In-flight Characterisation and Calibration of Galileo FOC Reaction Control System

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This paper presents the in-flight characterisation and calibration of the Galileo Full Operational Capability (FOC) Reaction Control System (RCS), performed by the CNESOC Flight Dynamics team during six LEOPs and Drift Stop & Fine Positioning phases, where a total of 14 S/C have been operated.

In the context of Galileo FOC, the CNESOC Flight Dynamics (FD) team is the result of a collaboration between CNES and ESOC centres with members from both establishments. In the timeframe August 2014 – June 2016, ten Galileo FOC S/C have been launched. Eight of them have been positioned in their target orbit; the other two have been recovered from launcher failure and positioned in a suboptimal orbit. Four more S/C are planned to be launched in November 2016, and eight more in the near future.

For each S/C, up to three drift start manoeuvres are performed as part of the LEOP. After a fixed drift period free of manoeuvres, up to three drift stop and up to eight fine positioning manoeuvres are performed. Such a large number of fine positioning manoeuvre, of progressively smaller size, is potentially required to reach the target orbit, defined by a very narrow orbital elements box: 5 m in semi-major axis and 2 mdeg in argument of latitude. In order to reach the target and possibly minimize the number of necessary manoeuvres, it is crucial for FD to be able to predict with sufficient confidence the RCS performances of the upcoming manoeuvre and apply the corresponding calibration factors to the manoeuvre computation.

The Galileo FOC RCS is a monopropellant (hydrazine) blow-down system with two redundant branches of four 1 N thrusters. The attitude control during manoeuvres is performed by the thrusters themselves through off-modulation pulses. The FD manoeuvre commands contain the total manoeuvre duration: hence, in order to command the required delta-v, the manoeuvre off-modulation ratio needs to be predicted by FD. In addition, manoeuvres of duration larger than 1 s can only be commanded as an integer number of seconds: this creates the need of treating in a special way manoeuvres whose duration is in the order of a few seconds.

In order to compute the thrust and off-modulation calibration factors for the upcoming manoeuvre, FD makes use of performance data of previous manoeuvres of the same S/C and of similar manoeuvres of other Galileo FOC S/C. Thrust and off-modulation factors have shown to depend in a complex way on a number of factors, such as tank pressure and manoeuvre duration: hence, the simple approach of directly using the observed performance of the last manoeuvre of the same S/C is not accurate enough and can lead to large misperformances. The post-processing of a large number of manoeuvres of different size and performed under different conditions has allowed FD to identify trends and correlations, and to prepare guidelines to follow during the calibration process, by nature semi-empirical and requiring decision-making.

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