17th International Conference on Space Operations, Dubai, United Arab Emirates, 6 - 10 March 2023.

SpaceOps-2023, ID # 332

EnMAP vs. COVID-19: How to prepare for and conduct a LEOP during a pandemic

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Abstract

The EnMAP (Environmental Mapping and Analysis Program) satellite was designed and built in Germany and contains a state-of-the-art hyperspectral camera as main payload. With its two spectrometers it is capable to analyse the solar radiation being reflected from the Earth's surface from the short-wave infrared to the visible range at a very high spectral resolution. Its data will allow scientists to answer questions concerning the environment and various ecosystems, agriculture and forestry, land use and water management as well as mineralogy and geology. The EnMAP mission is managed by the German Aerospace Center (DLR) in Bonn and operations are conducted at the German Space Operations Center (GSOC) near Munich. The satellite was built by the OHB System AG in Germany and was launched on April 1st 2022 from Cape Canaveral in Florida, USA. The Scientific Lead is conducted by the German Research Centre for Geosciences (GFZ). With a launch date of April 1st in 2022 the EnMAP mission was significantly challenged by the Covid- 19 pandemic in its last two years of validation and mission preparation as well as during the Launch and Early Orbit Phase (LEOP). The last two years did not only include a governmental lockdown which did not allow the team to work on-site, but also several extended periods of strict regulations concerning social distancing which did not only affect the validation and simulation campaign but also the LEOP itself. This paper will give an overview of the various challenges the Covid-19 pandemic has posed on the different phases of mission preparation and on the sensitive launch and early orbit phase. In addition, it will provide information how those challenges were dealt with by the mission operations team at GSOC. It also shows which additional constraints and risks were identified for the EnMAP mission due to the pandemic and the subsequent governmental regulations. Finally, the paper will provide lessons learned concerning "what really is important during the launch and early orbit phase" and how this was accounted for when preparing for the EnMAP launch.
Keywords: Satellite Mission Operations, LEOP, Low-Earth Orbit, Remote Sensing, Covid-19, pandemic

Acronyms/Abbreviations

Attitude and Orbit Control System (AOCS)
Attitude Control System (ACS)
Corona Virus Disease 2019 (Covid-19)
Command System Operator (CMD)
Data Operations (DATA OPS)
Data System (DATA SYS)
Environmental Mapping and Analysis Program (EnMAP)
Earth Observations Center (EOC)
Flight Dynamics System (FDS)
Flight Director (FLIGHT)
Flight Modell (FM)
Ground Data System (GDS)
German Aerospace Center (DLR)
German Research Centre for Geosciences (GFZ)
German Space Operations Center (GSOC)
Hyper-Spectral Imager (HSI)
Launch and Early Orbit Phase (LEOP)
Mission Operations Director (MOD)
Mission Planning System (MPS)
Operations Mission Manager (OMM)

Orbit Control System (OCS)
Operational Validation Readiness Review (OVRR)
Power, Instrument and Thermal Subsystem (PITS)
Power and Thermal Subsystem (PTS)
Satellite Support Lead (Sat Lead)
Satellite Support Team (SST)
Sequence of Events (SoE)
Telemetry and Telecommand (TMTC)

1. Introduction

The EnMAP (Environmental Mapping and Analysis Program) satellite is a high-resolution imaging spectroscopy remote sensing mission that was successfully launched on April 1st 2022 on a Falcon 9 from Cape Canaveral in Florida, USA to a sun-synchronous orbit with an altitude of approximately 640 km. The satellite was built by the OHB System AG in Germany and operations are conducted at the German Space Operations Center (GSOC) in Oberpfaffenhofen near Munich. Archiving, processing and validation of the received satellite instrument data is done by the German Remote Sensing Data Center and the DLR Remote Sensing Technology Institute. The mission is managed by the German Aerospace Center (DLR) in Bonn and the Scientific Lead is conducted by the German Research Center for Geosciences (GFZ).

The mission is expected to have an operational lifetime of more than five years and to significantly contribute to the scientific community concerning space-based imaging spectroscopy products, providing information about the status of various ecosystems, focusing on issues related to soil and geology, agriculture, forestry, urban areas, aquatic systems, ecosystem transitions and associated sciences [1].

The EnMAP satellite is composed of the satellite bus providing power and thermal stability, orbit and attitude control, as well as satellite management and control. Communication in the sense of Telemetry and Telecommand (TMTC) is available via S-Band and Instrument Data as well as extended housekeeping information is downlinked via X-Band. The Hyper-Spectral Imager (HSI) relies on a prism-based dual-spectrometer, featuring two gain settings each [2]. The VNIR spectrometer covers the spectral range from 418.2 nm to 993.0 nm with a spectral sampling distance between 4.7 nm and 8.2 nm, namely 6.4 nm on average over 91 bands. The SWIR spectrometer covers the spectral range from 902.2 nm to 2445.5 nm with a spectral sampling distance between 7.5 nm and 12.0 nm, namely 10.0 nm on average over 155 bands [1]. Each detector array has 1000 valid pixels in spatial direction with an instantaneous field-of-view of 9.5 arcsec, realizing a geometric resolution of 30 m×30 m and a swath width (across-track) of 30 km [1][5]. Figure 1 shows the EnMAP satellite in artist view, Figure 2 shows the main control area at GSOC.

Fig. 1. EnMAP Satellite [5]

Fig. 2. Main control room at GSOC in Oberpfaffenhofen near Munich, Germany

With a Launch Date of April 1st 2022, the last two years of the validation and preparation phase of EnMAP as well as the highly sensible Launch and Early Orbit Phase (LEOP) was significantly challenged by the Covid-19 pandemic. The virus was first detected in the region of Wuhan (China) in December 2019 and quickly spread all over the world. When the pandemic state was declared by the WHO on 11-March 2020 [3] the EnMAP mission was within a phase of preparing for the Operational Validation Readiness Review (OVRR) scheduled for June 2020.

After a Germany wide governmental lockdown from March 2020 until May 2020 the final 2 years of mission preparation were strongly impacted by constantly changing governmental rules and regulations affecting the work life as well as the private life, e.g. not being allowed to work on-site, no trainings or meetings on-site, closing down schools requiring parents at home supporting home-schooling during their nominal work hours.

This paper will give an overview of the various challenges the Covid-19 pandemic has posed on the different phases of the mission preparation and on the sensitive Launch and Early Orbit Phase (LEOP). Section 2 will give an overview of the pandemic in Germany from 2020 until 2022 and how quickly changing rules and regulations by the government affected daily work at GSOC and the mission preparation phase in general. In addition, the section will shortly outline the hygienic concept in place at DLR/GSOC which was often more conservative than the governmental rules, especially in the second of the two years of final mission preparations. Section 3 of this paper will then outline how rules and regulation like the social distancing for example, was affecting different phases of satellite operations and different levels of mission support at GSOC. Section 4 will then provide information how those challenges were dealt with by the mission operations team, focussing primarily on the simulation campaign and conduction of the LEOP in April 2022. The discussion section will not only describe which additional constraints and risks were identified for the EnMAP mission due to the pandemic and the subsequent governmental regulations, but furthermore provide lessons learned concerning “what really is important during the launch and early orbit phase” and how this was accounted for when preparing for the EnMAP launch.

2. The Covid-19 pandemic and its influence on the work environment

The Corona Virus Disease 2019 (Covid-19) was first detected in the region of Wuhan (China) in December 2019 and quickly spread all over the word. The first Covid-19 case in Germany was detected on 27 January 2020 [4] and numbers quickly increased. The pandemic state was declared by the WHO on 11 March 2020 [3] followed by a seven week long governmental lockdown over all states in Germany from late March 2020 until early May 2020.

During this seven week long governmental lockdown it was not allowed to leave your home except for grocery shopping and urgent doctor appointments. Working in Home-Office was the primary way of work and only employees of system-critical facilities were allowed to drive to their company sites. Concerning personnel working in mission operations at GSOC different rules applied for the different levels of mission support depending on the classification of “system critical”. Level-1 support at GSOC is provided by a team of satellite command operators. This team is working 24 hours a day, 7 days a week according to a shift plan and is providing support for multiple low-earth orbit missions. Nominal support was provided by the Level-1 personnel even during the governmental lockdown as this low-level support includes also the daily commanding and health checks during ground station passes that are essential for monitoring satellite health and maintaining or restoring safe satellite operations. The Level-1 personnel was not only strictly separated from all other personnel working at GSOC from the start of the

pandemic until the middle of 2021, but it was also ensured that there are no "physical" contacts between the operators themselves. This was ensured by a shift and handover concept that included a non-physical handover over phone or Skype as well as operating different missions from different control rooms instead of having all missions together in one control room

The Level-2 personnel at GSOC consists of a team of subsystem engineers and flight directors for each satellite mission, who are responsible for the safety of the satellites. Level-2 personnel is nominally present at GSOC during office hours and an on-call support is provided if needed 24 hours a day, 365 days a year. Level-2 personnel was not allowed to come to work during the governmental lockdown for nominal work. Support was provided from home-office as far as possible. Only the person currently being on-call was allowed to work on the company site in case of satellite safety related activities or mission critical events. In order to achieve this, a lot of workarounds were implemented and many tools and software were made accessible from home by the DLR and GSOC IT, which was posing a huge workload on those people but guaranteed safe satellite operations at any time. With this effort done, DLR GSOC was able to operate all its missions in routine mode even during the complete lockdown whereas other operations centers had to sent at least some of their satellites to safe mode or to stop science operations.

After the governmental lockdown from March 2020 to May 2020, the remainder of the year was marked by strong regulations concerning the allowed number of people within a room, rules concerning social distancing and test strategies. Presence of Level-2 personnel on-site at GSOC was allowed only under specific circumstances. During the first weeks and months after the governmental lockdown, subsystem engineers and flight directors operating satellite missions were only allowed to work on-site only in case of urgent and important business. In the second phase after the governmental lockdown, work on-site was generally allowed, but offices were only allowed to be occupied by one person at a time and the number of people allowed to be present in the control rooms at GSOC was strongly limited. Meetings on-site were generally forbidden and could only be held under specific circumstances and after approval of a "Covid-19 crisis management group" at DLR.

During this phase, non-urgent tasks like software updates and experiments were postponed as far as possible concerning the flying missions. Regarding mission preparation some activities were delayed as far as possible due to the limited presence allowed on-site, whereas preparation activities like developing flight procedures was done from home as the availability of GSOC tools from externally was quickly facilitated by the institute manager.

Early 2021 work on-site at GSOC was again generally permitted to all mission operation personnel, but work in home-office was the default setting unless activities required an on-site presence. Strict rules applied concerning the number of square meters per person to allow for meetings and trainings, and hygienic concepts had to be derived for each event hosting more than 5 people. During the remainder of 2021 rules were relaxed over the summer and strict regulations were reinforced during the winter. Quickly and often changing rules by the German and Bavarian government posed a challenge when preparing the simulation and validation campaign which required a significant amount of people on-site. The next section will describe the effects that those regulations and rules had on the different phases of the EnMAP mission.

3. How social distancing was affecting different phases of the EnMAP mission

With a launch date of April 1st 2022, the last two years of the validation and mission preparation phase of EnMAP as well as the highly sensible Launch and Early Orbit Phase (LEOP) was significantly challenged by the Covid-19 pandemic. The mission preparation phase was not only challenged by a seven week long governmental lockdown but also in the following months, as presence of personnel on-site was strictly limited for the remainder of 2020 and even a huge portion of 2021. Effects on the EnMAP mission preparation timeline were not significant though due to external constraints like a change in Launch Vehicle causing delays within the mission preparation timeline independently of the pandemic. The effect of social distancing and governmental restrictions, e.g. concerning the number of people allowed in a room, was significantly larger during 2021, the last year prior to the EnMAP LEOP.

In general, a distance of 1,5 m between all people had to be ensured and concerning the number of people allowed in a room, a minimum of 10 square meters per person had to be assigned. A hygienic concept had to be derived for each training or validation event hosting more than 5 people within the same room, including concepts of social distancing, face masks, cleaning and test strategies. Concerning the validation activities requiring an end-to-end connection between GSOC and the Flight Modell (FM) on ground, the number of team members allowed to

participate in the validation sessions was therefore strongly reduced, limiting the transfer of knowledge within the team during the mission preparation phase.

During the year 2021 the primary focus concerning mission preparation of EnMAP was on the validation of flight and ground procedures as well as preparing and conducting training and simulation sessions including DLR internal colleagues from other institutes as well as external colleagues from the satellite supplier OHB. After 1.5 years of Covid-19 related restrictions, the first training session involving all colleagues planned to support the EnMAP LEOP was scheduled for September 2021.

The training campaign encompassed one internal cross-training of the GSOC team followed by a cross-training of the entire LEOP team including external colleagues from the satellite supplier OHB and the other involved DLR institutes (EOC, DLR Space Agency). The training sessions were followed by a set of three times two simulation sessions, with the purpose of preparing the entire LEOP team for the planned activities according to the Sequence of Events (SoE) as well as the unplanned challenges which they may encounter during the early days in orbit. Each simulation set comprised an internal simulation where the mission operations team is trained and a combined simulation where the gained knowledge is transferred to the external colleagues and vice-versa. Table 1 gives an overview of the team-wide Trainings- and Simulation sessions conducted at GSOC throughout the simulation and validation phase of EnMAP and during the Covid-19 pandemic as well as the duration of each event in days.

Table 1. EnMAP Simulation & Training Sessions at GSOC

	Internal	Combined	Duration [days]
Cross-Training Session	July 2021	September 2021	2
Simulation Set 1	July 2021	September 2021	2
Simulation Set 2	October 2021	December 2021	3
Simulation Set 3	January 2022	February 2022	3

Both EnMAP Training Sessions and the first set of internal and combined simulations were conducted in the German summer period (July-September) during a period of generally lower Covid-19 infection numbers. Training sessions were conducted in hybrid format to account for the 10 m² per person requirement within the used facilities. A predefined set of essentials lectures within the training sessions was conducted multiple times to facilitate participation of all team members on-site and intense discussions at those lectures while keeping the 10 m² per person requirement. Remaining sessions were performed with the essential personnel for this specific topic being on-site and the rest of the team joining online from their office or from home.

After 1.5 years of the Covid-19 pandemic Level 1 and Level 2 personnel were allowed in the same room for the first time for this purpose. To minimize the risk of widely spreading the virus within the mission operation teams, strict rules were applied concerning wearing face masks and social distancing. Furthermore, only fully vaccinated personnel were allowed to participate in the training sessions and a strict test concept was applied, with an obligatory self-test before entering the control room area and training facilities. The number of people allowed within the main control room during the simulation sessions was limited to the key personnel from GSOC and OHB whereas management related positions and flight dynamics service personnel were seated in separated rooms, remotely connected via voice-loop and screen sharing functionalities in a fully virtualized environment. Developing strategies how to perform a “physical contact free”, pure virtual shift handover was also an essential part of the simulation sessions when preparing for the EnMAP LEOP.

As the main part of the validation phase for the EnMAP mission was performed during the pandemic, transfer of knowledge and building a strong team between DLR and OHB personnel was a main focus of the simulation and training campaign for EnMAP. After the first set of simulation this resulted in a prolongation of the simulation sessions 2 and 3 from two days to three days each, adding a total of four additional days to the simulation campaign. Simulations were performed in shifts, with shift lengths of 6 hours each and one hour for the virtual shift handover on top.

For each simulation a hygienic concept was developed based on the current rules put in place by the government and the set of regulations provided by DLR which were often stricter. Each simulation had to be formally approved by the DLR “Covid-19 crisis management group” after evaluating the hygienic concept and purpose of the event. Hygienic concepts had to be regularly modified based on rules and regulations changing on short notice which posed a big challenge and an additional cost factor.

The EnMAP simulation campaign was successfully finished in February 2022 and no Covid-19 infections within the LEOP team were noted during or in the weeks after the simulations. The challenge of preparing and conducting the EnMAP LEOP during the Covid-19 pandemic will be described in the next session.

4. The challenge of preparing and conducting a LEOP during a pandemic

With a Launch Date of April 1st 2022 not only the simulation and validation phase of the EnMAP mission was strongly affected by the pandemic, but also the highly sensible Launch and Early Orbit Phase (LEOP) had to be prepared and conducted during this period. Several additional precautions and preparations were needed in order minimize the possible risk for the safety of the satellite and the mission. The following subsections will describe the hygienic concept derived and applied for the LEOP, as well as the additional constraints and risks that were identified for the EnMAP mission due to the pandemic and the subsequent governmental regulations. Furthermore, it will give an overview of the Covid-19 related issues that really did come up during the EnMAP LEOP in April 2022.

4.1 Hygienic Concept

With the experience of quickly changing rules and regulations during the simulation campaign in 2021 the hygienic concept for the EnMAP was developed early 2022 in close cooperation with the DLR "Covid-19 crisis management group". Even though Covid-19 infection numbers were high during the winter season, governmental rules and regulations were relaxed step-wise in the weeks before the EnMAP LEOP.

In close discussions with the DLR "Covid-19 crisis management group" and the GSOC Head of Department it was decided to maintain the strict rules, commonly known as 2G+ (fully vaccinated and tested) which had proven their effectiveness during the simulation campaign even though governmental and DLR regulations were stepwise relaxed shortly before the LEOP. Only fully vaccinated personnel were allowed to take part in the LEOP, daily self-tests were obligatory before shift start each day and personnel was required to wear medical face masks throughout the entire LEOP. On the other hand, in contrast to the hygienic concepts applied in the simulation campaign, for the LEOP it was decided to lower the mask requirement from FFP-2 to medical masks due to work regulations and the human factor. Why this decision was made and whether this posed an additional risk or lowered one will be discussed later in section 5.

In addition, for the LEOP and in the weeks before the expected launch date, all GSOC personnel entering the control room area had to be tested negative on that same day to minimize the risk of infecting members of the LEOP team in the work environment shortly before the expected launch date.

Furthermore, 10 days before the expected launch dates a shift concept was applied to the EnMAP team, having dedicated days to work on-site in line with the LEOP shift plan to avoid infections spreading from one shift to the next during office hours.

Social distancing concepts were derived for the catering facilities, limiting the amount of people at one table to two at a time and maintaining a distance of 1,5 m between one another in-line to pick-up food. As a catering facility a room was chosen that easily guaranteed the 10 m² per person requirement and in addition was equipped with an enormous ceiling height to minimize the risk of infection while eating. Figure 3 illustrate the seating-plan for the EnMAP LEOP including consoles left empty on purpose. As for the simulation sessions all non-essential personnel (e.g. Management) was sitting in separate rooms to minimize risk of infection.

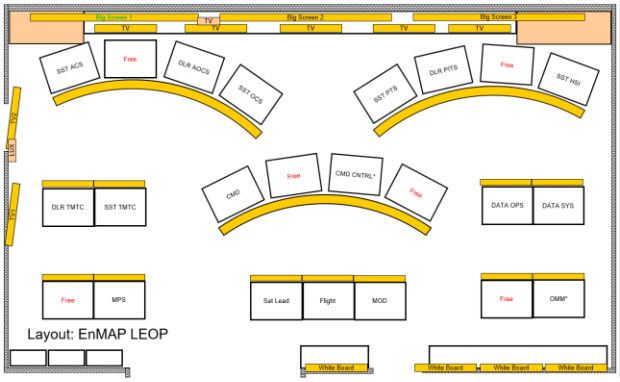

Fig. 3. Seating plan in the main control room during LEOP

4.2 Constraints and Risks

In addition to enhancing the hygienic concept which was thoroughly tested during the simulation campaign with the LEOP specifics (e.g. including catering) several constraints and risks had to be considered when preparing for LEOP. The EnMAP LEOP was arranged to last a minimum of 9 days and a maximum of 14 days, having 24/7 support for all subsystems. Three teams with 22 persons each were available covering all positions in and outside the control room.

The shift times included 30 minutes of time for performing a self-test and waiting for the results before entering common areas. Furthermore, one hour of shift overlap was included in the schedule to allow for a virtual shift handover in between ground station passes. For this purpose, it was necessary to block a larger amount of meeting rooms than for a LEOP under normal circumstances. In between shifts, control room equipment was disinfected, and the next shift was informed via a note on the big screen once being allowed to enter the control room. Performing a virtual hand over with your team members of a prior/later shift was practised within each of the six simulations performed in 2021/2022, and several improvements were integrated in this process during the simulation campaign. However, it was clear to everybody that the virtual handover, which was needed to minimize the risk of infections "jumping shifts" was not ideal compared to the nominal scenario with both shifts sitting together on one console in the control room for at least one ground station pass.

Two worst case events concerning the pandemic were discussed before the LEOP on a mission management level. First, the scenario that a large Covid-19 outbreak was taking place shortly before the launch date, forcing every person with a positive test result to stay at home in isolation and not being able to come on-site to support the LEOP. After intense discussion, it was decided to include the Covid-19 situation in the go/no-go criteria during the launch countdown. Two possible scenarios were included in the decision process to define whether the LEOP team was "go/no-go" from a Covid-19 perspective:

- The overall amount of infections within the entire LEOP team (all shifts): at least 65 % of the satellite supplier team had to show a negative test result from an official test-point 48 hours prior to the expected launch date.
- Critical positions within the LEOP team were defined and it was decided that at least two of three people (e.g. Flight Director, Sat Lead) or one of three (e.g. Subsystem Position at GSOC) on each of these positions were needed to be "go for launch".

Second, a matrix was derived concerning the allowance of personnel on-site in case of being a contact person to a Covid-19 positive person. This discussion was triggered after governmental rules concerning contact person management were relaxed early 2022. Based on governmental rules, every team member would have been allowed to work on-site even if a close family member would be sick with Covid-19 at that time.

It was decided to allow everybody on-site to work in the LEOP team in case of having a red warning in the Corona-App used by most team members, and also to be allowed to join in the control room even if one was in contact to a Covid-positive person not being a member of the own household.

However, it was decided not to allow personnel to work on-site during the LEOP in case a member of the own family or household was having an active Covid infection as the risk of infection at home was considered to be largest. Two explicit exceptions from this rule were stated though: concerning personnel working for the Flight Director or Sat-Lead position it was decided to allow their presence in the control room even if a child or spouse in the own household would be Covid-positive, as those positions were considered to be essential for conducting a safe LEOP and the risk of one shift conducting the LEOP without these positions was agreed to be larger than possibly slowly spreading the infection within the team of this shift.

Last but not least, an emergency plan was derived to cope with single drop-outs of team members during the LEOP due to positive Covid results during the self-tests or not being allowed to come on-site due to being a close contact person as described above. Different strategies were derived for the different shifts.

Concerning Team 1 (evening shift) being responsible for the satellite shortly after launch, supporting the first ground station passes, it was decided to fill any gap in Team 1 with a team member of Team 3 (day shift) as these first passes were decided to be the most critical ones and a missing person could pose a significantly higher risk than a gap in Team 3. In case of having a missing person in Team 1 on day 1, the shift separation concept described in section 4.1 would have been violated to reduce the risk posed by a missing person during the highly sensible first ground station passes.

Concerning Team 2 and 3 (night shift and day shift) missing personnel would not have led to any change in the teams, but depending on which position being empty, actions from the SoE would have been moved to later shifts or

in case of critical positions (e.g. Flight Director) being empty, this shift would have been declared "monitoring and safekeeping" only and all actions scheduled would have been moved in the SoE to a later shift.

4.3 EnMAP vs. COVID-19: the experience

After the validation and simulation phase the EnMAP satellite was successfully launched and separated from a Falcon 9 on April 1st 2022 at 16:38:26 UTC. Covid-19 infection numbers were high after the winter waves, but numbers were slowly decreasing. As included in the hygienic concept, each member of the EnMAP LEOP team was tested by a certified cite approximately 48 hours before the expected launch date and a copy of the official certificate was provided to the EnMAP Mission Operation System Manager and the leading Flight Director.

Out of all team members, one person was tested positive and three were already in isolation on the test day, Hence, 94 % of the team were able to support the LEOP from this point of view. Furthermore, since the positively tested person was neither planned for a critical subsystem position, nor a member of Team 1 supporting the first passes after launch, the "go"-criteria for launch as described in section 4.2. was fulfilled and no changes in the shift plan had to be performed on short notice. The other three persons already in isolation on the test day, were able to provide a negative test on the launch day or the day of their first shift and participate according to the original shift plan.

The positively tested person was part of the DATA positions. At GSOC nominally two persons are planned to monitor the DATA system which includes all ground data systems needed to command and monitor the spacecraft from the control room. Since this position needs to monitor many processes, two persons nominally support this to have enough hands available to quickly react to problems arising shortly before or during a ground station contact. The EnMAP LEOP was successfully supported with one person sitting on console and the other person supporting remotely from home giving advice on how to react. No severe anomalies were observed in this subsystem during the shifts and all problems could be handled by the one person in the control room at all times.

In addition to the one Covid-positive person identified during the pre-launch test strategy, one person could not attend the LEOP due to being a close contact person with a positively tested spouse. This became known only on the launch day but was again luckily neither a person occupying a critical position nor a member of Team 1 supporting the first passes. Hence, no short notice changes in the shift plan were needed, however since it was a management position on GSOC side in charge of decisions and organisational support it was decided to fill this position with an experienced but project external employee on-site for the first five days and to have remote support from home by the person not allowed to work on-site due to the contact person management rules.

Hence, one person was added to the EnMAP LEOP team on very short notice, who was not trained for this purpose but was constantly supported by the trained person via phone and mail during all passes and all discussions in Shift 2 (night shift) for the first four days. Luckily this person had an intensive background of the project due to his former roles and positions at GSOC and a very large experience with LEOPs and mission operations in general and was available for night shifts on short notice.

During the 14 days of LEOP conducted by the EnMAP team in Oberpfaffenhofen near Munich, no additional person was positively tested by the daily test concepts, no additional person dropped out during the LEOP due to sickness or becoming a close contact person and no infections were identified after the LEOP. Table 2 gives an overview of the available personal during the LEOP in the three shifts. Each shift team was primarily made up of GSOC and OHB personnel, with a representative from the Space Agency (Mission Manager) in each shift and the Mission Operations Manager (OMM) from EOC supporting one shift. On the GSOC side, the Flight Director (FLIGHT) was the person in charge closely working together with the Satellite Lead (Sat Lead) on OHB side. For each satellite subsystem, support was provided by GSOC and OHB personnel: An Attitude and Orbit Control (AOCS) engineer from GSOC was working closely together with his OHB counterparts from the Attitude Control (ACS) and Orbit Control (OCS), a Power, Instrument and Thermal System (PITS) engineer from GSOC together with Power and Thermal (PTS) and Instrument (HIS) specialists from OHB, and the Telemetry and Telecommand (TMTC) engineers from both companies. From the GSOC side additional support was provided by DATA OPS and DATA SYS engineers monitoring all systems needed for telemetry reception and commanding in the control room, a GDS engineer responsible for connections between the ground station and the GSOC systems, a CMD operator sending the prepared commanding files to the S/C, and representatives of the Flight Dynamics and Mission Planning Services as well as Mission Operation Director (MOD). Quality Assurance from GSOC side was available on-site during daytime for the entire duration of the LEOP.

Table 2. Available personnel and planned positions during EnMAP LEOP

	Team 1 (first shift)	Team 2 (night shift)	Team 3 (day shift)
FLIGHT	X	X	X
AOCS	X	X	X
PITS	X	X	X
TMTC	X	X	X
MOD	X	missing	X
MPS	X	X	X
DATA OPS	X	X	missing
DATA SYS	X	X	X
FDS	X	X	X
GDS	X	X	X
CMD	X	X	X
Sat Lead	X	X	X
SST ACS	X	X	X
SST OCS	X	X	X
SST PTS	X	X	X
SST HSI	X	X	X
SST TMTC	X	X	X
Space Agency	X	X	X
OMM	X	not planned	not planned
Quality Assurance	not planned	not planned	X

5. Discussion

The EnMAP LEOP was conducted successfully at GSOC over a period of 14 days with three shifts during the Covid-19 pandemic, in a period with high numbers of infections but numbers showing a decreasing trend with spring season coming up. During the preparation phase of the LEOP, especially in the weeks before the launch date, governmental rules were step-wise relaxed even though the number of infections stayed on a high level. However, one essential governmental rule was not relaxed at this time and was a main argument for maintaining the strict rules and regulations at GSOC until successful finishing the LEOP even though rules in Germany and also at DLR were relaxed by then. This rule was: if tested positive one has to go into isolation at home for several days.

Hence, it was not possible to simply separate these team members by using two control rooms and include positively tested persons in the LEOP by separating them physically within the GSOC premises. Instead, positively tested team members were forced to stay home until the infection was over and tests were negative again.

In addition to the risk that Covid-positive team members were forced to stay at home, not being able to support the LEOP from the control room area, another factor was considered when developing the hygienic concept for the EnMAP LEOP. Social distancing was a well-known method to keep the risk of infection low, but social distancing is nothing that comes easy to the human and stands to some extend in contrast to working as a team. It became quite clear during the simulation phase that the team members were very disciplined with keeping distances between one another as long as everything was running smoothly. However, in case of anomalies on ground or with the spacecraft it is essential to have as much knowledge as close together as possible and keeping a distance of 1,5 meters between each team member while for example discussing about a plot or tool content, turned out to be very hard and was quickly forgotten while trying to find a solution to the problem. Furthermore, it had to be taken account that during the course of several hours and days during the two week long LEOP the overall exposure time to one another is quite large anyways and periods without face masks sum up quickly while taking a coffee or having lunch together on consecutive days.

Hence, it was decided that the human behaviour had to be considered when developing the hygienic concept for the EnMAP LEOP and the biggest focus needed to be “to identify and isolate (possibly) contagious persons” from

the rest of the team and to avoid contact between the shifts and to non-LEOP personnel as far as possible. For this reason, everybody at GSOC needed to perform a self-test before entering the control room area in the weeks prior to the expected launch date. In addition, the shifts were separated from one another already 10 days before the LEOP and a strict test policy and contact person management was applied. Furthermore, it was not allowed for the EnMAP personnel to attend the launch event at GSOC as this event was not applying such strong regulations and up to 100 internal and external guests were expected. This of course, was a harsh decision that needed to be made, but it was needed in order to keep the risk of infections within the EnMAP team low.

However, being stricter on many issues as governmental or DLR rules at that time, one rule was relaxed for the duration of the EnMAP LEOP compared to the hygienic concepts applied during the simulation campaign. It was allowed to use medical face masks during LEOP, whereas during the simulation campaign FFP2 masks had to be worn at all times in the control room and the meeting rooms. This rule was relaxed because governmental work rules concerning the usage of FFP2 face masks are quite strict in Germany and regular "mask breaks" would have to be included during the LEOP regardless of the situation and safety of the spacecraft. Regular mask breaks were of course possible during simulations, but could not be guaranteed during LEOP. Furthermore, it was commonly known by that time that wearing FFP2 masks for several hours continuously had physical effects (e.g. fatigue, headaches, concentration issues) on several team members. During a LEOP though, the team needs to be at the top of their performance level at all times to cope with potential critical situation arising. Hence, priority was again given to keeping (potential) contagious persons away from the rest of the LEOP team and a strict physical separation of the three teams, as infections were expected to spread between one shift to some extent.

Concerning lessons learned from conducting a LEOP during a pandemic, two points need to be mentioned. First, the concept of social distancing to avoid an infection to spread within a group of people stands in contrast to the concept of conducting a LEOP, where one is aiming to collect as much knowledge and experience as available, as closely together as possible. Within one shift, it was decided to allow discussion and analysis of failures sharing a console if needed to solve a critical issue quickly, but in between shift teams there was not contact in the weeks prior and throughout the extend of the LEOP. It was a clear decision pro facilitating a quick failure analysis and being aware of the infection risk, in combination with avoiding possible infections to "jump shift" so in the worst case, one shift may drop out halfway through the LEOP but not several persons would be sick in more than one shift.

The virtual handover concept needed to minimize the risk of infections "jumping shifts" as outlined in section 4.2 was of course not ideal compared to the nominal scenario of both shifts sitting together on one console in the control room for at least on ground station pass. The concept of the virtual handover was thoroughly tested in all six simulations performed and the process was step wise improved. However, some technical limitations persisted and should be a point for future missions to be able to cope better with the next pandemic.

Facilitating phone conference including screen sharing would have further improved the quality of the virtual hand overs, but was not possible for all team members due to technical limitations and security reason in the operational environment and should be improved for future missions. In addition, facilitating screen sharing for more than one person would be ideal to have virtual handover sessions not only one-by-one but also including the current and next shift personnel of the industry support in those discussion while sitting in different control rooms.

6. Summary and Conclusion

The EnMAP mission was successfully launched on April 1st 2022 on a Falcon 9 from Cape Canaveral in Florida, USA in the middle of the Covid-19 pandemic. This paper gave a short overview of the EnMAP mission and its scientific purpose. Afterwards a rough outline of the pandemic was given and the different rules and regulations by the German government were described which strongly influenced the way of work during the Validation and Simulation phase of the EnMAP mission from 2020 to 2022. Main focus of the paper was then to describe the hygienic concept applied during the EnMAP LEOP and further restrictions and risks that needed to be considered, e.g. including the Covid-19 situation in the "go/no-go" criteria for launch and developing a Contact-Person Management guideline for the LEOP.

As the governmental rules were relaxed shortly before the LEOP even though numbers of infections were still at a high level and positive tested persons still needed to isolate themselves for several days instead of working on-site, it was agreed to apply more strict rules during the LEOP than would have been needed by law. Furthermore, some of the rules were extended over the entire facility to minimize the risks of infections spreading at GSOC shortly before or during LEOP and hereby posing an unnecessary risk.

Overall, the EnMAP mission was very lucky considering the number and positions of the Covid-19 infections that really did occur during this highly sensible phase and it was learned from this process, that getting all the

available knowledge physically together is the most important thing when conducting a LEOP. Furthermore, it was learned that the human factor has to be considered when developing hygienic concepts which are intended to work under realistic conditions and are not only paperwork. Finally, some technical advances were identified and explained in the discussion section that will be helpful and will increases the likelihood of conducting a successful LEOP during the next pandemic.

Acknowledgements

The EnMAP mission is supported by the DLR Space Agency with funds of the German Federal Ministry of Economic Affairs and Climate Action. We would like to thank all colleagues from the Agency, from the satellite supplier OHB and from DLR and GSOC who were involved in the preparation and conduction of this very successful LEOP in April 2022.

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