

Towards hydrogen-powered electric aircraft: Physics-informed machine learning based multi-domain modeling and real-time digital twin emulation on FPGA

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In response to environmental concerns related to carbon and nitrogen emissions, hydrogen-powered aircraft (HPA) are poised for significant development over the coming decades, driven by advances in power electronics technology. However, HPA systems present complex multi-domain challenges encompassing electrical, hydraulic, mechanical, and chemical disciplines, necessitating efficient modeling and robust validation platforms. This paper introduces a physics-informed machine learning (PIML) approach for multi-domain HPA system modeling, enhanced by hardware accelerated parallel hardware emulation to construct a real-time digital twin. It delves into the physical analysis of various HPA subsystems, whose equations form the basis for both traditional numerical solution methods like Euler's and Runge–Kutta methods (RKM), as well as the physics-informed neural networks (PINN) components developed herein. By comparing physics-feature neural networks (PFNN) and PINN with conventional neural network strategies, this paper elucidates their advantages and limitations in practical applications. The final implementation on the Xilinx® UltraScale+™ VCU128 FPGA platform showcases the PIML method's high efficiency, accuracy, data independence, and adherence to established physical laws, demonstrating its potential for advancing real-time multi-domain HPA emulation.