COMMERCIALIZATION IN COLUMBUS: LOOKING BEFORE LEAPING

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ABSTRACT

Since the launch of the Columbus Module to the International Space Station (ISS) back in 2008, experiments to be executed on board were usually developed by a team of established scientists and engineers answering an ESA call of opportunity. A payload operations center was then assigned acting as the interface between the scientists and the Columbus Control Center (Col-CC) for the preparation and execution of the experiment activities.

In 2018, Columbus will receive its first commercial payloads, and with that, also the processes established in the 10 preceding years for preparing and performing payload operations have to be reassessed, and if needed adapted, to the changing times.

Traditionally, the Columbus Flight Director has always had a detailed insight in the ESA payload operations occurring in the European ISS module. This was established, amongst others, through continuous real-time contact with the responsible payload operations center, detailed planning inputs to the ISS timeline, and centralized, reviewed procedures following common standards.

Commercial payload operators often desire more flexibility and a shorter turn-around time than accommodated by the traditional processes. Moreover, a commercial center testing a new technology may not be willing to share the details of their payload or to reveal malfunctions. At the same time, it is the Columbus Flight Directors responsibility to oversee the planning and execution of activities in Columbus, as well as guaranteeing safety and the efficient use of crew time and on-board resources.

This article will explain the differences between commercial and government-based activities in the Columbus module as experienced by the Columbus Flight Control Team (FCT) at Col-CC. It will discuss which processes needed to be adapted, and how the FCT deals with the reduced insight in on-going operations. Finally, the first lessons learned will be presented.

Introduction

In 2018, the European Columbus module of the International Space Station (ISS) has hosted a commercial payload for the first time. Traditionally, experiments and technology demonstrations in Columbus have been initiated by ESA sending out an announcement of opportunity to the scientific community. The submitted proposals are then assessed and only some proposals go to the next phase. This is a lengthy process, closely guided by ESA.

Seeing the need for a quicker turn-around and an easier access to space to non-governmental institutions and clients, ESA has started partnerships for private payloads.

This article discusses first the set-up of European ISS operations, then looks at experiment preparation and execution for the traditional experiments vs. commercial experiments, and highlights the critical processes. It focuses on the real-time and near-real-time parts of ISS operations that are affecting the Flight Control Team (FCT) at the control center for the European part of the ISS, the Columbus Control Center, or Col-CC. By near-real-time the process is meant by which information on how to execute an experiment is provided to Col-CC by the experiment responsible center. The experiment

enters then the ISS planning processes. This planning gets more and more refined the closer to the planned experiment execution time. With info on the experiment available, Col-CC can also assess if all is in place for safe operations as well as assess if any further specific preparation is required.

European ISS operations set-up

There are 5 main control centers for ISS operations: 2 in the United States of America, with the Johnson Space Center in Houston the most famous, one in Japan, one in Moscow, but also one in Europe: the Columbus Control Center (Col-CC), in Munich, Germany. Every International Partner (IP) is considered to be the expert of their module, so in case crew has questions or there are malfunctions, there is an expert Control Center to handle the issues. There is of course an intense collaboration required between the IPs as no module is isolated from the others and because limited resources are being shared. Crew time is one of those precious resources and with the wide variety of scientific experiments with specific constraints, technology demonstrations and maintenance activities, planning is a major part of this collaboration.

Within Europe, Col-CC works together with several supporting centers, such as the European Astronaut Center (EAC) and several engineering services. There are also several payload operations centers spread over Europe. Traditionally they were called User Support and Operations Centers (USOCs) although over the years some centers have closed and new ones have joined, with different names.

For the purpose of this article and to clearly make the distinction between these traditional centers and the new commercial ones, the first ones will be called ‘USOCs’.

Flight Control Team

To understand how ESA ISS operations are performed the different roles present in the Columbus Flight Control Team need to be discussed.

The USOC operator, or USOC OPS, is the experiment responsible. Towards Col-CC, they are the ‘owner’ of an experiment and of its associated activities on the ISS, and have the expert knowledge. If there is any question about the experiment from crew or from other members of the FCT, the USOC OPS is the only one whose answer will be relied upon. USOC OPS needs to know how the experiment can be saved in case of malfunctions or comes up with work-arounds in case of problems and will review planned timelines to ensure that experiment constraints are fulfilled and all necessary information is provided to the crew. Another side of their job, not visible to Col-CC, is the USOC OPS interaction with the scientists and engineers that have created the experiment. The USOC is effectively the interface between scientists and engineers on one side, and the Columbus Control Center on the other side, bringing scientific research to the operational environment.

The Columbus On-orbit Stowage and Maintenance Officer (COSMO) is in charge of all hardware maintenance on-board as well as stowage. The ISS is notoriously packed and the Columbus module no less. Careful tracking of every item is required to make sure nothing gets lost. As an example, when experiment hardware is launched, COSMO will, in coordination with the International Partners, work on an unpack choreography for the ESA items in the launched spacecraft, taking into account the constraints provided by USOC OPS. For example, there can be items that have lifetime constraints or that need a specific temperature control. Moreover, for every activity to be performed by the crew, be it for a payload or systems maintenance, COSMO will provide detailed instructions for the crew where to find the necessary items.

The STRATOS position is in charge of ensuring the proper functioning of the Columbus module systems, meaning power distribution, thermal control, the data management system, communication assets and maintaining a healthy atmosphere for the crew. Most experiments rely on at least one of these resources, which are limited goods; hence coordination between the USOC and STRATOS is needed both in preparation and during real-time execution.

Planning is performed by the EPIC (European Planning and Increment Coordination) team, in close collaboration with all other positions. At certain times with regards to an ISS expedition, USOCs need to provide key information on their experiments to the EPIC team. Important info is for example the amount of time the crew will spend on an experiment and the constraints on the experiment execution. Experiments on human physiology often come with certain windows during which the sessions have to be performed, e.g. X days after launch, in the middle of the mission and shortly before return. Other experiments require the astronaut to follow a certain diet or to avoid exercise before the experiment. Sometimes an experiment will generate so much data that no other experiments can downlink data at that time due to the Columbus limits in bandwidth.

Half a year before execution of any of those experiments on board, the EPIC team will sit together

with the planning teams from NASA, ROSCOSMOS and JAXA to come up with a consolidated preliminary planning to avoid conflicts that would make scientific results invalid, or that waste crew time. Think for example of an ESA and NASA experiment around the same time, that require the astronaut to follow contradicting diets, an astronaut that has to wear a forehead sensor while also doing live contacts with schools and officials on Earth. Such situations need to be avoided.

Over time, the planning gets more refined, until at 6 days before a certain day, that specific day enters the Execution-6 days (E-6) process. All console teams then inspect the planning for that day, verifying that indeed all required operational products are available to the crew and/or the console positions affected by the activity. A procedure needs to be available describing step by step what needs to be done, stowage info needs to be available for crew activities, necessary resources (power, data rate, video support…) need to be planned correctly, and no conflicts between different activities should be present. The position leading this effort is the COMET (Columbus Operations and Mission Execution Timeline engineer), who is the console representative of the EPIC team. COMET gathers inputs from the different positions, coordinates with the International Partners if needed, and ensures that corrections are implemented. The same process is repeated at E-3 and E-1, such that every ISS day has been reviewed thoroughly at least three times in the operational real-time environment.

The Columbus Flight Director (Col-Flight) is the position overseeing all other positions and the single point of decision towards the International Partners. Col-Flight is responsible for safe operations in Columbus, and for the efficient use of resources including crew time. As such, the Col-Flight needs awareness of and insight in all on-going activities, and all decisions and actions have to be approved by the Columbus Flight Director, who will then ensure the ISS Flight Director's awareness of on-going Columbus activities.

The Eurocom is the European Communicator to the crew. In case of crew questions, the subject matter expert console position will provide the answer to Col-Flight, and with Col-Flight's go, Eurocom will voice up the message to the crew.

USOCs and Commercial centers

Traditionally, each experiment that ESA has decided to operate isassigned to a USOC. It is then the task of the USOC to familiarize with the experiment and to set up a working relationship with the scientists and engineers designing the experiment, to translate the science requirements into operational products.

The USOC personnel follow an internal training, but also an ESA organized training, partly shared with the Columbus Control Center personnel. Hence the USOC is trained to follow the common processes established over the years and documented in so-called Joint Operations Implementation Procedures (JOIPs).

Commercial Operations Centers can come in different sorts. They may have designed their own experiments, of which afterwards they want to commercialize the results, or the technology. They may operate a platform that allows installing different kinds of experiments coming from their customers, in short, they are providing a service. The Commercial Center might not be willing to share all information, either because it is in their interest not to make sensitive information public, or because they don't have the insight themselves. For the Col-CC FCT and especially the Columbus Flight Director, this is a big change from traditional practices.

Experiment Preparation

USOCs

Activities performed on ISS are prepared extensively, as often one only has one opportunity to perform the experiment, and should be prepared for any question, any malfunction. So preparation often starts more than a year in advance, and even several years for long-term running, complex experiments.

The first info that is provided by the USOC to Col-CC are the crew time estimates, the Ground Rules and Constraints, and the Mission Operation Integration Concept (MOIC). Ground Rules and Constraints (GR&C) describe the way the experiment should be scheduled. An example could that an experiment needs to be scheduled within a certain number of days after crew arrival on board.
The MOIC gives an extensive overview of the experiment in operational terms. It discusses which equipment is needed, whether it will be launched with a specific vehicle, or if it is already on board, and in that case, if it needs to be borrowed from an International Partner. It illustrates the equipment set-up, describes what the experiment will look like or what crew has to do, if video support is required, which resources are required, if specific safety issues are to be addressed, time constraints on the activities, what-if scenario's, if there will be interactions with other console positions

during execution… Everything operational (as opposed to for example science data processing etc.) should be documented in the MOIC. The MOIC is reviewed by the Col-CC FCT to help identify open questions and issues to be worked.

Next, the information needs to be translated to operational products. These are the documents used on console, which are available for all console positions, and undergo review and configuration control. Examples are Procedures, Flight Rules, Payload Regulations, Planning Requests…

All activities are performed following validated procedures. This is true for the on-board crew performing actions, but also for experiments run from ground by tele-commanding. All commanding has to be tested on an engineering model on ground, and all crew procedures will have had several test runs on ground as well. They also undergo an extensive review process by the Col-CC team, engineering, and the safety team.

Planning Requests (PRs) are the templates used by the EPIC team to create the planning, and need to contain all the information required to execute an activity on-board. They need to be filled in by the USOC as activity owner, and are then reviewed and approved by the EPIC team when all info is available in the correct format. Info that needs to be in the PR is the name and duration of the activity, the crew member that will execute the activity, a reference to the procedure, the location of the activity, the resources required, the origination of the activity (ESA, NASA…), and the relation of the activity with other activities, for example, one activity needs to follow directly after a specific other activity, or needs to be scheduled on two crew members in parallel, etc. The PRs and GR&Cs are crucial for the EPIC team to create a planning.

If applicable, a Flight Rule or a Payload Regulation has to be written. Flight Rules can be seen as the laws on board the station and are meant to facilitate decisions in real-time, by analyzing different cases in advance. For example, there are Flight Rules documenting how many power inhibits need to be put in place before a power connector can be (dis)connected, or listing which actions to take in case of prolonged power outages. Payload Regulations serve a similar goal, with the difference that they only govern payloads, and that they mostly are IP specific (e.g. ESA Payload Regulations), whereas Flight Rules are known and used by the whole community. Any safety related item needs to go in a Flight Rule, and a Flight Rule will always overrule a Payload Regulation following the priorities Crew-Vehicle-Mission. The need for a Flight Rule or Payload Regulation is identified by the USOC or the Col-CC FCT based on the MOIC, or the Safety Data Package that comes with every experiment.

Only when all Ops Products are available, with no open items, the lead Columbus Flight Director will give the "go" to the EPIC team to schedule the activities into the real-time world.

Commercial centers

With the different set-ups of Commercial Centers, their way of preparation also greatly varies. A complex experiment that uses both ESA and NASA assets has no choice but starting preparation early, following established processes, purely because of the complexity and Col-CC having the necessary NASA contacts for coordination. In this case, the contribution of Col-CC is mostly to provide extra guidance and help to centers that are new to ISS operations. Although this takes more time than for established USOCs and is largely based on goodwill, the intense contact also creates a mutual understanding, and a trustful relationship.

For commercial projects in Columbus only, there has been a push for simplification and acceleration, following also the goal of having a quicker, less complicated process to get experiments executed on board. Especially in the first phase, the learning phase, it is then expected that there will be some hiccups, and this has also been observed.

Several of the deliverables needed to make the planning have been received late or incomplete, resulting in very late changes to the planning, even to the extent that a scheduled USOC activity had to be removed from the timeline to allow the commercial activity to be performed in time for PR reasons. This was a priority call made by ESA. Moreover, certain readiness items had not been completed very close to the activity execution time, and others were not even known to the Col-CC team. This then had to be handled by the on-console team instead of during preparation.

Could this have been handled differently? From FCT point of view, it would have probably been better if the FCT was more involved in the preparation of the commercial payloads. It is understood that commercial centers are hesitant to share technical details for strategical reasons, but solutions can be found for that, such as non-disclosure agreements. Several issues would have been caught earlier with the experience of the Columbus FCT, especially for safety and security items and areas that touch the interfaces with the International Partners.

Given the Columbus Flight Director's responsibility for all ESA activities happening in Columbus, especially for crew safety and vehicle integrity, the Col-Flight is used to having all the insight. Not having that makes them uncomfortable and inquisitive, coming up with all possible what-if scenario's. A good cooperation from the beginning, with the commercial center addressing all those concerns in the preparation phase, again creates a trust relationship, which then over time allows relaxation. Whereas commercial centers would prefer to keep their training largely internal, it should be considered if it were not more beneficial the other way around: a thorough training focusing on ISS operations set-up, duties and responsibilities of the different positions, and potentially even on-the-job training at Col-CC. Such training would improve mutual understanding, as well as creating a personal relationship between the teams.

Besides that, the Columbus Control Center and ESA, and potentially the IPs, should look into how the planning processes can be adapted to a society, a market, for which also in space time is money.

Experiment Execution

USOCs

An experiment enters the real-time world at 6 days before execution. From that point onwards, any problem, any modification, is handled by the people on console, as opposed to the back-offices handling the preparation. So in addition of handling what is going on on-board in that instant, the Columbus FCT and the USOC will also have their eye on the upcoming days already. Hence in this period the USOC is expected to be on console whenever days are being reviewed that have their experiments, which is, as mentioned before, at execution -6 days, -3 days and -1 day. 'Being on console' means one is at the workstation where telecommands can be sent, telemetry received, and the person is logged in to a voice communication system that connects USOCs, Columbus FCT, the FCT of the International Partners, and the on-board crew.

In those days before an activity, the Columbus FCT will walk through the procedures and consult the USOC about any remaining open question with the idea that several pairs of eyes see more than one, especially with the different point of views of the different positions. Also real-time changes in the on-board configuration can affect an upcoming activity. Another aspect that happens fairly often is that a change in planning on NASA side affects activities of the other International Partners. This can go in two directions: a higher priority item might come up, which then forces experiments out of a timeline, or time frees up. It will be no surprise that repairing life support equipment has a higher priority than performing a scientific experiment. On the other hand, sometimes an IP activity is removed from the timeline, opening up time for an ESA experiment. In this case,with approval of the Columbus Flight Director, it is the USOC that needs to provide correct and complete inputs to COMET, to plan their activities. This is of course only possible if the USOC and potentially supporting scientists are available on the proposed timeslot, and if it can be confirmed in time to the planning community that ESA will be ready to take the timeslot.

If any question or concern comes up from crew, from NASA, or any issue is spotted by the Columbus FCT, it is Col-Flight's responsibility to make sure the question gets answered or assess if the raised concern is strong enough to remove the activity from the timeline. This will always be discussed with the USOC, and often, even if the concern is serious, an acceptable work-around can be found. However when the USOC is not available, the Columbus Flight Director will have the make the decision themselves, and is entitled to act conservatively. Despite the Columbus Flight Directors often having many years of experience in the project and being familiar with the long-running experiments, they cannot take responsibility for moving or changing activities without the USOC confirming. Hence, USOC availability is crucial in the days preceding important experiments.

On the day of execution, the USOC needs to be on console well in advance of the activity. Many experiments can be performed without crew involvement, purely by ground commanding. The USOC gets the go from Col-Flight, who makes sure there are no contra-indications for starting the experiment, and who also needs to be aware of what activities are going on to react properly to unexpected events.

The USOC stays on console and monitors the experiment for as long as it is active, even if no commanding is needed or long periods of time. This is to monitor that the experiment runs well, and to react appropriately in case of an anomaly. Recently, so-called 'unattended operations' been introduced, in which the USOC goes off-console while the experiment is running. In this case, no commanding is required for the experiment, and Col-CC has enough insight in the running equipment to ensure safety in Columbus. If there are any contra-indications, the experiment can be switched off on Col-Flight decision.

For experiments with crew involvement, it is also the USOC that needs to have the reply to the crew's questions and concerns. The USOC will provide answers and advice to the Columbus Flight Director, and with their go, Eurocom will voice it up. The crew interaction needs to go via Col-Flight as they have the big picture in mind, taking into account the remaining time, the impacts to other activities, and assess the feasibility of the instructions to the crew.

Every unexpected behavior of the experiment is called an anomaly and needs to be reported to the Columbus Flight Director. In the worst case, immediate safing is needed to not affect the rest of the Columbus module. For less serious cases, a recovery action can often be found.

Col FD needs to know about anomalies to assess if the anomaly might affect other subsystems, and will discuss this with the appropriate console positions. If the anomaly is payload internal, the USOC can propose a recovery action or work-around. Sometimes the recovery needs support from another console position, e.g. a power cycle of the outlet used by the experiment, by the STRATOS position.

All in all, real-time operations can be very complicated and multi-faceted, and USOCs undergo a strict training. USOCs as well as Columbus FCT need to perform simulations before they are certified to do real operations. In such simulations, a whole timeline is run with all console positions, and a surrogated crew on ground simulates the crew activities. Problems are inserted throughout the day, which FCT and USOCs need to manage appropriately.

Commercial centers

Console presence is very expensive in terms of human resources, and commercial centers tend to try to minimize their involvement in the traditional console processes. For example, whereas crew activities will always be performed following configuration controlled, reviewed procedures following the common standards, for ground only-procedures, this is no longer the case. Contrary to the USOC ground procedures, Col-CC has no insight in the commercial centers ground commanding procedures.

While their experiment is active and being commanded, the commercial center will not be available on console to report on-going activities and to be informed about ISS events that could impact the commercial service. Problems will only be reported in case the commercial center needs support from a console position for the recovery, or if it is suspected that the root cause of the problem does not reside within the commercial payload.

For the commanding, it is ensured that the commercial payload center cannot send any safety-related commands, by the ESA safety review during experiment preparation.

The reduced console presence puts additional load on the Col-Flight console. First of all there is no insight anymore in all activities going on in the module. All payloads and the Columbus module in total are 'safe by design', meaning that for the worst cases (e.g. fire) the payload and the Columbus module have automatic reactions to mitigate the danger, but in case crew reports e.g. a loud noise, an unusual smell…, the Columbus Flight Director, supposed to be aware of anything happening in Columbus, cannot provide an explanation. Due to proprietary information reasons, the commercial center may not be willing to share details about the running experiment. If deemed necessary, Col-Flight can of course instruct the STRATOS position to deactivate the payload by stopping power provision. In summary, the commercial center not being available on the loops reduces awareness of the Flight Director, but also creates a risk for the commercial center that their payload gets switched off when not strictly needed.

Secondly, the commercial center also requests services from Col-CC. USOCs that are available on the voice loops are aware of events happening on-board the station, and on ground sites. On-board system malfunctions may impact payload operations, e.g. power failures, failures on the thermal control system… and may require payloads to be switched off. Malfunctions on ground sites can interrupt the data stream between station, Col-CC and the Commercial Center. As mentioned earlier, late notice replanning can be required that doesn't allow the commercial payload to receive the required resources. Commercial Centers are usually requesting Col-CC to inform them of such events and the impacts. This will be usually done by e-mail or phone, which are not considered operational tools. Whereas usually the USOC will copy these events from the voice loops and inform Col-Flight about their impacts, for the commercial centers it is rather the other way round: Col-Flight has to assess impacts to a system they do not have insight in.

Thirdly, the commercial centers are not required to inform Col-Flight about payload internal anomalies. The goal of the commercial payload might exactly be the testing of new technology, and in that case also the malfunctions will be proprietary information. This at first sounds reasonable and even logical, but the problem is that in this way the commercial center, which is not the expert on the Columbus module or on

the ISS, decides which problems affect the module and which not. The problem is worsened by not being present on console, and potentially missing clues from crew, from STRATOS telemetry, that a bigger problem is going on. As an example: a pressure drop in the commercial experiment, that for the commercial center might be assessed by the commercial center as indicating a sensor failure. Or even worse, the commercial center might not even be aware because the data go directly to the customer. At the same time, crew reports an unusual smell in Columbus. When all the pieces are put together it strongly hints to a venting of some kind from the commercial experiment into the cabin, but if the information is not shared, the puzzle becomes tricky to solve.

Final considerations

Up till now, the Col-CC handling of commercial operations has been very much tailor-made: every project is so different from the others, that processes have been adapted for every occurrence specifically. With the first lessons learned, it is time to take a step back and assess if a generic approach can be implemented.

In the past, the Col-CC FCT attitude has been aimed very much towards mission success, one of their duties towards ESA. In case of anomalies, all positions will work together to find a solution and implement it as soon as reasonably possible. With the increased demand for unattended experiment runs, it might be time for Col-CC to see their role more as a service provider: make sure the Columbus module functions nominally, inform payload centers about on-going issues, but apply a hands-off approach for – at least – ground-only experiments. The Columbus FCT will no longer follow-up readiness for such experiments; the readiness for the experiment will be presented by the payload center, and then the EPIC team tries to find a suitable time for execution. If there are problems, it is up to the payload center to propose a solution when they are ready, but it would no longer be Col-Flight driving and prioritizing this process. Mission success becomes the responsibility of the payload center.

Unfortunately, this – from Col-CC side – "relaxed approach" can only be applied to the relatively simple case of ground-only experiments. Crew time, as a resource, is so precious that activities involving the on-board crew need to be planned well in advance and all details need to be ready. Here, Commercial Centers will have to adapt and present readiness in time. If they are planning to support crew activities, they need to be trained properly and perform simulations. The Columbus Flight Director needs to have the certainty that personnel supporting crew activities knows what is expected from them, knows all the details of the payload, and knows how to get the crew safely through the activity.

Safety is the other area where there cannot be compromises. The safety review for commercial experiments needs to be done with the assumption that operations will be unattended. The safety review should not only look at the standard working of the payload, but should also look into what-if scenario's with multiple malfunctions. This info needs then to be available to the Flight Director on console, as most likely there will not be a payload expert available on console at the time problems arise. ESA will have to create a process that ensures all safety related info is readily available, while fulfilling the Commercial Center's eventual desire for secrecy.

The risk that is present when processes are not reconsidered for the new situation, is that the Columbus FCT, and especially Col-Flight, needs to cover the gaps. This happens more and more already, with Commercial Centers but also USOCs not being available when questions arise and decisions have to be taken due to cost reductions. Thanks to the long experience of the currently working Columbus Flight Directors, no issues have risen yet this way, but it is unavoidable that at some point, due to lack of knowledge, lack of time to think, too much focus on mission success or any other factor, there will be a wrong decision. Science results might be lost. This is the risk that is taken and currently is only inferred to be acceptable. No explicit statements from ESA or the payload centers are written down accepting this risk. Moreover it needs to be ensured that the Columbus Flight Director is not overloaded with concerns and questions on running experiments, and as such loses the mental bandwidth to recognize payloads as a side-matter when critical issues show up. There is the risk that the Flight Director is becoming an executing function in stead of an overseeing, decision making function, and in the most extreme case this can lead to safety impacts.

Commercialisation in the International Space Station is not stoppable and neither should it be. Space, microgravity, needs to be an accessible resource for the benefit of science and society. From the point of view of the Columbus Flight Control Team, we would like to press for openness, both on commercial center and FCT part. There is a lot to be learned from each other, and it is an exciting time, but safety and the intelligent use of precious resources should never be compromised.