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# SURROGATE NEURAL NETWORK MODEL FOR INTEGRATED ASCENT TRAJECTORY OPTIMIZATION OF THROTTLEABLE HYBRID ROCKETS

**Abstract**

This paper proposes an original approach to the integrated optimization of a hybrid-propellant three-stage launch vehicle which makes use of a surrogate neural network model in place of the complex internal ballistics of throttleable engines.

Current interest in hybrid propulsion is rapidly increasing, as hybrid rocket engines (HREs) can be easily throttled and restarted, and can potentially employ green, safe, non-toxic propellants. Moreover, regression rates up to 4 times that of the traditional axially-injected "pyrolyzing" fuels (such as HDPE or HTPB), have been recently achieved by means of swirled injection technology and paraffin-based fuels, thus allowing the use of HRE even for high-thrust applications such as lower stages.

Due to the strong coupling between the hybrid rocket design and the generation of thrust, which plays a major role in the determination of the ascent trajectory, an integrated optimization approach is required to maximize the overall launch vehicle performance, resulting in the formulation of a multidisciplinary optimization problem, aimed at determining both the optimal HRE design and flight parameters that maximize the rocket payload. As the ballistic model of rocket engines becomes more accurate, the computational effort for solving such an integrated optimization problem increases. Indeed, when considering throttleable engines, the computational burden may easily become prohibitive.

In this respect, machine learning techniques represent an appealing solution. In fact, a neural network (NN) can be used to model the complex dependency of HRE performance on a number of motor design parameters, obtaining a computationally lightweight and low-cost tool that can be effectively used within an optimization code for the integrated design of an HRE and the associated ascent trajectory.

This paper extends current state-of-the-art techniques for the development of a fast and accurate NN-based surrogate model, for the performance prediction of an HRE, to the case of throttleable engines. Numerical results are presented for a study case involving a hybrid three-stage launch vehicle to low earth orbit, where the thrust magnitude of the first stage is actively controlled in order to ensure the respect of realistic mission constraints, such as maximum dynamic pressure, $Q\alpha$, and maximum axial accelerations.