JEM Exposed Facility System and Operation

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International Space Station (ISS) is currently constructing. For Japanese Experiment Module (JEM) “Kibo,” ELM-PS (Experiment Logistics Module - Pressurized Section) and PM (Pressurized Module) were launched in 2008, and JEM Exposed Facility (EF) and ELM-ES (Experiment Logistics Module - Exposed Section) were launched in 2009. This paper describes the system summary, features, and operation of JEM-EF.

1. Introduction

Construction of the International Space Station (ISS) is gradually progressing. The pieces for the Japanese Experiment Module (JEM; also called “Kibo,” which means “hope” in Japanese) were launched on separate space shuttle missions: the Experiment Logistics Module – Pressurized Section in March 2008; the Pressurized Module in June 2008; and the Exposed Facility and the Experiment Logistics Module – Exposed Section in July 2009. In-orbit experiments have gradually begun to be conducted.

Development of the Exposed Facility began with a conceptual design that was drawn up in the 1980s. After that, its development proceeded as follows: drawing up of a basic design in 1992, drawing up of a detailed design in 1998, manufacturing and testing of a flight product, transport to the Kennedy Space Center in 2008, and then final inspection and maintenance. Finally, it was launched on the space shuttle STS-127 in July 2009.

This paper describes the results of the development of the Exposed Facility, which is now in use as Japan’s first exposed system on the ISS.

2. Outline of the system

As shown in **Fig. 1**, the Exposed Facility provides a space of approximately 6 × 5 × 4 meters in which science experiments can be conducted in an exposed environment with up to ten payloads (0.8 × 1.0 × 1.85 meters) attached circumferentially. The Exposed Facility can supply the payloads with electricity, communications capability, thermal control fluids, and other resources.

3. Results of development

The Exposed Facility is a system attached to the Pressurized Module that is designed to supply electricity, communications capability, exhaust heat, and other services to payloads. It is made up of structural, electrical, communications, and thermal control subsystems, as well as equipment exchange units.

This paper provides an outline of some of these subsystems, and describes the difficulties the authors faced during their development.

3.1 Structural subsystem

Developing a structural subsystem made the assembly of large space structures in which various kinds of system equipment can be mounted possible. The Exposed Facility is structured as follows.

It consists mainly of panels, frames, and mounting structures for the Space Transportation System (STS) (**Fig. 2**).

The structural development phase preceded the development phase for the systems, subsystems, and components. The structural subsystem was developed to allow the incorporation of design changes to the structural interface should any arise as a result of system design changes.

Major design changes to the structural interface include making internal equipment in Orbital Replacement Units (ORUs) for extravehicular activities (EVA) – E-ORUs, launching cameras and lights in the Exposed Facility, and developing EVA-support devices

3.2 Robot essential Orbital Replacement Units (R-ORUs)

Components for the Exposed Facility are made in ORUs. If any component malfunctions, it can be replaced in an ORU. The highly reliable recovery system this established was one of greatest achievements of the development.

Mechanisms arranged on the upper surface of the Exposed Facility that can be replaced by using the small fine arm or through EVA are called Robot essential Orbital Replacement Units (R-ORUs) (**Fig. 3**). The following components are designed as R-ORUs.

- Exposed facility – power distribution box (EF-PDB)
- Survival power distribution box (SPB)
- Exposed facility system controller (ESC)
- Video switcher (VSW)
- Fluid pump package (FPP)

R-ORUs feature two bolts that enable simultaneous structural mating and resource connection. It was technically difficult during development to achieve structural mating while maintaining quick disconnect (QD) alignment accuracy for resource connection. After repeated

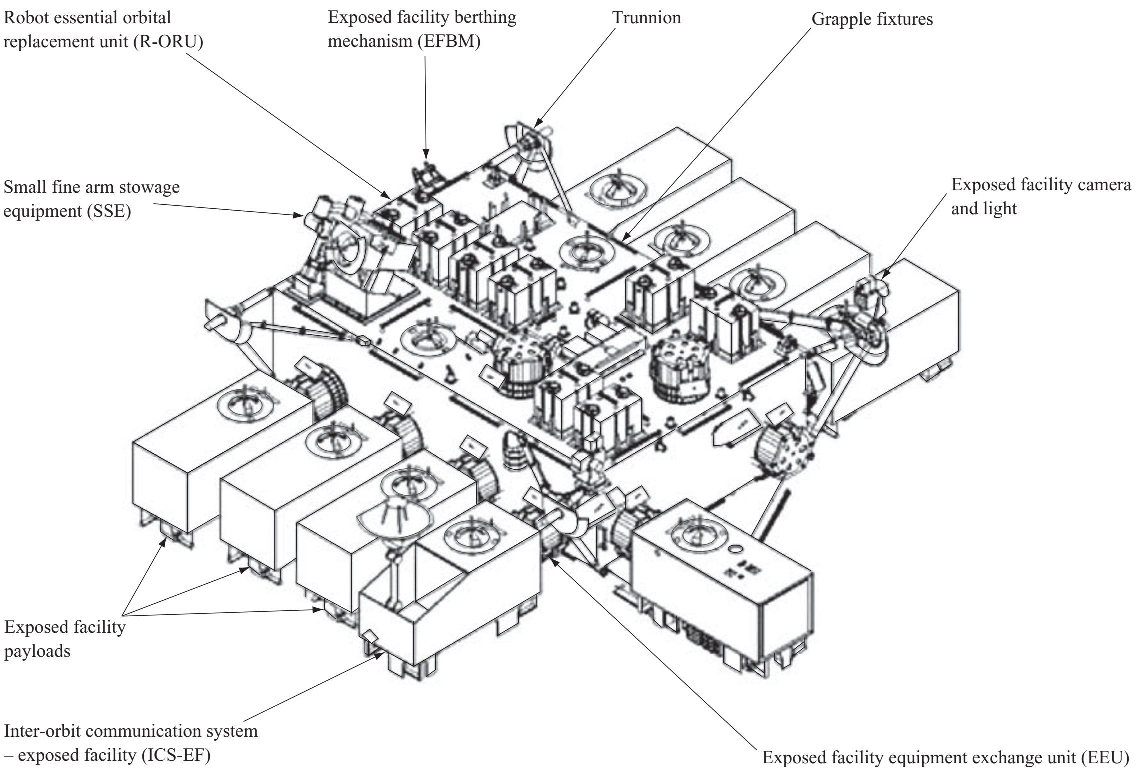

Fig. 1 Exposed facility configuration

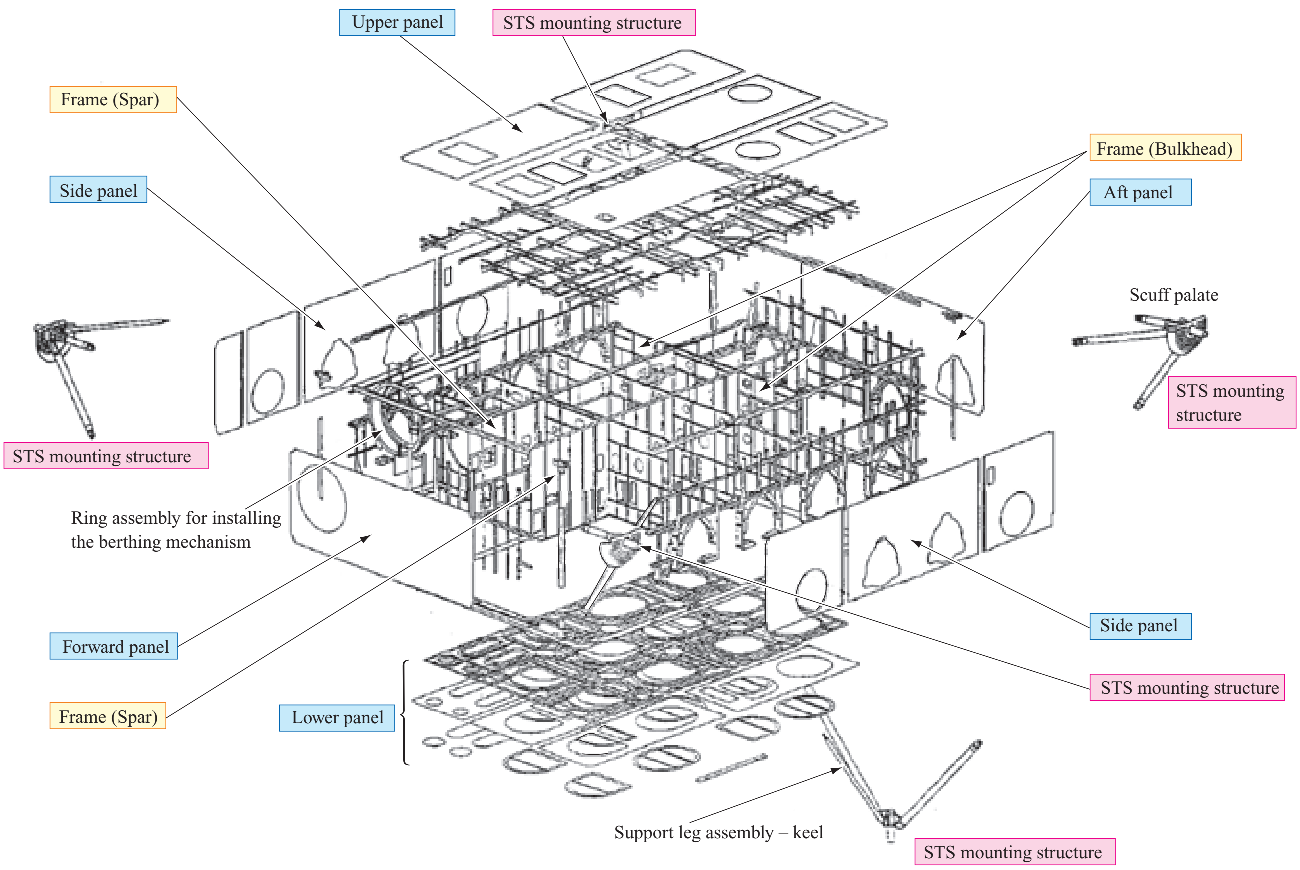

Fig. 2 Structural subsystem

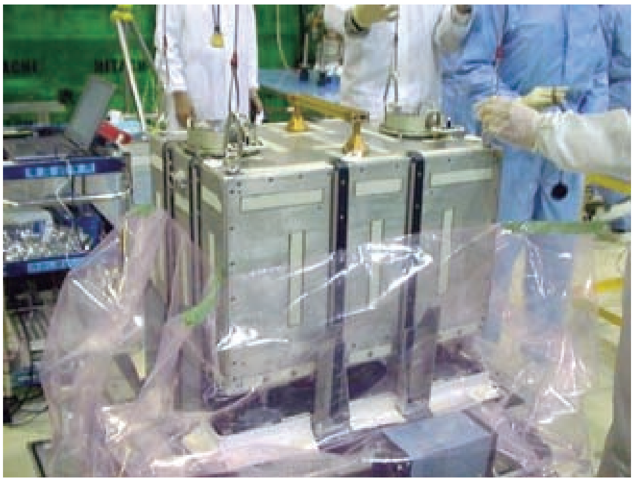

Fig. 3 R-ORU configuration

development tests to design, develop, and improve the alignment unit, the authors were finally able to overcome this technical difficulty (**Fig. 4**).

R-ORUs are also equipped with visual indicators that allow the crew engaged in EVA to visually check if the bolts have been tightened. This is another feature of R-ORUs as manned space equipment (**Fig. 5**).

3.3 Extravehicular activity Orbital Replacement Units (E-ORUs)

In addition to R-ORUs, the Exposed Facility is equipped with Extravehicular activity Orbital Replacement Units (E-ORUs) on its lower surface. E-ORUs also contributed to improving the reliability of the Exposed Facility system.

E-ORUs can only be replaced by EVA crew. The following components are designed as E-ORU (**Fig. 6**):

- Thermal interface unit (TIU)
- Heater control equipment – a (HCE-a)
- Heater control equipment – b (HCE-b)
- EEU driver unit (EDU-a/b)

E-ORUs feature six structural mating bolts and two resource connection bolts that are independent of each other.

Each R-ORU is relatively light, with an approximate mass of 20 kg, and is designed to bear launch loads by means of two bolts. Meanwhile, each E-ORU has an approximate mass of 60 kg and is designed to bear loads by means of six structural mating bolts.

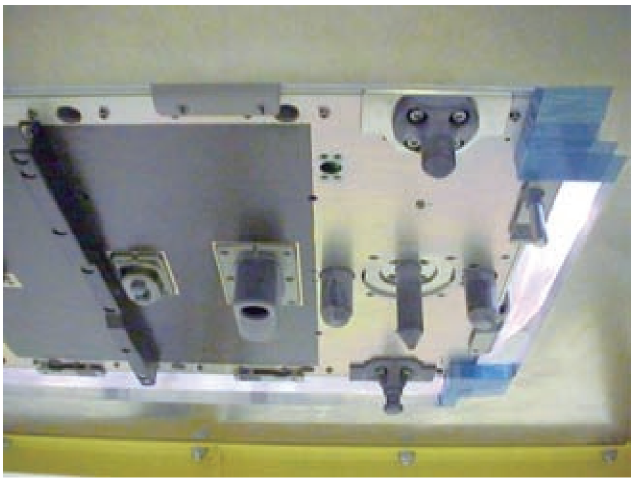

Fig. 4 Lower side of R-ORU

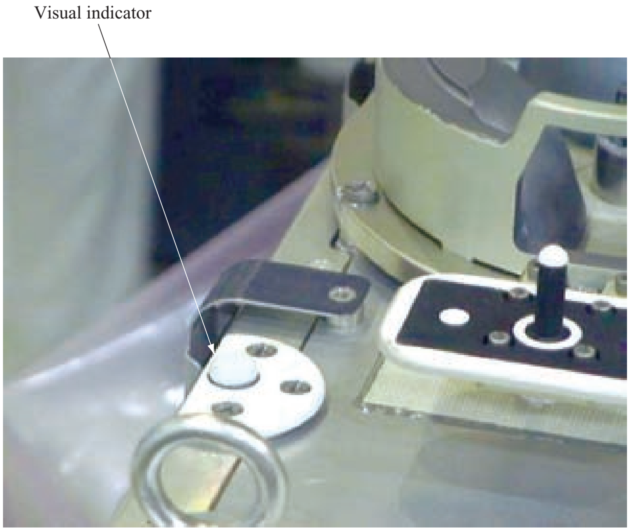

Fig. 5 Visual indicator

Fig. 6 E-ORU configuration

3.4 Equipment exchange unit subsystems

Used for connecting/disconnecting payloads and supplying them with resources, the Equipment Exchange Unit Subsystem consists of the following components.

- Exposed facility unit (EFU : **Fig. 7**)
- Payload interface unit (PIU : **Fig. 8**)
- EEU driver unit (EDU)

The EFU can grasp a PIU that has been positioned by the robotic arm, overcome the robotic arm load to absorb any positioning errors, and be connected to (or disconnected from) the PIU. For these operations, the EFU is equipped with a variety of components, including ① three fixing arms, ② a link mechanism to synchronously drive the three fixing arms, ③ ball screws, ④ gears, ⑤ motors, and ⑥ fixing arm position detectors.

The interface between both units (EFU and PIU) is equipped with electric, optical, and fluid connectors to supply payloads with electricity, communications capability, thermal control fluids, and other resources. These connectors are connected

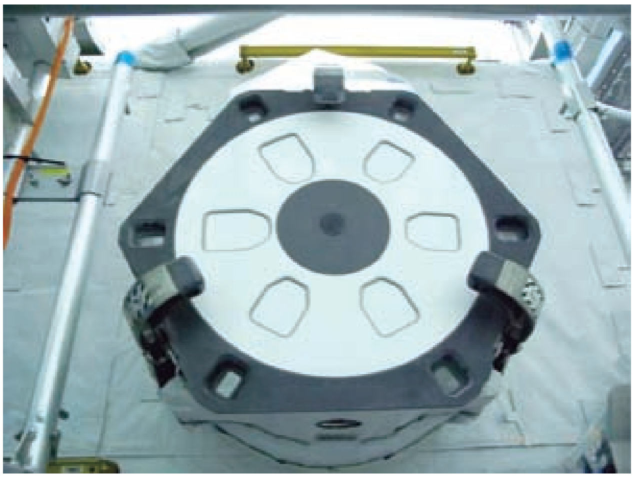

Fig. 7 EFU

Fig. 8 PIU

and disconnected at the same time as the equipment exchange mechanism is mechanically connected and disconnected.

Major technical difficulties that the authors overcame in the development of the equipment exchange subsystem are described below.

3.4.1 Interface with the robotic arm

The authors tested the interface in tandem with the robotic arm to ensure that the positioning performance and load characteristics of the robotic arm were taken into account in the interface design. The robotic arm can only be operated in a zero gravity environment, so the authors prepared a simulator for 6-axis movements at the end of the arm, and then obtained and verified basic data.

3.4.2 Reduction in size and weight

To equip the Exposed Facility with 12 EFUs, the authors developed a single drive mechanism and a single actuator for operations ranging from positioning to connection and disconnection, and took other measures to significantly reduce the size and weight of the EFUs. The authors also took into account in-orbit loads and rigidity requirements in the design of the structure, and took measures to achieve weight reduction such as manufacturing large components (e.g., the EFU structure) by cutting them from forged aluminum.

3.4.3 Connection and disconnection performance affected by temperature difference

A thermal vacuum test revealed that if there was a temperature difference between the two mechanisms, they would thermally deform, preventing them from connecting properly. To overcome this problem, the authors reshaped the guide pins and guide-hole contact areas.

After this design change, the authors conducted a temperature difference test using a vacuum chamber, and this confirmed that a temperature difference between the two mechanisms of up to 80°C is tolerable.

To ensure the safety of manned missions, the authors also held discussions and coordinated with the National Aeronautics and Space Administration (NASA). These were conducted over a number of years starting from the beginning of development to address safety issues following the occurrence of certain abnormalities such as the jamming of the EFU subsystem. After the authors took the following safety measures, they succeeded in obtaining NASA's approval in its safety review.

3.4.4 Connection of the Experiment Logistics Module – Exposed Section (ELM-ES)

(1) The subsystem is designed to minimize risk.
(2) In the event of a jam, a releasable PIU (**Fig. 9**) is used for disconnection.

3.4.5 Connection of standard payloads

(1) The subsystem is designed to minimize risk.
(2) The subsystem can bear in-orbit loads in most situations.

For situations in which the subsystem cannot bear a load, the following measures are taken.

① Driving the EFU in reverse
② Reattempting disconnection with the robotic arm
③ Driving the EFU during EVA
④ Manipulating the robotic arm by means of EVA navigation

4. Operations (In-orbit assembly scenario)

The Exposed Facility is attached to the Pressurized Module of JEM by means of the Space Station Remote Manipulation System (SSRMS) and the Shuttle Remote Manipulator System

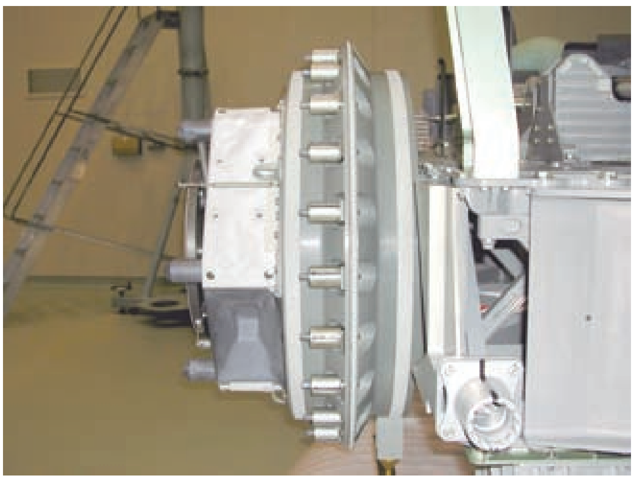

Fig. 9 Releasable PIU

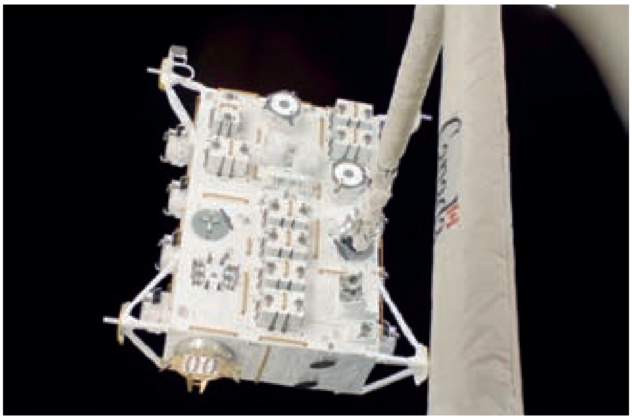

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Fig. 10 EF transfer

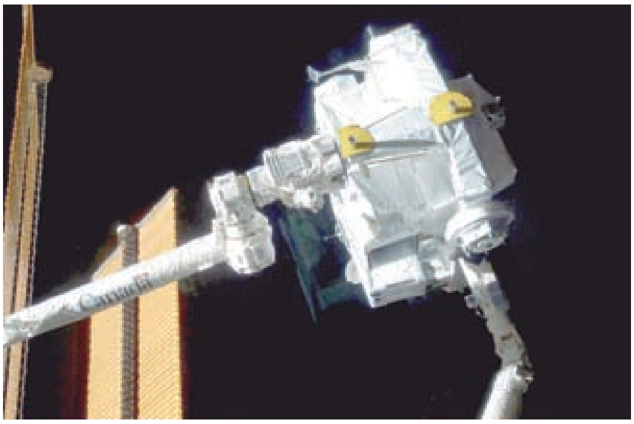

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Fig. 11 ELM-ES transfer

(SRMS), and this is followed by the immediate start of the system equipment (**Fig. 10**).

Originally, these transfer operations were to be performed using the SSRMS only. To reduce the time required for transfer operations, however, the authors adopted a transfer procedure called a double handoff. (In such a procedure, the SSRMS takes the Exposed Facility out of the shuttle cargo bay and hands it over to the SRMS. After that, the SSRMS transfers the base to the MT translator and receives the Exposed Facility.)

After these transfer operations have been performed, the Experiment Logistics Module – Exposed Section is also transferred to the Exposed Facility using the SSRMS and the SRMS (**Fig. 11**).

The following three pieces of the Experiment Logistics Module – Exposed Section are transferred to the Exposed Facility (**Fig. 12**): Monitor of All-sky X-ray Image (MAXI), Space Environment Data Acquisition Equipment – Attached Payload (SEDA-AP), and the Inter-orbit Communication System – EF (ICS-EF).

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Fig. 12 EF payload transfer

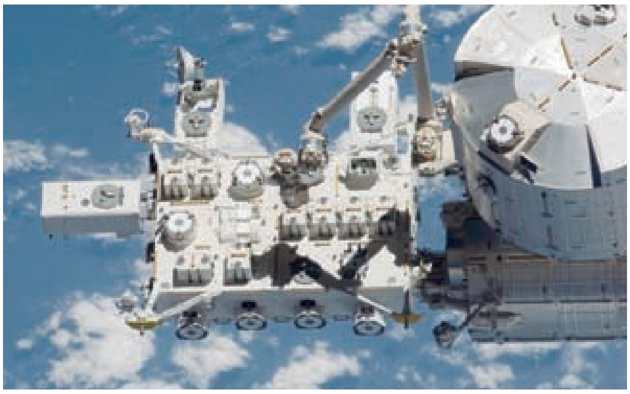

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Fig. 13 On-orbit EF configuration

5. Conclusion

The Exposed Facility is now operating stably and providing electricity, communications capability, thermal control fluids, and other services to the Inter-orbit Communication System (ICS) and the payloads. It is expected to continue to perform well in future missions (**Fig. 13**).

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