Ground Validation of JEMRMS

Fumihiro Kuwao*, Masanobu Nishio*, Akiko Otsuka*

Yasufumi Wakabayashi**, Naoki Satoh**

*NEC Toshiba Space Systems, Ltd

4035 Ikebe-cho, Tuzuki-ku, Yokohama, 224-8555, Japan

**National Space Development Agency of Japan (NASDA)

2-1-1, Sengen, Tsukuba, 305-0047, Japan

E-mail: otsuka.akiko@ntspace.jp

Phone: +81-45-938-8225 Fax: +81-45-938-8324

1. Introduction

Japanese Experiment Module Remote Manipulator System (JEMRMS) is the first Japanese manned space robot.

Several Space experiments will be carried at JEM that is attached to International Space Station (ISS). JEMRMS missions are to support JEM exposed experiments and/or maintain JEM exposed facility (EF).

JEMRMS has been developed as the engineering model (EM) and the proto-flight model (PFM).

Series of tests using JEMRMS EM/PFM were done in order to verify the fundamental performance and/or design requirements.

Some tests are unique because of JEMRMS uniqueness as the first Japanese manned space robot.

In this paper JEMRMS verification results including some unique tests are described in order to present its current status.

2. JEMRMS

(1) Mission

JEMRMS main mission requirements are to support JEM exposed experiments and/or maintain JEM exposed facility (EF) as the followings. (Figure 2-1)

-Manipulate JEM elements

JEMRMS handles JEM elements, such as Exposed Facility (EF), Exposed Logistic Module Pressurized Section (ELM-PS) and Exposed Logistic Module Exposed Section (ELM-ES) to support JEM assembly operation.

- Manipulate Experiment Payloads

JEMRMS exchanges Experiment Payload, which is carried by ELM-ES and is attached to EF to do exposed experiment.

- Manipulate EF system ORU and/or mission ORUs

JEMRMS exchanges failed EF system ORU and/or mission ORU.

-**Execute dexterous operation**

JEMRMS performs dexterous operation to support exposed experiments.

-**Provide EVA support**

JEMRMS holds Orbit Support Equipment (OSE) in order to support Extravehicular Activity (EVA).

(2) System constitution

JEMRMS is remotely controlled by the crew in the JEM PM.

JEMRMS has two robot arms, Main Arm (MA) and Small Fine Arm (SFA). MA handles JEM elements and Experiment Payloads. SFA is grappled by MA and handles the EF system and/or mission ORUs.

These two arms are controlled from the RMS Console located inside PM. RMS Console that has some crew interfaces such as Hand Controllers, Laptop Workstation, Television (TV) monitors and switch panels.
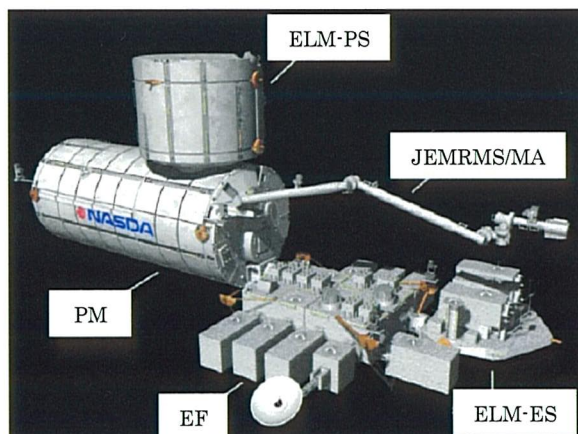
JEMRMS will be launched by the following three NSTS flights: 1J/A, 1J and 2J/A.

RMS Console will be launched by being stored in ELM-PS and transferred to PM on-orbit.

MA will be attached to PM by Hold Release Mechanism (HRM) and launched.

SFA will be stored in SFA Transportation Container (STC) that is attached on ELM-ES.

1J/A	RMS Console (Figure 2-2)
1J	MA (Figure 2-3), HRM
2J/A	SFA, STC

Figure 2-2 RMS Console

Figure 2-1 JEM Overall Image
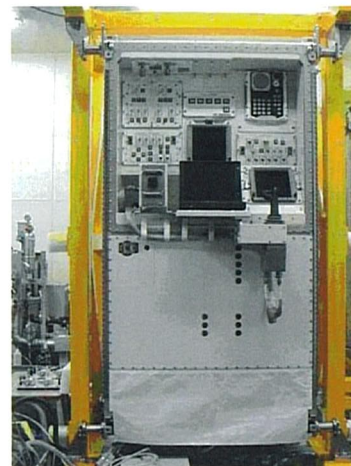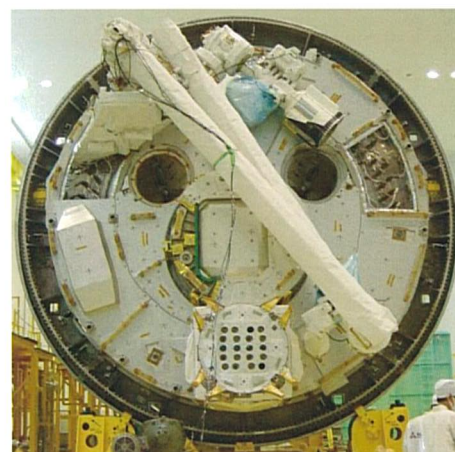

Figure 2-3 Main Arm attached on PM

(3) System Function and Performance

The main functions of JEMRMS are the followings.

- JEMRMS System Management

JEMRMS has I/F with PM Electric Power System (EPS), PM Communication and Data Handling System (C&DH) and ISS C&DH system.

JEMRMS can distribute electric power to JEMRMS components.

To prevent catastrophic hazard, such as payload release or collision, JEMRMS is qualified as two-fault tolerant system regarding catastrophic hazard.

Unique function to prevent collision is interference check function, such as region check and self collision check.

- JEMRMS Arm Operation

In order to let crew control MA and/or SFA via RMS Console, RMS Console is equipped crew I/F components. Crew can send commands through RMS Laptop Terminal (RLT) and monitor JEMRMS status. In manual mode, crew controls arm through Hand Controllers (H/Cs).

To carry out missions, JEMRMS prepares various arm control modes. (Table 2-1, 2-2)

- Viewing

During JEMRMS operation, TV camera images are provided to crew. JEM has several exposed TV cameras and their images are transferred to RMS Console.

RMS Console can provide TV camera images to crew.

JEMRMS has ranging function using its wrist camera image and JEMRMS frame calibration is based on the ranging result.

Table 2-1 JEMRMS Arm Control modes

Control mode
Joint Auto
Joint OCAS
POR Auto
POR OCAS
Manual
Single Joint
Position Hold
Limp
Brake

Table 2-2 Characteristics of MA and SFA

Item	MA	SFA
Degree of Freedom	6	6
Length (m)	10	2
Mass of Handling Payload (kg)	Max 7,000	Max. 300
Positioning (mm/degree)	±50/±1	±10/±1
Tip Force (N)	30 or more	30 or more

(4) Development Status

JEMRMS primary design started in 1990 and primary/detail/sustained design had been reviewed.

Overall JEM design had been also reviewed at JEM PDR/CDR/PQR. Along with JEM design phases, Safety reviews were also held and SR/Phase III of Flight 1J&1J/A was done.

JEMRMS has been developed as the engineering model (EM) and the proto-flight model (PFM). With the series of tests using JEMRMS models, JEMRMS function and performance requirements were verified

JEMRMS is now in the process of preparing for the shipment to the launch site. (Table 2-3)

Table 2-3 JEMRMS Development Schedule

FY	90	91	92	93	94	95	96	97	98	99	00	01	2002
Primary Design Review			▲ PDR										
Development Test		JEM PDR▼	φ0/1SR▼			φ0/1△SR▼							
Critical Design Phase						CDR#1-1▲	CDR#1-2▲	:DR#2▲					
EM System Test						JEM CDR#1▼	φIISR#2▼	φIISR#3▼ / JEM CDR#2▼					
Sustain Design Phase											PQR#1▲ PQR#2▲		△PQR▲ PSR▲
PFM System Test											JEM PRQ#1▼	φIIISR FLT 1J&1JA▼	JEM PQR#2▼

3. JEMRMS Verification

(1) Verification Plan

Through its development phase, JEMRMS verification is done using EM/PFM.

Environment test was done during component and/or subsystem (MA, SFA, RMS Console etc.) level test.

As system-level tests, system function and performance that is achieved by several components was planned to be verified. (Figure 3-1, 3-2) And I/F checks including internal and external of JEMRMS is the essential in system-level test.

As JEMRMS is the first Japanese manned space robot, some unique test and analysis was planned.

(2) Performance Verification

-RMS S/W function/performance verification.

Although JEMRMS is one of the elements of JEM, its I/F among S/Ws is very complicated. JEMRMS has four internal buses, two external buses, three application S/Ws and eight firmwares.

RMS S/W function/performance was verified in RMS Console S/W integration test and PFM system test.

RMS Console S/W Integration Test was done as RMS Console subsystem level test in order to verify function/performance achieved by RMS Console S/W.
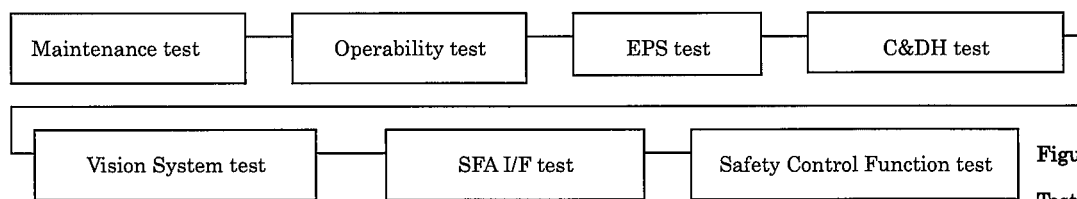
Maintenance test — Operability test — EPS test — C&DH test

Vision System test — SFA I/F test — Safety Control Function test

Figure 3-1 EM System Test Flow

EPS/C&DH/C&T test — MA Control system test — Human-In-the-Loop (HIL) test

Co-operation Performance test — Ranging test — MA Overall Performance test

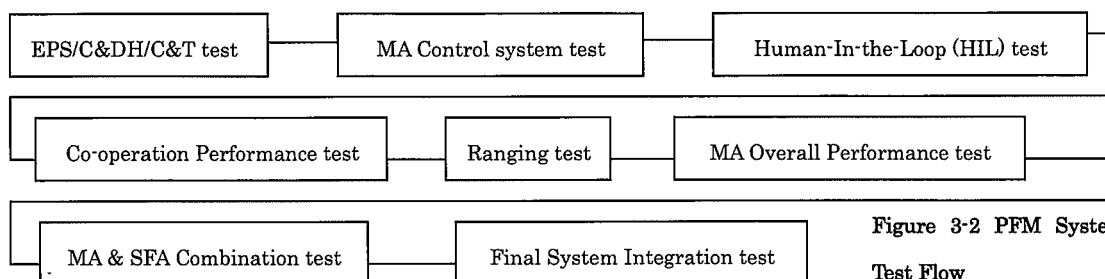MA & SFA Combination test — Final System Integration test

Figure 3-2 PFM System Test Flow

After RMS Console S/W Integration Test, some buses and firmwares I/F were remained unverified.

These unverified bus and firmwares I/F were verified in PFM system test.

With these series of tests, RMS S/W function/performance was verified.

-Arm Control Performance

SFA motor current off-set should be set zero before its operation and due to the residual current, pulsation of SFA tip is caused.

To evaluate its effect on SFA operation, pulsation was monitored precisely and effective current-off-set elimination procedure was analyzed.

The test was done as PFM system test using RMS Console, MA and SFA.

As a result, after the proposed SFA motor current-off-set elimination procedure, crew can operate SFA even with small tip pulsation. (Figure 3-3)

(3) I/F Verification

JEMRMS has various kinds of I/F.

Besides its internal I/Fs, JEMRMS has many I/Fs, with JEM other elements during JEMRMS robotic operation.

And JEMRMS has I/F with ISS regarding C&DH and C&T.

JEMRMS internal and JEM element I/Fs were verified at JEMRMS and JEM overall system test.

In order to verify ISS I/F, some joint tests were done.
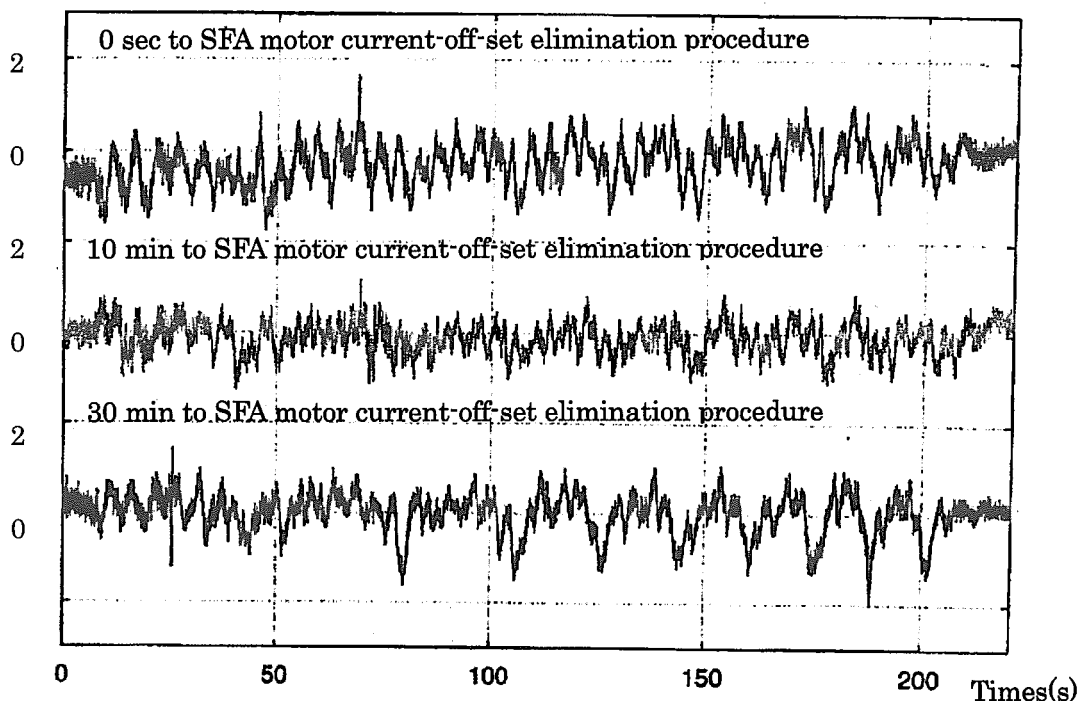
Transnational Pulsation (mm)

Figure 3-3 SFA Tip Pulsations

-C&DH Joint Test

JEMRMS main computer, Management Data Processor (MDP) has C&DH I/F with C&C MDM, ISS computer through JEM System Local Bus #2.

C&DH Joint Test has been done serially.

    #1A: protocol level check

    #2:   application S/W level check

#1A was done at NASA/JSC and #2 was done at TKSC.

The purpose of joint test is to confirm the communication function, so S/W fidelity is very important.

The test was done by connecting MDP/FEU with C&C MDM and flight-level S/W was installed MDP/FEU.(Figure 3-4)

With test results, C&DH I/F between JEMRMS/MDP and C&C MDM was verified.

-C&T Joint Test

JEM TV camera images are transferred to ISS/VSU and VSU distributes selected images to JEM.

C&T Joint Test was done at NASA/JSC and its purpose was to verify the transmission quality and synchronization of video signal.

Same as C&DH Joint Test, fidelity of test equipment is important.

TVM/FEU and TV Camera/PM were prepared as test equipment, and were connected to NASA ground equipment.

TVM/FEU and TV Camera/PM are equivalent with flight models regarding video signal processing.

C&T I/F between JEM and ISS was verified by this joint test.
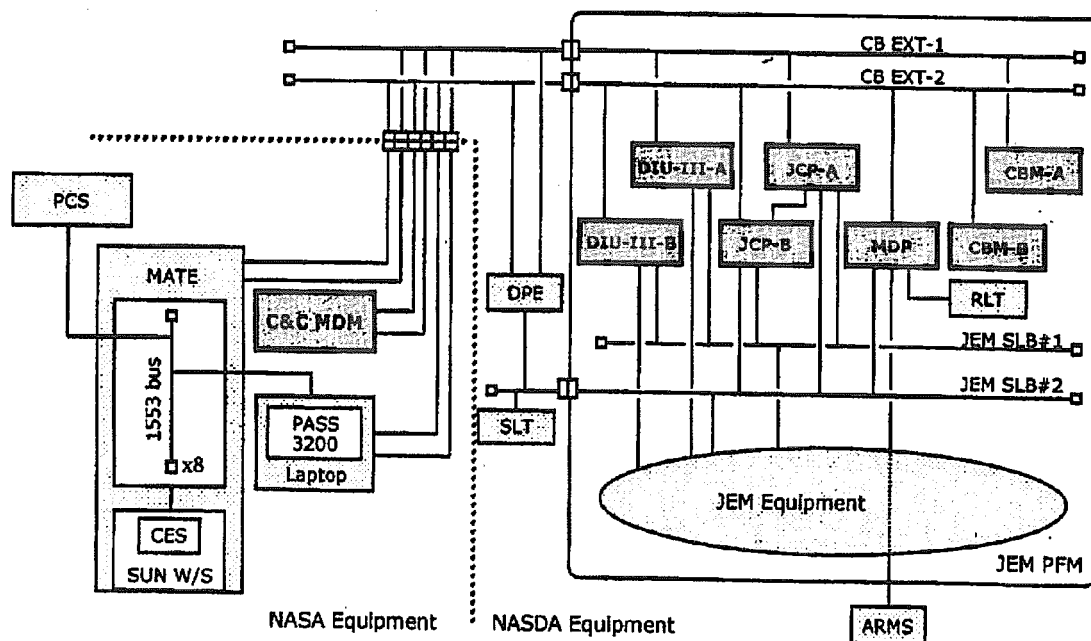
Figure 3-4 C&DH Test Configuration

(4) Operability Verification [1]

Crew via RMS Console operates JEMRMS and also maintain. For both activities, operability is essential.

To evaluate JEMRMS operability, several tests were performed and JEMRMS PFM was verified to carry out missions.

-GUI Evaluation

RLT is the key component for crew to interface with JEMRMS. RLT provides JEMRMS status and crew can send commands through RLT. So its GUI is very important for operability. (Figure3-5)

Even though RLT GUI was designed based on ISS GUI standards, RMS unique design was applied.
GUI evaluation was done for several times with NASA astronauts and their comments were feedback to GUI design.
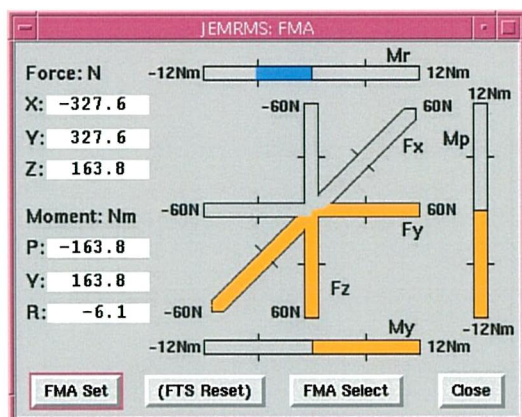
-Human-In-the-Loop (HIL) Test

To evaluate operability of JEMRMS, some NASA astronauts demonstrated MA and SFA mission standard scenarios with JEMRMS PFM.

Mission standard scenario is selected as to be the most typical scenario for MA and SFA mission. For MA, standard P/L exchange mission between EF and ELM-ES and for SFA, EF system ORU exchange mission between EF and ELM-ES is selected.

For HIL test, some procedures were modified due to the restriction of the ground test.

Crew evaluated each operation step by filling in evaluation sheet. and made comments for improvement of JEMRMS operability.

Almost all comments were feedback to JEMRMS.

Figure 3-5 GUI Sample

Figure 3-6 HIL Test

-FCIT

To demonstrate maintenance operation, crew did Flight Crew Interface test (FCIT) with some flight components.

The purpose of FCIT is to evaluate accessibility of each component.

To demonstrate this operation, crew did Flight Crew Interface test (FCIT) with some flight components.

-Recovery Procedure Demonstration

When some failure is detected, JEMRMS processes auto-safing procedure and let crew inform the failure by error message on RLT.

After the safing process, recovery procedure can be carried out.

Recovery Procedures were demonstrated as one of PFM level test and all error messages and recovery procedures were confirmed.

4. Conclusion

During JEMRMS development phase, some new verification process was applied to verify the uniqueness of JEMRMS, the first Japanese manned space robot.

With these new tests, PFM was verified to be ready to flight and now under flight integration process.

JEMRMS mission will start since 2007.

Reference

[1] Motohashi, "NASA Crew Evaluation of JEMRMS Operation Console", (in Japanese) 41st Ukaren, Oct. 1997.