS) and two new JAXA payload racks, Kobairo rack and MSPR (Multi-purpose Small Payload Rack) were transferred to ISS/KIBO (Japanese Experiment Module: JEM). In addition to Saibo rack and Ryutai rack which are already in operation in KIBO, in total 4 Japanese experiment payload racks start operations in KIBO. Then KIBO payload operations embark on a new realm, full utilization phase. While the number and variety of microgravity experiments become increasing, simultaneous operation constraints should be considered to achieve multi-task payload operations in ISS/KIBO and ever more complicated cooperative operations between crewmember and flight control team/science team are required. Especially for g-jitter improvement in ISS/KIBO, we have greatly advanced cooperative operations with crewmember in the recent increment based on the microgravity data analysis results. In this paper, newly operating Japanese experiment payloads characteristics and some methods to improve g-jitter environment are introduced from the front line of KIBO payload operations.

1. Introduction
Since August, 2008, utilizing two JAXA payload racks (SAIBO rack and RYUTAI rack), variety of experiments have been performed in the International Space Station (ISS)/Japanese Experiment Module (JEM), or KIBO. In addition, JAXA exposed payloads and NASA payload racks (MELFI and
Express Racks) are constantly in operating in KIBO. On January 22nd, 2011 (JST), KOUNOTORI2 brought two new JAXA payload racks, KOBAIRO rack and MSPR (Multi-purpose Small Payload Rack) to KIBO. Then KIBO payload operations embark on a new realm, full utilization phase.

In order to perform variety of experiments simultaneously in KIBO, the system resources of KIBO such as power, coolant, communication and tracking, command and data handling, and some other resources which experiment support equipments can provide, should be carefully planned and delivered to each experiment payload. Moreover, it is important that microgravity environment should be carefully controlled based on the microgravity data collection and analysis and cooperation between crew and flight control team are essential key to success for good microgravity environment in a manned space system facility like ISS/KIBO. JAXA flight control team, microgravity analysis team and Marangoni experiment science team have been continuing an effort to achieve good microgravity environment in ISS/KIBO with crew and International Partners since Increment 17 and we have recently acquired new lessons learned regarding possible correlation between crew motion and g-jitter during crew sleeping time. These finding are expected to be utilized to reduce g-jitter ISS/KIBO crew sleeping time.

2. New JAXA payload racks

2.1. Kobairo rack overview

KOBAIRO rack consists of Gradient Heating Furnace (GHF) and rack outfitting. The GHF is a vacuum furnace that contains three heating blocks for one sample cartridge. Their positions and temperatures can be independently controlled, and various temperature profiles in the direction of sample cartridge axis can be realized. This facility will be mainly used for high quality crystal growth experiments using unidirectional solidification. GHF has an automatic sample exchange system that can accommodate up to 15 samples to reduce crew operation. The three independent heating zones can realize various temperature profiles to meet with variety of experiments from researchers. Various experiments can be performed continuously by installing 15 sample cartridges (Max.) in Sample Cartridge Automatic Exchange Mechanism. Specification and outlook of KOBAIRO rack is shown in table 2.1-1. and figure 2.1-1. [1].

| Specifications |
|----------------|
| **GHF Characteristics** | Heating Temperature Range | End Heater : 500 to 1600 deg. C (Moving distance : Max. 200 mm) |
| | | Central Heater : 500 to 1600 deg. C (Moving distance : Max. 250 mm) |
| | | Auxiliary Heater : 500 to 1150 deg. C (Moving distance : Max. 250 mm) |
| | Temperature Stability | ±0.2 deg. C or better |
| | Temperature Accuracy | ±0.4 % or better |
| | Temperature Gradient | Up to 150 deg. C/cm (at 1450 deg. C) |
| | Heating Block Speed | 0.1 to 200 mm/hr or 600 mm/hr |
| | Speed Stability | ±1 % or better (10 to 200 mm/Hr) |
| Sample Monitoring                  | Insertion Slot Diameter |
|-----------------------------------|-------------------------|
| Temp.:                            | φ 40 mm                 |
| Up to 10 points * 2 ranges (Hi/Lo) |                         |
| 5 points (standard) * 2 ranges (Hi/Lo) |                      |
| Pressure:                         |                         |
| Diaphragm pressure sensor, Pirani gauge transducer, | |
| Cold cathode transducer           |                         |
| Marking Device                    | Pulse current interface is available (Marking). |
| Continuous operating time         | 300 Hours at maximum temperature |
| Max. Power                        | Up to 5300W             |
| Cartridge                         |                         |
| Dimension                         | Boss : 93 mm Cartridge : 505 mm (φ 34.4 to 36.1 mm) |
| Mass                              | Up to 6 kg              |
| Max. sample dimensions            | φ 31 mm x 370 mm L (common sample cartridge) |
| Temperature Monitoring            | 5 points (Max.10 points) |

| Sample Cartridge Automatic Exchange Mechanism |
| Water Pump Package (WPP) |
| Gradient Heating Furnace (GHF) |
| Payload Power Distribution Box (PPDB) |
| Avionics Air Assembly (AAA) and Smoke Detector (SD) |

**Figure 2.1-1.** This figure shows appearance of Kobairo rack.

### 2.2. MSPR overview

Multi-purpose Small Payload Rack (MSPR) is the rack to accommodate the researcher-made experiment equipment in JPM. MSPR provides Combustion Chamber for Experiment (CCE) which is used to conduct a combustion experiment. MSPR has interfaces with KIBO resources such as JEM Exhaust line, GN2 line and Moderate Temperature Water line. These facilities are used inside of Work Volume (WV) which is the work space to be conducted combustion experiment and other experiments as well.
MSPR consists of DC/DC Converter Unit (DCU), Multi Protocol Converter (MPC), Hub Unit (HBU), Video Compression and Recording Unit (VCRU), and CCE. Laptop PC is used by sending commands to experiment devices. Specification and outlook of MSPR is shown in Table 2.2-1. and figure 2.2-1. [1].

| Workspaces Table | Work Volume (WV) | Specifications |
|------------------|------------------|----------------|
|                  | Work Volume (WV) | A workspace for the experiments, such as Aquatic Habitat experiments and the combustion experiments. And also accommodate other equipments for science and educational missions within its function. Dimensions: 600mm(H)*900mm(W)*660mm(D)(356[L]) Functions & Properties: N2 gas supply and exhaust line of JEM are available. Heat rejection, smoke detection from the user’s equipments. Cutting off the power supply at emergency. Relieving the requirement level of noises and electric emissions from user’s equipments. |

| Small Experiment Area (SEA) | A volume for small size experiment which do not need much resource such as crystallization experiments. Dimensions: ≧300mm(H)*440mm(W)*516mm(D)(68[L]) Functions & Properties: Heat rejection, smoke detection of the user’s equipments. Cutting off the power supply at emergency. Relieving the requirement level of noises and emissions from user’s experiments. |
|-----------------------------|--------------------------------------------------|

| Workbench (WB) | A work table for crews maintaining user equipments, exchanging samples and reviewing data etc. Dimensions: 900mm(W)*600mm(D) (0.54[m2]) Functions & Properties: Putting in storage into the rack when it is not in use. |

| Enclosed Chamber (can be accommodated in WV) | Chamber for Combustion Experiments | A double enclosed vessel for the combustion and other experiments that needs enclosed and/or exhaust systems in JEM. Capacity: More than 100[L] Functions & Properties: No damage is found in the case of 100[L]gas (at normal temperature and pressure) leakage. All functions and resources for WV are available. |

| User’s Interfaces | Power | Supplied interfaces: 28[VDC], 16[VDC], 5[VDC] Power Supply: Work Volume and Small Experiment Area... Total 500[W] Workbench 100[W] (16[VDC]; for LAPTOP PC) |

| Videos | As MPSR, one of followings is available (recorded, |
Communication Protocol: Ethernet, USB
User’s equipments ⇔ LAPTOP PC,
LAPTOP ⇔ PC  Users on the ground

3. Continuous effort for microgravity environment in KIBO

3.1. Background and past microgravity measurement in KIBO

3.1.1. Marangoni experiment overview. Marangoni convection is a surface-tension-driven flow. A liquid bridge of silicone oil is formed into a pair of disks in Fluid Physics Experiment Facility Experiment Cell (FPEF-EC) [2]. The liquid bridge is very sensitive to g-jitter because it is not contained and is sustained by the only surface tension between supporting disks [3]. Therefore, this experiment is performed during crew sleeping period (21:30 - 06:00) when g-jitter is expected to become slightly calm.

3.1.2. Past microgravity measurement results summary since increment 17

a) Increment 17
The first Marangoni Experiment was performed in KIBO. The experiment was going well part of the way, but at the final phase of the experiment series, liquid bridge breakup occurred for the first time. After analyzing the microgravity data, it was found some g-jitter was generated at the timing of liquid bridge breakup during crew sleeping time. And also the analysis showed that the taller liquid bridge tends to vibrate more greatly and that strong g-jitter might have the possibility of causing the liquid bridge breakup [4] [5]. Even though the disturbance is occurred in other modules than in KIBO, it may affect Marangoni Experiment from g-jitter perspective.

b) Increment 19/20
The number of crewmembers in the ISS has been increased from 3-person operations to 6-person operations since May, 2009. In order to provide a crew sleeping location pro tempore in

Figure 2.2-1. This figure shows appearance of MSPR.
preparation for 6-crew person operations start in ISS, the crew quarters equipment needed to be temporarily installed in KIBO. We coordinated this issue with NASA operations team and agreed to measure micro G data for all possible crew sleeping configurations in KIBO. Finally, the analysis result showed that crew quarters configuration did not affect Marangoni experiment and g-jitter with crew sleeping in KIBO was lower than ISS microgravity acceleration performance (SSP41000) [6].

c) Increment 23/24
We performed some series of Marangoni experiment continuously and still observed long liquid bridge vibrating largely sometimes. At the expedition crew debriefing, the crewmembers advised us to call-up a heads-up message to all crewmembers at the evening Daily Planning Conference (E-DPC) just before we perform long liquid bridge experiment at night.

d) Increment 25/26
Per crew advice, we identified the special nights which we needed the most quiescent micro-g environment for long length liquid bridge experiments with 50 or 60 mm tall of 50 mm diameter. Then we have started to call up a heads-up message to crew at E-DPC just before we perform long liquid bridge experiment. It was very effective to obtain cooperation from all of the crew including Russian cosmonauts. G-jitter level was definitely reduced compared to previous increments because crews might pay attentions when they moved around during Marangoni experiment with taller liquid bridge.

3.2. Microgravity measurement during crew activity time in KIBO

3.2.1. During Increment 25, we measured microgravity data in KIBO during crew working time with KIBO internal camera view and by using MMA (Microgravity Measurement Apparatus) in order to investigate the following correlation between crew motion and g-jitter.

a) What kind of crew motion may generate critical disturbance to our experiment?
b) How much g-jitter will be generated by crew motion?
By analyzing the microgravity data and KIBO internal camera view, we are expecting to reduce g-jitter which is generated by crew motion in future experiment.

3.2.2. Microgravity measurement condition is as follows. MMA consists of TAA (Tri-Axial Accelerometer), RSU (Remote Sensor Unit), NCU (Network Control Unit) and MLT (MMA Laptop Terminal). Measurement parameter is shown in table 3.2.2-1.

| Measurement Time       | 2010/10/07 08:03:32 - 2010/10/08 00:03:33 |
|------------------------|------------------------------------------|
| Sampling Rate          | 1220.7 Hz                                 |
| Filter Cutoff          | 300 Hz                                    |
| MMA Sensors (RSU and TAA) | RSU ID: 3011  TAA ID: 3005               |

3.2.3. Analysis results are shown in Table 3.2.3-1. This table shows the summary for the correlation between g-jitter over 50 µG and crew motion. 50 µG is approximately equivalent to ISS standard microgravity requirement. Each axis for micro-G data is related to KIBO direction as follows. X axis (Overhead-Deck), Y axis (Starboard-Port) and Z axis (Forward-Aft). Refer to figure 3.2.3-1.
**Figure 3.2.3-1.** This figure shows MMA sensor and ISS/KIBO axes.

| KIBO Internal Camera View | MMA Data | Time | G-Jitter |
|---------------------------|----------|------|----------|
| Time                      | Crew Motion | Time        | G-Jitter          |
| 14:31:50                  | Moving towards KIBO by pushing Deck side in Node2 | 14:31:53 | 70 µG (X axis) |
|                           |           | 14:31:54 | 120 µG (Y axis) |
| 14:33:56                  | Grasping the handrail at O3 | 14:33:55 | 120 µG (X axis) |
|                           | Moving in front of JPM1 Airlock (Aft to Fwd) | 14:33:57 | 150 µG (Y and Z axis) |
| 14:35:40                  | Kicking the deck side in front of Airlock | 14:35:40 | 150 µG (Y and Z axis) |
| 14:38:16                  | Grasping the handrail at A5 to stop | 14:38:19 | 70 µG (X axis) |
|                           |           | 14:38:18 | 100 µG (Y axis) |
| 14:43:36                  | Touching the rack at A7 | 14:43:36 | 100 µG (Z axis) |
| 14:44:24 – 14:44:28       | Unstowing something from F8 rack | 14:44:28 | 100 µG (Z axis) |
| 14:49:15                  | Kicking the deck side in front of Airlock to move | 14:49:14 | 50 µG (X axis) |
|                           |           | 14:50:56 | 150 µG (Y axis) |
| 14:50:55                  | Touching the handrail at O3 | 14:50:56 | 250 µG (X axis) |
| 14:50:56                  | Grasping the handrail at O6 to stop | 14:50:56 | 100 µG (Y axis) |
|                           |           | 14:54:59 | 50 µG (Z axis) |
| 14:54:59                  | Putting CTB in front of Airlock | 14:54:59 | 100 µG (X axis) |
|                           |           | 14:57:07 | 100 µG (X axis) |
| 14:57:22                  | Grasping the handrail at O7 to move (Fwd to Aft) | 14:57:20 | 50 - 100 µG (Y axis) |
|                           |           | 14:57:35 | 50 µG (Z axis) |
|                           |           |           | continuing for about 30 |

**Table 3.2.3-1.** This table shows MMA measurement data analysis results (crew motion vs. g-jitter).
| Time      | Action Description                          | Accelerations          |
|-----------|---------------------------------------------|-------------------------|
| 14:57:36  | Grasping the handrail at D6                 | 200 µG (X axis)         |
|           |                                             | 100 µG (Y axis)         |
|           |                                             | 150 µG (Z axis)         |
| 14:57:37  | Grasping the handrail at D4                 |                        |
| 14:57:52  | Grasping the handrail at deck side to move  | 14:57:52               |
| 14:59:48  | Kicking the rack at D7 to move upward       | 14:59:48               |
| 15:02:17  | Touching the rack at D8 by foot             | 15:02:15               |
| 15:03:35  | Grasping the handrail at O8 thru O5 to move | 15:03:37               |
| 15:05:02  | Touching the rack at A5                    | 15:05:03               |
| 15:05:06  | Pushing the rack at A5                     | 15:05:05               |
| 15:05:07  | Touching the rack at D4 by foot             | 15:05:08               |
| 15:05:08  | Pushing the rack at D4 to move              | 15:05:08               |
| 15:05:10  | Touching the rack at D6 to stop             |                        |
| 15:06:13  | Kicking the rack at D8 to move              | 15:06:12               |
| 15:06:14  | Touching the rack at D5                    |                        |
| 15:10:56  | Grasping the handrail at O3 to stop         | 15:10:57               |
| 15:13:15  | Touching the rack at F7 by foot             | 15:13:15               |
| 15:14:52  | Touching the rack at D7 by foot             | 15:14:52               |
| 15:16:16  | Touching the rack at D7 by foot             | 15:16:17               |
| 15:16:17  | Kicking the rack at D7 to move              | 15:16:17               |
| 15:16:19  | Grasping the handrail at D4                 | 15:16:20               |
| 15:16:24  | Pushing the forward side in Node2 and grasping the aft side handrail | 15:16:28               |
| 15:19:22  | Grasping the overhead handrails to move     | 15:19:27               |
| 15:20:15  | Touching the rack at D8 by foot             | 15:20:15               |
| 15:22:33  | Working around F7 (Unstowing something and so on.) | 15:22:39               |
| 15:22:43  |                                           | 15:22:43               |
| Time     | Event Description                                                                 |
|----------|-----------------------------------------------------------------------------------|
| 15:23:35 | Working around F7                                                                 |
| 15:23:39 | Closing the rack panel at F7                                                      |
| 15:23:45 | Handling CTB in front of Airlock                                                 |
| 15:48:09 | Touching the rack at A8 by foot                                                  |
| 15:48:13 | Touching the rack at D8 by foot                                                  |
| 15:58:31 | Shaking body with the foot restraint at D5                                       |
| 16:00:58 | Kicking the rack at D8 and grasping the Airlock upper side to move               |
| 16:04:35 | Touching the rack at D8 by foot                                                  |
| 16:16:17 | Grasping the handrail at O6                                                      |
| 16:16:49 | Touching the rack at D8 by foot                                                  |
| 16:19:59 | Grasping the handrail at O5                                                      |
| 16:35:08 | Opening the panel at F7                                                         |
| 16:41:27 | Stowing CTB at F7 and closing the panel                                         |
| 16:42:18 | Grasping the handrails in Node2                                                 |
| 16:50:29 | Touching the rack at F7                                                         |
| 17:26:55 | Working around F7 (Stowing something and so on.)                                |
| 17:27:59 | Touching the rack at D7 by foot                                                  |
| 17:47:01 | Grasping the handrail at O7                                                      |
| 17:48:51 | Touching the rack at D7                                                         |

### 3.2.4. Based on the analysis result, the following lessons learned are acquired.

a) When crew moves grasping the overhead handrails, g-jitter over 100 µG often occurs.

b) When crew touches the rack at deck side by hand or by foot, strong g-jitter does not seem occurred. But when crew moves from overhead to deck side and then touches the deck side, or when crew kicks the rack at the deck side to move, g-jitter over 100 µG is generated, especially in X axis.
c) When crew was working in the vicinity of Airlock, strong g-jitter was not observed.

d) When crew used the voice loop to communicate ground team, g-jitter was not observed.

e) Even though crew sometimes used a laptop terminal at A7, g-jitter was not observed at that time.

f) When crew stowed/unstowed something to/from Cargo Transfer Bag (CTB), some g-jitter occurred. But operations in the JLP did not generate g-jitter.

3.3. Waste and Hygiene Compartment (WHC) usage and g-jitter

In addition to micro-G data measurement in crew day time, we also measured micro-G data in crew sleep time during Marangoni experiment. To monitor liquid bridge motion real-timely during experiment, we observed downlinked image of liquid bridge via Image Processing Unit (IPU). Measurement parameter is shown in table 3.3-1.

| Measurement Time | 2010/10/27 22:00 - 2010/10/28 05:00 |
|------------------|-----------------------------------|
| Sampling Rate    | 398.6 Hz                          |
| Filter Cutoff    | 120 Hz                            |
| MMA Sensors      | RSU ID: 3011                      |
|                  | (RSU and TAA) TAA ID: 3005        |

We still observed liquid bridge was vibrating so much unexpectedly for several times during experiment, especially when we performed long liquid bridge experiment. The next day after we observed some big disturbances to liquid bridge during crew sleeping, we confirmed with crew and NASA/Houston Flight Control Team (HFCT) whether they had something which rang a bell on midnight g-jitter.

According to crew answer and HFCT’s confirmation on the related telemetries, we found that some crew motion related to the Waste Hygiene Compartment (WHC) may generate g-jitter which may impact on Marangoni Experiment. (See figure 3.3-1.)

![Figure 3.3-1. This is a figure an appearance of Waster Hygiene Compartment (WHC). WHC is located at Node 3.](image)

By imposing WHC current telemetry on the micro-G data at the time when we observed big disturbances, the following features were inferred. (See figure 3.3-2. and figure 3.3-3.)

1) Big g-jitter occurred just before/after WHC usage. In case of figure 3.3-2 and figure 3.3-3, the vibration level was about ±20 µG (from 0.1 Hz through 0.5 Hz) in Y and Z axis. This value is almost equivalent to the ISS microgravity acceleration performance (SSP41000), however, it is larger than usual during crew sleeping timeframe. It means WHC itself is not the direct vibration source, but
crew moving or door opening/closing may generate some g-jitter which may cause big vibration on the liquid bridge. (Vibration continuous duration was about 30 seconds for each just before/after WHC usage.)

2) By analyzing crew motion with downlinked KIBO internal camera video, crew movement velocity is thought to be about $\frac{8}{7} \text{[m/s]}$. Per this velocity, crew can move $34.3 \text{[m]}$ in 30 seconds, for example, from Service Module to Node 3.

3) The similar features were confirmed in other timings when big g-jitter occurred. The g-jitter level was almost $\pm 20 \mu \text{G}$ in all cases.

Figure 3.3-2. This figure shows correlation between big disturbances and WHC current telemetry (GMT300-301). When WHC current value increased, low frequency (less than 0.7 Hz) g-jitter was also increased. For example, typical g-jitter related to WHC usage (from GMT 301/0:41 – 1:07) is shown in Figure 3.3-3.
This figure shows MMA data and WHC current data on GMT301. Just before/after WHC usage timing, g-jitter occurred. It means that WHC is not the direct vibration source but some crew motion related to WHC may generate g-jitter. The vibration level was almost $\pm 20 \mu G$ (from 0.1 Hz through 0.5 Hz) in Y and Z axis.

Because all crew members have kindly cooperated to be quiet at night when we perform long liquid bridge experiment, we would like to reduce too much crew constraints during the night based on these new findings. From the above results, we will ask crew to open/close the WHC door/shutter softly or to grab the handrails softly, and move quietly and slowly in order to reduce a big g-jitter may be caused by crew motion related to WHC activities.

3.4. Future work plan
For future work to improve microgravity environment in KIBO, we are planning to conduct more challenging experiment and microgravity data measurement. For example, in the Increment 29/30, we will try to perform Marangoni experiment during crew working time in order to assess whether we can conduct Marangoni experiment during crew working time without liquid bridge breakup or not. Because we have no plan to use the Experiment Cell in future again which we’ll use in this trial, we do not need to request any cleanup activity by crew even though liquid bridge breakup would occur.

In addition, we are thinking about the possibility to measure microgravity data with support of International Partners while the ROBONAUT is operating during crew sleeping time which may simulate crew motion. We are expecting that microgravity data analysis can be more quantitative since ROBONAUT can move predetermined forces.

4. Summary and future KIBO payload operations
Microgravity environment in KIBO has been greatly improved over the past year due to advanced microgravity measurement and analysis, and of course, crew cooperation during sleeping time is highly appreciated. Moreover, these microgravity measurement and analysis required close cooperation by both International Partners and crewmembers, and then this cooperation has resulted in building a good relationship and enhancing the bond among us in order to achieve good science success in ISS/KIBO as a team.
Through comparing the MMA data and other related data such as onboard internal camera video and the WHC telemetry, we are expecting to narrow down the possible causes of g-jitter during crew sleeping time to crew motion related WHC usage. For example, we’ll ask crew to reduce g-jitter may be caused by crew motion related to WHC usage such as grabbing the handrails to move or opening/closing the door/shutter of WHC. This request will be applied to reduce g-jitter when we are planning to conduct Marangoni Experiment in crew day time for trial. We would like to share the lessons learned we have got through these experiences with crewmember and International Partners to reduce crew constraints during the special night when we perform long liquid bridge Marangoni experiment. For the future, we will aim to perform further challenging experiments utilizing good microgravity environment in ISS/KIBO.

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