Paper ID: 19169
oral
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SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM (D2)
Poster Session (P)

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A POSSIBILITY BASED MISSION DESIGN OPTIMIZATION FOR THE SPACE LAUNCH VEHICLE

Abstract

In this study, a mission design optimization for the Space Launch Vehicle(SLV) is performed using PBDO(Possibility Based Design Optimization) method to consider epistemic uncertainties in design variables/parameters in analyzing the system.

The mission design process of the SLV is developed by integrating discipline functions categorized in configuration, weight estimation, aerodynamics, mission analysis, staging, propulsion, and trajectory modules. Before the main mission design process is started, initial values of the specific variables are guessed or estimated using data mining techniques based on accumulated SLV launching data. Through the multidisciplinary optimization(MDO) method the baseline configuration of the rocket is represented as a result. For the optimization problem, the total weight of a rocket is an objective function to be minimized. And there are several design variables such as length to diameter ratio, mass ratio, thrust to weight ratio, and velocity distributions. The imposed constraints correspond to mission velocity, altitude, and pitch angle at the final position.

Uncertainty in variables/parameters may be presented in problems that rely on statistics-based equations, simplified analysis methods, unclear design requirements, or physical uncertainties such as weather, manufacturing tolerances, and many others. Failing to account for these uncertainties will lead to designs that are not sufficiently conservative to guarantee the satisfied requirements are met. PBDO is a method for accounting for uncertainties by modelling each source of uncertainty as fuzzy numbers. The shape and width of the fuzzy number is typically determined by expert experience or by examining any available data relevant to the variable/parameter.

This research implements an in-house PBDO solver by the use of a sequential solution strategy. The process begins with a full deterministic optimization using a Sequential Quadratic Programming (SQP) optimizer followed by a reliability assessment phase. An anti-optimization is performed on each constraint to determine the worst possible combination of uncertain variables/parameters within the boundaries defined by each fuzzy number. This information is used to shift the constraints further into feasible design space. A deterministic optimization is performed using the shifted constraints. This process is repeated until the results converge.

By applying PBDO, the SLV mission design becomes significantly more conservative than the deterministic solution. In this sense, it is demonstrated that much more reliable and safer design can be obtained and used as an entry point to the next level of design process with more 'certain' design variables/parameters.