Integrated Thermal Analysis of a Cooled Turbine Nozzle Using the AxSTREAM Software Platform Coupled with Ansys

Efficient turbine vane cooling designs are increasingly important in improving the thermal efficiency of gas turbines. Evaluating the performance and reliability of a cooling design requires knowledge of the temperature distribution on the vane surface and the cooling air mass flow rate. The estimation of the vane temperature distribution is a conjugate heat transfer problem, which usually requires a computationally intensive 3D computational fluid dynamics, finite element method (CFD-FEM) simulation. However, this approach is not suitable during early design phases, when the cooling system geometry changes frequently throughout design iterations[1].

Thermal analysis of the cooled turbine nozzle is one of the main steps in analyzing turbine cooling. At the preprocessing stage, the most important task is to determine the temperatures and heat transfer coefficients for the blade surfaces[2]. This white paper highlights how to couple relevant AxSTREAM and Ansys tools to solve steady-state thermal analysis of cooled turbine nozzles.

/ Calculate Internal and External Flows of Turbine Blades

AxSTREAM System Simulation™ calculates the internal cooling flows of the turbine blade. The inner wall temperature of the cooling orifices is taken as an initial assumption. The outlet static pressure of the cooling orifices is kept constant. The fluid temperature and heat transfer coefficient of the internal cooling walls are the output parameters that are transferred to Ansys Mechanical for the thermo-structural calculation later on. Ansys CFX calculates the external flow around the blade based on the initial assumption of the external wall temperatures used. The fluid temperature and heat transfer coefficient of the external wall are calculated and transferred to Ansys Mechanical, which calculates the steady-state thermal analysis of the vane based on the external and internal fluid temperatures and heat transfer coefficients. The inner wall temperature of the cooling orifices and the external wall temperatures of the blade are output parameters. The initial temperatures are compared with the calculated ones for each iteration in AxSTREAM ION™ and if the difference between temperatures is less than the estimation error 1e-3, the calculation is complete. Otherwise, the calculated temperatures become the new initial assumptions and the calculation is repeated until convergence is achieved.

To address these challenges, the decoupled approach — 1D correlation-based, 3D CFD, and 3D FEA analysis — is presented here (Figure 1).

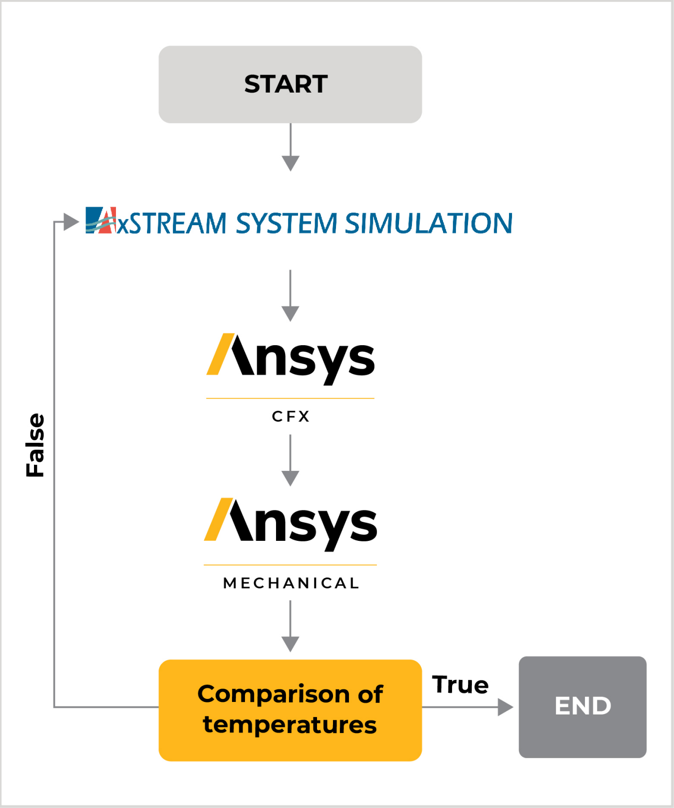

Figure 1. Integrated workflow in AxSTREAM ION™ solving the thermal characteristics of a cooled turbine nozzle.

What would ordinarily be a manual and complex task is made much easier and faster using AxSTREAM ION. AxSTREAM ION is an intelligent software program that integrates and automates workflows, enabling users to transfer data to and from different software programs and iterate between design and analysis steps for new product development, as well as visualize the digital version of a machine to investigate reliability and equipment aging against real-world conditions. Embedded optimization algorithms let users perform multidisciplinary optimization and data analysis to gain and share insights into their simulation results. In the current case, AxSTREAM ION transfers the relevant data between AxSTREAM System Simulation, Ansys Mechanical, and Ansys CFX according to the following flowchart until a convergence (agreement) of the solvers involved is reached (Figure 2).

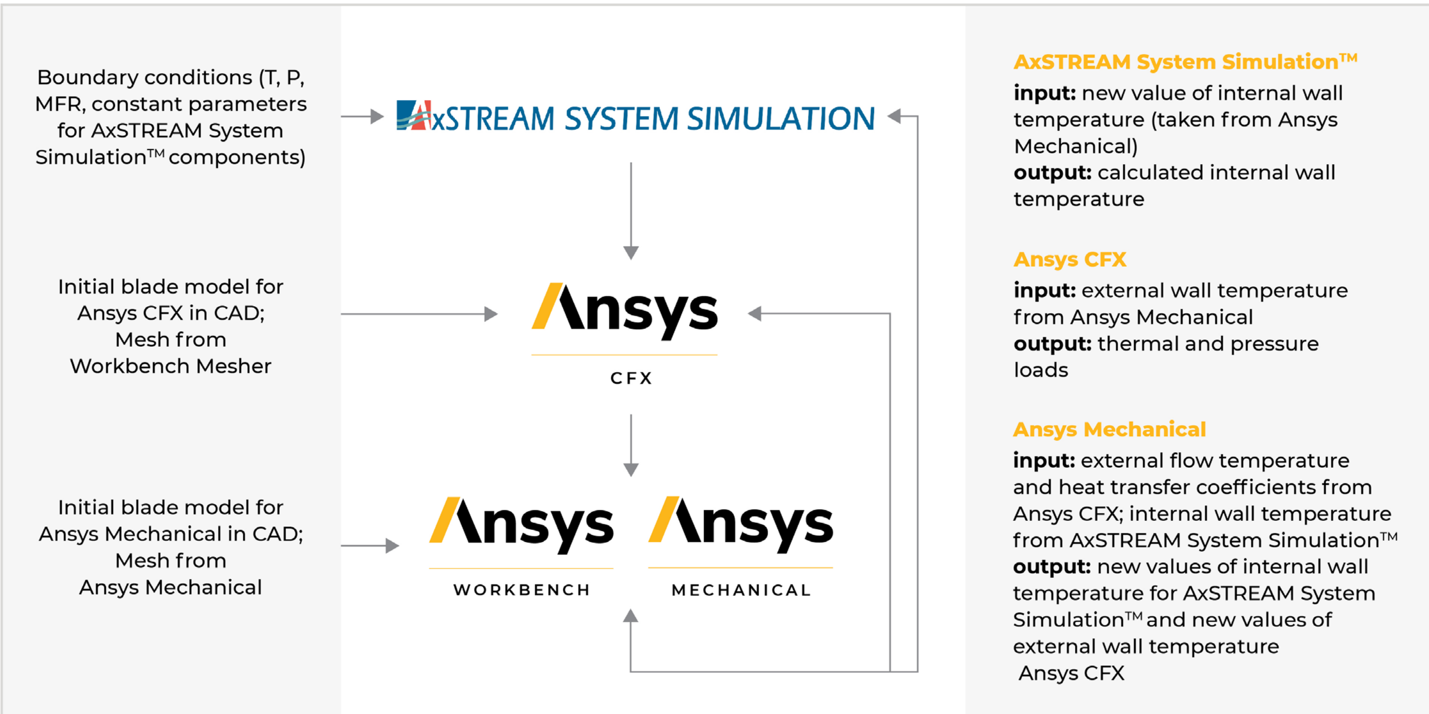

Figure 2. Flowchart with input and output parameters from solver to solver.

The nozzle cooling has been modeled using a discretization approach in AxSTREAM System Simulation. This thermal-fluid network model calculates the heat transfer coefficient values and fluid flow temperatures at each section, which are used as boundary conditions for the thermal stress analysis in Ansys Mechanical (Figure 3).

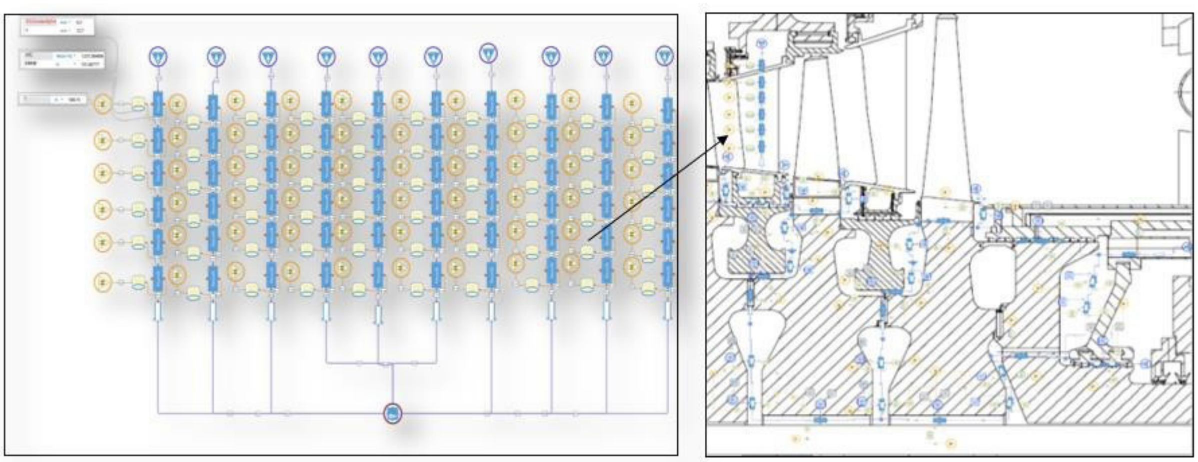

Figure 3. Scheme in AxSTREAM System Simulation™

After all calculations in AxSTREAM ION have been completed and have converged, the temperature distribution can be confirmed for the external flow around the blade. The steady-state thermal analysis is then performed based on the correct external and internal fluid temperatures and heat transfer coefficients (Figure 4).

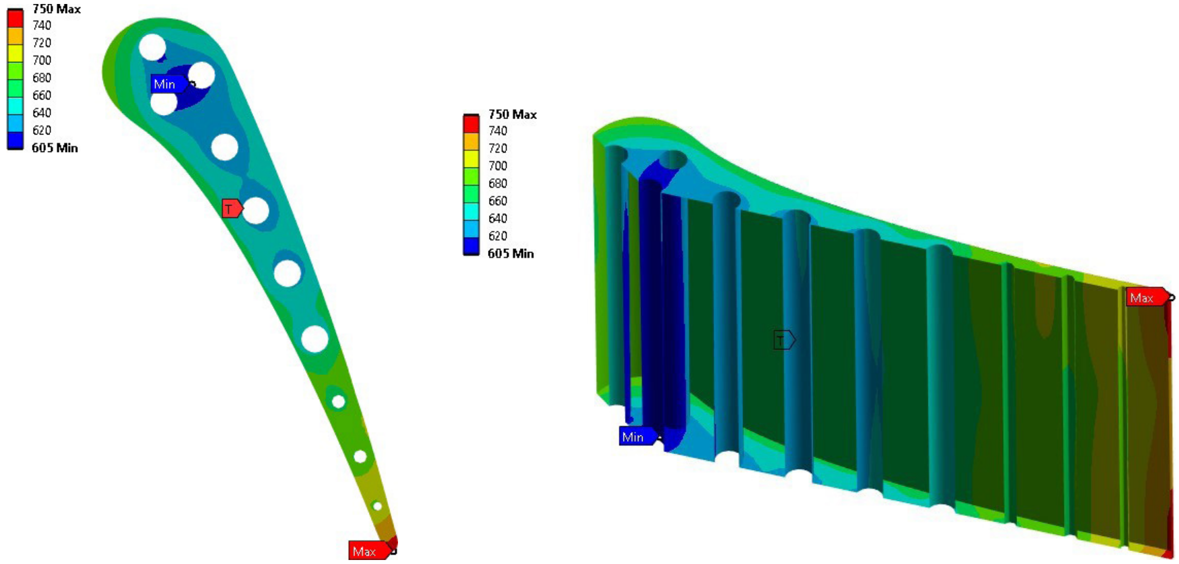

Figure 4. Nozzle temperature distribution at tip section.

Automated Workflow Is 3X Faster

In conclusion, thermal state analyses and the determination of external cooled nozzle turbine temperatures can be easily automated using AxSTREAM ION without the painstakingly manual iterations, preprocessing, and post-processing usually linked to these kinds of tasks.

With this automated workflow in AxSTREAM ION, solving the presented task took about four hours, which is significantly less than with manual iterations. This frees engineers to perform other tasks and enables them to be productive outside of working hours without compromising personal time. If done manually, the user would need to change boundary conditions, run cases, and reload tables with results for every iteration in AxSTREAM System Simulation, CFX, and Mechanical tools. This process would take three times longer than the proposed method using AxSTREAM ION, representing an approximate 65% time savings when compared to a manual approach.

References

1. Schöffler, R., Grunwitz, C., & Brakmann, R. G. (2023, June). A Semi-Empirical Model for Conceptual Turbine Vane Cooling Design and Optimization. In Turbo Expo: Power for Land, Sea, and Air (Vol. 87011, p. V07BT13A013). American Society of Mechanical Engineers.

2. Catalani, I., Balduzzi, F., Bianchini, A., Ferrara, G., Pini, N., Mosciaro, L., ... & Hoffer, P. A. (2023, June). A Computationally Efficient Method for the Thermo-Structural Analysis of a Turbocharger Turbine Wheel Under Engine Transient Operation. In Turbo Expo: Power for Land, Sea, and Air (Vol. 87035, p. V009T18A007). American Society of Mechanical Engineers.

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