FAST LOW EARTH ORBIT ACQUISITION PLAN OPTIMISER

Sérgio Brás, Itziar Barat, and Berthyl Duesmann

15th March 2016, Dartmstaat, Germany

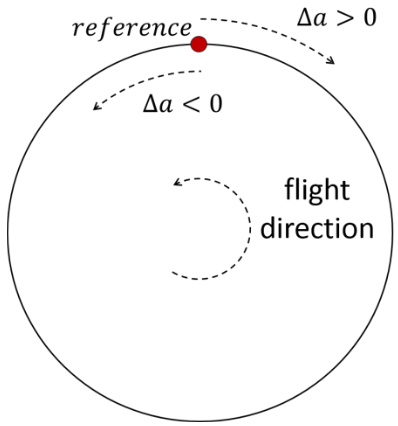
Outline

1. Perturbation Analysis of the Nominal Orbit
2. Algorithms
    a. Constant rate of change of semi-major axis
    b. Step-wise semi-major axis changes
3. Interface
    a. Single plan optimiser
    b. Paramatric analyser
4. Examples
5. Conclusions

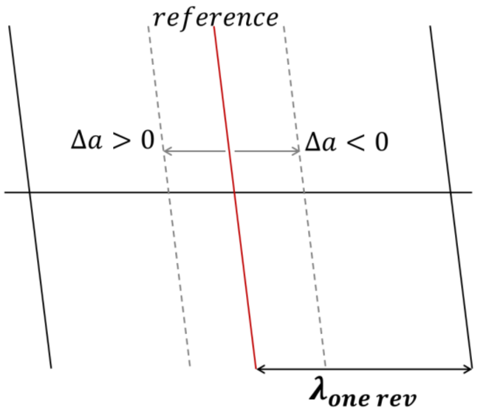
Perturbation Analysis of the Nominal Orbit

Resorting to a perturbation analysis of the nominal orbit a relation between the semi-major axis difference to the nominal (Δa) and the rate of the orbital drift is established . For sake of simplicity the inclination is assume to be nominal.

$$\Delta\lambda_{\Delta i=0}(t) = \frac{k_a}{P_\Omega}\int_{t_0}^{t} \Delta a(\tau)d\tau$$



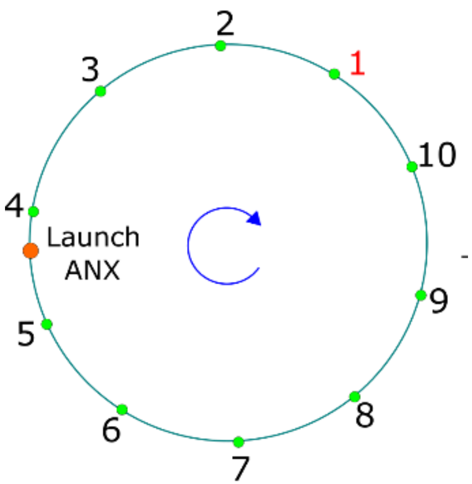
Orbital plane representation



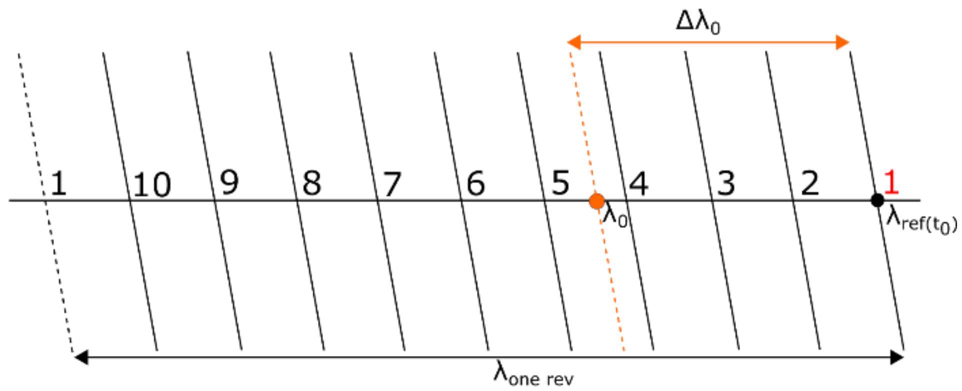
Ground-track representation

Algorithms

The initial drift ($\Delta\lambda_0$) is obtained from the difference between the equatorial distance between the ascending node of the of injection orbit and the ascending node of the reference orbit after launch.



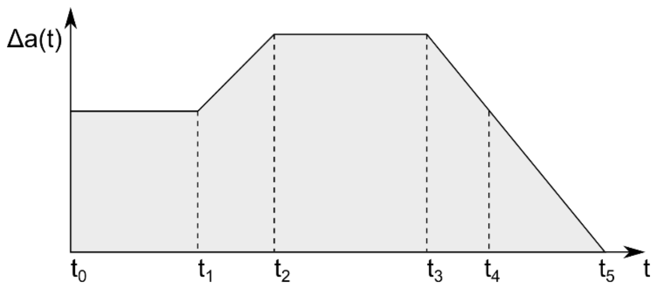
orbital plane



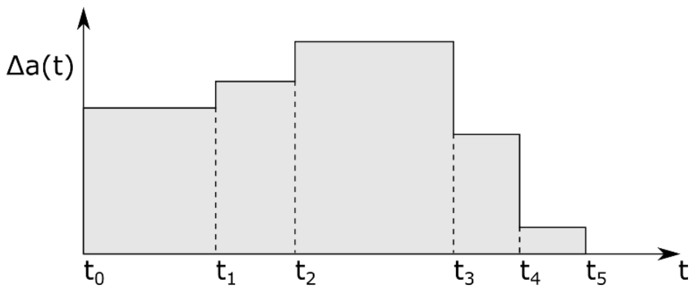
ground track

Algorithms

Two strategies are proposed to compute orbit acquisition plans.



Constant rate of change of semi-major axis

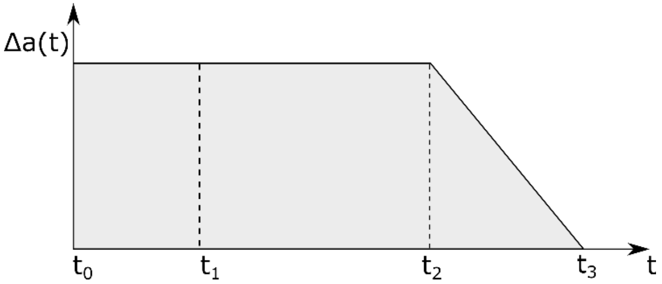


Step-wise semi-major axis changes

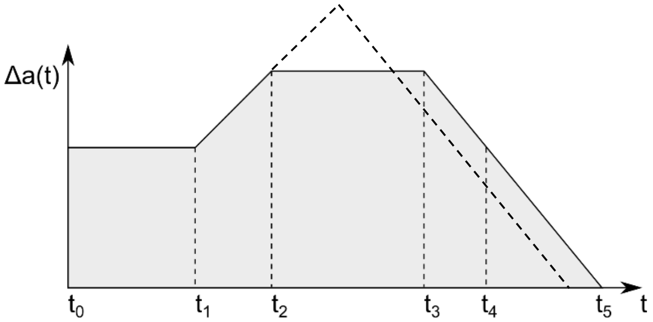
Algorithms that minimise either the <u>duration of the orbit acquisition</u> or the <u>Delta-V consumption</u> are developed using both strategies.

Algorithms - Constant rate of change of semi-major axis

1. Minimisation of the Delta-V consumtion

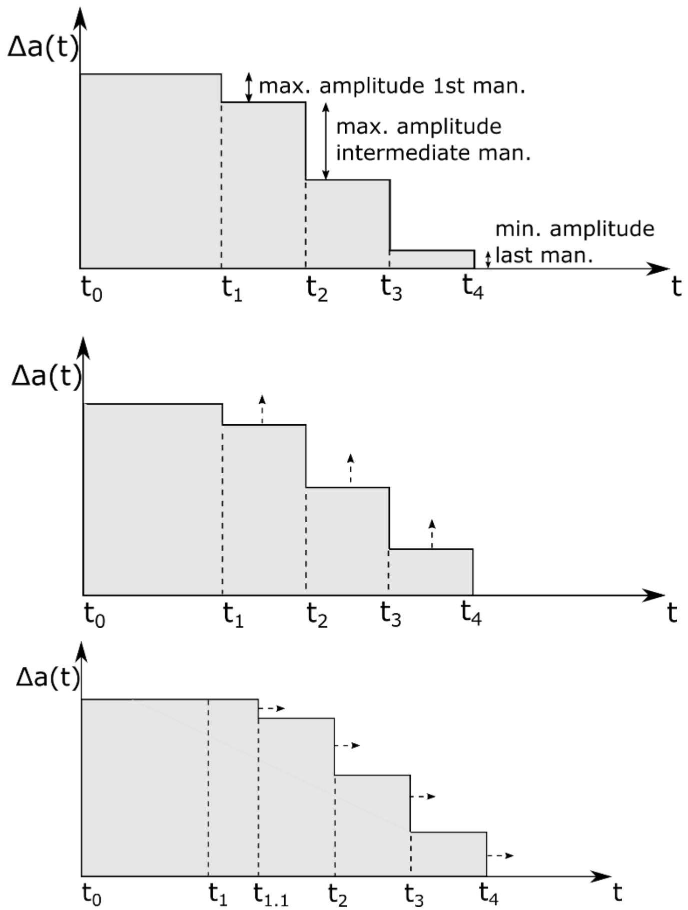


2. Minimisation of the orbit acquisition duration



Algorithms – Step-wise semi-major axis changes

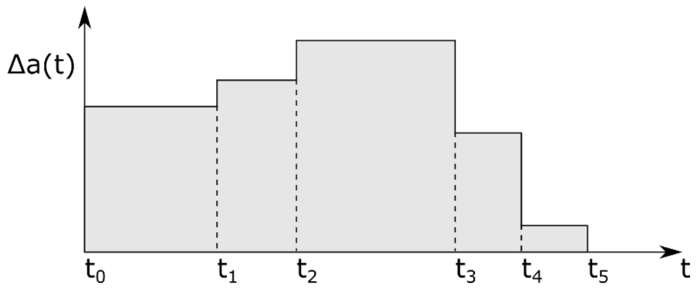
Minimisation of the Delta-V consumtion



1. Computation of the minimum absolute drift. The target node is the next node in the drift direction.
2. To reach the target node, firstly the sizing amplitude of the manoeuvres is adjusted while satisfying the manoeuvre constrains.
3. If necessary, duration of the drift in the injection semi-major axis is increased until the target node is achieved.

Algorithms – Step-wise semi-major axis changes

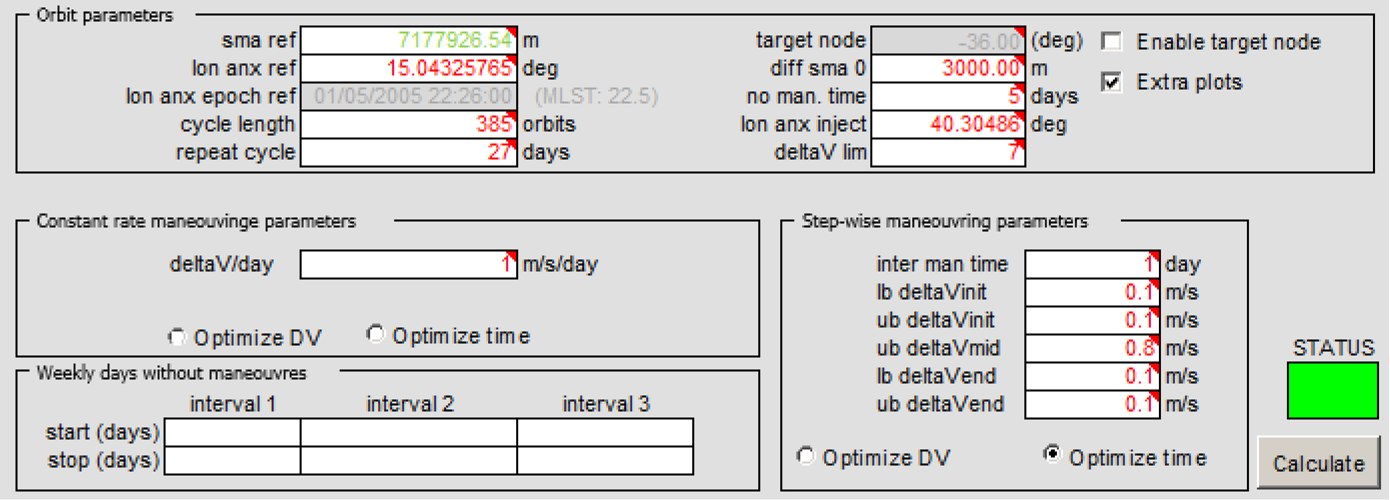
Minimisation of the orbit acquisition duration



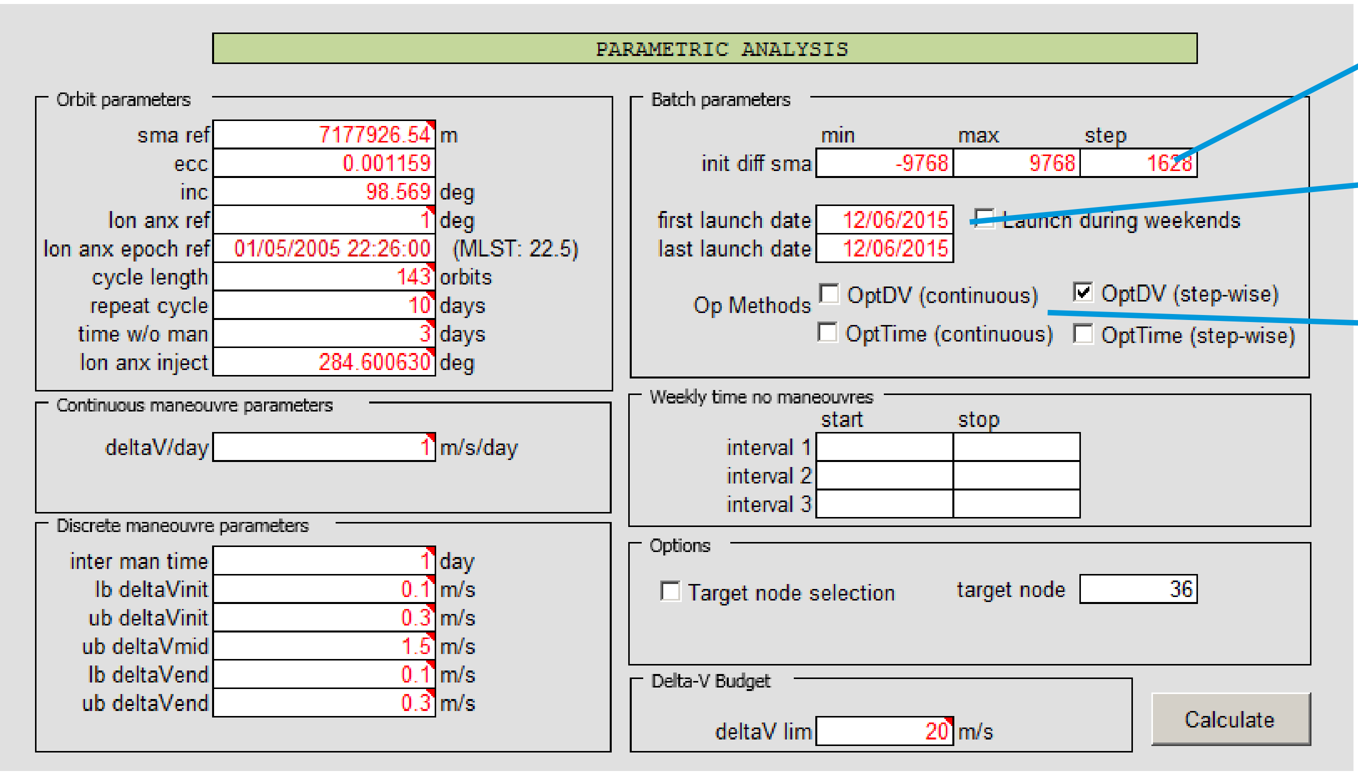
1. The adopted strategy is similar to the one used in the minimisation of the Delta-V consumption.

2. However, the target node and the number of manoeuvres are not known à priori and a derivative-free minimum search method needs to be used to determine them.

Interface (1) - Single plan optimiser



Interface (2) – Paramatric analyser



Test several SMA dispersions

Test several launch dates

Test the different algorithms

Examples (1)

Scenario:

Sun-synchronous orbit

Repeat cycle: 27 days, Cycle length: 385 orbits

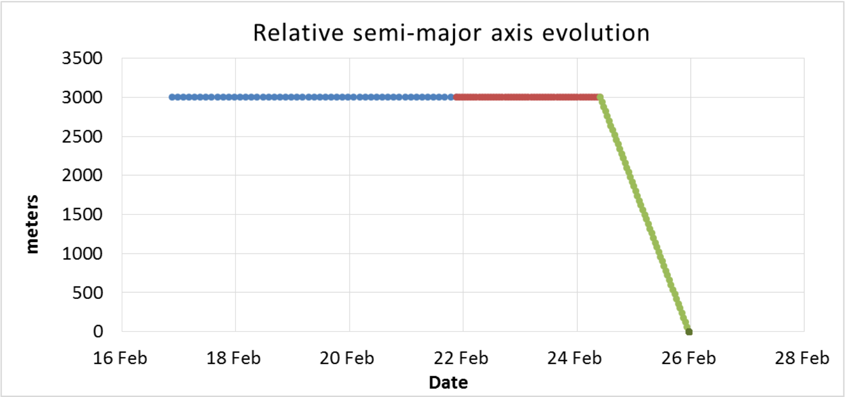
Thj: 3000 m higher

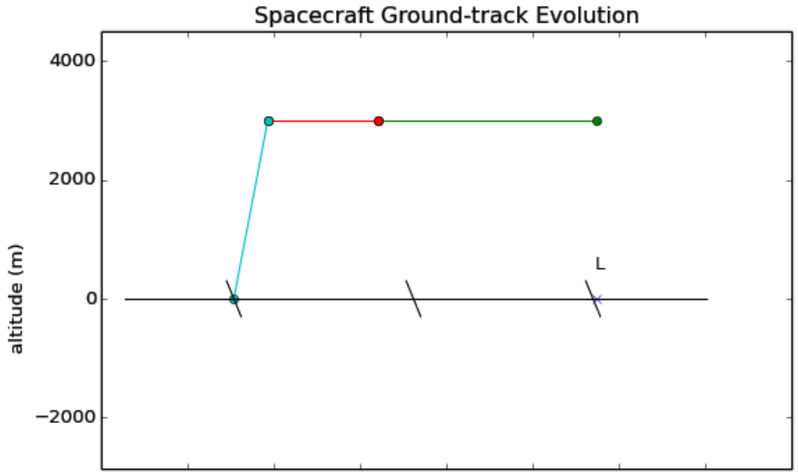
Initial delta inclination: nominal

Manoeuvres possible after L+7 days

Delta ground track: 209834.76 m

Delta-V manoeuvrability : 1 m/s per day





Optimization using constant rate manoeuvres minimising Delta-V consumption:

- Duration: 9.09 days, Delta-V: 1.56 m/s

Examples (2)

Scenario:

Sun-synchronous orbit

Repeat cycle: 27 days, Cycle length: 385 orbits

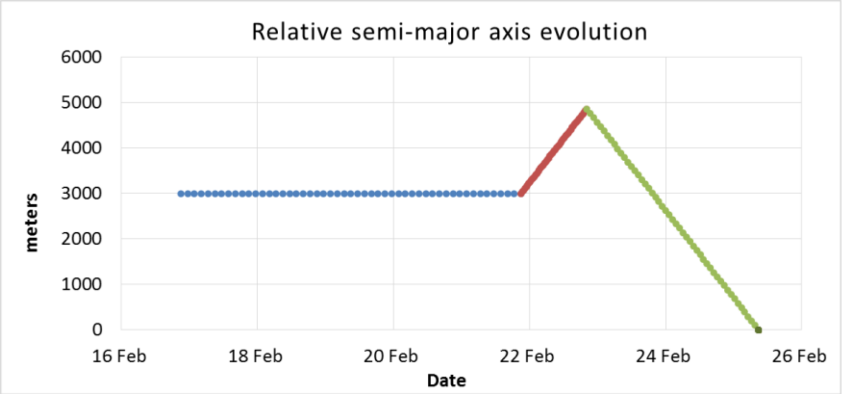
Initial delta semi-major axis: 3000 m higher

Initial delta inclination: nominal

Manoeuvres possible after L+7 days

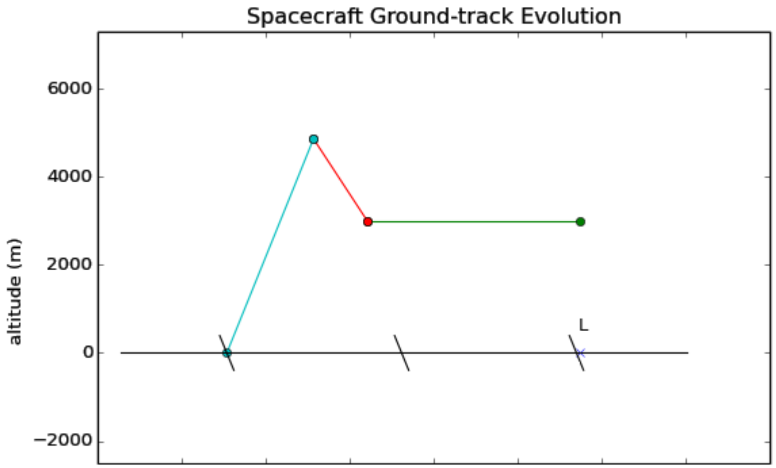
Delta ground track: 209834.76 m

Delta-V manoeuvrability : 1 m/s per day



Optimization using constant rate manoeuvres minimising time

- Duration: 8.49 days, Delta-V: 3.49 m/s



Examples (3)

Scenario:

Sun-synchronous orbit

Repeat cycle: 27 days, Cycle length: 385 orbits

Initial delta semi-major axis: 3000 m higher

Initial delta inclination: nominal

Manoeuvres possible after L+7 days

Delta ground track: 209834.76 m

At least 1 day between manoeuvres

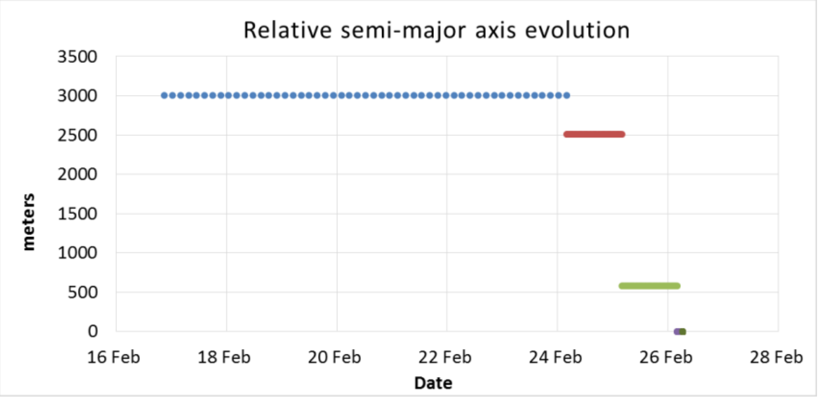
Max. Delta-V 1st and last man.: 0.3 m/s

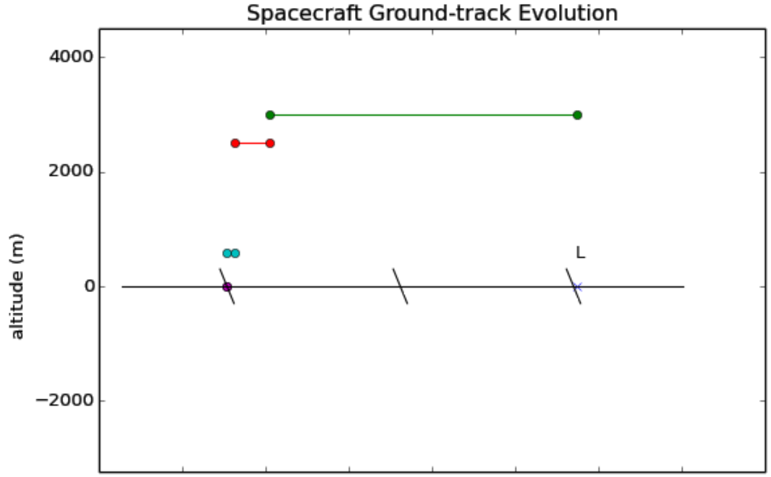
Min. Delta-V 1st and last man.: 0.1 m/s

Max. Delta-V intermediate man.: 1 m/s

Optimization using step-wise manoeuvres minimising Delta-V consumption:

- Duration: 9.38 days, Delta-V: 1.56 m/s





Examples (4)

Scenario:

Sun-synchronous orbit

Repeat cycle: 27 days, Cycle length: 385 orbits

Initial delta semi-major axis: 3000 m higher

Initial delta inclination: nominal

Manoeuvres possible after L+7 days

Delta ground track: 209834.76 m

At least 1 day between manoeuvres

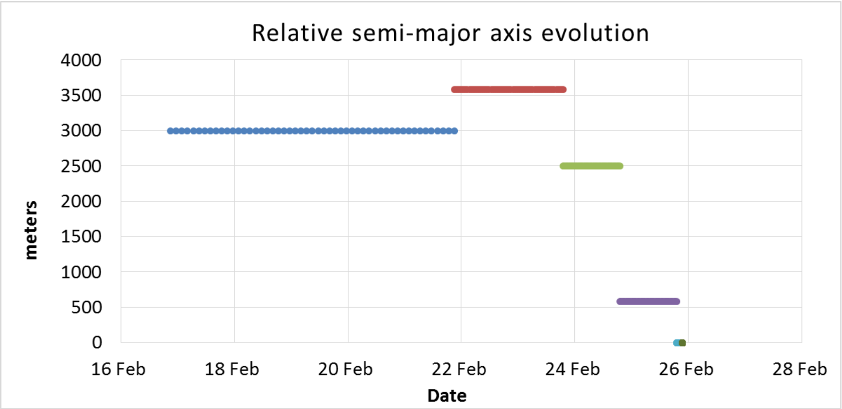
Max. Delta-V 1st and last man.: 0.3 m/s

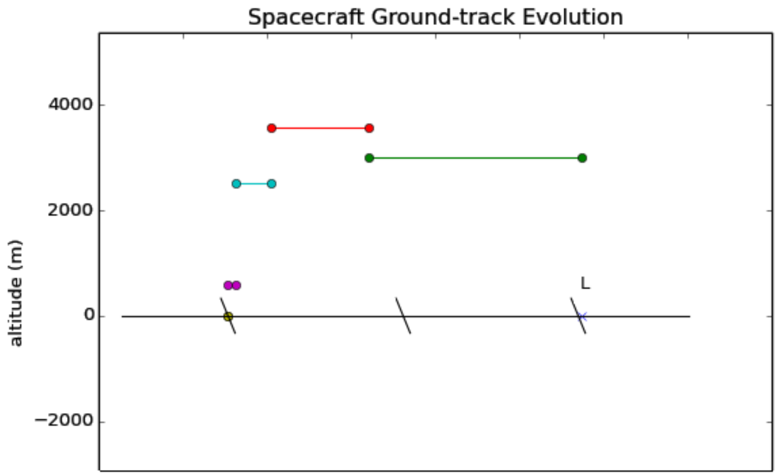
Min. Delta-V 1st and last man.: 0.1 m/s

Max. Delta-V intermediate man.: 1 m/s

Optimisation using step-wise manoeuvres minimising time

- Duration: 9.02 days, Delta-V: 2.16 m/s





Examples (5)

Scenario:

Sun-synchronous orbit, MLST: 10h00

Repeat cycle: 10 days, Cycle length: 143 orbits

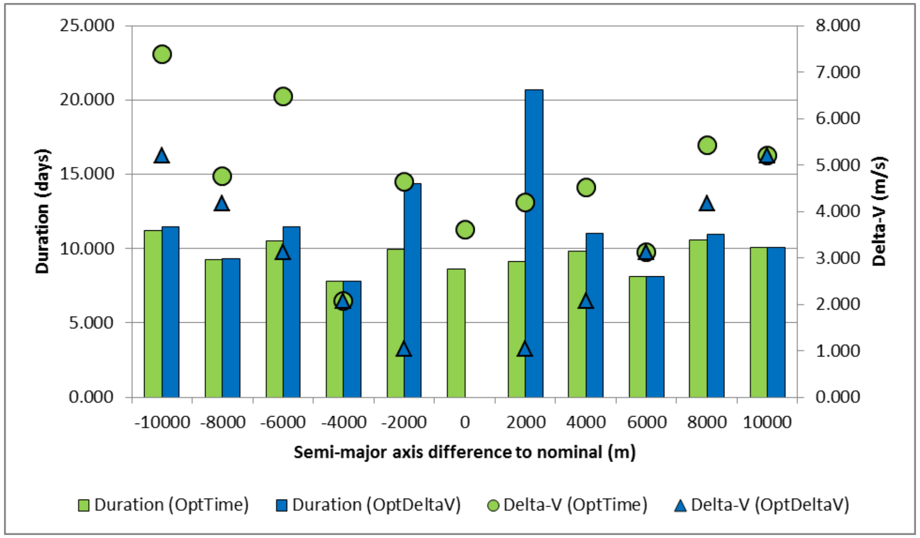
Initial delta inclination: nominal

Manoeuvres possible after L+5 days

Max. Delta-V 1st and last man.: 0.3 m/s

Min. Delta-V 1st and last man.: 0.1 m/s

Max. Delta-V intermediate man.: 1.5 m/s



Orbit acquisition duration and Delta-V required for various semi-major axis differences to the nominal.

For some initial semi-major axis, the consumption of more propellant does not lead to significantly shorter acquisition times as in the cases of Δsma=−10000 m, Δsma=−6000 m, Δsma=−4000 m, and Δsma=8000 m. Moreover, for the analysed cases, it is possible to acquire the desired ground track in less than 11.5 days by using a maximum of 5.2 m/s Delta-V. For Δsma=2000 m, the possibility to increase the drift rate by an earlier manoeuvre allows a much shorter acquisition time than if only natural drift is used.

Examples (7)

Scenario:

Sun-synchronous orbit, MLST: 10h00

Repeat cycle: 10 days, Cycle length: 143 orbits

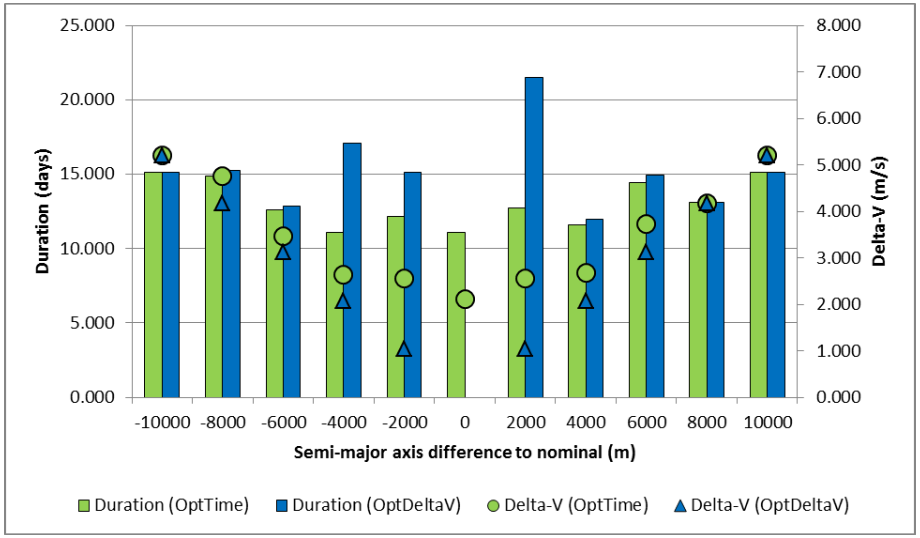
Initial delta inclination: nominal

Manoeuvres possible after L+5 days

Max. Delta-V 1st and last man.: 0.3 m/s

Min. Delta-V 1st and last man.: 0.1 m/s

Max. Delta-V intermediate man.: 1.5 m/s



Orbit acquisition duration and Delta-V required for various semi-major axis differences to the nominal in case the <u>time between manoeuvres is **two** days instead of one.</u>

If the orbit determination and planning times take two days instead of one, the acquisition time is higher. In this case, the minimum acquisition time is around 11 days and can be up to 15 days for larger injection errors. Interesting enough, in this case, the minimisation of the duration of the orbit acquisition phase leads to smaller Delta-V consumption than in the previous case.

Conclusions

1. Four different algorithms were developed and implemented on a tool for rapid orbit acquisition plan analysis and design.

2. These algorithms exploit two different strategies:
   a. Constant rate semi-major axis changes
   b. Step-wise semi-major axis changes

3. The tool computes acquisition plans minimising the orbit acquisition duration or the associated Delta-V consumption

4. Some examples illustrate some of the potential uses of the tool.

5. Each plan is computed in an few seconds.