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Galileo Constellation Operations, Training and Simulations

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From the first GALILEO Launch in October 2011 the GALILEO operations preparation, planning and execution have evolved in parallel with dedicated training and simulations process and organization refinement. The GALILEO Operations Training and Simulations process is based on the certification requirements and its plan and schedule is adapted to face the different operations phases and lifecycle of each new spacecraft of the GALILEO constellation taking into consideration personnel specific background, role and tasks. Being GALILEO a satellites constellation based system with a ground control and mission segments placed in different European countries, its operations requirements are very high. The constellation schema foresees parallel control and maintenance of all spacecraft in a long time and evolving scenario. It means that Spacecraft Operations have to monitor and control several satellites while preparing, in parallel, the operations of the future ones to be launched until the end of the full constellation deployment. The paper describes the Training and Simulations activities carried out by DLR GfR at the GALILEO Control Centre in Oberpfaffenhofen, how these activities have evolved from the first GALILEO launch to now and what is foreseen to happen in the future during the constellation development phase until full deployment, when the GALILEO system full operational capability will permit the provision of the GALILEO Navigation Services to the world users community. The paper focuses on the high level of expertise and competence of DLR GfR personnel gained within the In Orbit Validation and Full Operational Capability phases of the GALILEO program and on the challenges DLR GfR will face with the GALILEO Constellation Operations, Training and Simulations in the future.

Nomenclature

m	=	total number of simulations
n	=	simulation number
k	=	number of certification simulations
T_0	=	simulation start in GST
d	=	day

I. Introduction

GALILEO is Europe's program for a Global Navigation Satellite System (GNSS), providing a highly accurate, guaranteed global positioning and timing service. The complete GALILEO constellation will consist of 30 satellites in three orbital planes at an angle of 56 degrees to the equator. With the satellites taking about 14 hours to orbit Earth at altitudes of 23 222 km, there will always be at least four satellites visible anywhere in the world[1].

The IOV phase is the first of three incremental implementation steps or mission phases to develop the GALILEO System and to validate its in-orbit performance. The Full Operational Capability (FOC) phase will deploy in full the ground and space infrastructure as required to achieve full operational capability. The purpose of the final Exploitation phase is to operate the FOC infrastructure and to provide navigation services over the entire system lifetime. The Galileo core system components are the Space Segment (SSEG) including launch services, the GALILEO Control Segment (GCS) and the GALILEO Mission Segment (GMS). The GCS is operated by the DLR Gesellschaft für Raumfahrtanwendungen (GfR) mbH as a company of the German Aerospace Center DLR, having its seat at the Galileo Control Center (GCC-D) in Oberpfaffenhofen. The GMS is operated by Telespazio SpA as a company of

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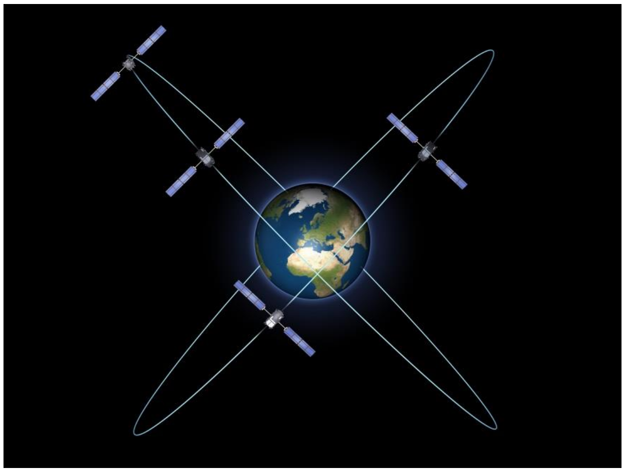

Figure 1. Simulated 3-dimensional view of the GALILEO IOV constellation (IOV PFM, FM2, FM3 and FM4 satellites)

Finmeccanica and Thales at the Galileo Control Center (GCC-I) in Fucino.

In addition to the ground segments, support facilities have to be available as they are fundamental for the deployment, validation and maintenance of the GALILEO system. Launch and Early Operations Phase (LEOP) Control Centers (LOCCs) at CNES in Toulouse and ESOC in Darmstadt are required for providing LEOP services for all satellites of the GALILEO constellation. An In-Orbit Test (IOT) Station in Redu (B) is setup for providing a means to test the satellite functions and performance after launch and separation. The IOV constellation consists of 4 satellites and provides the capability of broadcasting globally a set of navigation signals and other navigation data supporting a number of services. The IOV constellation depicted in Fig. 1 is thus the first step towards the final FOC constellation of 30 satellites. On October 21, 2011 the successful launch of the first two GALILEO satellites IOV L1 PFM and IOV L1 FM2 took place initiating the IOV phase followed by successful IOV L1 IOT campaign. On October 12, 2012 the successful launch of the second two GALILEO satellites IOV L2 FM3 and IOV L2 FM4 took place followed by successful IOV L2 IOT campaign.

The training of personnel for the first (IOV L1) and second (IOV L2) launches was based on a Training Need Analysis (TNA) provided by the customer. The main objectives of the IOV L1 and L2 simulations campaigns were to train and validate personnel for all operational phases as well as to validate systems and interfaces. After the IOV L1 IOT campaign, the training plan had to be revised according to changing training needs and requirements imposing a more certification-based training approach. The following section describes the GCC training and certification process applied to the GALILEO satellites of the FOC phase starting with the launch of the GALILEO satellites FOC L3 FM1 and FM2.

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II. The GCC Training and Certification Process

To develop and propose an appropriate GCC training and certification process several post-launch (IOV L1 and L2) requirements have been taken into account from which the most important ones are: (i) Changing task-, team- and role-based training needs, (ii) Refresher or recurrent training for experienced and qualified engineers to maintain qualification/certification, (iii) Possibility of cross- and re-certification, (iv) Flexibility regarding training methods and time slots to account for changing resource constraints, trainee and trainer availability, (v) Assessment of trainees to measure their system knowledge and qualification progress by means of written or verbal tests and assessment reports, (vi) Simulation campaign as the last training method to validate, qualify or certify personnel for real operations, and finally (vii) Trainers are assumed to have appropriate training skills and expertise in their training subjects.

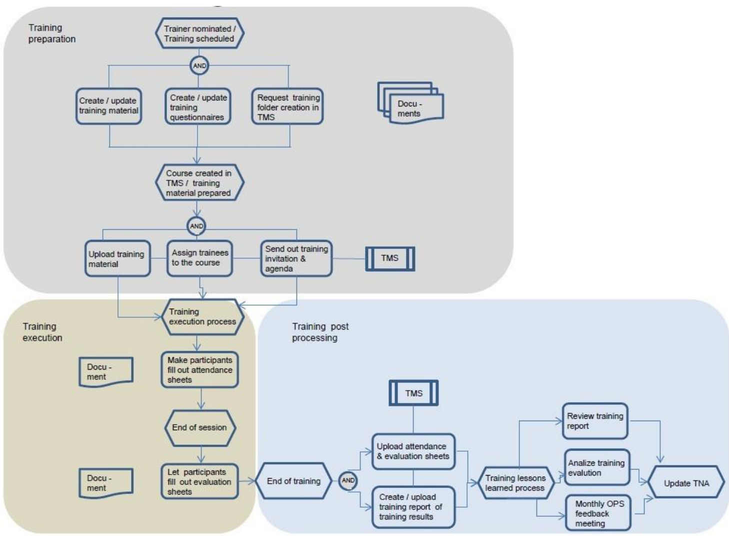

Figure 2. The GALILEO Operations Training Process Trainer view

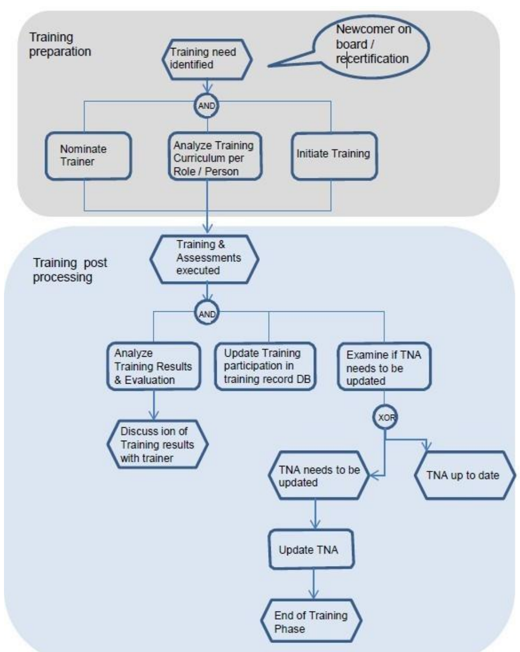

Figure 3. The GALILEO Operations Training Process Local Training Manager view

Fig. 3 and Fig. 4 describe the contents and chronological order of main training processes from the trainer and local training manager perspective.

Based upon these requirements, a multi-level training approach with three different training process entry levels

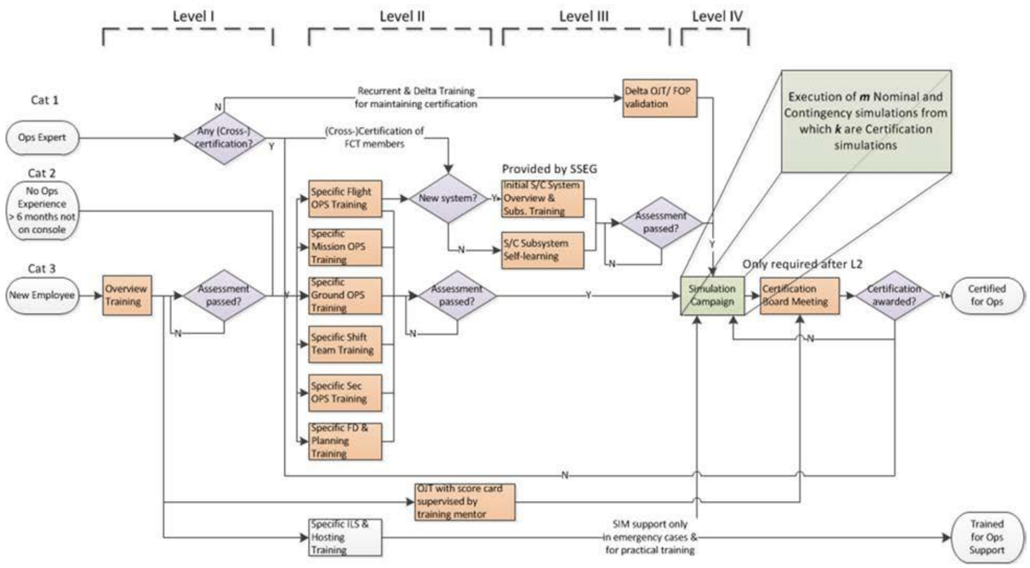

Figure 4. The GCC multi-level training and certification process with its three different training process entry categories accounting for different training needs, system knowledge and operational experience of trainees. The process is planned to be re-started ~ 7 months prior to each launch assuming a training period of ~ 6 months.

has been developed. The process is depicted in Fig. 4. The core process starts with the Cat 3 trainee – new employee – who has to go through the whole training curriculum from Level I to IV to achieve the required level of skills and knowledge for certification. So-called training and simulation participation matrices assign roles and trainees to Level I – III courses so that every candidate knows which course she or he has to take. Waivers may be requested for certain training courses if the Cat 3 trainee can prove knowledge and/or former operations experience. Recurrent and delta training as well as training for supporting teams like IT and network operations support is captured by training side processes. If cross-certification is desired the Cat 1 trainee has to step in again on Level II of the process. In case of cross-certification within the Flight Operations team the Cat 1 trainee can directly start with Level III training. The process has to be re-started ~ 7 months prior to each launch assuming a training period of ~ 6 months. In the following, scope and purpose of the training levels are described in more detail.

Level I

Level I is the GALILEO system overview training with GCS and GMS introductory courses. It is applicable to all newcomers regardless of their role and task. For this reason, Level I training shall be organized in a 4- or 5-day block with theoretical presentations done by the trainers. This approach allows trainees to socialize with each other and experts to refresh basic system knowledge. A multiple choice test has to be successfully answered for each introductory course as qualification for the next training level. On-the-Job Training (OJT) already starts during or after Level I training sessions and is continued throughout the training process. Training mentors create lists of tasks to be performed by the teams. These lists will be used to create so-called scorecards in which the trainee's OJT tasks are scored. Each time an experienced engineer judges that the trainee is proficient on a task he signs off the score on the trainee's scorecard. Each team member has her or his specific OJT scorecard based on her or his specific role and tasks.

Level II

Level II is meant to be the operations specialist training consisting of task- and role-specific training courses for GCS and GMS teams like the Flight, Ground and Mission operations teams. Level II training shall be done as self-learning combined with practical exercises. In case of multiple needs from trainees of different teams, a classroom presentation can be setup. A multiple choice test has to be successfully answered for certification-relevant courses as qualification for the next training level. Practical exercises will be assessed by the trainer, complemented by discussion with the trainee team.

Level III

Level III is an intermediate training level mainly devoted to the Flight Ops team. This level covers satellite subsystem training and is supposed to be done by self-learning. A subsequent verbal assessment by the training mentor will qualify the trainee for the final simulation campaign. The trainee has to answer to a questionnaire with open questions. Initial subsystem training will be provided by SSEG in case of a new satellite system. Subsequent assessment is done by multiple choice tests provided by the manufacturer.

Level IV

Level IV is the simulations campaign training for final qualification and certification. The successful accomplishment of all previous training levels is a prerequisite. The objective of this approach is to assess and certify system knowledge/system matter expertise, to assess and certify operational skills and awareness for nominal and contingency operations under realistic conditions. The simulations officer will assess the performance in a final certification simulation related to specific objectives defined in the certification profile. The number of certification simulations k and which simulation will be a certifying one depends on certification needs of personnel. The assessment report or certification profile card is the most important reference for final evaluation in the Certification Board (CB) meeting. If a trainee has failed her or his certification simulation the CB has to decide if the candidate has to do another certification simulation or repeat the training starting from Level II (see Fig. 2).

A simulations campaign can also be seen as a main validation step of a mission operational validation approach. The satellite and ground simulator is the prime data source for ground segment validation testing, for staff training and for exercising the complete ground system in a predefined series of simulations prior to launch[2]. The system simulator is also required as a means of validating operational procedures. As already mentioned in the introduction, this approach has been mainly applied to the IOV L1 and L2 training and simulations campaigns. However, FOC simulation campaigns will have to focus on training and certification of personnel. Additional system and operational product validation needs will be covered by delta training, i.e., delta systems and Flight Operations Procedure (FOP) validations performed by qualified operations experts (see Fig. 2). For systems and FOP validation purposes, the simulations officer normally setup dedicated validation simulations. For the IOV L2 simulations campaign, training-relevant and validation-relevant simulations have been combined to keep up with the pace of the project. Training and validation simulations can be further used to create training relevant S/C configurations for breakpoints generation. That reduces the time effort to prepare simulations.

III. Simulations Planning and Execution

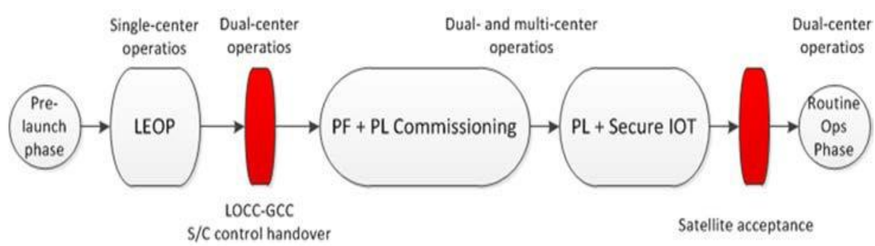

Figure 5. The GALILEO operational phases with single, dual- and multi-centers Operations

LOCC and GCC simulations campaigns validate, qualify or certify trainees and teams for the satellite operational phases shown in Fig. 6. The simulations campaign plans provided by the simulations officers of each center prior to each simulations campaign defines the total number m of simulations, the scenarios and the schedule required to train and validate their personnel. In case of a new satellite system (e.g. the FOC SSEG w.r.t. the IOV SSEG) the entire Flight Operations team has to be certified for opera- ting the new satellites, meaning that Flight Ops team members have to re-start the training process on Level III (see Fig. 4). The LOCC flight operation team needs to be re-trained and re-validated for the critical LEOPs of the next launches as well, especially for FOC L3 although certification is not required.

The sequence for a simulation *n* within the simulations campaign is divided in three major phases: Phase I – simulation preparation, Phase II – simulation execution and Phase III - simulation follow-up work. The flow or process is presented in Fig. 6.

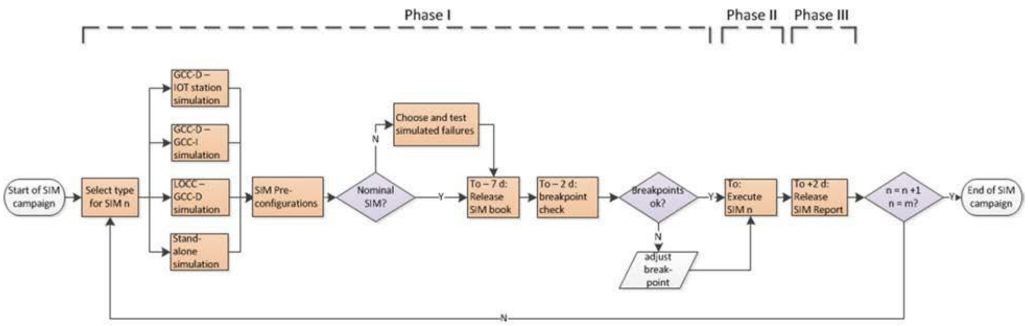

Figure 6. The applied simulation planning and execution sequence for a stand-alone or multi-control-centers simulation *n* with its three distinct phases: I – preparation, II – execution and III – follow-up work. The simulations campaign is accomplished when the total number of planned simulations *m* is reached.

Phase I

In order to prepare a simulation the first step is to choose the simulation type. The following stand-alone and multi-control-centers simulations types are considered:

1. Joint GCC-D and IOT station simulation, also referred to as inter-sites simulation
2. Joint GCC-D and GCC-I simulation, also referred to as GCC inter-control-center simulation
3. Joint LOCC and GCC-D simulation, also referred to as LOCC/GCC inter-control-center simulation
4. Stand-alone simulation

LOCC simulations only consist of types 3 and 4 whereas GCC-D and GCC-I simulations consist of all types. IOT station personnel are only remotely involved since this center does not have its own simulator. Single-center operations are always trained through stand-alone simulations. Training for dual-center operations considers stand-alone and inter-control-centers simulations. Platform (PF) commissioning scenarios are trained in stand-alone simulations at GCC-D whilst LEOP scenarios are trained in stand-alone simulations at LOCC. Command and Control handover and special operations like the drift stop maneuvers are typical scenarios for joint LOCC/GCC inter-control-centers simulations. The drift maneuvers are started in LEOP. During the satellites' drift to its target position within the orbital plane the LOCC and GCC-D still exchange Flight Dynamics (FD) products until official FD handover to GCC-D after Payload (PL) IOT. PL and secure IOT operations require multi-control-centers operations, thus the involvement of all 4 centers LOCC, GCC-D, GCC-I and the IOT station but not necessarily at the same time. Training is therefore performed through alternating inter-sites or inter-control-centers simulations. Routine contact scenarios are trained in the framework of GCC inter-control-centers simulations, thus as a joint GCC-D/GCC-I simulation.

Each simulation type requires pre-configurations and definitions, i.e., a scenario description, general information, initial spacecraft (S/C) and environment configurations, participating trainees and teams, ground elements and infrastructure setup as well as an activity timeline. S/C systems and environment are configured on the simulator by the simulations officer and saved as a so-called "breakpoint" that is a huge data vector containing the status of all modeled parameters for a certain simulated epoch. The detailed Sequence of Events (SoE) is created by the planning team based on the simulation book provided by the simulations officer. The SoE mainly lists all events and activities to be executed for a satellite in a chronological order and with procedures references. The overall timeline can then be visualized in the training or control room as a Gantt chart, also highlighting ground stations visibilities and contacts durations. The entire configuration is described in a simulation book at GCC-D and in a briefing note at LOCC. In case of a contingency simulation, the simulations officer has to define failure cases and to eventually test them on the simulator. To do so she or he restores the breakpoint, sets the simulator in run mode and injects available failure commands and tests them especially regarding Failure Detection, Isolation and Recovery (FDIR) reactions.

About 7 days prior to starting the simulation session, the simulations officer releases the simulation book or the briefing note and invites the participating personnel. In case of multi-control-centers simulations, a joint simulation book or briefing note is the preferred solution. About 2 days before simulation start, the simulations officer checks the initial S/C configuration together with Flight operations team member and trainees by restoring the breakpoint and setting the simulator in run mode. In case of deviations, the simulations officer adjusts the breakpoint and saves it again. Typical deviations are missing TM packets or a wrong S/C unit configuration.

Phase II

The simulation day normally starts with the setup and configuration of the simulator for which the support of the ground team is required. Especially for time-tagged commanding in routine contacts or maneuvers simulations the system time has to be synchronized with the simulated epoch which is normally in the future. This requires a time configuration of the S/C monitoring and control system. Meanwhile, the training room infrastructure is configured by the hosting team to display the Gantt chart, S/C monitoring and control events and times on special screens. At GCC-D the simulation briefing is done in a meeting room (usually the day before the simulation execution) in which the simulations officer describes scenario, training objectives, important events and the initial S/C configuration. In case of multi-control-centers simulations, a joint simulation briefing is performed in teleconference with the other centers. Before the simulation start the trainees prepare their consoles for the simulation. At T_0 the simulator is set in run mode and the start of the simulation is announced by the simulations officer in the simulations studio via the operations voice loop. After simulation end the simulations officer invites the team to a simulations de-briefing (usually the day after the simulation execution) to discuss observations, simulated or real anomalies, change requests and learning effects.

Phase III

The follow-up work is to analyze all raised observation reports, change and planning requests. These reports and requests are tracked in the anomaly tracking tool in which special GCC projects are available for simulations and training purposes. Based upon the simulation observations reports, planning and change requests as well as debriefing and personal notes, the simulations officer writes and releases the simulation report containing the performance assessment of trainees and teams w.r.t. training and certification objectives.

In the following section, the configuration of the LOCC/GCC inter-control-centers simulation will be explained in more detail since the command and control handover is considered as a critical phase in which satellites are handed over from one control entity to another one and requiring a special setup.

IV. The joint LOCC-GCC Control Handover Simulation

In order to handover the control of a spacecraft from LOCC to GCC in a controlled and well-structured way the handover phase has been split into the following sub-phases: (i) pre-handover, (ii) handover and (iii) post-handover phase. The handover of a spacecraft from LOCC to GCC has always to take place in a joint pass that ensures that both control centers have adequate duration, visibility and access to the spacecraft to complete the handover activities. The pre-handover phase is devoted to joint FD activities like orbit determination whereas in the main handover phase the GCC-D flight ops team takes over responsibility by sending first test and up-linking time- tagged commands via the GCS ground stations. The handover phase is formally accomplished when the GCC-D operations director signs off a formal handover report sent by the LOCC operations director. The purpose of the post-handover phase is to archive the entire LEOP Telemetry (TM) and Tele- command (TC) history pro- vided by LOCC.

The main objectives of the command and control handover simulation were to exercise the interfaces between the different teams, especially between the flight operations and the FD team and to validate operational interfaces and handover operations. Interfaces are required for (a) real-time TM and TC data transfer between LOCC and GCC, (b) near real-time TM flow from GCC to LOCC realized by rapid file transfer, (c) FD data transfer from

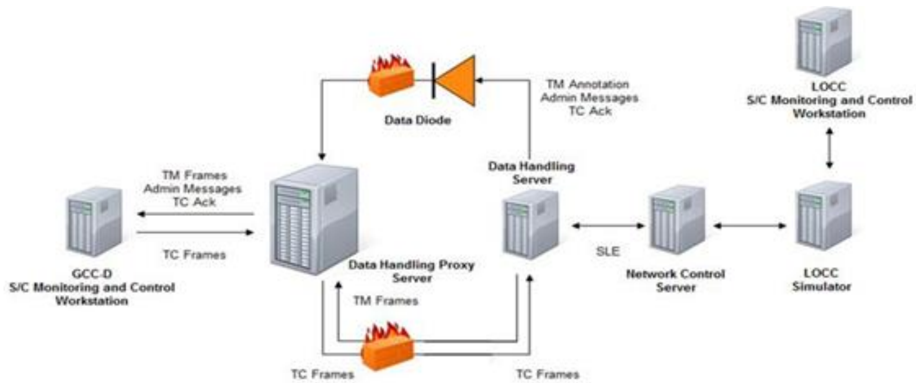

Figure 7. Sketch of the network setup for an inter-control-centers simulation in which one simulator sends real-time TM data to the S/C controlling workstations of both centers and receives real-time TC data coming from both S/C controlling workstations

LOCC to GCC and (d) voice communication links. Rapid files contain chunks of recorded TM. To transfer orbit information from LOCC to GCC and rapid files back to LOCC the standard GALILEO data distribution network is used. For verbal communication between both centers dedicated loops of the voice communication system are used. To train and validate all these interfaces as well as the handover operations in a joint LOCC/GCC inter-control-center simulation the following constraints had to be taken into account: Starting with identical initial S/C and thus breakpoint conditions, choosing a site in which GCS and LEOP ground stations are very close to each other, and finally having an uninterrupted simulation run.

The requirement to transfer TM and TC frames in real-time and the other constraints imposed a special network setup between LOCC and GCC-D in which only one simulator shall run the entire simulation. The simulator has to send TM packets to the S/C monitoring control systems of both centers and has to receive TC packets coming from both S/C control systems. Due to technical constraints and time synchronization issues the LOCC simulator had been selected to run the joint simulation which required a re-configuration of the LOCC simulator such that it is able to also model the selected GCS ground stations. The GCC-D S/C controlling system time had to be synchronized with the LOCC S/C controlling system time running in the future. Fig. 7 depicts a sketch of a possible network setup required for inter-control-centers simulations. To send simulated TM and receive TC packets to and from GCC-D the LOCC simulator is connected via a so-called network control server to the data handling server in the GCC-D training room where they are parsed or assembled. From there TM annotations, TM messages and TC acknowledgements are unidirectional forwarded to a proxy server whilst TM and TC frames can only be routed bi-directional to and from the proxy server.

An alternative would have been a setup in which the GCC-D simulator takes over the control of the simulation for example after the handover phase or even earlier. This would have implied a short stop of the simulation, saving the breakpoint, sending it to GCC-D, restoring it on the GCC-D simulator and re-configuring the GCC-D S/C monitoring and control system. This approach was deemed to be too risky and would cause an inacceptable interruption of the simulation. However, it was deemed to be very useful for the stand-alone PF commissioning simulations at GCC-D since the saved and transferred LOCC handover breakpoint allowed a seamless continuation of further stand-alone PF commissioning simulations at GCC-D using the handover breakpoint as the initial PF commissioning breakpoint.

V. Satellite Simulator

The satellite simulator provides a simulation of the GALILEO constellation of satellites, as well as the ground control network of TT&C stations. For each satellite, the simulator provides a behavioral model which responds to TC and provides downlinked TM information. The simulator is capable of defining, storing and running a range of constellation satellites and ground station scenarios. These scenarios are to reflect the evolving configuration of the constellation and ground segment as well as failure conditions in various system elements. The simulator will be used by the Operations Team to assist with the validation of operational products as well as providing a training environment to exercise nominal and anomalous operational situations.

Simulation activities play a central role in GCS operations preparation, validation and training pertaining to routine, special and contingency operations. Specifically simulation activities are used in support of:

1. development and validation of routine, special and contingency flight operating procedures
2. validation of on-board software patches prior to upload to the spacecraft
3. simulation of satellite and TT&C failure conditions
4. satellite fault diagnosis through the simulation of candidate scenarios
5. satellite TM/TC database validation
6. new software implementation validation
7. operations staff training
8. operations rehearsals

Intensive simulation campaigns will be performed prior to the launch of the first IOV satellites and then again prior to the launch of subsequent satellites. In addition a certain amount of simulation activity is foreseen throughout the mission lifetime in support of:

1. the training of new operations staff
2. refresher training for existing operations staff
3. procedure development and validation to enhance operations or accommodate changing circumstance e.g. a satellite failure

It is important that the simulation environment is as representative of the real operating environment as possible in order that simulations are performed with a high degree of fidelity. Individual satellites within the constellation are faithfully simulated using "real" on-board software, provided by the satellite manufacturer, running within an emulated execution environment. The simulator accepts, reacts to and rejects all TCs that the real satellite would accept, react to or reject, namely all TCs identified in the satellite TM/TC database. It also accepts valid encrypted Secure TCs (STCs) and generates corresponding TC acknowledgments although the contents of the STCs themselves are not interpreted or processed.

Similarly valid navigation data messages are also accepted but again not interpreted or processed. The effects of any injected satellite failures are realistically modeled not just in the unit concerned but also to interfacing subsystems (for example unit failure may cause emergency reconfigurations, battery discharging, LOS at Ground Station, etc.). The orbital behavior of each satellite is simulated in order that the contacts with the simulated ground stations are realistically modeled. This orbit model can also take into satellite delta velocities (Vs) corresponding to maneuvers execution.

User commands are entered directly via terminal keyboard commands while operational commands are received from the Mission Control System (MCS). User commands include the injection of faults, changing of model parameters and direct issuing of TCs. The simulation environment contains a Man Machine Interface (MMI) to allow simulator runtime behavior to be actively monitored and controlled. The MMI displays the status of all spacecraft in the constellation including all model parameters and variables. The simulation environment traps all exceptional conditions and displays error messages and dialogues for all erroneous actions and anomalous behavior. The simulation environment also provides the infrastructure for event logging so that events such as Acquisition of Contact (AOS) and Loss of Contact (LOS) times and eclipses can be logged and displayed via the MMI. To support scenario generation for training exercises, the simulation environment also has the capability to convert simulation logs into command procedures for execution at the simulator console.

The simulator rejects all TCs that the real spacecraft rejects. All valid TCs are defined in the satellite database. The spacecraft simulator generates all housekeeping telemetry that the real spacecraft generates including acceptance/execution of TCs. To respond correctly to TCs and a changing space environment, the spacecraft simulator also contains detailed models for: spacecraft attitude & orbit determination & control, data control & distribution, electrical power supply & distribution, thermal environment & control and additionally provides modeling of the space environment.

The ground simulator models multiple ground stations and simulates not only ground station equipment but also the S-Band space link to the satellites. The simulation of ground station equipment is limited only to those components required to contact the spacecraft (uplink of TC and downlink of TM) and is based on a generic ESA model rather than a faithful representation of the GALILEO TT&C stations.

VI. Training Management System

A central Training Management System (TMS) has been introduced to support and manage all training related issues and to ease the steering of the training program. This tool shall be used by trainees, trainers and the training managers as well. Besides functional aspects, the TMS plays a vital role in providing courses, course material and

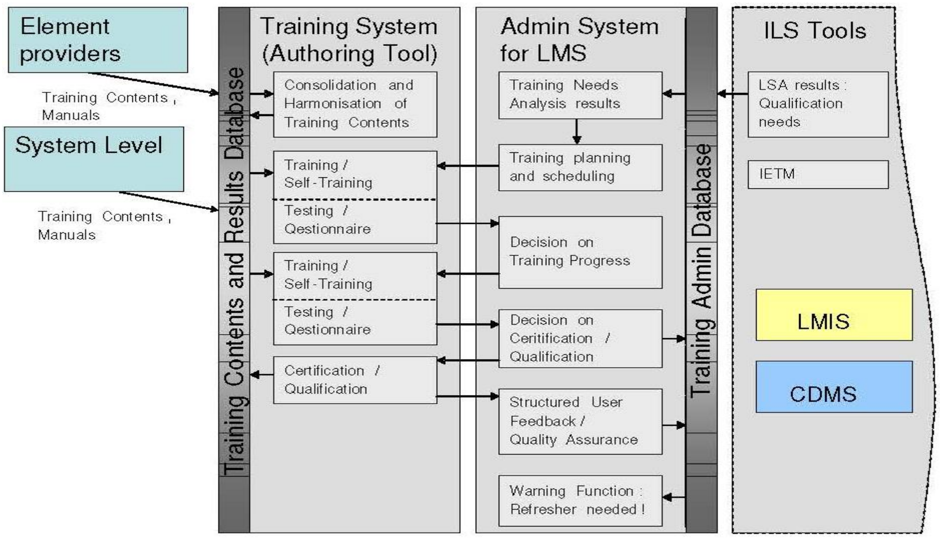

Figure 8. TMS Tool Environment

interaction capabilities to all connected sites and trainees.

The TMS is the central interface and access point to all related training activities. The TMS has been installed at GCC-D site and is available to GCC-I (Fucino) site and remote sites via online access. The usage of the tool is restricted to authorized users. User privileges regulate the usage of the system. The TMS tool environment is shown in Fig. 8.

VII. Lessons Learned and Advancements

After the IOV L2 IOT campaign, the first joint simulations campaigns working group meeting took place at GCC-D to discuss lessons learned together with the GCC-D training manager and LOCCs/GCCs simulations officers. This section summarizes lessons learned from IOV L1and L2 real operations having an impact on the definition and configuration of future FOC simulations.

Constellation flight operations concept

Nearly all L2 simulations were run with only two S/Cs. Current IOV operations already require the execution of parallel activities for PFM, FM2, FM3 and FM4 satellites. E.g., after the control handover of the IOV L2 second satellite, reduced routine operations already had to start for the first IOV L2 satellite together with the parallel full routine operations execution for the two IOV L1 satellites, indicating that a full IOV and future FOC flight constellation will have overlapping operational phases and the requirement to execute many activities in parallel. Discussions of lessons learned gained from constellation operations of other missions state the training need for constellations flights with multiple S/Cs[3]. To setup an advanced IOV + FOC constellation simulation the L3 simulation timelines will have to consider constellation flight scenarios with 4 or even 6 S/Cs. The distributed version of the simulator is available at GCC-D for the FOC L3 simulations campaign. This version is designed and configured to run in parallel the entire IOV + FOC satellites constellation in one single simulation scenario.

Multi-control-center operations concepts

The GALILEO mission operations concept requires single-, dual- and multi-control-centers operations to execute joint activities in the different operational phases.

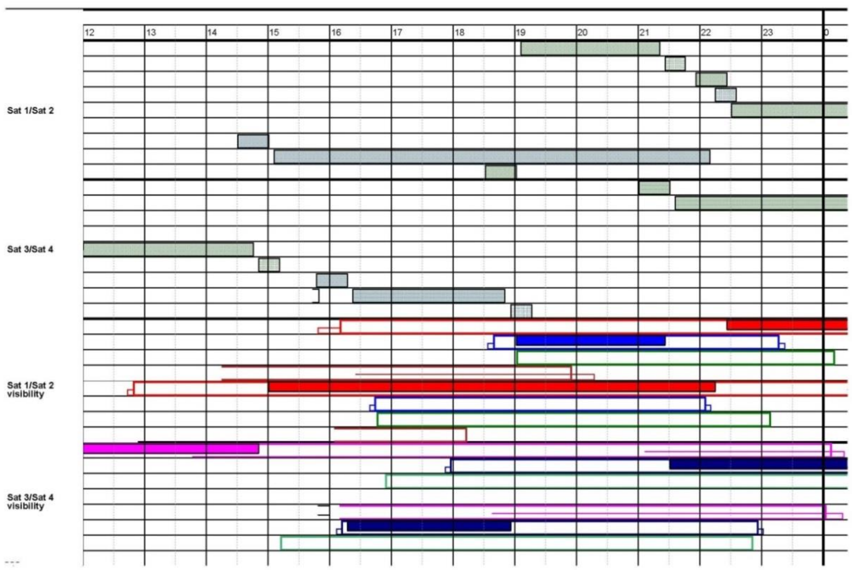

Figure 9. Simplified example of Gantt chart visualizing a timeline of 4-spacecrafts constellation flight with contact operations in parallel

Many of these activities and operational interfaces have been validated in the IOV L1 and L2 simulations campaigns in the framework of the operational validation concept as described in chapter II and are being proved in the on-going IOV mission phase. In a current human space flight mission personnel are trained and certified in various joint simulations showing that multi-control-centers training and operations is a state-of-the- art approach4. However, a constellation flight simulation in an inter- or multi-control-centers environment will further advance the level of IOV simulations regarding FOC operational requirements. Fig. 9 shows a simplified example of 4-spacecrafts constellation scenario for an advanced inter-control-centers IOV simulation to train routine contacts activities in parallel.

Automation for constellation operations

A high degree of automation and autonomy is achieved using a number of novel tools that are integrated into a coherent ground system to perform all required operations functions[3]. In the area of routine task execution, a new multi-control-centers mission planning approach will be applied in the near future to make use of automation capabilities for command sequence generation and SoE execution[5]. The GCC planning facility will creates so-called Short-Term-Plans (STP) based on a planning data base containing activity definitions and rules like ground station visibilities. The planning facility then sends the STP to the S/C monitoring and control system that automatically generates all required command sequences for all activities to be executed during the different contacts. To create the command sequences the S/C control system refers to an internal procedure file archive. This automated approach can be used to prepare and execute any future stand-alone or multi-control-centers simulation. The planning facility in the training room creates a STP-based SoE for simulation purposes based on activity information provided by the simulations officer. It is assumed that the simulation timeline will always deviate slightly from the real operations timelines stored in the planning database because operational products might not be available or due to other resource constraints. The planning facility then sends the training STP to the S/C monitoring and control system in the training room that automatically generates the command sequences for the simulations. The current approach is that a S/C controller, a S/C operations engineer or a trainee has to manually load the FOP commands sequences at the S/C monitoring and control system based on the provided STP-based SoE.

Inter-control-centers constellation simulations

The IOV + FOC require more and more training, validation and certification simulations involving more control centers and sites like in real operations during which parallel special operations will be executed together with routine operations on different satellites of the constellation e.g. parallel routine contacts operations on IOV + FOC satellites (involving GCC-D and GCC-I) together with special operations on FOC satellites (involving LOCCs and GCCs). Next simulations campaigns will focus more and more on inter-control-centers constellation joint simulations involving GCCs and LOCCs in the same simulations scenarios.

Training approach vs. Launch delays

Launch delays heavily impact the training and simulations schedule. When a launch is delayed the training and simulations need to be performed further to keep the operations personnel ready up to the launch date. The certification process takes it into consideration and ensures that the operations personnel are certified in time before the launch. Delays have impact on resources and people availability. Training and simulations schedule needs to be flexible enough to face launch delays even for months or years. In general delays give more time for operations personnel to further validate procedures and exercise operational scenarios within simulations and rehearsals.

Training schedule vs. ongoing Satellite Operations

Operations personnel requiring continuous up-to-date training and certification count towards hundreds of people considering both Galileo Control Centers in Oberpfaffenhofen, Germay (GCC-D) and Fucino, Italy (GCC-I). The training and simulations plan covers the certification and its maintenance/upgrade of all these people. The training schedule is very dense and varies w.r.t. the ongoing activities depending on people and resources availability, and training needs. Training and certification simulations are performed continuously and in parallel with the ongoing constellation operations on aligned but separated (for security reasons) environments. Simulations and Rehearsals run on the Training and Validation Chain (VAL) while Constellation Operations run on the Operational Chain (OPE).

Galileo Services impact on Training, Simulations and Certification concept

Galileo Services availability by 2016 has a heavy impact on the overall training, simulations and certifications process and plan of both GCC-D and GCC-I. Additional training needs and operational scenarios have to be added and harmonized into the existing training requirements plan and schedule. Simulations need to increase in number and scenarios accordingly. Certification process needs to be extended to ensure operations personnel is properly trained also on the new operational requirements impacted by the services. The operational interfaces will increase to include new customers and centers, for example the European GNSS Agency (GSA) and the European GNSS Service Centre (GSC), managed by GSA), which is an integral part of the European GNSS infrastructure providing the single interface between the Galileo system and the users of the Galileo Open Service (OS) and the Galileo Commercial Service (CS).

VIII. Conclusions

The currently applied GCC training process accounts for the evolving training needs and resource constraints within the IOV mission + FOC preparation phases. Certification guidelines have been presented which are being successfully implemented in the FOC training process on a very cost-effective basis. Training relies on highly skilled and experienced trainers and training mentors being involved in real operations.

Combining purely training- and certification-based with validation-based simulations as a merged simulation concept seems to be the preferred solution for the fast pace of the project. The merged concept expresses the IOV to FOC specific transition from a validation- to a certification-based simulation approach.

The timeline for the advanced inter-control-centers simulation includes overlapping operations phases and parallel activities for four satellites making IOV + FOC simulations much more realistic and advanced w.r.t. constellation flight and multi-control-centers operations. The configuration of the command and control handover simulation can be used as a valuable reference for the setup of any other multi-control-centers simulation.

Future contingency simulations will have to consider more inter-control-centers scenarios failures on constellations satellites and ground parallel operations to better prepare and qualify operations and hosting teams for real constellation contingency operations.

The automated command sequence generation approach will make the preparation of future stand-alone and multi-control-centers simulations much more time- and cost-effective and will optimize inter-control-centers joint simulations and operations.

Appendix A
Acronym List

AOS	Acquisition of Signal
CB	Certification Board
CDMS	Central Documentation Management System
CNES	Centre National d'Etudes Spatiales
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ESOC	European Space Operations Centre
FD	Flight Dynamics
FDIR	Failure Detection, Isolation and Recovery
FM	Flight Model
FOC	Full Operational Capability
FOP	Flight Operations Procedure
GCC	Galileo Control Centre
GCS	Galileo Control Segment
GfR	Gesellschaft für Raumfahrtanwendungen
GMS	Galileo Mission Segment
GNSS	Global Navigation Satellite System
GST	Galileo System Time
IETM	Interactive Electronic Technical Manual
ILS	Integrated Logistic Support
IOV	In-Orbit Validation
IOT	In-Orbit Testing
LEOP	Launch and Early Orbit Phase
LOCC	LEOP Operations Control Centre
LMS	Local Maintenance Manufacturers Support
LMIS	Logistics Management Information System
LOS	Loss of Signal
LSA	Logistics Support Analysis
MCS	Mission Control System
MMI	Man Machine Interface
OJT	On-the-Job Training
PF	Platform
PFM	Proto Flight Model
PL	Payload
S/C	Spacecraft
SLE	Space Link Extension
SoE	Sequence of Events
SSEG	Space Segment
STC	Secure Tele-command
STP	Short-Term Plan
TC	Tele-command
TM	Telemetry
TMS	Training Management System
TNA	Training Need Analysis
TT&C	Telemetry, Tracking and Command
V	Velocity

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