AUTONOMOUS ORBIT CONTROL FOR ROUTINE STATION-KEEPING ON A LEO MISSION

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Abstract: *Autonomous Orbit Control (AOC) allows station-keeping activities to be managed on-board. The satellite's orbital parameters are provided by the navigation function of the flight software. They are compared to a reference orbit and the AOC controller computes in-track and cross-track corrections. Maneuvers are then determined, taking into account AOC maneuver slots available along the orbit. Slots are selected to ensure an optimal maneuver. If not available, a "best effort" maneuver is performed instead. Simulations for altitude ranges of 450-1000 km have demonstrated that an in-track error window of ±2000 meters can be achieved, and ±1000 meters for cross-track error. Furthermore the AOC can be implemented even if the satellite is not on the reference orbit, by commanding the satellite to follow a continuous trajectory called transition orbit to come back to the reference. AOC flight software is being developed by Astrium Satellites for the next generation of Earth observation satellites in LEO. Functional and performance validation will be carried out in 2012-2013 time frame.*

Keywords: *Autonomous Orbit Control, autonomous, station-keeping, LEO*

1. Introduction

Station keeping operations for Low Earth Orbit spacecrafts are usually completely managed by the ground segment in a complex and time consuming process through the following steps:

- ground station visibilities for the download of GNSS data from the satellite or for doppler and angular measurements,
- orbit determination providing the spacecraft's orbital parameters,
- maneuver computation, taking into account mission constraints,
- station visibility to upload the maneuver plan,
- realization of the maneuver (mission is usually stopped at this time),
- station visibilities and orbit determination to perform maneuver calibration and extrapolation of the new orbit,
- prediction of orbital events with the updated orbit, for ground station pointing and mission scheduling.

As the station-keeping requirements are getting more and more stringent in terms of both cross-track and in-track windows, the operational workload increases dramatically due to the need of frequent maneuvers. For a low altitude mission and a high level of solar activity (thus major effect of the air drag perturbation), orbit determination should even be performed several times

per day. In this context, on-board Autonomous Orbit Control (AOC) is the answer to meet system requirements and reduce the workload of operational teams. Furthermore, an AOC is able to control the satellite's orbit in a very narrow station-keeping window around a reference orbit. This allows to simplify the ground system architecture and interfaces as all components (mission scheduling, ground station pointing, …) will use a shared reference orbit defined on the long term and not a frequently updated orbit coming from the orbit determination process.
Up to now, only a few in-flight experiments have been performed in Europe such as CNES DEMETER AOC experiment in 2005 which demonstrated the feasibility of in-track autonomous control as a routine feature.
Astrium Satellites is now leading the development of a fully operational Autonomous Orbit Control function for a Sun-synchronous Earth Observation mission. Algorithms use techniques inspired by feedback control in order to simplify on-board computations and avoid complex flight dynamics calculations.

2. AOC Requirements and Design

The AOC shall be able to manage both cross-track and in-track position errors with a performance target from one to a few km whatever the latitude. It shall be applicable to a wide range of altitudes (typically 450-1000 km) and solar activity levels, meaning that algorithms shall be robust to highly variable levels of air drag perturbations. The AOC algorithms are divided into three high level modules:

- reference orbit management
- controller computations
- maneuver implementation

Spacecraft position and velocity are provided by GNSS measurements handled by the navigation function of the on-board Attitude Determination and Control Subsystem (ADCS). The orbital elements of the orbit are compared with the reference orbit. Then the proportional-derivative controller computes the orbital corrections to be performed, and the last module computes the maneuvers taking into account operational constraints (Fig. 1).

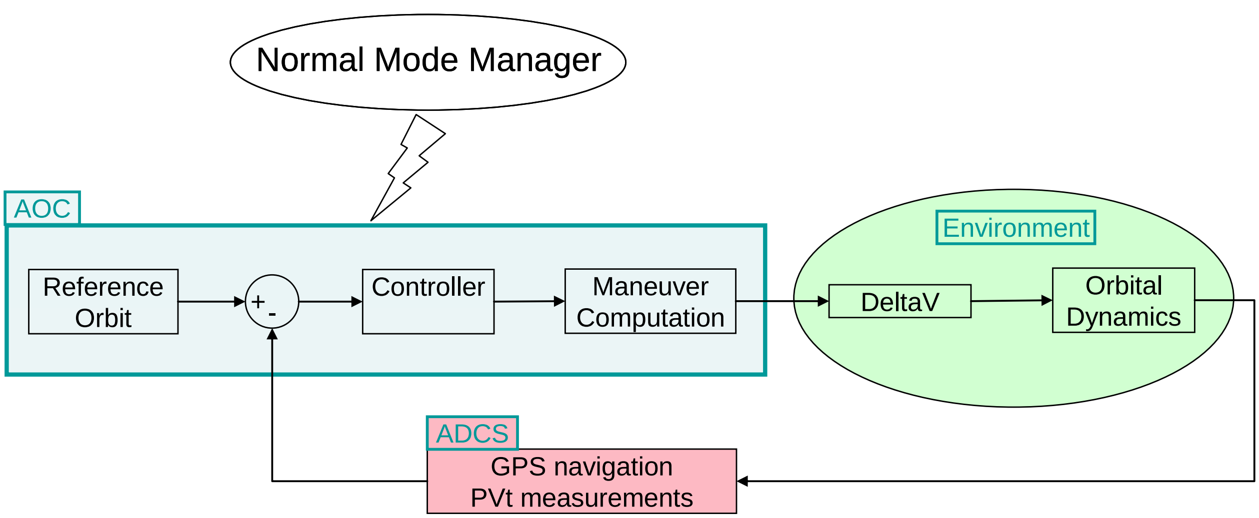

Figure 1. AOC integration in a closed loop environment

2.1. Reference orbit

For the mission considered here, the nominal orbit is a near-polar, Sun-synchronous and phased one. The station-keeping activities consist in controlling the satellite trajectory around the reference orbit, complying with an *in-track* (altitude, phasing) and a *cross-track* (inclination, local solar time) maximum error window (Fig. 2).

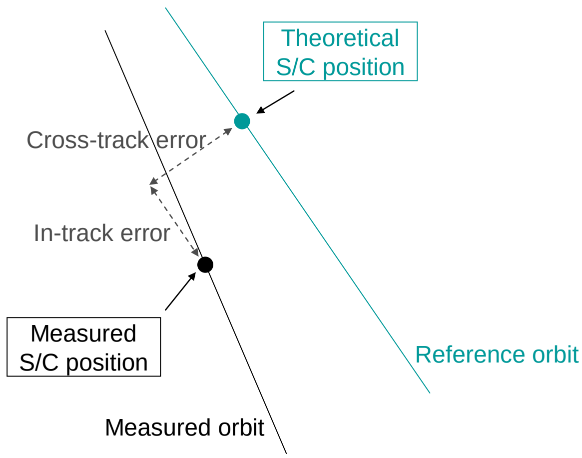

Figure 2. Definition of in-track and cross-track errors

The main characteristics of the reference orbit are recalled hereafter:

- phased orbit defined by the parameters (n, p, q). The nodal period is defined by $n+\frac{p}{q}$ revolutions per day,
- Sun-synchronous orbit with a given local time for ascending node,
- frozen eccentricity,
- given longitude L_0 of the ascending node at the reference date T_0.

The longitude of the ascending node L_{AN} and the argument of latitude α can be expressed at any time T_{cur} with Eq. 1:

$$\begin{aligned} L_{AN} &= L_0 - 2\pi \cdot (T_{cur} - T_0) \\ \alpha &= 2\pi \cdot \frac{(T_{cur} - T_0)}{n+\frac{p}{q}} \end{aligned} \tag{1}$$

with the longitudes and the argument of latitude α in radians and the times in days.

The terrestrial potential only depends on longitude and latitude. A numerical propagation of the reference orbit is performed taking into account the Earth potential only. Between 50 and 80 zonal and tesseral terms are considered, depending on the orbit's altitude. A Fast Fourier Transform (FFT) is then performed on each orbital parameter with respect to the longitude and the argument of latitude (AOL).

The harmonics produced by the FFT are expressed as modulus, ascending node pulsation, AOL pulsation and phase $\left(A_i, \omega_i^{L_{AN}}, \omega_i^{\alpha}, \varphi_i\right)$ and the orbital parameters are computed with Eq. 2:

$$parameter(L_{AN}, \alpha) = \sum_{i=1}^{n} A_i \cdot \cos\left(\omega_i^{L_{AN}} \cdot L_{AN} + \omega_i^{\alpha} \cdot \alpha + \varphi_i\right) \quad (2)$$

with n = number of harmonics selected for this parameter.
The choice of the number of harmonics n is driven by a trade-off between the accuracy of the re-computed orbital parameter and the onboard computational constraints. Figure 3 presents the difference between the re-computed orbit and the full perturbation orbit with respect to the number of harmonics (the same number has been taken for the six orbital parameters).

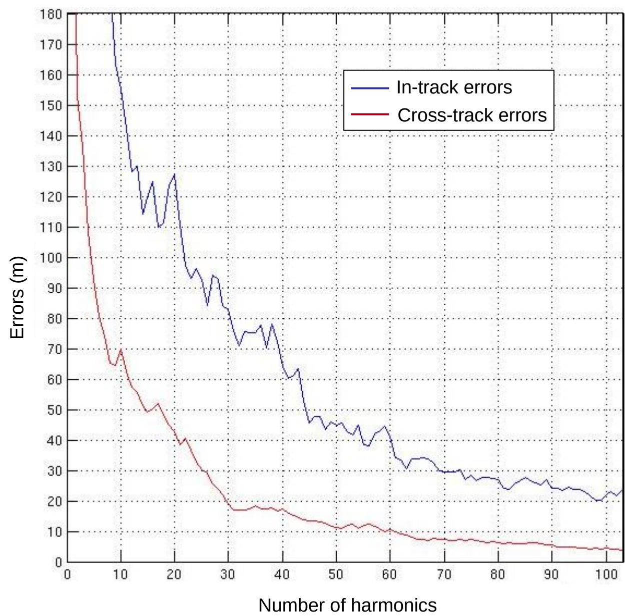

Figure 3. Errors on satellite's position with respect to the number of harmonics

The acceptable in-track and cross-track errors depends on the size of the station-keeping window and the altitude. Generally n varies between 1 (for semi-major axis for ex.) and 40 (for eccentricity for ex.).

Each time it is activated, the AOC computes the reference orbit related to the time of activation. Then the on-board navigator provides an estimate of the satellite's orbital parameters based on the measurements of the GNSS receiver.
The orbital parameters of the measured and reference orbits are then compared and the result $\left(\Delta\alpha, \Delta\Omega, \Delta e_x, \Delta e_y\right)$ is provided to the AOC controller ($\Delta\alpha$ = delta argument of latitude, $\Delta\Omega$ = delta right ascension of ascending node (RAAN), Δe_x and Δe_y = delta of eccentricity vector).

2.2. Controller

The commanded drift values of the argument of latitude $\Delta\dot{\alpha}_{com}$ and the RAAN $\Delta\dot{\Omega}_{com}$ are determined using a proportional-derivative controller. The measured values of $(\Delta\alpha, \Delta\Omega)$ presented in §2.1 and an estimate of their derivative values $(\Delta\dot{\alpha}, \Delta\dot{\Omega})$ provide the controller input (Eq. 3).

$$\begin{cases} \Delta\dot{\alpha}_{com} = -K_D^{\alpha} \cdot \Delta\dot{\alpha} - K_P^{\alpha} \cdot \Delta\alpha - K_S^{\alpha} \\ \Delta\dot{\Omega}_{com} = -K_D^{\Omega} \cdot \Delta\dot{\Omega} - K_P^{\Omega} \cdot \Delta\Omega - K_S^{\Omega} \end{cases} \tag{3}$$

The control of the eccentricity is simpler. It consists in a direct compensation of the measured difference in e_x and e_y (Eq. 4).

$$\begin{bmatrix} \Delta e_x \\ \Delta e_y \end{bmatrix}_{com} = -\begin{bmatrix} \Delta e_x \\ \Delta e_y \end{bmatrix} \tag{4}$$

The controller output $\Delta\dot{\alpha}_{com}$ and $\Delta\dot{\Omega}_{com}$ are then converted in semi-major axis and inclination commands Δa_{com} and Δi_{com} (Eq. 5).

$$\begin{cases} \Delta a_{com} = \dfrac{-2a}{3n_0\left[1+\dfrac{7}{2}J_2\left(\dfrac{a_e}{a}\right)^2\left(4\cos^2 i - 1\right)\right]} \cdot \Delta\dot{\alpha}_{com} \\ \Delta i_{com} = -\dfrac{T_\Theta}{2\pi \cdot \tan i} \cdot \Delta\dot{\Omega}_{com} \end{cases} \quad \text{with } n_0 = \sqrt{\frac{\mu}{a^3}} \tag{5}$$

a = mission semi-major axis $\quad$ i = mission inclination $\quad$ a_e = Earth radius
J_2 = second zonal term of Earth potential $\quad$ μ = Earth constant of gravity
T_Θ = sidereal year ≈ number of seconds in one year

On a LEO orbit, the semi-major axis naturally decreases because of the drag effect and the main variation is a secular linear lowering. As a result the free drift of $\Delta\alpha$ presents a parabolic variation and thus a one-sided limit cycle is sufficient for AOL control. $\Delta\Omega$ also presents a parabolic evolution as the free drift of the inclination also presents a linear secular variation. The station-keeping maneuvers are then computed only when both conditions are met:

- the controlled parameters $\Delta\alpha$ and $\Delta\Omega$ exceed the pre-defined threshold while reaching the upper side of the control window (Fig. 4),
- the pulsations $\Delta\dot{\alpha}$ and $\Delta\dot{\Omega}$ have the same sign than $\Delta\alpha$ and $\Delta\Omega$, to avoid maneuver computations when the parameter is still above the threshold but a maneuver has already been performed.

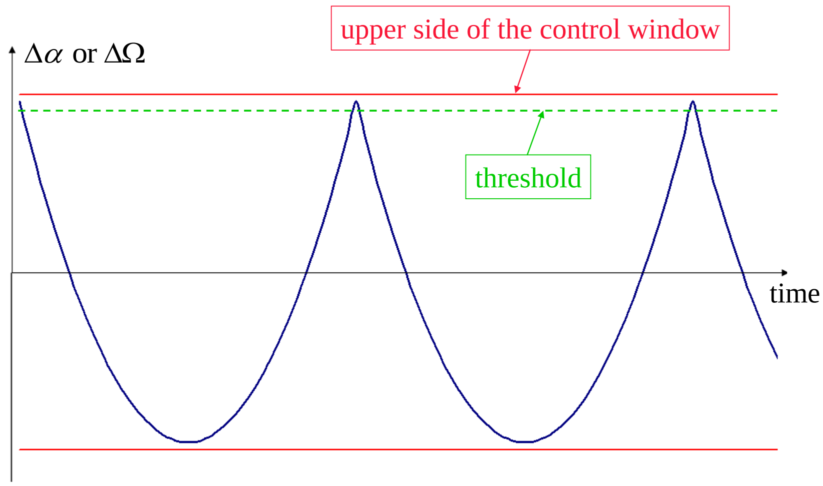

Figure 4. One-sided limit cycle for AOL and RAAN control

A lower threshold is also implemented in order to avoid any crossing of the lower side of the control window. This can occur in the following cases even if the controller tuning is correct:

- the orbital dynamics has decreased since the maneuver was executed. The implemented correction was then over-sized with respect to the observed evolution of the perturbations.
- the maneuver was over-sized despite a correct estimation of the future perturbations. This could appear if the environmental dynamics is very low and the minimum deltaV allowed for the maneuver has been reached.
- for high altitude orbits, the periodic effect of the solar radiation pressure (SRP) on the semi-major axis could be greater than the drag effect and induce a increase of the semi-major axis during a part of the year (Fig. 5).

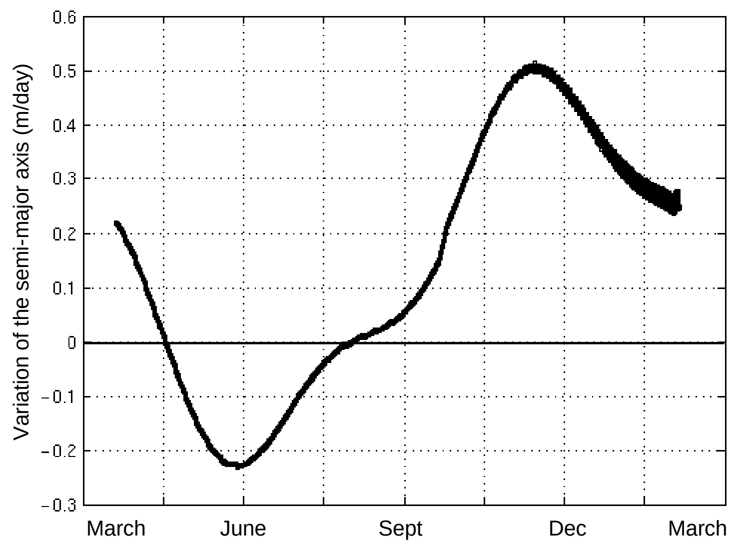

Figure 5. Variation of the semi-major axis due to a greater SRP effect than drag effect

One main concern with the controller is to avoid any overshoot due to an unsuitable tuning. In particular the control of the argument of latitude is very sensitive to air drag effects linked to the atmospheric density. During a ten to twelve year mission, the solar activity follows a complete solar cycle from low activity to high activity levels as depicted in Fig. 6.

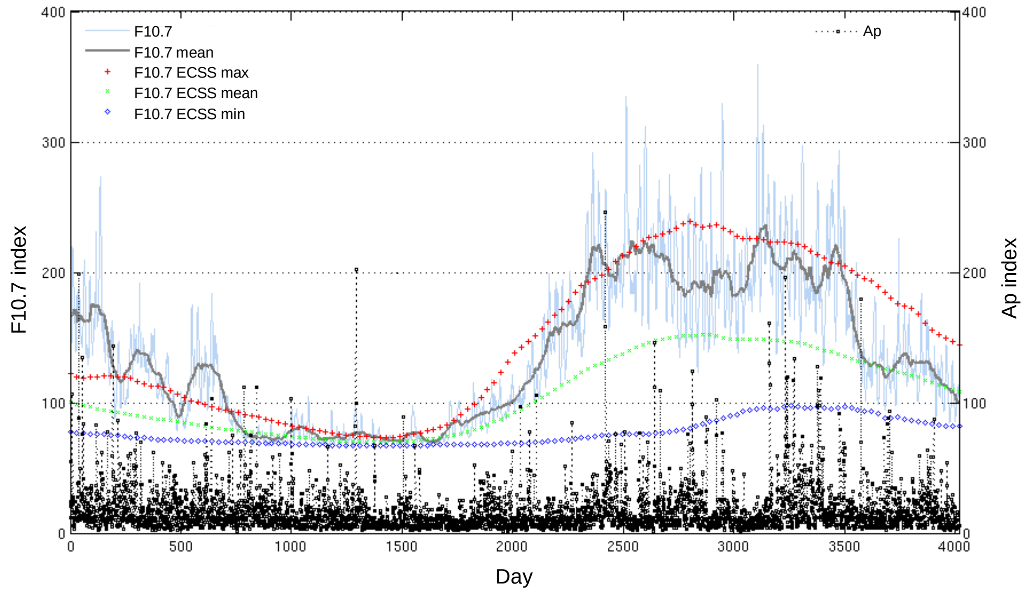

Figure 6. Evolution of the solar flux index F10.7 and Sun geomagnetic index Ap during a 11-year solar cycle

These variations of the solar activity imply huge variations of the AOL acceleration $\ddot{\alpha}$ thus different sets of gains are necessary to tune the AOL controller during the spacecraft lifetime. This is achieved through an auto-adaptative tuning of the controller gains, using an estimate of the in-track acceleration. The controller gains are then interpolated in a pre-defined table according to the estimated value of $\ddot{\alpha}$ (Fig. 7).

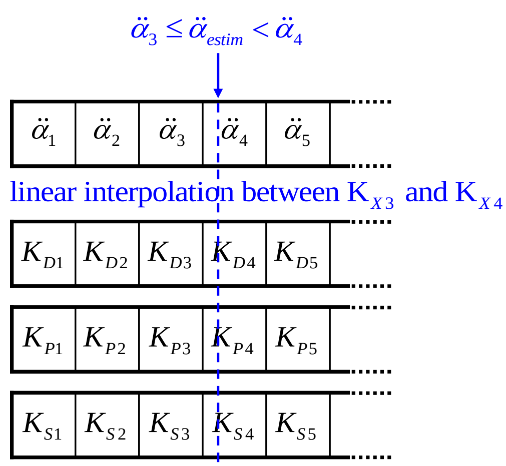

Figure 7. Interpolation of AOL gains depends on the estimated value of $\ddot{\alpha}$

The final output of the controller module is then the orbital parameter corrections $\left(\Delta a_{com}, \Delta i_{com}, \Delta e_{x\_com}, \Delta e_{y\_com}\right)$ to be applied to the current orbit to get back on the reference orbit.

2.3. Maneuver computation

The maneuver computation consists in converting orbital corrections into tangential (in-track) and normal (cross-track) deltaV impulses.
For inclination correction, optimal maneuvers are usually performed at the Ascending Node (AN) or the Descending Node (DN) of the orbit. If the inclination maneuvers are *combined* ones - mixing inclination normal corrections and semi-major axis tangential ones - it is necessary to perform two maneuvers (at AN and DN) in order to minimize the eccentricity disturbance.
Semi-major axis and eccentricity corrections are performed with tangential maneuvers. Most of the time it is recommended to perform two maneuvers to optimize the eccentricity variation while achieving the semi-major axis correction.
Generally the mission must be stopped while the spacecraft performs the maneuvers, as the required attitude usually does not comply with observation constraints. This is not an issue when the rate of the maneuver is low and predictable, but in the case of an autonomous orbit control this point is critical.
The use of an AOC allows specifying a very narrow station-keeping window. It is then possible to perform antenna pointing and mission scheduling using the reference orbit instead of a frequently updated determined orbit. However the drawback is that numerous small corrections are needed to achieve this accuracy. The dates of these corrections are not known at ground level because all the maneuver determination process is on-board.
Thus the maneuver computation process must be driven by operational constraints. AOC slots shall be reserved in the mission timeline and uploaded on-board to allow station-keeping activities to be performed without any overlapping with mission activities.

2.3.1. Maneuver slots

Generally AOC slots are available where no mission is required, above oceans or poles for an optical observation mission for example. They can be defined either in AOL for each orbit or with starting and ending dates. A maneuver can be performed if the centroid of the thrust belongs to an authorized slot. It means that the start or the end of the thrust can be located out of the limits of the chosen slot. Thus the definition of the slots must take into account the following margins:

- the maximum duration of a deltaV. This value is defined at system level.
- the maximum duration of the pointing maneuvers : rotation of the satellite from cruise pointing to thrust pointing, and return to cruise pointing after the thrust.

The AOL of the tangential maneuvers are set by the constraints on eccentricity corrections, unlike pure semi-major axis corrections that can be performed anywhere on the orbit. This is not an issue if the optimal AOL are within the slot limits. But most of the time it will not, and usually it is also not possible to just cancel the maneuver and wait for more suitable slots on following orbits.

The solution is to replace the optimal maneuver by a “best effort” maneuver, choosing the nearest slot with respect to the optimal AOL (Fig. 8).

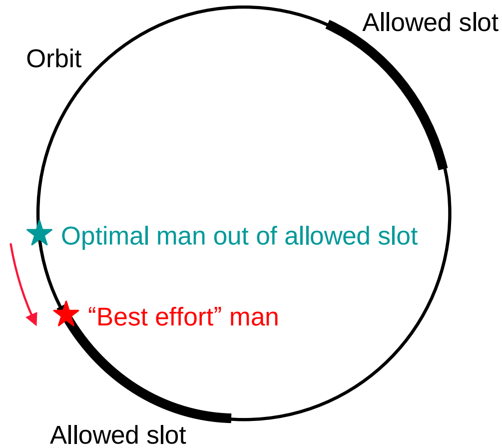

Figure 8. “Best effort” maneuver when the optimal AOL is not available

The drawback of a “best effort” maneuver is that the eccentricity correction is not optimal. Even more the second tangential maneuver may also be canceled or not optimal because of the slot constraint. As the two maneuvers for eccentricity correction are not optimal, it is not necessary to keep two separate corrections. Only one maneuver is used instead for both semi-major axis and “best effort” eccentricity correction. The AOC allows to perform frequent maneuvers and the eccentricity will statistically converge to the targeted frozen one. However the computation of the AOC slots must take into account a constraint of equal distribution of allowed AOL on the whole orbit in order to ensure a tight control of the eccentricity.
Concerning the inclination corrections, the classical maneuver sequence has been chosen with combined deltaV performed at ascending and descending nodes. This implies that some slots containing the orbit’s nodes must be reserved for inclination control. However the rate of inclination maneuvers is much lower than the rate of tangential corrections.

Blinding issues must also be taken into account in the slot definition process. In particular the instrument shall never be pointed towards the Sun, to avoid camera blinding and comply with thermal constraints. This is a major constraint especially when the instrument’s line of sight is in the same direction than the thrust. Moreover blinding check must also consider the Sun declination, depending on the considered season (Fig. 9).

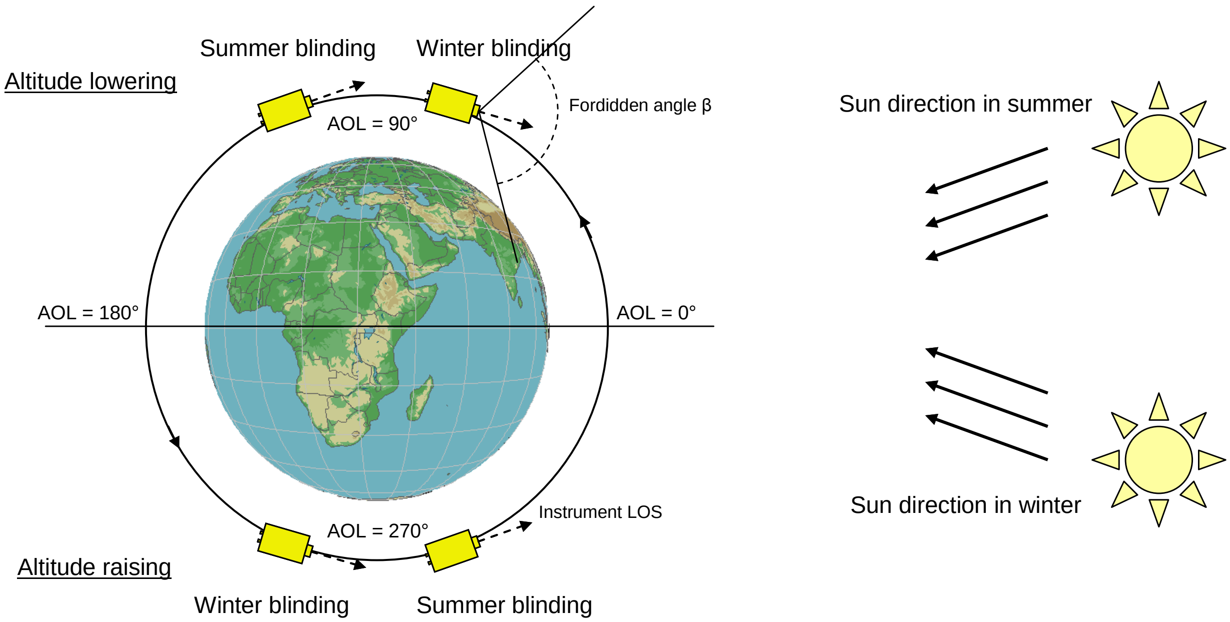

Figure 9. Instrument blinding depends on the season on a polar orbit

Figure 10 presents safe and blinded ranges of AOL, in the case of altitude raising maneuvers. As it is season dependent, the values vary according to the day of the year. The yellow area represents the AOL values for which the angle between the line of sight of the instrument and the Sun is greater than a blinding angle β. The grey area corresponds to the orbital parts in eclipse. Thus the safe AOL for the instrument are the combination of the yellow and grey areas, and white areas are blinded ones.

Inclination maneuvers are perpendicular to the orbital plane so for most Sun-synchronous orbits (local solar hour of ascending or descending node near noon) they present no blinding issues.

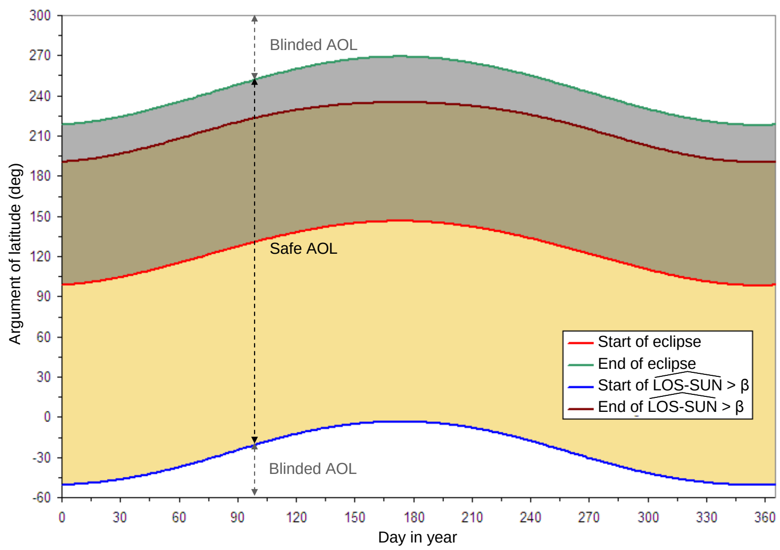

Figure 10. Ranges of blinded and safe AOL during altitude raising maneuvers

When both normal and tangential maneuvers are required, priority is given to inclination maneuvers because they are combined ones, mixing normal and tangential components. Inclination slots (including ascending and descending nodes) are also less numerous than for in-track correction. Figure 11 presents the order of priority for maneuver computation.

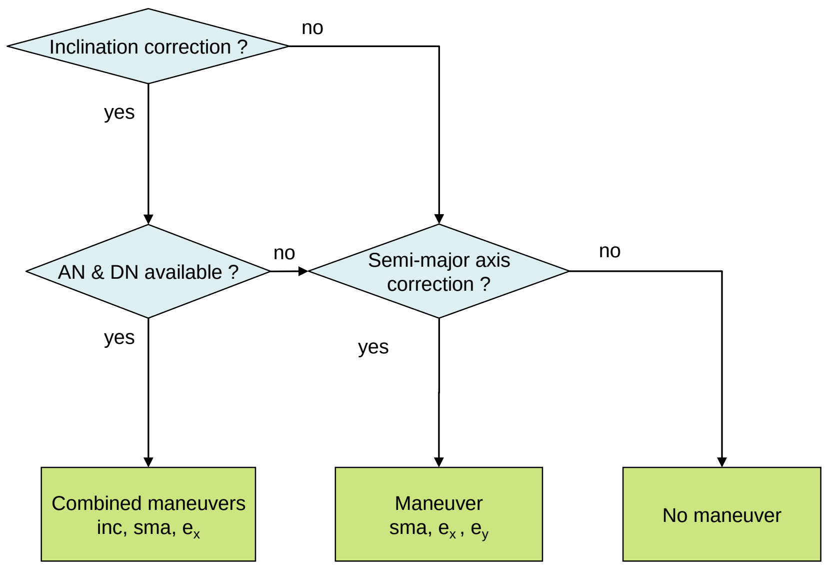

Figure 11. Order of priority for maneuver computation

2.3.2. Propulsion sub-system constraints

For a low altitude orbit and a narrow control window the number of maneuvers can quickly increase and require several corrections per day. It is then necessary to reduce the total number of maneuvers performed during the lifetime of the spacecraft in order to be compliant with the qualification domain of the thrusters.

A deltaV threshold has been introduced in the AOC algorithms to avoid too small maneuvers. No deltaV lower than a given minimum value $\Delta V_{\min}$ shall be performed. If the computed deltaV is lower than $\frac{\Delta V_{\min}}{2}$ then the maneuver is canceled. If the value of the deltaV is between $\frac{\Delta V_{\min}}{2}$ and $\Delta V_{\min}$ then the deltaV is set to $\Delta V_{\min}$. Any deltaV greater than $\Delta V_{\min}$ remains unchanged. We saw that the control of the argument of latitude is very sensitive to the air drag effects linked to the atmospheric density. Thus to reduce the number of maneuvers the value of $\Delta V_{\min}$ must be determined taking into account the solar activity level. This parameter is then be chosen in a table of values as a function of the $\ddot{\alpha}$ estimation, the same way auto-adaptative AOL gains are managed (refer to Fig. 7). Of course this could lead to propellant over-consumption if the value of $\Delta V_{\min}$ is too high. The AOC could command a continuous round-trip between the edges of the station-keeping window, in particular for high altitudes and low solar activities. Adjustment of the minimum deltaV value must be carefully tuned in order to avoid such a behavior.

Note : the auto-adaptative gains also contribute to the reduction of the number of maneuvers: keeping the same AOL controller tuning when the solar activity evolves from low to high level could lead to performing under-sized deltaV and so increase the number of maneuvers.

In addition, for mono-propellant propulsion sub-systems the chemical reaction and so the thrust is produced when the propellant is in contact with the catalytic bed within the combustion chamber of the thruster. To produce an efficient thrust the chemical reaction must be performed at high temperature. Thus the combustion chamber needs to be heated in advance before the maneuver. To take into account these durations, the AOC computes maneuvers on the two next orbits instead of a single one. Moreover the AOC is then also able to select the best slot for the maneuver among two orbits. For example it is worth waiting for an orbit before performing the maneuver if an optimal slot is available on the second one. The "best effort" maneuver may also be more efficient if the nearest slot can be chosen among two orbits instead of one.

3. AOC Performance Assessment

3.1. Simulations

An analysis of the orbital perturbations and the design of preliminary algorithms were carried out by Astrium Satellites in 2008-2009. A simulator was then developed for studies and preliminary performance validation in 2010-2011. It is used to simulate the environment and the orbital dynamics, the satellite's navigation that provides GNSS data, the propulsion sub-system and of course the AOC algorithms.
Simulations covering a complete satellite lifetime show that the AOC is able to maintain the spacecraft in a typical ±2000 meters in-track window (an example for high altitude is depicted in Fig. 12). The solar activity level considered for the simulations is a realistic one and corresponds to the solar flux F10.7 and geomagnetic index Ap values measured between 1982 and 1993, covering a complete solar cycle during the 11-year simulated time (refer to Fig. 6). ECSS smoothed values, usually used for propellant budget estimate, are not representative of the solar storms and short term events that result in significant air drag variations.

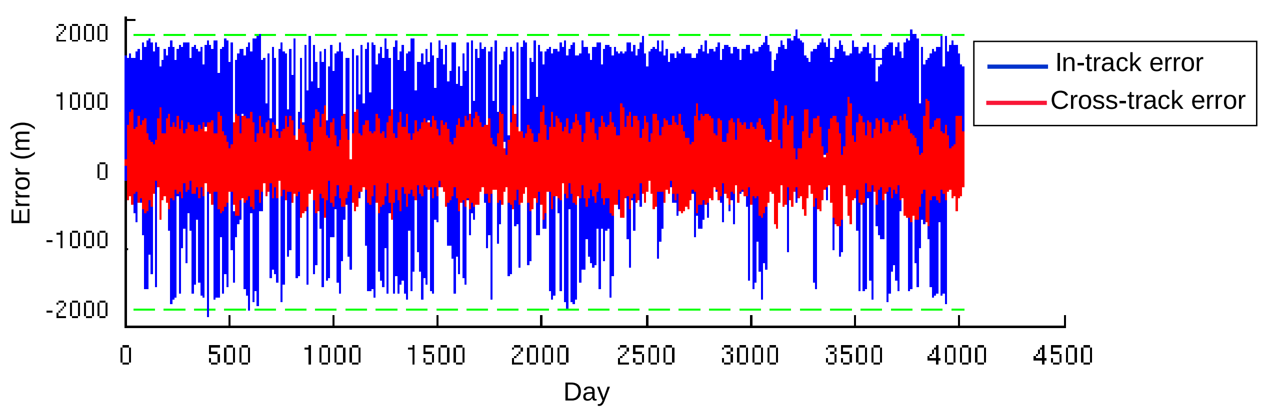

Figure 12. In-track and cross-track errors during a 11-year station-keeping

Cross-track errors do not depend on the altitude of the spacecraft or the solar activity. The evolution of the inclination and the RAAN follows smooth and slow variations. The inclination maneuvers are performed at ascending and descending nodes thus the size of the cross-track window depends on the rate of maneuver slots containing AN and DN. Figure 12 presents a cross-track window of ±1000 meters that could be easily adjusted upwards or downwards.

Eccentricity control is a major concern in the AOC concept. It depends not only on the number of the dedicated maneuver slots but also on the distribution of the slots along the orbit. Uncontrolled eccentricity can cause oscillations of the in-track error and thus a station-keeping window infringement. Figure 13 presents the e_x-e_y plot related to the ±2000 m in-track window. It shows limited errors thanks to the correct global distribution of the slots.
The e_y component is controlled by tangential maneuvers performed near the Earth poles. Thus e_y is more difficult to manage due to blinding issues concerning the instrument (refer to Fig. 9). Maneuver slots around the poles must be equally distributed on ascending and descending parts of the orbit to globally compensate the forbidden AOL.

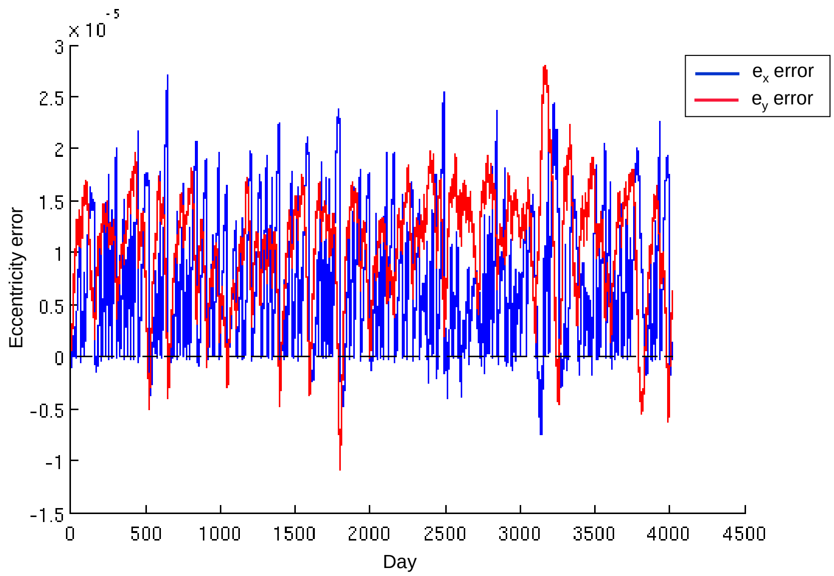

Figure 13. Eccentricity errors during a 11-year station-keeping

For this simulation the mean rate of maneuvers was 0.3 man/day with a maximum of 4 man/day for high levels of solar activity. A total number of 1200 maneuvers were performed in 11 years. Of course these figures depend on the altitude of the orbit and can reach a mean value of 1.5 man/day and a total of more than 6000 maneuvers.

The cost of the inclination control remains unchanged whenever the altitude of the orbit. To comply with a ±1000 m cross-track window the mean deltaV per maneuver is about 0.2 m/s and the rate one maneuver every two weeks.
The cost of semi-major axis and eccentricity control is much more dependent on the altitude and for a ±2000 m in-track window the mean deltaV per maneuver can vary between 0.01 and 0.1 m/s and the rate between 0.1 and 2 man/day.

In any case the cost of the station-keeping is equivalent between AOC and classical “manual” one. The difference only concerns the rate and the deltaV of the maneuvers, numerous maneuvers implying low deltaV for each.

3.2. Transition orbit

From an operational point of view it would be interesting to start the AOC even if the spacecraft is still out of the station-keeping window, but close enough to consider that $\frac{\Delta a}{a}$, $\frac{\Delta i}{i}$, etc. represent small values. This condition is met in the following cases:

- First use of the AOC after the launch or after a set of maneuvers commanded from the ground.
- Return from safe mode. The AOC is stopped when the spacecraft encounters an anomaly, up to the return to normal mode. During this time no station-keeping activities are performed and the orbit drifts away from the reference.
- Conjunction alert. In order to compute the probability of collision with a debris or another spacecraft, the AOC must be inhibited in order to keep the orbit stable, i.e. not perturbed by autonomous maneuvers.
- Re-phasing of the satellite on its orbit. This can be either achieved in a semi-autonomous mode (manual maneuver to set the drift, then transition orbit) or in pure AOC mode (both the drift and the phasing steps covered by the transition orbit).

The transition orbit corresponds to a continuous trajectory followed by the AOC to come back to the reference orbit. The in-track and cross-track windows are then centered on the new trajectory so the AOC can be enabled and the mission re-starts immediately (Fig. 14). No further maneuver computation or orbit determination need to be performed at ground level.

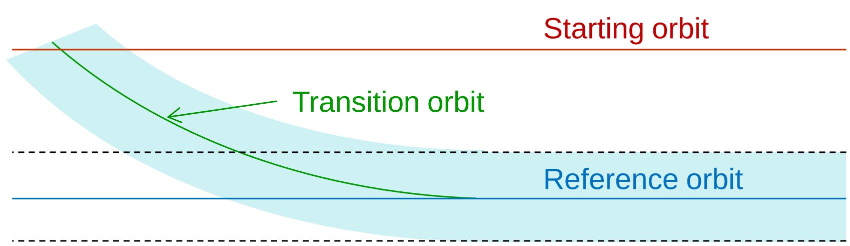

Figure 14. Station-keeping window is centered on the transition orbit

The expressions of the accelerations $\ddot{\alpha}$ and $\ddot{\Omega}$ can be linearized near the reference orbit (Eq. 6):

$$\begin{Bmatrix} \ddot{\alpha} = K_{\alpha a}(a,i)\cdot\dot{a} + K_{\alpha i}(a,i)\cdot\dot{i} \\ \ddot{\Omega} = K_{\Omega a}(a,i)\cdot\dot{a} + K_{\Omega i}(a,i)\cdot\dot{i} \end{Bmatrix} \quad (6)$$

A first integration provides the rendez-vous conditions for the semi-major axis and the inclination, a second one for the AOL and the RAAN. The eccentricity aspect is covered by the semi-major axis solution, with possibly a slight over cost if the cost of the eccentricity correction is greater than the semi-major axis one.

Figure 15 presents examples of semi-major axis and inclination evolution for $\Delta a = -5$ km and $\Delta i = +0.01$ deg. Three kinds of trajectories are represented: polynomial order 2, polynomial order 3 and piecewise linear function.

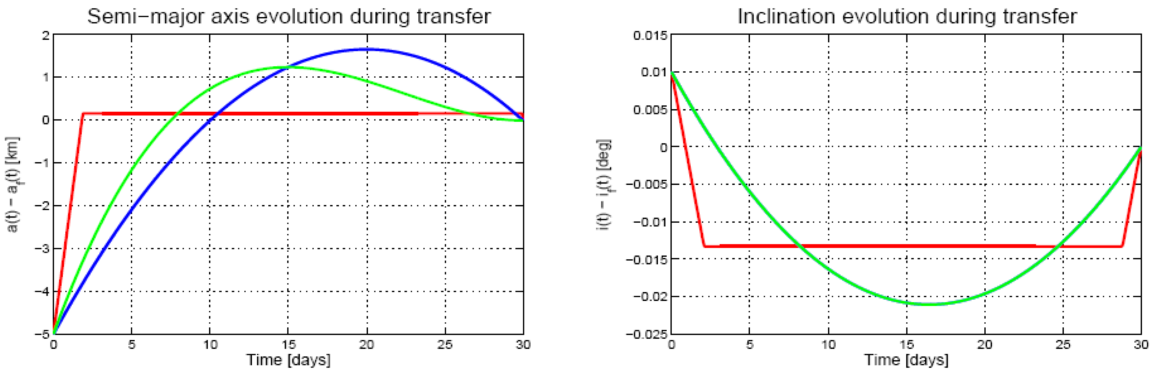

Figure 15. Semi-major axis and inclination evolution during transition to reference orbit

4. Conclusion

The advantages of using an on-board Autonomous Orbit Control are straightforward. First the use of a reference orbit shared by the ground and the space segment, simplifies the mission scheduling, the antenna pointing, etc. All activities that classically relied on an orbit regularly determined at ground level can now be planned in the long-term. No more maneuver computations or orbit determinations are required on-ground, thus reducing the workload of the operational team.

The use of AOC implies a global balance between mission and station-keeping constraints. Maneuver slots must be equally distributed along the orbits in order to ensure an efficient control of the in-track error. Cross-track error management is easier and only requires some slots to include the ascending and descending nodes. The determination of the slots must also take into account system requirements such as blinding avoidance or maneuver maximum/minimum duration.
Optimal eccentricity control requires maneuvers to be performed at specific arguments of latitude on the orbit. However when the maneuver slots do not contain these positions on orbit the maneuver shall not be canceled and a “best effort” maneuver is computed. The maneuver is performed at the nearest argument of latitude available in the slots of the two incoming orbits.
It has been showed in simulations that an in-track error window of ±2000 meters can be achieved by AOC for altitude ranges of 450-1000 km, and ±1000 meters for cross-track error.

Thanks to the concept of transition orbit it is possible to start the AOC even if the satellite is not in its station-keeping window yet. The transition orbit corresponds to a continuous trajectory followed by the AOC to come back to the reference orbit. In-track and cross-track constraints apply on this orbit thus mission can start immediately.

The prototyping phase is now over. In 2012 Astrium Satellites has developed AOC flight software for the next generation of French observation satellites. Intensive campaigns of functional and performance validation have just started by now and will continue on 2013.

5. References

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