

METHODS OF PERFORMING LARGE SCALE, MULTIDIMENSIONAL PARAMETRIC STUDIES FOR SPACE LAUNCH SYSTEM MISSION ANALYSIS

W. B. Stein*

Optimizing a large number of trajectories over a wide range of parameters is a difficult and computationally intensive, particularly when the parametric space has a large number of dimensions. Solving parametric studies like these require good initial conditions for each optimization case, which results in a significant amount of manual interaction and human judgment and can be time consuming.

The Space Launch System (SLS) uses POST2 (Program to Optimize Simulated Trajectories II) to simulate different ascent trajectories and perform mission analysis. SLS mission analysis currently uses two types of large scale, multidimensional parameter spaces. The qualifying factor between these spaces is the grid density, which determines the set of applicable solution methodologies. One type has a relatively low number of dimensions (2-3), but a large number of grid coordinates (2000-4000), whereas the second type has a relatively low number of grid coordinates (150-350), but a higher number of dimensions (7-10).

A framework was created using the python programming language with the scikit-learn machine learning module to automate these analyses. This framework handles the creation of the parametric space, writing input decks, running POST simulations in parallel, and parsing relevant data from the results. It then applies various statistical methods and machine learning techniques to solve for the initial conditions of each POST input deck for a given set of trajectory targets. The purpose of this framework is to provide a flexible, automated approach to solving any parametric space by starting with a single, well optimized POST input deck.

SLS mission analysis uses a high point-density parameter space for in-space analysis which couple POST and Copernicus, an in-space simulation tool, in an End-to-End architecture [1]. A large grid of POST ascent trajectories is created which serve as a reference table and interpolation basis for Copernicus. Each grid point consists of a separate, optimized POST simulation, and the grid coordinates are determined by targeting parameters set in POST. Typically, Block-1 grids vary apogee vs launch inclination, while Block-1B grids are launch inclination vs payload mass.

*Propulsion Science Tech Fellow, Guidance, Navigation, and Mission Analysis Branch, Jacobs Space Exploration Group, Marshall Space Flight Center, Huntsville, AL, 35812, U.S.A. william.b.stein@nasa.gov

Various solution methodologies can be employed to solve this type of problem. These methods operate under the assumption that the solution space is continuous and smooth unless near a numerical constraint. An initial seed case is developed manually and optimal initial conditions are established. The seed case is then copied and run across the parameter space to serve as an initial guess, with a subset of these cases solving due to the internal optimizer in POST. Based on the number of cases that successfully optimized, a regression method is chosen to better estimate the initial conditions that failed. Applicable regression methods for this type of problem are second order linear, k-nearest neighbors, and support vector machines. Typically, two to three iterations of second order linear regressions are needed to completely solve the Block-1 and Block-1B grids for this application.

SLS performs mission analysis on low point-density parameter spaces, as well. These are used during the development of statistically representative vehicles using a Maximum Likelihood Estimation (MLE) process, and are employed in conjunction with a Design of Experiments (DOE) grids for the Block-1 and Block-1B configurations. These vehicles are the used to estimate maximum load conditions and accelerations, and are used as bounding or stressing cases for aerodynamic, structural, and thermal analyses.

Beard and Hanson [2, 3] initially developed this statistical process during the Constellation program as a way to represent each vehicle as a statistical combination of manufacturing uncertainties. This process utilizes DOE to represent different combinations of manufacturing uncertainties in order to reduce the computational burden on the analyst.

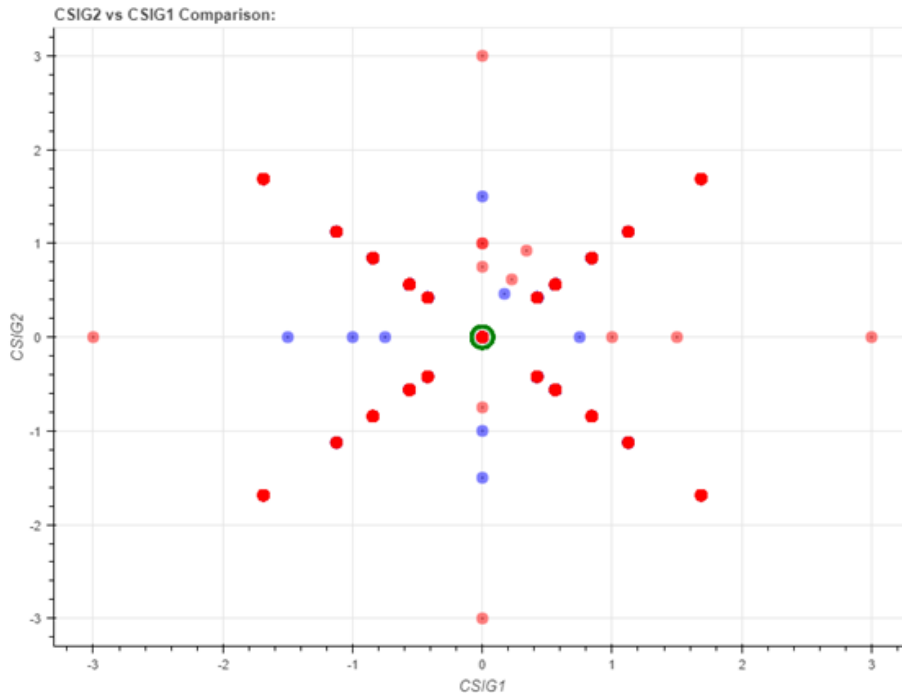


Figure 1. Example Cross-Section from a Ten Dimensional Face-Centered Cubic Grid, CSIG1: Solid Rocket Booster Propellant Mass Sigma Level, CSIG2: Solid Rocket Booster Burn Rate Sigma Level

This results in multidimensional DOE grids that can be difficult to solve using only regression techniques due to a lack of information in any given dimension. This type of parametric study requires methods that create additional points interior to the DOE grid and along dimensions of high sensitivity. One method is to propagate each POST input deck relative to a preceding point. This is performed by copying the optimal u-vector from the initial case to the new coordinates, using it as the initial conditions in the new POST deck. This then creates a task graph of different calculation vectors along which POST is propagated. Each vector is then processed in parallel. Once a sufficient amount of data has been created to reinforce areas of the grid, regression methods are used again to solve the entire parameter space.

While this paper focuses on the specific application for the SLS launch vehicle, this framework and solution methods can be applied to any type of mission analysis or simulation. This framework provides flexibility to rapidly solve large scale, multidimensional parametric studies without large amounts of user interaction, thus allowing for more responsive trade studies and exploratory analyses. This paper discusses the two types of parametric studies and how they are employed during SLS mission analyses. Finally, the most appropriate choice of numerical methods for each grid type is discussed.

REFERENCES

- [1] R. Whitley. Combining Simulation Tools for End-to-End Trajectory Optimization. *AAS/AIAA Astrodynamics Specialists Meeting*, (AAS 15-662), April 2015.
- [2] J.M. Hanson and B.B. Beard. Applying Monte Carlo Simulation to Launch Vehicle Design and Requirements Verification. *Journal of Spacecraft and Rockets*, 4, January 2012.
- [3] ARES Corporation. Some Notes on the Use of Statistical Methods in the Design of Launch Vehicles. Technical report, Marshall Space Flight Center, January 2009.