HIGH FIDELITY END-TO-END ORBIT CONTROL SIMULATIONS AT EUMETSAT

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ABSTRACT

Mission Analysis studies, carried out prior to launch, are normally based on classical perturbation analyses; they provide invaluable insights into orbit maintenance activities, (i.e. ΔV budgets, maneuver needs/frequencies) and their related impacts such as on the planned mission unavailability. Indeed, when it comes to real satellite operations, the preliminary analyses have to be further optimized, when incorporating specific operational aspects: control strategies have to be robust to certain anomalies (including sufficient control margins, involving maneuver re-planning for a day later, etc) or other specific operational constraints, such as necessity of maneuvers execution during working hours. In addition, unavoidable maneuver predictability aspects, including physical materialization of propulsion systems on-board, together with space environment uncertainties, may also lead to non-negligible effects on the implementation of the preliminary orbit maintenance strategy into actual operations.

In this paper, the approach adopted recently by EUMETSAT is presented: this allows for simulating end-to-end orbit maintenance operations in a realistic and high-fidelity manner. Special emphasis is made on the practical results obtained in the frame of future and on-going Geostationary (GEO) and Low-Earth-Orbit (LEO) satellite operational systems of EUMETSAT.

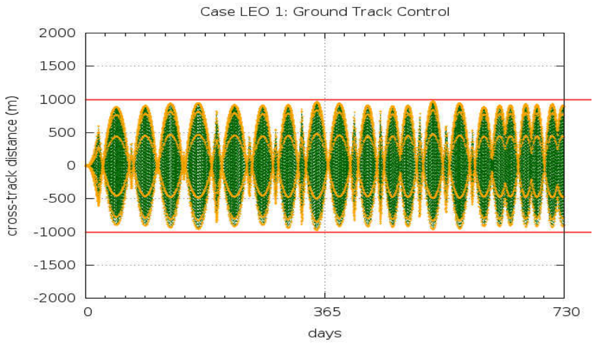
Thanks to the exploitation of modern technologies, high-level programming languages and associated packages in the area of space flight dynamics, it is possible to implement, with a high degree of fidelity, simulations of actual operations, accounting for all processes and logic of real operations. This includes variability of space environment disturbance with respect to predictions (i.e. air-drag and solar radiation pressure), orbit determination uncertainties, maneuver predictability issues, maneuver cross-coupling effects, maneuver implementation issues (quantization, long burn effects), time constraints between the different on-ground processes, other operational constraints (i.e. eclipse related, working hours) and even well-defined contingency scenarios (implemented over simulated time in a stochastic manner). The simulations are performed of high fidelity models for the disturbance forces and orbit dynamics, using numerical integration, over very long time spans (up to full satellite lifetimes), using different combined controls, implementing contingencies (i.e. “missed maneuver” cases) and monitoring key parameters (such as control deadbands violation). Moreover, the robustness of the selected maneuver concepts and operational strategies can be tested and analyzed against a range of different varying parameters, implementing these simulations in a Montecarlo sense (or other space search algorithms) by which thousands of simulations are performed and analyzed.

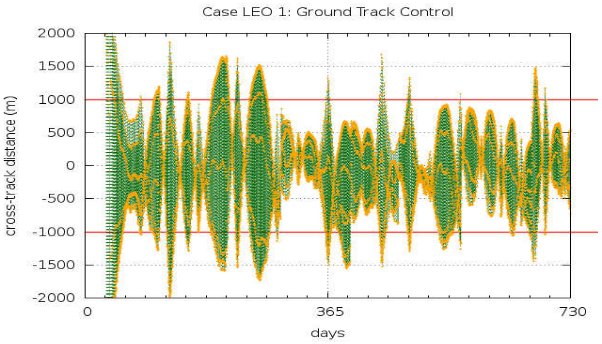
The paper will briefly introduce the above-mentioned innovative concept and implementation, with focus on obtained results in the frame of current and future EUMETSAT satellite systems.

For current satellites, MetOp-A case is analyzed: the spacecraft was launched on 2006, and it flies a LEO Sun-Synchronous orbit, with 29 day repeating ground track controlled within ±5 km and Mean Local Solar Time controlled within ±2 minutes. This case simulates long-term real

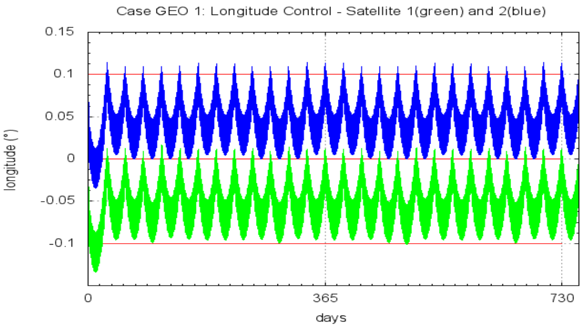
operations mimicking operations to date, as well as projecting them to the planned end-of-life, including several options for lifetime extensions and accounting for all current uncertainties.

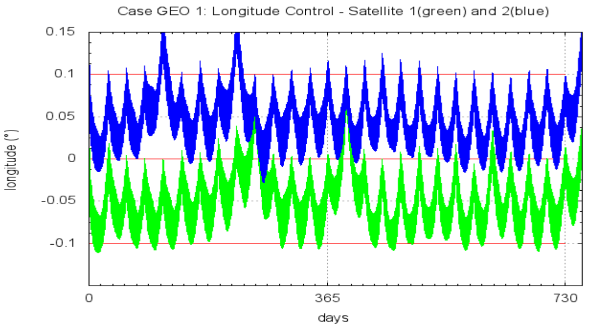
For future satellites, two cases are presented. The first case is Sentinel-3, part of the European GMES program, flying a Sun-Synchronous orbit too, but with a tight ±1km ground track control (figure below left shows cross-track distance to reference ground track on the basis of no uncertainties; figure below right shows same control but under the real environment and operational constraints). Sufficient margins and combined out-of-plane and in-plane control will improve this, maximizing fuel lifetime and minimizing violations and maneuver numbers.





The second case is based on constellation simulations for the future Meteosat Third Generation geostationary program that foresees up to 4 satellites (carrying different payloads) co-located in the same longitude slot. Different long term simulations are performed, including classical eccentricity/inclination (e/i) co-location, as well as standard longitude separation, in both cases with North/South, East/West and eccentricity control. Figures below show same longitude separation controls and operational strategy, with and without uncertainties and contingencies.





Figures below show, for an e/i scheme, under realistic and operational conditions, the inter-satellite distance (minimum reached 7 km, although co-location scheme should have guaranteed ~10km in the absence of uncertainties/contingencies) and angular separation as seen from a ground antenna (key parameter for maintaining the antenna sharing operational concept).