EMCS – Operation of an ESA Payload in a NASA Rack

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The European Modular Cultivation System (EMCS) was launched to the International Space Station (ISS) in 2006. Originally it was installed in the EXPRESS Rack 3 located in the US Laboratory "Destiny" but in 2008 the rack was moved to the ESA "Columbus" Laboratory. The Norwegian User Support and Operations Centre (N-USOC) is the Facility Responsible Centre for the EMCS.

The EMCS is an ESA payload in a NASA EXPRESS Rack, hence the EMCS Operators interact with both the NASA Payload Operations Integration Center (POIC) in Huntsville and the Columbus Control Centre (Col-CC) in Oberpfaffenhofen. The communication flow depends on whether the experiment running in the EMCS is an European or American experiment. In addition to the two control centers, the operator must interact with ESA, the science team, engineering support and NASA Ames Research Center (if U.S. experiment) or other industry teams responsible for the Experiment Unique Equipment (EUE) developed for the specific experiment. In this paper the complex EMCS operation scenario will be described and challenges and lessons learned will be discussed.

I. Introduction

IN 2006 the ESA-developed payload European Modular Cultivation System (EMCS) was launched and installed onboard the International Space Station (ISS). Originally it was installed in EXPRESS Rack 3 in the US laboratory "Destiny", but in 2008 the rack was moved to the ESA "Columbus" Laboratory. The EMCS is a multi-user cultivation facility that supports biology experiments. Up to present seven plant experiments have been performed in the EMCS onboard the ISS, and five more plant experiments are planned to be executed.

The Norwegian User Support and Operations Centre (N-USOC) is nominated by ESA as the Facility Responsible Centre for the EMCS. N-USOC is an important contributor during planning, development, integration and execution of the different experiments that utilize the EMCS. There are nine User Support and Operations Centres (USOCs) located across Europe. Under the overall management of ESA the USOCs are carrying out the majority of tasks related to preparation and in-flight operations of different multi-user facilities. N-USOC is a part of the Centre for Interdisciplinary Research in Space (CIRiS) at NTNU Samfunnsforskning AS, in Trondheim, Norway.

This paper will describe the complex operation scenario when conducting experiments in the EMCS, an ESA payload integrated in a NASA rack in Columbus. The responsibilities of the different parties N-USOC interact with during operations will be described and lessons learned will be presented.

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II. EMCS Operations – Responsibility sharing between NASA and ESA

The EMCS is a multi-user cultivation facility that supports biology experiments. The cultivation system has so far been used for experiments with plants, but can also be used for small animals, microorganisms and cell cultures. The EMCS is monitored and fully controlled from ground via telecommanding and by preprogrammed scripts. Crew support is only needed for activities like experiment preparation, Experiment Container (EC) insertion/removal, disassembly of experiment hardware and maintenance activities between experiments. The EMCS on orbit is shown in Figure 1.

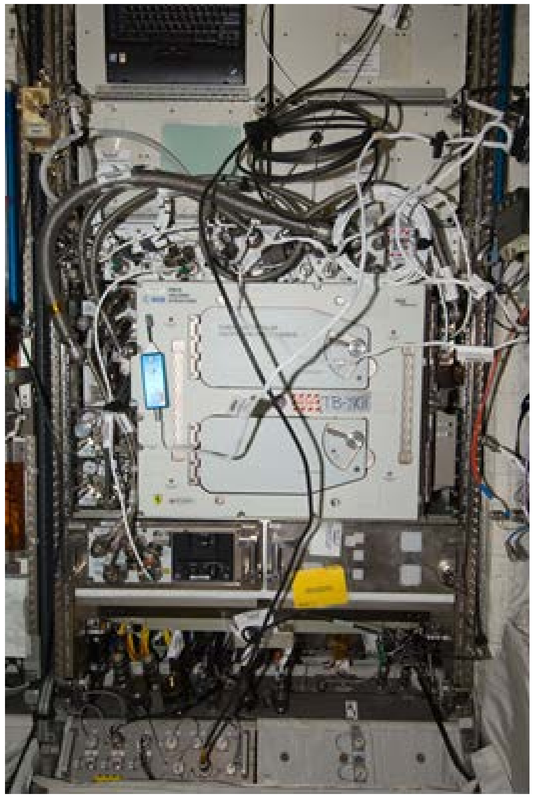

Figure 1. EMCS on orbit, integrated into EXPRESS Rack 3 inside the Columbus module.

The EMCS is owned by ESA and integrated in EXPRESS Rack 3, owned by NASA. The various roles and responsibilities, interfaces, and hardware/software/data exchanges between ESA and NASA are identified and described in several documents [2, 3, 4, 5]. ESA and NASA has agreed to accommodation of one (1) ESA and one (1) NASA experiment in the EMCS facility each calendar year on average, depending on availability of projected resources. It is also decided that any experiment that uses the EMCS shall have an Experiment specific Payload Integration Agreement (PIA), jointly developed between ESA and NASA. A selection of the most important responsibility sharing tasks impacting operations, agreed upon by ESA and NASA, are outlined in Table 1.

Table 1. The most important responsibility sharing impacting operations, agreed upon by ESA and NASA[2].

Responsibilities	NASA	ESA
Provide consumables and experiment-specific hardware	Responsible for NASA EMCS experiments	Responsible for ESA EMCS experiments
Planning, scheduling, implementation and coordination of ISS payload crew training	Perform	Participate
Provide utilization resources, including crew time, upmass and downmass, resources required to perform experiment specific setup, teardown and cleanup tasks	Responsible for NASA EMCS experiments	Responsible for ESA EMCS experiments
Provide operations integration, integrate operational planning, process operational products and provide POIC Cadre support	Responsible for both ESA and NASA experiments	Support for both ESA and NASA experiments
Provide stowage for experiment-specific items	Responsible for NASA EMCS experiments	Responsible for ESA EMCS experiments
Provide maintenance and sustaining engineering for the EXPRESS Rack 3 facility	Responsible	-
Provide corrective maintenance and sustaining engineering for EMCS	-	Responsible
Provide the preparations and conduct of EMCS Experiment operations, and maintain the operational interfaces to the POIC Cadre	-	Responsible, performed by N-USOC
EMCS sub-rack real-time operations and anomaly resolution	-	Responsible, via N-USOC
Real-time rack level operations and anomaly resolution	Responsible (POIC)	-

III. EMCS Ground Segment and Organization of the involved centres

During execution of an experiment in the EMCS, the N-USOC console is manned 24 hours, 7 days a week. The main operational interfaces for N-USOC is the NASA Payload Operations and Integration Center (POIC) and the ESA Columbus Control Centre (Col-CC). Figure 2 shows a flow scheme of the communication between the N-USOC, the NASA and ESA operation centres and the ISS.

The Lyndon B. Johnson Space Center (JSC)

The Lyndon B. Johnson Space Center (JSC), located in Houston, Texas, is the NASA centre responsible for astronaut training, systems and flight control. One of the major roles of JSC is the Mission Control Center (MCC-H), which coordinates and monitors all human spaceflight for the United States. N-USOC has no direct link to MCC-H.

NASA Payload Operations and Integration Center (POIC)

The NASA (POIC) is part of the Huntsville Operations Support Center (HOSC), located in Huntsville, Alabama. POIC is the headquarter for science and payload operations accommodated in the NASA EXPRESS Racks. The EMCS is located in EXPRESS Rack 3, thus POIC act as the support centre for EMCS operations. Telecommands and telemetry to and from the EMCS are made possible to N-USOC over the internet, via VPN and TReK

(Telescience Resource Kit). The main positions N-USOC have direct or indirect interface towards at POIC during experiment conduct are:

- Payload Operations Director (POD)
- Payload Rack Officer (PRO)
- Operations Controller (OC)
- Timeline Change Officer (TCO)
- Data Management Controller (DMC)
- Payload Communications Manager (PAYCOM)

In addition to these the N-USOC console position monitors several other loops for awareness.

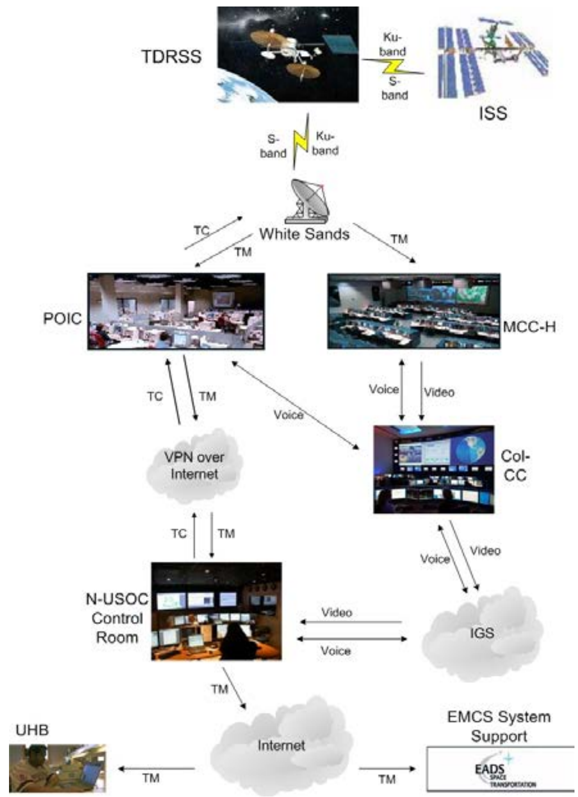

Figure 2. A flow scheme of the communication between N-USOC and ISS, TM: Telemetry, TC: Telecommands.

Columbus Control Centre (Col-CC)

All USOCs are connected to the Columbus Control Centre (Col-CC), which is the mission control centre for the European Columbus module on the ISS. Col-CC is a DLR facility located in Oberpfaffenhofen, Germany. Voice communication and real-time video are provided to N-USOC from Col-CC via the Interconnection Ground Subnetwork (IGS). The USOCs are responsible of the payload operations and Col-CC is responsible for the Columbus module on system level as well as coordination of all the European operations on payload and system level. The Col-CC positions N-USOC has interface, directly or indirectly, towards during EMCS experiment conduction are:

- Columbus Flight Director (Col FD)
- Columbus Operations Coordinator (Col OC)
- German Space Operations Centre Ground Controller (GSOC GC)
- Columbus Stowage and Maintenance Officer (COSMO)
- European Communicator (EUROCOM)

EMCS Engineering Support

During operations the N-USOC has engineering support by the EMCS Industrial Operation Team (IOT) at EADS Astrium. EADS Astrium provides EMCS hardware and software support from their industry site in Friedrichshafen, Germany. N-USOC forwards the EMCS telemetry to EADS Astrium via secure internet connection, which allows them to monitor EMCS telemetry real-time.

EMCS Users Home Base (UHB)

The user – a scientific group or an industrial partner – which performs an EMCS experiment may be connected to N-USOC so science telemetry is forwarded to their home base and they are able to monitor the experiment real-time. For NASA provided EMCS experiments NASA Ames Research Center receive real-time telemetry and also have a console position which is manned during phases of the experiment which are especially critical regarding science.

IV. EMCS Operations

A. Operation of a NASA Experiment in the EMCS

The operation of NASA-provided experiments performed in the EMCS is based on agreements between ESA and NASA, as described in Chapter II. These agreements define the role of each team during integration and realtime operations. NASA ARC Life Science Division has been defined as the overall responsible for the American experiments performed in the EMCS. They manage all technical aspects of the EUE building, science and planning activities. N-USOC is responsible for the EMCS facility during experiment planning, ground testing and real-time operations, with engineering support from EADS Astrium. N-USOC is also available for reviewing NASA products if necessary.

During real-time operations NASA ARC receives telemetry from EMCS and participates in the on-orbit operations from their console. NASA ARC is the main responsible for the specific American experiment. To illustrate the operation of NASA experiments in the EMCS, the Plant Signaling experiment performed in July 2011 will be used as an example.

During Plant Signaling realtime operations NASA ARC (call sign: Plant Signaling) was on console during Plant Signaling crew activities and during critical stages of the experiment, like watering and plant growth check points. The Principal Investigator (PI) was following the experiment at ARC premises and was thus able to support and be involved in any decisions affecting science. N-USOC (call sign: EMCS Ops) was on console 24/7 during the whole experiment.

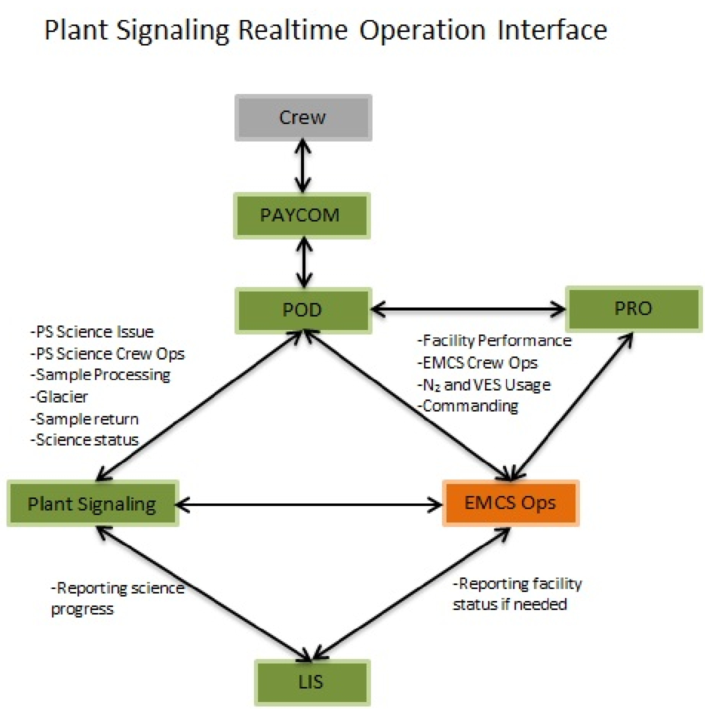

Figure 3. Plant Signaling communication flow during realtime operation. The green boxes illustrate NASA positions, all located at POIC, except for Plant Signaling located at NASA ARC. The orange box represents the N-USOC team and the grey box the crew member assigned for the Plant Signaling experiment.

Figure 3 outlines the real-time communication interfaces between the centres involved in the Plant Signaling operations. The Plant Signaling team answered any questions regarding science and supported the Plant Signaling crew operations, like sample processing and transport of samples to cold stowage. They were also responsible for the sample return process from ISS to ground. The EMCS Ops position monitored and controlled the EMCS facility, with engineering support from EADS Astrium. EMCS Ops was also responsible for the EMCS specific crew operations and for all coordination with the POIC ops positions, POD and PRO, regarding commanding, nitrogen and vacuum usage. In addition to that both teams had to report science status and progress, and facility status to the Lead Increment Scientist (LIS).

B. Operation of an ESA Experiment in the EMCS

As for the operation of NASA experiments, operation of ESA experiments in the EMCS is based on agreements between ESA and NASA. In the following section the operations scenario for the ESA-provided EMCS experiment Genara A will be described. Genara A was successfully performed on the ISS in July 2010. For Genara A operations an Experiment specific Payload Integration Agreement (PIA)[6] was developed. The PIA described the deviations from the Standard Integration Agreement (SPIA) and the unique agreements coordinated between the International Space Station Program (ISSP) and ESA. The unique agreements developed for Genara A are listed below:

- **Operations**: ESA was the responsible for integration and operations external to the EMCS facility. NASA was responsible for integration and operations within the EMCS facility as well as the EMCS facility within EXPRESS Rack 3.
- **Stowage**: NASA provided cold stowage assistance during sample transport to Earth. NASA Cold stowage team transported the sample from the descent shuttle to the Kennedy Space Centre. ESA transported the samples from KSC to the final destination in Europe.
- **Working Space on-board**: NASA provided MWA (Maintenance Work Area) engineering data and drawings for safety and training.

For EMCS experiments the N-USOC operators with the prime interface towards POIC (call sign: EMCS Ops) are on console 24/7 during the whole experiment. For Genara A operations N-USOC had interfaces both towards the POIC and towards the Col-CC. The interface towards Col-CC was provided by operators working for another ESA payload (Vessel ID System). The operators with interface towards Col-CC (call sign: N-USOC Ops) were on console during normal office hours and for Genara A specific crew activities that required interaction with Col-CC. Both EMCS Ops and N-USOC Ops were located in the same room and consolidated all information before responding on the loops.

Figure 4 illustrates the communication flow between the different centres during the Genara A realtime operations. The NASA POIC team was the overall responsible for the EMCS and Express Rack 3 activities, marked green in figure 4. EMCS Ops coordinated all EMCS activities with the POIC positions POD and PRO. All crew questions regarding insertion/removal from the EMCS, EXPRESS Rack 3, crew laptop and MELFI were directed to the POIC team at Huntsville, as seen on the left side in the figure. The POIC team was also responsible for MELFI, the freezer used as cold stowage for the Genara Samples.

The Col-CC team was the overall responsible for the experiment Genara A, marked blue in figure 4. N-USOC Ops coordinated all Genara A specific activities outside of the EMCS with the Col-CC position Col-OC, and stowage of the Genara A hardware was coordinated with COSMO. All crew questions related to the experiment specific Genara A activities were directed to the Col-CC team at Oberpfaffenhofen, as seen on the right side in figure 4. Since the EXPRESS Rack 3 is located in the Columbus module, collaboration between other positions within the POIC team and the Col-CC team was also required. Col-OC and PRO worked together to provide Columbus resources to the EXPRESS Rack 3 like venting, vacuum and nitrogen during the Genara A operations.

During planning of the Genara A operations it was recognized that the operation scenario was complex and that the complexity also affected the crew activities. In order to help the crew to understand the organization and avoid any misunderstanding or confusion during the experiment operations, an explanation chart was created and provided to the crew members assigned for the experiment. Figure 5 shows the information that was provided to the crew. It was meant to illustrate which centre was responsible for what part of the experiment and which questions should be directed to either the POIC or to the Col-CC.

In addition to the communication on the loops with the two operation centres, EMCS Ops and N-USOC Ops also interacted with the Principal Investigator (PI), the EMCS engineering team, ESA Mission Science Office (MSO) and ESA Payload Operations Manager offline.

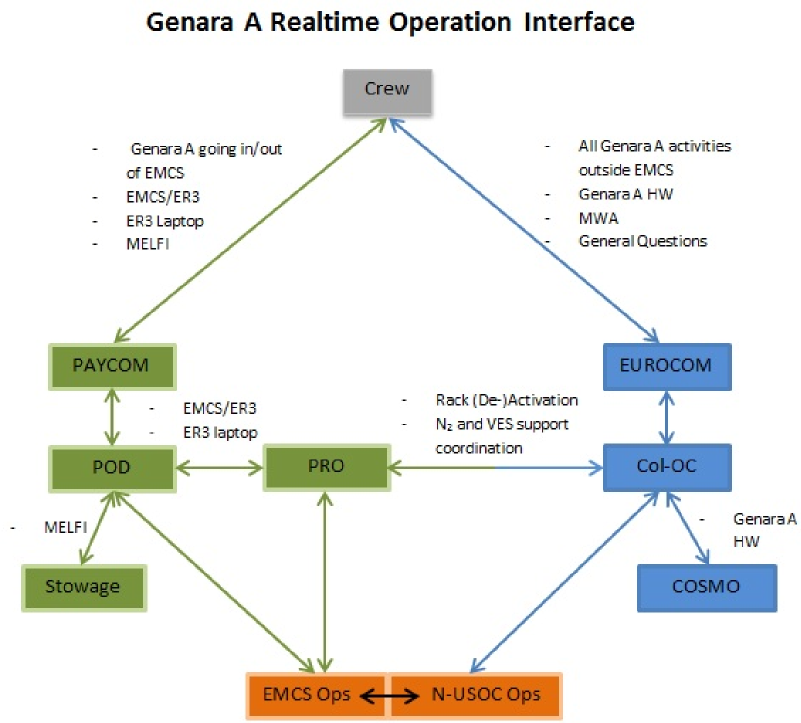

Figure 4. Genara A realtime operations interface. The green boxes show the positions that EMCS Ops interacted with at NASA POIC located in Huntsville. The blue boxes show the positions that N-USOC ops interacted with at Col-CC. The orange boxes show the two positions located at N-USOC in Trondheim. The grey box illustrates the crew on the ISS.

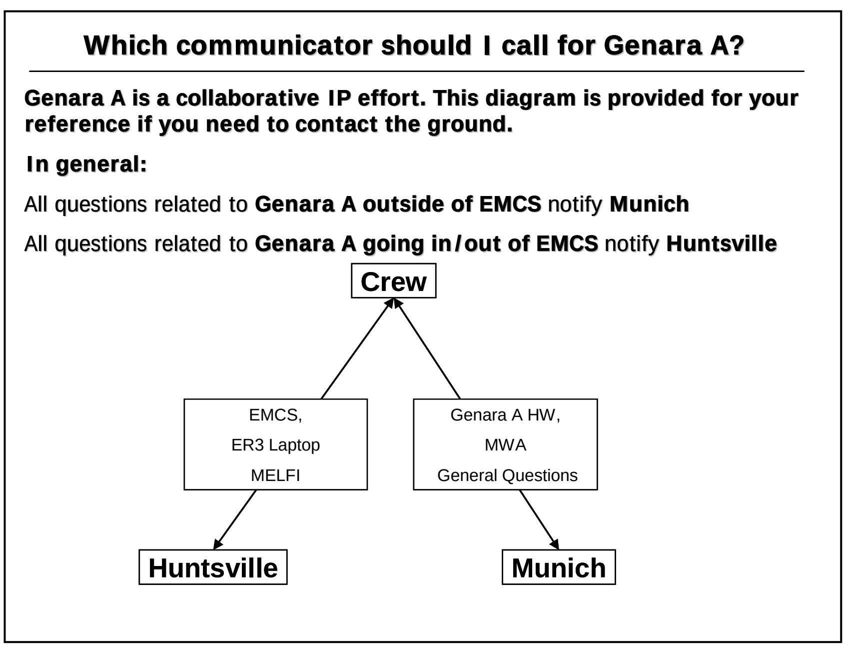

Figure 5. The chart provided to the crew to illustrate which questions should be directed to the POIC or the Col-CC

V. Challenges and Lessons Learned

Before realtime operations start, a lot of time and resources have been spent on planning. What so many people have waited for and prepared for is finally happening, and you only have one go. It is essential for successful operations that the planning has been thorough, that every step of the operation has been thought through and that all possible scenarios are prepared for. Although it is impossible to foresee and prepare for every single thing that can happen, it is possible to be prepared for unexpected events and know what to do and who to contact when changes or anomalies occur. In order to achieve a well prepared operations team it is crucial that the experience gained from previous operations are actively used when preparing for the next experiment. That means to prioritize spending time after each operation to thorough evaluate all aspects of the performance.

One of the main challenges for EMCS operations has been to create a whole team awareness and understanding of the responsibility sharing agreements for each specific experiment. The execution of EMCS experiments usually takes place only once or twice a year, thus it can be challenging to maintain the skills and knowledge of the operators and centres involved.

The Plant Signaling experiment was the third American experiment executed in the EMCS in cooperation with the NASA Ames Research Center, utilizing the same Experiment unique equipment (EUE). As all the involved parties had gained a lot of experience since the first American experiment in 2006, the planning and execution of the Plant Signaling experiment was very efficiently performed. One lesson was learned from the second American experiment, Tropi2, conducted in February 2010. The POIC team was then not fully aware of the different responsibilities the N-USOC team and the ARC team had. Questions about science or planning were often directed to the EMCS Ops position and it was not clear that the ARC team was not on console 24/7. This was recognized during the evaluation after the experiment execution, and the information to the POIC team was improved before the next experiment. As a result the communication during Plant Signaling operations went very smooth, the correct teams were approach as issues arose and all teams cooperated very well.

The responsibility sharing also affected the crew operations. At the end of the experiment run the crew was to remove the Experiment Chambers (EC) from the EMCS, do sample processing and insert the samples into cold stowage. EMCS Ops were responsible for the crew procedure regarding EC removal, ARC was responsible for the crew procedure regarding sample processing and the cold stowage team for the cold stowage insertion. After performing these procedures, the ISS crew gave feedback that from their point of view the whole sequence of steps could have been outlined in one single procedure, since all activities were time critical and linked together. Crew feedback is very valuable for the ground teams to improve operation products, the crew opinion will be taken into consideration when planning of the next experiment. For the crew and the operations they perform, it might be an improvement if the procedures and the whole ground community stands out like one unified team, working towards the same goal.

Although having both the ARC team and the N-USOC team on console during experiment execution makes the operation environment more complex, the two teams together have a greater knowledge and expertise than only one centre would have.

The ESA experiment Genara A, executed in July 2010, had an even more complex realtime operations structure (as described in Chapter III, B). An Experiment specific Payload Integration Agreement (PIA) was developed, where the roles and responsibilities of the parties involved were defined. The PIA was an important contribution as a basis for the planning phase and for recognizing how complex the experiment planning and execution would be, early in the process. Thus an important part of the experiment planning was communicating to all involved parties the guidelines for the communication flow, and explaining the roles and responsibilities for everyone involved. This also included the crew on ISS. As described in chapter III, a chart was sent to the crew before experiment execution, where the communication flow and responsibilities during the Genara A realtime operations where visualized. The chart was believed to be efficient, as after several crew calls during realtime all of them were directed to the correct centre.

Even though planning and agreements for all steps had been made, it was discovered that the realtime planning and re-planning that often occurs during operations, were not clearly agreed on in advance. At one point when realtime re-planning had to be performed, there was confusion regarding whether the Col-CC position Col-OC or the POIC position OC was responsible for it. Fortunately, the professional teams at the POIC and the Col-CC were able to discuss and make proper decisions realtime.

On N-USOC side during Genara A, there was a challenge having operational interfaces both towards the POIC and towards the Col-CC. Usually, for EMCS experiments the N-USOC operators with the prime interface towards POIC (call sign: EMCS Ops) are on console 24/7 during the whole experiment. Operators working with Col-CC must be certified by ESA through a dedicated training and certification process provided by ESA. At N-USOC there were only a few operators certified for working with Col-CC for another ESA payload (Vessel ID System). These operators (call sign: N-USOC Ops) were on console during office hours. For Genara A it was decided that the N-USOC Ops also had to be the interface towards Col-CC for the EMCS experiment Genara A. It was important that both the EMCS Ops and the N-USOC Ops were located in the same room and had the possibility to consolidate all information before responding on the loops. Although this was a new configuration for N-USOC the operators successfully adapted to the situation. In the end the expertise on the Col-CC side regarding the Genara A experiment, combined with the experienced POIC and N-USOC teams regarding EMCS operations, led to successfully performed Genara A realtime operations.

In general the EMCS operations have been considerably streamlined during the past years. From the start of the EMCS operations in 2006 the N-USOC team has gained more experience, both with the payload, the groups involved and the work processes related to operations on the ISS. Communication with the other centres and mutual awareness has improved. It is recognized that all the different parties involved in operations are important for the overall success of the experiments. Every team involved is expert in their field and contribute to the best possible results from the research done on the ISS. EMCS operations, either with an American or European experiment, are complex. The operators must have thorough knowledge about realtime communication interfaces, experiment specific equipment and experiment science, as well as be familiar with the technical aspects of the EMCS. Even though good support is provided from other teams it is important that the N-USOC operator has a good general understanding of each of these areas to improve responsiveness and make operations more dynamic. To maintain and improve the high standard of the EMCS operations, the N-USOC team emphasizes working with lessons learned, dedicated operators training, simulations and the creation of “what if scenarios” before each experiment.

VI. Conclusion

Operation of an EMCS experiment on the ISS involves responsibility sharing and communication between many different parties. This is illustrated by two experiments: The NASA experiment Plant Signaling and the ESA experiment Genara A.

Plant Signaling was the third American experiment performed in the EMCS in cooperation with the NASA Ames Research Center. The fruitful collaboration and the experience after performing several similar experiments together have led to a very efficient and streamlined experiment execution.

The European Genara A experiment had many teams involved and N-USOC had to adjust their operations concept to accommodate to the Genara A interface requirements. This was the first time EMCS experiment execution involved both the NASA Payload Operations Integration Center (POIC) and the Columbus Control Centre (Col-CC) simultaneously. It was a challenging process for all parties involved, but good collaboration between ESA and NASA on all levels led to successfully performed operations.

The N-USOC team contributes to the international cooperation and utilization of the EMCS by having professional and well prepared staff on console and continuously working to improve performance during both the planning and the operations phase.

The EMCS is an ESA payload, located in a NASA rack in Columbus. Consequently, EMCS Operators interact with both the POIC and the Col-CC. An important lesson learned is that the involvement of many different parties in operations is valuable and ensures that the expertise in all applicable fields is represented. Many different teams and centres make up a highly complex operations environment, and successfully performed operations are dependent on detailed planning, preparation and good communication flow between all parties involved.

Appendix A

Acronym List

ARC	Ames Research Center
CIRiS	Center for Interdisciplinary Research in Space
Col-CC	Columbus Control Centre
Col-OC	Columbus Operations Coordinator
COSMO	Columbus Stowage and Maintenance Officer
DMC	Data Management Controller
EADS	European Aeronautic Defence & Space Company
EC	Experiment Container
EMCS	European Modular Cultivation Module
ER3	Express Rack 3
ESA	European Space Agency
EUE	Experiment Unique Equipment
EUROCOM	European Communicator
GENARA	Gravity Related Genes in *Arabidopsis*
GPOC	Generic Payload Operations Concept
GSOC GC	German Space Operations Centre Ground Controller
HW	Hardware
ICD	Integration Control Document
IGS	Interconnection Ground Subnetwork
IOT	Industrial Operations Team
ISS	International Space Station
JIP	Joint Installation Plan
JSC	Johnson Space Center
LIS	Lead Increment Science
MCC-H	Mission Control Center – Houston
MELFI	Minus Eighty degrees Laboratory Freezer for ISS
MSO	Mission Science Office
MWA	Maintenance Work Area
NASA	National Aeronautics and Space Administration
NTNU	Norwegian University of Science and Technology
N-USOC	Norwegian User Support and Operations Center
PAYCOM	Payload Communications Manager
PI	Principal Investigator
PIA	Payload Integration Agreement
POD	Payload Operations Director
POIC	Payload Operations and Integration Center
PRO	Payload Rack Officer
SPIA	Standard Payload Integration Agreement
TC	Telecommands
TCO	Timeline Change Officer
TDRSS	Tracking Data Rely Satellites System
TReK	Telescience Resources Kit
TM	Telemetry
UHB	Users Home Based
VPN	Virtual Private Network

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