The importance of preparation to realize the successful teleoperation of a space explorer in mysterious caverns beneath the lunar surface

Kazuya Imaki (JAMSS) and Satoru Nishizawa (JAMSS)

Contact Author: Kazuya Imaki
Affiliation: Japan Manned Space Systems Corporation
Address: Tsukuba Space Center/Space Station Operations Facility, Tsukuba-shi, Ibaraki-ken, JAPAN
Email: imaki.kazuya@jamss.co.jp
Phone: +81-29-855-7526
FAX (optional): +81-29-855-3484
Presentation Preference (oral or poster): poster
Keywords (no more than 5): International Space Station, Lessons and Learns, Ground Systems, IV&V, training

---

Abstract

The successful teleoperation of a space explorer is not only to accomplish things as planned but also to appropriately respond to every contingency situation to keep its mission continues. In order to maximize the performance of space mission telescience and eventually affecting the fulfillment of mission science objectives, well-thought-through preparation and arrangement should be taken into account as well as its mission concept and strategy.

1. OVERVIEW

There are few cases in operating a spacecraft or space explorer that it does not unexpectedly encounter some forms of off-nominal situations. In the operations of the International Space Station (ISS) which is a representative spacecraft, not only the nominal operations plans based on the mission plans but also operations plans for every possible off-nominal situation are taken into considerations.

The operations plans are documented according to the pre-defined format so that all of the ground mission operators called flight controllers could take the same actions in a specific time frame if needed under a unified command. In addition, a systematic training program for the flight controllers is established to acquire and maintain the necessary skills to implement the operations plan as a team while maintaining a good situational awareness and making timely decisions when needed.

Those operations preparation listed here is essential for the operations of any of the spacecraft or space explorer since the mission success is heavily relied on the decisions made during the operations phase. Thus, a well-thought-through preparation and arrangement for the spacecraft or space explorer operations should be taken into considerations in advance. However, the little attention has been given to the importance of the operations preparation compared to those of the mission analysis or system design.

The Japanese Experiment Module (JEM), also known as KIBO (Hope) was assembled in space as part of the International Space Station (ISS) from 2008 to 2009 (Refer to Figure1). Since then, it has been operating nominally and bringing fruitful outcomes through various experiments on orbit. JEM is the first manned space system in the history of Japanese space program, and the operations experience is expected to make a large contribution to the next manned space exploration program.

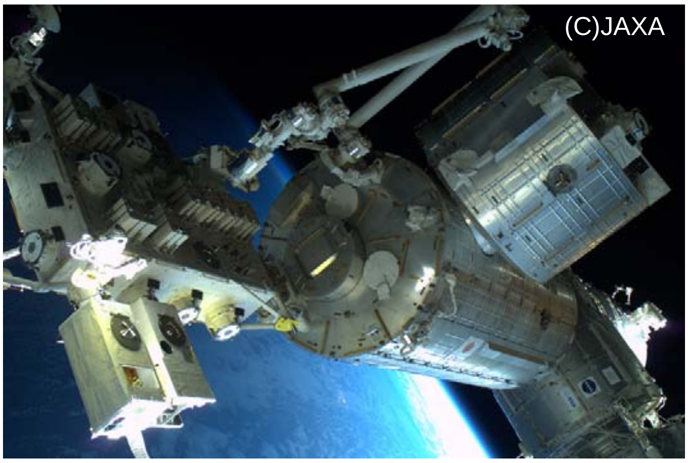

Figure 1: Japan Experiment Module “KIBO”

In this paper, the operational tips gained by the JEM real-time operations are introduced and then the application of those to the space explorer in the mysterious caverns beneath the lunar surface program is suggested (Refer to Figure2).

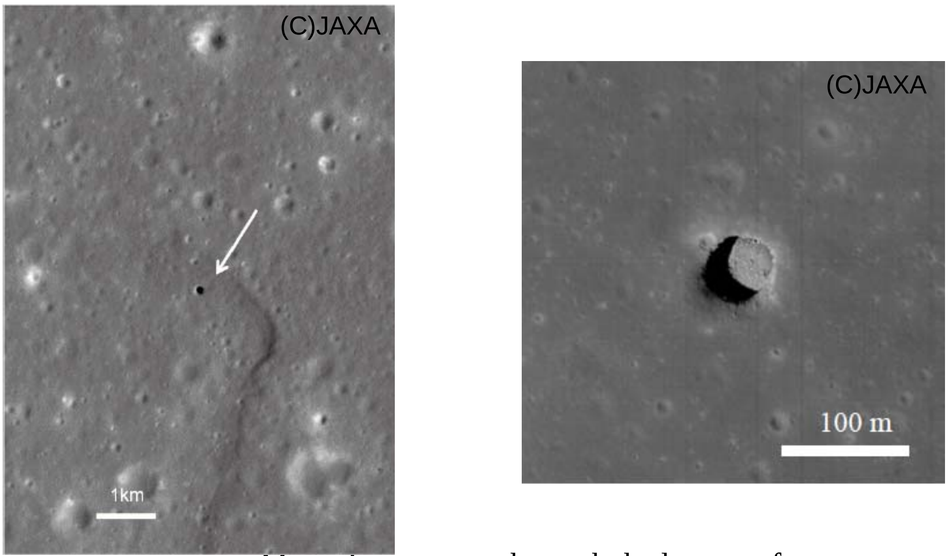

Figure 2: Mysterious caverns beneath the lunar surface

2. JEM OPERATIONS

The operations of the JEM including various hardware or software operations, data management, and experiment system are conducted using the operations procedures called Operations Data File (ODF). The ODF is developed according to the pre-defined format and it falls roughly into two categories; Nominal and Malfunction. Nominal ODF is used for the steady operations phase and is developed by the flight controllers based on the operations plan and applicable flight rules before conducting the operations. Malfunction ODF is used for the off-nominal event and is developed by the flight controllers thorough the extensive discussions including the engineers from the manufacturing companies considering the every possible off-nominal situation and troubleshooting options for each of the cases. The developed ODF is then verified before applying to the actual operations using the ground simulators or Operations Control System (OCS) (Refer to Figure 3) which is also used for the JEM real-time operations.

Figure 3: "KIBO" Operations Control System

Two of the essential parts of the success for JEM operations are the camera views and telemetry data from the ISS. Cameras are mounted on the ISS and can be downlinked to the ground. The telemetry data of the on-board equipments are also downlinked and displayed on the monitor via KIBO OCS. The camera views and telemetry data are continuously monitored by the flight controllers in KIBO OCS. In addition, on-board equipments are remotely controlled by sending commands via KIBO OCS. Even the KIBO robotics operations including the payload handing and dexterous maintenance operations are currently controlled by flight controllers.

3. OPERATIONS PREPARATION FOR LUNAR EXPLORATION

This section suggests the operations preparation for the successful teleoperation of a space explorer in mysterious caverns beneath the lunar surface focusing on the four important standpoints while discussing the operations tips gained by the JEM real-time operations.

(1) Space Explorer design for operability through JEM operations experience

It is an indispensable factor for the safe and steady mission accomplishments to work on the mission analysis or system design from the operational standpoint. The instruments on-board which monitor or detect the external environment for the science purposes also play an important role for the safe operations of the space explorer. One example is that a camera mounted on the space explorer for its science objectives could also be used as a source of information analyzing the situations of the explorer for flight controllers. Thus, the instruments on-board should be robust and redundant to off-nominal situations. It is also desired that the specification of the instruments meets the minimum requirements come from the operations community as well as the requirements for science objectives.

As the high-spec instruments which monitor or detect the external environment are designed, the operations of those needed to be well discussed. In the case of camera, eliminating the blind spots while considering the angle of view or camera mounted location is very important. If the camera had a blind spots or it has low visibility, it could be a potential risk for the mission success. In case of the JEM robotics operations from ground, the safety of robotics teleoperation is enhanced by ensuring so called Big Picture View which oversees the whole robotics arm and Task View or Side View which focuses on the specific point such as the tip of the robotic arm in dexterous operations (Refer to Figure 4). The Big Picture View is not assumed, however, for the space explorer including the lunar mission. Therefore, the effective use of alternative instruments such as the proximity sensors or ranging sensors combining with the Task View or Side View is important.

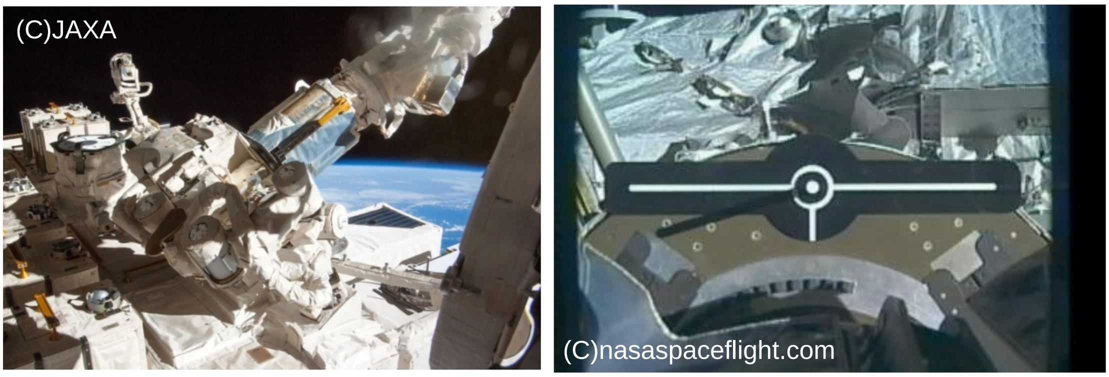

Figure 4: Task view of “KIBO” Robotic operations

Many different kinds of mechanical systems or robotics arm are currently under operation on the ISS and have been producing appreciable results for vehicle assemblies, payload handlings, and maintenance operations and so on. At the same time, off-nominal situations caused by the system failure or operational errors have been occurred continuously. Each of the off-nominal case is analyzed and the lessons learned acquired from the operations experience has been incorporated into the software of the system or operational products for the improvement of the operations. The further analysis of the lessons learned both in merits and demerits and reflects those into the design phase of the future space explorer is considered to be a key factor for the optimal development of the explorer.

(2) More efficient ground operations using hi-operability Ground System design

It is required for the ground operations personnel of a space explorer to be aware of the off-nominal situation using the telemetry data and deal with the situation immediately. The OCS has been used since the beginning of the JEM operations and the minor software updates has been incorporated into the system based on the requests from the flight controllers, especially in terms of the higher reliability and efficiency. The items for higher operability and further efficiency which require drastic or fundamental upgrades of the ground system are also identified over the years of experience of JEM operations in preparation of the future possible major upgrades of the system. Example is an automatic pop-up display function of the telemetry monitor display to immediately notify the abnormal indication and the details of the relevant equipments to its operator. If this function is implemented into the ground system, it will facilitate its operator to be aware of the off-nominal event and immediately respond to the troubleshooting as a result. It also helps specifying the cause of failure by looking into the details data of the relevant equipments. Another example is the automatic commanding function which corresponds to a specific off-nominal event, which would implement the immediate and assured recovery in response to a failure.

It is not needed to stick to the command and telemetry function as a ground system and utilizing the other function such as to visualize the graphics dedicated to robotic arm operations of a space explorer leads more efficient ground operation. It would be possible to visualize a simulated Big Picture View with computer graphics by using the on-board sensors or joint angle sensor data of a robotic arm even if there are no on-board cameras which provide Big Picture View. A similar computer graphic system has been used for the JEM mechanical and robotics operations and the multifaceted support for the efficient operations has been provided.

As the Commercial Orbital Transportation Services (COTS) get into full swing, ground control system with a strength of a private sector which considers the efficiency and hi-operability for the operators are started to garner attention. It is believed to be one of the important elements for the mission success to make arrangements of the ground system design which considers the lessons learned from the JEM or ISS ground operations.

(3) Reliability and Consistency Control for System Hardware and Software

It is one of the significant issues which could lead to improvements of operations technique for a future space explorer to increase the reliability and consistency of the entire items involved in the operations by bridging items such as ground control system, operations product such as the ODF and Technical documents, software, and hardware of the explorer. For example, it could be a cause of error or inconsistency of the ODFs or technical documents if those are developed by multiple members or different groups. However, it is almost impossible that all of those products to be developed and managed by a single entity with profound understanding of the software and hardware. Therefore, it can be said that there remains possible mis-operations or human error in operating a space craft.

Currently, the technology for the Independent Verification & Validation (IV&V) has been developed to increase the reliability of on-board software, especially in the field of aerospace and train systems. New approach is underway to apply this technology to straddle multiple areas of software, hardware and operations products. If this technology is also applied to the system design or developments of operations products, it would realize the end-to-end operations preparation as a while mission. Furthermore, it is expected to bear good ripple effects in reducing the mission planning period or reducing costs by eliminating the overwrapped activities.

(4) Systematic Training Program for Flight Controllers for Mission Success

It is required for all of the flight controllers in JEM operations to have enough skill, knowledge and attitude for the appropriate and timely decision makings when needed. The success of the mission while maintaining safe and steady operations relies on the operators on console of ground system even if newer technology or good operation products are developed. It is necessary to make a space explorer in a safe configuration even in the contingency situation with explicit decision makings.

The training program for the JEM flight controllers has been continuously improved over the years of ISS operations by changing training methods and approaches. A systematic training program for the flight controllers are established and further challenges are underway so that flight controllers acquire necessary skills and knowledge in a less training period. In addition, the essential skills to be qualified as a good operator are also identified through the JEM training experiences. It is necessary to make a most of the accumulated training techniques from JEM training in anticipation of future space explorer.

4. CONCLUSION

It is the operations phase that witnesses the significant changes which result in success or failure of the mission of a space explorer which spans long periods of time. In order to maximize the performance of space mission and to achieve its science objectives, a well-thought-through preparation and arrangement should be taken as well as its mission concept and strategy. In addition, it should stated that the operational lessons learned from previous and ongoing mission including the JEM operations are incorporated into a future space mission and expected to help produce fruitful science results.

References

[1] Haruyama, J., Sawai, S., Mizuno, T., Yoshimitsu, T., Fukuda, S., and Imaeda, R.: Geological context around the lunar vertical holes where SLIM will challenge to land on

[2] Haruyama, J., Saito, Y., Nishino, M., Hashimoto, H., Kobayashi, K., Yokobori, S., and Shirao, M.: Science and utilization of lunar and Martian hole-structure and its associated lava tube

[3] Haruyama, J., Sawai, S., Mizuno, T., Yosihmitsu, T., Fukuda, S., and Nakatani, I,: Exploration of lunar hole, possible skylight of underlying lava tube, by small explorer

[4] Haruyama, J., Hioki, K., Shirao, M., Morota, T., Hiesinger, H., van der Bogert, C.H.,Miyamoto, H., Iwasaki, A., Yokota, Y., Ohtake, M., atsunaga, T., Hara, S., Nakanotani, S., Pieters, C.M.: Possible lunar lava tube skylight observed by SELENE cameras. Geophys. Res. Let. 36, L21206 (2009), doi:10.1029/2009GL040635

[5] Cushing, G. E., T. N. Titus, J. J. Wynne, and P. R. Christensen (2007), THEMIS observes possible cave skylights on Mars, Geophys. Res. Lett., 34, L17201, doi:10.1029/2007GL030709

[6] Haruyama, J., Morota, T., Kobayashi, S., Sawai, S., Lucey, P. G., Shirao, M., Nishino, M.N.: Lunar Holes and Lava Tubes as Resources for Lunar Science and Exploration, in Badescu, V. (Eds.), Moon - Prospective Energy and Material Resources, Springer, pp. 139-164.