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Investigation on the influence of nonuniform initial temperature on the transient heat transfer measurement of film cooling

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ABSTRACT

Numerical and experimental investigations on the influence of nonuniform initial temperature on the transient heat transfer measurements are presented in this paper. The case of film cooling is investigated. When the initial wall temperature is nonuniform, the results of heat transfer coefficient and film cooling effectiveness, which are calculated by the equations derived with constant initial temperature, could deviate from the true values badly, especially in the condition of short test duration. Using initial wall temperature which is higher than the real values causes the results of heat transfer coefficient and film cooling effectiveness lower than the true values. And lower initial wall temperature produces higher results of heat transfer coefficient and film cooling effectiveness. However, when the initial temperature distribution in the region where conduction plays more influence on the wall surface temperature than the convection is well fitted by the cubic polynomial, accurate results can be obtained by the new equation which is derived from 1-D unsteady conduction model with nonuniform initial wall temperature. Some suggestions are also introduced to reduce the influence of nonuniform initial temperature when the initial temperature distribution is difficult to obtain and the equation derived from constant initial temperature has to be employed.

1. Introduction

Nowadays there are mainly two types of heat transfer measurement technique: steady state measurement technique and transient measurement technique. Transient heat transfer measurements are more and more employed by researchers because of short experiment duration which is able to reduce the experiment cost and workload, and is required in short-duration test facilities. At the beginning, it was used at high temperature in shock tunnels for the measurement of surface heat flux [1]. The use of transient technique at lower temperature started from Russell et al. [2] and Clifford et al. [3]. They employed phase change paints to study heat transfer within gas turbine blade cooling passages. Ireland and Jones [4,5] were the first to present a transient heat transfer measurement technique using thermochronic liquid crystal (TLC) coating where they tracked the movement of a single band of liquid crystal during a transient experiment. In Ireland and Jones [4,5], the basic principles and the data reduction method for the transient heat transfer measurements were also described in detail. The normal assumptions are that the test plate is a semi-infinite solid and the transient temperature response is governed by the one-dimensional heat conduction into the model. When the material of the model has a low thermal diffusivity (e.g. Perspex) a one-dimensional (l-D) assumption is often a good approximation, since the surface temperature response is limited to a thin layer near the surface and the lateral conduction is small [6]. Following the step of Ireland and Jones, Jones and Hippensteele [7] measured the heat transfer coefficient on a compound-curve surface in a transient wind tunnel with TLC. Metzeger et al. [8] employed the transient liquid crystal method for local heat transfer measurements on a rotating disk with jet impingement. Ekkad and Han [9] and Zehnder et al. [10] measured the heat transfer characteristics in a square two-pass channel through the transient technique with TLC. The experiments mentioned in [2–10] are classified as a two-temperature system because the thermal boundary conditions are set by a single gas temperature and the wall temperature. Transient heat transfer measurement techniques are also widely used in three-temperature systems where boundary conditions are set by the freestream temperature, wall temperature, and injection temperature, such as film cooling experiments. Because both of the heat transfer coefficient and the film cooling effectiveness η are unknown at every measurement location, at least two equations are needed to obtain the two parameters. Vedula and Metzger [11] proposed a two-test strategy for film cooling transient measurement in which two experimental tests were performed with different local fluid temperatures to determine both the heat transfer coefficient and the film cooling effectiveness. Chambers et al. [12] further developed this idea to a three-test strategy for film cooling transient measurement. And Drost et al.

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