Conjugate Heat Transfer using Large Eddy Simulation in Rib Roughened Cooling Channels

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Abstract

In this work, computations will be performed to study the flow and the conjugate heat transfer in rib roughened cooling channels of turbine blades. Turbulence will be simulated and modeled via Large Eddy Simulation. The computation will be validated through the comparison with existing experimental data for the cooling channel flow.

Keywords: Conjugate Heat Transfer, Large Eddy Simulation, Gas Turbines, Turbine Blade, Cooling Channels

1. Introduction

The Turbomachinery industry tries to comply with both the claims for environmental awareness and the rising use of energy. Hence, the requirements for performance and efficiency of gas turbines increase. One method to improve the cycle performance of gas turbines is to increase the turbine inlet fluid temperature. Although improvements of the temperature resistance of the materials have been made over the last decades, the turbine inlet temperature exceeds the melting temperature of the material in modern gas turbines (see figure 1). Hence, the turbine blades have to be cooled. Since life of a turbine blade is reduced by half with an increased temperature of 30 Kelvin [2], engineers have to predict the local heat transfer coefficients and temperatures accurately. Furthermore, the pressure drop should be as low as possible and at the same time, the cooling efficiency as high as possible. Therefore, cooling channels are turbulated, for instance by obstacles such as ribs. Thus, the complexity of the flow field increases and it is not possible to predict the wall temperature a priori.
To gain reliable results for efficient thermal design of turbine blade cooling, both the heat conduction in the solid and the convection have to be taken into account simultaneously, which is called a conjugate heat transfer (CHT) problem.

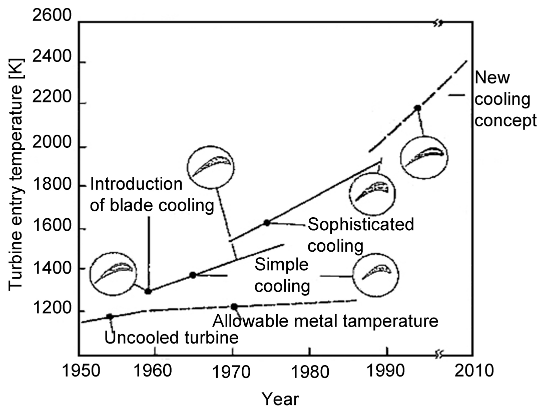

Figure 1: Variation of turbine entry temperature and the allowable metal temperature over several decades[1].

Although CHT is a coupled problem, many studies compute the solid and the flow field separately. It

could be shown that this approach does not lead to satisfactory results in comparison with experimental investigations [3]. Besides the attempt to calculate CHT uncoupled, there are mainly two different approaches to solve CHT problems in a coupled manner as described by Verstraete [4] and summarized as follows. The first approach, the conjugate method, computes both the fluid domain and the solid domain at each time step simultaneously. For the conjugate method, one monolithic solver for both fields is used.
However, a major problem in CHT is that the characteristic time scale in the solid is usually about orders of magnitude larger than in the fluid. Due to the computation of both fields at a small time step, the conjugate method is computationally less efficient than the second approach, the coupled method. In this method, the fluid and the solid field are solved by separate solvers. The fluid field is solved and interrupted after some time steps in order to renew the boundary conditions at the interface to the solid domain which is computed by a steady state approach. By using two different solvers for the solid and the fluid, the coupled method provides an opportunity to treat the different appearing time scales computationally more efficient, although an iterative procedure is needed between the fluid and the solid solvers.
The complex, unsteady flows in cooling channels affect the heat transfer coefficient. Reynolds Averaged Navier-Stokes (RANS) methods are not able to reproduce those complex flow conditions. Large Eddy Simulations (LES), which resolve a part of the turbulent spectrum, provide more accurate results to predict the heat transfer [5].

2. Objectives

After reviewing literature and the state of the art, we aim to solve the CHT problem in cooling channels with a coupled approach using LES for the flow computation in order to achieve more accurate results in comparison with RANS simulations. Since LES are more expensive than RANS, we aim to accelerate the process of the coupled computations by developing a method which takes the different characteristic time scales of the solid conduction and the flow convection into account.
Finally, after validating our numerical approach with analytical solutions and existing experimental investigations [6], we aim to study rib roughened cooling channels and the influence of different parameters of the turbulators on the heat efficiency and the pressure drop.

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