Providing initial payload and science capabilities in the Columbus Module

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After the first few weeks of operations of the European module "Columbus" which was attached to the International Space Station (ISS), first experience with the distributed payload operations concept was gained. The functional interfaces between Columbus and the payloads are described as well as the operational interfaces between the Columbus control center in Oberpfaffenhofen and the payload control centers spread out all over Europe.

I. Introduction

IN February 2008 the Space Shuttle "Atlantis" delivered one of the European contributions [1] to the ISS program, the module "Columbus" to the International Space Station. During the STS-122 (1E) mission the module was attached to "Node 2" on its starboard side and the first activation of all system components was performed. In parallel the crew started the first outfitting tasks for the four European payload racks, which required extensive and crew time intense mechanical setup activities to remove launch fixations, to install further hardware components and to support ground checkout and commissioning. Also relocation was required for most of the racks, since the launch position inside the Columbus module had to be different from the on-orbit configuration due to Space Shuttle center-of-gravity considerations. After the relocation, the payload racks were physically mated to the Columbus Systems which provide power, cooling, gaseous nitrogen, vacuum, venting, and data interfaces.

An EVA performed during 1E was necessary to install the two Columbus External payloads which were launched on a dedicated carrier inside the Space Shuttle cargo bay. Thermal considerations required an immediate activation of these payloads, as soon as they had been attached to the Columbus External Platform Facility (EPF).

One of the external Payloads (SOLAR [2, 3]) is a sun observatory which can be tilted around two axis in order to track the sun during "ISS day", while its three instruments measure the solar spectra in different wavelength regions. The other experiment platform attached to Columbus is the European Technology Exposure Facility (EuTEF [4, 5]), which hosts nine different scientific experimental setups which investigate the space environment or the behaviour of materials/instruments in it (debris measurements, radiation and temperature studies, plasma conduction, tribology, etc).

Inside Columbus the four payload racks serve different scientific areas. Human physiology under zero gravity condition is the subject of investigation of the European Physiology Module (EPM), which is currently equipped with an electroencephalogram (EEG), an electrocardiogram (ECG) and a kit to take various samples (blood, urine, saliva). A first experiment for EPM is planned in the second half of 2008.

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BIOLAB [6, 7, 8] offers different means for investigations dedicated to small plants and invertebrates behaviour under different gravity fields ranging from 0g to 2g (generated by two independent centrifuges). A robotic and fully automated section allows the injection of fluids to the experiment containers on the centrifuges; apply pre-defined atmospheric conditions to the samples, different light conditions and the usage of spectrometric and microscopic analysis methods. The manual section of BIOLAB allows the crew to manipulate the experiment containers within the sealed environment of a glovebox and to store temperature-sensitive materials or specimen inside two thermal-controlled units. Currently BIOLAB is in use for the WAICO experiment, which studies geotropism related phenomena on Arabidopsis roots.

The Fluid Science Laboratory (FSL) allows the investigation of fluids under the effect of weightlessness. Various analysis methods are implemented inside that rack ranging from high-resolution or high-speed imaging with different illumination techniques to holographic interferometry. FSL is for the time being configured to support the GEOFLOW [9, 10] experiment which simulates the fluid dynamic effects of the interior of the earth.

A versatile facility is the European Drawer Rack (EDR) which provides housing and resources for smaller sub-payloads. Currently a crystal growth experiment [11] (PCDF - Protein Crystallisation Diagnostics Facility) is in preparation - the first PCDF unit is already installed onboard, the second one will follow with the next Shuttle flights.

Following an international agreement two American owned payload racks have been moved during the STS-123 (1J/A) space shuttle flight into Columbus. The Express Rack 3 (ER-3) and the Material Science Glovebox (MSG) have already been installed inside the US Lab of the International Space Station. Now they have been relocated inside Columbus. The Express Rack is a versatile rack comparable with the EDR facility and hosts the European EMCS sub-payload, while the European built MSG is dedicated to material science providing a glovebox, video equipment and various resources for scientific utilization.

Also an additional American external payload was installed in two EVAs on the Columbus EPF during the 1J/A mission. Materials ISS Experiment 6 (MISSE-6) is owned by the US Department of Defence and is exposing various materials and functional surfaces to the space environment.

Payload	Responsible FRCs
BIOLAB	Microgravity User Support Centre (**MUSC**), Cologne, Germany
EDR	**ERASMUS**, Noordwijk, The Netherlands
EPM	Centre d'Aide au Développement des activités en Micro-pesanteur et des Opérations Spatiales (**CADMOS**), Toulouse, France
EuTEF	**ERASMUS**, Noordwijk, The Netherlands
FSL	Microgravity Advanced Research and Support Centre (**MARS**), Naples, Italy
SOLAR	Belgian USOC (**B.USOC**)

Table 1. Columbus European payloads and the responsible USOC

II. Distributed operations concept

The national diversity of Europe is also reflected in the Columbus operations concept. The European Space Agency (ESA) has adopted a decentralized scheme for the utilization of European payloads.

So-called User Support and Operations centers (USOC) - provide the interface between the science community and the ISS operations teams. Some of them act as Facility Responsible Centers (FRC) and own the overall operational responsibility for one of the Columbus payload facilities. These centers are listed in table 1. Other USOCs are grouped as a second layer below a FRC. Those are called Facility Support Centers (FSC), support subfunctions, subpayloads or subexperiments of a given Columbus payload. FRCs and/or FSCs are interfacing with the scientists organized in the User Home Base (UHB) as smallest unit in the hierarchy.

Since during the 1J/A mission also American payloads operated by the Payload Operations and Integration Center (POIC) in Huntsville have been integrated into Columbus, POIC acts as USOC for Columbus as well.

On the highest level the payload community (namely the FRCs) interacts with the Columbus subsystem level, which is controlled and operated by the Columbus Flight Control Team (FCT), located at the Columbus Control Center (COL-CC), at the DLR premises in Oberpfaffenhofen, Germany. This center has the overall responsibility and authority over the Columbus module including built-in or attached ESA payloads and reports directly to the lead ISS control center in Houston, Texas.

At COL-CC a Columbus Flight Director leads operations and manages several subsystem positions. Furthermore an EUROCOM is available to talk directly to the crew for any Columbus related issues.

Within the Columbus FCT a dedicated position, called Columbus Operations Controller (COL-OC) acts as the overall coordinator of the payload activities. It is staffed 24/7.

From a contractual point of view the USOCs are directly reporting to ESA, while the Columbus Flight Control team in Oberpfaffenhofen is operated by DLR (Deutsches Zentrum für Luft- und Raumfahrt) under the Industrial Operations Team (OIT) contract between EADS and ESA.

III. Ground system setup

The various centers in Europe share a common ground network for exchange of information, issuing commands to the Columbus module and distributing telemetry from the system and the payload components of the space station. An essential part of the ground system is the Data Services Subsystem (DaSS), which can be considered as data pool accessible by all European partners and the US control centers as well. The central node is located at the COL-CC center within the German Space Operations Center (GSOC). This center is connected to Houston and Huntsville (and therefore via White Sands and the TDRS satellite system to the ISS) via dedicated high secure network lines. All Telecommands from the USOCs or from COL-CC are broadcasted to Houston this way and are then uplinked via S-Band. For telemetry different channels are available:

S-Band packets are downlinked from the ISS to either Houston or COL-CC. In their S-Band packet, Houston has implemented a subset of the Columbus telemetry. This telemetry is processed in Houston but can then be accessed by the European partners as so-called Processed Parameters (PP), which are made available via the DaSS.

For Columbus systems a dedicated and configurable S-Band data packet pool is defined. Although the US assets are used to downlink this data, the packets are not processed in Houston, but passed over to COL-CC directly, where the data is extracted, calibrated and displayed. A subset of this Columbus Systems data is also injected into the DaSS and is therefore visible as PP for the USOCs and the US centers as well. This serves the need of the USOCs to have insight into the Columbus side of the system to payload interface.

Telemetry can also be downlinked using the Ku-Band link from the ISS to the Payload Operations and Integration Center (POIC) in Huntsville. This link is used for both Columbus Systems Telemetry and Columbus Payload Telemetry. The payload data can be divided in 3 main groups: the payload Health and Status data, the payload Housekeeping data and the science data.

The payload Health and Status data contains very generic payload telemetry especially aiming at the Columbus interface and safety related parameters. The Payload Health and Status Packets are forwarded to COL-CC, where they are processed. Again, this data can be distributed to the USOCs as PP via the DaSS.

The Housekeeping data of the payloads goes down to specific subsystem details of the corresponding facility. The Housekeeping Packets are forwarded from POIC to the USOCs (via COL-CC). This Housekeeping data is processed solely by the USOCs. Some of these parameters have been determined important for COL-CC as well and are therefore put by the USOCs as PPs into the DaSS for COL-CC retrieval.

Science data is interpreted directly by the UHBs and are not published in the DaSS, since they are not important for the operations community and are also considered as sensible data.

Analog and/or Digital Video can also be downlinked from the various onboard cameras via Ku-Band to COL-CC and the USOCs.

The operational information exchange and documentation utilizes a dedicated software tool suite to which all European entities have access. Among them the most important tool is the Columbus Electronic Flight Note (CEFN) system which is used to document operational information including the capability to do European wide reviews and approval processes managed by the Columbus Flight Director.

For voice communications a multiple channel voice system (VoCS) is used which allows access to all relevant communication loops with the capability to control and restrict access (no access, listen-only, talk) position specifically. All required US voice loops are also available as well as space-to-ground and air-to-ground loops for crew communications.

IV. Resources provided by Columbus

The approach for the European payload complement is designed in a modular way - the payloads are not an integral part of the module, but Columbus provides standard mechanical and functional interfaces for the internal and external payloads. Those interfaces are under COL-CC control and it is a COL-OC task to command and monitor them. The rack bay standard supports the integration of International Standard Payload Racks (ISPR).

A. Power interface

120V supply voltage is provided to each of the internal payload bays via two separate lines, each of them connected to one of the two ISS power strings which supply power to Columbus via the Power Distribution Units (PDU). This redundancy concept allows a one-failure-deep power availability for payloads with continuous power requirements. The MAIN feeder provides 6kW or 3kW, respectively, depending on the rack bay location in Columbus, whereas the AUX feeder provides 1.2kW in any case. It is up to the payload developer whether they integrate the power redundancy into their payload design or whether they rely on the MAIN power feeder only. Currently FSL is the only ESA rack which is designed fully power redundant, the other racks require in case of MAIN power failure a crew action to swap the power supply umbilicals.

On the four external payload platforms also two 120V power channels (NOMINAL and SURVIVAL) are provided to each payload location. The current ESA payloads utilize the SURVIVAL power string only to power heaters which guarantee the survival of the devices in the space environment, whereas only the NOMINAL power string allows actual operation and science conduction. From inside Columbus crew is able to switch each of those channels individually, but since the external payloads share the PDU power outlet with internal payloads in a complicated manner a close coordination and a sophisticated flow of events has to be followed whenever an affected payload's power status is changed.

B. Thermal interface

While the external payloads can dissipate the generated heat to the space environment it is essential for the internal payloads to have the capability to remove the thermal energy via a dedicated Columbus water cooling loop, which is provided at each internal rack bay. It is up to the payload developer how to implement this rack-internally, thus some payloads use an internal secondary water or air loop, which interfaces with the Columbus coolant via a heat exchanger, whereas other payloads utilize the Columbus cooling loop directly. The collected thermal energy generated by all payloads, the Columbus systems and the crew's metabolic heat load is introduced via heat exchangers into the ISS external cooling system, which uses ammonia as coolant and then radiated into space.

C. Data interface

In general three kinds of data traffic are distinguished. The MIL 1553B based Low Rate Data (LRD) satisfies the basic requirements for safe and stable payload operations. Via that interface the payloads are required to send essential parameters (health and status data) which allow to determine the basic functionality of the payload. This includes so-called Caution and Warning messages which are used ISS wide to notify and alert crew and ground in case of off-nominal situations and contingencies. The high priority (Emergency) message uses a different dedicated interface, which is explained in more detail below. The LRD bus is also used to transfer a predefined set of ISS and Columbus parameters (i.e. attitude, velocity,...) to the payloads as well as to distribute the on-board time signal.

The Medium Rate Data (MRD) channel based on an Ethernet LAN is used for commanding the payloads. Also the Housekeeping data, which provides insight into the payload subsystem are broadcasted via MRD. As long as the scientific results are not considered as high rate (i.e. images), also science data is sent on that channel. Columbus also offers a file transfer protocol which allows up- and downlink of files to the Columbus Master Memory Unit (MMU) and the lateral transfer from/to the payloads using the MRD channel.

Fiber optic cables connect the payloads to the Video Distribution and Processing Unit (VDPU) of Columbus which allows the routing and also digital compression of bitstream data or video (analogue and digital). Via the High Rate Multiplexer (HRM) the various input channels are multiplexed and integrated into the overall ISS high rate data downlink. This interface is considered as the High Rate Data (HRD) interface.

All these above mentioned data interfaces are available at each rack and external payload position together with dedicated connections for US racks, which are used by NASA provided racks in Columbus for direct communications with the US Orbital System (USOS) data management system.

D. Science resources interface

For internal payload’s science operations Columbus provides gaseous Nitrogen and vacuum/venting capability. The latter resources allow the connection of the payload to the environmental vacuum via two dedicated lines. While the vacuum line is used to maintain vacuum conditions with almost no mass flow, the venting line is dedicated to dump a certain payload volume into space to reach vacuum conditions.

E. Safety interface

Except the above mentioned Caution and Warning messages sent via the LRD link the external payloads have no further safety interface with Columbus, since they do not impose any hazard to the crew in Columbus.

This is different for the internal payloads which are considered as potential sources of fire and toxical materials. Therefore several measures have to be implemented to ensure safe operations. All internal powered payload volumes which are not exchanging air with the cabin require to have an access port for the Columbus fire extinguishers as well as an internal smoke detection, which is under permanent surveillance of the vital telemetry controller (VTC) of Columbus via a dedicated line. Also a Rack Power Switch (RPS) has to be implemented to allow the crew to remove the power completely (on PDU outlet level) from the rack bay. This RPS is directly connected to the PDU and putting this switch into the OFF position acts also as inhibit against inadvertent commanding of that PDU outlet.

In addition to the above mentioned safety flags via the LRD bus each rack bay is also provided with a hardwired connection to send a Warning or an Emergency message to the VTC. Currently only Biolab utilizes the latter option.

F. I/O interface

For the external payloads a dedicated I/O computer (External Command and Measurement Unit - XCMU) interface allows to send pulse or level commands on hardwired lines, to acquire analogue, digital measurements and temperatures from the external payloads. This interface is used by both ESA payloads, since it allows (very limited) communication with those, when they are not powered (i.e. to monitor temperatures or to send the initial switch on command).

V. Interfaces between Payload community and Columbus Control Center

As mentioned before the COL-OC position acts as the link between the Columbus Flight Control team and the FRCs. However, for stowage and planning tasks also dedicated interfaces are established between the FRCs and the Columbus On-Orbit Stowage and Maintenance Officer (COSMO) or the Columbus Operations Planner (COP), respectively. In the following paragraphs the interface represented by COL-OC is explained in more details.

A. FRC - COL-OC interface

The main interface between the FRCs and the Columbus FCT is the COL-OC position which is acting as a coordinator for all USOCs on behalf of the Columbus Flight Director.

COL-OC is the focal point when the FRCs have real-time requests for resources provided via the above defined interfaces from Columbus or crew requirements. COL-OC has also to assist the Columbus Flight director in payload related decisions, i.e. to resolve conflicting requests of different FRCs.

All commanding to the payloads is routed through COL-CC and the COL-OC position has to enable the FRCs for commanding. This was implemented since the Columbus Flight Director has to coordinate all commanding activities with the Houston Flight Director, whose command assets are used. Therefore the Flight director has to have the overall control over commanding by all Columbus entities.

Since the overall safety responsibility for the Columbus module resides at COL-CC, there is also functionality implemented that COL-OC has to enable the FRCs specifically for all payload commands which has been classified as “hazardous” (all commands, which could create a hazardous situation or which reduces the level of control of a hazard).

Also troubleshooting in case of malfunctions on the Columbus side of the interface is led by COL-OC, who is supported by the corresponding subsystem engineers of the FCT. For failures on the Payload side of the interface COL-OC has a coordination role and assesses the impacts to Columbus subsystems and to other payloads, whereas the FRC is the main actor in malfunction resolution.

B. FRC - COSMO interface

The COSMO position interfaces with the USOCs directly for any issues regarding stowage on board. He is responsible for any items which are moved by the on-board crew inside Columbus and therefore involved in most of the payload mechanical activities which are performed by the crew. COSMO is also maintaining the Columbus Plug-in Plan which summarizes and organizes the usage of the standard data and power receptacles inside the Columbus module. These receptacles are also used by the payload community i.e. to power the payload provided laptops.

For the above mentioned subjects the FRCs are contacting the COSMO position directly.

C. FRC - COP/planning interface

The USOCs are responsible for the planning of their payload activities and therefore a direct interface to the planning world was established for the FRCs. For real-time and near-real-time planning inputs and changes the FRC can contact the COP directly; however the COL-OC is involved in most cases in this process as well, since he needs to maintain awareness on all payload related tasks. The near-real-time planning timeframe is defined as the current execution day plus 7 days. Any planning inputs which exceed this timeframe are handled by the long range planning process, for which the FRC interfaces with the so-called Columbus Long range planners. A dedicated software tool is used to collect the relevant planning information.

D. Other interfaces

In off-nominal situations it is also foreseen that the FRCs can directly contact the corresponding subsystem engineer and discuss any issues directly passing by the nominal COL-OC interface.

VI. Pro and Cons

The above presented and currently implemented payload operations concept for Columbus should briefly be discussed based on the first experience gathered during operations.

The concept of the distributed control centers in Europe is reflecting the knowledge distribution all over Europe.

However there are also some difficulties which are generated by the fact that control centers are spread out over Europe. For sure all inter-center coordination meetings are rather complicated, since they are either connected with extensive traveling or have to be conducted via teleconference. Slight differences in the operational concepts of the various centers due to lack of insight into the operations of the other center(s) caused some difficulties. Compared to other space-flight nations like USA, Russia or Japan Europe has also to deal with a variety of languages which make operations even more complicated. It is a challenge, but also a pleasure to work with people from different countries and different cultural background.

It turned out that one of the most challenging issues is the contractual setup of the control centers which have to interact during operations without having a direct contractual relationship with each other. That complicated the situation during operations several times in the past.

VII. Conclusion

In our paper the concept of payload operations in Columbus was presented and shortly discussed under the impression of the first weeks of Columbus operations. The next months and years will lead to a more profound assessment of the efficiency of the implemented setup and may lead to slight adaptations and changes of processes and interface definitions.

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