OPERATING A SATELLITE CONSTELLATION: HOW WE KEEP SWARM FLYING

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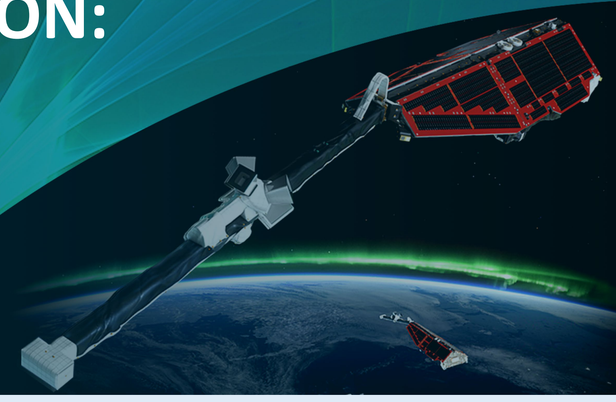
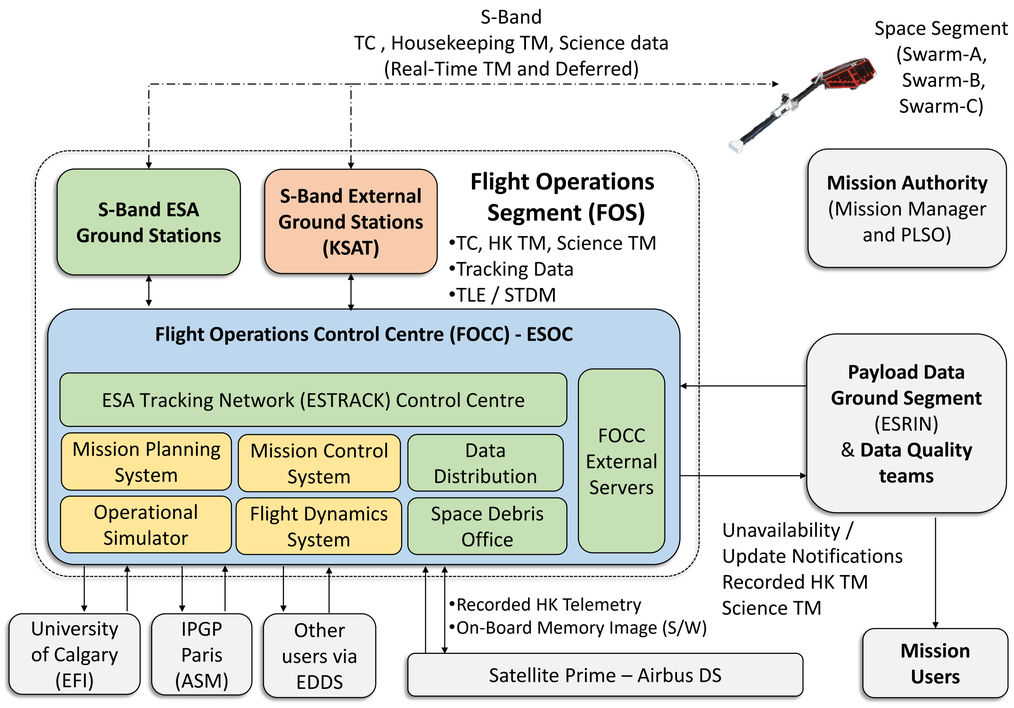


The Swarm Ground Segment and Flight Operations Segment

The **Swarm Ground Segment** is devoted to execute all activities on ground that are needed to the mission to fulfil its objectives, from the operations to the science exploitation.
The big actors within the Ground Segment are the **Flight Operations Segment** (FOS), the **Payload Data Ground Segment** (PDGS) and **Data Quality** teams, the **Mission Management** and **Post-Launch-Support-Office** (PLSO), the industrial support of the **Prime** (Airbus Defense and Space) and the **instrument teams**.

What are the **main elements of the FOS**?

- **S-Band Ground Stations of ESA**'s network: Swarm ground segment uses **Kiruna-1** and **Kiruna-2** antennae to perform TT&C. The network is controlled by ESTRACK Control Centre at ESOC
- **S-Band Ground Stations of KSAT**'s network in Norway: the network, controller by Tromsø (TNOC) uses for Swarm **SG3, SG11, SG25** antennae in Svalbard, and **TROLL-1** and **TROLL-9** antennae in TROLL, Antarctica (used for contingency only to offer South Hemisphere coverage)
- **The ESOC's Flight Operations Control Centre (FOCC)** – see right side.



This poster wants to offer a general overview of the **Flight Operations Segment**, both at control centre level (Flight Operations Control Centre) and Ground Stations level: the **functions of the Flight Operations Control Centre teams at ESOC** are:

- **Command and control** the constellation to ensure monitoring via S-band link
- **Monitor the status of space and ground segment**, including out-of-limit parameters, on-board events, status of the data dissemination and systems, including the Mission Control System, Mission Planning System and the Comms network
- **Downlink of housekeeping & science data**, via S-band and relay the housekeeping and science data to PDGS and special users (Airbus, PLSO)
- The Flight Dynamics team **performs daily Orbit Determination** from GPSR data and produce dedicated products to support G/S planning
- The Flight Dynamics to **monitor the constellation orbits and plan for manoeuvres**
- **Perform weekly Mission Planning** and uplink the weekly schedule containing the commands to be executed offline by the on-board timeline during the week (support of passes, housekeeping commands, instrument commands, etc…) and Replanning
- **React to on-board anomalies** and plan the contingency actions according to operational procedures, depending on the criticality
- Keep the constellation safe and **prepare and execute Collision Avoidance Manoeuvres** when necessary, based on adequate Risk Assessment
- Keep the **Flight Operational Procedures (FOP)** and the **FOS operational simulator** up to date, implementing updates when necessary
- Ensure **adequate level of training** of the Flight Control, Flight Dynamics and all teams with respect to routine and contingency recoveries
- Support implementation of dedicated requests from the Mission Authority, user's community or instrument teams
- Ensure that all systems are updated to counteract hardware and software obsolescence of the ground systems

Where we work: the Flight Operations Control Centre at ESOC

The European Space Operations Centre (ESOC), is ESA's spacecraft control centre, located in Darmstadt, Germany.
ESOC's workforce is involved in the design of the interfaces of the missions since the very beginning (Phase-A) and develops the Flight Operations Segment of new missions during the Phases B-C-D of the development phase, focusing on reliability and reusability of the ground segment products and processes. Preparations are supported by Readiness Tests, System Validation Tests and Simulations of the critical phases of the mission:
ESOC supports the LEOP (Launch and Early Orbit Phase) from the well-known Main Control Room, **commissioning, routine phase and disposal of the satellite and ground segment**.
At ESOC we operate three main mission families: Earth Observation Missions (Copernicus and Earth Explorers), Planetary missions and Astronomy missions.

OPS-O Department of Mission Operations
OPS-G Department of Ground Systems Engineering & Innovation
OPS-S Space Safety Programme Office
OPS-OE Earth Observation Missions
OPS-OA Astronomy Missions
OPS-OP Planetary Missions
OPS-ON Ground Facilities Ops Division

When a mission's LEOP is declared finished, operations are transferred usually to a mission's family **Dedicated Control Room (DCR)** in a routine setup and configuration.

How do we run operations?

But how operations are conducted? Well, let's try to have a look of what we do and how! The hearth of the day-to-day activities is the **Mission Control System**: this software is in charge to receive the HK/science from the ground station equipment and send commands to be radiated. In particular, the MCS automation takes care to support all S-band G/S passes automatically, based on a specific time-schedule produced one week before. The routine commands to connect to the G/S, downlink the data, etc. are sent by the system. The MCS decodes all incoming data and ingests it, showing which TM is outside its nominal limits and flagging it, reacts upon specific packets and generates alarms, and ultimately archiving the housekeeping and science telemetry, distributing the science data file to the Payload Data Ground Segment in ESRIN. Based on the criticality of the information ingested, the MCS can just flag the information for the Flight Control Team or escalate this by passing it to a system capable to notify the team via SMS. It is the case for severe ground segment and space segment anomalies: the on-Call SOE is notified right away

Mission Control System automation & notification

The **lights-out operations concept: MCS automation & notification**

What happens in case of an anomaly? If the anomaly is something known and clear, the FCT will implement the recovery activities as agreed in the Flight Operations Procedures. It's the case of instruments reboots, such as EFI or VFM in some known cases and documented anomalies, or a SEFI (Single Event Failure Interrupt) affecting data downlink. If the anomaly is something new, an Anomaly Review Board is called, with the support of the Mission Management, Post-Launch Support Office, Industry and PA, to define the way forward.

24/7 on-Call personnel

THE ELEMENTS OF THE FLIGHT OPERATIONS CONTROL CENTRE & TEAMS

To get to know the teams involved in day-to-day operations of Swarm at the Flight Operations Control Centre at ESOC, we can have a look into the boxed below. Each team is described in its main duties, responsibilities and… challenges!

FCT Flight Control Team **SOM S/C Ops Manager** **SOE S/C Ops Engineer**

The **Flight Control Team** defines, implements and executes all satellite operations activities. This includes operations preparation, generation and update of Flight Operations Plans and procedures, execute daily, weekly and non-periodic operations such as on-board software patches, payload activities (gain map calibrations, etc.). At the same time the team responds to contingencies on the ground and on-board segments performing analysis and recoveries. The **Spacecraft Operations Manager (SOM)** supervises the team and its interfaces with the other teams, the **Spacecraft Operations Engineers (SOEs)** are in charge of the day-to-day operations and, according to their expertise and tasks, perform dedicated ops, trend analysis, monitoring. The Swarm mission does not have Spacecraft Controllers anymore, this role has been discontinued in favour of the reliability of the ground systems and Mission Control System automation and dedicated activities performed by the **On-Call SOE on duty**.

Data Systems and Software Support

The **Data Systems teams** are in charge to develop, implement and maintain the **Mission Control System (MCS)** functionalities, ancillary systems such as EDDS to ensure E2E satellite control capabilities and data distribution.

Data Systems Simulator

The **Data System simulator teams** oversee the development and update of the FOS simulator, used by the FCT to test new procedures, keep the team trained and update satellite on-ground configuration.

Product Assurance & Quality

The **Product Assurance & Quality** team oversees the Anomaly Reports & Boards and prepares/update all PA-related docs, Lessons Learned, Risks.

FD Flight Dynamics Team

The **Flight Dynamics team** is responsible for the support to mission analysis, orbit and attitude aspects, including constellation manoeuvres generation, attitude monitoring, orbit determination, CAM preparation, monitoring of the fuel consumption.

GOE Ground Operations Engineers

The **Ground Operations Engineers (GOEs)** and their Manager (GOM) is in charge to oversee the ground-station interface with the mission and internal/external station networks and the Operational facilities aspects.

Comms, Hardware and OCC

A variety of **ESOC teams support** the mission in the frame of the overall infrastructure maintenance & evolution, network, internal tools and systems, especially in a multi-mission and as-a-service framework for the whole site.

FACTS & STATISTICS

Swarm is the first Earth Observation constellation of ESA

Most of operations are carried out offline with no operator on console

Swarm multi-spacecraft and **multi-domain** Mission Control System & ancillary have been often used to test new technologies (antennae testing, new Mission Control System generation, new Mission Planning…)

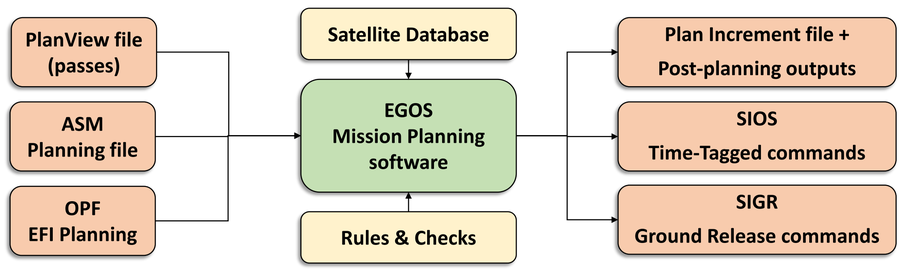
Swarm Flight Control Team: 1 SOM and 8 SOEs of five different nationalities

The Flight Control Team is fully shared with CryoSat-2 mission

On this date 8th of April midday, Swarm will have completed

58315 orbits for Swarm-A
57604 orbits for Swarm-B
58311 orbits for Swarm-C

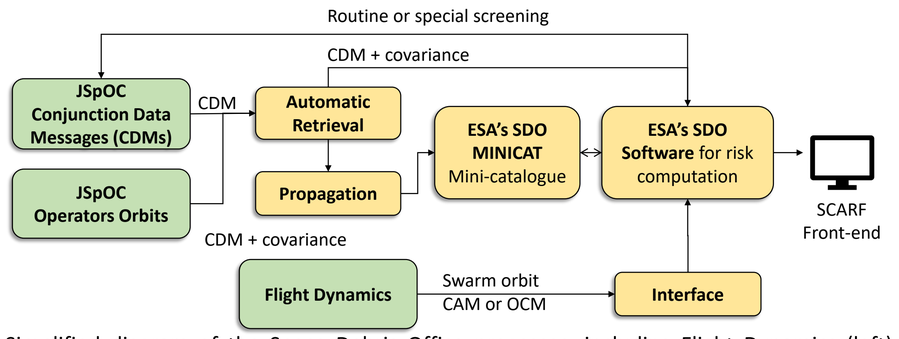
A view on… the Mission Planning System



The **Mission Planning** is an activity performed weekly devoted at generating the schedule increments, both for ground and on-board execution. The output include commands to support S-band passes, instruments and so on.

Collision Avoidance Management

Collision Avoidance Management is a process established to make sure that the ground segment is notified about high-risk conjunction events against space debris and operational or passive satellites within a specific time-frame and reacts upon those events with a specific Collision Avoidance (COLA) procedure. ESA's entity delegated to provide the service to the mission in matter of Collision Avoidance is the Agency's Space Debris Office, located at ESOC, Darmstadt, Germany. SDO interfaces with the US Air Force Space Command (JSpOC) to receive Conjunction Data Messages and screen new events.
Why collision Avoidance? The increasing amount of space debris has become a real threat to operations (let's think about at least one "big" collision in space, the COSMOS/IRIDIUM event). To mitigate the risk, the teams have the **duty to perform COLA monitoring, Risk Assessment for all medium and high-risk events**.
When an event becomes "high risk"? If the probability of collision between a Swarm satellite and a debris exceeds **1E-4**, i.e. 1 / 10000, within 3 days to the Time to Close Approach (TCA), the event is "high risk" and the procedure to perform a dedicated Risk Assessment is initiated (see diagram on the right).
In addition to screen continuously updated orbits of the chaser or the target (Swarm), the parties can agree to start implementing a **Collision Avoidance Manoeuvre** to **mitigate the collision risk down to 1E-6 or below**, by executing a manoeuvre against or along the velocity vector.
The manoeuvre is then sent for screening to SDO and JSpOC (see below) to confirm the safety. IF then the risk is confirmed, the final GO for CAM is given, and the manoeuvre uplinked.



Simplified diagram of the Space Debris Office processes, including Flight Dynamics (left) and simplified diagram of the Collision Avoidance Management process at ESOC for a given mission (from Warning to CAM uplink and execution (right).