

International R&M/Safety Cooperation Lessons Learned Between NASA and JAXA

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SUMMARY & CONCLUSIONS

Presented are a number of important experiences gained and lessons learned from the collaboration of the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA) on the CoNNeCT (Communications, Navigation, and Networking re-Configurable Testbed) project. Both space agencies worked on the CoNNeCT Project to design, assemble, test, integrate, and launch a communications testbed facility mounted onto the International Space Station (ISS) truss. At the 2012 RAMS, two papers about CoNNeCT were presented: one on Ground Support Equipment Reliability & System Safety, and the other one on combined application of System Safety & Reliability for the flight system. In addition to the logistics challenges present when two organizations are on the opposite side of the world, there is also a language barrier. The language barrier encompasses not only the different alphabet, it encompasses the social interactions; these were addressed by techniques presented in the paper. The differences in interpretation and application of Spaceflight Requirements will be discussed in this paper. Although many, but definitely not all, of JAXA's Spaceflight Requirements were inspired by NASA, there were significant and critically important differences in how they were interpreted and applied. This paper intends to summarize which practices worked and which did not for an international collaborative effort so that future missions may benefit from our experiences. The CoNNeCT flight system has been successfully assembled, integrated, tested, shipped, launched and installed on the ISS without incident. This demonstrates that the steps taken to facilitate international understanding, communication, and coordination were successful and warrant discussion as lessons learned.

1 INTRODUCTION

The NASA has developed an on-orbit, adaptable, Software Defined Radio (SDR) and Space Telecommunications Radio System (STRS). It is a test-bed facility on the International Space Station. The CoNNeCT Project's operational name for

the flight system is the Space Communications and Navigation (SCaN) Testbed. The SCaN Testbed payload was launched on the Hope Transfer Vehicle # 3 (HTV-III) vehicle on July 21st, 2012 and was installed on the Express Logistics Carrier (ELC) 3 at the P3 location on the International Space Station (ISS) two weeks later. Figure 1 shows the SCaN Testbed on the ELC 3 at the third port, P3, location on the ISS. The SCaN Testbed provides an adaptable SDR/ STRS based facility to conduct a suite of experiments to advance the SDR/STRS Standards, reduce risk by advancing the Technology Readiness Level (TRL) for spaceflight hardware and software, and demonstrate space communication links critical to future NASA missions.

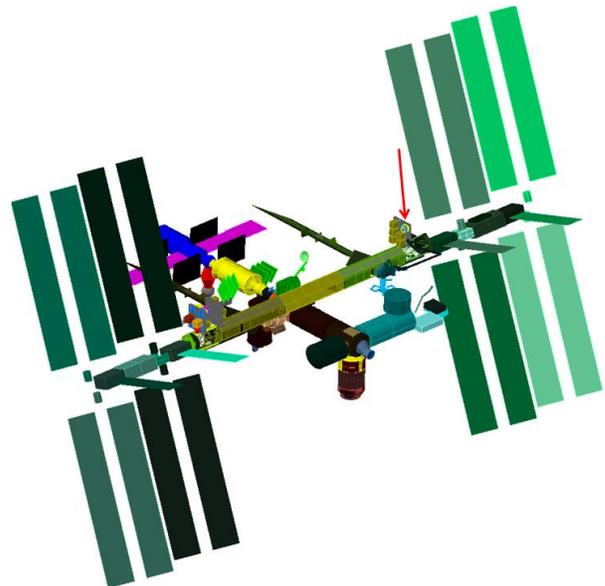


Figure 1: The SCaN Testbed on the ISS

Now that the payload has been turned over to JAXA, integrated on the launch vehicle, launched, and installed, this paper focuses on the "big picture" lessons learned. Previous papers at the RAMS 2012 Symposium went into more detail

on the specifics of both the flight payload design[1] and the ground support equipment[2]. Those papers go into more technical details whereas this paper is focused on the collaborations between the multiple NASA field centers and the multiple JAXA installations. For an overall view of the flight system, see Figure 2 which shows the SCaN Testbed/ExPA (ExPRESS Pallet Adapter), Radios and Infrastructure Components.

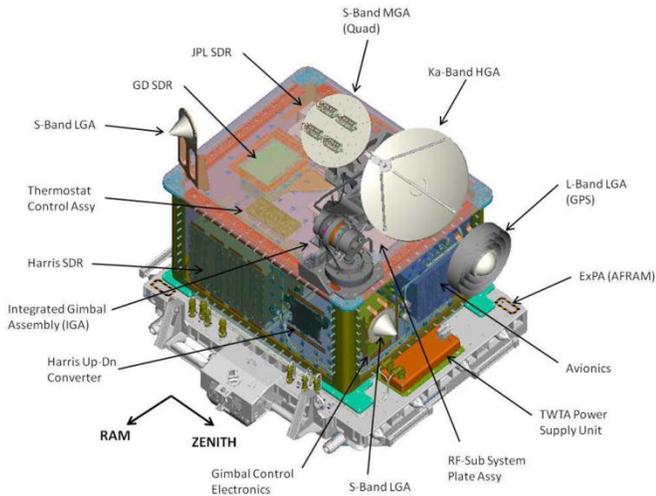


Figure 2: SCaN Testbed, ExPA, Radios and Infrastructure

2 UNIQUE CHALLENGES IN WORKING WITH JAXA

Because of the multi-center, multi-contractor, and multi-national nature of the design, assembly, integration, test, and launch of this spaceflight payload, many unique challenges had to be overcome. This paper focuses on the interactions of the multiple NASA centers, primarily the Glenn Research Center (GRC) and the Johnson Space Center (JSC), with the JAXA Tanegashima Space Center (TNSC) and Tsukuba Space Centers. Among the challenges were: differing languages, cultures, time zones, security, and communication formats.

2.1 Language and Written Communications

The most obvious challenge is the differences in the American and Japanese languages and alphabets. Whereas communications between the United States and French or Spanish speaking countries are eased by the shared basic Latin alphabet, the Japanese writing system uses three main scripts. These scripts are: kanji (Chinese characters), hiragana (for native words), and katakana (for foreign language, or loan words).

2.2 Cultural Differences

Americans tend to be more casual and informal than the Japanese. In Japan, interactions are more purposeful and tend to have a socially prescribed order. For example, the exchange of business cards has a specific etiquette that should be followed as well as how team members are seated at a conference room table. Depending upon the rank of the parties and the formality of the engagement, bowing at

greetings and departures may be deeper and longer.

Because of these cultural differences, there are opportunities for misunderstandings during technical meetings or problem resolution meetings.

2.3 Time Zones

Japan is approximately half of the way around the world from Cleveland Ohio and Japan Standard Time (JST) is 13 hours ahead of Cleveland Daylight Savings Time (EDST). When technical meetings and reviews are taking place in one country, the other is at rest. Simple phone calls must be planned and coordinated so that both parties are available. Furthermore weekends start earlier in Japan and of course end later for the US.

2.4 ITAR/EAR Restrictions

Because of the advanced technology employed in each of the 3 SDRs, they were treated as containing hardware that is specifically designed or can be modified as a “subsystem for a Spacecraft System or Associated Equipment article.” As such, the SDRs are designated by the State Department as being on the U.S. Munitions List (USML) XV (e & f), as defined in the International Traffic in Arms Regulations (ITAR), 22 CFR (Code of Federal Regulations) 120-130, and were export controlled. Having the flight payload classified as ITAR/EAR (Export Administration Regulations) caused extra precautions in handling not only the hardware but also the design and mission data associated with the hardware. Furthermore all written and verbal communications are controlled.

2.5 Communication Formats

While Japanese A size paper is identical to the International Standards Organization (ISO) A-series (with slightly different tolerances), the area of B-series paper is 1.5 times that of the corresponding A-paper, so the length ratio is approximately 1.22 times the length of the corresponding A-series paper. Documents, drawings, presentations, etc. are typically presented in format and size that does not match with what a US engineer has in their folders, notebooks, and file cabinets.

Furthermore, due to conflicting technologies, in most cases foreign phones will not work properly in Japan. For those phones that do function as they would back in the US, expect very high international usage fees. This becomes an issue when large parties visit Japan for technical meetings.

For the SCaN Testbed the most significant communications challenge encountered was the difference in interpretation and verification of spaceflight requirements. The following section of the paper is dedicated just to this topic.

3 INTERPRETATIONAL DIFFERENCES

The NASA SCaN Testbed team experienced the greatest challenges and thus opportunities for Lessons Learned when it worked on the interpretation of spaceflight requirements and their validation and verification with the JAXA team. The most interesting aspect to this is that many of the JAXA requirements have a NASA heritage but there were distinct

differences in how each agency interpreted them.

3.1 Project Requirements

Project or Mission Requirements were mostly handled through interactions between NASA Headquarters (HQ), NASA GRC, the Jet Propulsion Laboratory (JPL), and NASA JSC. JAXA was informed of mission requirements as necessary to enhance their understanding of the overall mission of the payload that they were launching. Similarly, NASA was only informed superficially about the other JAXA payloads that shared the same HTV flight. Both NASA and JAXA understood that requirements and verifications that were not directly tied to the Safety & Mission Assurance Requirements, namely in the Safety and Reliability areas, were secondary and did not have to be distributed without a need to know. Indeed, some of these requirements were restricted by proprietary and/or ITAR/EAR limitations.

3.2 Safety and Reliability Requirements

System safety requirements typically address all phases of the mission, from ground processing and launch through on-orbit operations and decommissioning/disposal. Since SCaN Testbed was not to be operated on the ISS Japanese module, the JAXA safety requirements were applicable only for the ground processing through HTV separation from the launch vehicle. The JAXA safety requirements for design and processing were derived from the NASA payload safety requirements. The same documents as required by NASA were also mandatory for JAXA (hazard reports, safety data packages), and in addition they required unique safety compliance matrices. While a Preliminary Hazard Analysis (PHA) is common method for developing the safety assessment within safety data packages for NASA, it is not required to be submitted to the safety panel. JAXA required completion and submittal of the PHA as part of the total safety deliverable.

With the exception of the ground processing at JAXA, reliability requirements were mostly tied to mission requirements and thus JAXA did not require direct submissions of reliability data related to flight. Where GRC's reliability analysis was invaluable was in its application to avoiding ground processing, integration, and turnover problems at TNSC. Many of the TNSC ground processing hazards identified, entailed control and verifications methods that relied on certification to standards such as NASA-STD-5005C, the NASA Ground Support Equipment (GSE) Standard[3]. The project's approach to certification to these best practices and standards required the generation of: System Block Diagrams (SBD), PHAs, and Failure Modes and Effects Analysis (FMEA). Many of these SBDs, PHAs, and FMEAs had been generated for the ground processing at GRC and were directly applicable to TNSC because the same exact GSE was used. In fact, TNSC-specific analysis was very limited because of the project's purposeful decision to use the same exact equipment to reduce variability. These hazard controls and verifications were submitted to JAXA for review and closure in SCaN Testbed's formal Hazard Reports. The

JAXA officials were satisfied with the project's approach and approved all Hazard Reports without delving into the specific details of the SBD, PHAs, and FMEAs. More specific details on the project's approach to reliability & system safety analysis, along with examples, are available in reference [2].

3.3 Methodology and Practices

With regard to safety processes, JAXA nominally has the same safety process as NASA and they are careful in following it. For example, when going through the NASA flight safety process, it has become acceptable for the NASA payload safety review panel to have the Phase III flight safety review months in advance of shipment to the launch site and for the project to come to the review with open action items. They are nominally closed to the safety verification tracking log and tracked to closure. JAXA does not operate in this manner for their ground/launch safety. They will not hold the Phase III ground /launch safety review until all verifications are closed with the exception of those to be closed at the launch facility.

From our experience at the ground/launch safety reviews, JAXA performs a significant amount of evaluation prior to the actual review, such that the reviews themselves are short and concise. Reviews took at most half a day to conduct, versus a comparable flight review taking 1.5 to 2 days. Ground/launch reviews are conducted in person or via WebEx/telecom. They do not hold reviews solely out-of-board, such as what is usually done by NASA.

JAXA has issued a summary presentation to explain what they expect for their safety process in addition to the guidance in their safety documents.

4 PROBLEM RESOLUTION

The challenges and issues stated above were addressed by multiple techniques. In reality, JAXA provided more contributions to addressing the language challenge than NASA did! Although a few members of the SCaN Testbed External Interfaces team learned the fundamentals of the Japanese language, the JAXA team was much more fluent in English than the NASA team was fluent in Japanese. Sticking points were handled by drawing pictures, pointing to drawings, or directing the JAXA team to NASA documents.

Potential problems that could be based on cultural difference were addressed by a series of courses developed by the External Interfaces team for those personnel that would be traveling to Japan for the various engineering, safety review and turnover meetings. These 1 to 2 hour courses were based on lessons learned from previous visits to Japan, and NASA Kennedy Space Center (KSC) experiences during the integration and turnover of two HTV-II On-orbit Replaceable Unit (ORU) payloads at the TNSC. These series of courses were very effective because the Safety Review and Ground Integration Teams did not commit any major cultural blunders nor suffered cultural shocks during their trips to Japan.

As expected, time zone differences were simply handled by either the SCaN Testbed team or the JAXA team shifting their work day to accommodate late teleconferences in their time

zone that synchronized with the work day on the other side of the world.

As the external communications Point of Contact (POC), the External Interfaces Team facilitated all communications & presentations between JAXA, NASA GRC and JSC. This allowed for consistent, focused and single-point-communications between the Project and JAXA. When project technical experts were required to interface with JAXA technical experts, this Team was involved in order to maintain continuity across all communications to both JAXA and the ISS Office.

The External Interfaces Team was successful in performing the integration function by anticipating issues before they materialized by proactively working with the ISS Office and International Partners (Russian Space Agency, JAXA, Canadian Space Agency and European Space Agency) to work developing problems.

The External Interfaces Team was integral in the development of all Safety Data Packages, the presentations to both JAXA and the ISS Safety Review Panels, and worked closely and early with the Extravehicular Activities (EVA) and the ISS and JAXA Extravehicular Robotics (EVR) Teams avoiding any problems with these critical functions.

The relationships developed by the External Interfaces Team with key personnel at JAXA, KSC and ISS Office were critical in the success of the SCaN Testbed integration. The HTV exposed pallet was in co-development with the SCaN Testbed resulting in numerous discoveries in the analytical integration of the payload. This Team provided insight and forewarning into the imminent changes to carrier requirements, capabilities and limitations saving project resources in rework and potential unrecoverable interface problems. Furthermore they were able to negotiate non-standard services and hardware with JAXA, KSC and the ISS Office.

The SCaN Testbed was the first Flight Releasable Adaptor Mechanism (FRAM) based payload to be integrated and launched at TNSC resulting in numerous discoveries throughout the physical and analytical integration. It was necessary to identify, obtain and provide at the launch site all required FRAM handling and critical lift equipment, procedures and required training to safely and efficiently integrate the SCaN Testbed. Among the problems resolved were:

1. JAXA processes that were often not defined or unclear (e.g. safety, interface control, request for services)
2. The physical and environmental boundary between the SCaN Testbed, FRAM, Passive FRAM and HTV's cargo carrier platform
3. Roles and responsibilities between JAXA, ISS Offices and the NASA GRC
4. Communications between JAXA, ISS Offices and NASA GRC.

Numerous logistical problems were resolved: because the

cost to ship hardware to Japan is exorbitant, the team negotiated leaving all FRAM lift hardware at the launch site for future FRAM-based payloads and ORUs thus eliminating the need for any payload / ORU to ship lifting/handling hardware; installation and inspection procedures were developed and coordinated and provided to the ISS Office for future use; and the shipping container base was the payload work-stand, eliminating the need to ship a FRAM-based stand or performing unnecessary critical lifts of the SCaN Testbed.

As the POC for all data transfers to JAXA, the Export License, packaging, shipment, Japanese Customs, inspections, un-packaging, ground handling, ground processing, turn-over, integration to the Exposed multipurpose Pallet, training and travel logistics for 15 travelers was managed by the External Interfaces Team. The documentation that accompanied each of these activities has been shared with the ISS for future use.

International telephone service was addressed by pre-coordinating which team members were bringing their work cell phones, finding out if their phones worked in Japan, and if so, activating international service on those phones just for the travel period. Very few team members brought their personal phones with them; a high percentage of those that did experienced erratic phone behavior.

During the 4 weeks of work in testing and preparing the payload for turnover at the TNSC site, the Ground Processing Team developed a successful work tempo to each work day. First, an early morning coordination meeting was held for the Team at the hotel where all the members were collocated. After arrival at the TNSC site, issues and problems were addressed directly between the SCaN Testbed's JAXA Test Manager, and the JAXA's NASA Interface lead, while both Agencies continued their respective work. Work was never called to a stop to address an issue/problem that required a large team wide meeting. Work was stopped, however, multiple times for lightning warnings in which case the entire facility had to be cleared for safety reasons. Figure 3 shows the NASA (right side of the picture) and JAXA (left side of the picture) Ground Processing Teams after the successful installation of the SCaN Testbed onto the HTV's cargo carrier platform.



Figure 3: SCaN Testbed Ground Processing Teams

5 LESSONS LEARNED

Although the intent of this paper is to pass on Lessons Learned to future international collaborative spaceflight missions, the CoNNeCT Project benefitted from the adoption of previous Lessons Learned. By observing the HTV-II ground processing, the External Interfaces Team conceived of a method to move the SCaN Testbed and Ground Support Equipment without assistance from JAXA eliminating significant coordination and ground-processing time. The inclusion of an HTV-IV Team member from KSC to observe and learn lessons from the SCaN Testbed's ground processing at TNSC will increase the likely success of HTV-IV because the HTV-IV Team will adopt the SCaN Testbed's methodology for the integration and ground processing of one payload and two ORUs.

A series of Lessons Learned Workshops were held post turnover at the NASA GRC. These Workshops included inputs from all the NASA Field Centers involved with the SCaN Testbed.

From the inception of the Ground/Launch safety process, there was misinterpretation of what data was needed (which forms to be completed) for the Phase 0-I-II ground/launch safety review. Previous safety and reliability experience regarding flying hardware on HTV was, in retrospect, irrelevant, and lead to the provision of incomplete or missing data to JAXA. This caused confusion for JAXA and resulted in extra pressure for the whole team when attending the safety review in Japan. The lack of a direct interface to a JAXA safety and reliability counterpart to be able clarify requirements exacerbated this situation. The SCaN Testbed safety engineers were used to informal communication channels where they could call or e-mail someone on the NASA safety panel for information. Lesson Learned: It is important to have a clearly understood communication channel/process to allow for resolution of questions and issues prior to the JAXA safety reviews.

Communication with JAXA is primarily through protocols and action items. As part of the learning process in working with JAXA, the team learned it needed to be clear in the agreements and understanding of what will be done by both parties (NASA and JAXA). JAXA requires this level of clarification. Lesson Learned: When working with JAXA, if agreements in work responsibilities or understanding of positions on topics is not captured in the protocols and action items, there can be confusion in what is expected to be completed (and when).

SCaN Testbed also benefitted through the utilization of a well-defined verification and validation (V&V) process. Throughout the payload development after the Critical Design Review (CDR)/Phase II safety review, there were numerous verifications to be addressed – engineering, safety, program, carrier(s). Having a well-defined process was good for the work with JAXA, since they would not hold the Phase III ground/launch safety review without the required verifications completed. Lesson Learned: Having a defined verification and validation process made completion of processing all the

verification requirements possible. But it was important that all parties that needed to weigh-in on the verifications were part of the process, otherwise the verifications had to be revisited and possibly redone.

As mentioned in the Reliability Requirements section above, having a thorough, well documented, and configuration controlled set of reliability analysis is invaluable for avoiding “near misses” from a safety, reliability, and programmatic viewpoint. Although initially generated to satisfy NASA and project Reliability and Maintainability (R&M), and Safety Requirements, the SBD, PHA, and FMEA dataset was used later to satisfy JAXA R&M, and Safety ground processing requirements.



Figure 4: Successful launch on H-IIB from TNSC

Having stated the issues, problems, and lessons learned on this international collaborative effort, the most important fact to note is that the final result was a successful launch and installation on the ISS. Figure 4 shows the successful launch of the SCaN Testbed on the HTV-III carrier atop the H-IIB launch vehicle.

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Dwayne Kiefer supported the launch of 15 payloads into space providing expertise in safety, systems engineering, integration, and project management. He joined NASA as a student at the Case Western Reserve University Center for Commercial Development of Space in 1989. He transferred as a contractor to the NASA Glenn Research Center in 1992 and has supported numerous science research projects including several Microgravity Aircraft campaigns.