Enabling Parametric Optimal Ascent Trajectory Modeling During Early Phases of Design

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During the early phases of engineering design, the costs committed are high, costs incurred are low, and the design freedom is high. It is well documented that decisions made in these early design phases drive the entire design's life cycle. In a traditional paradigm, key design decisions are made when little is known about the design. As the design matures, design changes become more difficult -- in both cost and schedule -- to enact. Indeed, the current capability-based paradigm that has emerged because of the constrained economic environment calls for the infusion of knowledge acquired during later design phases into earlier design phases, i.e. bring knowledge acquired during preliminary and detailed design into pre-conceptual and conceptual design. An area of critical importance to launch vehicle design is the optimization of its ascent trajectory, as the optimal trajectory will be able to take full advantage of the launch vehicle's capability to deliver a maximum amount of payload into orbit. Hence, the optimal ascent trajectory plays an important role in the vehicle's affordability posture as the need for more economically viable access to space solutions are needed in today's constrained economic environment.

The problem of ascent trajectory optimization is not a new one. There are several programs that are widely used in industry that allows trajectory analysts to, based on detailed vehicle and insertion orbit parameters, determine the optimal ascent trajectory. Yet, little information is known about the launch vehicle early in the design phase – information that is required of many different disciplines in order to successfully optimize the ascent trajectory. Thus, the current paradigm of optimizing ascent trajectories involves generating point solutions for every change in a vehicle's design parameters. This is often a very tedious, manual, and time-consuming task for the analysts. Moreover, the trajectory design space is highly non-linear and multi-modal due to the interaction of various constraints. Additionally, when these obstacles are coupled with *The Program to Optimize Simulated Trajectories* [1] (POST), an industry standard program to optimize ascent trajectories that is difficult to use, it requires expert trajectory analysts to effectively optimize a vehicle's ascent trajectory.

As it has been pointed out, the paradigm of trajectory optimization is still a very manual one because using modern computational resources on POST is still a challenging problem. The nuances and difficulties involved in correctly utilizing, and therefore automating, the program presents a large problem. In order to address these issues, the authors will discuss a methodology that has been developed. The methodology is two-fold: first, a set of heuristics will be introduced and discussed that were captured while working with expert analysts to replicate the current state-of-the-art; secondly,

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leveraging the power of modern computing to evaluate multiple trajectories simultaneously, and therefore, enable the exploration of the trajectory's design space early during the pre-conceptual and conceptual phases of design. When this methodology is coupled with design of experiments in order to train surrogate models, the authors were able to visualize the trajectory design space, enabling parametric optimal ascent trajectory information to be introduced with other pre-conceptual and conceptual design tools. The potential impact of this methodology's success would be a fully automated POST evaluation suite for the purpose of conceptual and preliminary design trade studies. This will enable engineers to characterize the ascent trajectory's sensitivity to design changes in an arbitrary number of dimensions and for finding settings for trajectory specific variables, which result in optimal performance for a "dialed-in" launch vehicle design.

The effort described in this paper was developed for the Advanced Concepts Office [2] at NASA Marshall Space Flight Center.

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[1] Brauer, G.L., Cornick, D.E., Habeger, A.R., Peterson, F.M., Stevenson, R., "Program to Optimize Simulated Trajectories (POST). Volume 1: Formulation Manual," NASA-CR-132689, 01 April 1975.

[2] Waters, E.D., Garcia, J., Beers, B., Phillips, A., Holt, J.B., Threet, G.E. Jr., "NASA Advanced Concepts Earth-to-Orbit Team Design Process and Tools," AIAA SPACE 2013 Conference and Exposition.10-12 Sept. 2013; San Diego, CA; United States