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THE COLUMBUS GROUND SEGMENT – A PRECURSOR FOR FUTURE MANNED MISSIONS

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The European decentralized operations concept enables all participating countries to establish a transnational centre of competence that actively cooperates in European participation to the International Space Station (ISS). To this end eighteen European facilities and three International Partner centres are interconnected by a Ground Segment providing data, voice and video services via the central hub at the Columbus-Control Centre.

Operating this Ground Segment is a significant challenge for the Ground Operations Team at Col-CC, not only due to the vast number of facilities and the related world-wide distribution, but also because of the number of different users (Columbus and ATV flight control, payload facilities, engineering support, PR) with their specific operational needs and constraints. In contrast to previous short duration missions with sequential mission phases, the continuous ISS operations support requires consideration to the current increment execution in parallel with preparation and training of following increment(s) and post increment evaluation. The long lifetime duration of 12+x years requires continuous maintenance and sustaining engineering of the ground segment infrastructure with focus on the life-span of individual components as well as life-cycles of entire technologies. Replacement of equipment or systems must be performed with minimal impact on real-time operations, and in coordination with increment execution/preparation activities. An important component of this structure is the application of human resources. An experienced team of qualified operators and engineers is to be trained to maintain a level of proficiency that is applied over this long period.

The above is reproduced in a system architecture is required supporting parallel real-time operations, simulation (preparation) and test (sustaining engineering) activities with varying instances of system configurations. For some systems however, like voice and video, different instances are not feasible, therefore rigid configurations are applied. The organisational approach of the Col-CC was established by running three main control rooms with individual ground operations performed in dedicated rooms. This concept required the ground operations team to be organised in a new approach. New processes and a suite of tools for anomaly resolution and configuration control were developed with everything is tied together by a powerful ground operations and resource planning.

This Columbus Ground Segment required a new approach, which shall be discussed here. Its distribution capability and requirement implementation is unique in the human space exploitation activities but can indeed be seen and applied as a precursor for future manned space missions, which require multi-national collaboration.

I. INTRODUCTION

In the beginning the space programs were self standing national activities, often in competition to other nations. Today space flight becomes more and more an international task. Complex space mission and deep space explorations are not longer to be stemmed by one agency or nation alone but are joint activities of several nations. The best example for such a joint (ad-) venture at the moment is the International Space Station ISS.

Such international activities define complete new requirements for the supporting ground segments.

The world-wide distribution of a ground segment is not any longer limited to a network of ground stations with the aim to provide a good coverage of the space craft. The coverage is sometimes – like for the ISS-anyway ensured by using a relay satellite system instead. In addition to the enhanced down- and uplink methods a ground segment is aimed to connect the different centres of competence of all participating agencies/nations.

From the space craft operations point of view such transnational ground segments are required to support distributed and shared operations in a predefined decision/commanding hierarchy. This has to be taken into account in the technical topology as well as for the operational set-up and teaming.

Last not least increases the duration of missions, which requires a certain flexibility of the ground segment and long-term maintenance strategies for the ground segment with a special emphasis on non-intrusive replacements. The Russian space station MIR has been in the orbit for about 15 years, the ISS is currently targeted for 2020, to be for over 20 years in space.

II. THE ESA GROUND SEGMENT – A UNIQUE NETWORK

Fig. 1: The ESA Ground Segment

ESA's contributions to the ISS are the Columbus module and the ATV support vehicles. Both missions are operated and supported by using one ESA ground segment.

Distribution

In order to respect the special ESA set-up allowing each member state to actively participate in a mission, a decentralized operations concept was implemented with transnational active centres of competence in each contributing country:

- The main Columbus Control Centre (Col-CC) in Oberpfaffenhofen, Germany
- The ATV Control Centre (ATV-CC) in Toulouse, France
- Three Engineering Support Centres (ESC) for technical support for the Columbus module and the ATV space crafts
    - Bremen, Germany
    - Turin, Italy
    - Les Mureaux, France
- 9 User Operations Control Centres (USOC) for Payload Operations
    - Toulouse, France
    - Noordwijk, Netherlands
    - Neaples, Italy
    - Cologne, Germany
    - Zuerich, Switzerland
    - Odense, Denmark
    - Trondheim, Norway
    - Madrid, Spain
    - Bruxelles, Belgium
- Operations Management Team (OMT) in Noordwijk, Netherlands
- European Astronaut Training Centre (EAC) in Cologne, Germany
- Artemis Ground Station for ATV support in Redu, Belgium

The European facilities are connected to and interact with the International Partner Control Centres:

- The ISS main Control Centre (MCC-H) in Houston, USA
- The Payload Operations Centre (HOSC/POIC) in Huntsville, USA
- The Russian Control Centre (MCC-M) in Moscow, Russia

Interconnection

All these facilities comprise the ESA Ground Segment. They are interconnected by a terrestrial based Wide Area Network (WAN), the so-called Interconnection Ground-Subnetwork (IGS). This strange name has some historical reasons.

The network is a private network running over a public WAN provided by a commercial service provider. It is somehow remarkable that due to security reasons it is a pure terrestrial network.

As shown in Figure 1 the IGS has a star-like topology with Col-CC as the central hub. The Col-CC acts as central service provider to all European facilities and as the hub to/for the International Partner sites.

Services provided by Col-CC are:

- Data
  Telemetrie is downlinked from the ISS to MCC-H, HOSC and MCC-M, routed to the Col-CC and from there distributed to the European facilities either raw or processed, depending on the nature of the data
- Commanding for Columbus
  User Control Centres command their payloads via a central command system at Col-CC which routes the commands to the command system at MCC-H for uplink to the station

- Voice
  A central voice system at Col-CC is connected to the voice systems of MCC-H, HOSC and MCC-M. Remote keysets are provided to all European sites directly connected to the voice matrix at Col-CC. A self standing voice system at ATV-CC is connected to Col-CC system.
- Video
  A central video matrix at Col-CC provides access to different video sources like on-board video from MCC-H and MCC-M.
- Ops Support Tools
  A suite of smaller, web-based applications for planning, anomaly handling, logs, information exchange, etc is available at Col-CC. NASA tools are replicated at Col-CC to be accessible from European users via the IGS.
- Connectivity
  Point-to-point connections are configured between some sites for discrete applications.

Multiple User Profile

It is remarkable that this ground segment supports two totally different missions:

- Columbus, the European laboratory and European payload execution on-board the ISS in general and
- ATV, a support and transport vehicle flying to and docking at the station.

Although two different missions operated from two different control centres, it made perfectly sense to use a common infrastructure as the majority of the communication needs are the same. Video, Voice, Ops Support Tools (at least the NASA and Ground Segment tools) are commonly used services. The fact that ATV-CC has a separate voice system is simply related to the chosen system and to ease configuration as both systems are separated. The Telemetry and Telecommand system of ATV is of course separated as well, whereby station data and ATV data while ATV is docked to the station is available via the common data routing system.

Even the payload operations differ depending where the payload is located. Payloads located in the Russian or US segments are using MCC-M or NASA command systems and by-passing the Col-CC systems, payloads located in Columbus are operated via a commanding interface connected to the command system of Col-CC.

On top of real-time operations Training and Simulation activities, Public Relations and service provision to International Partners have to be supported.

One consequence of this multi usage profile was that the ground segment operations and engineering was decoupled from the flight operations. Therefore Col-CC provides two separate functions, Columbus operations and ESA ground segment operations. The ESA ground segment operations running from a dedicated control room within the Col-CC. This is a significant difference to other centres like MCC-H where the Ground Controller (GC) is part of the flight control team and is sitting in the main control room.

This separation of the ground segment requires ground segment requires a separate and decoupled resource planning function.

III. CONTINOUS OPERATIONS

Parallelism of Activities

A standard space mission (e.g. satellite positioning) or even the previous manned short duration missions often have more sequential mission phases.

Design -> Implementation -> Training and Validation -> Execution (launch) -> and post activities.

The continuous operations of the ISS lead to a parallelism of these activities for different mission subsets named increments. During the running increment is executed, the last increment is post-evaluated and the next increment with future payloads is already in preparation. Consequently the ground segment has to support different activities in parallel often with the need that the ground segment is adapted or re-configured for new payload requirements. This leads to execution of simulations and validations activities in parallel to on-going operations with two different configurations of the systems.

To support this, the main ground systems at Col-CC are available three times in different instances:

- **Real-Time**
  for Operations
- **Simulation**
  for Preparation and Training
- **Test**
  for Sustaining Engineering and Validation

All three instances are totally decoupled and can be configured separately to support:

- Different configurations for operations and preparation
- Testing & Validation of new configurations, software/hardware releases and ops products
- Different data basis (rt data vs. sim data)
- Training with Simulator(s) and failure injections

For some systems/services different instances are not feasible. The video system can anyway route different video channels, the voice system is also only one system due to the singularity of the interfaces to the international partners and the keyset distribution in Europe. A separation is done via dedicated voice loops for real-time and simulations.

Facilities have to be doubled as well. The Col-CC has three main control rooms:
- One for real-time operations
- One for simulation and preparation
- A back-up control room in a different building.

All three rooms are connected to different monitoring and control system (3 instances), which can be connected to the different data sources (real-time data or simulators). During routine phases, where no back-up room in hot-stand-by is required, both, the back-up and the non-active control room, are used for preparation activities.

The necessity of this approach can be illustrated with the usage profile of all three control rooms for 2010.

	Usage	Description
K4/3/11	365,0 d	Usage for real-time operations
K4	+259,0 d	Simulation/Test/Maintenance
K3	+201,1 d	
K11	+ 77,3 d	

Table 2: Usage profile of all three main control rooms during 2010

The hours of usage above are summed up to days and the room preparation is not taken into account. It was even surprising for us to find out that on 172,3 days all 3 control rooms were used in parallel!

For the ground segment operations two Ground Operations Control rooms are available:

- the main Ground operations Control Room (GOCR) for real-time operations,
- the back up control room (BUGOR) in the back-up centre.

The back-up room is used for supporting simulations and validation activities by an additional separate Ground Control Team in parallel to real-time operations.

The ground segment is capable to support two different activities in parallel without any interference

Real-time Execution and Simulation or Test

The ATV mission can be supported in parallel to on-going Columbus operations. Whereby only one simulation can be supported at one time (either for Columbus or for ATV) and during critical mission phases of ATV only real-time operations (Columbus and ATV) can be supported. This is due to the complexity of the ATV mission.

Nearly permanent coverage

The ISS uses a relay satellite system for communication with the ground. Consequently the ISS has a nearly permanent coverage. There is an average of less than 10 times per day where a total Loss of Signal (LOS) period is longer than 10 minutes. LOS periods greater than 30 minutes are very rare.

Although very good and comfortable for experiment operations, this coverage is problematic for maintaining the ground systems as these activities should have less or no impact on on-going operations. To deal with this problem the ground operations/planning differentiates between two categories of maintenance:

Planned Maintenance

These are activities someone would normally understand as ‘maintenance activities’. Regular work to keep the systems alive. Activities, which can be planned (hopefully) and prepared way in advance.

The Col-CC engineering team monitors the ground systems permanently and is in close contact with the vendors. Whenever a maintenance activity is needed, an input to the ground operations planning function (described in the following sections) is done. The planner is looking for a feasible timeslot based on the following input:

- urgency/need date
- services affected
- external interfaces affected

- resources required (engineering team/operations teams/vendor)
- impact on operations
- possible impact on other systems
- maximum duration of outage/downtime
- possible workaround

For activities with significant impact on services and operations, the ground operations planner will coordinate with the planners for on-board activities and in parallel the ground controller team will coordinate with the flight control team(s) and external partners via flight notes describing the activity and possible impacts. It has been shown very useful in the past to include major ground activities in the on-board timeline for awareness.

Often such maintenance activities have to be done around LOS slots and sometimes an activity has to be broken up in a sequence of smaller parts fitting in a sequence of some LOS slots. Performing such maintenance in sequence requires a precise planning and discipline of every involved person as it has to be taken into account to stop the maintenance work in-time to be able to restore the service at the end of each LOS.

Another option, to perform maintenance during crew sleep, is not possible as the Col-CC engineering team is staffed during office hours only – everything else would not be affordable.

This planning is a very complex and iterative process requiring a good coordination of all involved cadres and a sufficient lead-time. The most complicated task here is to reflect the needs of all current missions and the possible impact of preparation campaigns of future missions.

Nevertheless real-time operations, especially with astronauts are a very flexible task by nature. Therefore, after all the planning and preparation, the last and final word has still the acting flight operations team on-console. Every activity is started after the ‘go’ of the flight director on-console and is performed in close coordination with him/her.

Another measurement to minimize the impact on real-time operations is of course a strict configuration management process. If possible, every change or upgrade of a system is carefully tested and formally validated using the test facilities/instances described above. A successful validation including the required maintenance procedures is a prerequisite for starting the planning process of a change in the real-time system.

Unplanned Maintenance

This is basically a more diplomatic expression for troubleshooting. Whenever a system has a failure or shows a significant degradation of performance, which requires an immediate action it is the task of the ground control team on console to coordinate the repair with all affected and involved parties.

Taking into account the high service availability needs for manned space operations and ATV, the core network and the essential ground systems at Col-CC are redundant. For most cases the fail-over is automatic, for other cases the ground controller at Col-CC has procedures and tools to manually fail-over or to restore services and to keep service interruptions to a minimum.

However failures have to be localized and analyzed, which is in such a complex ground segment often not an easy task. Especially in an end-to-end service involving systems of different entities (e.g. ESA and NASA), it requires sometimes troubleshooting on both sides to localize where a fault resides.

Any broken equipment has to be exchanged or repaired in a short time frame to restore redundancy again. Software patches may have to be implemented and installed.

In these cases the planning and coordination processes are the same as described above, but executed in near real-time by the on-console personnel. Whereby the configuration management and quality assurance processes are as important as for planned changes at least. Ad-hoc ‘emergency’ processes and decision boards as well as a strong anomaly reporting system are essential for this.

It should be noted that the redundancy of the systems and network can sometimes be more a burden then a help:

- Often the automatic failover mechanism is a single source of failure itself. Outages of a complete service can be caused by a faulty or unsuccessful switch-over to the redundant system. Or the failover mechanism does not initiate a failover because of a wrong status interpretation or a non detection of a failure occurs.

- After a failure and fail-over it has to be ensured that the system does not swap to an undefined state during the repair or at re-activation.

- Switch back after a failure is sometimes more intrusive as the actual failure was.

On the other hand, if it is possible to decouple the redundant path, troubleshooting can be done on the passive path without interfering the operations on the active one. This strategy is sometimes also used for planned upgrades and changes on systems either when it is not possible to use a test facility to validate the changes beforehand or during the change to avoid a service interruption.

IV. LONG LIFETIME

At the moment the ISS life-time is targeted to until at least 2020. The implementation of the ESA ground segment started in 2001 and first part was gone operational already in 2004. Fully in operations is the ground segment since 2006. This means that the systems have to be kept alive for roughly 20 years.

This long life time has to be reflected in the design of the ground segment as well as in the maintenance.

Flexible Integration of New Experiments

The ground segment must be designed modular to be capable to integrate new experiments, new user facilities, and new services.

For this a good and early preparation of new experiments is required. Sometimes it would be even optimal that the ground segment is involved as early as possible in the development phase of an experiment to support the definition phase for communications requirements etc. But most of the time this is not the case. Therefore the ground segment engineering must be very flexible and sometimes just creative.

Long-time Maintenance

The main objective is of course to keep the services of the ground segment up and running over the entire life time with as less as possible service outages and interruptions. This is can be divided into two main tasks:

Preventive maintenance

It is obvious, if you want to keep a system alive, you have to do maintenance on a regular basis. But what does that mean for an IT-System? There is no regular change of oil or an exchange of a drive belt necessary for software after n hours of operations. There are very rare items for such regular mechanical maintenance like batteries, etc..

For most cases it is more reasonable to perform hardware maintenance event driven. Single components of high available equipment like fans, power supplies, hard drives, etc. are by default or have to be redundant implemented. Therefore it is more cost and resource effective to replace such components after a failure has occurred than preventive after pre-defined operations time. In general it should be considered that any preventive exchange does not necessarily guarantees the availability of a component, therefore it is more important to implement effective redundancies.

A continuous and regular (!) in deep monitoring is required to detect failures of components or even degradation in-time - to the most possible extend in real-time. The Col-CC has implemented a hierarchical monitoring system for real-time monitoring: so-called Element Managers monitor dedicated systems and provide summary monitoring information to an umbrella monitoring system operated by the ground controllers on console. In addition to the on-console monitoring, engineers check and analyze off-line during their office hours log files and perform routine system checks on a daily base.

The difficulties of an effective system monitoring are:

- *Filtering/monitoring of meaningful data*
  Among the mass of logging information and parameter a system provides, it is essential to monitor the important data. This is sometimes not easy to asses before a failure occurs.
- *Polling rate of monitoring data*
  There is a trade of between the traffic the frequency of a monitoring parameter request generates on a system and the delay of the detection of a malfunction. A high polling rate can generate a higher load on a network than the actual business data. It has also to be considered, which data rate a human operator can handle.
- *Correlation of monitoring data*
  Which combination of monitoring values indicate which degradation.

Such a monitoring is not set-up in the beginning and left untouched after. It is an iterative process and a daily task of the engineering team to refine the monitoring of the systems over the entire lifetime.

Again an effective and powerful anomaly tracking system (and process) is required to support the maintenance in the following aspects:

- Workflow of maintenance activities
- Documentation and control of changes
- Quality Assurance and Configuration Management
- Knowledge base for later re-occurrence of failures
- Correlation of malfunctions to detect systematic failures, etc.
- Inventory control/spare part status

Spare part handling

To guarantee a fast replacement of failed equipment a stock of spare parts is required, especially for critical services or components.

Col-CC hosts a local spares stock. In addition essential spare parts are stored at external facilities and international partner sites to avoid down times due to shipment of equipment from Col-CC to a facility. Where appropriate and more cost efficient the provision of spares is part of the maintenance contract with dedicated vendors.

Inventory and spare part management is mandatory. It has to be carefully assessed which spare parts are required and distributed to which facilities. Spare parts have to be re-ordered in time after usage. In order to guarantee a fast replacement the spare parts have to be either preconfigured or configurations have to be prepared and stored.

It should also not be forgotten that spare parts have to be maintained as well! A bad example happened once when the replacement of a CPU card in one of the Col-CC systems led to a total system outage as the spare card had a bad battery on-board which caused after a failover and reboot a loss of the system configuration. Due to incomplete system documentation by the vendor the battery maintenance had been overseen.

Obsolescence management

Especially for a long life time an obsolescence management in different aspects is essential.

Every commercial vendor has to be innovative to stay in business. Consequently at least hardware has only a limited time of being produced and more important of being maintained. End of life and end of support times of equipments have to be carefully monitored and taken into account as early as possible. Decisions have to be made:

- To procure enough spare parts (in-time) to survive a certain time after end of support – with this long life time this is not yet an option.
- To search for new products and either support a smooth transition part by part when failure occur or
- To replace each component at once

In the later case a transition plan has to be defined with the scope of minimizing impact on operations. This leads then to a more complex planned maintenance activity to be handled as described above.

Software is often considered as ‘freezeable’ meaning with a certain version of a software, the development (or procurement) of the software can be stopped. The system stays on this software and is not updated any longer. This is only possible in very rare cases if at all.

- Software is running on an operating system, which, especially if it is a commercial operating system, is maintained as well and has a certain life time. It is very likely that it is required to update software to be compatible with a new operating system or patch. Col-CC tried to avoid this by using mainly Linux systems, but…
- Computer hardware has to be supported by the operating system (drivers, processors, patches, etc.). If the computer hardware has to be replaced due to obsolescence, this might require an update of the operating system and in consequence an update of applications as well. So happened at Col-CC e.g. with the exchange of console computers.
- Applications interfacing with other applications and/or services, which are subject to be changed. Either these applications are third party software with a regular patch policy, applications are modified to implement new project requirements, or applications are handled by partner organizations, …

Last not least it should not be forgotten that the IT world is changing very fast and sometimes even entire technologies change or becoming obsolete.

Two years ago the WAN of the ESA ground segment was migrated from ATM technology to MPLS because ATM is not longer supported and offered by commercial service providers. Back-up dial in lines are still ISDN although ISDN is subject to become obsolete in the near future.

The video system has to be migrated from analogue to HD digital as analogue equipment is barely available, more expensive and – this is another driver – not supported by the International Partners any longer.

A last reason can be that a vendor of a system leaves the market for a system for economical reasons (also happened to Col-CC). In this case it might be necessary to exchange components or an entire system with another product of a different vendor.

Sustaining Engineering

The fast and innovative IT world gives also room for locking into new technologies over such a long life time. Apart from obsolescence there are other reasons for migrating systems:

- Better performance
- Lower operating costs
- Cheaper maintenance costs
- Easier maintenance with less resources for engineering and/or operations, which leads again to cheaper operating costs
- New user requirements

It is one task of the engineering team at Col-CC to evaluate new technologies and search for new, easier and cheaper solutions.

The long life time forces the entire project to be very cost effective and to continuously watch for cost reduction options. It has to be permanently evaluated if the user community really requires the provided functionality or if something can be made easier and cheaper. This has the high risk that user needs are overcome by budgetary constraints.

Already Performed Migrations

Although a total operations time from about 7 years, the ESA ground segment has already undergone some major system migrations or renewals:

- *WAN*
  As already described above the entire WAN was changed from ATM technology to MPLS because ATM will not longer be supported by commercial service providers. This required a temporary change of the central communication node at Col-CC to support both technologies in parallel and the step-by-step migration of the different facilities/IGS end points to MPLS. The most intrusive part was of course the migration of the International Partner gateways as data source for the entire ground segment.
- *SAN*
  The central data archive (storage area network) at Col-CC was replaced by another system as major components reached end of support. The difficult part was the migration of the redundant operational systems and that the archive migration went hand-in-hand with a change to a new operating system.
- *LINUX*
  The exchange of the console computers and servers required an update of the operating system together with the portation of nearly all software products including the main monitoring and control software to the new operating system.
- *VoCS*
  As the vendor left the market segment, the maintenance of the Voice Conferencing System at Col-CC became difficult and expensive, especially taking into account the end of life of some components and upcoming changes of interfaces to international partners. The difficulty of the migration was that this system as the central system in the ESA ground Segment had ‘single’ interfaces to the international partners not supporting hybrid connections but have to be migrated at once.

V. GROUND OPERATIONS

In the terminology of ESA’s operations teams within the ISS project, the Ground Control Team (GCT) is the team operating the ESA ground segment from Col-CC. In the opposite to the GCT, Flight Control Teams (FCT) for Columbus at Col-CC, and for ATV in ATV-CC control the spacecrafts Columbus and ATV.

Organization

The complex ground segment and the need to support the different missions and activities via one ground segment led to the separation of the Col-CC Ground Control Team from the FCT. The GCT was organized together with the ground segment engineering team at Col-CC in one department as shown below.

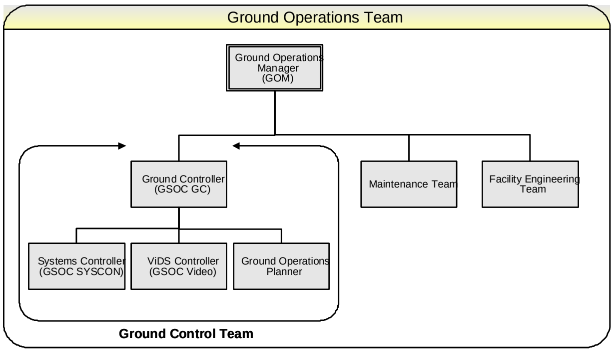

Fig. 2: Ground Operations Team Organization

The Col-CC Ground Operations Team is comprised of the Ground Control Team and the offline Engineering and Maintenance Teams.

Ground Control Team

The Ground Control Team has two console positions

- *The Ground Controller (GC)*
  GCT on-console lead, coordination with all users and international counterparts and responsible for external services

- *The System Controller (Syscon)*
  Technical expert for all Col-CC systems and internal services. Cross-trained with system engineering team to support off-line engineering.

- *Video Controller*
  Staffed by the video engineering team; only on console for dedicated activities

Apart from on-console GC and Syscon, both positions have the off-line tasks to coordinate and support increment preparation as interface between the users and the system engineering team.

System Engineering Team

The system engineering team is comprised by engineers/experts for each dedicated system at Col-CC. The engineers work pure off-line but have dedicated consoles or working places for accessing their systems in the system area.

The close organization and coordination of both functions; ground operations and engineering led to a very effective and fast and well organized ground segment handling.

System Area

In difference to NASA’s approach the GCT at Col-CC is not part of the FCT and is not located in the main control room but has its own control room. This is done because the GCT has to deal with more users than the Columbus FCT and therefore it would more disturb to have the GCT co-located than help.

The Ground Operations Control Room (GOCR) is located in the system area where the main system/server rooms and the main back rooms for system engineering are located. This supports a close coordination between engineering and ground control during maintenance activities. In addition the system area is a high restricted area in both aspects physical and IT access. The location of the control room in this area allows the direct network access to the systems by the GCT on console. This is another difference to e.g. NASA’s approach: the GCT at Col-CC has a much more active role in operating the ground systems. He/she has to actively configure the systems and does level 1 troubleshooting by his own and therefore is equipped with dedicated tools and direct access to the ground systems.

In the beginning, when we set-up this approach of GCT separation it was often said that it is essential that the GC is located in the main control room to ‘feel the atmosphere of the current real-time situation’ and so being able to react faster to the needs of the FCT. It can be said that the first years of operations clearly showed that it was more important to localize the GCT close to the engineering world as it is more difficult to coordinate the system operations with the engineers than to pass on the system status to the FCT and coordinate activities with the FCT via voice loops. Especially because the communication via voice loops is anyway the must between operator consoles.

Ground Segment Planning

One important part of the ground segment operations is the ground segment operations and resource planning.

At Col-CC this planning is a completely self standing function, separate but of course with dedicated interfaces to on-board, mission, and simulation planning functions.

The Ground Operations Planner (GOP) is responsible for planning the resources and the support of the ground segment to real-time operations, simulation and training activities, validation and test activities and ground segment maintenance. For migration projects as well as for increment preparation he/she plays an active role in coordinating the different parties and requirements.

A dedicated planning tool and process was developed for the ground segment planning. The output is a detailed timeline, which acts as the main working guideline for the GCT on console.

The GOP concentrates on the mid-term and short-term planning. The short-term planning is detailed and needs a fine granularity to allow to derive the above mentioned ground operations timeline.

In the past the long-term planning was done by each planning function more or less separately and was coordinated with other planning functions rather late. This sometimes led to situations, where resource conflicts could not be solved because of a late detection. It was experienced that due to the involvement of International Partners, external support, or dependencies on mission preparation milestones activities often have to be planned rather early and therefore a conflict detection and resolution must start in the long-term and mid-term planning already. To deal with this situation a integrated planning working group chaired by all planning functions was established to concentrate on the long-term planning with the main aim of early conflict resolution.

Maintenance Structure

With the organization described above, the Col-CC Ground Operations provides the following maintenance structure:

	Team	Avail.	Description
Level 1	GCT	24/7	User Helpdesk Service Restoration / back-up activation
Level 2	Sys Eng	8/5	Preventive maintenance Trouble shooting
Level 3	Vendor		Vendor support acc. Maintenance contracts

Table 1: Maintenance Structure

Operator Profile

Starting with the usual operator profile for a satellite mission performed by the control centre, we learnt that the ground operator for this complex ground segment must provide additional skills.

User coordination

A manned space mission has per default a need for intensive verbal coordination (voice communication) on various voice loops. In this project the large user community and the different mission objectives expand the need of verbal coordination on the loops even more, especially for the Ground Controller, as he is the point of contact for service requests, ground anomaly reporting and status, maintenance coordination, etc. This is a significant difference to former mission. The GC takes various user requests and has to coordinate with all involved parties as well as he/she actively transport ground segment status and information to users.

During the first months of Columbus operations it was found that the GC needs to play an active role even in on-board troubleshooting of experiments. The user is usually an expert for his/her experiment, but has only rare knowledge of on-board and on-ground dataflow. The dataflow after leaving Columbus and entering the US assets was -to some extend- terra incognita for the Columbus module experts of the FCT as well. AS the Col-CC GC is responsible for the interfaces to NASA, he/she has implicit a quite detailed knowledge about the NASA ground system and the dataflow from the station to the European user. It should be also noted that different type of data are running over different paths on-board and on ground. Therefore the GC became a key position to support payload troubleshooting end-to-end from the experiment to the user console.

This support function was extended further and the GC became a permanent member of a tiger team for supporting payload anomalies. Since then a part of the GC training and certification program is the participation in the Columbus User Level and Columbus Payload Training courses in the European Astronaut Training Centre in Cologne.

Deep System knowledge

For the level 1 maintenance support as described above, the GC and Syscon require deep system knowledge. Although both are provided with a sufficient amount of very detailed troubleshooting and recovery procedures, a complex and highly integrated ground segment requires an understanding and a careful analysis of failures to decide which recovery procedure to apply. Often it is the case that a failure of one system is visible by strange effects on other systems first.

This necessary system knowledge is ensured by a cross-training of the GCT in ground systems engineering and a close coordination between the System Engineering Team and the Ground Control Team. Individual members of the GCT are nominated for dedicated systems and work very close together with the accordant engineers to jointly generate operations procedures and to support validation of system changes. This working relation ship proved to be very effective. One limitation is that the GCT personnel have shift work on console and the majority of the co-operation tasks have to be worked during the rare office days. On the other hand the shift work requires alternative ways to pass information of changes on to the entire team.

The Col-CC GCT uses some web-based information flow tools, a controlled update mechanism of operations procedures and a wiki-style knowledge base for the information propagation.

Profile

The operators at Col-CC have usually an engineering degree or equivalent. Each individual has to undergo a formalized training and certification programme, which lasts for the GCT approximately 6 months.

It is difficult to keep constant shift work attractive for such high profiled personnel over a longer period of time. Therefore the individuals are assigned to different mini-projects like migrations, sustaining engineering tasks, ATV support, etc. to enable them to do work off-console and get further experience in other aspects of the programme.

Nevertheless is has to be dealt with changes of personnel and a recognizable attrition rate. A positive and friendly working relation ship is essential to keep the team motivation. Several initiatives are done to keep the attrition rate low. It would be beneficial to be able to offer alternative positions within the same project. This would keep the knowledge to some extend, which is the main problem. But although such an international project provides always some vacant positions, the amount of free positions in total is of course very low.

Another alternative is a frequent position rotation. This is not envisaged by Col-CC as we see the negative effects at other centre where this is done. The persons stay in the project but the knowledge is lost to some extend due to the amount of job rotations in parallel. Especially operations teams have to re-build up constantly. Furthermore it is still true that an experienced operator get his experience by doing his (one) work for some years.

VI. SUMMARY

The ESA Ground Segment for Columbus and ATV in its distribution capability and requirement implementation led to quite some new approaches for the ground operations.

The long life time and the continuous operations put additional constraints on operations and especially on the maintenance of all systems.

It can indeed be seen and applied as a whole or at least in certain aspects as a precursor for future manned space missions, which require multi-national collaboration.