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Comparative study of large eddy simulation of film cooling using a dynamic global-coefficient subgrid scale eddy-viscosity model with RANS and Smagorinsky Modeling☆

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ABSTRACT

An eddy-viscosity subgrid-scale model proposed by You and Moin [1] applied in large-eddy simulation of a film cooling flow at Re = 4700. The present model needs only a single-level test filter, and therefore is more suitable for large-eddy simulation (LES) in complex geometries. The present model is not more complicated than the dynamic Smagorinsky model in implementation and does not require any ad hoc spatial and temporal averaging or clipping of the model coefficient for numerical stabilization. In addition, the computational cost is not more expensive than that of the dynamic Smagorinsky model. The numerical results of present study are compared with experimental data, Reynolds Averaged Navier–Stokes (RANS) and Smagorinsky model which are in excellent agreement with the existing experimental ones in comparison with computational results of RANS and Smagorinsky model.

1. Introduction

To improve the efficiency and the specific thrust of modern gas turbine engines high turbine inlet temperatures are required. Therefore, efficient cooling techniques such as film cooling [2] are often used to enable the blade material to sustain the high target temperatures. In film cooling method, jets of cool air are ejected through row of holes in the surface of the blade. This provides a thin layer of cool air downstream of the film cooling hole, which insulates the blade from the hot mainstream flow and acts as a heat sink to cool the blade surface. Due to the interaction between the coolant jet and the surrounding laminar or turbulent boundary layer around the blade the flow in the vicinity of the discharge holes is particularly complex. The flow patterns are characterized by the development of a horseshoe-like vortex wrapped around the jet exit and a counter-rotating vortex pair (CVP), which is formed as the jet transitions into the cross-flow and dominates the far field. Film cooling effectiveness depends on many parameters like cooling hole shape, cooling hole inclination, arrangement of row of holes, properties of mainstream fluid, coolant to mainstream blowing ratio, density ratio and momentum flux ratio. Accordingly most of the numerical studies [3–17] in literatures have been performed to investigate the effects of aforementioned parameters on film cooling flows and less concentration on more accurate numerical simulation of film cooling problems is made especially in Large eddy Simulation [18–26]. In this paper, a new eddy-viscosity subgrid-scale model proposed by You and Moin [1] was used for large-eddy simulation of a film cooling flow. Considering the shortcomings of previous subgrid-scale models described below makes the advantages of this promising model in simulation of turbulence film cooling flow more obvious.

A major drawback of the Smagorinsky subgrid-scale eddy-viscosity model used in large eddy simulations is that the model needs to be closed with an empirical constant, which has been found far from being universal and difficult to adjust to the characteristics of the turbulent flow field and computational resolution [27]. These shortcomings of the Smagorinsky model were overcome by Germano et al. [27] through a dynamic procedure for determining the model coefficient. The shortcoming of dynamic procedure proposed by Germano et al. is numerical instability since its value often becomes negative and/or highly fluctuates in space and time which needs additional numerical procedures [28–31]. Vreman [32] developed a new subgrid-scale eddy-viscosity model. In this model, vanishing subgrid-scale dissipation for various laminar shear flows is theoretically guaranteed even with a non-

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