Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **9**, No. 2, pp. 485-500

DOI: 10.4208/aamm.2015.m1078
April 2017

LES of Normally Impinging Elliptic Air-Jet Heat Transfer at Re = 4400

Yongping Li[1], Qizhao Lin[1] and Zuojin Zhu[2,*]

[1] *Department of Thermal Science and Energy Engineering, University of Science and Technology of China, Hefei, Anhui 230026, China*
[2] *Faculty of Engineering Science, University of Science and Technology of China, Hefei, Anhui 230026, China*

Received 30 April 2015; Accepted (in revised version) 9 May 2016

Abstract. Jet impingement induced heat transfer is an important issue in engineering science. This paper presents results of large eddy simulation (LES) of normally impinging elliptic air-jet heat transfer at a Reynolds number of 4400, with orifice-to-plate distance fixed to be 5 in the unit of jet nozzle effective diameter D $(=\sqrt{ab})$. The elliptic aspect ratio (a/b) is 3/2. While the target wall is heated under some condition of constant heat flux. The LES are carried out using dynamic subgrid model and OpenFOAM. The distributions of mean velocity components, velocity fluctuations, and subgrid stresses in vertical and radial directions, and the Nusselt numbers involving heat transfer through the target wall are discussed. The comparison with existing experimental and numerical results shows good agreement.

AMS subject classifications: 65C, 76F, 80A

Key words: Large eddy simulation, impinging air-jet, orifice-to-plate distance, subgrid heat flux, elliptic aspect ratio.

1 Introduction

Jet impingement is a conventional method to enhance heat transfer [1,2]. Increasing the normal velocity gradient and turbulence intensity of fluid flow near the impingement surface can improve the heat transfer [3]. Impinging jet with heat transfer has become an ad hoc problem in engineering science due to its great significance in applications. Before introducing the main objective of this paper, a research background of impinging jet flows, including experimental work [3–24] and numerical simulations [25–55] is presented below.

*Corresponding author.
Email: zuojin@ustc.edu.cn (Z. J. Zhu)

Elliptic jets have decided advantages for technological applications over circular jets as reported by Hussain et al. [7]. To explore advantages achieved by jet forcing due to self-excitation, using hot-wire measurements and flow visualization, Hussain et al. [7] have studied an elliptic whistler (i.e., self-excited) air jet of 2/1 aspect ratio which, in contrast to an elliptic jet issuing from a contoured nozzle, displays no axis switching, but significantly increased spread in the major-axis plane. They found that its near-field mass entrainment is considerably higher (by as much as 70%) than that of a non-whistling jet. Unexpected dynamics of the elliptic vortical structures in the whistler jet compared to that in the non-whistling jet. Vortices rolled up from the lip of the elliptic pipe impinge onto the collar, producing secondary vortices; interaction of these two opposite-signed vortices is shown to cause the different behaviour of the whistler jet.

The mixing due to a heated elliptic air-jet was measured by Zhang and Chua [12]. They measured velocity and temperature for a contoured contraction nozzle elliptic air jet with a 2/1 aspect ratio issuing into stagnant unconfined surroundings, with hot-wire and cold-wire anemometers. The experimental results suggest that the use of heated elliptic jets could offer enhanced mixing performance in relevant applications.

Many numerical studies have been carried out by means of direct numerical simulation (DNS), Reynolds averaged Navier-Stokes (RANS) modelling, and large eddy simulation (LES). To predict turbulent impinging circular jets whose orifice-to-plate distance in the unit of jet-nozzle diameter (H/D) was fixed at 2, and 6, the jet issuing Reynolds number was fixed at 2.3×10^4 and 7×10^4, with an extended version of the finite-volume code TEAM based on RANS modelling, Craft et al. [25] obtained numerical results of the impinging jet and compared with experimental data of Baughn and Shimizu [5], Cooper et al. [6]. After predicting heat transfer due to circular jet impingement, Park and Sung [26] reported that their nonlinear low-Reynolds-number k-ε model is generally satisfactory, in this model the limiting near-wall behavior and nonlinear Reynolds stress representations are incorporated.

Zuckerman and Lior [27] conducted RANS modelling of impinging jet heat transfer, in which the selected model equations, the quantitative assessments of model errors, and the judgments of model suitability were provided. To explore the heat and fluid flow performance of deflector under periodic jet impingement, using the RNG k-ε model [35], Zhang et al. [34] have recently found that temperature variation of heat resistance layer in deflector occurs stable periodic fluctuations after four impingement periods; the temperature of the impinged wall surface increases with the decrease of jet distance or the increase of horizontal angle.

LES results of a forced semi-confined impinging circular jet were reported by Olssen and Fuchs [37]. The Reynolds number was 10^4, and the inflow was forced at a Strouhal number of 0.27. The orifice-to-plate distance in the unit of jet-nozzle diameter H/D was set as 4. By studying the mean velocity, the turbulence statistics, the subgrid scale (SGS)-model effects, the dynamic behavior of the jet with a focus on the near wall region, they confirmed that the existence of separation vortices in the wall jet region, and revealed that these secondary vortices are related to the radially deflected primary vortices generated