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SYSTEM-OF-SYSTEMS TOOLS FOR THE ANALYSIS OF TECHNOLOGICAL CHOICES IN SPACE PROPULSION

Abstract

Space mission architecture design spaces are large, complex, and involve a large number of variables and metrics of interest. These features make space mission design a challenging task for decision makers. Difficulties arise from many factors: performance, cost, and risk constraints become less obvious due to complex interactions between the systems involved in the mission; decisions regarding long-term goals can heavily impact technological choices for short-term parts of the mission, while conversely decisions in the near future will impact the whole flexibility of long-term plans. Furthermore, the competition of individual space agencies that characterized the first years of the space era and that was later gradually replaced by collaborative effort, has in the last few years being substituted by another approach, where the space community is broadening its borders, and space agencies from different countries are collaborating with industry and commercial partners towards large-scale endeavors. This paradigm shift is prompting the development of non-traditional approaches to the design of space missions. These approaches should build upon the expertise acquired during the decades of space endeavors and add a perspective that accounts for the novel characteristics of future space missions. This paper reports the results of the first year of a continuing collaboration of the authors with subject matter experts from NASA, to develop and demonstrate System-of-System engineering methodologies for the analysis of space mission design. The System-of-Systems perspective complements the traditional analysis of systems engineering with a comprehensive viewpoint that addresses issues of risk and performance at the level of the whole space mission, based on the analysis of the constituent systems and the impact of their interactions. We present the procedure that we followed to develop and apply our methodology, obstacles found, steps taken to improve the methods based on the needs of experts and decision makers, required data for the analysis, and results produced by our holistic analysis. In particular, we focus on the analysis of technological choices for space propulsion (chemical, nuclear thermal, solar electric), which is a prime example of the new type of challenges faced by mission designers, including both complex interactions between subsystems in different

type of propulsion, and availability of different providers. Our methods were used for identification of critical systems and sets of systems based on cascading effects of performance degradation, assessment of the robustness of different designs in the operational domain, and simultaneous analysis of schedule dependencies between the constituent systems.