EUROSTAR 3000 INCLINED ORBIT MISSION : LIFETIME OPTIMISATION IN CASE OF INJECTION WITH A LOW INCLINATION

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ABSTRACT

The EADS ASTRIUM EUROSTAR 3000 platform is dedicated to geostationary orbit missions (such as telecommunication). One of the EUROSTAR 3000 program, currently in development, is an inclined orbit mission (Fig. 1.).

For an inclined orbit mission, the lifetime duration directly depends on the initial inclination and on the inertial right ascension of ascending at the Beginning Of Life (BOL).

The optimisation of these parameters is strongly linked to the launch date and completely depends on the inclination of the injection orbit delivered by the launcher.

This paper presents some results of the mission analysis performed by EADS ASTRIUM in the frame of this EUROSTAR 3000 inclined orbit mission. It first explains the optimisation usually performed in the case of an injection with a high inclination. It then focuses on the innovative case of injection with a low inclination : the principles of the choice of the arguments of perigee to be specified to the launcher is described, as well as the impacts on the launch window with respect to the other constraints.

Fig. 1. Artist view of a EUROSTAR 3000 platform

1. INCLINED ORBIT MISSION : THE INFLUENCE OF THE LAUNCH DATE

1.1 The station keeping cost

The main orbital perturbation for a geostationary satellite is the Sun and Moon gravity, which induces an inclination drift. The control of this perturbation corresponds to an approximated value of 50 m/s. That is to say approximately twenty times the cost of the longitude/eccentricity control.

In case it is acceptable by the payload mission, the use of an inclined orbit –even with only few degrees- has a major impact on the propellant budget of the spacecraft during its operational life.

In order to maximise the benefit of the authorised free drift given by the inclined orbit, the initial point for the beginning of life of the spacecraft shall be correctly targeted (Fig. 2.).

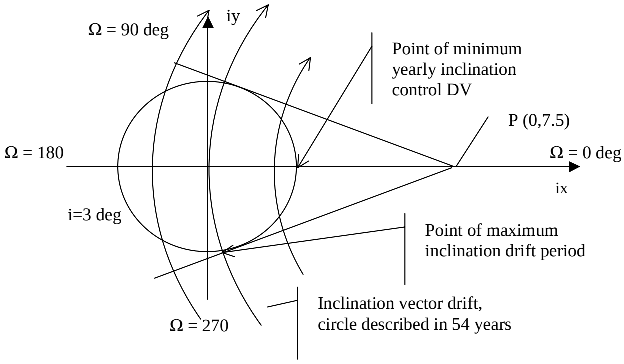

Fig. 2. Principles of the inclination drift for a geostationary spacecraft on an inclined orbit.

Because of system constraints, the launch window of the Eurostar 3000 plateform -like most of the spacecraft- is defined in order to have the Sun towards the apogee.

In addition to that, the line of nodes and the line of apsides are basically the same in order to perform combined manoeuvres to reduce the inclination while increasing the perigee altitude. Thus the initial Right Ascension of Ascending Node (RAAN) can take any value between 0 and 360 deg in an inertial frame, depending on the launch date (Fig. 3.).

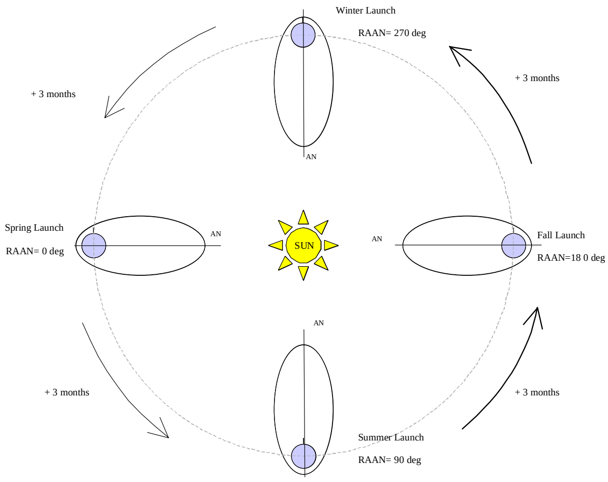

Fig. 3 Orbit orientation and RAAN versus the launch date

So, if during the transfer the inclination is reduced to the Beginning Of Life value (BOL) -with 3 degrees for example- without achieving a node line rotation during the transfer; the benefit of using an inclined orbit strongly depends on the launch date because the initial inclination (ix,iy) will be somewhere on the circle which radius is equal to the inclination (Fig. 2.).

1.2 Global optimisation : Launcher, LEOP and station keeping

In order to reduce the impact of the launch date on the propellant budget, a first level of optimisation can be performed : a global optimisation taken into account the transfer cost and the station-keeping cost. Indeed, it can be more fuel efficient to target a specific initial inclination point (ix,iy) at the end of the transfer phase in order to have the benefit of more inclination free drift, even if it costs more propellant during the transfer from the injection orbit to the inclined geostationary orbit. The injection orbit can also be adapted with a higher altitude of perigee or a lower inclination to improve the orbital lifetime

Fig. 4. shows the achievable lifetime for a given initial propellant mass with respect to the injection Right Ascension of Ascending Node (RAAN) in an inertial frame.

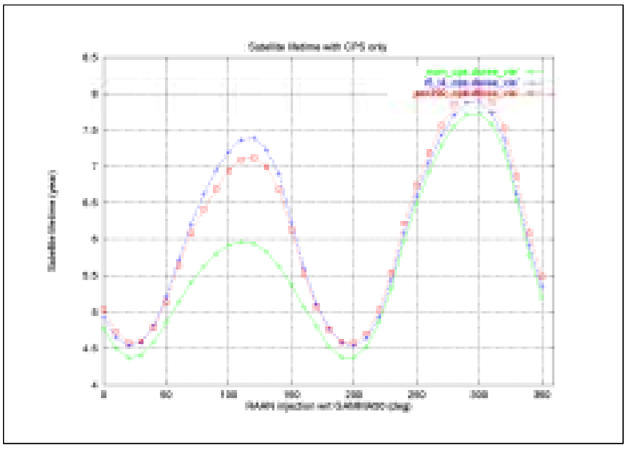

Fig. 4. Lifetime versus inertial RAAN at injection with different injection orbits

1.3 Optimisation in the case of fixed parameters at injection.

If the launcher offers no flexibility for the choice of the orbit at injection, the optimal inclination targets for the end of the transfer phase corresponds to very limited node line rotations (Fig. 5.).

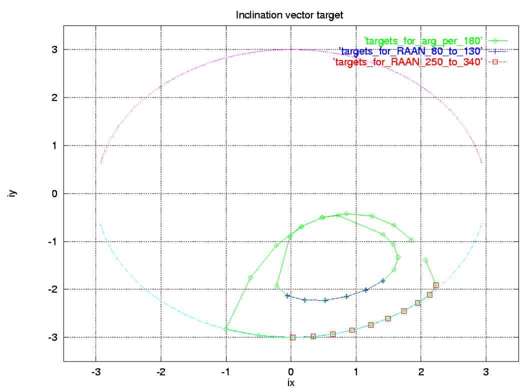

Fig. 5. Inclination targets at the end of the transfer phase

In that case the achievable lifetime can be very different depending on the launch date.

2. OPTIMISATION IN THE CASE OF AN INJECTION WITH A HIGH INCLINATION

2.1 Principles

In case of a high inclination at injection (more than 15 deg. for example), an optimization can be done with a slight modification of the argument of perigee. This is, in order to have the optimal right ascension of ascending node at the end of the orbital transfer. This is achieved thanks to a node line rotation during Liquid

Apogee Engine Firings (LAEF), without any significant propellant penalty.

For example with only five different values of the argument of perigee, the BOL inclination is always in the optimal area of the inclination plane thanks to a node line rotation obtained with a low propellant penalty (Fig. 6.).

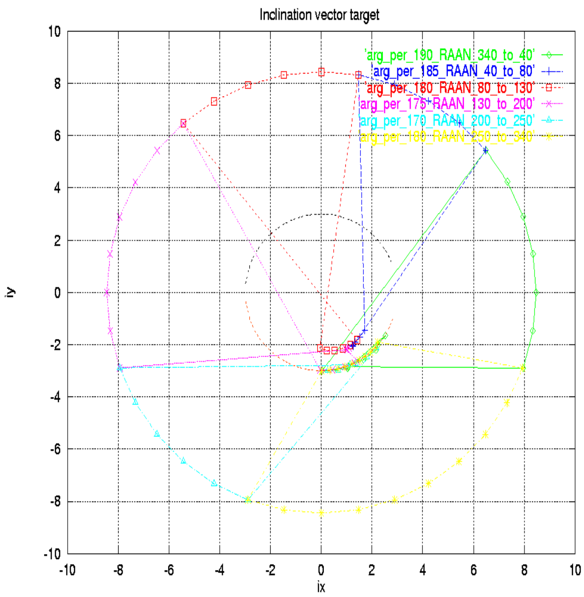

Fig. 6. Inclination targets at the end of the transfer phase with an optimised argument of perigee.

As an example, for unfavourable launch period, the gain is about 2 years of lifetime (Fig. 7.) thanks to an optimal choice of the argument of perigee at injection among only 5 values. The choice depends on the inertial RAAN at injection, that is to say on the launch date and time. The choice of the argument of perigee for each RAAN corresponds to the curve with the longest lifetime (Fig. 7.).

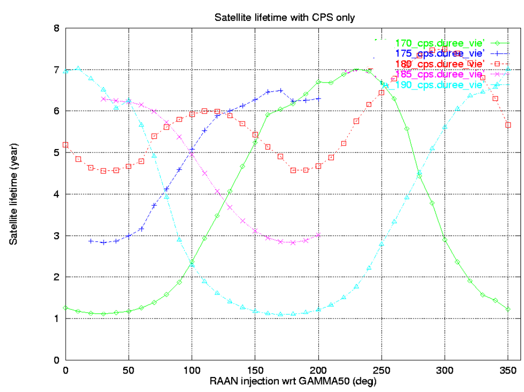

Fig. 7. Achievable lifetime for each argument of perigee versus the inertial RAAN at injection

2.2 Operational implementation

If the launcher offers flexibility the optimisation can be completed choosing the optimal argument of perigee for each launch date taking into account the fact that the injection RAAN also depends on the time of the launch in the day(Fig. 8.).

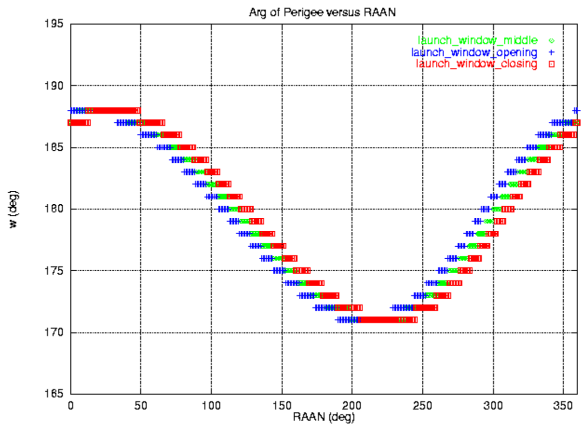

Fig. 8. Choice of the argument of perigee versus the inertial RAAN at injection

With such an optimisation, the initial domain for the inclination targets at the end of the transfer is really restricted to the area where the benefit of the free inclination drift during the operational mission is maximised (Fig. 9.).

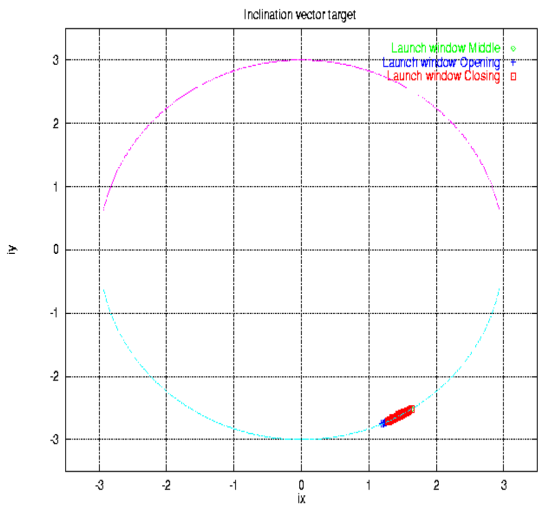

Fig. 9. Inclination targets at the end of the transfer phase with an optimised argument of perigee.

Thanks to the optimised argument of perigee, the required node line rotation is obtained with a very reduced propellant cost. For example in the presented case, there is a difference of only 40 m/s between the maximum and the minimum required delta velocity to realise the transfer with the Liquid Apogee Engine Firings (LAEF) (Fig. 10.).

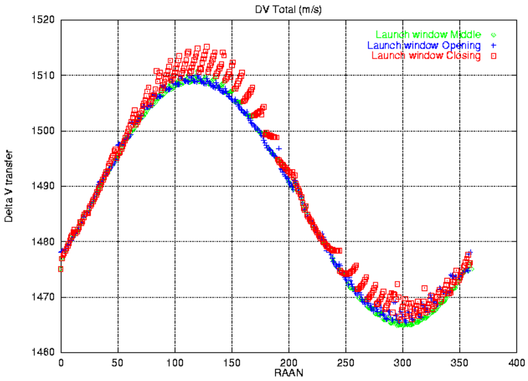

Fig. 10. Required delta velocity for the transfer phase.

As an example, this method with an optimized argument of perigee for each launch date allows to gain up to 2 years lifetime in the most unfavourable launch date. The lifetime with chemical propulsion subsystem is at least 7.5 years. The lifetime with the electrical propulsion subsystem is more than 19 years.

3. OPTIMISATION IN THE CASE OF AN INJECTION WITH A LOW INCLINATION

3.1 Description of the problem

Some launchers usually inject directly in the equatorial orbit plane, yielding low inclination at injection. In these cases, the spacecraft does not perform significant out of plane delta velocity during the Launch and Early Operation Phase (LEOP), so the node line rotation cannot be performed during the transfer phase by the LAEF.

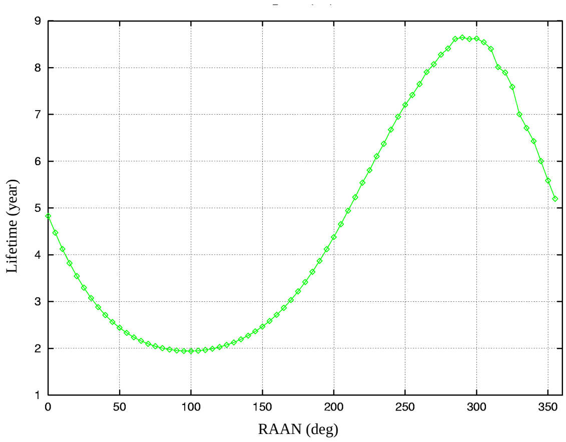

Fig. 11. Lifetime versus inertial RAAN in the case of a low inclination at injection.

For example, in the analysed case, with classical orbital parameters at injection, the lifetime will be between 2 and 8,5 years depending on the launch date (Fig. 11.).

3.2 Principles of the innovative approach

Since the launcher can inject the spacecraft directly into an orbit with the final required inclination, there is no need to have the line of apsides and the line of nodes parallel. The orbital transfer will consist in Apogee Engine Manoeuvres in the orbital plane, without out-of-plane components.

Thanks to this condition, the argument of perigee can be set up in order to have the optimal value for the inertial RAAN at injection. Indeed, the launch window computation determines the launch time in order to have the apogee of the injection orbit towards the Sun, and thus, if the argument of perigee is correctly chosen for each season, the inertial RAAN at injection can have always the same optimal value around 295 deg (Fig. 12.).

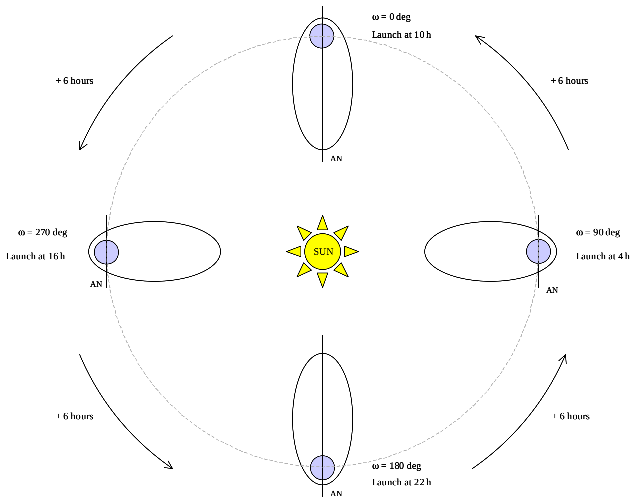

Fig. 12. Orbit orientation for each argument of perigee

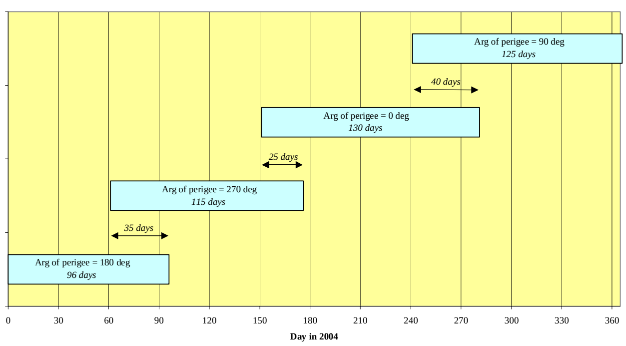

Fig. 13. Overlap of each injection orbit case

In order to manage the potential launch delays, a minimum overlapping period between the different injection cases can be useful (Fig. 13.).

The main drawback of such a strategy is the different longitude at injection for each injection case. So it is necessary to define a specific transfer strategy for each argument of perigee.

3.3 Impact on the launch window computation

Since a specific transfer strategy is computed for each argument of perigee, the launch window shall be computed for each of the injection orbits. The need to guarantee the Sun presence in the spacecraft Sun sensor field of view naturally set the launch time in order to have the apogee of the orbit approximately towards the Sun.

It has been shown that the longest lifetime is achieved with a selection of the optimal inertial RAAN at 295 deg. In this example, if the inertial RAAN is in the range [225 deg : 340 deg], more than 6 years lifetime duration can be achieved (Fig. 11.). Thus, a constraint on the date and launch time which induces an inertial RAAN at injection in this range [225 deg : 340 deg] is superimposed on the launch window computation.

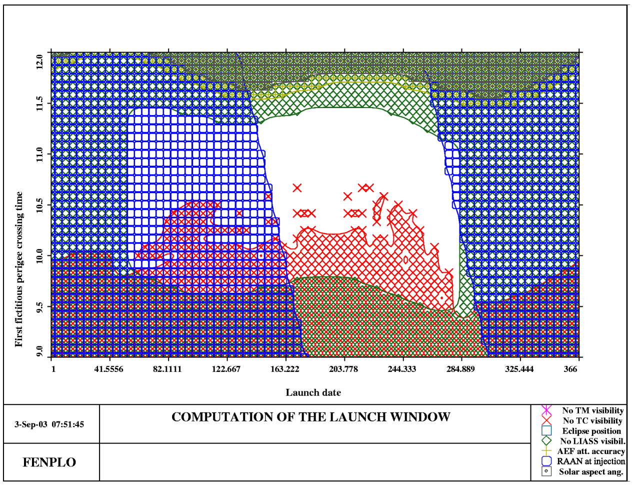

Fig. 14. Launch window for w=0 deg with the Sun sensors using the summer canting angle.

Thanks to the four possible values of the argument of perigee, four launch windows are computed. Then, considering the synthesis of these four launch windows, the launch remains possible over the whole year. The specific additional constraint on launch date and time induces an inertial RAAN at injection in the optimal range that ensures at least 6 years of orbital lifetime in the analysed case with a given propellant mass.

Fig. 14. and Fig. 15. shows the computed launch windows for two of the four cases : one is with the summer canting angle of the Sun sensors, whereas the other one is with the winter canting angle. It has to be noticed that the launch time is not the same : for an argument of perigee equal to 0 deg the first fictitious perigee crossing time is around 11h (Universal Time), whereas for an argument of perigee equal to 180 deg the first fictitious perigee crossing time is around 22h (Universal Time).

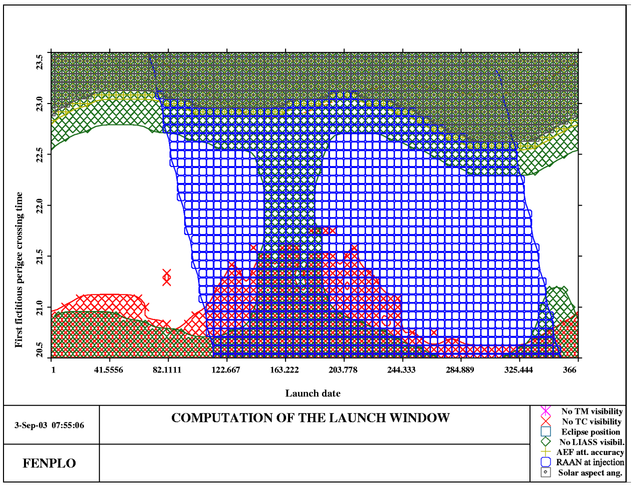

Fig. 15. Launch window for w=180 deg with the Sun sensors using the winter canting angle.

4. OPERATIONAL IMPLEMENTATION

In order to reduce the range of the inertial RAAN at injection and increase the achievable lifetime, it was decided for the operational implementation to compute a specific argument of perigee, valid over a typical 30 days period. A set of arguments of perigee was provided to the launch service to specify the parking orbit. This set covers all possible launch dates in the year. The angle between the line of apsides and the line of nodes can take any value in the [0; 360°] range.

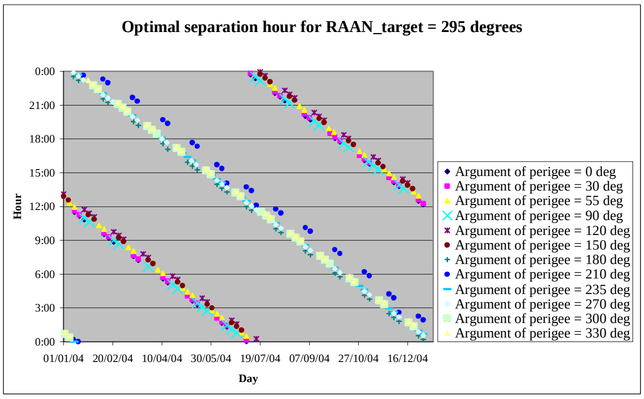

Fig. 16. Optimal separation time to have an inertial RAAN of 295 deg.

For each argument of perigee the longitude at injection is different, thus, twelve transfer strategies were designed and twelve launch windows were computed.

Fig. 16. shows for each of the twelve injection orbits the required separation date and time to have the optimal inertial RAAN at injection of 295 deg. Though there is a solution for each date and for each injection orbit, the final acceptable solution corresponds to the intersection with the other system constraints and most particularly the presence of the Sun in the Sun sensor field of view when it is required (apogee of the orbit towards the Sun direction).

This is clearly illustrated on Fig. 17. and Fig. 18. with the computed launch windows for two of the twelve cases : one is with the summer canting angle of the Sun sensors, whereas the other one is with the winter canting angle.

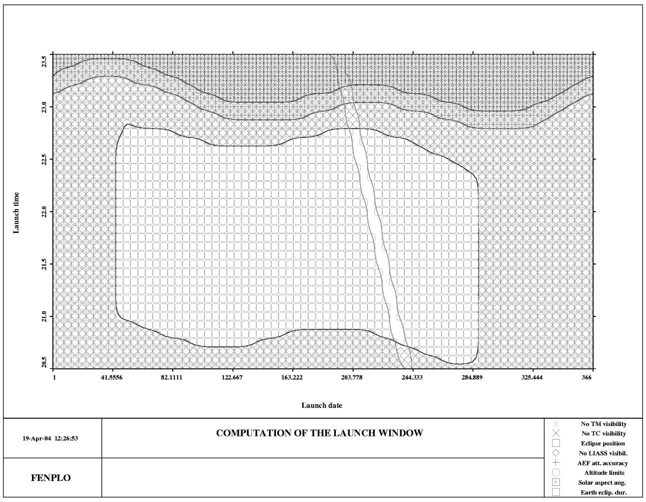

Fig. 17. Launch window for w=0 deg with the Sun sensors using the summer canting angle.

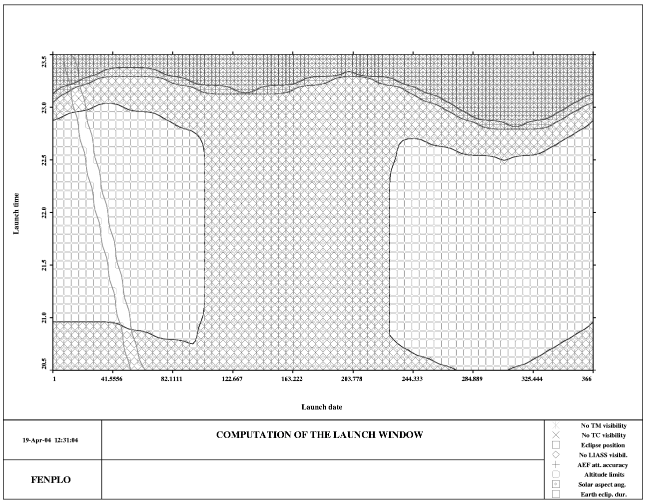

Fig. 18. Launch window for w=180 deg with the Sun sensors using the winter canting angle.

Finally the twelve injection orbits covers the whole year and the time at separation can take any value during the day but is completely defined for each argument of perigee and launch date. The synthesis of the computed launch windows for each injection orbit is illustrated on Fig. 19.

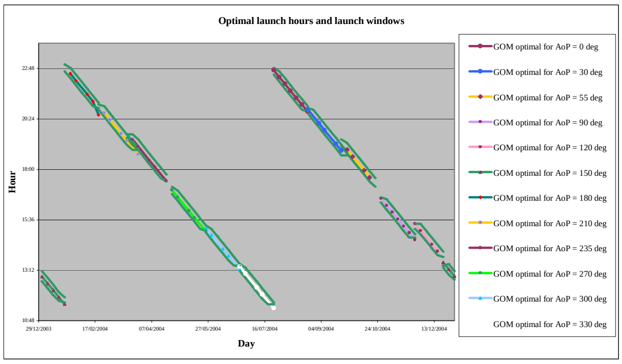

Fig. 19. Synthesis of the launch window for each injection orbit.

With a reduced 15 minutes launch window the inertial RAAN at injection is kept at +/- 2 deg from the optimal value for any launch date in the year.

For the analysed case of the example, the lifetime is about 8.6 years for any launch date in the year. The optimal inclination path followed by the inclination control is presented on Fig. 20.

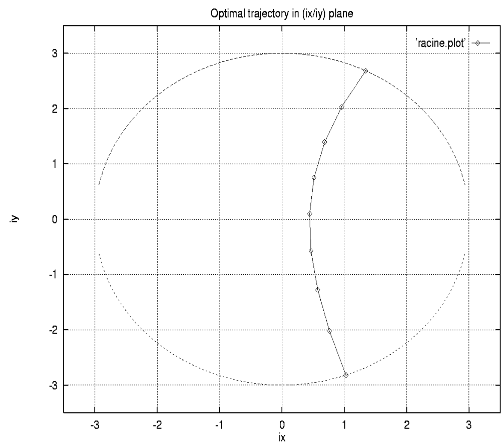

Fig. 20. Optimal inclination path ($RAAN_{inj}$ = 295 deg).

5. CONCLUSION

This strategy allows improving orbit lifetime of inclined GEO satellites significantly for previously unfavourable launch dates in case of injection with a low inclination.

This optimisation was proposed and is already selected for application for one EUROSTAR 3000 inclined orbit mission scheduled for launch in the coming year.