Application of Extreme Values Analysis for the Definition of Operational Domains of Liquid Rocket Engines

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Abstract

In the early stage of the development of a liquid propulsion engine, its propulsive performance needs to be assessed including numerous sources of variations, related to hardware scattering, uncertainties in the involved physical phenomena in combustion organs or power transmission sub-systems or interface conditions of the tanks / feeding systems.

The use of numerical models is invaluable to predict the span of global engine performance. Besides, the same tools can be used to compute the required coverage of key physical parameters driving the endurance of each sub-system.
The qualification plan of the engine stems from these domains.
A classical approach consists in building the domains as the envelope of the key physical parameters (min and max value) over all possible operation points resulting of Monte-Carlo draws on all identified sources of variation. However, it is very conservative since it doesn't take into account correlation between parameters, nor their underlying distribution. This results into unnecessary stress to qualification hardware and overdesign of test benches. Besides, such a Monte-Carlo based approach is computationally ineffective when dealing with extreme coverage.

This paper presents a less restrictive approach, more in line with the original goal of tailoring a qualification plan to ensure equal qualification coverage of the engine while realistically accounting for the extreme values of sub-system drivers. It relies on recent advances in extreme value analysis and random simulation techniques to estimate rare event probability.

As an application, these techniques have been applied to: a) the domain of the thrust chamber of HOMER project, a demonstrator aiming at demonstrating capabilities required for multiple space applications e.g. the soft landing or hazard avoidance for a Planetary/Lunar lander and reactivity for a space servicing vehicle; b) to the turbine of the turbopump of LOX/methane engine from a preliminary research project.