Gas Turbines and HPC: Raytheon and Argonne Turn Heat Up, Waste Down

The big gas turbines that power aircraft operate under tremendous heat loads that exceed the melting point of some components. The stress of this inferno threatens the integrity and durability of the engine; and today's energy-efficient, compact designs aggravate the problem by placing flames closer to the turbine wall, raising the temperature of the turbine blades and combustor liners.

Thermal management is therefore of great interest to turbine designers.

Manufacturers use "film cooling" techniques to protect turbine surfaces from the high-temperature flows coming from the engine. Essentially, cooling air shoots out of the blades through numerous tiny holes, creating a thin layer of cooler air on the external surface and reducing heat transfer from the main flow. To optimize this exchange, designers use computational fluid dynamics (CFD) to simulate the flows coming out of the engine and the effects of cooling-air flow rates and cooling-hole angles, arrangements, and design, besides wildcards like the age, history, and location of an aircraft. Nevertheless, the computational resources required to produce a fine-grained model of the flow near the turbine walls are beyond the resources of most manufacturers.

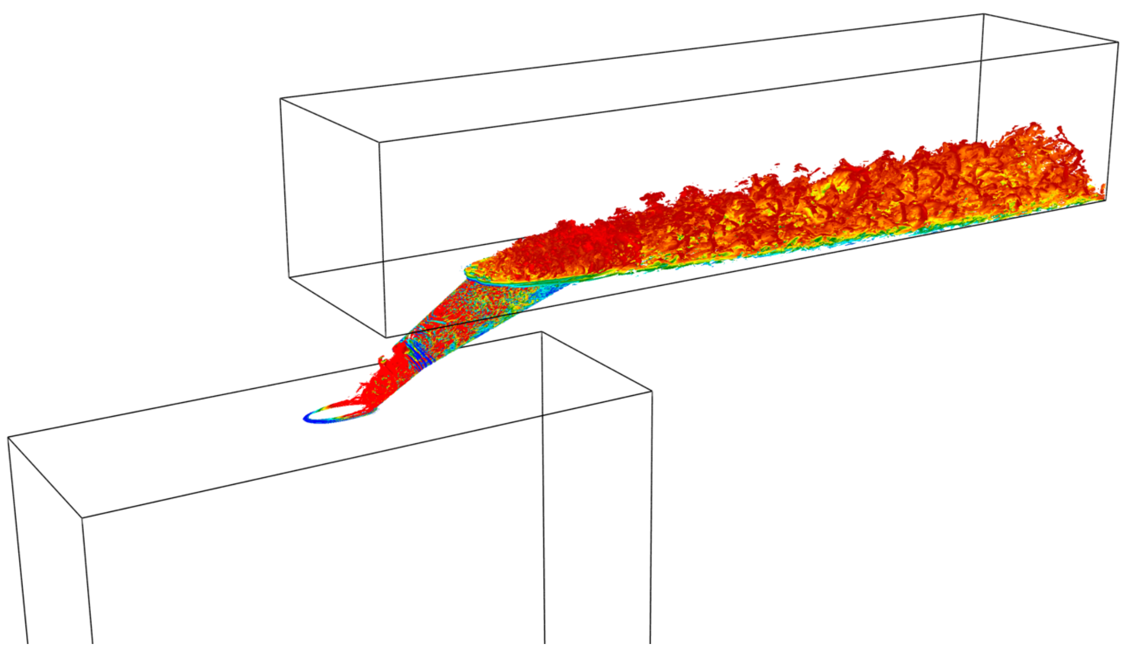
Engineers at Raytheon Technologies Research Center (RTRC) sought to improve the fidelity and predictive value of low-order, engineering-level film-cooling simulations by leveraging machine-learning (ML) techniques to predict near-wall flow dynamics accurately, with coarse resolution—aiming to reap the benefits of high fidelity and low cost simultaneously. Partnering with HPC4Mfg, they tapped Argonne National Laboratory for the expertise and screaming-fast supercomputers they'd need to skip years of incremental steps forward.

The team began by developing high-resolution, wall-resolved large-eddy simulations (WRLES) of the turbine film-cooling configuration using Argonne's massively parallel Nek5000 high-order spectral element CFD solver, which has shown excellent scalability on leadership-class supercomputers for a variety of large-scale flow problems. Building a data-extraction framework to convert output to data files for analysis, they generated high-fidelity datasets for training machine-learning (ML) wall models.

For *a priori* analysis of ML wall models, Argonne tested an artificial neural network (ANN) and light gradient-boosting machine (LightGBM) as potential surrogates for data-driven wall modeling; LightGBM won for its quick training time and better accuracy in predicting the wall shear stress. The trained ML-based wall model was integrated within Nek5000 for *a posteriori* wall-modeled LES studies. An efficient algorithm was developed to balance the computational load and accelerate the WMLES, allowing distributed inference of wall-shear stress from the LightGBM model. The team's hybrid simulation–AI demonstration studies aimed to show that ML can help develop fast, accurate design models for optimizing turbine film-cooling schemes. With this innovative simulation-driven design framework, designers can increase combustor-inlet temperatures while reducing turbine cooling air—thereby lowering fuel consumption without sacrificing component life. A 10% reduction in high-pressure turbine cooling air can lead up to 1% reduction in thrust-specific fuel consumption of the gas turbine engine.

Shared beyond RTRC to the larger research community through publications and presentations, the tools and findings of the project will be valuable for fields like stationary power generation, offshore-wind energy, and civil aviation where turbine systems are prevalent.

Among the potential first adopters industrially will be aviation and power-generation original-equipment manufacturers (OEMs) such as RTRC, General Electric, Rolls Royce, Solar Turbines, and any others looking to save fuel, reduce emissions, increase component life span, minimize maintenance, and exploit AI and digital twins for designing next-generation efficient technologies. RTRC plans to use the simulation tools for design and optimization of their future jet-engine cooling schemes.



Vortical structures (colored by velocity magnitude) predicted by wall-resolved large-eddy simulation (WRLES) of a canonical gas turbine film-cooling configuration