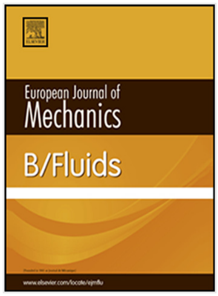

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Numerical study of a turbulent impinging jet for different jet-to-plate distances using two-equation turbulence models

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Abstract

Numerical results of a turbulent impinging jet on a flat plate are compared with experimental reference data from ERCOFTAC. Four different jet-to-plate distances from $H/D = 2$ to 14 have been considered at a jet Reynolds number of 23,000. Local flow and heat transfer characteristics are analyzed using the SST turbulence model by Menter and an additional turbulence production limiter by Kato and Launder. For the smaller jet-to-plate distances of $H/D = 2$ and 6, the Kato-Launder turbulence production limiter reproduces the heat transfer in the stagnation region very well. At the higher values $H/D = 10$ and 14, the modification underpredicts the reference data.
The near-wall grid resolution at the target plate has been varied for a jet-to-plate distance of $H/D = 6$. The results show the influence of the dimensionless distance of the first node near the wall on flow and heat transfer characteristics. A comparison of a hybrid and a block-structured grid assesses the influence on the mesh topology.

Keywords

Impinging jet — RANS turbulence model — Kato-Launder — Heat transfer — Near-wall treatment

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INTRODUCTION

Impinging jets are a common cooling technique also widely used in modern aero engines, e.g. as internal cooling systems for turbine vanes and blades or as cooling systems for combustion chamber walls and turbine casings. Achieving high heat transfer coefficients, impingement cooling is an efficient way to counteract locally occurring high heat loads. For cooling large areas, impinging jets are arranged in rows or arrays. This cooling concept finds application as a temperature control for turbine casings. Depending on engine operating conditions, considerable variations of thermal loads lead to a change in blade tip clearances. A reduction of these clearances is essential to increase the efficiency of aero engines. By directing a controlled flow of impinging air onto the turbine casing, clearances remain nearly constant at their optimum. The so-called active-clearance-control (ACC) system consists of several tubes surrounding the turbine. After entering the tubes, coolant air exits via numerous holes directed to the external side of the casing, where it cools the outer casing.

With respect to the highly complex flow mechanisms of impinging jets [1–3], it is necessary to get a deeper understanding of the ACC system. Therefore, we are investigating flow and heat transfer characteristics numerically at the Institute of Aerospace Thermodynamics (ITLR) at the University of Stuttgart. Due to the geometry's complexity and an enormous number of impinging jets, the use of RANS simulations is indispensable. Hence, turbulent structures inside the jets need to be modeled. To make sure that the numerical setup is able to reproduce flow and heat transfer characteristics correctly, a validation is of importance. The European Research Community on Flow, Turbulence and Combustion (ERCOFTAC) [4] provides a detailed set of validated experimental data from literature for a single impinging jet at different jet Reynolds numbers and jet-to-plate distances (Case 25). The heat transfer characteristics for this reference data set have been measured by Baughn and Shimizu [5] and Baughn et al. [6, 7]. The detailed description of the flow characteristics is given in Cooper et al. [8].

Several studies discuss the influence of turbulence models with the described reference data set, e.g. [9–11]. Coussirat et al. [9] compared one-, two- and four-equation models varying the jet-to-plate distance $H/D = \{2; 6; 10\}$ as well as the jet Reynolds number. The v2f model showed the best agreement to the reference data. Beside the v2f model, the SST turbulence model by Menter [12] was also recommended by Zuckerman and Lior [13] as the best compromise regarding computational speed and accuracy for impinging jet configurations. Draksler and Kon ar [14] combined the standard SST turbulence model with a turbulence production limiter given by Kato and Launder [15]. They focused their study on a jet-to-plate distance of two. The Kato-Launder limiter improved the numerical accuracy of heat transfer predictions. Vittori [10] compared the Kato-Launder limiter to another limiter called Clip Factor to reduce turbulence kinetic energy, focusing on flow phenomena.