Chance constrained optimization for launcher GNC validation

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Launcher GNC traditional validations are based both on linear analysis (frequency domain response) and on Non Linear (NL) analysis (simulation for time domain performance). Validations shall be made on a wide domain of variation of influent parameters; leading to robustness issues since robust analysis methods and algorithms are complex to implement into efficient engineering processes and are often limited by their computational complexity. Traditional validation includes on the one hand Worst Case (WC) validation that is based on gridding worst cases defined using analytical techniques and simplified launcher model. On the other hand, Monte Carlo (MC) simulations are run for probabilistic requirements verification. Main drawbacks of these methods are that they are either local and deterministic (worst case methods) or global and stochastic but very time consuming (statistical methods).

To enhance traditional validation plan, a widely developed approach is to use optimization based methods to **ensure better coverage of the parameter space** and to **identify worst case configurations** in terms of uncertainties, flight conditions and perturbations. In this approach, we use bounds for uncertain parameters in a deterministic manner, thus the parameter space is a hyper-rectangle. In the literature, optimization methods were successfully applied in frequency and time domain. However, in case of multiple parameters and a specification with a probability level, this approach is very pessimistic since the probability for all the parameters to be close to their bounds at the same time is low (assuming independent parameters).

The aim of this paper is to propose a novel method that includes a chance constraint on the domain of variation of the inputs during the optimization process, for worst case identification during validation process. Chance constrained optimization principle and mathematical definition will be defined in the full paper. This constraint is based on the probability density function associated to the vector containing all uncertain inputs. The algorithm rejects all points in the parameter space that are below a threshold computed according to the probability objective. The domain explored by optimization is thus defined by (with η the desired probability and x the uncertain input vector):

$$D_X = D_X(\delta) = \{x \in \Re^n / p_X(x) \geq \delta\} \quad \text{where } \delta \text{ and } \eta \text{ are related by } E_X\left[1_{X \in D_X(\delta)}\right] = \eta .$$

Then, results obtained for launcher application will be presented justifying the method and demonstrating the interest of the developed method. The reduction of the explored domain to a more realistic one was confirmed, as illustrated on Figure 1.

This method's development and evaluation was done on benchmarks representative of next generation launchers ascent. It represents an **effort reduction to identify worst cases** and the chance constraint allows **exploring a more probable domain** thus reducing the pessimism. Future work shall study the link between probabilities of inputs and probabilities of outputs as the latter is mentioned in GNC specification. This method could also be extended to correlated inputs.

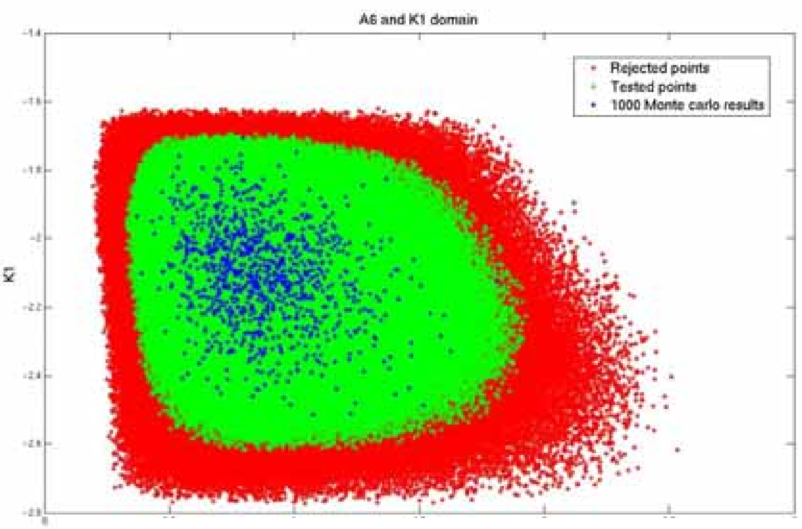

Figure 1: aerodynamic and actuator efficiency domains