Non-nominal Attitude Manoeuvres during Metop-A extended Lifetime

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Almost 10 years after launch, Metop-A's last inclination-control manoeuvre was executed in August 2016. Following this, and provided all required systems perform nominally, its lifetime will be extended allowing the local time to drift until its de-orbiting, which will aim at complying with the international regulations on space debris. Analyses have led to the conclusion that the platform can behave correctly even though out of its design envelope but, in order to make the most of the measurements from the instruments on-board the satellite, used both for weather prediction and for climate monitoring, yaw manoeuvres would be required for solar calibration. Besides, plans have been developed to take advantage of the last months of operations, when two sister satellites will also be flying, to perform technology tests with Metop-A's suite of instruments. Some of these tests involve pointing the spacecraft's instruments to the deep space, which requires stopping the routine rotation of the satellite around its pitch axis. This paper shows the Flight-Dynamics aspects of those yaw manoeuvres and of the stopping of the pitch rotation, none of which were considered in the satellite's design, together with results of simulations performed to prove their feasibility.

Key Words: Spacecraft Lifetime Extension, Earth Observation, Attitude Manoeuvres

1. Introduction

Metop-A is the first of the satellites constituting the space segment of the EUMETSAT Polar System (EPS). It was launched in October 2006 with a planned operational lifetime of five years. More than ten years later it is, however, still in operation and providing high-quality data, very valuable for weather prediction and climate monitoring, especially when used in combination with those coming from the second spacecraft of the series, Metop-B, launched in September 2012.

Although designed before current international regulations on space debris were established, it is EUMETSAT's desire to comply with them while extending the satellite's operational lifetime for as long as possible, for the benefit of their user community and, ultimately, of the whole society. In order to achieve this double objective, strategies have been designed for the extension of the mission on a drifting local time[1] and for the spacecraft de-orbiting.[2]

Analyses show that the platform and instruments will continue working satisfactorily during the foreseen drift in local time. But, as discussed in Ref. 3), the Global Ozone Monitoring Experiment (GOME) spectrometer requires regular Sun calibrations, which will not be possible beyond 2018 during certain periods of the year with the satellite's nominal attitude. Although an analytical mode is under development to overcome this issue, dedicated yaw manoeuvres could allow these calibrations again if and when needed.

In addition, there is an interest to perform with Metop-A and its instruments, once Metop-C data can be used operationally, certain technology tests that could improve Metop climate and meteorological products through additional instrument characterisation and new processing algorithms. The knowledge gained could be applicable to all Metop satellites, including re-processing of past data, as well as to future LEO missions. One of these possible tests consists in pointing the Metop instruments to the deep space instead of to the Earth by maintaining an inertial attitude during a complete orbit.

Although the satellite is not designed for performing such attitude manoeuvres, these can be achieved by consistent modification of some parameters within the Attitude and Orbit Control System (AOCS) commands: application of large yaw biases in the Sun sensor command and in the definition of the gyroscope alignment for the first case, or modification of the parameters defining the spacecraft rotation while programming the masking of the Earth sensor and stopping the rotation of the solar panel for the second. Simulations have been carried out to assess the feasibility of these operations and their impact on the mission and, especially, the probability of complying with the international regulations on space debris: if they, intentionally or accidentally, brought the spacecraft to a thruster-controlled attitude mode, they would reduce the amount of fuel available for de-orbiting.

2. Metop-A lifetime extension

Metop-A nominal orbit is a Sun-synchronous orbit with a Local Time of the Ascending Node (LTAN) of 21:30. All platform sensors and instruments, as well as the spacecraft's solar panel, have been designed and aligned taking into account the geometry corresponding to this orbit.

However, the mandate from EUMETSAT's user community to extend the satellite's orbit for as long as possible, even aiming at an overlap with Metop-C operational phase, while maintaining a very high probability of achieving the spacecraft re-entry within 25 years after the end of operations, has led to discontinuing inclination control in order to save the fuel needed for lowering the orbit enough to achieve that time to re-entry.

Unfortunately, the option to compensate or reduce the drift in local time by adapting the orbital altitude to the changing inclination is not acceptable from the operational point of view: Metop-A is operated in parallel to Metop-B and, in the future, Metop-C sharing the same ground station in Svalbard for tracking, telemetry, commanding and data downlink. All satellites share the same frequencies, which means that there needs to be alternation in the usage of the available antennas. If the orbital period of one of the spacecraft became different from the others' operational measures would have to be put in place in order to avoid interferences. Such measures would over-complicate operations, on one side, and would lead to loss of data from one of the satellites, on the other.

Consequently, the satellite's lifetime extension following the abandonment of inclination control will be performed on a drifting local time.

3. Yaw manoeuvres

Due to the increasing deviation from the nominal angle between the orbital plane and the Sun direction, at some point during the mission the GOME Sun slit will no longer be able to acquire the Sun for the required solar calibrations.[3] As seen in Fig. 1, a short period where such calibrations will not be possible will take place around February 2018, followed by a longer one between January and March 2019 and an even longer one between November 2019 and April 2020. After August 2020, solar calibrations with nominal attitude will only be possible for a short period of time around June 2021.

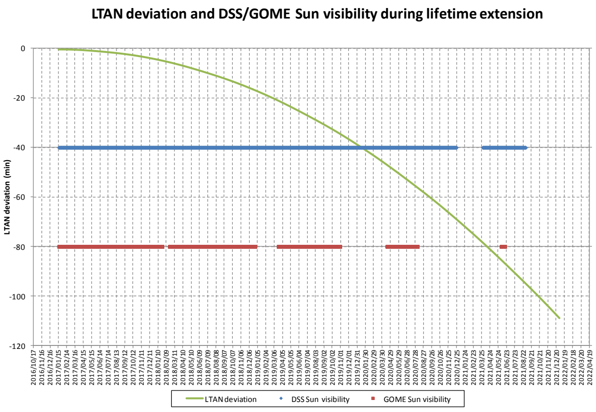

Fig. 1. Evolution of the LTAN deviation and of the Sun visibility from the Digital Sun Sensor and from the GOME Sun slit.

A way of allowing GOME Sun calibrations during those periods where the LTAN evolution and the nominal attitude do not provide the needed geometry is to compensate the drift in local time with a rotation of the satellite around its yaw axis so that the calibration slit of the instrument can point to the Sun.

Nominally, Metop-A operates in yaw-steering and local-normal pointing mode, with a rotation law enabling to compensate for the Earth rotation velocity in the orientation of the spacecraft and to point the instruments in the direction of the local normal. The frame with respect to which AOCS performances are monitored and controlled is the so-called spacecraft attitude piloting frame. This is nominally parallel to the satellite frame, defined as a fixed reference frame with respect to the spacecraft body, but commanding capability is provided in order to be able to define rotations, in all three directions, of the piloting frame around the satellite frame. These rotations are uplinked in the form of the transformation matrices from the gyroscope axes to the desired piloting frame, for the two gyroscopes selected for attitude monitoring. It is to be noted that these rotations, contrary to the ones aiming to the correct orientation of the spacecraft prior to out-of-plane manoeuvres, are carried out making use of the spacecraft wheels and magneto-torquers, and not the thrusters. This means that, if everything works as expected, they do not imply a waste of fuel and do not have an impact on the achievable re-entry times.

The spacecraft and AOCS design assumes such rotation biases to be small, well within the degree (actually, the spacecraft manufacturer specifications assume the maximum pointing biases to be 0.5 degrees), and to be used only for selecting as piloting frame the most favourable for the payload. But the rotation required in order to compensate for the drift in local time in the orientation towards the Sun could be as high as 10 degrees, which means that in principle it is not clear that the satellite and its systems would be able to cope with it. There is consequently a need to perform further analyses and simulations, generating and sending to the satellite simulator the commands required for applying such rotation biases.

The AOCS of the Metop spacecraft provides an autonomy of 36 hours, but it needs to be regularly commanded from ground in order to upload, among others, the position within the Digital Sun Sensor (DSS) where the Sun is to be expected, to help with the control around the yaw axis, the apparent shape of the Earth, needed by the Digital Earth Sensor (DES) for accurate measurement of the pitch and roll de-pointing from the local normal direction, and the position in the orbit where to set the origin of the rotation of the solar panel around the spacecraft body. These commands will be affected by possible rotation biases to be applied to the satellite.

In order to modify the spacecraft attitude piloting reference frame, therefore, the EPS Flight Dynamics Facility (FDF) needs to compute the new rotation matrices for the selected gyroscopes, as well as the new parameters for the Sun and Earth sensors and for the solar panel. All these parameters are then sent to the Monitoring and Control System (MCS), in charge of generating the corresponding commands plus another one required for the AOCS to apply the change to the gyroscope matrices, and sending them to the Ground Station for uplink to the spacecraft.

For the application of a generic rotation bias, therefore, five different commands need to be uplinked, namely:

- update of the gyroscope matrices,
- reset of the operational attitude mode for the new matrices to be applied,
- update of the Sun sensor parameters,
- update of the Earth sensor parameters, and
- update of the solar panel parameters.

The Earth sensor and the solar panel parameters are only modified in case of pitch or roll biases. In case a bias is applied only in the yaw axis, as required for the acquisition of the Sun from the GOME instrument, those parameters are unaffected, so no uplink of the corresponding command is needed.

Uplink and activation of these commands needs to be coordinated to avoid contradicting information to be handled by the platform, which would lead to on-board reconfiguration of the AOCS and the need to recover for nominal operations. In particular, the update and activation of the transformation matrices need to take place before the first visibility of the Sun from the Sun sensor taking into account the updated parameters.

As mentioned above, small rotation biases were foreseen in the platform design, and have already been applied to both Metop-A and Metop-B following their LEOP and the transition to routine operations, in order to monitor and command the attitude around the instrument reference frame, rather than the satellite reference frame. But rotations of the order of magnitude required during Metop-A lifetime extension in order to place the Sun within the field of view of the GOME Sun slit are well above those values and need therefore to be validated against the satellite simulator in order to assess their feasibility and before being able to apply them to the flying satellite. In particular, it is necessary to ensure that the commanding of such large biases will not lead to a Safe Mode or other thruster-controlled attitude mode, which would mean the loss of precious fuel required for the de-orbiting of the spacecraft complying with the space debris regulations, that the generated commands result in the application of the actual attitude bias, and that the return to the control around the routine attitude reference frame following the acquisition of the Sun by the GOME instrument will be possible, in order to continue the provision of valuable measurements from the whole suite of instruments during the rest of Metop-A's lifetime.

In order to perform the needed assessment, different simulations in realistic conditions were performed, applying increasing rotations between 3 and 8 degrees around the yaw axis.

Figure 2 shows the evolution of the attitude with respect to the orbital frame before and after the application of a rotation bias of 5 degrees around the yaw axis. The evolution before the application of the yaw bias shows the nominal variation due to the yaw-steering and local-normal pointing, which is of around ±4 degrees in yaw around the 0. Following the uplink and activation of the change to the gyroscope transformation matrix (SHCONGYR and SHCHMODE in Fig. 2), and after a transient, the rotation in yaw changes to an oscillation of approximately the same values around 5 degrees, as expected. TT SHPARSSD marks the time at which the Sun sensor parameters become applicable. The updated values are then used when visibility of the Sun from the sensor takes place. Since this information is consistent with the one provided to the gyroscopes, it does not trigger any platform reconfiguration. Furthermore, it can be seen that the attitude evolution following the command is stable and does not lead to any problems in the two revolutions following the change.

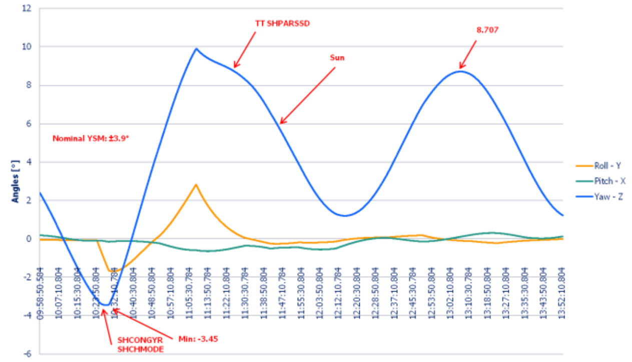

Fig. 2. Attitude following the command of a 5-degree yaw bias.

A further simulation commanding a bias of 3 degrees, followed by a return to the nominal attitude evolution and another bias of 8 degrees was performed. The resulting attitude evolution is shown in Fig. 3, where all transitions can be clearly seen.

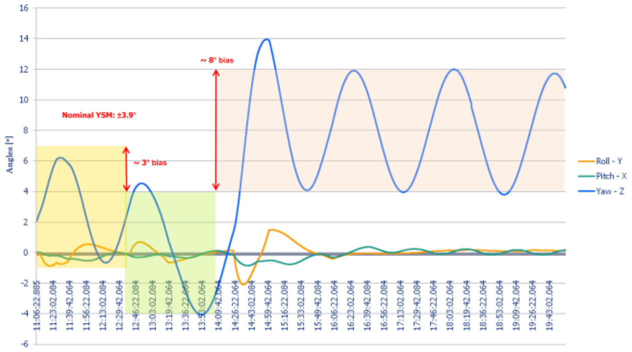

Fig. 3. Attitude across consecutive yaw-bias commands.

All in all, the simulations indicate that the platform seems capable of rotating around its yaw axis well beyond the specification with no reconfiguration resulting in fuel loss. It can be therefore concluded that the proposed approach of rotating the platform to compensate for the drift in the orbital plane and make GOME Sun calibrations possible when opportunities are no longer available with its nominal attitude seems feasible. Moreover, the simulations suggest that the biased attitude can be kept for longer periods of time in case of need (see Fig. 4).

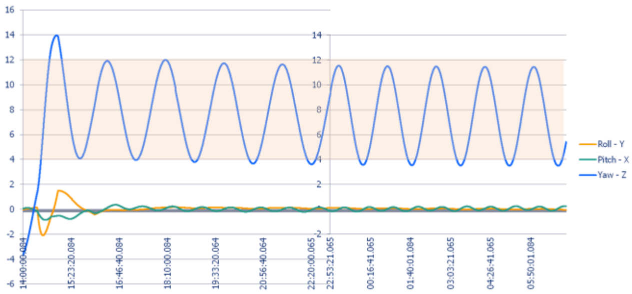

Fig. 4. Attitude stability after a bias of 8 degrees in yaw.

Unfortunately, when presenting these results to the spacecraft manufacturer their initial recommendation was to command, after the return to nominal attitude, the so-called

Rate Reduction Mode (RRM). This mode uses the spacecraft thrusters to stop any possible rotations and, once these are low enough, it is autonomously followed by Fine Acquisition Mode 2 (FAM2), which keeps a geocentric attitude with the help of thrusters. There is confidence that an operations sequence can be devised which avoids this, but further interaction with the manufacturer is required, as well as analyses and simulations, in order to confirm that such transition to RRM, which would make these manoeuvres unacceptable from the operational point of view due to the associated fuel consumption, can be waived.

It is to be noted that no final input has yet been received from the science team concerning the frequency and duration required for the GOME Sun calibration campaigns. Though, as shown above, the rotation of the platform to make Sun acquisition possible seems to be feasible, it involves the generation and uplink of non-nominal sets of commands both for applying the bias and for returning to the routine attitude mode. Besides, flying with a biased attitude will have a negative impact on the processing of the measurements obtained from the rest of the instruments on-board the satellite. Consequently, a trade-off will have to be performed taking into account the needs of the different instruments as well as the simplicity and robustness of operations.

A further factor to take into account is that, as seen in Fig. 1, at some point during the Metop-A lifetime extension the Sun will also disappear from the DSS field of view. This means that the measurement of the attitude deviations around the yaw axis will have to rely exclusively on the spacecraft gyroscopes. These have shown an excellent behaviour up to now, and analyses and simulations have shown that it is possible to keep routine operations of the spacecraft in those conditions by disabling the AOCS Sun sensor surveillances. However, no simulation has been performed yet in which yaw biases are applied beyond that point in time. The application of the bias itself should not pose any problem, since the rotation that will bring the Sun into the field of view of the GOME Sun slit will also make it visible from the DSS, but the operations themselves will become slightly more complicated due to the need to switch on and off the DSS. According to the simulation results shown above, in which the visibility of the Sun from the sensor does not result in any noticeable attitude change, the attitude around yaw based on only gyroscopes seems to be accurate enough not to result in any problems when getting back to the routine attitude reference frame. However, this point will have to be proven through further simulations in case such rotations are believed to be also needed once the LTAN drifts beyond the point at which the DSS can be used.

4. Technology tests

Although initially specified and designed for an operational lifetime of 5 years, the excellent performances of the Metop-A spacecraft have allowed operating it well beyond that, and in parallel with Metop-B, launched in September 2012. Reception and processing of measurements from both satellites in parallel has demonstrated to be of great advantage for operational weather prediction and for climate monitoring. It is therefore considered of high importance to keep routine operations of both satellites until the third spacecraft in the series, Metop-C, is launched and commissioned, in order to guarantee continuity of dual-satellite observations for the user community.

Once Metop-C is operational, and providing that both it and Metop-B perform as expected, Metop-A could be partially devoted, if considered advantageous, to performing technology tests, i.e. non-nominal operations with its instruments that can contribute e.g. to the validation or correction of instrument processing or calibration data coefficients, to testing of redundant sides to assess their degradation with age, or to pursuing more specific scientific returns. Such tests must have a minimum impact on the user data services and cannot impact end-of-life (EOL) operations or the probability of achieving the target re-entry time. In order to achieve this, the tests will be organised in carefully planned test campaigns, following a thorough decision process as to which tests can be allowed in view of the expected benefits, costs and risks. Tests with a potential impact on data generation or data quality, moreover, will be scheduled towards EOL, so that the users can benefit for as long as possible from continuous high-quality data from all three spacecraft.

5. Stop of the pitch rotation

Among the different tests currently envisaged, the one requiring the highest Flight Dynamics involvement is the stop of the spacecraft rotation around the pitch axis, in order to be able to point its instruments to the deep space instead of towards Earth. This would allow a detailed study of instrument antenna responses, space calibration views and asymmetric scan biases, which would be very beneficial for microwave radiometers and their data processing and recalibration activities. Besides, by stopping the spacecraft rotation at a specific position in the orbit, the test could also be useful to re-evaluate the bi-direction diffuser reflection distribution and to assess the spectral response function of the GOME spectrometer. Another position would allow observing the South Atlantic Anomaly (SAA) from the Space Environment Monitor (SEM) instrument’ telescope usually pointing in the anti-velocity direction, as shown in Fig. 5. This would of course require imposing constants to the time of the day at which the pitch-stop would have to be performed so that the revolution in inertial attitude includes an overflight of that region.

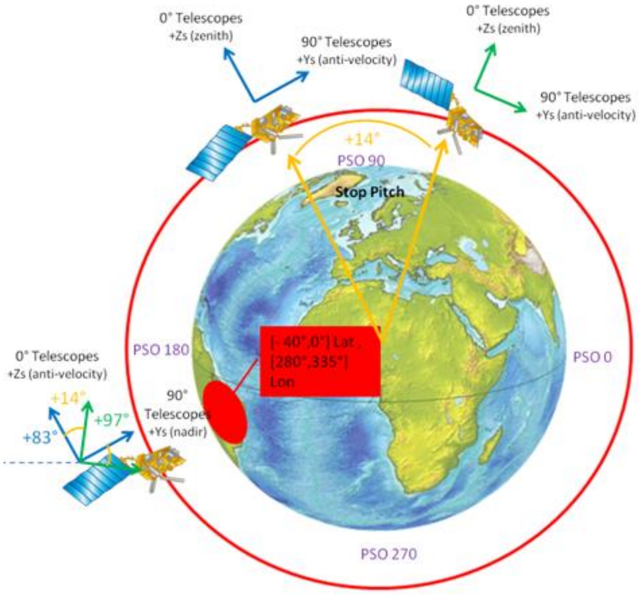

Fig. 5. Observing the SAA with SEM.

Unlike the yaw manoeuvre described above, this operation does not consist in the application of a constant bias to the nominal attitude evolution. In this case, what needs to be done is to stop the spacecraft rotation around the pitch axis that keeps it pointed to Earth. In order to keep the satellite's attitude in an inertial pointing, first of all the yaw-steering will be disabled, and after that the pitch rotation will have to be stopped.

The first step (disabling of the yaw-steering law) is an operation already foreseen in the spacecraft design and performed nominally before large manoeuvres, like the ones for inclination control. This does not imply anything out of the ordinary and will consequently not be discussed in this paper.

The second part of the operation, however, was not foreseen in the platform and AOCS design. But the parameters driving the rotation around the pitch axis are included in one of the commands sent routinely to the spacecraft, which means that it is theoretically possible to set them to zero, which should result in stopping that rotation. In parallel, also the rotation of the solar panel would need to be stopped, the feedback of the optical (Sun and Earth) sensors into the on-board attitude estimation would have to be disabled by introducing an artificial masking for all orbital positions (in the same way as a masking is introduced when the Sun or the Moon are expected to enter into the sensor field of view affecting the apparent shape of the Earth in the infrared), attitude control with magneto-torquers would need to be stopped (since the orientation of the Earth magnetic field in spacecraft axes would not be the expected one) and several AOCS surveillances would have to be disabled to avoid reconfigurations or unexpected transitions to thruster-controlled modes. All this is achievable via commanding from ground and, as in the case of the yaw manoeuvres, simulations are required to prove the feasibility of the operation.

Already the first simulations showed that the probability of returning to nominal attitude in a controlled manner, without transitioning to any thruster-controlled attitude mode, was rather low. This led to the decision of designing the operation in such a way that, following the period in inertial attitude, a transition to RRM. This has the advantage that the angular velocities at the time RRM is triggered are already close to zero and with the spacecraft almost in geocentric attitude, which means that the fuel consumption during RRM and FAM2 acquisition is very low, contrary to what could happen in case RRM is automatically triggered by the on-board software in an unfavourable geometry. Furthermore, RRM has the advantage of stopping the reaction wheels, thus removing the kinetic momentum accumulated due to the absence of wheel off-loading by the magneto-torquers during the test.

Even though fuel consumption is expected to be low, the fact that it is required means that this test could jeopardise the compliance with the international regulations on space debris. Consequently, it was decided to analyse the feasibility of performing this test after the de-orbiting manoeuvres of the Metop-A end-of-life operations, and before the subsequent possible final thrusts.[2)]

In order to analyse all possible scenarios, several simulations have been performed, stopping the pitch rotation both in the nominal orbit and in the end-of-life orbit following those de-orbiting manoeuvres. The objectives of these simulations are to confirm that it is possible to stop the rotation operationally for at least one orbit without triggering any unexpected anomaly or platform reconfiguration, to analyse the dynamical behaviour of the spacecraft and to check whether it is possible to stop this rotation at different orbital positions, for both orbit conditions.

The position in the orbit where to stop the rotation is driven by the expected scientific return and by the instruments' acceptable illumination conditions. At the same time, it is constrained by the forbidden windows for the update of the set of parameters including the ones controlling the spacecraft rotation, since according to the spacecraft manufacturer specifications these should not be updated within given angular distances from orbit positions related to Sun sensor and solar panel events. A further constraint is imposed by the fact that, for the operation to have a scientific return at all, the data collected in the period of inertial attitude need to be downlinked to ground. The transition to RRM and FAM2 will result in erasing the on-board memory and therefore the data collected during the test. This means that this transition, which should happen in the same orbital position as the stop of the pitch rotation for the fuel consumption to be as low as possible, must happen after the data have been downlinked (unless a special patch is applied to the spacecraft to avoid erasing the collected data after an RRM transition) and that the data downlink needs to take place while the pitch rotation is stopped (see Fig. 6). Consequently, the rotation needs to be stopped at a position guaranteeing that the attitude in the pass at which the data can be downloaded is such that the ground station is within the lobe of the on-board X-band antenna The feasibility of dumping the data while in inertial attitude is still to be confirmed and the range of position in the orbit for which this is possible has to be identified. Actually, a complete trade-off and assessment of the pitch stop position has still to be completed.

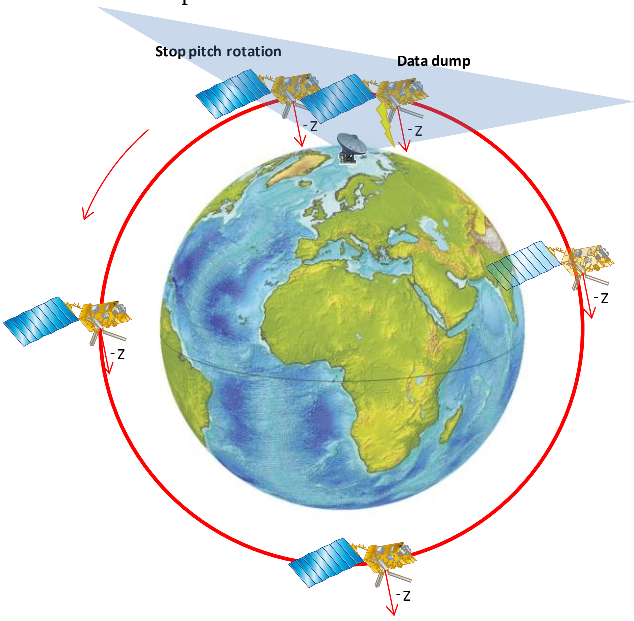

Fig. 6. Data dump after the test.

From the operational point of view, the stop of the pitch rotation is achieved by uplinking the required commands in a pass prior to the time at which it has to take place. All commands are time-tagged, meaning that they are programmed for a specific time and that the rotation stop can happen outside visibility. The restart of the rotation, also time-tagged, is achieved by sending routine commands for the spacecraft rotation and Earth sensor masking, re-enabling the solar panel rotation and the magneto-torquers actuation, and triggering a transition to RRM. Following this, and once transition to FAM2 has occurred, exit from the thruster-controlled attitude modes and transition to the operational attitude mode is commanded in the first available visibility.

As shown in Fig. 7 and Fig. 8, the commanding has the expected effect on the spacecraft rates, which are all estimated to be very close to zero following a short transition period. In these figures, X is the pitch axis, while Y is the roll axis and Z the yaw axis.

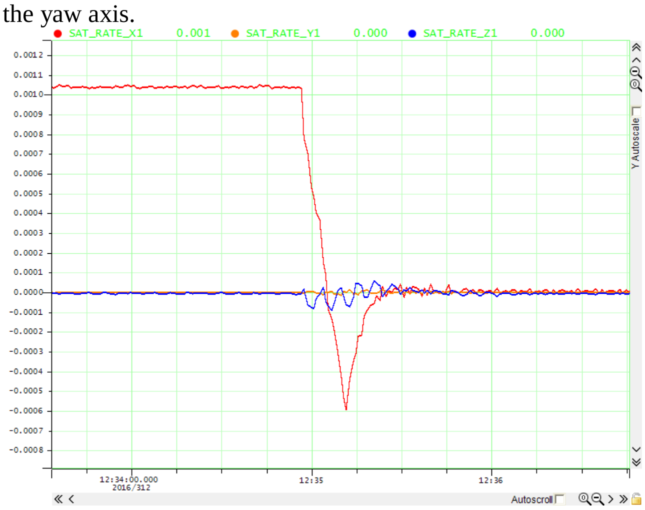

Fig. 7. Satellite rates when stopping the pitch rotation.

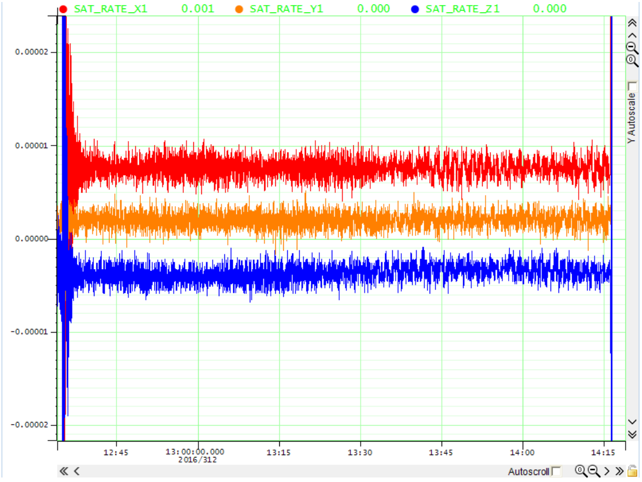

Fig. 8. Satellite rates during one revolution in inertial attitude.

The on-board estimation of the deviation from the commanded attitude around the time at which the pitch rotation is stopped in the same simulation is shown in Fig. 9, where it can be seen that the maximum value of that deviation is around 0.004 radians, well below the value of 0.026 radians that would trigger an on-board alarm.

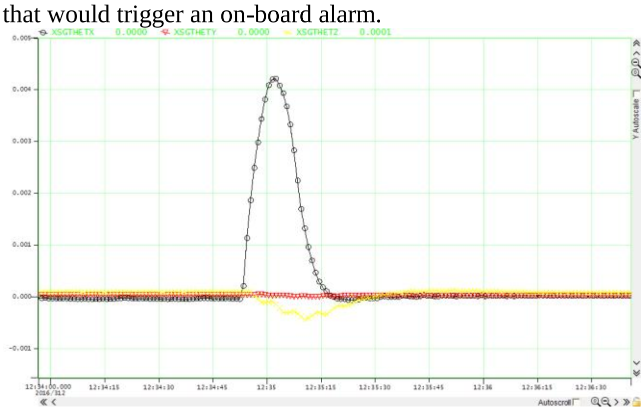

Fig. 9. On-board attitude estimation when stopping the pitch rotation.

Also the rotation of the solar panel is stopped, as expected, during the desired period, as seen in Fig. 10.

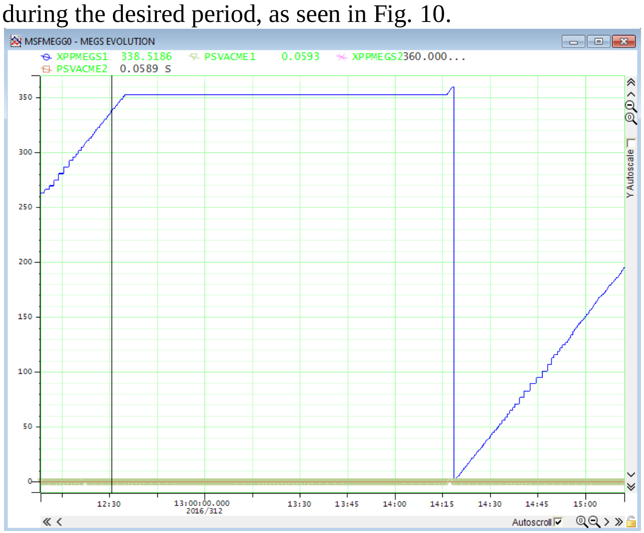

Fig. 10. Solar panel rotation around the revolution in inertial attitude.

The above figures correspond to a simulation using the nominal orbit and stopping the pitch rotation around the descending node. Very similar responses are observed when stopping the rotation at other points of the orbit (e.g. close to the North Pole and hence to the Svalbard ground station used for routine Metop commanding and science data downlink) or after the de-orbiting manoeuvres. Of course, the angle at which the solar panel is stopped depends on the difference between the position in orbit where the operation starts and the one at which the solar panel crosses its rotation origin. Spacecraft rates and attitude estimations are derived from the gyroscope measurements, which are the only ones used for attitude estimation during the interval of inertial attitude flight: measurements from the optical sensors, if any, are not meaningful in this non-nominal attitude mode.

An important aspect to be analysed is whether the reaction wheels, in charge of maintaining by themselves the spacecraft attitude during this revolution without pitch rotation because of the deactivation of the magneto-torquers, can cope with the resulting load without reaching saturation. The results from the simulations carried out so far indicate that saturation is not reached in any of the analysed scenarios. The observed values of the reaction wheels momentum are different in each of them, since the external torques depend on the position of the solar array and on the orbit altitude. However, the results obtained are not conclusive yet and must be considered preliminary: the satellite simulator was not designed to include fully representative models of the physical environment, so the values obtained so far may not be fully representative and need to be confirmed. A detailed analysis of the reaction wheels load using a tool that can model as accurately as possible the environment as well as the spacecraft and its attitude[4)] is currently ongoing in order to confirm whether it is expected that the reaction wheels do not reach saturation during the test. Further analyses and simulations will be performed in parallel by the spacecraft manufacturer.

A further element to be analysed is the fuel consumption due to the thruster-controlled attitude modes triggered in a controlled manner at the end of the operation. A preliminary assessment based on the pulse telemetry extracted from the satellite simulator for one orbit following the restart of the pitch rotation and the trigger of RRM results in an estimation of the fuel consumption of around 0.2kg, which would be acceptable from the fuel budget point of view. More detailed analyses will however be required, also from the spacecraft manufacturer, to confirm that the expected fuel consumption is acceptable.

6. Conclusion

The simulations and analyses performed so far have shown that both the yaw manoeuvre and the stop of the pitch rotation are feasible from the Flight Dynamics point of view. However, further and deeper analyses need to be carried out in both cases to confirm whether they can be acceptable from an operations perspective.

6.1. Yaw manoeuvres

In order to confirm whether the yaw manoeuvres described above are acceptable from the operations point of view, the following is still required:

- Information on the frequency and duration of the yaw manoeuvres so that they are useful for GOME Sun calibrations.
- Assessment of their feasibility when the LTAN deviation leads to the Sun not being visible from the Sun sensor during routine operations.
- Investigation on how to avoid (if possible) an RRM transition after the manoeuvre, since such a transition would completely invalidate the feasibility of this operation.

6.2. Stop of the pitch rotation

Regarding the technology test for pointing the spacecraft's instruments to deep space during a complete orbital revolution, the following is needed before a final recommendation to perform the operations can be issued:

- Further and more detailed analysis of the reaction wheel momentum values during the pitch-rotation stop operation.
- More detailed assessment of the fuel consumption during RRM and FAM2 following the restart of the pitch rotation.
- Assessment of the range of orbital positions favourable for stopping the pitch rotation, optimal for both the platform and for a mission return.

Acknowledgments

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