International Journal of Thermal Sciences 50 (2011) 1973–1983

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Computational analysis of turbulent forced convection in a channel with a triangular prism

Ali Cemal Benim [a,*], Himadri Chattopadhyay [b], Ali Nahavandi [a]

[a] CFD Lab, Department of Mechanical and Process Engineering, Duesseldorf University of Applied Sciences, Josef-Gockeln-Str. 9, D-40474 Duesseldorf, Germany
[b] Dept of Mechanical Engineering, Jadavpur University, Kolkata 700032, India

A R T I C L E I N F O

Article history:
Received 7 June 2010
Received in revised form
27 April 2011
Accepted 2 May 2011
Available online 31 May 2011

Keywords:
Turbulent forced convection
Triangular prism
CFD
RANS
URANS
LES

A B S T R A C T

Turbulent forced convection in a heated two-dimensional plane channel with a triangular prism is computationally investigated by a cascade of modeling strategies. Reynolds Averaged Numerical Simulations (RANS) and two-dimensional Unsteady RANS (2D URANS) are performed for the Reynolds numbers (Re) 2500, 5000 and 25,000. The Prandtl number is equal to 0.7 in all computations. For Re = 2500 and Re = 5000 three-dimensional URANS (3D URANS) and Large Eddy Simulations (LES) (which are by definition three-dimensional) are also performed. In the RANS and URANS computations, the Shear Stress Transport (SST) model is used as the turbulence model. In LES, the Wall-Adapting Local Eddy-Viscosity (WALE) subgrid-scale model is used. It is predicted that the heat transfer at the channel wall can be augmented by the triangular prism, where the prediction quality depends on the modeling approach used. URANS and LES predict generally much higher Nu values compared to RANS, and, thus, indicate a much stronger heat transfer augmentation by the triangular prism. It is demonstrated that the effect of the unsteady motion of the coherent vortex structures behind the prism, which are mainly responsible for the heat transfer augmentation, cannot be adequately represented by a RANS turbulence model, and an unsteady approach (URANS/LES) is needed for a better prediction. The comparison between 2D URANS and 3D URANS shows, on the other hand, that three-dimensional effects in large scales can also play some role, depending on the Reynolds number, which could rather be evidenced for Re = 2500. The predicted peak time-averaged Nusselt numbers in the downstream region of the prism by LES turn out to be much higher than those of URANS, due to small but intense vortical structures in the wall vicinity, that are resolved by LES. However, further downstream, LES and URANS converge and show a rather similar asymptotic behavior.

1. Introduction

Heat transfer augmentation is an important field of research, as it leads to savings in energy and costs [1]. In various branches of engineering, including e.g., process industries, there exist numerous applications of heat transfer in channels. Heat transfer enhancement in such channels is, thus, a point of concern. Within this context, different geometric arrangements such as vortex generators in the form of delta wing or winglet pair or by insertion of twisted tapes have been applied. Furthermore, flow around bluff bodies such as cylinder or square cylinder has also been investigated in detail due to their practical relevance. Influence of the presence of bodies with different shapes was investigated by Jackson [2] via FEM simulations for laminar flow.

A triangular prism element is a very basic configuration. However, its role has not yet been studied in sufficient detail. Abbasi et al. [3,4] indicated that use of a prism element could enhance the heat transfer in a plane channel. However, their numerical study based on the finite element method (FEM) was limited to the laminar regime. They found out that a significant heat transfer enhancement can be obtained using a triangular prism (TP) for Reynolds numbers around 100. An important flow feature enhancing the heat transfer is found, here, to be the periodic occurrence of longitudinal vortices behind TP that promote mixing and heat transfer, as it is generally observed for any bluff body [3–5]. In a further work, Abbasi et al. [6] investigated buoyancy effects and different outlet boundary formulations for the laminar flow past a triangular prism. They showed that the pattern of the Von Kármán street gets affected by buoyancy, depending on the Grashof number. Furthermore, they demonstrated that the so-called convective boundary condition (CBC) provides a better alternative to the more conventional Neumann boundary condition

* Corresponding author. Tel.: +49 0 211 43 51 409; fax: +49 0 211 43 51 410.
E-mail address: alicemal.benim@fh-duesseldorf.de (A.C. Benim).

1290-0729/$ – see front matter © 2011 Elsevier Masson SAS. All rights reserved.
doi:10.1016/j.ijthermalsci.2011.05.002