Advanced Electric Orbit-Raising Optimization for Operational Purpose

Sven Schäff[(1)], **Andreas Wiegand**[(2)]
[(1)]*Astos Solutions GmbH, Meitnerstrasse 8, 70563 Stuttgart, Germany, +4971189263315, sven.schaeff@astos.de*
[(2)]*Astos Solutions GmbH, Grund 1, 78089 Unterkirnach, Germany, +49772150142, andreas.wiegand@astos.de*

Abstract: *Telecommunication satellites located in the Geostationary Equatorial Orbit (GEO) are typically not directly placed there by the launch vehicle. The satellites are often injected in a Geostationary Transfer Orbit (GTO) and then transferred to the GEO using their own onboard propulsion system. State of the art for the GTO to GEO transfer is still the chemical propulsion.*

Just recently few satellites transferred or are transferring to GEO using Electric Propulsion (EP), since it is very attractive to exploit their high specific impulse reducing the propellant mass of the orbit transfer. Since the total spacecraft mass is reduced this yields launch vehicle cost reductions. Further, Electric Orbit-Raising (EOR) is now available for most telecommunication satellite platforms or at least under development.

But electric orbit-raising requires much more complex maneuver sequences than what is needed for pure chemical transfers. Since EP provides only small thrust magnitudes in comparison to chemical propulsion, the transfer lasts many months. A careful planning of the spacecraft attitude maneuvers is required in advance to fulfill this mission. In recent years, many software tools have been developed for the preliminary assessment of low-thrust orbit transfers. Unfortunately, most tools lack both maturity and accuracy necessary to fully exploit the capabilities of electric orbit-raising. For example, during the transfer any crossing of the GEO ring poses a certain collision risk with high value assets. Thus, the precomputed transfer trajectory has to avoid crossings of the GEO belt. Further, ground station visibility might be considered for transfer planning as well as limitations and constraints related to different spacecraft subsystems, such as eclipse handling, power generation, storage and consumption, or EP firing limitations in general. Other possible limitations are related to the attitude of the spacecraft or consider environmental aspects like the radiation dose.

Up to now, a closed loop GNC (Guidance, Navigation and Control) algorithm is used to simulate most of the abovementioned aspects. Typically, a reference trajectory does only include basic aspects like perturbations, but not more complex issues like restricted slew rates or limitations in thruster firings. They are only included in the GNC loop to simulate the real spacecraft behavior. As a result, the flown trajectory is different from the optimized reference trajectory. Any deviation from the reference trajectory must be considered and therefore a cyclic update of the maneuver plan by re-optimization is mandatory. Possible strategies for an operational concept where the spacecraft state is updated by orbit determination to re-optimize the maneuver plan will be summarized.

But an optimized orbit transfer as reference trajectory under consideration of the aforementioned model and mission issues would be a benefit for the spacecraft operations since the processing is simplified. Further, it is an important step towards full spacecraft autonomy. For example, such a reference trajectory and its maneuver plan could directly be used for the operations. This paper will show the capabilities of very sophisticated low-thrust orbit transfers with increased optimality to reduce the need of GNC simulations. Using Non-Linear Programming (NLP) to optimize the attitude profile in combination with detailed modelling of *complex mission constraints and limitations of the spacecraft model is essential, especially under consideration of tight accuracy and fidelity requirements for achieving optimality in sense of propellant consumption and transfer duration. One example of a GTO to GEO low-thrust transfer will be detailed to demonstrate the benefits of the introduced methodology.*

Keywords: *Electric Orbit-Raising, Re-Optimization of Orbit Transfers, Operational Chain, Slew Rate Optimization, Non-Linear Programming.*