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The Human Factors: Training and Knowledge Transfer (HFT) in a 24/7 Multi-Mission environment

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Abstract

The Multi-Mission Flight Support team (MMFS) is a specialised group within the German Space Operations Center (GSOC). For more than 20 years, the team has efficiently operated multiple Low Earth Orbit (LEO) satellites concurrently. In January 2024, the team added two Geostationary Earth Orbit (GEO) satellites to its fleet of supported satellites. The scope of work for the GEO satellites is clearly defined as part of the mission requirements; the cost and time were also pre-defined, compromising on quality was not an option. Given these constraints, the first GEO SPACON training was developed and delivered at the GSOC resulting in our first cross trained LEO and GEO trained Spacecraft controllers. In less than 4 months, we were ready to add the GEO satellites to the MMFS fleet and support them all effectively and reliably in 24/7 operations. The Multi-Mission Team plays a critical role in advancing the multi-mission concept of operations within the space industry by efficiently managing diverse missions, capitalising on synergies and fostering expertise among team members. This paper will touch on the training process and explain how we merged operational concepts to leverage synergies and successfully integrate 2 GEO satellites into the existing fleet of 5 LEO satellites.

Keywords: GEO, LEO, Training, Multi-Mission Operations.

Acronyms/Abbreviations

DLR	German Aerospace Center
FLD	Flight Director
FOP	Flight Operation Procedure
GEO	Geostationary Earth Orbit
GOP	Ground Operation Procedure
GSOC	German Space Operations Center
LEO	Low Earth Orbit
LEOP	Launch and Early Operations
MMFS	Multi-Mission Flight Support
SPACON	Spacecraft controller

1. Introduction

1.1. Overview of GSOC and the MMFS team.

For more than 20 years the Multi Mission Flight Support (MMFS)Team have supported L1 shift operations for LEO missions at the German Space Operations Center (GSOC), working on a 24/7, 3-shift schedule. Before the integration of two new GEO satellites at the beginning of 2024, the team supported the daily operation of 8 different satellites across 5 missions, with different payloads and operation concepts.

To ensure high-quality service and continuous improvement, the team is composed of a core group of experienced technicians who bring institutional knowledge, and newly graduated engineers who offer fresh perspectives on processes and procedures.

1.2. MMFS Existing Training

Each team member undergoes training for every mission over a period of 6 to 8 weeks, culminating in certification (see Figure 1). The training, managed and supervised by the MMFS team leader, focuses on one mission at a time and it includes detailed instruction on mission-specific manuals, procedures, and lessons learned.

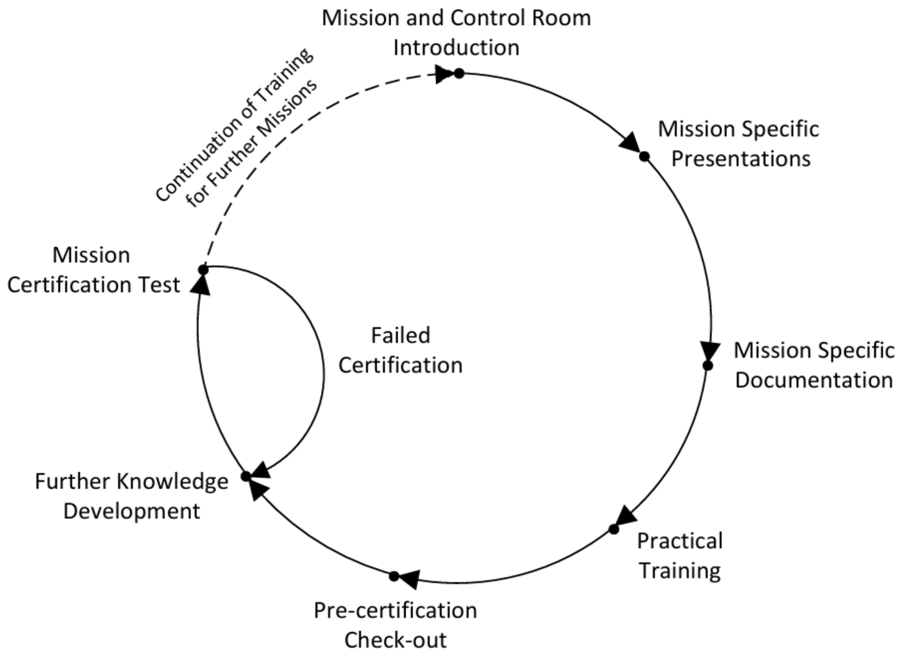

Fig. 1. MMFS training process for a single mission [2]

The first phase of a spacecraft controller's training focuses on the fundamental aspects of Operations, providing an in-depth knowledge of the ecosystem in which it operates. Even before undergoing mission-specific training, the spacecraft controller (SPACON) must become familiar with all the actors involved, including the ground stations used and the communication protocols essential for coordinating operations. This preparation is essential to ensure the handling of a pass for LEO missions. In addition, the SPACON must have a clear understanding of the structure of the operational network, the role of different departments, the IT tools common to several missions, and the protocols needed to communicate and document any significant events. Early simulations and exercises allow for the evaluation of the trainee's progress and competence. Subsystem presentations provide insight into the role of each subsystem in the mission. Trainees engage in simulations, replays, and role-playing exercises to develop skills in commanding and problem-solving. Beyond these activities, MMFS have created internal documents that continue to evolve over time. Every time a new team member joins, they're encouraged to provide feedback on the training materials, ensuring the documentation stays current and evolves into the most effective version possible.

Continuous evaluation by all team members ensures trainees' progress is monitored, and by the sixth week, assessments are conducted to verify readiness. Certification involves practical examinations, Q&A sessions, and evaluations by experienced MMFS team members and quality managers. Successful trainees are certified to independently perform mission-related tasks and will always be backed up by a more experienced team member during their first shifts.

1.3. LEO and GEO Satellite Operations Overview

LEO and GEO missions have different operational demands. In LEO missions, the workflow revolves around the spacecraft's pass over a ground station. Operator activities are concentrated during the ~10-minute high-intensity window when the spacecraft is in direct view, as well as the 15 to 30 minutes before and after the pass. These pre- and post-contact periods involve tasks such as preparing commands for transmission, logging activities, and verifying received files. Under normal conditions, there are intervals of up to 90 minutes (with an average of 45 minutes) where no contact with any of the spacecraft occurs. Outside of the pass or pass related activity times the operators are able to focus on activities that are classed as offline tasks.

On the other hand, GEO missions demand 24/7 monitoring due to the continuous connection with the spacecraft. Audio alarm systems are employed to alert operators to anomalies or potential issues promptly, ensuring no critical events go unnoticed and enabling quick responses when needed. To mitigate the physical and mental strain of extended monitoring and prolonged periods of sitting, discretionary 15-minute breaks are integrated into shifts. These breaks provide opportunities for operators to step away, refresh, and return focused and ready to efficiently continue with their tasks.

GEO mission requirements also ask for the monitoring of both primary and backup systems for commanding and control, adding complexity to operations. This necessitates the adaptation of the control room to accommodate the additional systems, ensuring smooth operations and redundancy management in case of anomalies. Regular breaks and a well-equipped control room are crucial to effectively manage the demands of continuous, around-the-clock monitoring.

2. Integrating GEO and LEO Operations

2.1. New Operational Concept for MMFS

The new operational concept introduces two shift patterns: one follows a 24/7 schedule with three shifts, and the other operates on a 16/5 schedule with two shifts. This structure means that on regular working days, two operators will be on site, allowing them to share the workload during peak activity periods. However, during nights and holidays, only one operator will be responsible for all tasks. To ensure support during these times, an additional team member will be on-call, with the requirement to be on site within one hour if needed. This approach aims to mitigate the increased workload caused by multiple anomalies in both LEO and GEO, ensuring continued smooth operations even during non-nominal conditions.

2.2. Synergies Between LEO and GEO Operations

Cross certified team members allow for the seamless transfer of expertise. The team, already knowledgeable in satellite operations, brings valuable experience in managing dynamic environments, troubleshooting, and optimizing daily activities. Their familiarity with the control room environment, operational tools, and team dynamics ensures a quick learning curve when adapting to GEO-specific challenges. Additionally, the integration of new team members fosters a cross-pollination of ideas between LEO and GEO operations, driving improvements in both domains.

During the transition period our experienced team were able to recommend improvements based on their knowledge and experience. These changes were also able to be quickly implemented and resulted in a more efficient workflow. The operational pace of GEO and LEO mission activities contrast. The LEO environment is faster-paced and more agile, this contrast revealed opportunities for optimization, leading to increased efficiency across all missions. One of the simplest examples was the introduction of a new handover form inspired by the one used in LEO operations, the new form is easier to read and ensures a clearer and more efficient transfer of information, ultimately improving coordination and decision-making.

2.3. Challenges and Solutions in Merging Operations

The merger of LEO and GEO operations was successfully completed within three months of the official takeover notification. This integration demanded both efficiency and the preservation of service quality. Key challenges included modifying the control room layout to incorporate GEO operations, training team members with no prior in-house GEO mission experience, restructuring shift patterns to manage a larger satellite fleet and workload, streamlining control room workflows to support both LEO and GEO operations simultaneously, automatising previously manual activities and developing a structured training program for new team members. This specific aspect is detailed in Section 2.4.

2.3.1. Control Room Adjustments

The control room underwent minor modifications to accommodate the new operational requirements. A dedicated GEO command station was established, increasing the number of screens per satellite from the usual three to nine to enhance monitoring capabilities. Audible alarm systems were installed to provide immediate alerts to operators. Additionally, ergonomic improvements, such as upgraded chairs, were introduced to ensure operator comfort during long shifts.

To optimize workflow and simplify daily operations, additional command stations for the use of LEO missions were strategically placed next to those dedicated to GEO operations, and the fact that virtualized machines [3] are used allows for significant flexibility in handling the LEO missions. Secondary network and scheduling screens were relocated across the control room to enhance accessibility and efficiency in the newly organized layout.

2.3.2. Training of the Initial Team

Training the first team members was one of the most significant challenges before the merging of the GEO and LEO teams, as the MMFS team had no prior mission specific knowledge in GEO mission operations. The amount of documentation available was immense and needed to be filtered and organised for relevance, requiring the first operators to review all materials and determine their importance. This time investment saved a vast amount of time ensuring that only relevant information was included in the developed training program.

During the transition phase shadow shifts exposing our team to routine activities and specific operations assisted in understanding the workflow and routines. However, participation was restricted to only two individuals at a time, which limited the number of team members who could be trained at the simultaneously, adding complexity to the process and limiting exposure to infrequently performed tasks.

2.3.3. Workflow Optimization in the Control Room

During office hours, one operator now handles tasks previously associated with MMFS operations, while another manages the newly integrated GEO-related activities. In case of contingencies or overlaps, they can support each other's tasks. When only one person is on shift, potential conflicts between LEO and GEO activities may arise. To keep track of LEO shift-related tasks, the "*GSOC Blue Clock*" tool displays real-time scheduling information on secondary screens in the control room, highlighting activities that require immediate attention. To manage time-critical GEO activities effectively, a similar tool has been developed that includes all the routine activities as well as the possibility to add additional customised tasks.

2.3.4. Automation of activities

To improve efficiency and reduce the manual workload on operators, several GEO routine tasks were automated, such as eclipse monitoring and station keeping manoeuvre (SKM) monitoring. By minimizing manual interventions, automation has reduced human error, and optimized workflow management allowing the operators to focus on higher-priority tasks. Automation has reduced the manual workload of the operator, but it is still necessary that the operator remains vigilant in case of anomalies or other issues that could arise. The GEO automation complements the preexisting automation implemented for several LEO projects, together contributing to a more sustainable and scalable control room environment that supports both LEO and GEO activities with greater efficiency.

2.4. Developing and Implementing GEO Training for SPACONs

The training program for GEO missions has undergone a structured evolution, adapting to the growing expertise of the team and refining its methodology over time. Initially, although the team was vastly experienced and respected for LEO operations, they had no prior experience with GEO operations. This meant that a comprehensive training approach was required. As knowledge and experience accumulated, the training program transitioned through distinct phases, ultimately reaching a stage where training was fully integrated with LEO operations. The key details of this progression are summarized in Table 1.

The first phase, *Initial Training*, began once the contract was awarded. It focused on building foundational knowledge. This phase lasted three months and concluded with the official takeover on the second of January 2024. During this phase, four individuals were efficiently trained and certified over a period of 10 weeks. The training involved reading comprehensive documentation and participating in shadow training sessions with the incumbent SPACON team these sessions were limited to a maximum of two people at a time. During this Initial Training period, the mission certification board consisted of experienced FLD's.

The second phase, *Training Process Consolidation*, marked a transition period where already LEO-certified members joined the training process, facilitating knowledge transfer and refining the overall training methodology. This phase began with the operations takeover and lasted for eight months, culminating with the certification board comprising of MMFS team members and supplemented by an FLD. Six individuals were trained, with certification provided by FLD and supported by already certified MMFS team members. Shadow training benefited by full access to the control room. Training materials were more structured, consisting of a selection of the preexisting resources, and the average training period was reduced to 8 weeks.

The final phase, *Fully Developed Training Program*, represents the point at which the program became self-sufficient and fully integrated with MMFS training concept. This transition was marked by the optional removal of FLD supervision for certification, as the team's competence and expertise reached a level where external oversight was no longer required although it was welcomed and encouraged. The external certification board continues to be welcome during the certification process and their feedback is always valuable and can enhance the process further. This phase is ongoing, with six individuals trained by February 2025. Institutional knowledge has become an important part of the training, while documentation has been developed to complement the preexisting and materials. With an optimized structure, the training program now operates efficiently, with an average training period of 6 weeks.

Table 1. Differences between phases of training development

	Initial training	Training process consolidation	Fully developed training program
Phase start	Contract resolution announcement	Operations takeover	Certification takeover
Phase end	Operations takeover	Certification takeover	Ongoing
Phase duration	3 months	8 months	Ongoing
People trained	4	6	6[a]
Average training period	10 weeks	8 weeks	6 weeks
Shadow training	Previous SPACON team, limited availability [b]	MMFS, full access to the control room	MMFS, full access to the control room
MMFS support	Minimal	Already certified team members	Institutional knowledge
Documentation	Broad and unfiltered pre-existing material	Selected preexisting material	Mix of preexisting and inhouse developed material
Certification	By FLD	By FLD supported by a MMFS team member	By MMFS supported by FLD

[a] Number of people certified as of 1st of February 2025
[b] Only two people at a time could take part

The structured evolution of the GEO training program has ensured a smooth transition from an inexperienced team to a self-sufficient and well-integrated operational structure. Building on prior LEO certification experience, refined training methodologies, and progressively reducing external oversight, the program now sustains itself with internal expertise. This development not only strengthens GEO mission operations but also aligns the training process with broader organizational goals, ensuring long-term success and adaptability.

3. Results and Impact of GEO Integration

3.1. Performance and Operational Success

The MMFS team has been supporting the GEO mission for approximately 15 months, during which the team has faced and successfully resolved a range of challenges. These challenges have included troubleshooting various anomalies that have arisen during mission operations. The origin of the anomalies rarely is related to operator performance but often stemmed from different elements of the system such as the different telemetry streams, the ground networks or the mission control system used. As a result, the team has adapted and refined its approach to anomaly management, implementing strategies that safeguard mission success while minimizing operational downtime. Anomaly troubleshooting is guided by established reference materials such as the Ground Operation Procedures (GOPs) and Flight Operation Procedures (FOPs), which ensure that each issue is approached systematically. However, the team's experience with LEO missions has influenced their troubleshooting practices, leading to the development of a more thorough and proactive log-keeping system. Over time, these log entries, initially created to document anomalies, have transformed into an invaluable knowledge base. This repository enables operators to quickly reference past issues and solutions, significantly reducing response times and improving overall troubleshooting efficiency.

The introduction of an on-call spacecraft controller (SPACON) has proven to be a critical support system. The on-call SPACON ensures that less experienced spacecraft controllers can access expert guidance when faced with operational uncertainties. Additionally, even seasoned operators benefit from this system, as it allows them to receive timely assistance during complex or major anomalies that require collaborative troubleshooting. If an issue requires direct intervention, the on-call SPACON, typically available remotely, will move to the control room to mitigate and resolve anomalies in real time.

This system has brought remarkable benefits, improving both efficiency and cost-effectiveness. By allowing just one operator to be on-call instead of requiring two on shift at the same time, the on-call SPACON model makes better use of labour resources without sacrificing mission performance. Keeping one operator on-call costs less than maintaining a dual-operator setup, leading to better reliability and smarter resource management.

3.2. Implications for the Space Operations Industry

The increasing complexity of modern space operations has led to a growing reliance on multi-mission environments [4, 5], where spacecraft operators manage multiple missions simultaneously. Through years of experience, these operators develop a highly specialized skill set that allows them to efficiently prioritize tasks, troubleshoot unexpected technical issues in real time, and coordinate activities across diverse mission teams. In addition to their technical expertise, they possess strong communication and analytical skills, enabling them to assess mission data effectively and collaborate seamlessly. Their ability to perform under high-pressure conditions is essential for ensuring mission success, while continuous learning allows them to adapt to evolving technologies and operational challenges.

The multi-mission approach offers significant advantages over traditional single-mission models. Managing multiple spacecraft within a unified operational framework improves resource efficiency, enhances mission continuity, and enables organizations to operate a broader range of missions with a leaner, more adaptable workforce. As the number of active satellites and mission complexities continue to grow, the ability to oversee multiple missions simultaneously not only optimizes operational efficiency but also strengthens overall system resilience.

Training teams to handle diverse orbital mission profiles provides substantial long-term benefits for the industry. Operators experienced in managing satellites across different mission profiles develop a broader understanding of spacecraft operations dynamics, failure modes, and mission-critical decision-making. This versatility allows them to adapt swiftly to new mission objectives and technological advancements while improving their ability to address unexpected challenges. Furthermore, a workforce skilled in multi-mission operations fosters innovation, as insights gained from different mission domains contribute to refining procedures, identifying tasks that can be automated, and ultimately contributing to mission successes.

4. Conclusion

The integration of GEO satellites into the MMFS team at GSOC has provided valuable lessons and insights, particularly in cross-training, operational adaptability, and efficient resource management. One of the key takeaways was the importance of developing a comprehensive training program that enables spacecraft controllers (SPACONs) to seamlessly transition between LEO and GEO operations. This approach reduced certification times and streamlined operational workflows. Additionally, the need for flexibility in both team structures and control room design became evident, especially as the MMFS team adapted to the increased workload and more complex satellite missions.

Key achievements include the rapid development and implementation of the first GEO SPACON training program, which enabled cross-certification and quicker mission integration. Furthermore, operational efficiency was significantly improved through the introduction of a new tool for tracking tasks, the suggested changes in procedures and the automation of routine tasks, such as eclipse monitoring and station-keeping manoeuvres. The control room also underwent enhancements, with dedicated GEO command consoles and ergonomic changes to support both LEO and GEO missions. Additionally, the introduction of an on-call SPACON model ensured expert support during critical times without the need for dual-operator shifts, optimizing team resources.

Currently, there are no foreseen planned expansions for MMFS, but the team remains highly adaptable and prepared to take on new missions. The flexibility shown in integrating GEO satellites into the existing framework for LEO missions demonstrates the team's readiness to handle future satellite operations, regardless of the mission profile. A potential future improvement could involve restructuring the control room to better accommodate the needs of daily operations, moving away from the LEOP-centric design and towards one focused on long-term mission management.

To sum up, the MMFS team's ability to integrate GEO operations with LEO mission expertise exemplifies the value of cross-training, adaptability, and continuous improvement. As the team moves forward, these lessons and achievements will serve as the foundation for future expansions and optimisations.

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