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軌道上静電浮遊炉（ELF）実験実施に係る地上準備

Ground Preparation for the ISS onboard experiments using the Electrostatic Levitation Furnace (ELF)

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1. Introduction

Through the initial verification of the equipment, nominal operation of the Electrostatic Levitation Furnace (ELF) has started in the International Space Station (ISS). Many themes have already been selected through the public announcement by JAXA, and various preparations are being made at the Tsukuba Space Center before launch for the onboard operation. In this paper, we mainly introduce various compatibility tests before launch.

2. Electrostatic Levitation Furnace

The ground-based ELF was initially developed by Rhim et al. in the Jet Propulsion Laboratory [(1)], and in Japan, many improvements of the ELF system have progressed at JAXA (formerly NASDA), contributing to the progress of the research for the thermophysical property at extreme high temperature on the ground.

Currently, various thermophysical properties can be measured at the JAXA Tsukuba Space Center and ground-based ELF in various places, but there are some subjects to be resolved. As one of these solutions, the development of an onboard ELF (ISS-ELF) has been promoted in order to respond to materials that are difficult to levitate and melt on the ground. In 2016, the ISS-ELF was completed flight model assembly and launched, and the initial verification of the equipment onboard was carried out [2)]. There, ISS-ELF development team faced many problems, but engineers and scientists solved them step by step, and the probability of success of the experiment has increased[3)].

Both procedures are designed to ensure that valuable space experiments do not fail as much as possible; users can pre-check and control experiments using JAXA ground equipment. Currently, themes from both academic and corporate are selected and carried out, many themes have been adopted, and experiments are being conducted sequentially on track.

The implementation of the onboard ELF experiment is a process as shown below. Basically, the user prepares the sample and performs the compatibility test necessary for the flight on the user's own (JAXA helps some tests as needed).

User inquiries -> Confirmation -> Contract -> Compatibility tests -> Flights -> Onboard experiments
-> Sample return to the ground-> Weight measurement -> Data analysis -> Data and samples delivery to users

3. Compatibility test on the ground

In the microgravity experiments in the ISS, there are some restrictions such as safety for the astronaut or equipment, load capacity at launch, and so on. After being selected as a theme for onboard experiments (including the candidate theme), pre-flight tests will be conducted on the following items.

Confirmation of heating ability by laser, and evaporation property

To confirm that heating ability by the semiconductor laser wavelength and output power (980nm, 40Wx4) inside the ELF. This is because high evaporation can stain glass windows and electrodes in the ELF, fatally affect heating and levitation control, and the renovation may not only take valuable work time for astronauts, but in some cases make it impossible to continue experiment. In addition, the evaporation property by the laser heating is confirmed, and samples that evaporate too intensely are excluded as flight samples after consultation. When glass windows and electrodes in the ELF are dirty by evaporation, it is considered to affect heating, temperature measurement, and levitation of subsequent experiments. Operations by crew can be cleaned to some extent, but it is not complete, and resource security and various adjustments occur. In order to secure valuable experimental time and more user usage opportunities, screening will be conducted at the pre-flight as much as possible, and transfer to other samples will be considered.

Surface charge measurement

Experimental samples have various surface charge properties depending on their elements, composition, and process. For a more reliable levitation procedure or stability inside the ELF, the surface charge characteristics of the sample should be measured by the Faraday cup before launch.

Hygroscopicity test

Depending on the sample, moisture in the air is absorbed and collapsed into sample holders. Even if it is not noticed when loading into the sample holder on the ground, it may get out of the shape after transporting into the ISS and until the experiment is performed. The sample holder transported to ISS is visually confirmed by the astronaut. If the shape is broken due to hygroscopicity, it may enter the gap of the holder and cause a rotation failure, so the holder will not be used. Therefore, it is not possible to experiment with all samples entering the holder. Thus, the sample is calmed in a state of over humidity in advance, and it is confirmed that the sample does not cause hygroscopicity.

Vibration test

Vibration and hypergravity are added to the sample during transport to a rocket launch site or by rocket to the orbiting ISS. As with the hygroscopicity, when sample fracturing in the holder is confirmed, since the holder is not used, it is confirmed that it is a property that does not crush by applying simulated vibration at the time of rocket launch in advance.

Inspection of the absence of bubbles inside the samples by X-ray transparent image

At the experiment in the ELF, rapid heating is sometimes required depending on the sample characteristics. If there are bubbles in the sample, the gas may expand rapidly, apply pressure in the sample, and rupture. In the ISS, debris drifts in the air indefinitely, which can harm astronauts, equipment, etc. Therefore, the X-ray transparent image in the sample is taken by X-ray, and samples available with bubbles are excluded from the flight samples.

Diameter and weight measurement

A micrograph of the sample is taken to measure the diameter, and samples are weighed. Confirm that it matches within the maximum/minimum diameter range for the sample holder loading.

Loading and packing on sample holders

After the samples passed all tests, the sample is sequentially loaded using a dedicated jig. After loading, it is packed in a nitrogen atmosphere to avoid oxygen and moisture as much as enough, and to be transported to the ISS.

There are other tests that are specific depending on the theme individually. In addition, if data can be obtained in ground tests before a flight, results may be obtained without conducting the experiment in the ISS.

4. Onboard experiments, recovery of the samples to the ground

The sample holder transported in the ISS will be stored in the transport bag until the time of the experiment. At the time of the experiment, the crew removes the holder from the transport bag and visually checks the condition of the sample. The holder is then attached to the ELF sample cartridge and the cartridge is set to the ELF. That's all the crew has done.

The ELF is remotely started by operation team in Tsukuba, and the experiment is started while the User Integrator (UI) has coordinates of the experimental user (researchers or companies). According to the characteristics of the sample, the time required for one experiment is typically 1 or 2 hours, including preparation and post-treatment (data downlinking).

In order to avoid unintended impact and acceleration changes during levitation and melting, experiments are basically conducted at crew bedtime.

During the levitation and melting experiment, a magnified image for density measurement, a sample temperature (and pyrometer camera image) using a pyrometer, a whole observation image in the chamber, equipment status, etc. are downlinked. After the experiment, analysis according to the experimental content is performed using downlinked data. Using the density measurement as an example, the volume at each temperature during melting is calculated by the magnified sample images, then, matching them with temperature at each time. After all the experiments of the holder, the holder is removed and packed again by the astronaut and is on its way back to the ground.

After returning to the ground, by measuring the sample weight, the density (= weight / volume) is calculated in conjunction with the volume information at each temperature described above. Analysis results are provided to the user at any time. After taking a micrograph, the sample is returned to the user.

The above is a flow of a series of microgravity experiments in the ISS. Although it may seem complicated at first time for the general users, the main element is a procedure to avoid failure as much as possible on valuable experimental opportunities. From a basic technical view, there is no significant difference from ground experiments conducted at the laboratory level, and JAXA has facilities for compatibility test, and it is not available to request excessive equipment and burdens for the general users.

5. Conclusion

In this paper, we introduced a series of flow from preparation to completion of the microgravity experiments in the ISS, which are generally thought to have a high load of users by compatibility tests on the ground. In microgravity experiments using the ISS, not limited to ELF, it has been operated to make it easier for users to use it due to the accumulated experience so far, and the persons in charge (clerically and technically) can answer questions. It is expected that this paper will lead to finding more potential users, and it will be part of the creation of results using the way.

References

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