Experimental and Numerical Study of Jet Impingement Cooling for Improved Gas Turbine Blade Internal Cooling with In-line and Staggered Nozzle Arrays

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OBJECTIVES

A gas turbine engine requires high-temperature and high-pressure cycles to achieve higher efficiency and power density. Thermodynamically, it is an expensive process as the coolant needs compression with as high as 40% of the coolant supplied from the compressor. Developing cooling capabilities to gain a higher turbine inlet temperature requires a greater understanding of the physics of airflow behavior. Companies seek the adoption of DMAIC process (Define, Measure, Analyze, Improve, Control) at the early stage of New Product Development and/or the quality control stage of current products.

APPROACH

This study represents experimental and numerical results of jet impingement cooling using in-line and staggered nozzle arrays with different coolant flowrates and different distances between the hot plate and the coolant nozzle (SOF). Thermal image processing is used for experimental data acquisition. Computational Fluid Dynamics (CFD) is used for simulating the flow domain and clarify different complex heat transfer and flow phenomena, primarily the line-averaged and area-averaged Nusselt number and the crossflow effects.. A comparison between heat transfer enhancement with in-line and staggered nozzle arrays is implemented.

- Define: Heat transfer enhancement
- Measure: Temperature; Pressure drop; Stress
- Analyze: Nusselt number; Vorticity; Blade Life factor
- Improve: Nozzle configuration; Flow Optimization; SOF
- Control: Verify Improvements

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METHODOLOGY

- The scope of the study is an electrically heated stainless-steel foil (304 SS). As the electrical current passes through the foil, heat is generated due to the high resistivity of the foil material. The heated foil is cooled by compressed air.
- IR thermal imaging is employed to capture the surface temperature of the heated foil. The generated thermal images were subjected to post-processing to get the temperature distribution of the heated foil surface.
- The computational study was performed to model the flow and heat transfer interactions. The temperature distribution of the heated surface and the other boundary conditions were introduced.
- Mesh independent study was performed to determine the most suitable type and the number of the cells.

Experimental work
- Measurement devices calibration
- Boundary conditions measurments

Thermal image processing and data acquisitions

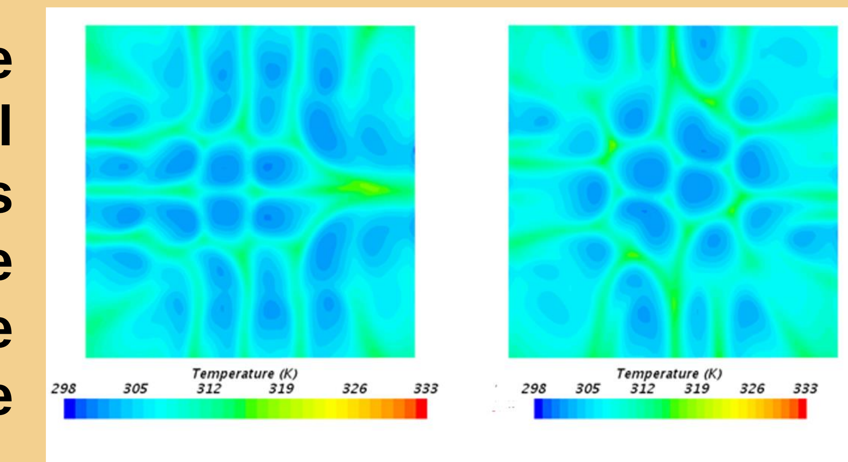
CAD modeling
- Material selection
- Stress analyses

CFD modeling
- Numerical and turbulence modeling
- Mesh independent study
- Data post-processing

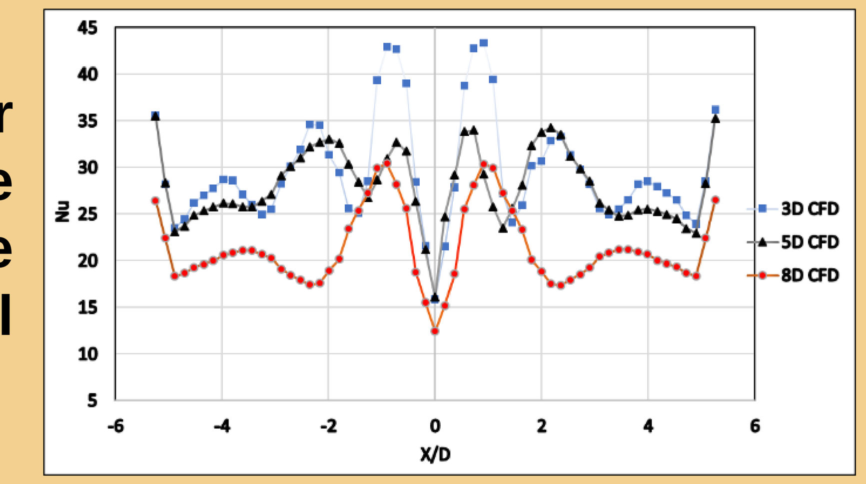
Validation

RESULTS

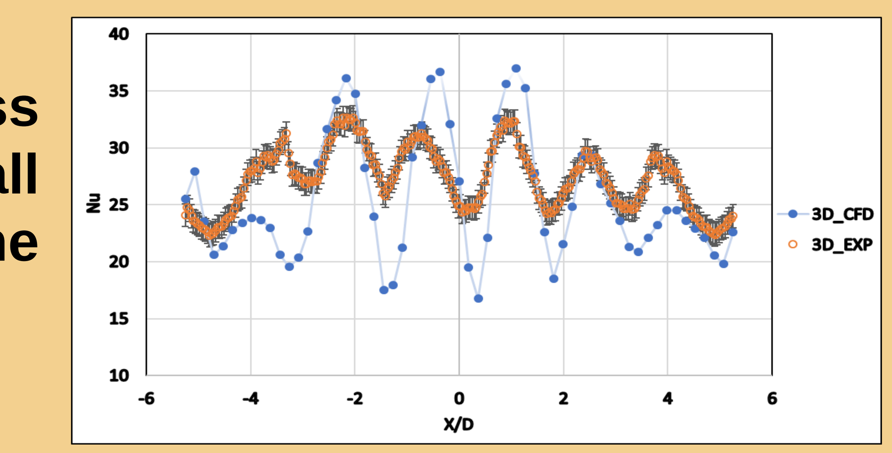
- The lowest temperature occurs at the spatial locations where the jets impinge. In-line nozzle arrangement is capable of achieving more active cooling.



- Local Nusselt number tends to decrease as the distance between the nozzles and the foil surface becomes longer.



- CFD validation with less than 15 % error for all cases included in the study.



CONCLUSIONS

- The amplitude of the local Nusselt number curve becomes less, and so does the number of the peaks (maximum and minimum) as the stand-off distance (SOF) increases.
- Impingement cooling jet trajectories are distorted by the crossflow over the foil surface.
- The in-line nozzle configuration is capable of achieving higher heat transfer rates. The degradation of the heat transfer rate is resulted due to the higher impact of staggered jets on the crossflow, which leads to the crossflows accumulation, and, therefore, degradation in heat transfer rates.

BIBLIOGRAPHY

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