AEROCOOL: Aerospike Engine Research on COOLing Through Biomimicry

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Aerospike engines eliminate the 30–40% efficiency loss from conventional bell nozzles, yet no aerospike has achieved full operational flight due to extreme thermal loads on the central spike: a 60-year engineering gap. This project presents AEROCOOL (Aerospike Engine Research On COOLing through biomimicry), a layered investigation of five biomimetic surface geometries - Porous Transpiration Layer (PTL), Micro-Channel Array (MCA), Hierarchical Ridge Network (HRN), Fractal Porosity Gradient (FPG), and Passive Airflow Guide (PAG) -applied to a CuCrZr aerospike spike and evaluated through ANSYS Fluent CFD (2.5M-cell mesh, realizable k-e), the novel ICARUS (Integrated Computational AI for Regression, Understanding & Simulation) ML surrogate across 500+ configurations, and physical testing on 3D-printed PLA prototypes via thermal imaging, as well as eventual static fire testing. The PTL design, inspired by sweat-based transpiration, had a 39% reduction in peak heat flux (4.07 vs. 6.61 MW/m², $p \ll 0.001$), 14% lower peak wall temperature (499 vs. 578 K), 63% longer time-to-critical-threshold (3.80 vs. 2.33 s), and 157% greater physical thermal endurance (108 vs. 42 s, $p \ll 0.001$). Structural analysis showed PTL reduces thermal stress by 38% (122.8 vs. 199.4 MPa), raises the structural safety factor by 62% (3.66× vs. 2.26×), extends fatigue life 328% per cycle (Coffin–Manson), and enables ~157% more reuse cycles (~13 vs. ~5). Critically, HRN increased heat flux by 155%, causing thermal stresses (509 MPa) past CuCrZr yield strength (450 MPa): showing that biomimicry without thermodynamic directional analysis is counterproductive.

Awards Won:

Fourth Award of $600