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Precise orbit determination of Galileo satellites based on hybrid empirical-physical models

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The Galileo constellation is approaching its full operational capability (FOC) and consists today of 3 active and healthy In-Orbit-Validation (IOV) satellites and 21 FOC satellites. Precise orbit determination of Galileo satellites is challenging due to relatively low masses of satellites, large differences between X and Z bus surface areas, and complicated modeling of varying perturbing forces acting on the first pair of FOC satellites accidentally launched into high-eccentric elliptical orbits. The European Global Navigation Satellite System Agency released in November 2017 the geometrical and optical information which allows for generating of the mathematical model of the interactions between satellite components and electromagnetic perturbing forces.

In this study, we characterize the impact of direct solar radiation pressure, Earth's albedo, infrared radiation, and satellite transmitter antenna thrust on the Galileo satellites in nominal orbits, as well as on two Galileo in highly-eccentric orbits. We assess which perturbations can be absorbed by the new Empirical CODE Orbit Model (ECOM2) and what are the consequences of neglecting higher-order ECOM2 coefficients. We evaluate different models based on the analysis of satellite laser ranging (SLR) residuals, orbit predictions, and Galileo-derived geocenter coordinates.

We found that the most accurate Galileo orbits can be determined using a hybrid model consisting of the a priori physical model and estimating a small set of empirical orbit parameters which compensate for changes in the satellites' environment and small errors in the satellite surface properties. The purely physical model does not fully take into account effects such as Y-bias, solar panel rotation lag, that is the misalignment causing a constant acceleration perpendicular to the solar panel axis and the direction to the Sun. Estimating a large number of empirical ECOM2 parameters, such as twice-per-revolution parameters in the Sun direction, causes instabilities in determined satellites positions especially during eclipsing periods. The standard deviation of SLR residuals for eclipsing satellites decreases from 42 to 27 mm between the empirical orbit solution based on ECOM2 and the hybrid solution based on the physical box-wing model with estimating only three empirical constant accelerations, respectively. Thus, estimating a large number of empirical parameters should be avoided, whereas the hybrid model provides currently the best results for Galileo satellites in eclipsing periods.