# ESOC PRECISE FLIGHT DYNAMICS EMULATION FOR THE SWARM MISSION

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## ABSTRACT

The Swarm mission of the European Space Agency (ESA) is to provide the best ever survey of the Earth geomagnetic field, where variations on time scales from an hour to several years will be represented. The constellation will be constituted by a lower pair of satellites (altitude of 490 km) flying side-by-side and a single satellite flying higher (530 km). The spacecraft (S/C) design is largely based on the ESA mission Cryosat-2; the same sensors/actuators suite as for Cryosat-2 has been used, with the addition of 2 more cold-gas Orbit Control Thrusters (OCT) for inclination control and a GPS receiver unit. A long deployable boom carries the magnetometer package, which is placed at a sufficient distance from the S/C body to keep the magnetic disturbance at a minimum level. The S/Cs are launched together and separated in stowed configuration; the boom is deployed at an early stage of the LEOP. The S/Cs are currently scheduled for launch in the second half of 2012.

The Orbit Insertion Phase (OIP) will start immediately after the LEOP. Due to the low thrust of the OCTs compared to the required change in semi-major axis and inclination, several batches of manoeuvres are planned, each of which will comprise 40 to 90 manoeuvres. These manoeuvres are performed with different thruster' pairs (aligned perpendicular to each other) and an attitude slew is performed after each orbit manoeuvre.

Within the Flight Dynamics (FD) Division of the European Space Operations Centre (ESOC), a Swarm emulator has been developed. The main purpose of the emulator is to test the FD Command Generation and Attitude Monitoring subsystems and to train the whole FD team during operations preparation. In addition, the emulator is useful to analyse the AOCS on-board software behaviour in nominal and contingent situations, well in advance with respect to the ESOC-wide Simulation Campaign beginning. This has proved to be very valuable in Swarm FD system tests, where unexpected S/C dynamics have been found and investigated in two particular cases: yaw controller in Coarse Pointing Mode (nominal) and response to a stuck open Orbit Control Thruster (contingent).

The FD emulator reproduces in a very representative way the functionality of the AOCS on-board software relevant for FD needs, modelling with high fidelity closed-loop S/C dynamics, space environment, sensors and actuators. It can be run in real-time or accelerated mode (with

execution time up to 16x real-time). It responds to ground telecommands and injected failures; telemetry data is generated according to ground stations visibility and foreseen space-to-ground interfaces.

The emulator has been developed in Matlab®/Simulink® environment. Thanks to the similarity between the Cryosat-2 and Swarm S/C, a maximum reuse of Cryosat-2 emulator AOCS hardware and space environment models has been made, allowing the development of a highly representative system with limited development resources. Specific aerodynamics and pressure radiation models have been created based on surface geometry properties provided by the S/C manufacturer (for stowed and deployed boom configurations). The cold gas propulsion system model has been calibrated using pressure regulator and thrusters firing ground tests results. Generic components, such as environment models and ephemerides access, rely on interfaces to legacy code, with the improvement of some models as required by Swarm accurate simulation needs (i.e. introduction of Earth atmospheric density models depending on solar activity). The AOCS on-board software has been implemented with a new efficient approach, based on direct import of pseudo-code from AOCS requirements documentation.

In this paper, the design and implementation of the FD Swarm emulator will be presented. Its deployment and application for operations preparation will be described, with focus on:

- Characterization of attitude manoeuvres in terms of duration, attitude profile and fuel consumption.
- LEOP contingency scenarios, including star trackers failure due to solar flare, biased/noisy magnetometers and GPS receiver data.
- Coarse Pointing Mode (CPM) yaw controller behaviour. In CPM, the S/C is Earth pointing, roll/pitch control is performed using Earth sensors data and yaw control is performed using magnetometers data. During nominal LEOP system tests, it was observed that the yaw angle stabilizes in some emulations around 0 deg ("forward flight", i.e. with the boom oriented opposite to the velocity vector), in other emulations around 180 deg ("backwards flight"), or keeps drifting. This result was unexpected, and led to an investigation at on-board software level also involving Flight Control Team and S/C manufacturer, which clarified the behaviour and confirmed the validity of the emulator results.
- OIP system tests, particularly important for FD, since the OIP is not exercised during the ESOC-wide Simulation Campaign, which covers only the LEOP. In one system test, an OCT has been simulated stuck open at the end of a manoeuvre: the on-board software did not detect the failure and did not isolate the thruster branch as expected. Investigations revealed that the failure detection logic is based on torque demand, and the torque generated by this OCT is small enough to be controlled by Attitude Control Thrusters. Such a scenario would lead to a considerable propellant waste, depending on the time it takes to intervene with ground commands. The analysis also showed that the torque level generated by another OCT is 20 times higher (because of different thrusters mounting), and would indeed trigger automatic failure detection.