COMPREHENSIVE APPROACH TO ELECTRIC PROPULSION FOR INNOVATIVE SPACE PLATFORMS

Christopher Andrea Paissoni

Summary

This dissertation investigates the new mission opportunities and methods enabled by innovative propulsion space systems based on electric propulsion devices. In recent years, the international community has advanced new technological development roadmaps targeting expanding the utilisation activities in space toward future challenges. Among the identified roadmap building blocks, the electric propulsion field has been recognised as one of the most impacting sectors where several innovations could represent true cornerstones. In particular, the consolidation of the adoption of Hall Thruster devices has nowadays enabled the possibility of adopting innovative architecture alternatives to extend the benefits of these technologies further. Embracing these benefits and considering the new space market needs, space system concepts already presented in the past can be renewed for a feasibility assessment.

This is the case of the space tug proposed to provide On-Orbit Servicing for the Geostationary market. This reusable system should transfer telecommunication satellites from their deployment orbit up to their final GEO positions. In addition, it can be exploited for relocated the telecom satellites to a new GEO position to capitalise on free-market shares. To obtain the preliminary design at the component level of the space tug, including the capability of analysing the alternative propulsion subsystem architectures, a multi-input/output software tool has been developed. This user-friendly virtual environment allows the derivation of the main mission and system budgets sizing of the space tug subsystems pat the component level in an iterative process with a trajectory propagator necessary to simulate the predefined mission profile.

Then, the optimal space tug configurations are evaluated by mean of a trade-off analysis among the considered alternative design solutions considering figures of merit which guarantees the pros and cons of the alternative propulsion subsystem architecture impacts.

The capabilities developed tool has been further extended by introducing both analysis and design blocks necessary for the feasibility assessment of a Very Low Earth Orbit mission. In particular, the strong interaction of the spacecraft surrounding environment characterised by the high level of drag generated by the exposed surfaces forces to introduce unconventional design methods to embrace all possible cross effects that impact the design and operation of the spacecraft itself. In this analysis, this problem was challenged through the introduction of an MDO process for the definition of a Pareto front of optimal solutions. According to the selection criteria defined by the user as a result of a stakeholder needs evaluation, the optimal solution is selected and further analysed in terms of operative altitude ranges, alternative solar array configuration, and trajectory evolution with a preestablish in-orbit demonstration scenario.

As a part of the evaluation of the innovative spacecraft architectures introduced in this work, a fundamental aspect has been identified in the reliability of the architectures usually included in the trade-off process. The evaluation of this system feature is often a critical process due to the intrinsic complexities of the system and the lack of knowledge of the different mode of failures.

Therefore, in the current technology taxonomy, the development of methodologies aimed to evaluate the health status of the involved component is clearly highlighted to extend the understanding of modes of failure and improve the information necessary for the evaluation of the component reliability.

This key aspect has been investigated in the dissertation to develop an Engine Health Monitoring (EHM) method for Hall thruster-based system exploiting the Gas Path Approach (GPA), which is a health monitoring methodology already largely used in the aeronautic field.

The GPA consists of the identification of the deviations of a set of unmeasured parameters, representing the health status of the components from their nominal values. This is accomplished by investigating the variations of a set of measured parameters set from their nominal values correlated to the set of unmeasured parameters through a coefficient matrix called Influence Coefficient Matrix (ICM).

The followed approach was divided into two steps. First, a phenomenological model of the Hall thruster has been introduced and exploited to derive the theoretical ICM coefficients between the two parameters sets. Second, relying on experimental data, the ICM has been derived through a numerical method, and its coefficients have been consequently compared with those related to the theoretical matrix. Finally, to demonstrate the effectiveness in the failure detection capability of this method, a set of experimental data collected during a test campaign on SITAEL's HT20k DM, where a failure on the feeding system of the thruster occurred, were exploited.