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THE MULTI-MISSION OPERATIONS CONCEPT AT THE GERMAN SPACE OPERATIONS CENTER

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ABSTRACT

The paper describes capabilities and activities of the German Space Operations Center (GSOC) which operates communication, navigation and earth observation satellites as well as Columbus, a human spaceflight mission. DLR offers its partners operations services for the different mission types on a modular basis. For many mission types DLR has the advantage to further offer the complete end-to-end services by additionally involving DLR's Remote Sensing Data Center and several DLR research institutes like the Remote Sensing Technology, the Microwave and Radar, the Robotics and Mechatronics and the Communications and Navigation institutes, all located at the same DLR site in Oberpfaffenhofen near Munich.

GSOC supports the phases Operations Preparation, Training and Simulation, LEOP Operations, Commissioning Phase, In-Orbit-Tests and Routine Operations as well as the Rundown Phase and Deorbiting. Regarding the Operations Systems GSOC provides the Development, Configuration, Operations and Maintenance of the Flight Operations System (FOS), the Mission Planning System (MPS) and the Flight Dynamics System (FDS). GSOC also manages the Ground Data System (GDS) which comprises the Operations and Maintenance of Control Room Facilities, Computer Systems, Local and Wide Area Networks as well as the DLR Ground Station in Weilheim complemented by a network of Ground Stations of our partner organizations.

The typical Earth observation mission is run at GSOC in a multi mission mode. A single multi-mission operations team (1st level support) monitors and controls up to 6 satellites on 24h/7days a week in the Satellite Control Center. Currently the missions CHAMP, GRACE, BIRD and TerraSAR-X are supported. For communication satellites like the SATCOMBw mission GSOC has a another dedicated 1st level operations team. In both areas there is support given by project dedicated 2nd level subsystem engineers. For Galileo, the new European Navigation Satellite System, another specialized team in the new Galileo Control Center building manages and operates the mission. The future area of On-Orbit Servicing satellite missions will also require a dedicated 1st level operations team, but GSOC seeks synergies on the subsystem operations engineers' level with other missions. The demanding Human Spaceflight mission Columbus requires a dedicated 1st level 24/7 operations team to cover at least six on-console positions at the Columbus Control Center at any time. They are supported by another team which is mainly responsible for facility operations and maintenance.

The paper depicts the synergies of a multi mission control center but also shows the areas where the projects run on independent systems and teams.

INTRODUCTION

German Space Operations Center

GSOC started its space activities in 1968. Since then more than 50 different space missions have been actively supported from its control center in Oberpfaffenhofen, near Munich, Germany, during mission preparation and mission execution. Additionally GSOC's ground station in Weilheim, Germany, has not only contributed to most of the GSOC's own satellite missions but provided tracking support for satellites of many partner organizations and companies all over the world. Currently GSOC is in charge of flying seven missions: ISS Columbus, CHAMP, BIRD, GRACE, SAR-Lupe (BackUp), TerraSAR-X and GIOVE-B. Two new satellites namely COMSATBw1 and TanDEM-X are going to be launched in late 2009, up to 4 new satellites in the year 2010. GSOC is one of the few control centers in the world where human spaceflight and satellite missions are performed under one roof.

The spaceflight activities cover

- operations of Manned Missions like Spacelab, MIR or ISS Columbus
- operations of Earth Observation and Scientific Satellite Missions like ROSAT, Equator-S, CHAMP, GRACE, BIRD, TerraSAR-X, TanDEM-X, TET
- operations of Communication Satellite Missions like TV-Sat, DFS-Kopernikus, EUTELSAT, SATCOMBw
- operations of Europe's Navigation Mission Galileo

Basis for all these kinds of space missions is not only an experienced and motivated operations team but also a reliable ground operations system. The proper and stable operations of communication infrastructure (control rooms, ground stations, data networks) are of highest importance for successful spaceflight operations. In an ever changing world new technologies have to be taken into account if they can be applicable for space operations. Therefore a space technology group has been established to look ahead and come up with new ideas (e.g. on-board navigation systems, mission planning systems) to further improve space operations.

The German Space Operations Center is organized in three departments and one subsidiary covering

- Mission Operations, Project Coordination, Training
- Control Center, Communication, Data Transfer, Ground Stations
- Flight Dynamics, Navigation, Simulations of Rendezvous & Docking
- Galileo Operations, Hosting, Logistics

GSOC has 170 DLR staff and 150 staff from contractor companies, supporting mainly software development, special expertise, peak situations and shift work.

Fig. 1: GSOC with SCC and Col-CC

Satellite Control Center

A variety in type of satellite missions is operated from within the Satellite Control Center (SCC) and the affiliated ground station in Weilheim. Earth Observation satellites in Low Earth Orbit as well as Communication satellites in the Geostationary Orbit require different mission approaches. Dedicated teams for both fields have been built up, still using to the maximum extent tools and processes and procedures wherever appropriate.

Columbus Control Center

A large portion of the work effort at GSOC is dedicated to the operation of the European Columbus module as a part of the ISS. With the docking of the European Columbus module the Columbus Control Center (Col-CC) monitors and controls the Columbus module, configures and operates the ground communications network and coordinates the payload operations. The Columbus Control Center works together with the User Support and Operations Centers (USOC) in nine European countries, the Engineering Support Centers (ESC) in Bremen, Germany and Torino, Italy. Important counterparts are the NASA control centers in Houston and Huntsville as well as the Russian Flight Control Center in Moscow and the JAXA Control Center in Tokyo.

Galileo Control Center

The Galileo Control Center (GCC) is part of the core ground segment. The Galileo navigation satellites are controlled from here and mission data is received through a globally distributed ground station network. The Galileo Control Center is equipped with state-of-the-art infrastructure in order to meet the high demands made on the Galileo infrastructure and to ensure failure-free operation for the next 20 years. Important navigational data as well as the reference time which is relevant for all Galileo applications are generated on the ground in the control centers and transmitted to the Galileo satellites via the ground stations.

Fig. 2: Galileo Control Center

Weilheim Ground Station

The Weilheim Ground Station Complex consists of several spacecraft tracking stations with 3 S-, 1 Ku-, 2 X-, 2 C- and in the future 1 Ka-Band antenna, concentrated in an area of approx. 0.15 km². They provide support for space missions mainly in the S-band and Ku-band frequency ranges.

In compliance with the Consultative Committee for Space Data Systems (CCSDS), the Weilheim station complex is classified as both, a Deep Space Network (Category B), and a Non Deep Space Network (Near Earth Network, Category A).

The stations are operated independently from each other and are equipped with redundant hardware components. The station complex provides an Uninterrupted Power Supply (UPS) System consisting of two redundant commercial electrical power aggregates of 720 kW. All antennas and station facilities are monitored and controlled from a dedicated station control room. The operational support is managed and scheduled by the Control Center at Oberpfaffenhofen.

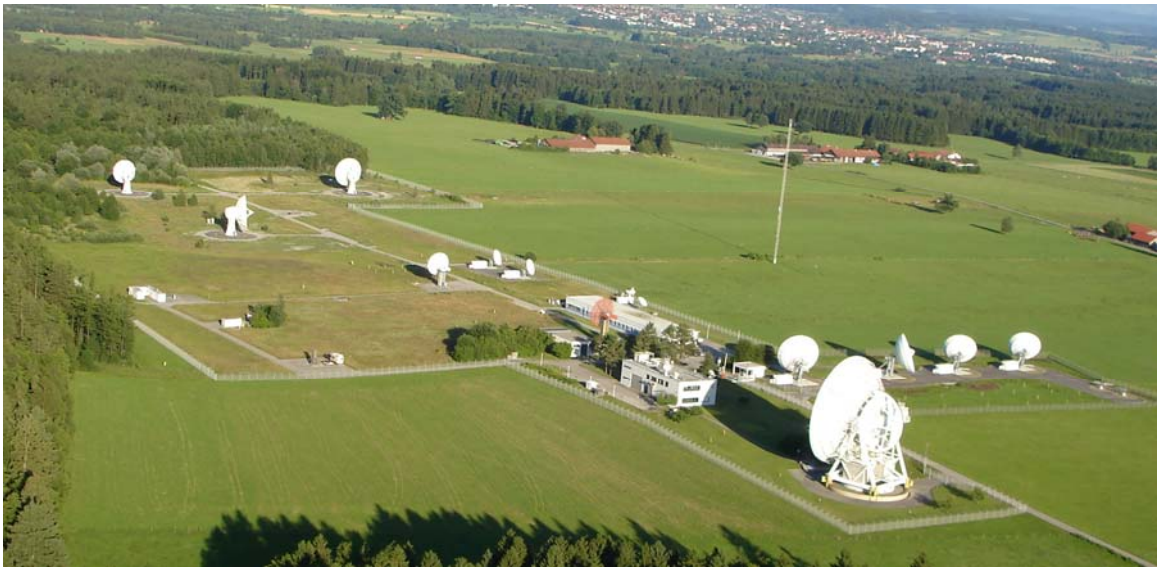

Fig. 3: Weilheim Ground Station Complex

PROJECT PHASES

The German Space Operations Center is involved in most of the space missions covering the complete project cycle. The work is organized along the project phase definition laid down in ECSS, the European Cooperation for Space Standardization, which is an initiative, established to develop a coherent, single set of user-friendly standards for use in all European space activities. The involvement starts with operations related contributions to the various study phases, preliminary studies in Phase 0, feasibility studies in Phase A and Design studies in Phase B. Thorough preparation of the operations facilities and the related activities must be ensured during the Detailed Design Phase (Phase B), the Implementation in Phase C and finally the Integration, Validation, Training and Simulation in Phase D. Status and results of the mission preparation are periodically checked in several reviews, namely the Preliminary Design Review (PDR), the Critical Design Review (CDR), the Technical Acceptance Review (TAR) and finally the Operations Readiness Review (ORR). These reviews form the major milestones in order to control the achieved progress. Operations begin with Phase E1 (LEOP), followed by E2 (Commissioning) and the usually long-lasting Operations Phase E3. The Deorbiting in Phase F should be considered as well although operations are not always possible because of spacecraft anomalies at the end of the lifetime.

SPACE PROJECTS

GSOC has built up an operational infrastructure which requires a certain load and utilization to remain cost efficient. GSOC presents itself as a reliable partner on the space market. Thus GSOC is involved in many missions in different phases (acquisition, preparation or operational phase). Particularly the following projects are currently in acquisition:

- Phase A: DEOS, S-OLEV, SmallGEO, H2Sat, EDRS, TSX-2, BIROS, TanDEM-L
- Phase A/B: HiROS
- Phase B: Asteroid-Finder, Paz (LEOP)

the missions in preparation phase:

- Phase C: TET, EnMAP
- Phase D: TanDEM-X, SATCOMBw

the missions currently in operation:

- Phase E3: CHAMP, GRACE, TerraSAR-X, GIOVE-B, ISS Columbus
- Phase E3: SAR-Lupe (cold backup)

The project driven activities are accompanied by research projects with new topics like Ka/Band technology or increased on-board intelligence.

A complex operations infrastructure needs an ongoing further development in the four areas:

- Flight Operations System
- Mission Planning System
- Flight Dynamic System
- Ground Data System (including Antennas and Control Rooms)

But not only enhancements or new development are to be taken into account, simply the maintenance and minor upgrades require permanent supervision.

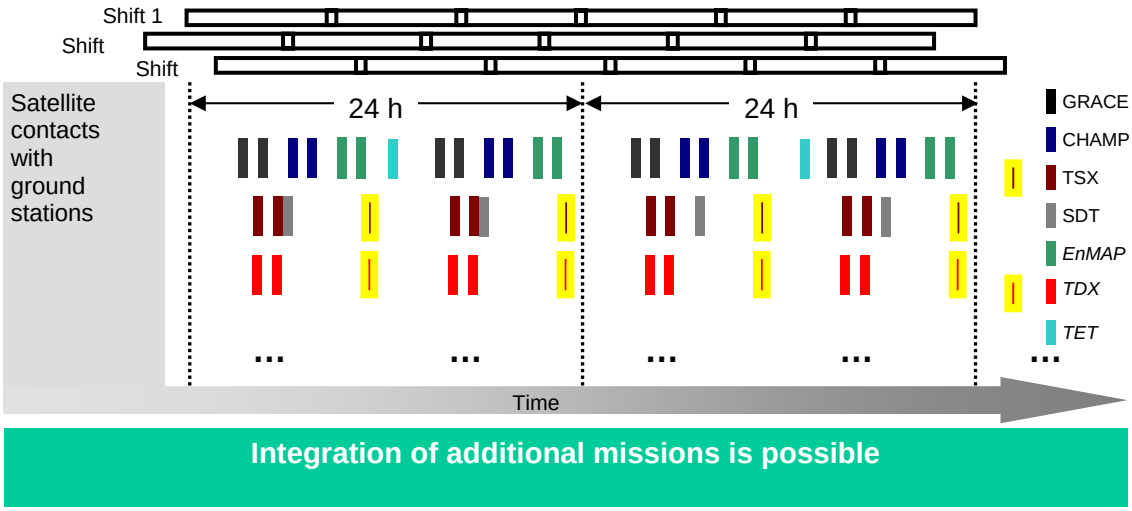

Fig. 4: Multimission Operations Scenario

SYSTEMS AND FACILITIES

Capable and reliable systems and facilities of the ground operations system for space missions are of highest importance.

Flight Operations System

The Flight Operations System is probably the most visible system with the closest contact to space flight operations. It ensures the surveillance and controlling of satellites, the monitoring of satellite subsystems.

The main tool for this purpose is the Mission Control System (MCS), a server based application software with its core elements the mission database and the Telemetry-/Command-System (TM/TC). Since a control center is not always free to select this tool, GSOC decided to introduce an additional layer on top of the TM/TC System, a common display system. A new approach introduces a second additional layer for visualization software showing the animated status of the spacecraft directly connected to real-time telemetry data.
Even though operations centers rely on the gained experiences of many missions this know-how is to be stored and archived and

forwarded to newcomers. It is very important to provide quick and easy access to this data which is nowadays very much facilitated by means of modern software. GSOC uses for its Mission Support System a web based information system which includes handbooks, dictionaries, procedures, services, logging, anomalies and contingencies.

The following software systems are used at GSOC for the Flight Operations System**:**

- TM/TC System (default: SCOS, but also EPOCH and MCS)
- Display System (SATMON, SATMON@Home)
- Visualization System (SatviZ)
- Offline Analysis System
- Procedure Development System (MOIS)
- Mission Support System (OpsWeb)

Additionally there are numerous small project specific Operations Support Tools which are developed or customized by the operations teams themselves.

Mission Planning System

The Mission Planning System generates after processing of all relevant requirements the mission timeline, long-term, mid-term or even short-term. Early in the project it can be used to support the mission analysis, after launch the Mission Planning System is a core system which supports the often complex planning process. It delivers detailed instructions for spacecraft (often direct commands with the related execution time) in the correct syntax to be transferred and used with the TM/TC system.

The Mission Planning System considers time dependencies, constraints, availabilities of resources, generates different solutions and showing the optimized one. The result is a timeline without conflicts.

The software system used at GSOC for the Mission Planning System (developed by DLR staff) includes**:**

- PINTA
- PLATO
- SCOTA
- TIMonWEB
- CMD-exporter
- MPS-database

Flight Dynamics System

The Flight Dynamics System supports the design and operations of a satellite mission with orbit and attitude related tasks.

To fulfill these tasks, the following software tools (among others) are developed and implemented at GSOC:

- Mission analysis (especially for geostationary and Earth-observation missions)
- Orbit and Attitude Determination
- Maneuver Planning for various mission requirements (e.g. geostationary, Low Earth Orbit Keeping, Formation Flying)
- Attitude Analysis for the on-board AOCS
- Precise Orbit Determination (e.g. for Radar Earth Observation Missions)
- Launch Window Computation (especially for geostationary missions)
- Collision avoidance monitoring

Ground Data System

The Ground Data System consists of the infrastructure of the Weilheim Ground Station (GS) as well as the control center infrastructure which supports the other subsystems. The term Ground Data System refers to the function managing the world-wide ground station network. The GS infrastructure comprises the antennae and their equipment on-site. Most of the components are shared with different missions. During LEOP (Launch and Early Orbit Phase) the Ground Station System consists of a world-wide antenna network in order to allow more and longer contacts with the spacecraft. During the routine phases there will be a primary ground station to enable the safe control of the spacecraft.

For redundancy purposes an additional station has to be kept proficient throughout the mission duration. Some stations allow tracking and/or ranging measurements to be used as input for flight dynamics purposes.

The Control Center (CC) infrastructure includes all the technical components that exist in the Control Center many of them are shared between several or all missions. Parts of the CC-Infrastructure are the Control Rooms with the console equipment, the internal data network organized in different LANs, the Voice Communication System, the Uninterrupted Power Supply (UPS) and Air Conditioning System, the Scheduling System, the Video Distribution System, the Automated File Distribution System and a number of other basic subsystems. Included are all communication devices at the Control Center and Ground Stations which have to be used to enable network wide communication traffic for TT&C and scientific data. Depending on the network availability requirements the core network elements are redundant and the links alternately routed. For all these systems a permanent maintenance is in place.

For any new mission several steps of planning, integration and operations have to be performed. Depending on the specific mission requirements the ground station network, the communications network and the mission specific control center architecture has to be evaluated. Coordination of frequencies for ground stations and spacecrafts has to be performed or supported. All subsystems have to be integrated and acceptance tested. Technical and operational interfaces to different agencies like CNES, CSA, ESA, ISRO, KARI, KSAT, NASA, SSC and others have to be specified, negotiated and integrated. All resources used by different missions or customers have to be scheduled and conflicts to be resolved.

End-to-End Chain for Earth Observation missions

For earth observation missions GSOC is in the position to be part of a wider service provider that does not only deal with mission operations but offers the payload ground segment and the instrument operations. The Payload Ground Segment (PGS) is provided by DLR's Remote Sensing Technology Institute and German Remote Sensing Data Center, the Instrument Operations by sensor specialists from DLR's Microwave and Radar Institute (TerraSAR-X), DLR's Remote Sensing Technology Institute (EnMAP), DLR's Institute of Robotics and Mechatronics (TET) and the German Research Centre for Geosciences GFZ (CHAMP, GRACE).

OPERATIONS STAFFING CONCEPT

Over the years GSOC's has developed an Operations Staffing Concept that comprises 24 hours/7 days Operations, 8/5 Engineering Support as well as 8/5 Management Support.

For basic functions there is 24/7 operations coverage, a combination of on-console and On-Call work. At least these three areas are engaged:

- Flight Operations
- Ground System Operations
- Ground Station Operations

Normal 8/5 Engineering Support is provided in most cases for:

- Satellite Subsystem Operations (AOCS/UPS, PWR/THM, TCR/OBC and for Communication Satellites only, Repeater)
- Ground Subsystem Maintenance and Sustaining Engineering
- Ground Station Maintenance and Sustaining Engineering
- Flight Dynamics Analysts

Coordination and overall project management is provided by the Project Management Team on an 8/5 basis:

- Project Manager
- System Manager
- Configuration Manager
- Quality Assurance Manager
- Security Manager
- Contract Manager

In many cases the customer or the scientific community sends staff to the control center, sometimes they are permanently on-site, in other cases they join the operations team on a fly-in basis for special mission phases.

GSOC also benefits from being part of DLR, the German Aerospace Center which provides logistic and specific support for Human Resources, Financial, Legal and Contractual affaires. 40-50% of GSOC's staff is provided by on-site subcontractor companies. Often vendors of hardware or complete systems also have access to the relevant equipment. All in all this setup that was constantly enhanced over many years has proved to be adequate for planning, preparing and conducting space missions by respecting the special project conditions and financial constraints.

OPERATIONS CONCEPTS

As already mentioned GSOC is active in operating missions in various types of orbits leading to different operations concepts.

Earth Observation Satellites in LEOP, Commissioning Test, IOT

GSOC is much experienced in handling the special requirements of initial operations. In the majority of the satellite missions GSOC's assignment included the Launch and Early Orbit Phase (LEOP) Operations. Following the LEOP (Phase E1) GSOC actively supports the Commissioning Tests and In-Orbit-Tests (IOT, Phase E2).

In the first days of a Low Earth Orbiting (LEO) satellite mission GSOC strongly recommends a minimum of one contact (of 10 minutes each) in each orbit. For special activities two consecutive contacts are desirable.

Earth Observation Satellites in "Routine" Operations

As a default GSOC's "Routine" Operations Concept for LEO satellites foresees 2 contact-sessions per day. One additional contact in each orbit can be made possible if required, e.g. for faster system response times.

GSOC's Earth Observation Missions Multi Mission Scenario was established in the years 2000-2002 when CHAMP, BIRD and two GRACE satellites were launched. The "Routine" Operations are provided permanently (24/7), day and night. There is more than one shift in case of parallel activities. This concept proved to be highly efficient through the synergies between various Earth Observation missions.

The Multi Mission Scenario has to respect some prerequisites and constraints. Every 6 to 12 hours there is a contact session (see Fig. 4). The duration of each contact including pre- and post-pass is approximately one hour. The contact sessions of different missions are in most cases not simultaneously. The specified satellite autonomy (12 to 72 hours) helps to handle overlapping passes. There is no dedicated team required for each mission taking advantage of the similarities in the subsystems of the different satellites.

The 3-Level Support Concept

Mission Operations is based on a 3-level support concept:

- 1st level: on-console operators (24/7)
- 2nd level support: On-Call sub-system engineers
- 3rd level support: Satellite H/W-experts

For levels-1 and -2 experience and the expertise of various missions are required.

The level-1 support is provided by on-console operators working 24/7. They are mission independent shift-operators (8.5h each) in different shifts. Their main tasks are TM/TC-checks, satellite health check and spacecraft commanding. Their tasks include problem solving according to available procedures. If they are not able to solve a problem alone they can call the level-2 support. This level-1 task is usually subcontracted. The minimum qualification of the involved staff is a bachelor's degree.

The level-2 support relies on subsystem engineers belonging to a mission independent pool. The normal working hours and together with On-Call cover 24/7. The level-2 main tasks are the handling of serious problems which could not be solved by operators (fast satellite recovery), problem solving according to needs; development of new flight procedures, validation of new S/W and new procedures. In the event of problems that can not be solved alone they are entitled to contact the level-3 support.

The level-2 staff is mainly DLR staff with a minimum qualification of a master's degree. The required On-Call team consists of:

- 1 Flight Operations Director (FOD) / DATA OPS (merged)
- 1 Attitude & Orbit Control System (AOCS)
- 1 Power & Thermal System (PTS)
- 1 TeleMetry & TeleCommand / OnBoard Computer (TMTC / OBC)
- 1 Mission-Planning-System (MPS)
- 1 Flight Dynamics (FD)

A MOS/FD/MPS On-Call team member has to be always in reach of the control center within less than one hour. All On-Call team members on duty can be contacted via mobile phone. They are capable to access documentation and spacecraft telemetry via Netbooks/PDA, UMTS sticks, and SATMON@HOME (for telemetry monitoring). Via the Internet access they are able to react by providing traceable recommendations for monitoring and control.

The level-3 support is provided by the spacecraft manufacturer's sub-system engineers. The experts are mainly mission dependant and usually only available on a 8/5 basis. They have dedicated contracts for each mission. Their main tasks are the adaptation and further development of new procedures and of new spacecraft software.

Communication Satellites Ops. Concept

For Communication Satellites the Multimission Operations Concept foresees a dedicated operations team with 24 hour coverage (level 1). It is comprised by a 24 h shift team (3*8.5 hours) and several satellite subsystem experts to provide the require expertise for the satellite subsystems AOCS/UPS, PWR/THM, OBC/DH/TCR and Repeater.

Columbus Operations Concept

Within the Columbus Mission Operations Service (MOS) contracted to DLR a 24/7 coverage (level-1) in the Columbus Control Center (Col-CC) for the 4 Flight Control Team (FCT) positions, the Flight Director (FD), Operations Coordinator / Columbus Operations Planner (OC/COP), Data Management System / Communications Officer (DMS/COMMS) and Columbus Systems (SYSTEMS) is requested. Within the Facility Operations and Maintenance (FOM) service two Ground Control Team (GCT) positions, the Ground Controller (GC) and the System Controller (SYSCON) also work on a 24/7 basis.

An 8/5 coverage is sufficient within the MOS service for the two project managers and the two Ops Support Tools (OST) software engineers and within FOM for two Ground Operations Managers (GOM), two Ground Operations Planners (GOP) and the experts for the 10 Col-CC subsystems.

On request (when needed) support is given by other GSOC staff out of GSOC's multi-mission environment.

The experience of the first months of Columbus operations showed that for many of the highly skilled first level staff pure on-console work is not acceptable for more than 3 or 4 months. Others operations team members took over the off-console tasks, but they were starting to loose the contact with the real-time operations world. Together with the Columbus Industrial Operator Team the number of FCT members was slightly enhanced. The whole FCT now comprises a pool of 10-11 certified FCT members for each of the 4 positions and the related off-console work.

In each position there are another 2-3 engineers on a one year training and certification program. With the new concept the on-console time of each one of the flight controllers could be reduced to 70% and in other cases down to 50% (depending on the additional tasks). The increased number of off-console days and the diversified tasks substantially helped to reduce the attrition rate in this project.

ON-CALL CONCEPTS

The above described 3-level operations concept requires a properly installed On-Call concept. A maximum of 30 days within 3 months in which the staff can be asked to be On-Call has to be respected. GSOC introduced two different kind of On-Call scenarios.

Satellite Operations

The Satellite Control Center On-Call Concept foresees for the 2nd Level support On-Call availability on a weekly basis from Monday 12:00 to next Monday 12:00. Outside the normal office hours the staff is expected to come in no later than one hour after being called in. However, in many cases the common analysis of the situation by phone contact already helps to overcome the problem. By the newly introduced means (better access to spacecraft telemetry and other operations support tools) the process of problem solving has improved.

Columbus Operations

The On-Call Concept for the Columbus Control Center differs between off-console positions (Col-CC subsystem experts, project managers) and FCT members. On-Call for off-console staff is requested on a weekly basis. In phases of Critical Columbus Operations On-Call availability can be extended to a larger team. The special scenario for on-console FCT positions foresees an On-Call period starting 8 hours before beginning of the shift work. The reason is to cover potential no-shows of an FCT member of the following shift. In case a team member announces that he is not able to come for whichever reason (illness, accident, …) the flight controller on-console has to stay 4 hours longer and the one of the next shift is supposed to come in 4 hours earlier. Thus he has to be informed up to 8 hours in advance compared to his planned shift begin.

CONCLUSION AND OUTLOOK

Since 1968 GSOC has successfully prepared and performed mission operations for more than 50 missions. The variety of satellite missions comprises earth observation missions in Low Earth Orbit (LEO), the navigation satellite mission Galileo in Medium Earth Orbit (MEO) as well as communication satellite missions in the Geostationary Orbit (GEO). The complex ISS Columbus mission operations made human spaceflight very visible at GSOC.

Over the last two decades there was a constant development towards stronger cooperation with partners outside DLR. The variety of customers allowed GSOC to gain expertise under numerous conditions. The new situation forced GSOC to find new efficient operations concepts in order to respond to the different requirements defined by the different projects.

Especially the Multimission operations concept of operating a family of spacecraft paved the way towards cost-efficient operations without increasing risk compared to stand-alone mission operations. Introducing the 3-level and the advanced On-Call concept proved to be very successful.

GSOC strives to extend its services around the core mission operations and will enhance its involvement in payload operations as part of an overall end-to-end service. For the coming years GSOC continues to consider itself a partner for DLR institutes, other agencies, industry and academia offering modern and reliable facilities as well as motivated and experienced staff.