Coupled optimization of launcher and all-electric satellite trajectories

M. Verlet [(1)], **B. Slama**[(1)], **S. Reynaud** [(1)], **M. Cerf** [(1)]
[(1)] *EADS Astrium Space Transportation, 66 Route de Verneuil, 78133 Les Mureaux, France*
[(1)] *Mathieu.verlet@astrium.eads.net*

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ABSTRACT

Maturity and performance of electric thruster technology have recently increased. Moreover, electric thrusters have already been used for missions involving interplanetary transfer, as well as for orbit insertion manoeuvers of satellites in geocentric trajectories, proving their reliability and effectiveness for high total impulse missions. This technology, currently used for Station Keeping purposes, is already foreseen for raising the orbit of a few GEO satellites. Indeed, the advantage of this technology in terms of mass savings for orbit-raising with regards to chemical propulsion is deemed to outweigh the loss due to a longer orbit-raising duration. As a result, satellite operators are now considering longer orbit-raising durations before having access to their payload and the use of Electric Propulsion (EP) as the main satellite propulsion system will probably become a reality for a larger number of satellites in the near future.

Electric propulsion could imply an injection strategy for GEO satellites different than the classic GTO strategy used for chemical satellites. This new injection strategy may have an impact on the launcher design and qualification domain. In this context, as prime of the ARIANE launchers family, Astrium Space Transportation (ST) has developed its own electric orbit-raising (EOR) optimizer and a global launcher and satellite trajectories optimization process in order to study the impact of all-electric satellites on its launcher family to ensure it remains competitive for the electric satellites market.

The problem of obtaining optimal orbit transfers using low-thrust propulsion has been investigated in great detail by Astrium ST. Two main strategies using the computation of minimum-fuel or minimum-time EOR problem were studied for different thrust-to-weight ratios and transfer durations. In order to optimize low-thrust trajectories, indirect and direct optimization methods are possible. Direct methods solve the optimal control problem by adjusting the control variables at each iteration while indirect methods use the principle of the minimum of Pontryaguin (PMP) which results from the calculus of variations. Even if the indirect method is harder to solve, it has the great advantage of giving the optimal trajectory. In order to solve the optimal low-thrust trajectory problem, Astrium ST opted for both approaches. This solver has been especially developed to solve the transfer between every foreseen injection orbit for an ARIANE launcher and a GEO one. The objective of having a final product usable by a non-expert on the subject was achieved with acceptable computation.

However, it was not possible to optimize the coupled launcher-satellite trajectory since the transfer optimization duration is too important. Therefore, very complete EOR tables were built with the optimal control optimizer either for minimum duration or for minimum consumption for several transfer durations and for several satellite configurations. These tables have been

included in the launcher optimizer process. The global trajectory optimizer performs a classic launcher trajectory optimization and selects the optimal satellite trajectory in the given table. It allows a faster convergence of the optimization process and gives results with a very good accuracy. The tool was successfully used to define the optimal injection orbit of all launchers of the ARIANE family for several GEO electric satellites.

This paper intends to present a global description of the two processes of optimization developed by Astrium ST. An example of the coupled optimization applied on the ARIANE5-ES launcher will be presented along with the main hypotheses, satellite assumptions and transfer duration constraints.