Abstract

Gas turbine components operate under severe thermal conditions that typically exceed the material allowable temperature of conventional alloys. To overcome this issue, efficient cooling techniques are employed to extract heat from turbine blades. Technological advances in recent decades have led to the development of sophisticated solutions that enable higher gas turbine inlet temperatures and consequently enhance the overall engine efficiency. In this context, innovative optimization algorithms play a key role in providing non-conventional solutions that drastically improve the cooling performance of the system. In this work, a multi-step design optimization approach is presented. This strategy combines the design complexity of a gradient-based optimized solution with the robustness of a parametric approach. During the first step, the baseline geometry of a square channel with transverse ribs was optimized with the adjoint method using the wall heat transfer coefficient as the objective function. The optimized solutions doubled the initial performance by deforming both the ribs and the channel walls into a W-shaped fashion. The main geometrical features that emerged during the first step were later reproduced with a parametric approach. In this way, only the features with the greatest impact on the thermal performance are kept, while minor deformations producing marginal effects are neglected. Overall, both the rib and channel shapes were modified using only six geometrical parameters. The design space of each parameter was explored over a wide variability range, and each sample was simulated with a Reynolds Averaged Navier Stokes (RANS) Computational Fluid Dynamics (CFD) simulation at Reynolds = 10000, 20000, and 40000. The Nusselt number Nu and the friction factor f of each configuration were collected in a dataset that was later used to train two Artificial Neural Network (ANN) models, which use the geometrical parameters and flow Reynolds number as input variables, while the Nusselt number ratio Nu_r/Nu_0 and the efficiency index ς as the objective functions. The predictive models were then coupled with a Genetic Algorithm (GA) that finds the optimal solutions at the desired value of Reynolds number. This second optimization step allowed for the possibility to adapt the geometries to a broader range of operating conditions (Re=10000-40000) and to provide the optimal configuration for a given Reynolds number using only a few geometrical parameters. The optimized solutions that combine the rib and the channel deformation achieved a better cooling efficiency than traditional W-shaped ribs in a square channel. Later, an High Pressure Turbine (HPT) vane equipped with diffusive endwalls was optimized to allow for ingesting a high-subsonic flow ($Ma = 0.6$) delivered by a Rotating Detonation Combustor (RDC). The main purpose of this activity is to investigate the prediction ability of machine learning tools in the case of multiple input parameters and different objective functions. Moreover, the model predictions are used to identify the optimal solutions in terms of vane efficiency and operating conditions. A new solution that combines optimal vane efficiency with target values for both the exit flow angle and the inlet Mach number is also presented. The impact of the newly designed geometrical features on the development of secondary flows is analyzed through numerical simulations. The optimized geometry achieved strong mitigation of the intensity of the secondary flows. As a consequence, the overall vane aerodynamic efficiency increased with respect to the baseline design. The concluding section of the thesis is dedicated to the application of internal cooling channels in the optimized vane. This activity allowed us to validate the efficiency of the two-step optimized channels in a realistic Vane application. Three configurations of cooling systems were studied using a Conjugate Heat Transfer (CHT) approach: smooth radial channels, radial channels with orthogonal ribs, and optimized radial channels. The optimized channels outperform conventional solutions with a significant mitigation of the vane metal temperature.