Available online at www.sciencedirect.com
ScienceDirect
International Journal of Heat and Mass Transfer 51 (2008) 941–947
International Journal of HEAT and MASS TRANSFER
www.elsevier.com/locate/ijhmt

Technical Note

An experimental study of heat transfer in a two-dimensional T-junction operating at a low momentum flux ratio

A. de Tilly, J.M.M. Sousa *

Mechanical Engineering Department, Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

Received 12 August 2007; received in revised form 5 October 2007

Abstract

A non-isothermal, two-dimensional T-junction operating at a low value of momentum flux ratio has been experimentally investigated. Mean and fluctuating measurements of temperature, coupled with a spectral analysis, have been used to characterise the dynamics of the flow for different flow conditions. A higher cooling effectiveness was found for the higher value of the Reynolds number due to an earlier development of large-scale structures. Heat transfer coefficients obtained employing the cross-flow temperature as a reference displayed an unusual behaviour. A better strategy was also proposed, taking into consideration the possible choices for the reference temperature.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: T-junction; Confluence flow; Low momentum flux ratio; Cooling effectiveness; Heat transfer coefficient; Reference temperature

1. Introduction

Confluence flows are very prone to the development of different kinds of instabilities (see e.g. [1–4]). This increases the difficulties to carry out accurate predictions of mean heat transfer in T-junctions [5]. Moreover, the fluctuating behaviour of velocity and temperature fields is often disregarded in related investigations. It is expected that supplementary investigations may improve our understanding of the dynamical phenomena involved and ultimately contribute to a better design of such flow elements.

In the work of Fukuda et al. [6], a low-momentum cold jet was discharged into a very hot cross-stream. Flow junctions employed in this context were originally designed according to traditional heat transfer coefficient calculations but the heat transfer analysis was neither appropriate nor able to anticipate thermal stripping. Coefficients for mean and fluctuating heat transfer have been obtained by Beck et al. [7] and Ogura [8], employing inverse and power spectral methods, respectively. However, these were calculated using a reference temperature which did not allow to fit the classical correlations for wall boundary layers, as noted by Noguchi et al. [9]. This is a consequence of the fact that several temperature entries exist in the flow, thus complicating the choice of a reference temperature.

It was shown by de Tilly [3] that the fluid structures strongly affect the heat transfer to the wall in these flows. These structures are usually associated with significant velocity and temperature fluctuations. On the other hand, heat transfer evolutions are traditionally correlated with mean temperatures [10]. However, Maillet [11] has pointed out that the theoretical means proposed in the literature are not adequate to model and efficiently predict heat transfer phenomena when two streams of different temperatures interact with a wall. For example, in the case of the cross-stream discharge of jets characterised by a high momentum flux ratio and different geometrical shapes, Jones [12] used several reference temperatures to model the mean heat transfer to the bounding surface.

The main objective of this experimental study is to seek physical coherence between the heat transfer to the wall and the flow behaviour in a non-isothermal, two-dimen-

* Corresponding author. Tel.: +351 21 841 7320; fax: +351 21 849 5241.
E-mail address: msousa@ist.utl.pt (J.M.M. Sousa).

0017-9310/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijheatmasstransfer.2007.10.012

Nomenclature

d	thickness of the secondary flow duct
f	frequency
h	heat transfer coefficient
H	height of the primary flow channel
J	momentum flux ratio, $J = \frac{\rho_j}{\rho_c}\left(\frac{U_j}{U_c}\right)^2$
L	length of the primary flow channel
PSD	power spectral density
r	linear correlation coefficient
Re_c	Reynolds number of the primary flow, $\frac{U_c H}{\nu}$
RMS	root mean square
s	stabilized height where the peak temperature fluctuations occur
St_d	Strouhal number based on thickness d, $\frac{fd}{U_j}$
St_s	Strouhal number based on height s, $\frac{fs}{U_j}$
T	temperature
U	mean flow velocity
w	width of the primary flow channel
x,y,z	spatial coordinate

Greek symbols

ϕ	heat flux
ν	kinematic viscosity
θ_w	cooling effectiveness

Subscripts

a	ambient
c	cross-flow, primary flow
iso	isothermal
j	jet, secondary flow
w	wall

sional T-junction, operating at a low value of momentum flux ratio. A contribution to improve our understanding of the origins of thermal stripping in non-isothermal T-junctions is also aimed at with the present investigations. Mean and fluctuating measurements of temperature, as well as power spectra, are used to characterise the dynamics of the flow for three different values of the Reynolds number. Subsequently, these results are integrated into the estimation and interpretation of mean heat transfer coefficient evolutions, considering the possible choices of reference temperature.

2. Experimental setup

2.1. Description of the test section and conditions

A schematic representation of the confluence zone is shown in Fig. 1. Electronically-controlled air heaters located upstream (not shown) allowed to maintain inlet temperatures constant during the experiments. By changing the value of U_c, the Reynolds number Re_c characterising the primary channel flow could be varied among the values of 6500, 13,000 and 19,500. The secondary flow velocity U_j was adjusted to obtain a low value of the jet momentum flux ratio, which was defined as $J = \rho_j U_j^2 / \rho_c U_c^2$. A distinctive feature of the present investigation is the fact that a low value of the momentum flux ratio has been considered, namely $J = 0.01$.

The test section has an effective length $L = 300$ mm along the x-direction. The height and width of this channel are $H = 50$ mm and $w = 250$ mm, respectively. The duct from which the secondary flow emerges into the cross-stream spans the whole width of the main channel as a slot of constant thickness, $d = 15$ mm. Based on the large value of the ratio w/d, three-dimensional effects have been neglected. Consequently, only measurements at a plane located at the channel mid-span ($z = 0$) have been performed in this study and the whole analysis carried out in this paper has been made under the assumption of two-dimensional flow.

The flow upstream the confluence zone was approximately uniform due to a 1:20 contraction, and the free-stream turbulence level was kept at a nearly constant value of 2%. However, aiming to examine also the influence of the turbulence intensity on the mixing phenomena, a grid turbulator has been installed at the exit of the primary channel contraction in part of these experiments. In such cases, the turbulence level has been increased to roughly 10% in the vicinity of the jet slot.

Temperature measurements were conducted both for the case of streams with the same temperature ("isothermal") and non-isothermal cases, with especial emphasis on the latter. The "isothermal" case was characterised by the following temperature values: $T_c = T_j = 110$ °C and $T_a = 30$ °C. The temperature difference between the flow and the ambient air was high enough so that a non-negligible amount of heat was transferred to the bottom wall of the channel. Non-isothermal cases were investigated for $T_c = 110$ °C and $T_j = T_a = 30$ °C. The studied wall sketched in Fig. 1 was constructed with a smooth, opaque, 1-cm thick Teflon® plate with the aim of minimising heat conduction in the wall along the longitudinal direction. The remaining walls in the primary channel were metallic (steel) and silver-coated to minimize heat losses by radiation from the bottom wall.

2.2. Instrumentation

Temperature measurements were made near the bottom wall of the channel depicted in Fig. 1. Aiming to characterise the evolution of time-averaged and fluctuating temperatures at different stations downstream the jet exit, a thin

Download English Version:

https://daneshyari.com/en/article/662924

Download Persian Version:

https://daneshyari.com/article/662924

Daneshyari.com