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"Extended" On-Call Support for TerraSAR-X; minimizing payload outages

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TerraSAR-X is an advanced synthetic aperture radar (SAR) satellite for scientific and commercial applications realized in a public-private partnership between DLR and EADS Astrium, Germany. The launch was on June 15, 2007 into a sun-synchronous dawn-dusk orbit at roughly 514 km altitude. The main payload is a new generation of SAR instrument. TerraSAR-X had successfully completed its commissioning phase by the end of 2007 and it will be operated by the DLR for a period of at least 5 years. This paper describes the support provided by the mission operations team. The focus will be on the on-call support outside normal working hours.

Nomenclature

Δv	=	Velocity increment due to thruster activity
t_0	=	Maneuver start time

I. Introduction

TerraSAR-X is an advanced synthetic aperture radar (SAR) satellite for scientific and commercial applications realized in a public-private partnership between DLR and EADS Astrium, Germany. The launch with a Russian DNEPR-1 was on June 15, 2007 into a sun-synchronous dawn-dusk orbit at roughly 514 km altitude with an 11 day repeat cycle.

The main payload is a new generation of SAR instrument. The secondary payload consists of a laser communication terminal (LCT) and a tracking and occultation experiment (TOR).

The mission has two main objectives:

1) to provide the scientific community with high quality SAR data for scientific research and applications, and
2) to support the establishment of a commercial Earth observation market and to develop a sustainable Earth observation service business in Europe.

The range of scientific applications is broad comprising hydrology, geology, climatology, oceanography, environmental- and disaster monitoring, as well as cartography.

TerraSAR-X will be joined by an almost identical spacecraft named TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) starting from the first half of 2010. TerraSAR-X and TanDEM-X will fly in close formation, separated by a distance varying between 200 and 2000 meter.

TerraSAR-X will keep on following its nominal orbit (the so- called "reference orbit"), whereas TanDEM-X will fly in an helical orbit around it.

The main objective of the TanDEM-X mission is to generate a global digital elevation model.

The two spacecrafts will have to fly together for at least two years.

TerraSAR-X successfully completed its commissioning phase at the end of 2007 and will be operated by DLR for a period of at least 5 years.

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Figure 1. *TerraSAR-X and TanDEM-X flying in formation.*

II. The TerraSAR-X Ground Segment

The TerraSAR-X ground segment at DLR consists of three major components:

1) the Mission Operations Segment (MOS) with personnel from the German Space Operation Center (GSOC),
2) the Instrument Operations and Calibration Segment (IOCS) at the Microwaves and Radar Institute (HR),
3) the Payload Ground Segment (PGS), cooperation between the Remote Sensing Data Centre (DFD) and the Remote Sensing Technology Institute (MF).

The TerraSAR-X Mission Operations Segment (MOS) consists of the following main components:

1) the ground station network,
2) the monitoring and control system (MCS),
3) Flight Dynamics (FD),
4) the Mission Planning System (MPS),
5) the Ground Data Systems (GDS).

The ground stations are connected to the GSOC via a communication network which allows the exchange of spacecraft telemetry, telecommands, voice traffic and auxiliary data like orbit data messages for antenna pointing and antenna angle tracking data.

Up to 2009, the DLR ground station in Weilheim supported the TerraSAR-X mission as prime station, with Neustrelitz serving as a downlink- only station receiving X- and S- band data.

Currently, the TerraSAR-X mission is supported by Neustrelitz only.

Neustrelitz belongs organizationally to the PGS and was formerly a downlink- only station. Uplink capabilities have been implemented in the year 2009. The ground station receives S- band (TerraSAR-X house keeping data) and X- band (SAR data) simultaneously.

FD is responsible for the orbit determination, prediction and maneuver planning.

FD receives the housekeeping products generated by the MCS. These are processed to generate orbit and attitude products necessary for SAR data processing. The data are placed on a pick- up point and made available to the ground segment.

FD has the demanding task of keeping the spacecraft flying within a tube of ±250 meters around the reference orbit. It plans the maneuvers by continuous orbital analysis and automatically generates the commands for their execution. FD also sends information to the MPS about the maneuver characteristics (Δv, t_0) in order to allow the MPS to properly plan SAR operations.

The MPS is responsible for generating timelines (i.e. sequence of events) for spacecraft and ground activities. It performs the planning of SAR operations (data-takes and data downlinks) and routine bus operations (house keeping memory dumps and transmitter switching). It delivers all commands for routine operations to the MCS, from which they are transmitted to the spacecraft.

The MPS has a direct interface to the PGS for receiving all the acquisition requests and for feedback. The requests are collected until a "planning session" takes place (twice per day in routine phase). The MPS then performs the complex task of searching for an optimal solution, taking into account various ground- and space-segment constraints and obeying to a set of rules. The finalized plan results in the mission timeline.

GDS is responsible for collecting and pre-processing the antenna angle data from the ground stations (when in auto-track mode) and for delivering the data to FD for orbit determination purposes. GDS receives orbit data messages (ODM) from FD, for the S-band ground stations antenna pointing.

GDS is also is responsible for the scheduling of all S-band ground stations. Schedule requests are received from the various missions (from the MPS in case of TerraSAR-X). Conflicts are detected and resolved in weekly meetings.

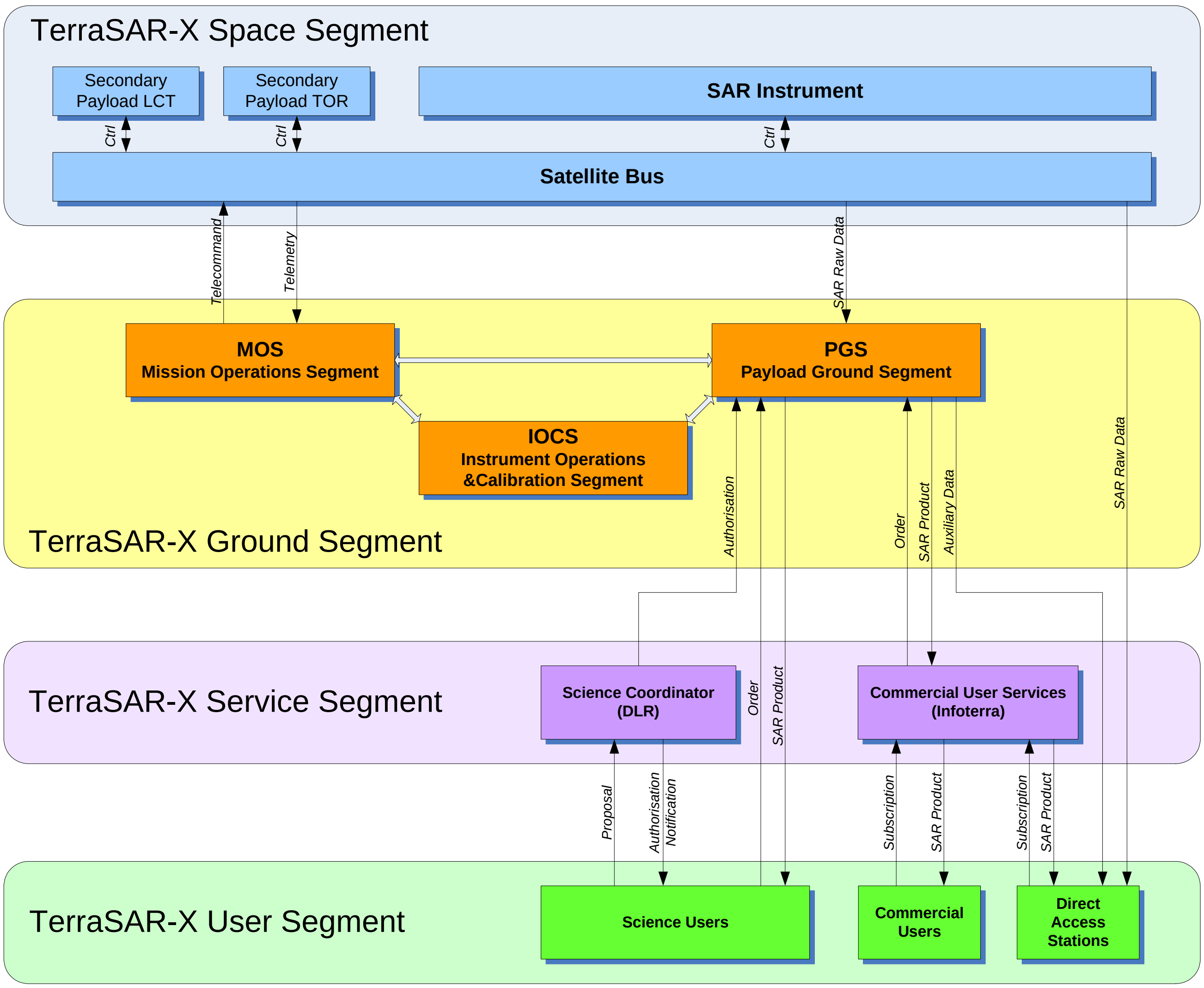

Figure 2. TerraSAR-X Operations System. *The Mission Operations Segment is shown as part of the Ground Segment.*

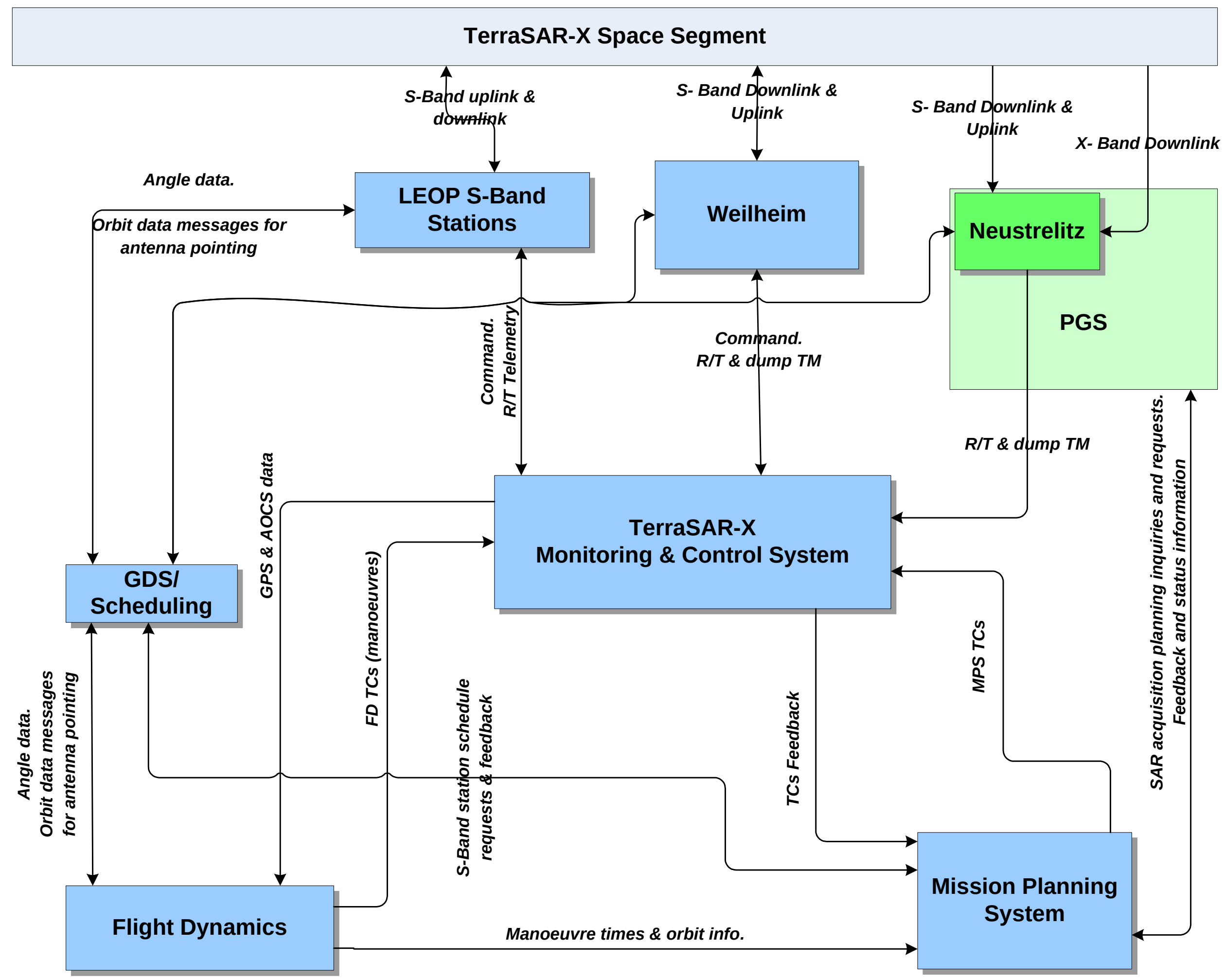

Figure 3. *TerraSAR-X Mission Operations Segment.*

III. The Mission Operations Team

The MOS is operated by the TerraSAR-X mission operations team.

The Flight Operations Directors (FODs) are responsible for the MOS and for the coordination of spacecraft operations.

The FODs are supported by the flight dynamics team, the ground data systems operators, the mission planning team, the sub- systems operations engineers, and the multimission flight support team.

The sub- systems operations engineers are in charge for monitoring the health and the performance of the spacecraft during the mission and for preparing and executing spacecraft operations under the FOD supervision.

The TerraSAR-X spacecraft subsystems are the attitude and orbit control system (AOCS), the power and thermal control system (PTS), the on board computer (OBC, including also the telemetry and telecommand system TMTC), the payload (SAR), and the secondary payload (TOR, LCT).

There are two engineers (one prime and one backup) assigned to every sub- system. Thus the subsystem operations engineering team is made up by ten people.

A Spacecraft Operation Support Team (SOST) from EADS Astrium is also under contract for background data evaluation and on- request support activities. The SOST is lead by the SOST Team Lead, an experienced Astrium spacecraft operations expert.

The mission operations team and the spacecraft operation support team can request the execution of non-routine spacecraft activities by preparing a “recommendation”. The recommendations are stored and visible on the

OPSWEB, an internet/intranet application used to support the spacecraft operations. The OPSWEB provides access to important information (documents, databases, web links and various operational products) and provides tools for anomaly reporting, recommendation handling and action item tracking.

The recommendations are checked on a regular basis by the FODs, who can approve one of them by signing it electronically. A recommendation will not be executed before the FOD signs it.

Critical recommendations have to be signed by a second person, usually the SOST team lead. This process is based on the excellent cooperation and experience with the joint operations team approach applied during LEOP and commissioning phase, which combines the expertise available on spacecraft manufacturer and on GSOC side.

The recommendations are then carried out by the flight support team operating the MCS in the control room twenty four hours a day, seven days a week. The FOD and the sub- systems engineers may assist the flight support team during commanding, depending on the operation’s criticality.

The flight support team is working in shifts. Each shift is presently made of two people supporting four flying missions.

The same multi- mission support concept applies to the Ground Data System (GDS) operators, who also work twenty four hours a day, seven days a week, operating the in-house networks and the ground station networks to serve several missions in parallel.

If a not nominal situation appears outside nominal working hours, here defined as the time between 7:45 am and 16:15 pm, a part of the mission operations team is ready to support the GDS operators and the flight support team. This is the “on call team”, and is described in the following chapter.

IV. The Science Mission Type On Call Team

The TerraSAR-X satellite and the original mission operations design were oriented towards design to cost, in the sense of a low cost satellite mission primarily for science services. The MOS teaming was set-up as a consequence, providing restricted operations team support availability outside nominal working hours.

The on call team was made by one mission operations engineer, supported by one MPS and one FD Engineer. For particular mission phases as well as during maintenance phase, the team was increased with more engineers. This applied, for example, in the week following an OBC software upload.

The main task of the mission operations engineer was to respond to critical situation, recovering a stable mission state. He was not expected to perform any action in case of uncritical issues, for which recovery activities were postponed to the following working day.

Situations where SAR operations were blocked or stopped were not recovered immediately, unless related to a failure endangering the mission.

As an example, the reaction of the mission operations engineer to an OBC reboot happening outside the nominal working hours is described in the following.

In case of a severe on board failure triggering a system reconfiguration, the satellite transitions into the Satellite Acquisition and Safe Mode (SAT-ASM). As part of this transition an on board computer reboot is performed. After the reboot, TerraSAR-X comes up with the S-band transmitter switched on and transmitting in low rate/low power. Not having additional autonomous recovery actions to higher satellite modes enabled, the spacecraft remains in these conditions. The time- tagged commands stored on board are lost, and the AOCS is in the so called Acquisition and Safe Mode (AOC- ASM). The AOC- ASM is a particularly robust AOCS mode using the thrusters for attitude control. Reaction wheels are used in the AOCS nominal mode (AOC- NOM).

The TerraSAR-X ground stations are nominally configured for the spacecraft to show up in the standard transmitter high rate/high power configuration. Thus, with the nominal recovery set-up, an OBC reboot occurring before the contact prevents from a successful acquisition of signal.

As soon as the flight support team in the control room is informed that no signal from the spacecraft can be acquired, the mission operations engineer is notified. Contingency procedures are in place allowing the multi mission team to perform a blind acquisition of the satellite by sending a high rate high power command in the blind.

After the contact is established the flight support team is able to deduce that an OBC reboot took place, and that the spacecraft is flying in a stable and safe SAT- ASM. The spacecraft health check is made by means of flight operations procedures released by the mission operations team. The mission operation engineer has then to confirm the satellite status.

Despite the spacecraft is out from its nominal mode (and SAR operations can not be executed), the work of the on call engineer can be considered finished. The activities to recover nominal operations will start on the next working day, when full support from the team is available.

The last action he has to do is to call the MPS and the FD engineers and to inform them about the events.

The main task of the MPS engineer is to recover as soon as possible from MPS problems by immediately repairing them or by finding an operational work around. These problems can either be caused by MPS internal failures or by external issues causing the MPS no longer be synchronized with the space segment. This is also applicable after an OBC reboot, where all the time tagged commands on board of the spacecraft are lost.

The MPS is a very complex system and a crucial point for performing SAR operations. A prompt recovery of issues can avoid them to propagate inside the ground system. For this reason, the MPS engineering on call support was deemed necessary since the beginning of the mission.

FD delivers to the ground system attitude products derived from the spacecraft telemetry, which are of crucial importance for mission data processing. Considering the requirements in terms of flight dynamics products latency, an FDS on call support was considered necessary during week ends and holiday times.

In SAT- ASM the satellite's AOCS is designed to minimize thruster actuations, which are nevertheless not completely excluded. All the TerraSAR-X thrusters are mounted on the same side of the spacecraft. Therefore, controlling the attitude with the thrusters implicate a non-negligible displacement from the very tight reference orbit conditions.

The recovery of the reference orbit, requiring FD support, was not considered a critical action. Therefore, it was normally postponed to the next working day.

All the on call engineers were changed on a regular (nominally two weeks) basis, following a turn over concept.

The on call engineers on duty were supposed to be always reachable via mobile phone, and were expected to be able, if requested, to reach the control room in less than one hour.

V. New Mission Requirements

Despite the on call strategy described so far was adapt at supporting the mission operations, it was not taking into account the challenging operations support implicit requirements of a more and more fully operational commercial mission.

The TerraSAR-X customers have big expectations in terms of spacecraft availability, and even short outages in the SAR operations are obviously unwillingly accepted.

Furthermore, TerraSAR-X is going to flight in formation with a twin spacecraft called TanDEM-X. To fulfill the mission requirements, the duration of the formation flight has to be longer than 2 years. Assuming TanDEM-X to be launched in the first half of 2010 as expected, and considering the LEOP and commissioning phase duration, TerraSAR-X would have to be operational at least until the beginning 2013. This means a total lifetime of at least five years. To save spacecraft resources for mission extension is therefore a particularly important issue.

Thus in case of spacecraft contingencies preventing the continuation of the nominal mission or even forcing a system reconfiguration to SAT- ASM, the recovery to normal mission operation condition has to be performed as soon as possible. This means it is of primary importance to quickly understand the cause of the mission interruption and to perform the actions necessary to bring back the spacecraft to nominal mission operations.

Summarizing, the following new requirements got across:

1) the time to recover SAT- NOM has to be minimized,
2) an unexpected radar operations outage has to be recovered as soon as possible.

VI. Enhanced On Call Strategy

The first objective is to reduce the waste of resources in terms of thruster activations and propellant. This objective is reached by minimizing the time in SAT- ASM. This is equivalent to a prompt recovery of AOCS-NOM, where no thrusters are used for attitude control.

As a first step the ground station network has been enhanced, providing observability and commandability with significant shorter reaction times of maximum 6 hours, instead of up to 13 hours in the original set-up.

Furthermore, the task of the mission operations on call team was changed from the recovery of a stable state to the recovery of the spacecraft's nominal mode.

To perform a safe transition from AOCS- ASM to AOCS- NOM, AOCS subsystem engineering support is needed. Furthermore, the transition should be performed only after the reason for the drop is identified and understood, and the spacecraft status checked.

For the analysis, as well as for the possible recovery actions, PTS and OBC/TMTC engineering support is often required. FOD support has also to be considered, for on call team coordination purposes.

Hence the mission operations on call team was expanded from three to six engineers.

The second goal was to begin again as soon as possible with nominal radar operations after an event hampering nominal SAR activities occurred.

To recover from possible radar related issues, SAR experts support is essential. The mission operations on call team was therefore enhanced with SAR experts, on call on the week end and during holidays times.

To perform radar operations requires not only the bus to fly in SAT- NOM, but also it to be in the correct orbit and position.

The recovery and the maintenance of the reference orbit is one of the tasks of FD. The task of the FD on call engineer was extended by including the support of the actions required to bring the spacecraft back to its reference orbit. A proper training campaign for the FD engineers was performed as a consequence.

The MPS On Call support was already deemed to be good, and was therefore not changed.

After having defined the tasks and the features of the new on call team, a number of challenges had to be faced. These are described in the following chapter.

VII. Challenges

According to German labor law an employee is not allowed to be on call for more than eighteen weeks per year. Theoretically, a pool of three engineers would be enough to cover one on call position for one year. Still the experience made operating previous missions showed that major planning problems appear when using this solution, and that a pool of at least four engineers is needed.

The pool of engineers supporting the former on call strategy included six mission operations on call engineers, four MPS engineers, and three FD engineers. The on call engineers were chosen among the TerraSAR-X mission operations, flight dynamics, and mission planning teams.

In particular, the typical mission operations on call engineer was a subsystem expert or a FOD trained to support the on call activities.

To support the enhanced on call strategy, a pool of twenty mission operations system engineers, four MPS engineers, and four FDS engineers is needed. This actually makes the mission operations on call team larger than the TerraSAR-X mission operations team!

The first challenge was therefore to find the missing engineers.

As a solution, roughly fifty percent of the team was established using engineers working on other missions. These engineers cover duties as much as possible similar to those they cover in the mission they support.

For example, the GRACE FOD supports the TerraSAR-X mission operations on call team as FOD. Similarly, one TerraSAR-X PTS on call engineer was responsible for the PTS system operations for the SARLupe mission, and is currently managing the EnMAP project in GSOC.

New employees also joined the mission operations on call team.

Formerly, the mission operations on call engineer was trained by classroom sessions giving an overview of the mission operations system and its possible failures, as well as a detailed knowledge of the standard actions to confirm the spacecraft is in safe operational conditions. The training was approximately three days long.

Since the task of the mission operations team changed from bringing the spacecraft to a stable state to the achievement of the operational mode, the training plan had to be reorganized.

The new team member is expected to be no longer a subsystem engineer having a rough overview of the mission operations system and of the standard recovery actions, but an expert having deep knowledge of a particular subsystem, as well as of the subsystem’s nominal and contingency operations.

The training is performed with classroom lessons, documentation reading and on- job training. Typically, the average training process takes approximately three personal months for the trainee and one for the trainer. A certification exam is made afterwards. Both training and exam are different depending on the on call area the engineer is expected to work in.

An additional issue was the definition of the rules of the on call support in terms of people availability.

Considering the TerraSAR-X mission requirements, it was decided to require only one person of the mission operations on call team to be never more than one hour far from the control room. He is, by default, the FOD, who is free to delegate another person inside the on call team.

He is the first point of contact in the control room if critical situations appear, supervising the multimission operations flight support team operators, and interfacing with the engineers who are giving remote support.

A FD engineer and one MPS engineer are supporting the mission operations engineer. In case of needs they also must be capable to reach the control room in less than one hour.

The next challenge was to find a way to let the team members provide an effective remote support.

A support via phone is often not enough. The engineers should have access to the proper documentation, as well as the possibility to refer to spacecraft’s telemetry.

This issue was solved by providing each mission operations on call engineer on duty with a laptop capable to connect anytime and anywhere to the internet by means of an USB Stick. Each laptop contains the on call documents, and the internet connection allows the access to spacecraft telemetry and operational tools.

The telemetry is viewed using the SATMON client application. This is also used in the operational environment at GSOC, and so the on call engineer has exactly the same displays available on the laptop as in the control room. The data is fed to the remote clients using the HTTPS protocol, which provides secure communications and has the additional advantage of being able to pass through most firewalls. Since some spacecraft telemetry parameters are classified, a filter had to be implemented to prevent these parameters from being distributed. This filtering does not have any side effect on the on call support, since these particular parameters are not strictly necessary for monitoring spacecraft health and operations.

Each FD engineer is equipped with a PDA in order to receive automated email notifications from his system. He is required to regularly check the status of the system and to detect anomalies in FD processing and product delivery.

The MPS engineer is geared with the same tools the mission operations engineer has.

The on call duty plan is made using a simple excel worksheet. Discussion are ongoing to let the on call planning be performed by the MPS, using tools which are derived from those planning the spacecraft's activities.

The manual planning is not an easy exercise since conflict may appear especially during holiday times or sick leaves. Planning problems becomes enormous when having engineers supporting more than one subsystem (for example one AOCS/PTS engineer, one FOD/AOCS engineer, and so on). That is why this solution was discarded, despite its advantages in terms of number of resources required.

The on call pool has to be kept trained and synchronized with the mission. While the FD and MPS engineers are constantly operating their system, some team members are most of the time busy with missions different than TerraSAR-X. Roughly 50% of the mission operations on call team is not involved in TerraSAR-X daily operations. A way to keep the engineers in sync with the project and properly trained had to be found.

The first possibility is to let each engineer overtake the prime support for the TerraSAR-X subsystem, using a turn over concept.

The second possibility is to let the prime engineer stay the same, asking him to distribute his tasks among the on call pool.

The first solution is hardly applicable. It would require the engineers to perform time consuming handovers on a regular basis. The second solution seems to be more feasible and is currently applied.

Still the move of the engineers to different projects sometimes reduces the motivation and the effort they can put in the TerraSAR-X mission. A source of motivation is the certification exam, which at the moment is planned to be performed on a yearly basis.

VIII. Future Development

With the former on call strategy, each project was supported by one mission operations engineer, one FD, one MPS engineer, the flight support operators, and the GDS operators.

Currently, the mission operations team is far larger than before.

The idea is to use the same team to support more missions at the same time.

This concept will be applied and tested as soon as the TanDEM-X spacecraft will enter its commissioning phase. TerraSAR-X and TanDEM-X will share the same on call team.

Additional training is foreseen for those engineers who were not involved in the TanDEM-X mission preparation. An effort of one man- month for each trainee and one man- week for each trainer is foreseen.

TanDEM-X uses a bus very similar to the TerraSAR-X one, and the MOS is also derived from the TerraSAR-X mission. This reduces the amount of training needed, which will mainly be focused on the formation flight related features.

The experience that will be made giving on call support to two spacecrafts flying in such a close formation is expected to be very interesting.

A similar experience was made in GSOC supporting the two GRACE spacecrafts, but the distance is in this case much bigger (roughly 200 km), allowing a longer reaction time in case of failures.

Should the experience with TerraSAR-X and TanDEM-X be positive, the same concept will be applied also for the future Earth observation missions.

If necessary, the on call team would be enhanced in particular area. One PTS on call engineer would probably be sufficient to support several mission in parallel, whereas the support of one AOCS engineer should be restricted to one or two missions. The reason for that are the uniqueness and the high complexity of the AOCS systems mostly equipping the spacecrafts.

IX. Conclusion

This paper showed the number of advantages of applying the enhanced on call strategy for supporting the TerraSAR-X mission. It also detailed its potential in terms of support of several spacecraft at the same time.

This approach ensures high availability of TerraSAR-X mission operations products, especially in terms of reduction of possible payload outages and in terms of resource saving.

The side effect is the large effort to be invested.

GSOC expects to reduce this effort by supporting more missions using the same on call team.

GSOC is looking forward to support future missions such as TanDEM-X, TeT, EnMAP to confirm the validity of this approach.

Acknowledgments

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