Ergonomics in International Space Station: It’s an almost life on the earth?

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ABSTRACT
Since 1961, over 1,200 people have made space flight. For the last ten years or so, 6 personnel are constantly staying at the International Space Station (ISS). The vast knowledge accumulated during this half century is utilized in the development and operation of human space systems including safety management. In the human space system operated in the low earth orbit of the earth, like the ISS, considerations from ergonomic stand point are required for the phenomena caused by absence of gravity such as the loss of reaction force, the loss of natural convection, the physical change of the crew body, and spatial disorientation. Also, psychological burden associated with living in isolated and closed narrow spaces caused by technical limitations represented by transportation costs from the ground, as well as restrictions on the total working hours by crew members and supply volume, should be taken into consideration. The safety of the entire system including operation shall be treated as a top priority as a necessity of a human system.

Keywords: Human spaceflight, International Space Station, Micro gravity, Safety management

1. Introduction

More than 1200 personnel have experienced space flight since Major Yuri Gagarin of former Soviet Union conducted the first human space flight in 1961, and six crew members have usually stayed at the International Space Station (ISS) for about past ten years. In the meantime, with precious sacrifice at times, many experiences have been accumulated and improvement of human space system has been advanced. For the objectives of human space flight, from the early "space race", recently research and development became the main. Many astronaut candidates were selected from ordinary engineers and researchers and actually worked in space.

The ISS is the largest human space system ever built and still in operation. It is an international collaborative project with 15 countries including Japan, the United States, Russia, Canada and European countries. Japan is participating in this project mainly by the Japan Aerospace Exploration Agency (JAXA) by developing and operating the "Kibo" Japanese Laboratory Module and the space transportation vehicle "Kounotori". "Kibo" is the first full-scale human space system for Japan, and "Kounotori" is the first spacecraft to approach and berthing with human space system. Through developments and operations of those, a lot of knowledge about the design, verification, operation and safety management of human space system, were learned. Early in the project, it depended largely on the accumulated knowledge of the United States, but especially after the successful completion of the first "Kounotori" mission, it became in an equal position.

In the ISS as a human space system, most of the things to consider from the standpoint of ergonomics are due to the

Figure 1. The International Space Station (ISS)
ISS is a unique laboratory facility on low earth orbit. The assembly was completed in July 2011 after more than 40 launches of Space Shuttles and other rockets.
environmental condition of microgravity. Furthermore, a considerable part of restrictions on development and operation including safety are behind the fact that the transportation cost from the ground to the low earth orbit is extremely high. Ergonomics at ISS aims to bring the activity on orbit as close as possible to the daily life on the ground as much as possible. Requirements are set as a compromise between constraints and state of art based on experience so far, and then applied to development and operation, again.

2. Consideration to microgravity environment

2.1 Loss of reaction force

In order to move on the ground, the body is moved in advance by kicking the ground with a foot and using the friction force with the sole of the foot as a reaction force. Since friction force becomes small on ice, it is difficult to walk like on the ground. In the microgravity environment, there is no weight, so there is no friction force on the sole of the foot as on the ice, we can not walk because we can not get forward progressing force. Also, even in work such as fastener engagement, your body will rotate around the fastener due to the counter torque during operation.

Therefore, it is necessary to appropriately arrange the handrail and the foot restraint in order to obtain a appropriate reaction force for movement and equipment operation. Particularly in the case of extravehicular activities where movement and visibility are greatly restricted due to wear space suit, the arrangement of the aids should be carefully examined from the design stage and verified its validity through underwater test simulating weightlessness.

2.2 Loss of natural convection

Natural convection occurs on ground due to the difference in specific gravity caused by temperature differences and concentration differences of the fluid, and agitate it. On the other hand, natural convection is extremely suppressed when the weight is lost in the microgravity environment. The fact that natural convection can be neglected is one of the major incentives for research and development at ISS. Meanwhile, harmful gases such as carbon dioxide due to exhalation tend to be unevenly accumulated in the atmosphere of the habitable environment, so active forced ventilation is mandatory. Also, with regard to heat generation from electric power consuming equipment, there is a possibility of not only damage to the equipment but also burns accompanying crew contacts, due to overheating after natural convection dissipation. It is necessary to properly design heat wasting and to make it equal to or lower than the contact allowable temperature of crewmembers.

2.3 Physical change

The microgravity environment causes anthropometric and physiological changes in the human body. Anthropometrically, the intervertebral space grows mainly by relieving compression by gravity, and the stature extends by approximately 3%. Also, as body fluid shifts, the upper body expands and the lower body becomes thinner. Furthermore, as neutral body posture in weak state, take slightly forward bending attitude specific to microgravity. These should be taken into consideration not only in the dimensions of clothes but also in system design such as layout of equipment.

It is well known that muscle mass and bone mass decrease remarkably in microgravity environment. This is because the load on the muscles including the anti gravitational muscle and the mechanical stimulation to the bone are extremely reduced. In the operation of ISS, an appropriate exercise load on crew members are imposed as measures to reduce muscle and bone mass. Although there are reports on
the influence on the visual function accompanying the stay of the ISS and the change in the immune function, further research is awaited for further research.

2.4 Spatial disorientation

Unconsciously on the ground, the direction of gravity is recognized by visual sense, vestibular sensation, and somatosensory sensation. In the microgravity environment, it is said that the information from these sensory organs is significantly different from the experience on the ground, and the difficulty of integrating them is the cause of so-called "space sickness."

In the planning of the interior layout of the human space system, it may be better to make the orientation of individual worksites less regulative by taking advantage of being in the microgravity environment, the volumetric efficiency of the entire system may be improved. However, in ISS, in order to make it easy for the crew members to recognize their own direction with respect to the entire facility in their daily activities, orientation of "up and down" is intentionally set. Arrangement of the direction for each work site and the placement of the light fixtures, are aligned to the orientation. However, in terms of the overall ISS structure, it is not possible for all the modules to align the whole ISS orientation, but even in that case the setting of "floor and ceiling" for each module is common.

3. Engineering constraints

Development and operation of a human space system will be carried out on the technical constraints. Among them, the most fundamental and most influential on all aspects is that the transportation cost from the ground to the low earth orbit is high. The total size of the system, the supply amount, the number of resident crew members, the crew change frequency, the reliability and the operational life requirement of the system components.

3.1 Psychological burden due to closure / isolation environment

Although the ISS has an internal volume of about 930 m3 for six crew members, the work and habitable volumes of crew members excluding the parts occupied by equipment are considered to be less than half of them. The crew will stay in this space for about 6 months. It is said that psychosomatic symptoms may appear when staying in such closed, isolated and life-threatening environments for a long time.

In the ISS, regular interviews with crew members by experts, communication with families, securing appropriate leisure time, delivering special foods (fresh fruits etc.) and letters etc. are carried out. Psychological adaptability is also evaluated from the selection stage of the astronaut candidate through examination at the closed facility on the ground. There have been no serious cases in space.

3.2 Constraint of total working time

Since the system is operated on the assumption of six crew members, the total number of hours that ISS can allocate to work is limited. System maintenance is also included in working time, so there is even less time to allocate to the ISS’s purpose of research and development. For this reason, the crew work time is recognized as one of the limited resources in the ISS, and is allocated according to the contribution of participating countries.

Therefore, in addition to designing such that experiment equipment does not require the crew operation as much as possible, when preparing work, detailed procedures and coping methods at the time of failure are prepared beforehand, and when necessary on the ground training is planned before their stay on ISS.

4. Safety management

ISS is a human space system, so crew safety is a top
priority. In safety management of human space system at JAXA, the knowledge, technology, experience, etc. obtained at each stage are reliably reflected to the next development and operation in a timely fashion. This is because JAXA is conducting all of the requirement setting, development, verification of the required specifications and operation. It can be said that it is a feature compared to other fields that it has constructed a mechanism to continuously improve. Most of safety management methods and tools for safety analysis are widely known, and can not be said to be state of the art at all. However, it seems that there are not many cases where these are applied exhaustively and systematically.

To ensure the system safety, hazard management process is as following.
A) Identification of hazards and their causes: Identify all hazards predictable by using Failure Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA), including the degree of damage.
B) Elimination of hazard cause, control and setting of its verification method: If the identified hazard corresponds to the 16 kinds of standard hazards defined in the ISS program, control and verify in a standardized way. Otherwise, control the hazard according to the priority order of hazard elimination, risk minimization design such as fault tolerance design, safety equipment, alarm / emergency equipment etc., operation procedure, preventive maintenance, and set an appropriate verification method.
C) Verification of hazard control method: Verify hazard control method by test, analysis, inspection, demonstration, or a combination thereof.

The results of these series of tasks are documented as safety assessment reports and are subject to safety review. Furthermore, for each and every operation period, integrated hazard analysis is conducted to evaluate the safety on the combination of experiments and the "Kibo" system that are simultaneously operated within that time period.

In the ISS program, safety requirements setting and safety review are carried out by an organization independent of the development team.

5. Conclusion

One of the goals of ergonomics in human space systems is to allow people living and working in space to spend the almost same life as on the ground without being conscious of they are in space. At present, development of new rockets aiming at reduction of transportation expenses is being promoted in countries including private enterprises. It is expected that the design and operation of a human space system will change dramatically if transportation costs dramatically decrease in the future. If the access to the low earth orbit becomes easier and more people go to low orbit for various purposes, a new Ergonomic consideration will be required to realize fewer restrictions and almost same life as on the ground. In principle, even consideration accompanying microgravity is not mandatory any more by introducing pseudo artificial gravity by centrifugal force.

Furthermore, in the future exploration mission beyond the earth's low orbit, for example, to the moon and Mars, since there is gravity smaller than the earth, it is necessary to construct a human space system adapted to the environment. Also, the radiation environment is much severe beyond the Earth's lower orbit. This is because the relaxing effect of the radiation environment due to the earth's magnetic field in the vicinity of the Earth disappears and there is a possibility that it is the most major restriction to human space exploration. In these respects, new efforts will be necessary.

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