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# MISSION OPERATION, GROUND SEGMENT AND SERVICES

# FOR THE GERMAN TET-1 MICROSATELLITE

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**Abstract**

The TET-1 mission ("Technologie-Erprobungs-Träger") is the core-element of the On-Orbit Verification (OOV) space program of the German Aerospace Center (DLR) with the goal to provide regular and short-term flight opportunities to industry and research institutes for in-orbit verification of new and innovative space-technologies. The main section of the paper focuses on the description of the mission elements provided by DLR, which are ground-segment, mission operations, services and products provided for the users and their integration into the multi-mission environment of DLR facilities – all of this at low cost with sufficient reliability and acceptable risks.
As TET-1 constitutes the first spacecraft of a program dedicated to promote new orbit technologies and to provide compatible and space-qualified small platforms for different space sensors, the paper concludes with an outlook on ground-segment extensions and operations concept enhancements to support cost efficient and reliable ground-systems and operational scenarios for this new family of micro-satellites.

## 1. INTRODUCTION

The author works since 1984 with GSOC - German Space Operations Center (part of German Aerospace Center – DLR) in the area of mission operations of geo-synchronous and low-earth satellites as well as human space-flight missions onboard the former MIR space-station. Since 1999, the responsibility of project-management for mission operations preparation and -conduct for four, sometimes overlapping earth observation satellite missions has resulted in valuable experiences especially in the field of multi-mission and multi-satellite operations.
After the last assignment as project-manager for the Mission Operations System for the German TerraSAR-X mission, the author took over the project-management for the ground-segment of the TET-1 mission in phase B, with phase C just about to start at the time being.

### 1.1. DLR's On-Orbit Verification Program

The OOV program of DLR [2] serves to bridge the gap between the product tested and qualified on the ground and the utilization of the product in space. With the help of regular and short-term availability of flight opportunities, industry and research facilities can verify their latest products under space conditions and demonstrate their reliability and marketability.

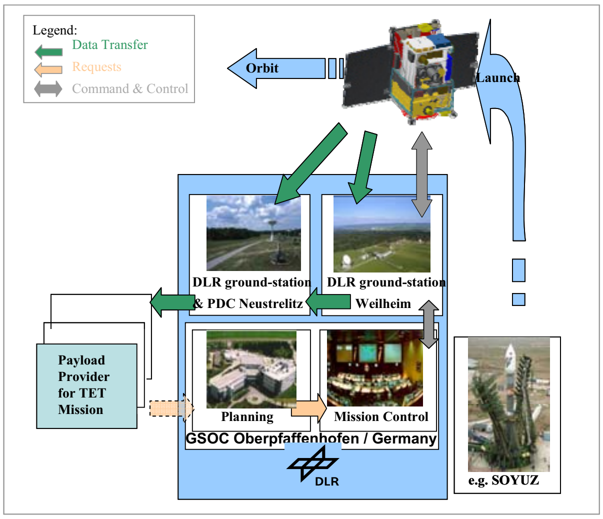


*FIGURE 1: TET Mission Overview*

The "Technologie-Erprobungs-Träger TET" (Technology Experiments Carrier) comprises the core elements of the OOV Program. Certain programmatic conditions (e.g. maximum reuse of existing technologies and facilities) were established for both space- and ground-segment to realize this as a low-cost mission within a relatively short time-frame under the leadership of an experienced industrial space-company as prime contractor.
The first TET-1 microsatellite - with eleven technology experiments as payload - is based on the already space-qualified BIRD satellite-bus and is planned for launch as piggy-back mid 2010 into a low-earth (500 - 600 km) and high inclination orbit for a planned mission of 1 year.

### 1.2. Scope and Conditions

The design and main functions of the TET-1 Ground Segment at PDR stage are presented which are based on existing and proven systems but also make use of co-operations between networks and innovative concepts like the common development of databases, flight-procedures and joint training and verification activities in project phase D together with the satellite manufacturer.

The user-community of this orbital verification platform mainly comes from research institutes and industry with little or no experience in space operations or knowledge of the very characteristic operational constraints of a low-earth orbiting satellite. Therefore, services for and products provided to the user community must be carefully analyzed, elaborated, implemented and tested during the preparation phase to ensure a satisfactory transition into the operational phase once the initial Launch and Early Orbit Phase (LEOP) is over.

To comply with the programmatic conditions and to fulfill all requirements regarding low cost but sufficient reliability, schedule and re-use of available systems, facilities and functions, the TET-1 mission has to be implemented, integrated and operated within the multi-mission environments of the German Remote Sensing Data Center (DFD) and the German Space Operations Center (GSOC) as overall responsible for the ground-segment and operations. This will be realized partially with GSOC under sub-contract by Kayser-Threde GmbH (industrial main-contractor).

The ground-segment and operations requirement for sufficient reliability and acceptable risk are contradicting with the available low budget and the externally defined schedule (piggy-back launch), hence only a consequent tailoring of ECSS requirements (according to ECSS M 00-02), in combination with the already mentioned re-use, co-operation and multi-mission approach provides a way out of this difficult situation.

Process and scope of the applied tailoring are not subject of this paper, but this is extensively applied in the areas of documentation (multi-mission instead of project specific), project planning and execution of reviews.

### 1.3. BIRD heritage

During early stages of the TET-1 mission study has shown, that the bus of the German BIRD micro-satellite (Bi-Spectral Infra-Red Detector) can be easily adopted for the needs of the TET satellites and other small satellite missions. It makes extensive use of the expertise gained in BIRD development and operation.
BIRD – developed, built, managed and operated entirely by the German Aerospace Center (DLR) itself - was launched in October 2001 on a PSLV-launcher from India into a sun synchronous orbit at an initial orbit of 570km and an inclination of 98 degrees. The primary objective of the BIRD mission was to test a new generation of infra-red sensors for the detection and scientific investigation of hot spots (forest fires, volcanic activities or coal seams) as well as the demonstration of new micro-satellite technologies in space. The nominal lifetime was designed to be 18 months. The project accepted that some of the electronic parts were not space proven due to cost limitations.

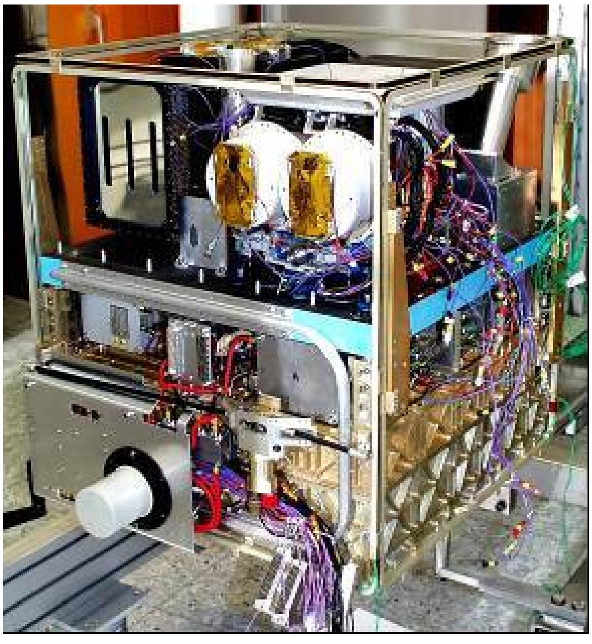

*FIGURE 2: BIRD-satellite – precursor for TET*

Despite some degradation of bus systems and sensors, BIRD is now in its seventh year of operation and still delivers high-resolution images in the infra-red spectrum today. Operations are carried out by a small expert team of the German Space Operations Center (GSOC) with occasional support by the manufacturing DLR-institute. As a micro-satellite low-cost mission, this became only feasible by almost exclusive use of DLR-owned ground-station resources and the full integration of operations into the multi-mission environment.

The BIRD satellite is divided into 3 compartments of similar size. In the lower and middle parts the spacecraft bus systems are contained, while the upper part mainly houses the payload (cameras and sensors for different wavelengths and applications).

The clear separation of the three compartments leaves enough space for various payloads. The payload section can be extended easily, and its envelope is mainly limited by the available space in the launch vehicle.
In general the BIRD hardware design and data handling software as well as the ground- and data-processing functions have delivered an optimal performance in practice. For building the new TET-1 satellite some proven hardware systems were no longer available. Therefore these parts had to be replaced by newer and improved systems, comprising the star cameras, the transmitters and receivers, the batteries, the reaction wheels and the gyroscope.
While BIRD employed a specific non-standard uplink interface, the overall TM/TC system of TET-1 will follow the CCSDS recommendations and will also be compatible with the standard ground station uplink equipment.

## 2. GROUND-SEGMENT DESIGN

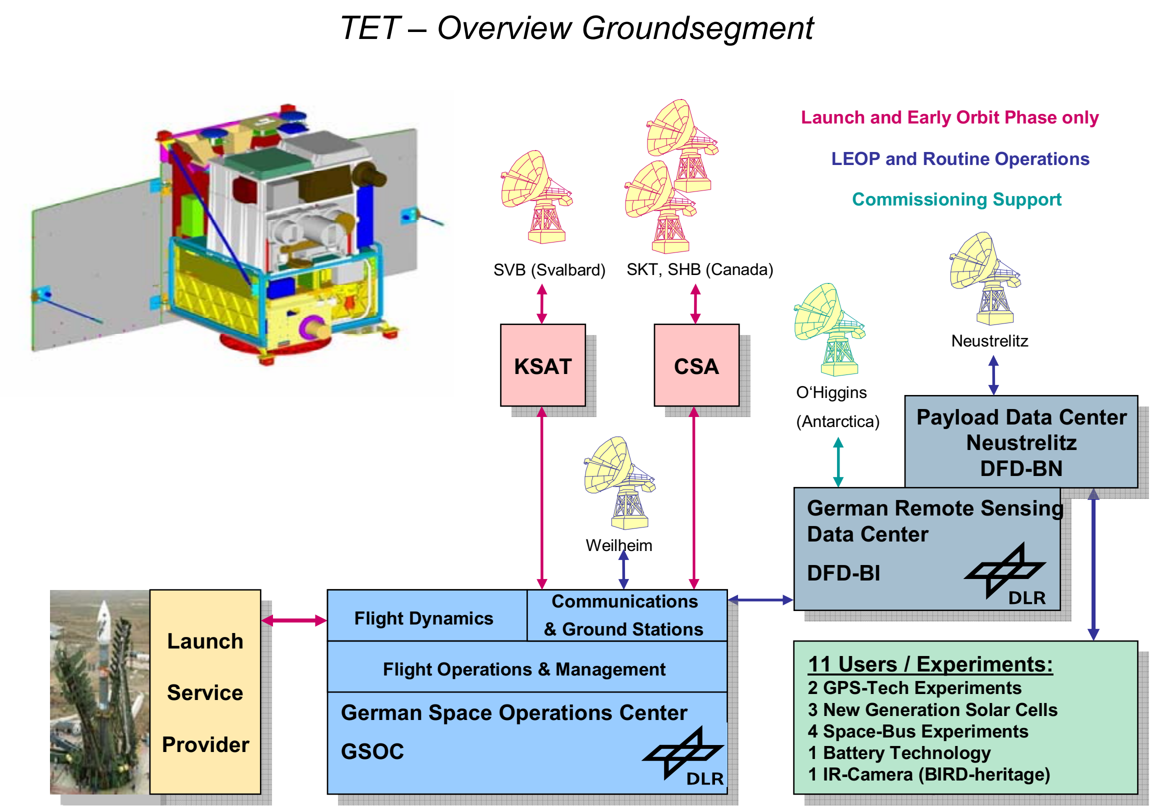


*FIGURE 3: TET overview groundsegment*

GS project management, integration, test and training as well as all LEOP-activities, routine mission operation and satellite control will be performed at the German Space Operations Center (GSOC).
Interfaces are established to the German Remote-Sensing Data Center (DLR-internal) and to external partners such as the launch-provider (data-exchange), to the Canadian Space Agency (CSA) and to KSAT (Norway) as providers of additional ground-stations for LEOP-support. DLR-owned S-Band ground-stations in Weilheim, Neustrelitz and O'Higgins/Antarctica (tbc) provide the necessary access to the satellite in the mission phases after LEOP.
This ground-station concept based mainly on DLR-owned resources is one of the reasons for cost-effective project design. However, operational requirements sometimes need to be tailored to the available uplink- and downlink-resources.
A so called Payload-Data-Center (PDC) will be provided at the location of the data reception-station in Neustrelitz. The main tasks are acquisition, extraction, processing (formatting to a generic ASCII format) archiving and provision of payload data.

The 11 users with their experiments onboard TET-1 retrieve (download) their data via a secure FTP interface.

The main goals for the design and implementation process of the ground-segment can be summarized as follows:

- Minimize number of project-specific systems and tools
- Make use of multi-mission core systems (Mission Data System, Flight Dynamics, networks,…)
- Use of multi mission documentation and combining documents reasonably
- Efficient pooling of multi-project resources and personnel

Below figure illustrates the main functions of the ground-segment and their interfaces. The core element – the so-called Mission Data System (MDS) – is already fully operational and available and just needs to be configured for TET. The only exception being the Mission Information Base (MIB) which is specific for each project as it contains the definitions of TM/TC and flight procedures.

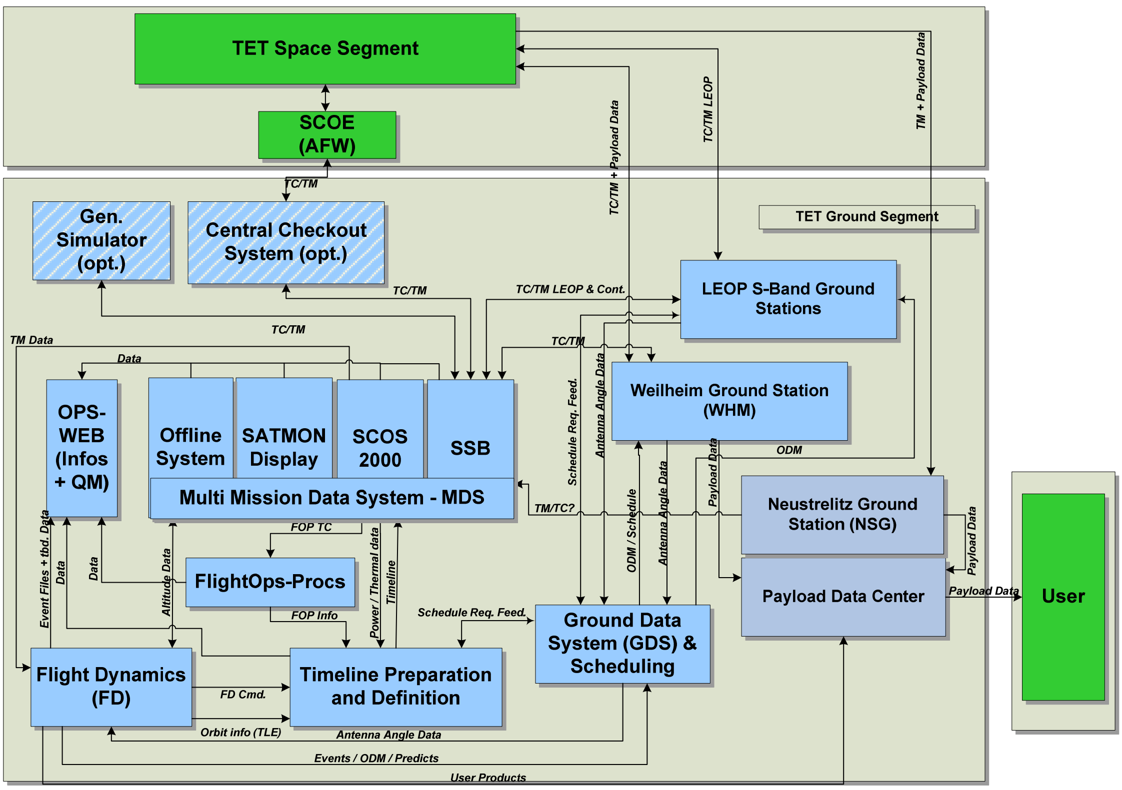


*FIGURE 4: TET ground-segment functional structure and interfaces*

## 3. INTEGRATED PROJECT AIT CONCEPT

The **"Integrated Concept" (IC)** employed at GSOC in most of the earth observation missions supported there emphasizes:

- early and consistent co-operation between the project partners (customer, spacecraft-manufacturer, payload provider, users, operators and ground-segment)
- use of resulting synergies in management and technical areas and
- establishment of overall efficiency

The goal is to minimize or even largely eliminate the inherent problems and risks of the conventional project approach which is characterized by separate and largely independent development, integration – and test chains on both sides of spacecraft and ground-segment. For more details see [1].

Main element of this "Integrated Concept" at GSOC is the so-called "Central Checkout System" (CCS) - a user-interface to the spacecraft and its components required during Assembly, Integration and Test. It constitutes the main component of the EGSE (Electrical Ground Support Equipment) as it is the main or only communication interface with the spacecraft from integration of the components until final checkout onboard the launch-vehicle. The CCS is entirely developed, integrated and maintained by the engineers and may also be operated by operations personnel of the German Space Operations Center at the site of the spacecraft until launch.

The CCS hardware- and software- components are identical or very similar to the Mission Data System used later to monitor and control the spacecraft in orbit, the same is true for the databases (telemetry and command), data-displays, procedures, application-software and a large number of tools. This makes the CCS a platform for early and efficient test and validation of space- and ground-systems on system-level, for transfer of know-how in both directions and for efficient training of the operations- and support teams.

Since 1998, GSOC has successfully prepared and conducted four satellite missions with 5 satellites under this philosophy. Based on positive experience during the past and current successful projects, GSOC has also proposed this concept for the TET mission.

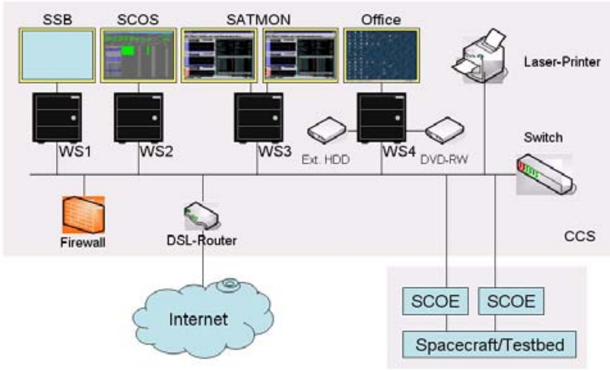


*FIGURE 5: Overview of proposed CCS for TET*

Above figure outlines the architectural design and main elements for one CCS. The main characteristics, synergies and benefits for the TET project are briefly summarized below:

- Concept - multiple use, common products and training, core-elements of Mission Data System are used
- Savings - training and simulation effort reduced by early training on CCS
- Savings - no dual development of key products, tools or systems necessary
- Structure - cost effective re-use of H/W and software modules
- Mobility - different locations at different times
- Schedule risks reduced – avoid critical delays in deliveries of customer furnished items (inputs to TMTC-database and flight-procedures)
- Common Human-Machine-Interfaces (HMI) and tools
- Common databases (TM&TC, data-displays, procedures ...)
- Common and co-operative process of generation and validation of operations and test procedures

Many above mentioned items are core tasks for preparation of mission operations, which quite naturally leads to the next important area.

## 4. MISSION OPERATIONS

For the TET mission the ground-segment will basically provide the execution of all necessary activities for a sound operation of the space segment and a continuous survey (monitoring & control) of functionality and integrity of all project elements. DLR-GSOC will perform this for all mission phases after launch for both the space segment and the ground segment.

During the mission preparation phase detailed analysis and planning of the mission operation will be undertaken and the operations processes will be designed, implemented, tested and validated. In the LEOP, bus commissioning- and routine operations phase telemetry data of the satellite and payload status is received and processed and telecommands for controlled changes of the satellite are sent. Onboard power and data storage availability, S/C attitude and payload requirements for previously scheduled payload events are compiled and executed.
In preparation for this, training sessions will be performed during project-phase D for all operations personnel at DLR/GSOC. The training comprises of class room and simulation sessions. Due to BIRD-heritage, the operational ground processes are already largely known to the experienced operations personnel at the control center GSOC and at the PDC in Neustrelitz.

After launch and successful orbit-injection and separation of TET from the launcher, GSOC is responsible for execution of early orbit operations. Below figure illustrates the first orbits after launch and the related coverage zones by the available ground-stations. LEOP is characterized as follows:

- Launch from Baikonour with Soyuz as secondary payload ("piggy-back")
- Separation from Fregat upper-stage after injection in desired orbital altitude. Separation location still to be selected appropriately.
- Spacecraft initiates automatic activation sequence and transits to safe-mode (attitude, power, thermal, communication)
- Initial acquisition of signal over DLRs Weilheim (Germany) ground-station, followed by Svalbard on Spitsbergen.
- Begin of orbit determination process utilizing tracking data gained from all ground stations.
- Start of checkout and ground-commanded configuration activities
- Support by 2 Canadian ground-stations begins after 3 orbits
- LEOP and bus commissioning duration: 7 days
- followed by activation of payloads and their checkout

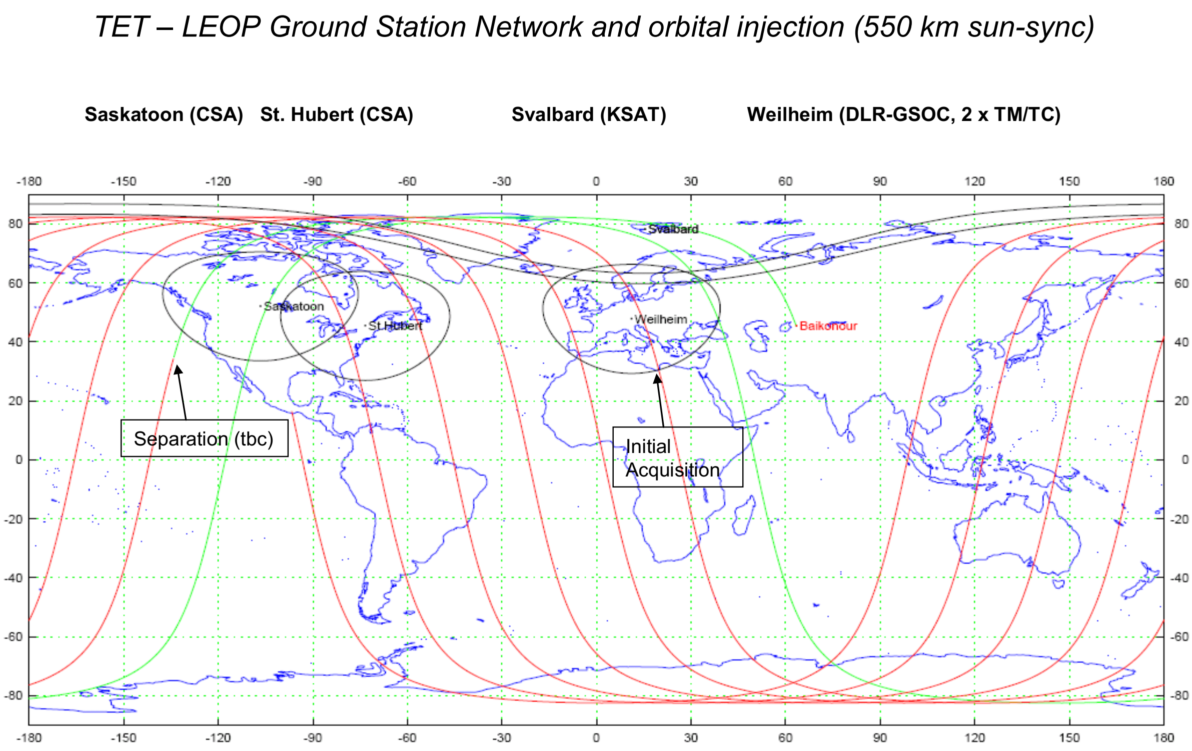


*FIGURE 6: TET LEOP station coverage and ground tracks*

The routine mission operation and satellite control will be performed by GSOC engineering personnel during normal working hours with the support of a multi mission flight operations team (MMFS-team) responsible for shift operations as required. Routine operation phase is characterized as follows:

- 3 different pre-defined payload scenarios are identified to the present:
    - Recurring activities on a weekly basis
    - Additional activities during 4 days once per month
    - Specific activities during 2 days at start and end of mission
- Ops-planning, health-monitoring and onboard maintenance at GSOC
- Upload of time-tagged executable commands to bus and payload: 3 days in advance, weekly cycle
- Commanding and TM-reception: once per day via Weilheim ground-station
- Upload of S/W and maintenance on request
- Download of data (payload and bus): 4 times per day
- Data reception and processing at Payload Data Center: automatic, 7 days a week

Operational tasks and responsibility within the ground-segment during mission conduction:

- The DLR ground station in Weilheim will serve as main uplink (TC) and housekeeping telemetry reception (HK-TM) station.
- The DLR ground station in Neustrelitz will be used as main downlink station for payload data but also provides backup U/L-capabilitiy in case of support conflicts.
- S-band data will be routed in real time from Weilheim and Neustrelitz to the Operations Center in Oberpfaffenhofen (GSOC) and all raw data will be stored at the receiving ground-stations for a limited period.
- Calibrated housekeeping data (i.e. uplink and downlink) will be archived at DLR/GSOC and can be used at GSOC for offline analysis, while payload data will be formatted to an additional generic ASCII format, provided and archived at Neustrelitz together with the raw instrument source packets and other auxiliary data products.
- Mission control, preparation and execution of flight-operations, health-monitoring and performance analysis is performed at GSOC, as well as permanent orbit determination utilising GPS data and ‘station predicts’ will be generated to support acquisition of the satellite by the ground-stations.
- Initially, a dedicated control team consisting of engineers and spacecraft-operators will conduct LEOP and the initial commissioning phase (duration 1-3 weeks, depending on mission progress).
- A soon as spacecraft and experiment activation and checkout are completed, all operations is transferred to the multi-mission environment - this refers to the control-facilities (consoles, control-room) as well as the operations concept (monitoring and control done by the Multi-Mission-Flight-Support-Team under supervision by engineers).

The above outlined operations concept for TET based on DLR-internal resources and on the multi-mission approach will make the most efficient use of the existing facilities, processes and teams as TET will be another mission added to the pool of presently 5 satellites permanently operated at GSOC.

## 5. INTEGRATION IN DLR's MULTI-MISSION ENVIRONMENTS

### 5.1. Mission Control at GSOC

With the exception of security relevant missions, all routinely operated projects at GSOC are integrated into the current Multi-Mission concept. Software, hardware, facilities, networks and teams are organized in a way to provide services to currently all missions in operation or under preparation. The goal is to:

- minimize the number of dedicated and project-specific systems and tools and to
- make the multi-mission system widely configurable to support a variety of missions

Nevertheless, new missions have to consider or establish compliance with the ground-segment at an early stage of the project. As the ground-systems and mainly the MDS are designed in compliance with ESA-PUS (Telecommand and Telemetry Packet Utilisation) and CCSDS standards, the requirements can easily be tailored in phase B. This was also done in the TET project.

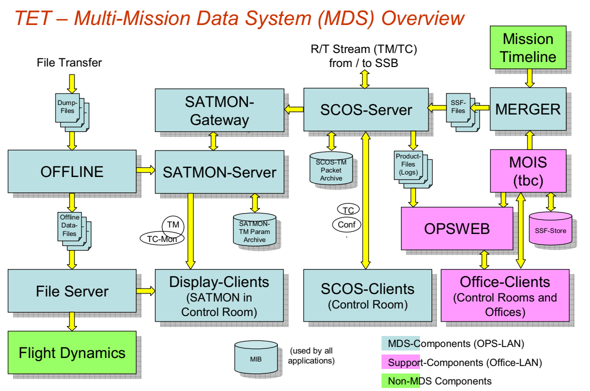


*FIGURE 7: GSOCs Multi Mission Data System for TET*

While above figure outlines the functional architecture of the main elements of the Mission Data System (including support components), the facilities and teams for routine-operations are characterized as follows:

<u>Multimission Control Room:</u>

- All missions are controlled from the same control room
- Each project has dedicated consoles to allow continuous work layout
- All computers are identical, as far as possible

<u>24 hour Operations Team:</u>

- Staff is provided by contractors
- 24 hour shift where one person is always available
- This person is reinforced in times of higher activities
- All multi-mission team members are trained on all spacecraft
- Team size is large enough to adapt the shift easily if needed
- The team is performing routine operations autonomously,
- supported by the spacecraft engineers during normal office-hours and on-call

<u>Future enhanced Multi-Mission concept (2009 plus….):</u>

- most consoles will be identical and interchangeable
- no more dedicated consoles, functions realized by employing a VM-concept (“virtual machines”)
- extended engineering support by home- or office-workplaces (except commanding)

## 5.2. Payload Data Center in Neustrelitz

The German Remote Sensing Data Center (DFD) operates a multi-mission ground station in Neustrelitz (Northern Germany). Presently data from 5 satellites are received in X-Band respectively from 4 satellites in S-Band.
Three 7.3 m antenna systems for S- and X-Band data reception are available at the station as well as a smaller 4m-antenna for S-Band data reception only. All antennas are operated in one common system and supervised by one operator.
Uplink capability for one of the S/X-band antennas is presently under implementation. Therefore also TC-services can be provided for TET-1 by Neustrelitz (NSG) if this should be required.

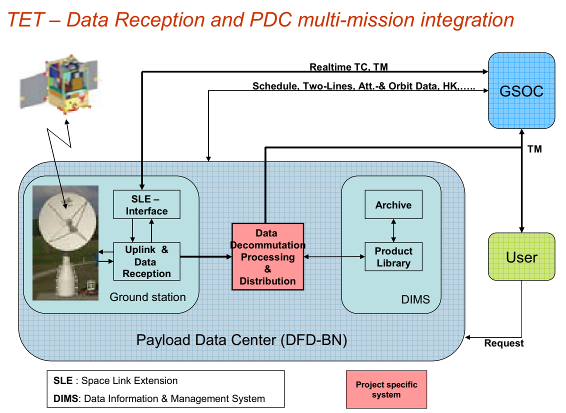


*FIGURE 8: Data reception and TET payload data center integration in Neustrelitz*

Above figure shows TM/TC-data flow and the basic functions required by the TET Payload Data Center, which is based on the generic ground station system and additionally on the Data Information and Management System (DIMS) running at DFD Oberpfaffenhofen and in DFD Neustrelitz as well. It serves for automatic payload data processing, archiving and distribution. However, the DIMS will be used in the TET project only for data archiving.
A mission specific software “Data Decommutation, Processing and Distribution” will be developed, which decommutates the CCDS-data at the receiving station and one file is generated for every one of the 11 instruments/experiments. Only this red marked system in above figure is project specific.

In parallel all payload data will be archived in the DIMS robotic archive and in case of retrieval request from the user for historical data, the above described process will be re-initiated.

## 6. SERVICES AND PRODUCTS

All users with experiments onboard TET-1 will be provided two payload data sets with different formats on a ftp-server. The Payload Data Centre (PDC) processes the received payload data during and immediately after data reception, which is planned 4 times a day.
The products (instrument source packets in raw binary form and as ASCII text file) will be made available at the ftp server 15 min after finishing data reception, secured by protected and selective access. The format of both payload data products for all 11 users is identical, while contents differ of course.
The user additionally receives all auxiliary data (required for calibration purposes or additional processing) provided by GSOC via the same interface. All data is stored on a permanent archive and a function for later retrieval is provided.

| Data Products | Content | Type | Availability | Remark |
|---|---|---|---|---|
| Auxiliary Data | - Ops-planning and as flown | tbd | Not restricted | |
| | - Orbit | tbd | Not restricted | |
| | - Attitude | tbd | Not restricted | |
| | - Bus-HK-data (including NVS) | ASCII | Not restricted | |
| | - Logs | ASCII | Not restricted | various |
| | | | | |
| Payload Data | Raw Instrument Source Packets (ISP) | Binary | User Specific (pass-word protected access) | Generic format, but specific content for each user |
| | Converted File | ASCII | User Specific (pass-word protected access) | One generic format for all users, contents specific. |

*TABLE 1: TET Ground-Segment Data Products*

It has to be noted, that improved infrared imagery products (based on BIRD-heritage) are on experimental basis only during the first year. An operational service in the sense of regular acquisitions of dedicated targets is not foreseen.

## 7. SUMMARY

The following list tries to summarize the characteristics of the overall project and mainly of implementing the ground-segment for the TET-mission:

- TET is an attractive and cost-efficient long-time validation platform for new technologies in orbit,
- based on space-proven platform of now 7 years in orbit, already operated before by the ground-segment (BIRD).
- Re-use of existing and qualified systems and processes within the ground-segment where reasonable and feasible
- Cost-efficiency at GSOC and in Payload Data Center through
  - Multi-mission operation
  - Multi-mission system
  - Use of multi-mission documentation also for project purposes
  - generic solutions as far as possible also for project-specifics (interfaces, networks)
  - adequate and consequent project tailoring
- Low risk for cost and schedule through proposed co-operation concept (CCS)
- Use of DLR-internal resources (e.g. networks, ground-stations)
- Extension of mission by at least one year possible

Operating and supporting quite different space-missions within a largely generic multi-mission environment is the driver and catalyst for a number of new technologies and innovative concepts not only in space but also on ground. Even as a micro-satellite mission, TET will nevertheless be one of the pacemakers in the evolution of efficient ground-systems and operational concepts.

## 8. OUTLOOK ON GROUND-SEGMENT CONCEPTS FOR MISSIONS BASED ON THE TET-BUS

=> TET-2:

One year follow-on mission of second satellite for on-orbit verification is planned

=> TET-1 extended mission for IR-imaging:

Operational Infra-Red earth observation mission planned for year 2 of TET-1 mission. Priority then on operational use of validated enhanced IR-sensor on TET-1 (BIRD-heritage)

=> Wildfire observation missions, based on TET-1 & 2:

12 hours revisit-times with 2 TET-type IR-monitoring satellites feasible, concepts and studies existing

=> DLRs SSB and Compact Satellite Asteroid Finder:

- The German Aerospace Center (DLR) aims to develop and operate a DLR - owned **standard satellite bus SSB** suitable for multi-type missions and applications.
- It is to provide independent and fast access to space for DLR's research institutes to enable independent and efficient research and technology development in space.
- DLRs Institute of Space Systems (RY) is commissioned to analyse and evaluate space systems with respect to their technological, economic and social relevance and to develop concepts for innovative space missions with high national and international visibility.
- A dedicated project named "Asteroid-Finder - Project Compact Satellite" was initiated within the Institute of Space Systems for the development and operation of the desired DLR's standard satellite bus and its first application in space.

**=> Outlook for the Ground-Segment:**

All of the above mission proposals and concepts can be serviced by the same ground-segment for TET-1 with minimum project specific adaptations or additions.

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[2] TET – OOV Homepage: http://www.dlr.de/rd/en/desktopdefault.aspx/tabid-2274/3396_read-5085