

Improvement of Automated POST Case Success Rate using Support Vector Machines

Mathew R. Zwack¹ and Patrick D. Dees²

Jacobs ESSSA Group, Huntsville, AL 35806, United States

During early conceptual design of complex systems, concept down selection can have a large impact upon program life-cycle cost. Therefore, any concepts selected during early design will inherently commit program costs and affect the overall probability of program success. For this reason it is important to consider as large a design space as possible in order to better inform the down selection process.

For conceptual design of launch vehicles, trajectory analysis and optimization often presents the largest obstacle to evaluating large trade spaces. This is due to the sensitivity of the trajectory discipline to changes in all other aspects of the vehicle design. Small deltas in the performance of other subsystems can result in relatively large fluctuations in the ascent trajectory because the solution space is non-linear and multi-modal [1].

In order to help capture large design spaces for new launch vehicles, the authors have performed previous work seeking to automate the execution of the industry standard tool, Program to Optimize Simulated Trajectories (POST). This work initially focused on implementation of analyst heuristics to enable closure of cases in an automated fashion, with the goal of applying the concepts of design of experiments (DOE) and surrogate modeling to enable near instantaneous throughput of vehicle cases [2]. Additional work was then completed to improve the DOE process by utilizing a graph theory based approach to connect similar design points [3].

The conclusion of the previous work illustrated the utility of the graph theory approach for completing a DOE through POST. However, this approach was still dependent upon the use of random repetitions to generate seed points for the graph. As noted in [3], only 8% of these random repetitions resulted in converged trajectories. This ultimately affects the ability of the random reps method to confidently approach the global optima for a given vehicle case in a reasonable amount of time. With only an 8% pass rate, tens or hundreds of thousands of reps may be needed to be confident that the best repetition is at least close to the global optima. However, typical design study time constraints require that fewer repetitions be attempted, sometimes resulting in seed points that have only a handful of successful completions. If a small number of successful repetitions are used to generate a seed point, the graph method may inherit some inaccuracies as it chains DOE cases from the non-global-optimal seed points. This creates inherent noise in the graph data, which can limit the accuracy of the resulting surrogate models.

For this reason, the goal of this work is to improve the seed point generation method and ultimately the accuracy of the resulting POST surrogate model. The work focuses on increasing the case pass rate for seed point generation. It is expected that by vastly improving the pass rate, more successful repetitions will be completed in the same timeframe, resulting in a higher probability that the global optima is found. This ultimately translates to graph data with less noise and surrogate models with higher degrees of accuracy.

¹ Systems Engineer, Advanced Concepts Office, George C. Marshall Space Flight Center/ED04, Huntsville, AL, AIAA Member.

² Trajectory Engineer, Advanced Concepts Office, George C. Marshall Space Flight Center/ED04, Huntsville, AL, AIAA Member.

Development of the new approach begins with an assessment of the information provided by the random repetitions method. As repetitions are completed, they are identified as converged or failed, with failures marked by a number of different reasons such as minimum or maximum altitude exceeded (altmin/altmax). When looking at the control vector space, regions of different failure types can be identified, leading the team to consider repetitions generation as a classification problem. Considering the problem in this fashion, a classifier can be fit to the random repetitions data and then be used to predict the success or failure of a new repetition prior to its submission to POST. If the classifier is accurate enough, it can be used as a filter for new repetitions to improve the probability of convergence.

This paper first addresses the feasibility of fitting a classifier to the random repetitions data. Random repetitions data for a simple example problem is produced and Support Vector Machines (SVM) are utilized to classify the data within the vehicle and control vector space. The classifiers are fit to random repetitions datasets of varying size in order to test the prediction accuracy. The SVM are shown to produce very high prediction accuracies for the given example problem, even when utilizing a relatively small amount of data from the random repetitions. This ultimately allows for a relatively short execution of random repetitions prior to execution of cases through the SVM. A comparison is given to show the time savings of this combined approach versus running straight random repetitions.

In addition, the example problem is expanded to include execution of the graph method from reference [3]. This allows for a full comparison between the SVM and random repetitions approaches in terms of surrogate model fitting. The example problem shows the ability of the SVM to produce more optimal seed points than the random reps method due to its increased case pass rate. Illustration of the differences in surrogate model fitting between the techniques ultimately leads to the conclusion that the SVM approach can produce a surrogate model with higher accuracy in a shorter timeframe than the straight random repetitions method.

[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] Dees, P.D., Zwack, M.R., Steffens, M., Edwards, S., Diaz, M.J., Holt, J.B., "An Expert-System Driven Method for Parametric Trajectory Optimization During Conceptual Design," AIAA SPACE 2015 Conference and Exposition. 31 Aug. – 2 Sept. 2015, Pasadena, CA, United States.

[3] Dees, P.D., Zwack, M.R., Steffens, M., Edwards, S. "Augmenting Conceptual Design Trajectory Tradespace Exploration with Graph Theory," AIAA SPACE 2016 Conference and Exposition. 13-16 Sept. 2016, Long Beach, CA, United States.